REAL CORP 2026

Manfred SCHRENK, Clemens BEYER, Tatiana POPOVICH,
Judith RYSER, Dana MAWLOOD (Eds.)

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of the 31st International Conference on Urban Planning, Regional Development and Information Society

TAGUNGSBAND



EVERYBODY PLANS ... SOMETIMES

CHERISH HERITAGE, PLAN NOW, CREATE A BETTER FUTURE!

A co-operation of

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Cherish Heritage, Plan Now, Create a Better Future!

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Manfred SCHRENK, Clemens BEYER, Tatiana POPOVICH,
Judith RYSER, Dana MAWLOOD

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REAL CORP 2026

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REAL CORP 2026 took place under the patronage of the Mayor of the City of Vienna, Dr. Michael Ludwig, and under the patronage of the Federal Minister of Education Christoph Wiederkehr, MA.



PREFACE

Manfred SCHRENK

Conference Director,
President CORP – Competence Center of Urban and Regional Planning

WELCOME to REAL CORP 2026, the 31st International Conference on Urban & Regional Development and Spatial Planning in the Information Society!

As urban and regional landscapes become more complex, planning is no longer a linear process. It is adaptive, participatory, and often unpredictable. In urban and regional development, planning is both a discipline and a gamble. This conference gathers thinkers and doers to navigate the space between vision and reality – shaping futures one decision at a time.
For three decades, the REAL CORP conference series has been at the forefront of exploring the profound impact of information and communication technologies (ICT) on urban and regional development. As we navigate an era of unprecedented change, marked by rapid technological advancements, evolving societal structures, and pressing environmental challenges, REAL CORP 2026 invites researchers, practitioners, experts, activists and policymakers to contribute to the discourse on "Cherish Heritage, Plan Now, Create Future!"

We are witnessing a paradigm shift in how our cities and regions function, are planned, and are experienced. From the pervasive influence of artificial intelligence and big data analytics to the imperative of climate resilience and inclusive governance, urban and regional landscapes are undergoing continuous metamorphosis. REAL CORP 2026 provides a vital platform to critically examine these transformations, share innovative solutions, and collectively envision sustainable and equitable futures.

The REAL CORP 2026 research question is: does technology and especially AI really revolutionise everything? Even CITIES, the biggest invention of mankind?

New technologies and especially AI lead to many changes in all aspects of life, including in cities and regions and, of course, in planning processes. Still cities and regions are not primarily a playground for "new technologies" but the main goal is to have sustainable, resilient and above all livable environments. The soul of a livable future often lies in adequate density, adaptive reuse, green infrastructure, and places where communities thrive, with eco-conscious urban design, human-scale architecture, and inclusive public spaces!
All this has to be planned, created, maintained and eventually renewed.

Planning is always an effort of many contributors and planners have to be part of all urban planning efforts – be it as experts, visionaries, strategists, co-ordinators, moderators and mediators, advocates and sometimes opposers. LET'S PLAN TOGETHER!

Welcome to Vienna! Welcome to Austria! Have a great conference!
Manfred SCHRENK, Clemens BEYER & the REAL CORP Team



Dear participants of REAL CORP 2026!

On behalf of the City of Vienna, I would like to extend a warm welcome to you all! I am delighted that such important topics as urban planning and regional development are on the agenda of such a high-profile conference. International exchange is the best way to tackle global challenges that affect us all equally.

This applies in particular to the impact of revolutionary modern technologies and AI in particular. It is no coincidence that the central research question of REAL CORP 2026 is whether these innovations will really change everything, including modern metropolises such as Vienna.

We are already feeling this change in our everyday lives: for example, more and more administrative procedures in Vienna can be completed digitally; the BRISE project, for example, is making building permit procedures paperless, faster, more efficient, more sustainable and more transparent. In addition, Vienna has become an AI innovation centre.

This process is guided by the principle of "digital humanism" – in other words, progress should make everyday life easier. The focus is on people, not progress.

In this context, education will become a key resource. Our industrial societies are transforming into knowledge societies. That is why it is so important to set the course now for the best possible preparation of our children and young people so that they are ready for the growing challenges of the digital world.

In addition, it will be important to focus even more than before on international exchange. Especially in times of national solo efforts and protectionism, it is important to keep multinational forums for communication and cooperation open. After all, science and innovation are only truly stimulated by encounters on an equal footing and by learning from each other.

That is why I am very pleased that REAL CORP 2026, a major international conference, is taking a close look at the characteristics and effects of these fundamental transformations. Especially now – when change is already becoming apparent – it is important and necessary to develop ideas about where and how far we as societies want to go. We must not allow ourselves to be driven by this innovation process, but must shape it ourselves with social awareness and clear objectives.

REAL CORP 2026 is making an invaluable contribution in this regard. I am very excited to see the results and wish you all a successful and, above all, insightful conference!

Michael Ludwig, Mayor and Governor of Vienna



Vision Education warmly welcomes participants to REAL CORP 2026!

Vision Education is honored to support the 31st International Conference on Urban Planning, Regional Development, and the Information Society in Vienna, Austria, in collaboration with CORP – Competence Center of Urban and Regional Planning. This important partnership reflects a shared commitment to advancing global dialogue and fostering academic and practical cooperation in the fields of urban planning, regional development, and the information society. As an institution committed to strengthening education and research in the Kurdistan Region of Iraq, Vision Education supports both private and public institutions while empowering citizens to contribute to positive change. Vision Education recognises the critical role of knowledge exchange, international collaboration, and interdisciplinary research in addressing the complex challenges facing contemporary cities and regions.

Sustainable urban growth, climate resilience, and technological innovation require forward-looking approaches that integrate education, policy, and practice at both regional and local levels. Through engagement with global academic networks and institutions, Vision Education seeks to contribute to the development of informed leadership, innovative research, and practical solutions that support sustainable and inclusive urban futures.

Partnerships such as this collaboration with CORP exemplify the value of building bridges between regions, institutions, and stakeholders to foster shared expertise, mutual understanding, and long-term cooperation.

We are proud to support this leading international conference, bringing together distinguished scholars, professionals, and policymakers in Vienna, and we look forward to the continued exchange of ideas that will help shape more resilient, sustainable, and intelligently planned cities for generations to come.

Idris Nechirvan Barzani, Chairman of Vision Education



Dear participants of REAL CORP 2026!

Our cities and regions stand at the threshold of a profound transformation. Climate change, demographic shifts, digitalisation, and evolving patterns of work and mobility are reshaping how we live, work, and move. Cities and regions are therefore central arenas for safeguarding quality of life, advancing sustainability, and strengthening social cohesion for all citizens.

Our shared goal is to create resilient, inclusive, and liveable urban environments. Research, technology, and innovation play a key role in achieving this objective. They provide essential tools for integrated spatial planning, enable evidence-based decision-making, and support sustainable solutions in areas such as energy, mobility, infrastructure, and public spaces. Strategic investment in research and innovation is indispensable to steering this transformation in a forward-looking and responsible manner.

Integrated neighbourhood and district development is a particularly powerful lever in this context. By linking spatial, social, ecological, and economic dimensions, it enables complex challenges to be addressed holistically and makes the benefits of transformation tangible for citizens. Well-designed integrated neighbourhoods can serve as showcases for innovation, foster social cohesion, and act as key building blocks for sustainable urban and regional development.

In this spirit, I warmly welcome REAL CORP 2026 to Vienna. With its focus on integrated urban and regional development, the conference provides an important platform for international exchange and brings the discussion to the Vienna Otto-Wagner-Areal – a place that exemplifies transformation, innovation, a vibrant architectural culture, and the close connection between research, technology, and urban planning.

KommR Peter Hanke, Federal Minister of Innovation, Mobility, and Infrastructure

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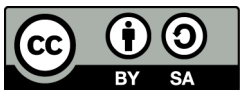
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Table of contents – Inhaltsverzeichnis:

PREFACE 5

3D City Models as Simulation Infrastructure: Open Tools, Proprietary Gaps and Application Scenarios in Everyday Planning 19
Peter Zeile, Daniel Broschart

A Digital Transformation Assessment on the Role of Building Information Model Training in Built Environment Institution Programmes: Lessons from South Africa 29
Nkosinathi Dube, Thembani Moyo, Thulisile Mphambukeli

A Governance Framework for Planning Approval of Housing Developments to Enhance Growth in the Economy 39
Nonhlanhla Bongiwe Charity Buthelezi, George Onatu, Clinton Aigbavboa

A Green(er) Roof over the Head: Reflecting on Strategies Targeting Homelessness with Urban Agriculture for Cape Town, South Africa 45
Louis Lategan, Charné Erasmus

A Spatiotemporal Analysis of Duhok's Urban Growth (2010–2025): A Narrative Review of the Duhok Master Plan 57
Haval Bankin Qasim Kittani

A Stakeholder-Driven Needs Assessment: Identifying Urban Challenges and Requirements for Satellite-Based Services Supporting Climate-Resilient Austrian Cities 63
Romana Berg, Martin Jung, Eliza-Maria Link, Diana Silvestru, Heinz Gallaun, Isabella Hinterleitner, Anna Kozlowska, Jan Peters-Anders, Katharina Köglberger, Viktoria Mentin, Daniel Deutsch

A Systematic Living Lab Approach for Community Engagement for Urban Regeneration – the S.M.I.L.E. Methodology 75
Caroline Cheng, Judith Thomsen, Anandasivakumar Ekambaram

A Systematic Review of Policy and Legislative Gaps in Advancing Sustainable Human Settlements in Small Rural Towns: A Case of South Africa 87
Lungile Mkhize, Trynos Gumbo

A Toolbox to Analyse Sustainable Mobility in Land-Use Planning Processes: Methodological Challenges and Approaches for Residential Developments in Rural Areas 93
Nazanin Zahabkar Aghdam, Jochen Eckart, Christian Rickert, Catharina Lutz

Accelerating instead of Waiving Planning: Opportunities and Challenges of Digital Building Land Cadastres in Urban Digital Twins 105
Stefan Fina, Florian Rack, Antonia Finger, Martina Königbauer

Affordable Housing in Emerging and Developing Economies: Exploring the Role of Urban Planning and Policy in African Countries 117
Parsa Arbab

An Analysis of the Role of Spatial Planning in Enhancing Rural Resilience to Flooding: A Case Study of South Africa 125
Takalani Mugada, Trynos Gumbo, Retsepile C. Kalaoane, Thembani Moyo

An Assessment of the Clean Air Zones (CAZ) Implementation in Developing Contexts: Social Equity Report for the City of Johannesburg 135
Abdulrasaq Ajadi Ishola, Trynos Gumbo, Tafadzwa Clementine Maramura

An Educational Approach to Planning the Future Spatial Development of a Small Town: The Case of Čakovec, Croatia 145
Lea Petrović Krajnik, Damir Krajnik, Tamara Zaninović

Analysing the Logistics Space near Cape Town International Airport in Comparison to the Seaport and Dry Port Environments 157
Masilonyane Mokhele

Analysing Urban Development Patterns: A Spatio-Temporal Analysis and Predictive Scenarios around Major Railway Stations/Terminals 167
Rohit Koiri, Ashly Augustine, Ankhi Banerjee

Architectural Rehabilitation of Charasteen Cave in Duhok: A Locally-Led Accessibility and Heritage Intervention within the UNESCO–EU MADAD Framework with Support from the Kurdistan Regional Government 179
Mahmood Albrifkany

Assessing Pedestrian Accessibility to Urban Land Surface Temperature Cold Spots in Bavarian Cities 191
John Friesen, Sarah Heinz, Ariane Droin, Michael Wurm, Tobias Leichtle, Mattia Marconcini, Hannes Taubenböck

Beyond Informality: Middle-Class Urbanisation, Hybrid Governance, and Resilience Challenges in African Peripheries 203
Lindokuhle Matshika, Trynos Gumbo, Karen Puren

Beyond Municipal Boundaries: Rethinking Public Amenities in Eswatini's Peri-Urban Transformation 211
Mhlalisi Mndzebele, George Onatu

Cherishing Human-Elephant Landscapes with GIS-LBS: A LUCIS-Based Negotiation Framework for Human-Elephant Coexistence in Sri Lanka **217**
Chethika Abenayake, Amila Jayasinghe, Kaveesha Lahiru, Sandaruwan Sankalpa, Gayesha Diwyanjali, Sandali Kangara, Chathura De Silva, Günther Retscher, Jelena Gabela Majic

Childhood Mobility Socialisation: The Influence of Social Environment, Infrastructure and Perception of the School Route on Active Mobility Modes **223**
Hans Peter Ellmer, Vanessa Weiß, Sebastian Seebauer, Irene Bergmann, Karlheinz Gürtl, Elisabeth Oswald

Co-Creating Urban Resilience by Community Engagement in Central Asia **231**
Madina Junussova, Chynarkan Saparova

Co-Productive Project Development in Urban and Regional Planning **239**
Sarah C. Schreiner

Combining Social Aspects of Climate Change with Urban Heat Stress Modelling – a Case Study from Bremerhaven, Germany **247**
Markus Groth, Steffen Bender, Ricarda Klafka

Community Perceptions of Municipal Stormwater Management in Durban, KwaZulu-Natal: Evaluating Progress and Challenges **259**
Basiiraa Moosa, Trynos Gumbo, Thulisile Mphambukeli, Thokozani Simelane

Condition Assessment of Cycling Infrastructure – A Step towards a Systematised Approach in Austria **269**
Karin Markvica, Stefan Portisch, Dominik Wieser, Christian Fürstler, Manuela Stögerer, Peter Saleh

Constitutional Energy Mandates and Local Governance in Post-Apartheid Spatial Planning **279**
Khatliso Simon Baas, Thulisile Ncamsile Mphambukeli

Critiquing the Implementation of the New Urban Agenda in Sub-Saharan Africa: A Systematic Review of Housing Policies and the Challenge of Upgrading Informal Settlements **291**
Mhlalisi Mndzebele, George Onatu

Digital Participatory Rural Appraisal Approach for Smart Sustainable Rural Development **297**
Papiya Bandyopadhyay Raut, Sandeep Kumar Raut, Vivek Kumar

Digital Systems Audit and Policy Alignment in the City of Johannesburg **305**
Thandekile Khumalo, Aurobindo Ogra

District Sub Centres as Foundational Elements in the Implementation of the 15 Minute City Model: Case Study of Albertfalva **315**
Boróka Szarvák

Earth Observation and Open Geodata for Sustainable Urban Planning – A Practical Case Study from the City of Munich, Germany **327**
Tobias Leichtle, Marlene Kühnl, Jeroen Staab, Dorothee Stiller, Stefan Gamperer, Klaus Martin, Robert Behringer, Michael Wurm, Hannes Taubenböck

Enhanced Communication Systems with Reconfigurable Intelligent Surfaces in Smart Cities: Bridging Wireless Connectivity and Urban Sustainability **337**
Y. E. Mohammed Ali, Abdulrahman Kh. Alhafid, Sedki Younis, Joan Atheel Ahmed

Enhancing Safety Perception for Disabled Users of BRT System through Closed-Circuit Television Cameras in Johannesburg **347**
Isaac Tabane; Trynos Gumbo

Evaluating the Effectiveness of SDG 11 Monitoring and Implementation Frameworks at City Level: A Case Study of Mbabane, Eswatini **353**
Wandile Thwala, Mhlalisi Mndzebele, Trynos Gumbo

Exploring The Impact of Intelligent Transportation Systems on Johannesburg Park Station and Transit-Oriented Development **365**
Tshiamo Domingo, Trynos Gumbo, Thembani Moyo,Mueletshedzi Phosho

Framing Spatial Decision Support Systems – A Multidisciplinary Perspective on Digital Decision Making in Spatial Planning **375**
Jonas Pauly, Julia Mayer, Christof Schroth, Rasha Abu Qasem, Martin Memmel, Karina M. Pallagst

From Crisis to Growth: Pre-Disaster Planning as a Catalyst for Sustainable Innovation and Circular Economy in European Cities **387**
Claudia Mayr-Veselinović, Anna Meyer, Julia Graf, Renate Renner

From Field Surveys to Climate Mitigation Support: Scaling Regional Hedgerow Carbon Estimates via Multi-Resolution Remote Sensing **401**
Dae Yong Kim, Sascha Fritzsch, Jessica Jennifer Arland-Kommraus, Matthias Pietsch

From Smart City to Meaningful City: A Results-Oriented Perspective on Urban Experience Quality, Governance, and Sustainable Value Creation **409**
Jörg Haupt, Hans Rüdiger Kaufmann

Gender-Inclusive School Architecture: An International Comparison **415**
Carla Schwaderer

Geosystem Services and Subsurface Planning – Case Studies in Two Swedish Municipalities **429**
Fredrik Mossmark, Anja Gustafsson, Emrik Lundin Frisk, Paula Lindgren, Lorena Melgaço, Marilu Melo Zurita, Victoria Svahn, Tore Söderqvist, Olof Taromi Sandström, Yevheniya Volchko, Jenny Norrman

Governing Green and Heritage-Led Revitalisation: Multi-Scalar Insights from the Nona Project in the Danube Region **437**
Ana-Maria Dragomir, Miruna Draghia, Alexandra Zlotea

Governing the Green Energy Transition through Transformative and Collaborative Planning – the Case of Burgenland's Regional Concepts for Energy Development ..... Fehler! Textmarke nicht definiert.
Raffael Koscher, Gernot Stöglehner, Alexandra Jiricka-Pürrer

Heating with a Novel Type of Retrofitted Thermal Facade Activation and Heat Pump in a Residential Block in Vienna **461**
Constanze Rzihacek, Magdalena Wolf, Thomas Keller, Tobias Pröll

Hijacked Buildings and Emerging Forms of Informality in South Africa: Insights from Recent Urban Case Studies **473**
Vuyiswa Letsoko, Ockert Pretorius

How can the Transformative Research Methodology be Applied to Regional Governance? **479**
Jörg Knieling, Franziska Ulrich

Identifying Vulnerable Population under Heat Stress: A Data-Driven Urban Risk Assessment Using Remote Sensing, Citizen Science and Census Data ..... Fehler! Textmarke nicht definiert.
Marlene Kühnl, Tobias Leichtle, Saskia Rupp, Michael Hiete, Christoph Beck, Christian Geiß, Hannes Taubenböck

If Planning is Complex and Political, maybe Planning is the Solution: Improving Infrastructure Quality in Global South Cities **499**
Thulisile Mphambukeli, Nomfundo Cele, Thembani Moyo

Implementation of a City Information Model on a Micro-Urban Scale: Qualitative Streetscape Analysis using the SSSEIC Method **505**
Susanne Tobisch, Daniel Löschenbrand, Angelika Psenner

Implementation of a Forecast-Based Predictive Controller in a Residential Building **519**
Bernhard Kling, Magdalena Wolf, Tobias Pröll

Implicit Sufficiency in Regional Planning? Insights from a Town Center Revitalisation Programme in Styria, Austria **525**
Alice Steiner, Eva Schwab, Aglaée Degros

Integrating Spatial Data and Indigenous Knowledge Systems for Resilient Urban Planning: Lessons from South Africa **537**
Thembani Moyo, Vuyiswa N Letsoko, Mhalisi G Mndzebele, Siphiwe G Mbatha, Nompumelelo P Mzobe, Trynos Gumbo

Integrating Traditional Authority Participation into Land Use Planning: Implications for Sustainable Rural Housing Delivery **545**
Nompumelelo Petunia Mzobe, Trynos Gumbo, Thembani Moyo, Sphiwe Mbatha, Vuyiswa Letsoko, Mhlalisi Mndzebele

It's A Kind of Magic! Addressing The Arnstein Gap in Planning with the QICE Public Participation Performance Framework **551**
Keiron Bailey

Land-Use Conflict and Traffic Congestion on the N12: Evaluating Planning Responses at the Moroka Bypass, South Africa **563**
Nkosinathi Dube, Thembani Moyo, Retsepile Charity Kalaoane, Thulisile Ncamsile Mphambukeli

Landschaftserleben für alle – Entwicklung eines Leitfadens zur Gestaltung von barrierearmem und erlebnisorientiertem Wandertourismus für Blinde und Sehbeeinträchtigte **571**
Tanja Kaiser, Sascha Henninger

"Intensify Industry by Double": How Environmental Policy can Foster Economic Densification **585**
Jan Zaman

Leaving No One Behind: Planning for Inclusive Resilience in Marginalised Communities **595**
Takalani Mugada, Trynos Gumbo, Retsepile C. Kalaoane, Thembani Moyo

Mapping Park Maintenance Disparities Across Johannesburg's Socio-Economic Landscape: A Pilot Assessment Study **603**
Abdulrasaq Ajadi Ishola, Trynos Gumbo, Tafadzwa Clementine Maramura

Media Narratives and the Case for Accelerated Digital Transformation in City of Johannesburg (2022-25) **613**
Thandekile Khumalo, Aurobindo Ogra

Methoden zur Bewertung erneuerbarer Energiewende-Potenziale im urbanen Gebäudebestand: Analyse-Ergebnisse aus dem Projekt EWV4EnergieWende **623**
Bente Knoll, Dinah Hohl, Natalie Lauer, Nazli Gercek, Andreas Kahr, Sarah Schlater

Methodische Lücken und digitale Potenziale: Kommunale Entscheidungsprozesse im Wandel der Planungskultur 635
Christin Juliana Müller

Multi-Level Governance and Contested Authority in Thaba Phatswa: An Institutional Mechanisms Approach under TRANCRAA 647
Malefu Brenda Mabalane, Thulisile Ncamsile Mphambukeli

Paid or Unpaid Social Housing? Rethinking South Africa's Social Housing Dilemma 657
Samson Olaoluwa Faboye, Innocent Musonda

Partizipative Energiesystemanalyse auf der Basis eines urbanen digitalen Zwillings und einer Smart-Meter-Datenanalyse zur Förderung von Plusenergiequartieren 663
Ernst Gebetsroither-Geringer, Basak Falay, Daniel Horak, Jan Peters-Anders, Ali Hainoun

Placemaking an der Schnittstelle von Stadt- und Tourismusentwicklung 675
Cornelia Dlabaja, Katharina Höftberger, Jana Werl

Plan Now, Ride Later: Simulation-Based Fleet Optimisation and Inclusive Service Design for Cities 687
Isabella Hinterleitner, Daniel Deutsch, Katharina Köglberger, Victoria Mentin

Planning and Governance Model for AI Enabled Spatial Intelligence and New Urban Economics 699
Shrimoyee Raut

Planning for the Margins: A Stakeholder-Centred Legislative Analysis of Sustainable Human Settlements Policy in South Africa's Small Rural Towns 705
Lungile Mkhize, Trynos Gumbo

Positioning Bus Rapid Transit as a Catalyst for Accessible Urban Commons: Case of Pretoria 713
Isaac Tabane; Trynos Gumbo

Positive Energy Districts and Energy Poverty 719
Clemens Mayer, Sebastian Seebauer, Andreas Tuerk, Michael Brenner-Fließer, Mia Ala-Juusela

Qualität der Nachverdichtung in Österreich 727
Hemma Hartl, Aglaée Degros, Eva Schwab

Quality Standards for XR Participation – Applications and Challenges in Smart, Participatory Urban Development 737
Heidi Sinning, Svenja Rogoll, Anja Wolter

Reimagining South African Urban Planning Education: Aligning Digital Skills with Professional Demands 751
Mhlalisi Mndzebele, Siphiwe Mbatha, Vuyiswa Letsoko, Thembani Moyo, Nompumelelo Mzobe, Trynos Gumbo

Rethinking Complementary Land Uses for Early Childhood Development Centres in Johannesburg's CBD 761
Nompumelelo Petunia Mzobe, Trynos Gumbo

Rethinking Public Space in the Global South: A Secondary Analysis of Spatial Justice in South African Cities 769
Vuyiswa Letsoko

Rethinking Spatial Potential Analysis with New Data: Integrating Supply, Demand, and Implementation Criteria in Municipal Heat Planning 775
Florian Rack, Stefan Fina

Rethinking the Smartness of Cities: Microclimatic Performance of Public-Private Transition Spaces in Dense residential Areas of Tokyo 787
Carina Kurz

Rising Costs, Stagnant Incomes in Johannesburg: Understanding Affordability Mismatch in Low-Income Households 795
Eugiania Khethani Ravele, Trynos Gumbo

Roll Out of Sustainable Solar Energy in Spatial Planning: A Focal Lens of Maseru, Lesotho 805
Jonase Nthunya, Trynos Gumbo, Retsepile Kalaoane, Siphiwe Mbatha

Smart Health Measurements on Urban Air for Smart Cities and Regions Matter 811
Hans Rüdiger Kaufmann, Richard Stoy, Thomas Schäfer, Matthias Rädle

Social Equity in Housing: Addressing Systemic Barriers in Johannesburg, South Africa 817
Eugiania Khethani Ravele, Mhlalisi Mndzebele, Trynos Gumbo

Spatial Determinants of Urbanisation in Debre Markos, Ethiopia: Modelling Building Footprint 829
Moges Wubet Shita, Haile Legese Zewale, Gerhard Navratil

Spatial Manifestation of Planning Culture in Graz: Understanding Planning Processes and their Influence on Public Space Design 839
Sabine Bauer, Eva Schwab, Aglaée Degros

Spatial Variability of Urban Land Price in Addis Ababa, Ethiopia 851
Haile Legese Zewale, Moges Wubet Shita, Gerhard Navratil

Stadtraumdiagnostik – Identifikation stressauslösender Faktoren öffentlicher Stadträume in Karlsruhe, Osnabrück und Würzburg **863**
Nina Haug

Stakeholder Mapping and User Perception of Mobility Management for Commuters and Students: A Comparison of 7 Case Studies in Central Europe – the GreenPATH Project **877**
Roman Klementschitz, Valerie Jeepjua, Oliver Roider

Straßendorf, Angerdorf: Historische Dorfstrukturen als neue Pole in einem polyzentralen Wien **885**
Daniel Löschenbrand, Susanne Tobisch, Friedrich Hauer, Angelika Psenner

The Bibliometrics Insight: Role of Spatial Planning in Just Energy Transition in South Africa **897**
Tshiamo Domingo, Trynos Gumbo

The Built Environment and Health Comorbidities in Urban Informal Settlements: Mechanisms, Evidence, and Interventions **905**
Thulisile Mphambukeli, Nomfundo Cele, Thembani Moyo

The Role of Land Use Planning in Influencing the Placement of Logistics Firms near the Port of Cape Town, South Africa **911**
Kwena Letsoalo, Masilonyane Mokhele

The Role of State-Owned Enterprises (SOEs) in Advancing a Just Energy Transition in South Africa **921**
Jonase Nthunya, Trynos Gumbo, Retsepile Kalaoane, Siphiwe Mbatha

The Slave **931**
Pietro Elisei, Vasily Popovich, Manfred Schrenk, Tatiana Popovich, Judith Ryser

The Social and Economic Development Implications of 4IR Technologies in African Housing Production Systems: Review of 3D Printin **935**
Mhlalisi Mndzebele, Trynos Gumbo, Wisdom Dlamini

Tools for Transformative Social-Ecological Infrastructure **941**
Barbara Laa, Lisa Gallian, Rebecca Hauschild, Stefanie Gülly, Michael Getzner

Training of Experts for Sustainable Use of Land **945**
Gerhard Navratil, Reinfried Mansberger, Thomas Bauer, Getie Gebrie, Belachew Yirsaw Alemu, Zinabu Getanhun, Aramde Fetene Mengistu, Anka Lisec, Sayeh Kassaw Agegnehu, Piotr Wężyk, Wojciech Krawczyk, Marta Szostak

Transforming Environmental Planning through Data-driven Structural Models and AI: Chances for Climate-Responsive Urban Landscapes in Riyadh, Saudi Arabia **953**
Amélie Meißner,Margherita Bertolero, Michael Gräf

Unsichtbare Gruppen – sichtbare Effekte: Eine Untersuchung potenzieller Auswirkungen von Untererfassungen in deutschen Melderegisterdaten und Meldepflichtsbefreiungen auf gängige visuelle Darstellungen von Bevölkerungsgrößen in SDSS **963**
Julia Mayer

Urban Circularity in Time: Rethinking Quality of Life through Circular Communities **975**
Barbara Goličnik Marušić, Damjan Marušić

Urban Drainage Failure in Durban's 2022 Floods and a SUDS Pathway to Improved Resilience **983**
Basiiraa Moosa, Trynos Gumbo, Thulisile Mphambukeli, Thokozani Simelane

Urban Mining Reloaded: Scanning Building Elements with Gaussian Splatting **995**
Peter Ferschin, Balint Kovacs, Ingrid Erb

Urban Policies and Measures to Asdapt to Excessive Heat: Madrid and London **1003**
Judith Ryser, Teresa Franchini

Utilisation of Urban Data in a Municipal Data Platform – A Field Report From the German MPSC Süd-West-Cluster **1013**
Martin Memmel, Rainer Kadel, Heinz Kirchmann

Verantwortung im Städtebau im Umgang mit Bestand, Leerstand, Ressourcen und räumlichem Erbe **1023**
Karina Brünner, Eva Schwab, Aglaée Degros

Visuelle und KI-gestützte Risikoanalyse von Ausfällen der Straßenverkehrsinfrastruktur zur Vermeidung klimabedingter Schadensereignisse durch eine erhöhte Waldbrandgefahr **1035**
Nicolas Matheis, Sascha Henninger

Vom Prompt zum Plan mit GenAI: Fotorealistische, synthetische Luftbilder im GIS als neues Werkzeug für Stadt- und Landschaftsplanung **1047**
Jeroen Staab

Von der Nische zur Norm! Mobilitätsprofile als Wissensbasis für die Förderung eines aktiven, nachhaltigen Mobilitätsverhaltens in niederösterreichischen Städten **1057**
Patrick Scherhaufer, Michael Braito, Sandra Wegener, Elisabeth Schauppenlehner-Kloyber

Von Klimarisiken zu Planungsentscheidungen. Konzeptionelle Ansätze für geodatenbasierte Klimawandelanpassung, entwickelt im GreenGEO-Projekt **1069**
Martina Majcen, Andreas Stöger, Bojan Stefanovic, Bente Knoll, Arne Meier, Dinah Hohl, Markus Karner, Wolfgang Sulzer, Harald Zandler

Von MS-COCO zur FGSV: Die Entwicklung und Validierung eines hierarchischen Klassifikationsschemas für die hochspezifische KI-gestützte Verkehrszählung in Deutschland **1081**
Jeroen Staab, Dorothee Stiller, Tobias Leichtle, Marlene Kühnl, Lena Huber, Stefan Gamperer, Klaus Martin, Robert Behringer, Helmuth Ammerl, Michael Wurm, Hannes Taubenböck

Warum passen Geographische Informationssysteme gut in den Schulunterricht? – Ein Beitrag zur Verankerung digitaler Geomedien in der Lehrerbildung **1093**
Katharina Fabisch, Sascha Henninger

What Residents Tell us about Urban Redevelopment Projects in Tokyo: A Comparison of Residents' Feedback and Government Narratives using Google Maps Reviews **1103**
Marian Stumpf, Melville Wolf-Heger

ZuZugLeben: Partizipative, soziale und klimaresiliente Vitalisierung einer Arbeitersiedlung der ÖBB – Erfahrung aus der Pilotumsetzung in St. Pölten **1115**
Ernst Rainer, Andreas Palenik, Vera Casper, Gerhard Hofer, Gernot Tscherteu,GurdrunPeller,Werner Sellinger, Markus Schuster, Guido Trampitsch

ZuZugLeben(s)Raum Passauer Straße – Tactical Urbanism als strategischer Baustein der Quartiersanierung **1125**
Andreas Palenik, Ernst Rainer, Werner Sellinger

Cost Optimisation – the Key to Energy Transition and Climate Protection **1137**
Roland Mösl

Der AACHEN-Kompass: ein innovatives Instrument zur frühzeitigen Verhandlung von Flächennutzungen **1153**
Alexander Dambietz, Nicole Arce Valdivia, Sarah Lambertus

Equity in the 20-Minute Neighbourhood: Residents' Perception in Wester Hailes, Edinburgh **1159**
Asrin Mahmoudpour, M. Reza Shirazi

From Market Value to "Climate Value": Quantifying EU ETS-2 Risks in Real Estate Valuations within the Austrian Real Estate Market and its Mitigation through Carbon Neutral Heating and Cooling **1165**
Paul Lensing

In Fourth Nature Concept, Form Follows Spirit **1173**
Simone Back Prochnow

Mapping 15-Minute Walkable Accessibility of Public Services in China's 11 National Urban Agglomerations: A Data-Driven Spatial Coverage Assessment **1179**
Jiajie Yang

Neuromarketing-Based Gamification for User Experience and Cognitive Load Management in Physical Therapy **1185**
Derya Yalcin Dogan, Hans Rüdiger Kaufmann, Adnan Kara

New Alliances and Microdevelopment Approaches for Affordable Housing in Southern Africa **1187**
Guido Spars

Regional Innovation Systems and Transformative Innovation Policy: An Embedded Approach **1193**
Markus Gruber, Michael Fischer, Andreas Maier, Konstantin Melidis

Small and Medium Size Cities: Smart, Sustainable, Resilient, Innovative with Best Quality of Life **1199**
Shepherd Samuel Nyakudya, Trynos Gumbo

Solution Paths – Paving the Way to Mobility as a Service by Analysing the Attitudes, Acceptance, and Barriers to the Use of On-Demand Mobility Services in East Styria, Austria **1205**
Nina Neundorfer, Rafael Bramreiter, Roland Sumper, Gottfried Köberl, Anna Kovacs-Gyori, Bernhard Novak, Luis Kepplinger, David Nagele, Christina Honeder, Matteo C. Sattler

Teilen ohne Barrieren: Anforderungen und Handlungsspielräume für barrierefreies Carsharing und Mitfahren **1213**
Kristin Hanna, Ivana Serafimovic, Natasa Hodzic-Srndic

The Affordability Crisis of Carbon-Intensive Heating: Assessing the Impact of EU ETS-2 on Households in Austria **1221**
Paul Lensing

The GERICS Process Model Approach to Integrate Future Climate Change Information into Adaptation Strategies **1227**
Markus Groth, Steffen Bender, Janna-Malin Gehrke, Peer Seipold

Überholverhalten von Kraftfahrzeugen gegenüber Radfahrenden im urbanen Mischverkehr: Empirische Untersuchung des Interaktionsverhaltens in Bogotá, Kolumbien **1233**
Martin Bejarano, Catharina Lutz, Jochen Eckart

Wiener Forschungsfragen: Wissen für eine klimagerechte Stadt **1239**
Johannes Lutter, Franz Oberndorfer, Katharina Meißner-Schöller, Bettina Stastny, Magdalena Holzer, Chiara Kupnik, Sonja Starnberger

Yes, we CAN! Data-Driven Decision Making with the Climate Action Navigator 1243
Veit Ulrich, Emily Wilke, Kirsten von Elverfeldt, Maria Martin, Sebastián Block, Ashwin Chandran, Danielle Gatland, Charles Hatfield, Gefei Kong, Satvik Parashar, Fatemeh Rafiei, Moritz Schott, Alexander Zipf

🏆 reviewed paper

3D City Models as Simulation Infrastructure: Open Tools, Proprietary Gaps and Application Scenarios in Everyday Planning

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1 ABSTRACT

Digital Twins are increasingly used as analytical frameworks in urban planning, supporting spatially explicit assessments of climate, energy and environmental risks. Based on interoperable 3D city models (e.g. CityGML/CityJSON) and shared geodata infrastructures, they enable scenario-based evaluations across multiple planning domains. This paper examines how Digital Twin workflows can support planning-oriented simulation tasks, with a particular focus on the interplay between open-source and proprietary tools.

Using the city of Landsberg am Lech as an applied case study, four thematic applications are investigated: solar framework planning in a protected historic ensemble, urban heat screening, pluvial flood risk assessment, and environmental noise scenarios. The workflows combine open data – most notably LOD2 building models and digital terrain models – with a hybrid toolchain including QGIS, GRASS GIS, Honeybee, ICETools, H-Risk, as well as proprietary environments such as Rhino/Grasshopper and ArcGIS Pro.

The results demonstrate that Digital Twins function most effectively as shared spatial reference systems for planning-oriented screening and orientation analyses, rather than as fully integrated simulation platforms. While physically based models such as PALM-4U represent the state of the art in urban climate modelling, simplified tools proved suitable for early-stage planning and comparative scenario evaluation. Overall, the study shows that hybrid workflows combining open and proprietary tools currently represent best practice, balancing transparency, methodological robustness, and planning relevance.

Keywords: Digital Twin, Open-Source Planning Tools, Hybrid Simulation Workflows, Noise, Urban Climate Simulation

2 INTRODUCTION

Contemporary urban planning is increasingly challenged by a set of highly complex, mutually dependent issues related to climate change, efficient resource use, and risk governance. Heat stress, pluvial flooding, noise exposure, and energy transition processes interact spatially and temporally, often exceeding the analytical capacity of traditional two-dimensional planning instruments. In this context, digital technologies have become central to contemporary planning practice. While the concept of the Smart City has primarily been associated with sensor-based, real-time optimisation and proprietary platforms (BATTY, 2018, p. 2; GRIEVES, 2014), the notion of the Open Digital Twin (DEMBSKI et al., 2020; KETZLER et al., 2020) emphasises a different paradigm: the creation of interoperable, transparent, and reproducible digital representations of urban space based on open standards and open data.

Open Digital Twins are not primarily visualisation tools but analytical infrastructures (ZIEHL et al., 2023). They integrate 3D city models, geospatial datasets, and simulation environments to support scenario-based planning, early-stage decision-making, and interdisciplinary collaboration. Their growing relevance is closely linked to the increasing availability of open geodata, such as Level of Detail 2 (LOD2) building models, digital terrain models (DTM), and open-source geographic information systems.

This paper investigates the role of Open Digital Twins in urban planning with a specific focus on climate-related applications. It addresses two central research questions:

- Which planning-relevant simulations can already be conducted entirely with open-source tools?
- In which areas do proprietary software solutions remain necessary due to regulatory, methodological, or institutional constraints?

Using the city of Landsberg am Lech as a case study, the paper demonstrates how a hybrid toolchain combining open-source and proprietary software can be implemented in practice. The contribution aims to provide both a conceptual framework and empirical insights for planners, municipalities, and researchers working with digital urban models.

3 STATE OF THE ART: SIMULATION-BASED URBAN PLANNING WITH DIGITAL TWINS

3.1 3D City Models as Analytical Infrastructure

The application of digital twins in urban planning has expanded significantly over the last decade, driven by advances in geospatial data availability, 3D city modelling, and simulation technologies. Rather than constituting a single methodological approach, digital twins increasingly function as integrative frameworks that support multiple thematic analyses (JEDDOUB et al., 2023). In current research and planning practice, four application domains are particularly prominent: solar energy assessment, urban climate modelling, hydrological risk analysis, and environmental noise evaluation (ZHU & JIN, 2025).

3.2 Solar Potential Analysis and Urban Solar Frameworks

Solar potential analysis represents one of the most mature and widely applied use cases of 3D city models in urban planning. The availability of LOD2 building data enables the calculation of roof orientation, inclination, shading effects, and annual solar irradiation with high spatial resolution. Numerous studies demonstrate that solar cadastre systems based on 3D city models provide reliable decision support for municipal energy strategies (BROSCHART et al., 2024).

Recent research increasingly emphasises strategic, city-wide solar planning beyond parcel-based assessments. Solar framework plans (Solarrahmenpläne) translate technical potential analyses into spatially differentiated planning instruments that integrate urban morphology, heritage protection, densification strategies, and policy objectives (ZEILE et al., 2025).

Methodologically, these approaches rely on reproducible GIS-based workflows. While open-source tools support transparent modelling of solar radiation and scenario comparison (ROUDSARI et al., 2013), proprietary software remains relevant for detailed economic or grid-related assessments. The solar framework plan presented at REAL CORP 2025 (ZEILE et al., 2025) illustrates how Digital Twins can serve as spatial decision-support systems that link energy analysis and urban planning.

3.3 Urban Climate and Heat Stress Modelling

Urban climate modelling has become increasingly important due to rising heat stress and the need for climate adaptation. Digital twins support this domain by providing detailed representations of urban form, which strongly influence radiation balance, airflow, and thermal comfort (LOPEZ-CABEZA et al., 2025).

Current approaches range from simplified surface-based models to entirely physical, three-dimensional atmospheric simulations. Open-source tools such as Ladybug/Honeybee enable accessible, iterative assessments of solar exposure and shading, while the PALM-4U model system represents a state-of-the-art, physically based approach to urban climate simulation (BAKLANOV et al., 2020; HELDENS et al., 2020).

Proprietary tools such as ENVI-met remain widely used for detailed microclimatic studies (BRUSE, 2000), although recent literature highlights the suitability of simplified models for planning-oriented, comparative analyses.

3.4 Pluvial Flooding and Surface Runoff Analysis

Hydrological risk analysis, particularly pluvial flooding, has become increasingly relevant in urban planning due to the rising frequency of extreme rainfall events. Digital twins enable the integration of terrain models, surface characteristics, and built structures to analyse runoff pathways and accumulation zones.

Open-source GIS environments such as GRASS GIS and QGIS provide robust tools for surface runoff analysis (SCHNEIDER, 2025; “SplashTool”). These methods support transparent, reproducible modelling and are widely applied in municipal risk mapping and climate adaptation planning. Proprietary platforms such as ArcGIS Pro offer extended functionalities and are often embedded in administrative workflows, while the underlying modelling principles remain transferable across software environments.

3.5 Environmental Noise Modelling

Environmental noise assessment constitutes an established application of digital spatial models. Noise exposure is strongly influenced by building geometry, street layout, and traffic volumes, making 3D city models particularly suitable for spatially differentiated analysis.

Recent developments in open-source GIS plugins, such as H-Risk (TAGUSARI, 2024), demonstrate that scenario-based noise modelling can support early planning stages by enabling relative comparisons of urban form, traffic management, and mitigation measures. For legally binding noise assessments, proprietary software remains dominant; however, the literature increasingly acknowledges simplified tools as complementary instruments in planning practice.

3.6 Synthesis

Across all four domains, the literature indicates a convergence towards scenario-based planning workflows supported by Digital Twins. While thematic priorities differ, shared methodological requirements – interoperable data models, reproducible simulations, and spatial transparency – are evident. Solar framework planning emerges as a particularly effective interface between technical simulation and strategic urban planning, highlighting the broader potential of Digital Twins as decision-support systems.

4 LANDSBERG AM LECH TEST-SITE

4.1 The (Open) Digital Twin of Landsberg am Lech

The city of Landsberg am Lech serves as a case study demonstrating how Open Digital Twin workflows can be implemented in municipal planning practice. As a medium-sized city with accessible open geodata, a heterogeneous building stock, and increasing challenges related to climate adaptation and energy transition, Landsberg am Lech represents a typical and transferable European planning context.

The digital twin used in this study follows a planning-oriented interpretation of the Digital Twin concept, as discussed in recent contributions (BROSCHART et al., 2025). Rather than aiming at real-time monitoring or sensor-driven control, the model focuses on spatial analysis, scenario development, and decision support for strategic and early-stage planning processes, aligning with research that positions urban digital twins as integrative spatial frameworks rather than purely operational systems.

The data basis consists primarily of open and municipal datasets, including a Level of Detail 2 (LOD2) building model, a high-resolution digital terrain model (DTM), land use information, and thematic layers related to vegetation, mobility infrastructure, and environmental constraints. These datasets were harmonised within a GIS environment using interoperable data models, enabling consistent use across multiple analytical domains.

Crucially, the digital twin is not conceived as a monolithic model but as a shared spatial reference system connecting different simulation tools and thematic analyses. In this sense, the model represents a planning-oriented digital twin, designed to support scenario-based analysis, comparative evaluation, and interdisciplinary workflows. This structure allows diverse planning questions – such as solar energy potential, urban heat mitigation, surface runoff, and noise exposure – to be addressed using a common geometric and semantic foundation while retaining methodological flexibility.

By emphasising openness, reproducibility, and thematic integration, the Landsberg am Lech Digital Twin demonstrates how municipalities can operationalise digital twins as practical planning instruments that support both technical analysis and strategic discourse.

4.2 Solar Framework Planning using the Digital Twin

Solar energy assessment constitutes a particularly relevant application of Digital Twins in historic urban contexts, where technical potential alone is insufficient as a planning criterion. In Landsberg am Lech, the Digital Twin was applied to develop a solar framework plan (Solarrahmenplan) explicitly addressing the challenges of solar energy deployment within a protected historic ensemble. The central planning question was not whether solar energy is technically feasible, but which types of solar installations are compatible with heritage protection requirements and urban visual integrity.

4.2.1 Planning Context: Solar Energy in Historic Ensembles

The historic core of Landsberg am Lech is characterised by a dense building fabric, heterogeneous roof typologies, and strict heritage protection regulations. In such contexts, conventional solar cadastres reach their limits because they typically identify technically suitable roof surfaces without accounting for visual exposure, material compatibility, or monument-preservation objectives.

The solar framework plan, therefore, reframes solar potential analysis as a spatial governance instrument. Its purpose is to support differentiated planning decisions by identifying zones where solar installations are permissible, conditionally acceptable, or to be avoided, and by distinguishing between different photovoltaic and solar thermal technologies. This approach follows the logic presented in recent CORP research (ZEILE et al., 2025), positioning solar framework planning as an interface between energy transition and urban heritage management.

4.2.2 Digital Twin as Analytical and Visual Reference

Solar irradiation analysis was used as a supporting layer within the framework plan, but did not constitute its primary decision criterion. Instead, irradiation values were interpreted in combination with roof typologies, visibility conditions, and conservation guidelines. This enabled the classification of roof surfaces into differentiated categories, such as suitable for non-visible installations, ideal for visually integrated systems, or unsuitable due to heritage sensitivity.

The analytical workflow combined GIS-based processing with parametric modelling environments. While open-source tools were used to prepare and structure the LOD2 data, subsequent analyses and visual evaluations were conducted in commercial software environments, including Rhino/Grasshopper and ArcGIS Pro (Fig. 1). This hybrid setup reflects planning practice, in which analytical requirements rather than licensing models guide tool selection.

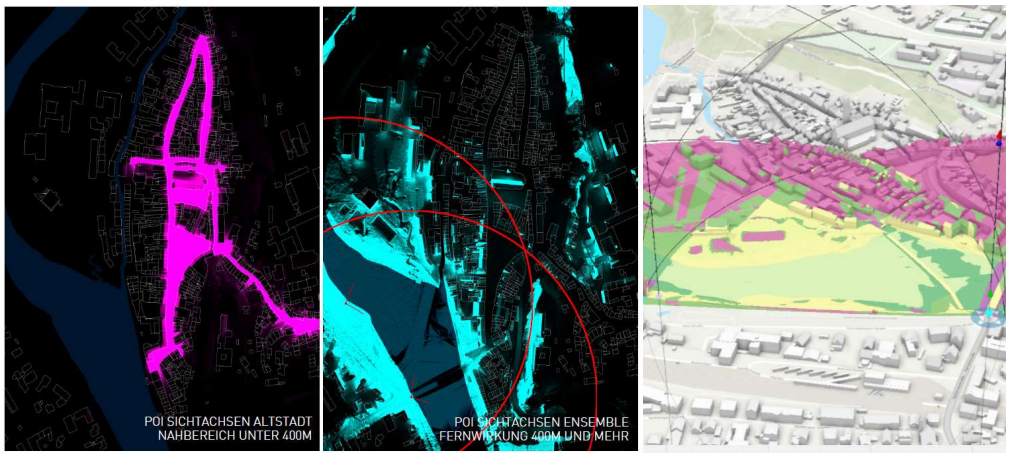


Fig. 1: Various approaches to visibility analysis using Rhino and ArcGISPro (left& middle: Herm & Benkeser 2025, right: own source)

4.2.3 Modelling Solar Suitability under Heritage Constraints

Solar irradiation analysis was used as a supporting layer within the framework plan, but did not constitute its primary decision criterion. Instead, irradiation values were interpreted in combination with roof typologies, visibility conditions, and conservation guidelines. This allowed the classification of roof surfaces into differentiated categories, such as suitable for non-visible installations, ideal for visually integrated systems, or unsuitable due to heritage sensitivity.

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4.2.4 Differentiation of Solar Technologies

A key contribution of the solar framework plan lies in its explicit differentiation among solar technologies. Rather than treating photovoltaic systems as a homogeneous category, the framework distinguishes between conventional PV modules, building-integrated photovoltaics (BIPV), solar tiles, and solar thermal systems. Each technology exhibits distinct visual characteristics and degrees of compatibility with historic roofscapes.

By linking technology categories to spatial zones within the Digital Twin, the solar framework plan provides concrete guidance for planners, heritage authorities, and property owners. In this role, the Digital Twin acts

as a mediating instrument, translating abstract conservation principles into spatially explicit planning recommendations.

4.2.5 Planning Relevance and Strategic Value

The Landsberg am Lech solar framework plan demonstrates how Digital Twins can support nuanced planning decisions in sensitive urban contexts. Rather than maximising energy yield, the framework prioritises contextual appropriateness and visual integration, thereby reducing the potential for conflict between energy policy and heritage protection.

Importantly, the Digital Twin does not replace detailed architectural design or approval procedures. Instead, it provides strategic orientation at an early stage, supports transparent communication among stakeholders, and increases planning certainty.

4.3 Urban Heat and Microclimate Assessment

Urban heat stress represents a critical challenge for cities, particularly in dense urban areas with limited vegetation and high surface sealing. Within Open Digital Twin workflows, microclimate assessment functions as an essential analytical layer for evaluating the spatial effects of urban form, materiality, and vegetation on thermal comfort. In the Landsberg am Lech case study, urban heat assessment was implemented as a planning-oriented screening and orientation tool, rather than as an entirely physical climate simulation.

4.3.1 Reference Framework: Physically Based Urban Climate Models

From a scientific perspective, physically based urban climate models such as PALM-4U represent the state of the art in microclimate simulation. PALM-4U enables high-resolution modelling of air temperature, radiant heat fluxes, airflow, vegetation–atmosphere interactions, and human thermal comfort, and its integration into Digital Twin environments is increasingly discussed in research and municipal climate adaptation studies (BENDER et al., 2023).

However, despite its methodological advantages, PALM-4U requires substantial computational resources, specialised expertise, and extended setup times. In the Landsberg am Lech case study, PALM-4U served as a conceptual reference model but was not applied operationally. Instead, simplified and more accessible approaches were selected to support exploratory planning questions.

4.3.2 Applied Tools: Honeybee and ICETools

Urban heat assessment in Landsberg am Lech was conducted using a combination of Honeybee (Grasshopper/Rhino) and ICETools (QGIS). These tools were selected to balance analytical relevance with practical feasibility in a planning context, as demonstrated in accompanying academic exercises.

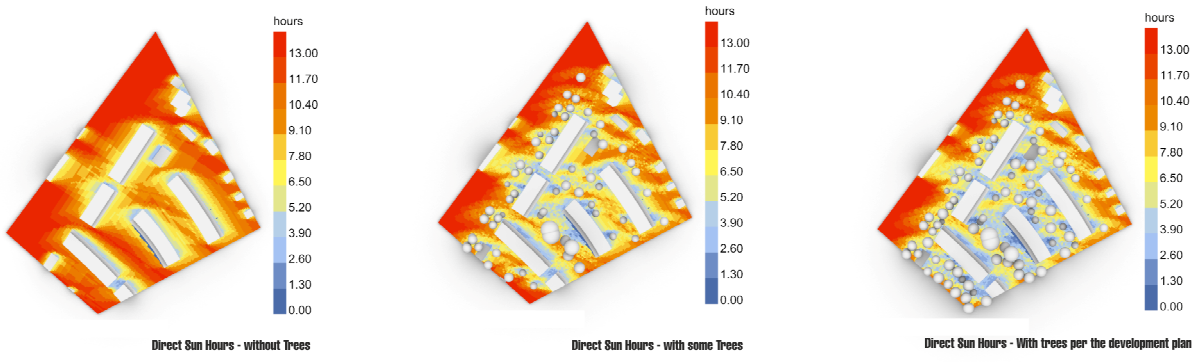


Fig. 2: Heat development in the xy new development area in Landsberg with varying vegetation densities, simulated in Heneybee. The areas with reduced heat stress due to vegetation are clearly visible. (Flores & Zumholte 2025)

Honeybee was used to analyse solar radiation exposure, shading patterns, and surface-related thermal indicators using the LOD2 building model and selected scenarios. Its parametric structure supports rapid iteration and comparison of spatial configurations, particularly regarding vegetation placement and building geometry. While Honeybee does not simulate atmospheric dynamics, it provides valuable insights into radiation-driven heat loads (see Fig.2).

ICETools was used as a complementary method to estimate surface temperature patterns based on simplified energy balance calculations. By integrating land cover, vegetation, and shading information, ICETools enables reproducible, low-threshold heat assessments that are well-suited for early-stage planning and scenario comparison.

4.3.3 Methodological Limitations of Tool Integration

Despite increasing tool availability, the integration of urban climate simulations into Digital Twin workflows remains methodologically fragmented. Tools such as ICETools and ENVI-met require substantial model reconstruction, as existing Digital Twin geometries cannot be used seamlessly. Buildings, vegetation, surface materials, and boundary conditions must be newly parameterised within each simulation environment, limiting reproducibility and increasing modelling effort.

Parametric environments such as Honeybee offer greater interoperability, as 3D city models can be imported directly. However, practical experience shows that combining LOD2 building geometries with digital terrain models (DTMs) poses significant challenges. At building–terrain interfaces, geometric inconsistencies may occur, leading to artefacts such as implausible surface temperature anomalies ("cold spots").

These issues are primarily caused by geometric and semantic mismatches between datasets generated for different purposes. Without careful preprocessing and validation, such inconsistencies can propagate into simulation results. Consequently, current Digital Twin workflows should be understood as loosely coupled toolchains, reinforcing the need for staged modelling approaches in which simplified tools support early decision-making and more complex models are applied selectively.

4.4 Pluvial Flood Risk and Surface Runoff

Pluvial flooding constitutes a recurring challenge in urban planning, particularly in compact settlement structures with high degrees of surface sealing. In the case of Landsberg am Lech, surface runoff analysis was implemented as a planning-oriented screening tool to rapidly identify spatial patterns, flow paths, and potential accumulation zones relevant to urban development and climate adaptation.

4.4.1 Data Basis and Digital Twin Integration

The analysis was based on a Digital Terrain Model (DTM) and the LOD2 building model, both of which could be directly integrated into the Digital Twin environment. The DTM provided the basis for modelling surface gradients and runoff directions, while LOD2 buildings served as physical obstacles that influenced flow paths and accumulation areas.

A key advantage of this approach is the flexibility in data preparation. Terrain data can be rapidly adjusted using grayscale heightmaps, enabling quick testing of alternative surface conditions or simplified scenarios. This allows planners to explore assumptions about surface sealing, microtopography, or redevelopment with minimal preprocessing effort, while ensuring consistent representation of terrain and built structures.

4.4.2 Modelling Approach and Tools

Surface runoff modelling was conducted using QGIS Splash Tools and ArcGIS Pro flow path analysis, both of which support direct use of terrain and building data without complex model reconstruction. The tools calculate flow directions and accumulation zones based on terrain gradients and produce visually intuitive results.

The modelling approach focuses on relative flow behaviour, highlighting areas where water is likely to concentrate during intense rainfall events. Rather than simulating exact water depths or temporal dynamics, the analysis identifies structural vulnerabilities in the urban fabric. While terrain and building data can be ingested directly, the modelling process remains loosely coupled to the Digital Twin and requires tool-specific parameterisation.

4.4.3 Visualisation and Interpretability

A central strength of the applied method is the visual clarity of the results. Flow paths, accumulation areas, and potential impact zones can be visualised directly within the Digital Twin, supporting intuitive interpretation by planners and non-technical stakeholders. As both tools operate on raster-based height models, results can be rapidly updated, enabling iterative scenario evaluation.

The pluvial flood analysis is explicitly coarse and exploratory. It does not account for underground drainage systems, sewer capacities, or time-dependent rainfall scenarios. Accordingly, results are interpreted as orientation maps for planning, not as regulatory flood hazard maps. Embedded within the Digital Twin, the analysis supports prioritisation and complements other thematic assessments in a holistic planning context.

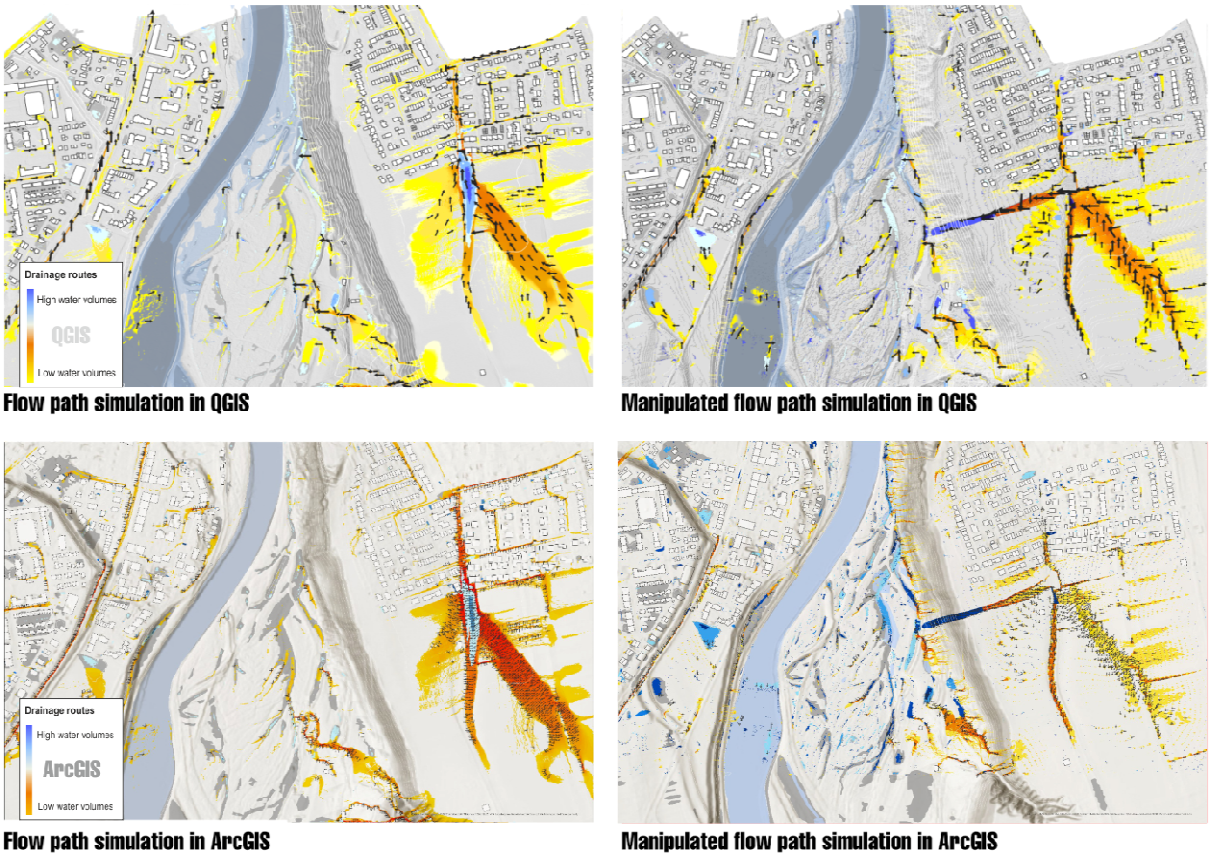


Fig.3: Comparison of the stream path simulation in QGIS and ArcGIS in the inventory (left side) and diverted water flow through terrain adaptation on the right (Kappeler & Schwarz 2025)

4.4.4 Planning Relevance and Limitations

The pluvial flood analysis conducted for Landsberg am Lech is explicitly coarse and exploratory. It does not account for underground drainage systems, sewer capacities, or time-dependent rainfall scenarios. Nevertheless, its value lies in its ability to quickly identify potential problem areas and support strategic planning discussions.

In line with the approach presented here, the results are interpreted as orientation maps for planning rather than regulatory flood hazard maps. They provide a robust basis for prioritising areas where further, more detailed hydrological or engineering analyses may be required. Embedded within the Digital Twin, the pluvial flood assessment complements other thematic analyses and contributes to a holistic understanding of spatial vulnerability in urban planning.

4.5 Environmental Noise Scenarios

Environmental noise represents an established but methodologically demanding field within urban planning. While norm-based proprietary software solutions often dominate noise assessment, recent work demonstrates that planning-oriented noise scenarios can also be explored within Digital Twin environments using simplified, transparent approaches. In the Landsberg am Lech case study, environmental noise modelling was therefore included as a supplementary analytical layer, in accordance with established methodological principles.

4.5.1 Planning-Oriented Noise Assessment

From a planning perspective, early-stage noise assessment focuses less on legally binding exposure values and more on relative spatial patterns. Key questions include the location of noise-sensitive uses, the influence

of urban form on sound propagation, and the potential effects of alternative planning scenarios. Digital Twins provide a suitable spatial framework for addressing these questions, as building geometry, street networks, and land use are already integrated.

4.5.2 Applied Tools and Workflow

In Landsberg am Lech, noise scenarios were explored using H-Risk in QGIS, integrating open street data, traffic assumptions, and building geometries. The LOD2 building model served as the geometric basis for modelling reflecting and shielding effects, while OpenStreetMap (OSM) road network data provided the source structure for noise emission modelling (Fig. 4).

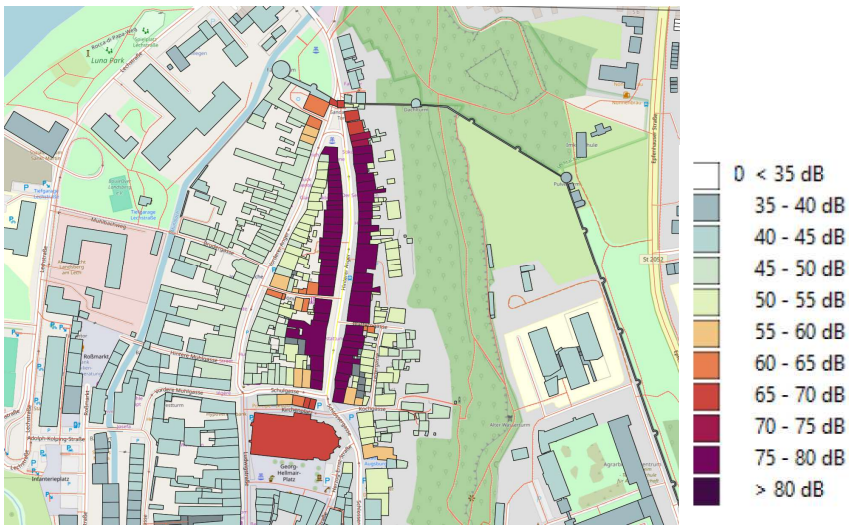


Fig. 4: Noise level at the facade 30km/h in QGIS/H-Risk (Strifler & Daum, 2025)

The workflow follows a simplified approach: traffic volumes and speed assumptions are parameterised, and resulting noise levels are calculated and visualised as spatial distributions. This enables rapid comparison of alternative scenarios, such as changes in traffic routing or street hierarchy. The Digital Twin ensures spatial consistency with other thematic analyses, while the noise analysis itself operates on a tool-specific abstraction rather than a fully integrated twin model.

4.5.3 Interpretation and Limitations

The applied noise modelling approach is explicitly non-normative. It does not replace standardised noise mapping procedures required for regulatory compliance. Still, it serves as a planning-oriented screening and orientation tool, highlighting areas where noise exposure may become critical under certain assumptions. Such simplified models are particularly valuable in early planning stages, where they support spatial awareness and informed discussion rather than final verification. For legally binding assessments, proprietary tools such as CadnaA or SoundPLAN remain necessary.

5 CONCLUSIONS, SYNTHESIS AND OUTLOOK

Taken together, the four applied use cases illustrate that the Digital Twin of Landsberg am Lech functions less as a fully integrated simulation environment and more as a shared spatial reference for planning-oriented screening analyses. This hybrid use of open and proprietary tools forms the basis for the comparative synthesis presented in this chapter.

5.1 Synthesis of Findings

This paper explores how Open Digital Twin workflows can support simulation-based urban planning, using Landsberg am Lech as a case study. Across the four thematic domains – solar framework planning, urban heat assessment, pluvial flooding, and environmental noise – the results demonstrate that the Digital Twin functions most effectively as a shared spatial reference system, rather than as a fully integrated simulation environment. The applied examples confirm that Digital Twins are particularly valuable for planning-oriented screening and orientation analyses. Their primary contribution lies not in predictive accuracy or regulatory compliance but in structuring complex spatial questions, enabling scenario comparison, and

supporting interdisciplinary communication. This finding aligns with recent research that positions urban digital twins as integrative planning infrastructure rather than operational control systems.

A central insight from the Landsberg am Lech case is that thematic simulations do not require monolithic or fully synchronised models. Instead, loosely coupled workflows, anchored in a consistent geometric and semantic base, allow planners to address different questions with appropriate tools.

5.2 Open-Source and Proprietary Tools: A Comparative Perspective

A key objective of this study was to assess the role of open-source and proprietary software within Digital Twin workflows. The results indicate that tool choice is primarily driven by planning objectives and methodological requirements, rather than by licensing models.

Open-source tools play a crucial role in early-stage planning and exploratory analysis by supporting transparency, reproducibility, and rapid iteration. Proprietary tools remain relevant where standardised procedures, normative requirements, or advanced physical modelling are required. Table 1 summarises the complementary roles of both tool categories across the four thematic domains.

Planning Domain	Open-Source / Accessible Tools	Proprietary Tools	Role within the Digital Twin
Solar Planning	QGIS, GRASS GIS, parametric modelling (data preparation)	Rhino/Grasshopper, ArcGIS Pro	Strategic spatial differentiation (Solar Framework Plan)
Urban Heat	Honeybee, ICETools	ENVI-met, PALM-4U (reference)	Screening and comparative scenario analysis
Pluvial Flooding	QGIS Splash Tools, GRASS GIS	ArcGIS Pro	Identification of flow paths and accumulation zones
Environmental Noise	H-Risk (QGIS)	CadnaA, SoundPLAN	Orientation and scenario comparison

Table 1: Open-Source and Proprietary Tools in Planning-Oriented Digital Twin Workflows

Rather than competing alternatives, open-source and proprietary tools form complementary components of hybrid workflows, with open data – particularly LOD2 buildings and terrain models – providing the stable foundation for both.

5.3 Methodological Implications for Digital Twin Use

The applied workflows highlight several methodological implications. First, full integration of simulation tools into a single Digital Twin environment remains limited, as climate, hydrological, and noise models typically require tool-specific abstractions of geometry and attributes.

Second, geometric and semantic mismatches – particularly at building–terrain interfaces – represent a persistent challenge across simulation domains. Acknowledging these limitations is essential to avoid overinterpretation and to maintain methodological transparency.

Third, a staged modelling approach emerges as a pragmatic strategy: lightweight, planning-oriented tools support early decision-making, while advanced, physically based models can be applied selectively when higher accuracy or regulatory compliance is required.

5.4 Outlook

Future developments in semantic data modelling, improved terrain–building integration, and the maturation of open-source simulation frameworks such as PALM-4U may reduce current interoperability barriers. At the same time, institutional learning and capacity building will be critical for responsible and effective Digital Twin use. Rather than striving for fully integrated, all-encompassing platforms, planning practice may benefit more from robust, modular Digital Twins that support thematic extension and methodological flexibility. The Landsberg am Lech case demonstrates that such an approach is already feasible and can meaningfully contribute to climate-responsive, context-sensitive urban planning.

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A Digital Transformation Assessment on the Role of Building Information Model Training in Built Environment Institution Programmes: Lessons from South Africa

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1 ABSTRACT

Digital transformation in the Built Environment is increasingly underpinned by the adoption and maturity of Building Information Modelling (BIM), a critical tool for enhancing technological skills and addressing complex infrastructure and service delivery challenges. However, the availability of comprehensive BIM training programs in higher education remains inadequate, limiting graduates' and practitioners' capacity to apply and integrate BIM effectively in professional contexts. This study adopts a mixed-methods approach to evaluate the maturity and integration of BIM training in South African Built Environment higher education programmes. The findings reveal that most available programs focus on introducing basic BIM concepts and adoption strategies, advanced training necessary for higher levels of BIM maturity is largely absent. While short learning programs have been developed to upskill industry practitioners, formal curricula face persistent barriers, including limited access to state-of-the-art facilities, software and licensing costs, and structural rigidities within module offerings. The study argues that these challenges undermine both the digital transformation within the Built Environment and the competitiveness of graduates entering professional practice. Ultimately, the findings underscore the urgent need for policy and institutional reforms to accelerate digital transformation and ensure that the Built Environment workforce is equipped with the skills required to meet the demands of contemporary urbanisation and infrastructure development.

Keywords: Digital transformation, training, higher institutions, Building Information Modelling, Built environment

2 INTRODUCTION

Adoption and maturity of revolutionary technologies such as Building Information Modelling (BIM) are critical in the Built Environment (BE) for improving project performance and enhancing infrastructure delivery. Digital Transformation (DT), driven by the principles of Industry 4.0, has advanced building systems significantly since the industrial revolution towards hybridised, intelligent and interconnected systems (Hazrat et al., 2023). Within the BE, Industry 4.0 technologies including big data analytics, artificial intelligence, virtual modelling and integrated project delivery are reshaping traditional infrastructure management approaches. This shift is particularly relevant in contexts facing infrastructure backlogs, rapid urbanisation and service delivery pressures, such as South Africa.

BIM occupies a central position within this digital transformation agenda. It provides innovative, effective and collaborative digital processes and management tools that equip professionals with the technological skills required to address complex infrastructure and service delivery challenges (Akintols et al., 2020; Omar & Dulaimi, 2023; Obi et al., 2024). According to McAuley and Behan (2019), BIM can be utilised for multiple analyses and performance predictions, particularly in projects requiring collaborative three-dimensional design applications. It reshapes and simplifies the BE by enhancing professional roles and responsibilities across the planning, design, construction, operation, and maintenance phases (Whyte & Hartmann, 2017). Furthermore, DT interventions contribute to notable productivity gains by supporting professionals with comprehensive, accurate, and real-time information for day-to-day decision-making (Kaushalya et al., 2024).

Numerous scholars argue that the evolution of DT has contributed significantly to mitigating climate and sustainability challenges in the BE by moving beyond traditional infrastructure management approaches (Muzi et al., 2022; Samuelson & Stehn, 2023). The shift from fragmented, time-consuming and financially costly traditional techniques towards multidisciplinary, digitally enabled processes enhances value creation across the infrastructure chain (Hajj et al., 2021). The adoption of DT further supports sustainable strategies

and green practices in urban BE contexts experiencing considerable environmental and social pressures (Stroumpoulis & Kopanaki, 2022). For example, large volumes of social and environmental data can be modified and virtualised in real time to identify potential threats, simulate predictive scenarios and recommend resilient infrastructure interventions (Daniotti et al., 2020; Muzi et al., 2022; Saka, 2022). Understanding information through data analytics thus provides multiple pathways for improving infrastructure performance and service delivery (Whyte & Hartmann, 2017).

Despite these advantages, graduates' and practitioners' capacity to effectively apply and integrate BIM in professional contexts remains constrained. Training programmes on BIM adoption are more critical than ever in responding to the demands of big data and rapid urban development. However, many higher education institutions experience inadequate BIM integration within their curricula, resulting in graduates who are insufficiently prepared for digitally enabled practice. Rather than expecting industry to shoulder the responsibility of upskilling graduates, scholars argue that students should be trained during their educational journey to become BIM-ready professionals, thereby avoiding additional financial and time burdens on industry (Iqbal et al., 2022; Olowa et al., 2022; Hazrat et al., 2023). At the same time, Yusuf et al. (2017) highlight that higher education institutions face challenges related to limited knowledge, skills, finances, and resources, which constrain the development of a high-standard BIM workforce. Iqbal et al. (2022) therefore advocate for stronger industry participation in collaborative seminars, workshops and international engagements to facilitate skills transfer to educators.

In developing countries, the adoption and maturity of DT, including BIM, big data analytics, virtual modelling, artificial intelligence, and green building technologies, remains comparatively slow (Saka, 2022). Although university–industry research collaboration is recognised as a key driver of technological innovation and BIM maturity (Iqbal et al., 2022), limited attention has been given to systematically evaluating the scope, depth and maturity of BIM training within university programmes, particularly in the South African context. This gap has significant implications for digital transformation and graduate readiness within the BE sector.

Accordingly, this study aims to evaluate the maturity and integration of BIM training in South African BE higher education programmes. To achieve this aim, the study employs a mixed-method approach comprising a literature review, surveys and semi-structured interviews involving students, academics and professionals in Urban and Regional Planning, Construction, Civil Engineering and Architecture. Through this investigation, the research seeks to provide empirical insights into strengthening BIM education as a strategic enabler of digital transformation in the South African Built Environment.

3 LITERATURE REVIEW

3.1 Digital Transformation in the Built Environment

In recent years, DT has increasingly differentiated performance across industries within BE, particularly in infrastructure construction and service delivery. Improvements in organisational capabilities and production efficiency have largely been driven by the integration of digital technologies (Samuelson & Stehn, 2023). Globally, regions such as the European Union have capitalised on the growth potential of DT technologies, including artificial intelligence (AI), robotics, advanced manufacturing, blockchain technologies, three-dimensional (3D) printing and the Internet of Things (IoT), particularly in managing and extracting value from big data (Daniotti et al., 2020). These technologies strengthen sustainable strategies across supply chains, enable real-time operational monitoring, and support resilience-oriented green practices (Stroumpoulis & Kopanaki, 2022). Consequently, the adoption of Information Technology (IT) is no longer optional but necessary to enhance stakeholder performance and infrastructure delivery outcomes (Kaushalya et al., 2024).

In developed countries, higher education institutions have increasingly aligned curricula with Industry 4.0 technologies, producing graduates who are digitally competent and responsive to evolving BE industry demands (McAuley & Behan, 2019; Daniotti et al., 2020; Stroumpoulis & Kopanaki, 2022; Hazrat et al., 2023). This alignment has strengthened the dominance of digital approaches in many developed contexts. However, the transition is not universally consistent. For example, in Italy, traditional construction management practices still dominate certain stages of the BE operational cycle despite the availability of DT technologies (Muzi et al., 2022). In developing countries, adoption is generally slower and more fragmented.

Although DT technologies form part of contemporary industrial discourse, higher education institutions in many developing contexts continue to lag in implementation (Benavides et al., 2020; Badran et al., 2022). Structural challenges, including corruption, weak governance, limited funding, and shortages of skilled personnel, restrict institutional capacity to modernise curricula and infrastructure (Hannan, 2023). In extreme cases, geopolitical instability further constrains digital adoption, as illustrated in conflict-affected contexts such as Syria (Habib, 2023).

These global dynamics resonate with realities in South Africa, where higher education institutions operate under financial constraints, uneven digital infrastructure and significant student enrolment pressures. While national policies promote digital innovation and infrastructure development, practical implementation within BE programmes remains uneven. As a result, digital transformation in the South African BE sector continues to be characterised by pockets of excellence rather than systemic maturity.

3.2 BIM Adoption and Training in Higher Education

Contemporary research positions BIM as a central enabler of digital transformation in the BE. Increasingly, BIM is integrated with emerging technologies such as IoT, augmented and virtual reality (AR/VR), AI, drones, robotics, 3D printing, and laser scanning (Prabhakaran et al., 2021; Liu et al., 2021). When integrated effectively, these technologies extend BIM beyond three-dimensional modelling into a dynamic decision-support ecosystem. For instance, IoT sensors embedded within buildings enable real-time data collection on structural performance, energy consumption, and environmental conditions. When linked to BIM platforms, these datasets support predictive maintenance and lifecycle optimisation. Similarly, AR/VR technologies enhance stakeholder engagement by enabling immersive visualisation of design alternatives prior to construction, reducing costly revisions. AI and machine learning algorithms applied to BIM datasets improve risk identification, detect design inefficiencies, and optimise scheduling processes (Bunse et al., 2025). Drone and laser scanning technologies facilitate the development of accurate as-built models, improving monitoring and quality control.

Despite these advances, the integration of BIM with advanced technologies remains uneven across regions and sectors. While BIM research continues to expand ranging from design coordination improvements to automation and robotics integration (Jayasena et al., 2024; Adegoke et al., 2026) the field has evolved in an incremental and fragmented manner, often lacking a coherent digital transformation narrative (Azhar, 2011; Volk et al., 2014; Yalcinkaya & Singh, 2015). Much of the literature focuses on adoption strategies, implementation barriers and best practices, yet comparatively limited attention has been given to educational maturity and curriculum integration, particularly in developing country contexts.

A recurring challenge identified in the literature is the difficulty of integrating BIM into existing organisational systems and workflows (Volk et al., 2014; Schroeder et al., 2020). Technical interoperability constraints, institutional resistance to change, and insufficient digital infrastructure frequently inhibit progress. These challenges are amplified in resource-constrained environments, where managing large-scale, data-intensive models places significant demands on hardware, software licensing, and specialist expertise.

The concept of BIM maturity provides a useful framework for evaluating implementation depth. Maturity models generally conceptualise BIM development along progressive levels:

- Level 0: A pre-BIM environment dominated by two-dimensional CAD drawings and paper-based documentation, with minimal digital collaboration. In many South African small and medium-sized enterprises, this level still characterises routine practice, particularly in municipal infrastructure projects.
- Level 1: Partial digitalisation through isolated 3D modelling tools. While visualisation improves, collaboration remains siloed, and data exchange is limited. Some South African universities introduce BIM at this level through standalone modelling modules without interdisciplinary integration.
- Level 2: Collaborative workflows supported by standardised data exchange formats (e.g., Industry Foundation Classes, IFC). Stakeholders share coordinated models, improving clash detection and reducing errors. Larger South African firms involved in commercial developments increasingly operate at this level, although adoption is inconsistent across sectors.

- Level 3 (and beyond): Fully integrated digital environments linking design, construction and operation across the entire project lifecycle. Cloud-based platforms, real-time collaboration, AI-driven analytics and automated processes define this level. In South Africa, examples remain limited and are typically confined to high-budget or multinational projects.

These maturity levels highlight that BIM adoption is not solely a technical issue but also an organisational and educational one. Institutional readiness, curriculum design, educator competence and industry collaboration are critical determinants of progression across levels. Although numerous studies examine BIM implementation in practice, fewer critically assess the scope and maturity of BIM training within higher education institutions, particularly in developing contexts. Existing research often assumes that educational institutions are adequately preparing graduates for digital transformation, yet empirical evidence from resource-constrained settings suggests otherwise. In South Africa, limited curriculum integration, insufficient interdisciplinary collaboration, and uneven access to digital infrastructure may hinder the production of BIM-ready graduates.

Therefore, a clear research gap exists in systematically evaluating the scope, depth, and maturity of BIM training within BE programmes in developing country contexts. This study addresses that gap by assessing BIM training across disciplines, identifying curricular and institutional barriers, and analysing implications for digital transformation and graduate readiness within the South African Built Environment sector.

4 METHODOLOGY

This study adopted a mixed-methods research design to systematically examine the role, delivery, and perceived effectiveness of BIM training BE programmes offered by higher education institutions. The use of a mixed-methods approach was justified on the basis that BIM adoption and maturity encompass both measurable structural elements (such as training exposure, curriculum content, and resource availability) and experiential dimensions (such as perceptions of competence, institutional readiness, and preferred learning platforms). Integrating quantitative and qualitative data, therefore, enabled triangulation, enhanced validity, and provided a more comprehensive understanding of BIM training dynamics (Whyte et al., 2017; Badran et al., 2022). While quantitative data offered measurable indicators of BIM maturity and training scope, qualitative insights contextualised these findings by capturing stakeholder experiences and institutional realities.

An online survey was administered in 2025 to capture patterns of BIM training provision, utilisation, associated challenges and levels of BIM maturity across professional and academic groups in the BE sector. The survey instrument was structured around four key thematic areas, namely Exposure to BIM training, Scope and content of BIM training, BIM maturity and advanced digital skills and Resources and institutional support. The development of the questionnaire followed a multi-stage process to ensure contextual relevance and methodological rigour. Initially, a draft instrument was developed based on a review of existing literature on BIM adoption, maturity models and digital transformation in higher education. Thereafter, the instrument was refined through consultation with key stakeholders from government departments, professional councils, industry associations and academic institutions. To enhance reliability and content validity, a series of focus group discussions were conducted prior to full deployment. These discussions served to verify the clarity of questions, align terminology with industry standards, and ensure that the instrument reflected both educational realities and professional expectations. Feedback from the focus groups informed revisions to question wording, response scales, and thematic categorisation, thereby strengthening the robustness of the final survey tool.

A total of 90 respondents participated in the study. Participants were purposively selected to reflect the multidisciplinary nature of the Built Environment sector. The sample comprised of Undergraduate and postgraduate students enrolled in BE programmes, Academics involved in curriculum development and BIM instruction and Industry professionals, including practitioners from Urban and Regional Planning, Construction Management, Civil Engineering and Architecture, as well as representatives from professional bodies and government departments. This distribution ensured representation across the education–industry continuum, enabling the study to assess both training provision and professional expectations regarding graduate readiness.

Data collection was conducted in 2025. The study adhered to established ethical standards and received formal approval from the University of Johannesburg Ethics Committee prior to commencement. Participation was voluntary, and informed consent was obtained from all respondents before completing the survey and participating in the focus group. Respondents were assured of confidentiality and anonymity, and data were securely stored in accordance with institutional research governance policies. Quantitative survey data were analysed using descriptive and inferential statistical techniques. Descriptive statistics (including frequencies, percentages and mean scores) were used to assess levels of BIM exposure, training scope and perceived maturity. Comparative analysis across participant groups (students, academics and professionals) was undertaken to identify alignment or discrepancies in perceptions of BIM competence and institutional readiness.

Qualitative data derived from open-ended survey responses and focus group discussions were analysed using thematic analysis. Responses were coded inductively to identify recurring themes relating to curriculum gaps, institutional barriers, infrastructure constraints and training needs. These themes were then compared with quantitative findings to enable triangulation and deepen interpretation. By integrating quantitative indicators with qualitative insights, the mixed-methods design provided a holistic evaluation of BIM training maturity, institutional barriers and implications for digital transformation and graduate preparedness within the Built Environment sector.

5 FINDINGS

5.1 Exposure to BIM Training

The survey findings indicate limited and uneven exposure to BIM training within Built Environment (BE) programmes. Approximately 60% of respondents reported that BIM is insufficiently integrated into core curricula and is often offered only as an elective or introductory module (see Figure 1). This suggests that BIM is not yet positioned as a foundational competency within many institutions. Early-stage exposure remains particularly limited, with students typically encountering BIM concepts late in their academic trajectory.

This delayed introduction restricts the progressive development of competence and confidence, undermining cumulative skills acquisition. The quantitative results therefore indicate that BIM training remains peripheral rather than embedded within programme structures.

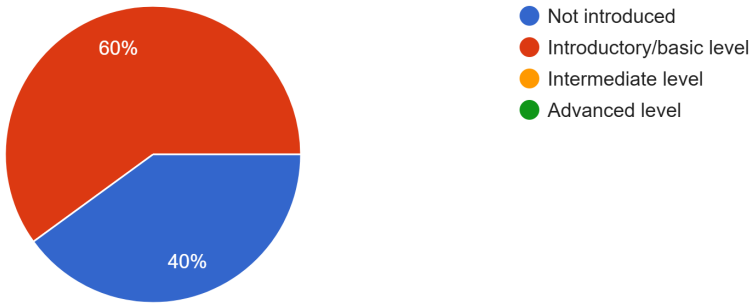


Fig. 1: Student Exposure to BIM Training

5.2 Scope and Content of BIM Training

Approximately 60% of respondents indicated that current BIM training is narrow in scope and insufficiently aligned with industry practice (see Figure 2). Training was reported to be predominantly software-centric, focusing on basic modelling functions rather than process integration across the full project lifecycle. Furthermore, respondents highlighted limited interdisciplinary collaboration within modules. This restricts students' understanding of coordinated workflows between architecture, civil engineering, construction management, and urban planning, a core requirement of BIM-enabled environments.

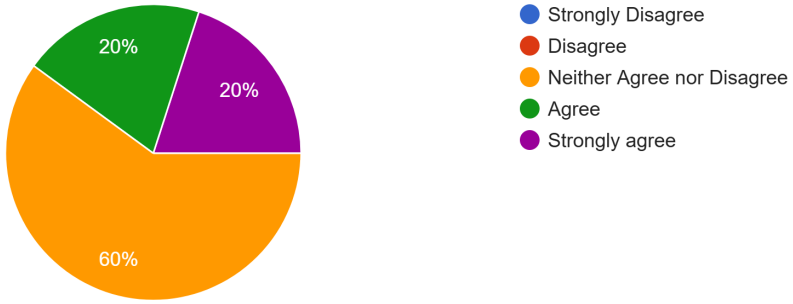


Fig. 2: Level of Training Resources and Curriculum Integration

These findings align with previous studies that identify fragmentation and incremental adoption in BIM education (Azhar, 2011; Volk et al., 2014). While institutions may introduce modelling tools, they often fail to integrate BIM as a collaborative, lifecycle-oriented process consistent with digital transformation narratives (Yalcinkaya & Singh, 2015).

5.3 BIM Maturity and Advanced Skills

Survey responses revealed generally low levels of BIM maturity, particularly in relation to advanced competencies such as:

- Multidisciplinary coordination
- Data management and interoperability
- Lifecycle integration
- Collaborative digital workflows

Although basic modelling skills were reported, progression towards Level 2 and Level 3 maturity (collaborative and fully integrated environments) remains limited. This finding echoes literature highlighting persistent institutional and technical barriers to BIM integration (Volk et al., 2014; Schroeder et al., 2020). The quantitative evidence, therefore, suggests a substantial disconnect between academic training and industry expectations, where BIM increasingly supports integrated decision-making and performance optimisation.

5.4 Resources and Institutional Support

Qualitative findings strongly emphasised institutional constraints. Figure 3 shows several participants cited High software licensing costs limiting student access, Outdated computer laboratories unable to support large BIM datasets, Limited cloud-based collaboration platforms and Insufficient continuous professional development for lecturers

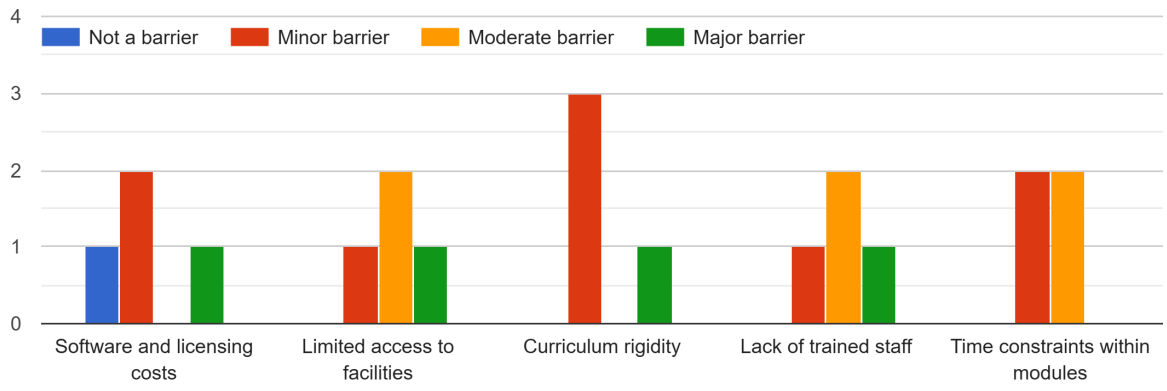


Fig. 3: Key barriers to BIM training

However, examples of good practice were identified. The University of Johannesburg Virtual Lab was highlighted as a valuable platform that provides students with remote access to BIM software and collaborative tools. This initiative demonstrates how targeted institutional investment can mitigate infrastructure constraints and enhance training quality. Participants further recommended dedicated BIM laboratories, structured lecturer upskilling programmes, stronger university and industry partnerships, and the development of national or regional BIM education standards. Such measures would align educational outcomes with industry expectations and strengthen digital transformation pathways.

6 DISCUSSION AND IMPLICATIONS

The findings confirm that BIM integration within BE curricula remains limited, uneven and insufficiently mature. This aligns with literature highlighting fragmented adoption and institutional resistance (Azhar, 2011; Volk et al., 2014; Schroeder et al., 2020). In the South African context, limited BIM integration has significant implications for graduate readiness and industry competitiveness. As infrastructure projects increasingly demand collaborative digital workflows, graduates lacking advanced BIM competencies may struggle to meet employer expectations. This perpetuates a skills gap and increases training burdens on industry.

Moreover, the dominance of software-centric training constrains deeper understanding of BIM as a process-driven digital transformation tool. Without interdisciplinary and project-based learning, students fail to develop competencies in coordination, data exchange and lifecycle management – all essential for higher maturity levels. Addressing these gaps requires systemic curriculum reform, sustained institutional investment and stronger alignment between academia and industry. By embedding BIM progressively across programmes, investing in digital infrastructure and enhancing educator capacity, higher education institutions can play a transformative role in advancing digital maturity within the South African Built Environment sector.

7 CONCLUSION

This study examined the role and effectiveness of Building Information Modelling (BIM) training within Built Environment (BE) programmes and identified significant gaps between current educational practices and the evolving demands of industry. The findings reveal that BIM integration within higher education remains limited, uneven and largely software-centric. Exposure is often delayed and insufficiently embedded within core curricula, while advanced competencies related to collaboration, coordination and lifecycle integration remain underdeveloped. Resource constraints, including high software licensing costs, inadequate digital infrastructure, and limited lecturer capacity, further inhibit progress. Collectively, these challenges weaken graduate readiness and constrain broader digital transformation efforts within the BE sector.

The study underscores the urgent need for policy reform and sustained institutional investment. Curriculum restructuring is required to embed BIM progressively across academic programmes, ensuring interdisciplinary and project-based learning that reflects real-world industry workflows. Institutions must prioritise investment in digital infrastructure, including dedicated BIM laboratories, cloud-based collaboration platforms, and updated software environments. Equally important is structured professional development for educators to ensure that teaching remains aligned with industry innovation. Strengthening industry–academia collaboration is critical to closing the identified gaps. Partnerships with professional councils, government departments, and private-sector firms can facilitate knowledge transfer, curriculum co-design, internship pipelines, and access to real-world project datasets. In addition, the development of national or regional BIM education standards would promote consistency in competency development, clarify expected graduate outcomes and align higher education outputs with industry benchmarks. Such standards could support coordinated digital transformation strategies at the sectoral level.

Future research should extend this work by exploring the effectiveness of university–industry partnership models in enhancing BIM competency development. Longitudinal studies tracking students from entry into higher education through to professional practice would provide valuable insights into how BIM skills mature over time and how curriculum interventions influence career readiness. Comparative studies across institutions or provinces could further illuminate structural inequalities and identify scalable best practices within the South African context. Ultimately, BIM training is not merely a technical curriculum component but a strategic enabler of digital transformation. Strengthening BIM education is essential to enhancing

graduate competitiveness, improving infrastructure delivery, and supporting sustainable urban development. In the South African context, characterised by rapid urbanisation, infrastructure backlogs, and pressing sustainability challenges, robust and integrated BIM training will play a pivotal role in accelerating digital maturity and equipping the Built Environment workforce to meet the complex demands of the future.

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reviewed paper

A Governance Framework for Planning Approval of Housing Developments to Enhance Growth in the Economy

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1 ABSTRACT

This research investigates the components of a governance framework for planning approvals of housing developments in Johannesburg, South Africa, with a focus on its linkages to economic growth. Through qualitative research, including interviews with 25 experienced professionals and analysis of municipal reports, the study identifies the roles of key stakeholders – such as municipal officials, technical experts, and community representatives – in the planning approval for housing development. Findings reveal that while multiple digital and administrative systems support planning approvals, their lack of integration hampers effective monitoring and reporting. The research highlights spatial disparities in development activity and demonstrates a correlation between certain approval types and economic growth datasets. However, fragmented governance structures and inconsistent reporting practices limit the ability to align planning approvals with broader economic and spatial goals. The study proposes a collaborative governance framework that incorporates standardized indicators, improved integration of digital systems, and multi-level oversight to enhance transparency, accountability, and turnaround times. While the framework may be tailored to the city of Johannesburg, the methodology and recommendations offer valuable insights for other metropolitan areas regionally and internationally.

Keywords: planning approvals, governance, housing, development, frameworks

2 INTRODUCTION

This research examines the planning approval processes for housing development.It highlights the challenges posed by fragmented and inefficient planning approval processes. The research investigates the stakeholders involved in planning approvals for housing developments in Johannesburg.It analyses historical trends in reported approvals alongside South Africa's Gross Domestic Product data set as one of the measures of economic growth and establishes a correlation between the types of planning approvals and economic growth. It proposes a governance framework to improve coordination, monitoring, and reporting of outcomes. The research is organised into background explanations, a problem statement, a literature review, key role players, input for the thematic governance framework, and a conclusion.

3 BACKGROUND

Nearly half of South Africa’s population resides within eight metropolitan municipalities, which function as principal centres for economic activity and administer substantial budgets. These metros – Nelson Mandela Bay, Johannesburg, Tshwane, Cape Town, Buffalo City, eThekwini, Mangaung, and Ekurhuleni – are responsible for governing significant urban areas. South African municipalities are categorised as Category A (metropolitan), B (local), or C (district), with Category A municipalities exercising exclusive authority within their regions. Johannesburg, one of the nation’s largest metropolitan areas, accommodates approximately 6.45 million residents, as reported in the 2022 census The city draws the highest levels of domestic and international investment nationwide and encompasses an area of about 1,644 square kilometres. In recent years, Johannesburg has prioritised considerable investment in digital infrastructure, particularly during the COVID-19 pandemic, to improve service delivery. Furthermore, Johannesburg has hosted prominent international events including the UN Global Summit (2002), FIFA World Cup (2010), and G20 and U20 Mayoral Summits (2025), establishing the city as a key venue for global urban dialogue.

4 PROBLEM STATEMENT

Governance and reporting within South African metropolitan municipalities are characterised by specialisation, fragmentation andnot too strong coordination arrangements, resulting in inefficiencies in both housing development and service delivery. While initiatives such as National Treasury’s Municipal Finance

Management Act Circular 88 have been introduced, legislative complexities arising from statutes like the Spatial Land Use Management Act (2013) and the National Environmental Management Act (1998) continue to complicate data management and administrative processes. Research indicates that convoluted procedures, overlapping reporting requirements between province and national governments, elevated system costs, and constrained regulatory capacity impede the effective assessment of economic growth. Stevens (2025) identifies regulatory overlaps, procedural complexity, high system costs, and limited regulatory resources as significant challenges. Similarly, Mokoele (2022) observes that multi-authority reporting leads to redundant and inconsistent data, thereby restricting evidence on how efficient planning approvals contribute to economic development, despite cities being recognised as engines of economic and employment growth. The City of Johannesburg (2022:150) highlights additional issues such as delays in processing planning applications, slow response times regarding requirements, inadequate bulk infrastructure, technological difficulties, and insufficient integration with related systems like billing. In 2023, the City of Johannesburg (2023:144) announced intentions to digitise manual planning procedures to improve transparency and efficiency; however, the effectiveness of these measures has yet to be determined. A key obstacle remains the absence of a cohesive governance framework capable of integrating planning data, building control, and economic growth metrics, which hampers the ability to accurately evaluate the impact of ongoing reforms.

5 LITERATURE REVIEW

Countries use planning and policies to promote development and need collaboration across government and sectors for effective results.de Visser &Poswa (2019) highlightthat in South Africa, the Integrated Urban Development Framework (IUDF) and the National Spatial Development Framework (NSDF) are used to guide infrastructure investment. The NSDF isa mandated in terms of Spatial Land Use Management Act of 2013 to direct national development. In addition, there are funding-related frameworks such as the Medium-Term Revenue and Expenditure Framework (MTREF) and the Integrated Financial Framework for Greening South African Metropolitan Cities (IFFGSAMC). These frameworks aim to align budgets with sustainability goals. South Africa also employs a Scenario-Based Planning Framework (SBPF), which introduces flexible planning through three growth scenarios: Nayi le Walk, Isibhujwa, and Gwara Gwara. The Nayi le Walk scenario envisions a positive future where the country moves toward achieving National Development Plan (NDP) targets. In contrast, the Isibhujwa scenario represents a continuation of existing trends, marked by low economic growth and high inequality. The Gwara Gwara scenario depicts a "struggling false dawn," where aspirations remain unfulfilled.

Furthermore, to these national frameworks, international approaches also offer valuable insights. For example, the Major Infrastructure Delivery Framework (MIDF) in England focuses on climate adaptation in water infrastructure and leverages expertise in procurement and engineering. Meanwhile, the National Planning Policy Framework (NPPF) of England aims to increase housing delivery, although it has faced critiques regarding its overall effectiveness (National Treasury: 2025; Sedighi,et al: 2025; Upton: 2019).

Despite the range of frameworks available, a significant challenge remains: these frameworks often lack amechanism of showing a clear connection between planning approvals for housing development and economic growth. For instance, despite the implementation of the NPPF, recent studies have shown that increases in housing approvals have not consistently resulted in measurable economic growth in several regions (Sedighi et al: 2025).

Recent studies by Mhlongo, Gumbo, and Musondo (2022) highlight ongoing challenges in South Africa's low-income housing sector, such as limited stakeholder involvement, weak accountability, and transparency issues. Despite multiple governance frameworks, these problems persist, underscoring the need for collaborative co-production models as proposed by Maila, Malan, and Mazenda (2024: 10), and Maila (2025), which require shared legislative understanding and active stakeholder participation. Irtyshcheva et al. (2023) stress the importance of clear objectives and robust tracking systems due to concurrent national and provincial responsibilitiesdepited by Mathonsi (2020), while Ndevu and Muller (2018) emphasize the critical role of local governments. Carter, Klein, and Day (2002) call for performance-driven, accountable public sector management. Although National Treasury (2017) introduced standardized performance indicators (MFMA Circular 88),continues to refine them, gaps remain in stakeholder coordination and evidence linking planning approvals to economic and spatial outcomes. The researchers have crafted the conceptual framework in figure1 below to emphasize the need for improved integration and monitoring, provide clarity

on stakeholder roles, reporting practices, and their connection to economic development, focusing on housing development context in Johannesburg. The conceptusal framework visually structures these concepts and variables and provides a basis for further research.

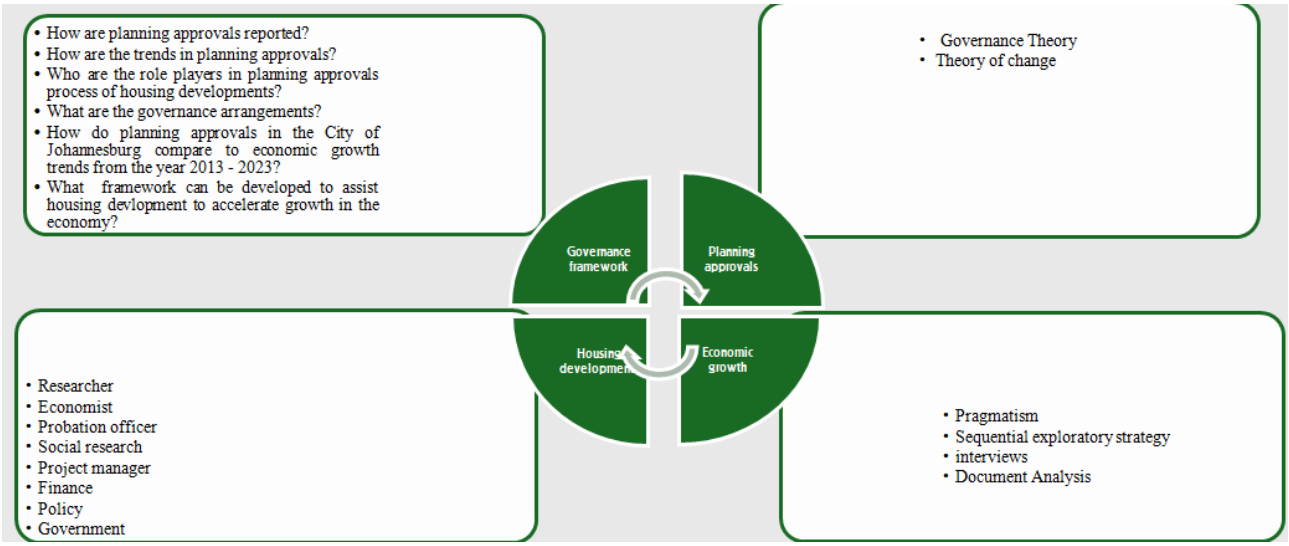


Figure 1: Conceptual Framework (Own diagram)

This study is grounded in Foucault's concept of governmentality (Kerr, 1999) to examine the governance frameworks shaping planning approvals for housing developments, with a particular focus on stakeholder roles and their links to economic growth. The researchers also acknowledge that post-2024 municipal planning in South Africa is now influenced by coalition governance, which necessitates balancing diverse interests alongside economic and spatial development (Kariuki & van der Waldt, 2025). Furthermore, this research draws upon Dean's (2010) refined concept of governmentality, which encompasses citizens' collective perceptions of governance. Notably, Stoker (1998), in conceptualising governance theory, clearly distinguishes between authority (government) and coordination (governance). The researchers also reference the work of Munzhedzi (2021), who asserts that effective governance involves both public and private service delivery. These considerations inform the formulation of the research questions.

6 RESEARCH QUESTION

The main question in this study is who the roleplayers are in the planning approval for housing development in Johannesburg, and what are the governance arrangements?

7 RESEARCH APPROACH AND METHODOLOGY

The study used a qualitative method, selecting around 25 experienced professionals for semi-structured virtual interviews about planning approval. Document analysis drew from city trend reports, annual reports, and systems from relevant agencies. The research focused on planning approval applications in Sunninghill, Inner City of Johannesburg, Kyalami, and Sandton.

8 FINDINGS

The study revealed the following: Reporting Practices: Planning approvals are recorded in annual and trend reports, as well as digital systems; reporting varies by application type and region. There are differences in how planning approvals are reported in the annual reports and no integrated national tracking mechanisms to better inform economic growth discussions. The study recommends further research and comparative analysis across metropolitan areas, emphasizing that current reporting gaps hinder effective monitoring and calling for greater integration at the national level.

Systems Supporting Planning Approvals: The main systems identified are as per table 1 below. At present, these systems are not fully integrated, which restricts the ability to conduct comprehensive monitoring and reporting.

System Name	Administrators
Town Planning Application System (TAS)	City of Johannesburg
Housing Subsidy System (HSS)	Provincial and National Departments of Human Settlements
Geographic Information System (GIS)	City of Johannesburg, Provincial and National Departments
Strategic Innovation Hub (SIH)	Provincial and National Human Settlements, National Cooperative Governance

Table1: Systems Supporting Planning Approvals

Trends in Planning Approval Applications within the City of Johannesburg: The planning approval process includes applications for rezoning, township establishment, subdivision/consolidation, special consent, site development/building plans, and township establishment. Outcomes are approved, refused, withdrawn, or appealed. From 2006 to 2023, the highest number of applications was in Johannesburg's inner city, followed by Sandton, Sunninghill, and Kyalami. See Table 2 for more details.

Application Type	Sunninghill	Sandton	Kyalami	Inner City
Rezoning	58	426	23	2323
New Township	8	0	12	33
Consent	42	188	22	1342
Subdivision / Consolidation	42	171	12	2644
Site Development	65	257	44	1337

Table 2: Development applications approved from 2006- 2023. Source: Own table extracted from the City Of Johannesburg development planning trend report for 2023/24Financial Year

The figures in table 2 illustrate spatial disparities in development activity across the city of Johannesburg. However, does not provide an explanation of why is it the case and what factors inform decision making.

Planning Approvals vs Gross Domestic Product in Johannesburg (2013–2023) Trends:Using data from Johannesburg's development trends report and GDP figures from Statistics South Africa, this analysis examines links between development application types and economic growth. Over the past decade, township establishment applications have shown a correlation with GDP, while zoning applications followed a different pattern. Figure 2 illustrates these findings.

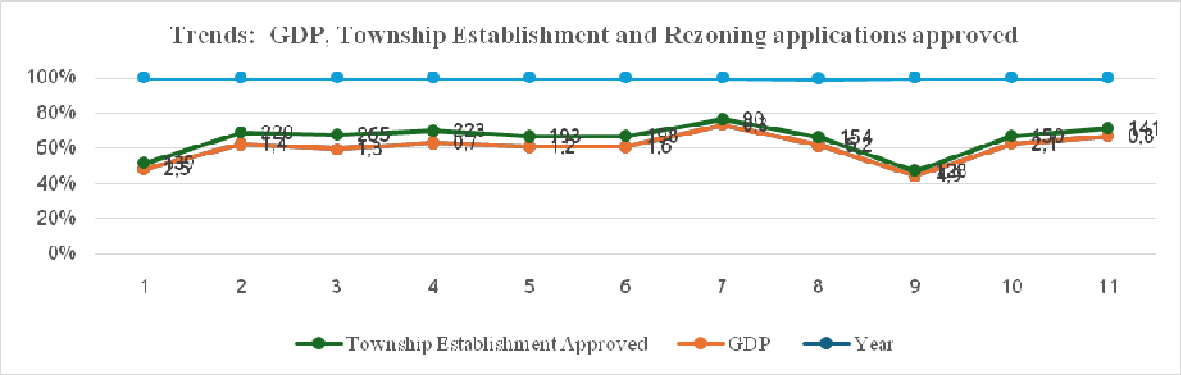


Figure 2: Graph comparison of trends in GDP, Township establishment applications approved and rezoning approcations approved (Source: Authors own diagram using City of Johannesburg data and Stats SA data sets on GDP Period from 2013-2023)

Key role players in planning approval for housing developments: The approval process involves consultants or developers who coordinate applications, and municipal officials who review and approve plans. Key professionals – town and regional planners (Planning Profession Act, 2002), engineers (Engineering Profession Act, 2000), conveyancers (Deeds Registries Act, 1937), land surveyors (Land Survey Act, 1997), community facilitators (Municipal Systems Act, 2000; Housing Act, 1997), project managers, valuers, and architects – all ensure compliance, safety, legal accuracy, inclusivity, and sustainability (Oladiran et al., 2025). Citizens, especially marginalized groups, also participate through objections and consultation. Researchers emphasize governance frameworks to enhance social inclusion and address spatial inequities.

The Governance Arrangements: The city has a solid governance system for development planning, guided by frameworks such as the MSDF, RSDF, Land Use Scheme, Bi laws, Nodal Policies, council-approved delegations, business processes, and procedural manuals with checklists. Delegated officials process applications, while tribunal members handle appeals and objections, supported by a secretariat that maintains records and follows the monthly scheduleof meetings. This promotes transparency, efficient project

approvals, and coordinated planning in Johannesburg. However, the connection between planning approvals and economic growth remains weak. Housing stakeholders include developers, officials, and experts, but economic growth is mainly discussed informally, with no formal forum. Early assessments consider land, infrastructure, transport, heritage, and socio-economic factors. City managers track economic growth, but resource constraints limit broader integration of these discussions.

Proposed components of the Framework for Planning Approval Monitoring: Respondents identified these key elements: 1) Municipal planning approvals require inputs such as rezoning and township establishment applications submitted by qualified experts. 2) Main activities involve processing, analysing, managing objections, and reporting on applications. 3) Outputs are assessed using transparent metrics and economic valuations. 4) Desired outcomes include improved environments, spatial transformation, job creation, and economic growth. Success depends on system maintenance, timely subsidies, and regular meetings to monitor progress and resolve application issues.

9 RECOMMENDATIONS

The study advises government to collaborate for greater transparency, accountability, and better alignment of housing planning approvals with economic and spatial goals. It calls for a governance framework that includes young, tech-savvy professionals to address youth unemployment, revised planning indicators, coordinated governance structures involving political and administrative leaders, and a digital platform to improve tracking and performance evaluation.

10 CONCLUSION

The study finds that current planning approval monitoring is fragmented and poorly linked to economic growth. It recommends integrated national and local tracking, updated indicators, and governance structures combining political and administrative oversight. It recommends the use of digital tools to address the technical complexity, improve transparency, accountability, and speed. These steps can strengthen housing developments in Johannesburg and similar cities.

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🏆 reviewed paper

A Green(er) Roof over the Head: Reflecting on Strategies Targeting Homelessness with Urban Agriculture for Cape Town, South Africa

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1 ABSTRACT

The homeless face desperate socio-economic challenges, not in the least, food insecurity. Vulnerabilities are intensified by changing climatic conditions, macroeconomic constraints, limited sanitation and poor nutrition resulting from restricted access in urban food deserts. Social support programmes and shelters mitigate some risks, with several adopting urban agriculture (UA) in developmental strategies to yield longer-term benefits. Examples are especially prominent in the global North, where non-profit organisations (NGOs), research collaborations and cooperatives have engaged in partnerships to target UA-based interventions for the homeless. Such strategies emphasise the provisioning and cultural ecosystem services (ES) delivered by UA as green infrastructure (GI). Framing UA as multi-functional GI and acknowledging additional regulating and habitat ES empowers advocacy in urban planning to advance UA practices in urban centres where space is at a premium and market forces favour more competitive land uses. Although UA is increasingly applied in the global South, approaches remain largely productivist and economic, prioritising food security, poverty alleviation and entrepreneurship. Very few published case studies link UA and homelessness in developing contexts. This is evident in Cape Town, South Africa, regarded as a leader in UA in Africa and home to a substantial homeless population, where information on such strategies remains limited. In response, this paper explores international precedents from the global North and turns to a case study of Cape Town to investigate which organisations integrate UA into interventions for the homeless and how. A qualitative approach is applied following semi-systematic literature reviews. The first examines international cases in the academic literature as part of the literature screening section. The second, under the paper's empirical component, reviews grey literature on Capetonian examples identified from an official database of registered homeless shelters in the city (n = 29). The literature on international cases revesals the dominace of the USA and emphasises intergovernmental involvement, multidisciplinary collaboration, securing long-term tenure, linking UA sites with supportive uses, using liminal open spaces such as rooftops, remediating brownfields, subsidising infrastructure, embedding volunteerism and co-production, providing training and identifying access points to markets. Findings from Cape Town–based shelters indicate that 17.2% of organisations have implemented UA-related interventions, most primarily focused on production and subsistence, with an auxiliary recognition of therapeutic benefits. Many of the operational characteristics identified in Northern case studies are also pertinent in interventions in Cape Town, underscoring their significance and contextualising their application. By identifying evidence-based principles from global North and Capetonian precedents, the paper highlights critical opportunities to embed UA within strategies addressing homelessness through more developmental approaches, facilitated by urban planning, to encourage cultural and other multi-functional ES beyond (ir)regular sustenance or a temporary roof for the destitute.

Keywords: Homelessness, Urban agriculture, Urban farming, Ecosystem services, Non-profit organisations

2 INTRODUCTION

Homelessness constitutes an extreme manifestation of urban vulnerability, modelled by intersecting economic, spatial and social exclusions that are particularly pronounced in cities of the global South (Pitt, 2022; Hopkins et al., 2024). Within this condition, food insecurity emerges not merely in episodic hunger but as a persistent and multi-dimensional deprivation that constrains health, autonomy and dignity. For the homeless, food insecurity is embedded in everyday urban relations. As such, limited purchasing power, restricted access to food storage and preparation and a dependence on charitable donations collectively undermine both nutritional adequacy and agency over food choices (Greene, 2019; Campagnaro et al., 2023). In Cape Town, South Africa, where deep income inequality, spatial fragmentation and uneven food environments persist (Haysom, 2021; Kanosvamhira et al., 2023), food insecurity among the homeless reflects broader failures in urban governance and social protection. Accordingly, food insecurity operates as

a critical lens through which the lived realities of homelessness and the limits of conventional relief-based responses, may be interrogated.

Urban agriculture (UA) has increasingly been positioned as a response to urban food insecurity, specifically within low-income and marginalised communities, where it is most often justified in terms of food provision. However, beyond this productivist framing, UA is also recognised internationally as an element of urban green infrastructure (GI) capable of generating a wider array of ecosystem services (ES), including social, cultural and health-related benefits (van Zyl et al., 2021). Research has shown that engagement with cultivation and green spaces can support psychological wellbeing, social connection and skill formation, outcomes that may be especially salient in contexts of profound vulnerability (Soga et al., 2017; Gibbens, 2019). Despite the increasing visibility of UA policy in Cape Town (Smit, 2016; Cilliers et al., 2020; Kroll, 2021), its relevance to homelessness and to food insecurity as a relational and structural urban condition, remains poorly conceptualised. This gap raises critical questions regarding the way food-based interventions are framed, valued and integrated within urban planning and social development. Against this background, this paper sets two research questions: Firstly, what good practice principles can be derived from international case studies of UA interventions in homelessness? Secondly, which organisations addressing homelessness in Cape Town include UA in their approach and what lessons are provided by these institutions for broader application?

The paper proceeds with the next section unpacking homelessness as a concept, its drivers and lived impacts, with a particular emphasis on food insecurity and dignity. This is followed by a discussion of UA as a multi-functional, nature-based developmental intervention and unpacking ES in UA in Section 4. International case studies of UA in homelessness interventions are then reviewed in Section 5 to distil key principles. Cape Town is subsequently introduced as the empirical case study, followed by a methodology section detailing the desktop review and dataset used. The results and discussion sections (8 and 9) examine the nature, scale and significance of UA initiatives linked to homelessness in Cape Town. The paper concludes with reflections and planning-oriented recommendations to integrate UA more systematically into homelessness responses in the city, also of value to other contexts in the global South and North.

3 COMING TO TERMS WITH HOMELESSNESS

Homelessness is a worldwide phenomenon affecting countries in the global North and South (Pitt, 2022). It is estimated that 150 million people, or 2% of the world population suffer from homelessness (Lidzhade and Mphambukeli, 2025), with the figure expected to increase under globalised neoliberal urbanism ruled by market forces. Within this system, prolific homelessness jars with aspirations for progressive world-class cities principled on rational order, the rule of law and codified planning to protect private interests. As such, the homeless are othered and stereotyped as perpetrators who increase crime, litter and dump, practice poor hygiene and contaminate, beg and devalue property by their presence as agents of the 'broken window syndrome' (Michaels, 2022). Such narratives bound in aversion from powerful private investors and fear amongst the voting public politicise the issue as an emotive challenge for local authorities framed by deep difference, professional and personal conflict (Hopkins et al., 2024). Broad brush condemnation of the homeless as a class of 'social failure, dysfunctionality and unproductivity' (Gerrard and Farrugia, 2015; Pitt, 2022:2) easily rationalises blunt political intervention. Yet even a shallow exposition of personal narratives or a frank confrontation of systemic drivers, may uncover accounts opposing freeloading by choice or deliberate ill intent. Rather, testifying to precarity of circumstance and last resort, aggravated by external factors beyond individual control. These include structural unemployment, migration, domestic violence and dysfunctional home environments, adverse childhood experiences, substance abuse and health challenges (Makiwane et al., 2010; Pitt, 2022; Hopkins et al., 2024; Lidzhade and Mphambukeli, 2025). In realisation, acknowledging that the homeless are often exposed to property threat, isolation, misconception, stigmatisation, harassment and violence and may face substance dependence, physical disability and disease (Rankin, 2019; Hopkins et al., 2024). Health concerns may be far reaching, including injuries, mental health challenges, sexually transmitted infections, respiratory ails like tuberculosis and other co-morbidities (UN-Habitat, 2020). These issues are severely impacted by changing climatic conditions and seasonality, lacking sanitation and ablution facilities and food insecurity in urban food deserts (Greene, 2019; Hopkins et al. 2024).

Food deserts do not reference the type, size and number of food retailers established locally, but rather lacking access to affordable healthy food amongst the poor even when retailers are plentiful (Smith et al., 2010). For the homeless, who often dwell in well-served urban areas, challenges include limited financial means and restrictions in preparing or storing food. This is especially problematic for perishable fruits and vegetables (Greene, 2019). Food insecurity overshadows basic hunger to include spatial, social, cultural, political and emotional aspects of food access (ibid), including the act and place of consumption (Campagnaro et al., 2023). Eating is often an undignified experience for the homeless as many scavenge for sustenance in bins, beg or are handed leftovers to consume publicly. Such meals are often nutritionally deficient, even hazardous, consisting of calorie rich processed foods or expired products. Alternatively, more nourishing meals may be accessed through soup kitchens and homeless shelters that may also provide temporary accommodation, sanitation and ablution facilities, clothing, blankets and possibly rehabilitation and developmental services (Brothers et al., 2020). Shared accommodation and meals may foster social cohesion in conviviality and camaraderie, but the interim nature of shelter support does not necessarily advance food security, nor do charitable services instil pride, self-confidence, self-esteem or self-reliance (Mjema et al. 2023). In addressing issues of nutrition, advancing food security, training and dignity in parallel, several organisations incorporate UA in developmental strategies addressing homelessness.

ES Category	Definition	Potential UA examples
Provisioning ES	Protection and restoration of natural resources and the capability of natural (e.g., rivers, biomes) or semi-natural (e.g., community gardens) green spaces to contribute physical products, materials or goods consumed directly by humans.	Community gardens, rooftop farms and alike produce fresh vegetables, fruits, eggs, honey, herbs and other food products often consumed by proximate residents, improving urban food security and reducing food miles. Urban gardens may cultivate medicinal and aromatic plant species used in traditional remedies or small-scale commercial products.
Regulating ES	The regulation of ecosystem processes that moderate natural and artificially induced environmental conditions. Benefits derive from capacities to control, reduce, or buffer ecological, climatic and biological processes alternatively requiring technical or engineered solutions.	UA vegetation contributes to local cooling through evapotranspiration and shading to reduce the urban heat island effect. Plants in UA systems capture particulate matter and contribute to pollutant removal from urban atmospheres. Soil enhancement is promoted via organic matter and reduced compaction, also preventing surface erosion. There are further contributions to nutrient cycling and soil quality stabilisation. UA systems can enhance pollinator habitat and activity and support populations of beneficial insects that regulate pests.
Cultural ES	The non-material benefits humans derive from ecosystems meeting cultural or spiritual needs when visiting, living in or enjoying views of green areas.	UA spaces provide green venues for recreation, passive enjoyment and aesthetic engagement with nature, especially valued in dense urban contexts. UA sites are often used for environmental education and gardening training, generally increasing ecological literacy and food system awareness, ultimately advancing skill development and employment opportunities. Shared involvement in UA projects fosters cultural expression, social interaction, networking, inclusion, community organisation and stronger sense of community identity. Exposure to green UA spaces, participation in gardening and contact with nature are linked with mental health improvements in decreased depression and anxiety, enhanced cognitive abilities, increases in attentional capacity, increases in life satisfaction and the benefits of physical activity like strength, fitness and flexibility.
Habitat services (or supporting services)	ES that conserve natural ecosystems and enhance urban biodiversity do not directly benefit humans but facilitate the fulfilment of all other ES by providing natural habitats.	UA sites, especially diversified gardens, increase urban biodiversity as habitats for flora, pollinators, insects and fauna often uncommon in built environments. Soils in urban horticulture systems regularly present enhanced biological diversity and nutrient cycling compared to non-vegetated landscapes. UA systems presenting diverse crops, including rare or heirloom cultivars, support the conservation of genetic resources in urban areas. Through green cover, flowers and sheltered microhabitats, UA supports the lifecycles of beneficial organisms, enhancing general ecological functions in urban areas.

Table 1: ES categories and potential examples in UA. Source: Constructed from Draper and Freedman (2010); Gonzalez et al. (2010); Soga et al. (2017); Gibbens (2019); Górna and Górny (2021); Lategan et al. (2021); van Zyl et al. (2021)

4 URBAN AGRICULTURE AS A NATURE-BASED SOLUTION AND DEVELOPMENTAL TOOL

UA is defined as the production of food and non-food crops and/or animal husbandry at micro and meta scale within and on the peripheries of urban areas (Hardman et al., 2022). UA includes all activities from cultivation to the entrepreneurial components of agri-processing, marketing and distribution (Cilliers et al., 2020; Chari et al., 2022). UA is acknowledged as a nature-based solution and element of GI, defined as a strategically planned, designed and managed urban network, consisting of various natural, semi-natural and man-made green and blue spaces that conserves ecosystem functions, contributes to biodiversity conservation and provides social, economic and health benefits through multiple ES (van Zyl et al., 2021). ES are the direct and indirect benefits all living species derive from the capacity of ecosystems to provide goods and services that satisfy needs (De Groot et al., 2010). ES have been classified according to provisioning, regulating, cultural and supporting/ habitat services. These categories are not mutually

exclusive, with multiple benefits derived simultaneously by GI elements like UA (van Zyl et al., 2021). Table 1 captures ES categories and potential manifestation examples in UA.

Recognising numerous ES (Table 1), highlights multi-functionality as a critical GI characteristic, which has provided planners with significant motivation and leverage to advance implementation internationally (Tsegaye et al., 2018; Cilliers et al., 2021). Yet, an overly naïve perspective should be avoided. A balanced approach recognises latent ecosystem disservices (ESD), acknowledging that ecosystem functions may deliver contrasting negative impacts (Davoren and Shackleton, 2021; Lategan, et al., 2021). For UA, examples may include invasive species or clearing indigenous remnants, continuous maintenance, operating expenses, security concerns of theft, squatting and vandalism. The threat of cultivation on urban sites contaminated by proximate pollutants like lead, arsenic from pesticides and polyaromatic hydrocarbon from exhausts, as well as residue and littering from discarded items related to substance abuse are noted (Bryld, 2002; Lategan et al., 2021). Fresh produce is also associated with microbial foodborne disease deriving from cats and birds, composting materials and fertilizers from livestock (Kaiser et al., 2015). Additionally, limited funding, skills and knowledge, staff shortages and a reliance on volunteer labour, limited markets and lacking consensus regarding success metrics often limited to biased cost-benefit analyses in favour of economic sustainability, are concerning (Biewener, 2016). Such challenges are exacerbated by limited research focused on UA benefits for vulnerable stakeholders like the homeless (Gibbens, 2019), with reflections limited to reports on disparate case studies. Section 5 attempts to relay some of these cases from the global North to evidence their general approach and distil potential lessons of practice.

5 REVIEWING SELECT GLOBAL NORTH CASE STUDIES OF URBAN AGRICULTURE IN HOMELESSNESS INTERVENTIONS

The examples summarised in Table 2 were derived from the academic literature on UA interventions targeting the homeless.

Project / Initiative	Organisational Type	Key Partners & Stakeholders	Approach & Model	Produce, Cultivation Methods & Facilities	Engagement with Homeless	Outcomes & Impacts
The Food Project/ Dudley Street Neighbourhood Initiative, Boston, MA & suburbs (1991)	Community-based nonprofit network	Foundations; municipalities; schools; hunger relief orgs	Youth employment, food donation, farmers markets. Food justice–oriented, educational UA integrating production, donation and market sales	Mixed vegetables; open-field cultivation; greenhouses; suburban farms (16 ha total); internships organic soil-based production; community gardens, farm, aquaculture facility, greenhouses and bioshelters, processing facilities and marketing outlets	Direct: produce and meals for homeless shelters and soup kitchens.	Food access, youth leadership, social cohesion
San Francisco County Jail – Garden Project, San Francisco, CA (1992 -2018)	Nonprofit re-entry programme	County jail; municipalities	Rehabilitative UA linking incarceration, skills and community service	Vegetables; tree planting; soil-based cultivation on institutional land	Indirect: food for homeless and elderly	25% lower recidivism
Sea Change, Inc. Philadelphia, PA (1993)	Nonprofit economic development corp.	Philadelphia Redevelopment Authority	Entrepreneurial and ecological UA as neighbourhood regeneration	Organic vegetables, herbs, flowers; 0.2 ha site; eco-village systems; organic farming, traditional and innovative technologies	Direct: employment and training	Skills, food production
Cook County Sheriff's Garden.Chicago, IL (1993)	Correctional UA programme	Univ. of Illinois Extension Urban Gardening Programme	Prison-based farming. Institutional rehabilitative UA	Vegetables; 557 m² prison garden; soil-based	Indirect: food for homeless; inmate rehabilitation	Reduced recidivism; food donations
Growing Home. Chicago, IL (1998)	Nonprofit social enterprise	City of Chicago; Community Development Block Gant; Coalition for the Homeless	Greenhouse farming; phytoremediation. Employment-focused UA with environmental remediation	Greenhouse, vegetables; raised beds; 0.4–1.2 ha brownfield site; phytore-mediation	Direct: homeless employment	Skills development; food production
Gino Organic Gardens. Chicago, IL (1998)	Volunteer-based and entrepreneurial	Local food nonprofits	Raised beds, donation model. Subsistence and donation-oriented UA	Mixed vegetables; raised beds; 670 m² vacant lot	Direct: homeless employment; Indirect: produce to homeless-serving orgs	454 kg produce donated in 1998

Seattle Youth Garden Works. Seattle, WA (1998)	University-affiliated programme	Universities; community partners	Market gardening; skills training. Workforce development UA	Market garden vegetables; soil-based plots	Direct: training homeless	Workforce readiness
Urban Oasis / Community Harvest. Washington, D.C. (Late 1990s)	Community-based project	Public housing authorities; schools	Urban farm. Employment-oriented UA in underserved areas	Vegetables, herbs, flowers; 0.2 ha farm	Direct: homeless employment	Food access in underserved area
Justiceville.Chicago, IL (Late 1990s)	Transitional housing initiative	Restaurants; housing providers	Herb cultivation for restaurants. Micro-enterprise UA	Herbs; 93 m² plot; soil-based	Direct: homeless residents farm	Income, skills
City Growers. Boston, MA (2010)	For-profit social enterprise / cooperative	City of Boston; institutions; volunteers	Sales-based; co-operative governance. Commercial UA with a social objective	Intensive vegetable production; 0.4 ha over four vacant lots; soil-based	Indirect: jobs, food to nonprofits	Employment, food access
Higher Ground Farm. Boston, MA (2013)	For-profit commercial UA	Private founders; volunteers	Rooftop commercial farming. Commercial, market-driven UA	Leafy greens, vegetables, flowers; 1,300 m² rooftop; open-air beds	Indirect: unpaid/volunteer labour	Proof of rooftop UA viability
St. Vincent de Paul Urban Farm. Dayton, OH (2013)	Shelter-based participatory research	Univ. of Dayton; Ohio State Univ.; shelters	On-site shelter farms. Therapeutic and participatory UA	Vegetables; 2,500–3,000 m² on-site shelter gardens; soil-based	Direct: shelter residents participate	Improved nutrition, mental health, lower recidivism
Growing Hope Gardens. Los Angeles, CA (2010s)	Nonprofit	Shelters; housing providers	Gardens in shelters and housing. Regenerative, empowerment-based UA	Organic regenerative gardens; shelter and housing sites; soil-based	Direct: stewardship and participation	Belonging, empowerment

Table 2: Synthesis of international examples of AU interventions in homelessness. Source: Constructed from Kaufman and Bailkey (2000); Biewener (2016); Gibbens (2019); Brothers et al. (2020); Mjema et al. (2023)

Findings captured in Table 2 are further detailed in Section 9 but is pertinent to acknowledge that all instances encountered are North American, calling the nature of similar approaches in the rest of the world, but especially in the global South, into question. If and how such approaches manifest in one of the global South's most developed and unequal countries, South Africa, and one of its most developed and unequal Cities, Cape Town, is particularly intriguing.

6 HOMELESSNESS AND URBAN AGRICULTURE IN CAPE TOWN, SOUTH AFRICA

South Africa is wracked by severe housing shortages resulting from colonial and apartheid rule, structural unemployment and a contemporary neoliberal approach that has reduced output in the state's low-income housing projects. Some 3.4 million prospective beneficiaries were captured on the national needs register by 2024 (RSA, 2024), most of whom are accommodated in informal settlements and informal backyard rental accommodation. Access to the informal sector, especially the backyard component, reflects resilience and agency amongst the otherwise destitute (Lategan and Cilliers, 2017) and the capacity for resource mobilisation and/or supportive kinship networks that assist in accommodation access (Lategan and Cilliers, 2019). These informal settlers are not considered homeless, but survive in precarity close to the verge of destitution should their circumstances change.

The housing backlog is concentrated in the country's metropolitan areas, particularly in eThekwini (Durban), the City of Johannesburg and City of Cape Town, mirroring instances of absolute homelessness. Cape Town is highlighted for a lack of literature on the phenomenon and a large comparative homeless population (Viljoen, 2025). Hopkins et al. (2024) report that only five dedicated studies have emerged on homelessness in Cape Town since 2013 and that the exact extent of the homeless population is unknown. A 2020 estimate projected a population of14357 homeless (ibid). Studies show that up to 71% are classified as chronically homeless, having experienced constant homelessness for a minimum of one year, or repeatedly over certain periods (Viljoen, 2025).

Life on Cape Town's streets is particularly inhospitable in gentrified business nodes managed under low tolerance private improvement cooperatives and crackdowns on vagrancy and squatting in the central business district (CBD) (Michaels (2022). Punitive responses call on law enforcement and private security to fine or remove the homeless based on bylaws of 'antisocial behaviour' (Pitt, 2022; Viljoen, 2025). Cape

Town's homeless further face harsh summers, wet winters and gale force winds in what is known as the Cape of Storms. Some respite from authorities, the weather and hunger may be found in shelters provided by the state and non-governmental (NGOs) and non-profit organisations (NPOs). However, offerings generally deliver maintenance services and temporary accommodation, mostly failing to facilitate more permanent transitions from homelessness supported by long-term developmental assistance in social services, substance abuse treatment, skills development and economic empowerment toward permanent independence (Hopkins et al., 2024). The basic accommodation offered is also scarce and institutions under capacitated, with only 3246 shelter beds available (Table 3). Many homeless further actively avoid shelters due to strict operating hours and rules, including curfews, a ban on drug and alcohol use or non-admission of couples (Viljoen, 2025). Even when such detriments are inconsequential and more developmental interventions offered, Cape Town's homeless are reticent to commit to longer-term stays given loss of income from begging or casual employment (Hopkins et al., 2024). The need for proven intervention strategies providing multiple longer-term developmental benefits, like UA (Table 2), is thus imperative.

There is significant potential to draw on existing support for and implementation of UA in the city. Cape Town is regarded as a front runner in UA (Jagganath, 2022) as the first South African city to deliver an UA Policy in 2007. This policy, along with the City of Cape Town Food Gardens Policy in Support of Poverty Alleviation and Reduction, support UA and food aid for indigent households and schools (Smit, 2016; Kroll, 2021). Food systems were also included in the city 2019 Resilience Strategy through targeted action plans. However, integration into broader urban governance and management has remained limited (Haysom, 2021). Furthermore, The OneCape 2040 Strategy proposes transitioning to an eco-friendly, inclusive, resilient and sustainable economy that supports UA and sources 80% of food locally. Yet, few political aspirations have been articulated (Kroll, 2021). Planning documents like the Municipal Spatial Development Framework (MSDF) (COCT, 2023) provides for protection and recognition of significant agricultural land like the Philippi Horticultural Area in the Cape Flats region that produces a large proportion of the city's vegetables. The Cape Flats accommodates approximately 6000 small-scale and micro-farmers who operate some 100 urban gardens. Most are located on school and municipal properties, whilst others occupy liminal spaces like road verges to constitute more informal practices (Kanosvamhira et al. 2023). UA practices closer to the CBD are also documented, including the Oranjezicht City Farm located in a prestigious suburb in the Cape Town City Bowl which has itself supported the establishment of at least twenty other local UA initiatives (Steenkamp et al., 2021). Despite a significant homeless population and advancements in the establishment of UA policies and practices along the informal to formal continuum, the literature is sparse and whether, and how, approaches to homelessness in Cape Town have incorporated UA, unknown.

Nr	Organisation	Capacity	Nr	Organisation	Capacity
1.	The Haven Night Shelter, Bellville	83	16.	Elim Night Shelter, Elsies River	70
2.	The Haven Night Shelter, Claremont	15	17.	Loaves and Fishes, Observatory	35
3.	The Haven Night Shelter, District Six	80	18.	Oasis Reach for Your Dream, Phillippi	80
4.	The Haven Night Shelter, Kalk Bay	18	19.	Ubuntu Circle of Courage, Blackheath	0
5.	The Haven Night Shelter, Kensington	60	20.	The Ark City of Refuge, Faure	1000
6.	The Haven Night Shelter, Kraaifontein	92	21.	Youth Solutions, Zonnenbloem	60
7.	The Haven Night Shelter Moira Henderson House, Woodstock	81	22.	Beth Rogelim, Cape Town	100
8.	The Haven Night Shelter Napier Street, Greenpoint	155	23.	Culemborg Safe Space, Cape Town	23
9.	The Haven Night Shelter, Retreat	115	24.	Culemborg Parking Lot Safe Space, Cape Town	230
10.	The Haven Night Shelter, Wynberg	57	25.	Paint City Safe Space, Bellville	250
11.	The Haven Welfare Organisation, Cape Town	0	26.	U-Turn Ministries, Claremont	30
12.	Owl Shelter, Lansdown	80	27.	U-Turn Ministries, Bellville	21
13.	Happy Valley, Simonstown	65	28.	TASP, Bellville	25
14.	Somerset West Night Shelter, Somerset West	54	29.	Hope Revolution, Faure	70
15.	The Carpenter Shop, Cape Town	40	Total:		**3246**

Table 3: Homeless shelters registered on the City of Cape Town Open Data Portal. Source: CoCT (2025)

7 METHODOLOGY

This paper employs data sourced from the City of Cape Town's Open Data Portal (CoCT, 2025) that provides publicly accessible municipal datasets across a range of thematic categories, including social development. Within this category, a 2025 dataset titled 'Homeless Shelters' was identified that indicates places of accommodation for the homeless within the City of Cape Town. It is acknowledged that the list

may not capture informal, faith-based, or unregistered initiatives operating outside of the City's officially recognised programmes. The twenty-nine organisations captured in the database are presented in Table 3.

Each organisation was subjected to a semi-systematic desktop review (Lategan et al., 2025) of grey literature (websites, media articles and reports) using key words and Boolean Operators to configure the following search strings: Organisation AND Cape Town AND Urban Agriculture; Organisation AND Cape Town AND Urban Farming; Organisation AND Cape Town AND Garden; Organisation AND Cape Town AND Food Security. Corresponding folders were created for each organisation and subfolders for each search query created on Endnote as reference management platform. Both deductive and inductive coding were completed using Atlas.ti. Results are discussed in Section 8.

8 RESULTS

Results demonstrate that 48.3% (n=14) of organisations referenced general gardening practices, whilst 17.2% (n=5) referenced larger scale UA activities more specifically, though not always directly by name. The relatively high number of instances recorded for gardening activities is largely due to the Haven Night Shelter collective with eleven branches, but one general website. Thus, making it impossible to gauge where and how much gardening takes place. The Haven Night Shelter and the Salvation Army's Beth Rogelim men's home mention resident involvement in garden-related activities (Haven Night Shelter, 2025; Salvation Army, 2025), with the available information suggesting that these activities are restricted to general maintenance and domestic gardening duties rather than a structured developmental strategy based on UA. The Somerset West Garden Project transformed a derelict park into a thriving urban farm that utilises volunteers from the homeless community, sells produce locally through a market and to restaurants and supplies the Somerset West Night Shelter and Thomas House of Hope (Atlantic Fertilisers, 2023). A Community gardening approach was also identified in the Ubuntu Circle of Courage organisation, which demonstrates how UA can support the homeless in personal development. The organisation is supported by the Western Cape Department of Agriculture (WCDoA) and the Cape Agency for Sustainable Integrated Development in Rural Areas (Casidra), with a five-year lease from a local company ensuring medium-term stability (Casidra, 2025a). The Happy Valley Shelter reports the existence of a vegetable garden damaged by a local baboon troop, calling for support to reestablish the space in recognition of its role in providing fresh produce for residents and in fostering a connection with nature (Happy Valley, 2025). However, no data were available on the garden's size, production capacity, governance, or operational model in contrast with other cases identified.

At the Oasis Reach for Your Dreams organisation, the Garden of Grace project trains residents, with the help of the Local Cape Roots company (Maledo, 2021), in the cultivation of a subsistence garden. The project has received support from the WCDoA and Casidra to upgrade infrastructure and increase production capacity (Casidra, 2025). The Garden of Grace supports nutritional needs but also advances personal growth, dignity and vocational opportunities whilst produce is sold locally in aid of broader food security concerns (Oasis, 2025). A wider focus at Garden of Grace sprouted the Gardens for Growth initiative that supports local families to initiate and maintain domestic food gardens, ultimately envisioning community-run enterprises that generate fresh produce and local employment whilst promoting climate resilience and ecological restoration (Casidra, 2025b). A focus on ecological functions is also evident in U-Turn Homeless Ministries' Living Roots Nursery in Claremont. Living Roots offers a distinct form of UA focused on horticulture, environmental restoration and sheltered employment and not food production. The indigenous nursery is operated by the formerly homeless in the final stages of U-Turn's rehabilitation programme (Shoba, 2023), with therapeutic benefits noted (Lemonaid and ChariTea Foundation, 2025). Living Roots is a social enterprise that generates income through plant sales, landscaping services and workshops, with profits reinvested into U-Turn's programmes (Volkwyn, 2023; Living Roots, 2026). Participants receive accredited training in gardening, landscaping, composting, first aid and environmental management, contributing to both personal rehabilitation and urban ecological outcomes (Lemonaid and ChariTea Foundation, 2025). Structured horticultural training is combined with practical food production in the Bellville CBD Food Garden, a purpose-built urban food production system integrated into a Safe Space for the homeless and vulnerable in collaboration between the Greater Tygerberg Partnership and social development NGO, MES and related to the Tygerberg Association for Street People (TASP). Founded on a 300 m² site, the garden was conceived during the COVID-19 lockdown to improve food security, health and

income opportunities. The project supplies fresh produce to a soup kitchen and sells surpluses to generate modest income for participants. Stakeholders emphasise dignity, mentorship, skills development and employability as central outcomes. Expansion plans to approximately 600 m² indicate a transition from pilot-scale production towards an expanded UA model (Alexander, 2021). The largest scale, and most mature, UA intervention was identified in the Ark City of Refuge's farm where a small vegetable garden evolved into an organic urban farm supporting a kitchen that provides approximately 3000 meals daily (Masiwa, 2024). The farm includes open-field production, tunnels, fruit trees and designated plots for school learners to gain agricultural experience. The project benefits from long-term partnerships with food retailer Shoprite, the WCDoA and other donors, who have provided infrastructure, training, seedlings, irrigation equipment and surplus food (Shoprite, 2021; Shoprite, 2024). Thirty to forty residents are empowered by direct participation in food production and receive permaculture training, enhancing their capacity for self-sufficiency. The farm further supports external organisations, including soup kitchens, crèches and old-age homes to position the initiative as a critical node in local food relief networks (The Ark, 2026).

9 DISCUSSION

This paper highlights homelessness as a heterogeneous condition affected by structural, spatial and personal impacts. Interventions that consider the homeless as a singular group risk strengthening stigma and advancing a disconnect between need and response. Sensitive UA initiatives are required that acknowledge homelessness as a condition of exclusion from urban citizenship and the right to the city. As alluded to previously, one of the principal considerations in claiming this right resides in meeting the basic human right to access adequate food. In keeping, studies on UA in the global South generally highlight issues of food security and poverty alleviation, adopting a reciprocal advocacy approach (Kanosvamhira et al., 2023). Studies in the Global North initially focused on a productivist approach but later acknowledged multi-level social and cultural factors (Kanosvamhira et al., 2023; Saguin, 2024). Thereby also recognising that food insecurity exceeds mere hunger to include indignity of access, preparation and consumption. Appropriately targeted UA practices thus reposition food access from charitable dependence to a communal participatory practice of agency, citizenship and community. The Food Project emphasises social cohesion and civic engagement alongside food production, positioning UA as a developmental and relational practice (Kaufman and Bailkey, 2000). Growing Hope Gardens and St. Vincent de Paul Urban Farm demonstrate how cultivation and shared meals can restore stewardship and belonging (Gibbens, 2019; Mjema et al., 2023). These cases also illustrate the value of embedding UA within supportive institutional settings, like shelters, transitional housing and correctional or rehabilitative environments, to connect UA sites directly with complementary social services. Thus, also suggesting that some of UA's most significant contributions for homelessness may not be caloric or economic, but rather social, cultural and psychological, espoused via routine, purpose, contact with nature and social interaction, as cultural ES. All Capetonian cases, bar U-Turn Homeless Ministries' Living Roots Nursery, focus primarily on sustenance and nutrition, reconfirming tendencies in the global South. However, most also recognise AU's therapeutic contributions and the advancement of personal development as significant drivers, often informed by structured training, skills acquisition and pathways to employability (Oasis Reach for Your Dreams, the Bellville CBD Food Garden, U-Turn Homeless Ministries and the Ark City of Refuge). This mirrors international precedents (Seattle Youth Garden Works, Justiceville, Growing Home) where workforce readiness, accredited training and transitional employment are central objectives rather than ancillary benefits (Kaufman and Bailkey, 2000). Activities pursued for income generation often benefit the broader community through fresh produce delivered to restaurants and sold at dedicated markets (Seattle Youth Garden Works, the Food Project, Somerset West Garden Project, Bellville CBD Food Garden, Ark City Refuge), or donated surpluses (Gino Organic Gardens, City Growers, the Food Project, Bellville CBD Food Garden), furthering general food security. The deliberate identification of access points to market, whether through farmers' markets, restaurant supply chains, or institutional procurement is important. Thereby enhancing financial viability and reinforcing dignity through productive participation to support a sense of achievement, contribution and belonging in aid of community assimilation.

External ties are significant in support of UA interventions for the homeless. International case studies like Seattle Youth Garden Works, Growing Home and City Growers and Capetonian examples like Ubuntu Circle of Courage, Oasis, Bellville CBD Food Garden and Ark City of Refuge illustrate that successful

initiatives are habitually rooted in intergovernmental involvement, multidisciplinary collaboration and public private partnerships. International and local cases further demonstrate that embedding volunteerism and co-production through resident participation, community volunteers and institutional partners, enhances ownership, social capital and programme resilience. Partnerships, sponsorships, goodwill and sound management are paramount in operating sustainably with security of tenure to allow UA interventions to mature and expand.

However, land access and tenure insecurity are often detrimental constraints to UA, specifically in high-value urban centres like the Cape Town City Bowl where market led competition is significant and risk of displacement imminent without explicit policy recognition, institutional land access and use rights. International examples demonstrate adaptive spatial strategies in response to such constraints, including the use of liminal and non-traditional spaces like rooftops (Higher Ground Farm) and the remediation of contaminated or underutilised brownfields (Growing Home), to expand the spatial repertoire available for UA in dense urban environments (Kaufman and Bailkey, 2000; Biewener, 2016). Comparable opportunities exist in Cape Town, and are already practiced in areas like the Philippi Horticultural Area (Kanosvamhira et al. 2023), but remain underexplored within homelessness responses.

Urban planning is thus identified as a champion for UA for its role in land use regulation, strategic development oversight and as multi-disciplinary entity with potential intergovernmental and private sector linkages (Górna and Górny, 2021; Skinner and Haysom, 2021; Ngie and Sithole, 2023). In many cases the strategic instruments informing planning policy and practice already support food-based uses like UA and more sustainable and environmentally sensitive development options like GI. However, as with other GI elements (van Zyl et al., 2021), urban planning professionals generally remain ill-equipped to integrate UA which may be illegal in many urban areas in contravention of traditional bylaws based on permittances and restrictions rooted in colonial conventions or benefitting neoliberalism and capital interests (Lee-Smith, 2013; Kroll, 2021; Matamanda et al., 2022). The absence of a definitive, proactive, integrated and pro-poor strategy focusing explicitly on the informal UA sector in Cape Town serves in substantiation (Skinner and Haysom, 2016).

Emphasising multi-functional ES, both informally and formally, beyond food for the homeless may be required to motivate UA in Integrated Development Plans (IDPs) and Spatial Development Frameworks (SDFs) aligned to South Africa's 2013 Spatial Planning and Land Use Management Act (SPLUMA) (Haysom, 2021). SPLUMA's emphasis on principles of justice, resilience and sustainability are prudent, especially when planners proactively consider ESD commensurate with a normative professional responsibility to separate incompatible land uses and guard against detrimental activities (Górna and Górny, 2021). In emphasising ESD, the paper cautions against the idealisation of UA. Risks related to soil contamination, food safety, labour exploitation and exposure to unsafe environments may disproportionately affect homeless participants. This is particularly evident in cases such as Growing Home, which addresses soil contamination through phytoremediation, highlighting that environmental risk is not incidental but structural. The ethical implementation of UA strategies for the homeless demands that environmental or institutional risks are not externalised for an already vulnerable group. The following section concludes the paper with six recommendations based on the discussion presented.

10 CONCLUSION AND RECOMMENDATIONS

Findings confirm that while Cape Town has a comparatively strong policy environment supportive of UA, the integration of UA into homelessness responses remains fragmented and opportunistic rather than systematic. Drawing on the literature, empirical findings and discussion, the following recommendations are proposed emphasising the role of urban planning in enabling homelessness-responsive UA strategies in Cape Town:

1. Integrate UA explicitly into homelessness and urban planning frameworks: UA should be recognised formally as an effective instrument in homelessness interventions within municipal planning instruments, including IDPs and SDFs. Aligning UA initiatives with SPLUMA principles would further legitimise their inclusion as instruments of spatial redress and inclusive urban citizenship. Explicit articulation would reduce legal ambiguity, protect UA from displacement and enable proactive land allocation.

2. Identify and secure land for UA via proactive spatial planning: Urban planners should lead targeted spatial analyses to identify suitable land for UA linked to homelessness services. This may include municipal land, school properties, rooftops, underutilised public land, servitudes, buffer zones and other liminal spaces. Secure tenure arrangements, even if time-bound, are critical to enable UA initiatives to advance, attract investment and deliver long-term benefits.

3. Promote multi-functional UA models beyond food production: Planning frameworks should explicitly recognise and incentivise the multi-functionality of UA, particularly enhancing and integrating cultural ES. In support, shifting evaluation metrics beyond yield, income, or traditional cost-benefit analyses to include dignity, wellbeing, agency and community integration to better reflect the objectives and outcomes demonstrated in both international and local case studies. This includes recognising UA sites co-located with shelters, safe spaces, rehabilitation centres and training facilities as critical social infrastructure and not ancillary land uses.

4. Support long-term, cross-sectoral partnerships: Evidence from both international and Capetonian cases highlights that successful UA initiatives in service of the homeless are secured by long-term partnerships involving multiple tiers of government, NGOs, academic institutions and the private sector. Urban planners may act as conveners to facilitate interdepartmental coordination between social development, environmental management, economic development and health departments, whilst also facilitating partnerships with civil society and donors. Such partnerships are essential to subsidise infrastructure, promote volunteerism and co-production in addition to ensuring sustained skills transfer and programme continuity.

5. Address environmental and ethical risks: UA initiatives involving homeless participants must guard the vulnerable against environmental and institutional risks. Urban planners should operationalise measures to guarantee that sites are assessed for soil contamination, water quality, food safety and exposure to hazards and that mitigation measures, including raised beds, phytoremediation, or controlled inputs, are implemented as required. Ethical practice will require that participation is voluntary, safe and empowering and not conditional or exploitative.

6. Expand empirical research on local UA initiatives: There is a clear need for further research on UA and homelessness in Cape Town and the global South. In-depth qualitative studies of existing initiatives that investigate governance arrangements, funding mechanisms, participant experiences and long-term outcomes would address existing shortcomings and strengthen the evidence base to inform more contextually appropriate policy design. Improved documentation of local successes is essential to move UA from isolated practice to strategic intervention. This research serves as a first step in this regard.

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🏆 reviewed paper

A Spatiotemporal Analysis of Duhok's Urban Growth (2010–2025): A Narrative Review of the Duhok Master Plan

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1 ABSTRACT

Duhok in the Kurdistan Region of Iraq has seen an expansion rapidly. The growth is so rapid that we think it goes against the planned development of the area. The Vossing Report's urban master plan is to be a guide for development until 2023. This narrative review will assess the effectiveness of the urban growth of Duhok governorate in the Iraqi Kurdistan Region. The main goal of this study is to show the current state of Duhok urban development. This study focuses on the different land use areas that were planned for and compares those that were developed with the residential and commercial land uses. Urban boundaries were determined based on the Google Earth Engine to demonstrate the difference between 2010 and 2025 with high-resolution satellite images. We then recorded land use via satellite images from other studies that were conducted to show the state of growth. Land use was mapped using Google Earth Engine. From this the intensity of urban growth was then used to measure the state of growth.

Keywords: Urban Sprawl, Master Planning, Duhok, GIS, Smart Growth

2 THEORETICAL PART

2.1 Overview of Duhok City in Iraqi Kurdistan

Dohuk is one of the three main cities of the Kurdistan Region of Iraq. It has grown rapidly in recent decades. This city is becoming a strategic economic and urban center with some environmental and planning challenges. Duhok lies in a valley between Bekhair and Zawa mountains around 585 m above sea level and the temperate of its climate is moderate to high in four seasons with all four season greatly seen in this city (Hassan & Kotval-K, 2019; Mohammed, 2013). It is called a Iraq's northern gateway for trade with Turkey and Syria. This has given the city its high economic importance, because of all fours seasons prints (Hassan & Kotval-K, 2019; Mohammed, 2013). Socially in a brief, Duhok is multicultural and multi religious with a Kurdish majority, Assyrian, Chaldean, Arab, and Armenian minorities (Hassan & Kotval-K, 2019). Population estimates range around 300,000–400,000+ in addition to numbers of strong in migration from rural Kurdistan other Iraqi regions, and refugees/IDPs (, 2025; Hussein & Al-Jameel, 2025; Taha, 2024).

Aspect	Main points	Citations
Natural setting	Between two mountain ranges; Duhok River green corridor	(, 2025; Hussein & Al-Jameel, 2025; Mohammed, 2013)
Economy & role	Border trade hub; fast post-2003 growth	(Hassan & Kotval-K, 2019; Hussein & Al-Jameel, 2025; Mohammed, 2013; Othman, 2014)
Land & environment	Surrounded by agricultural lands; rapid loss to urbanization	(, 2025; Mohammed, 2013; Mohammed & Ali, 2014)
Urban structure	Old core plus "urbanized villages" now city quarters	(Hussein & Al-Jameel, 2025; Raswol, 2017)

Table 1: Key Urban Characteristics of Duhok. Source: Key physical and functional traits of Duhok City Made by author based on the references

2.2 Urban Growth and Environmental Change of Duhok City

Since the late 1990s, Duhok has experienced a rapid growth largely unplanned urban expansion development driven by security, economic opportunities, and population growth (Mohammed & Ali, 2014; Hussein & Al-Jameel, 2025; Raswol, 2017; Othman, 2014). Remote sensing shows strong conversion of agricultural and vegetated land to built up areas between 1998–2016 (Mohammed & Ali, 2014; Mohammed, 2013). This has increased land surface temperatures, with built up and barren land reaching up to ~56 °C in summer, compared with much cooler water and forest areas (Mohammed, 2013).

2.3 Sustainability and Planning Issues of Duhok City

Studies highlight shortages of housing in green and open space and quality sidewalks plus car dependent development and informal settlements (Raswol, 2020; Raswol, 2017; Mohammed, 2013; Abdulsamad et al., 2019; Ali, 2016). Sustainability assessments has shown a weak progress in the 1990s with some improvement after 2005 in compact mixed use and walkable neighborhoods and protection of agriculture and

urban agriculture areas such as Shindokha (, 2025; Raswol, 2020; Hassan & Kotval-K, 2019; Raswol, 2019). Duhok is a strategically located for trade and is one of the rapidly growing Kurdish cities shaped by mountains, trade routes, and migration. Its fast expansion has brought economic opportunities but also stretches and environmental stress plus infrastructure gaps for that reason it has made a sustainable urban planning which is also a central challenge for its future.

3 METHODOLOGY

3.1 Research Framework

The study follows an approach to analyze urban growth. The study checks the papers that were published in the same area. The author has devised a narrative review designed to trace the cognitive and historical development of Duhok's master plans based on what was set by the Vossing Report. The spatiotemporal analysis using Google Earth Engine (GEE) from 2010 to 2025 was generated to transform theoretical planning into empirical spatial data. This structure ensures that research results are translated from theoretical knowledge into practical application.

3.2 Search Strategy and Boolean Search

To identify relevant literature a systematic search was conducted in the Google Scholar database following the methodology of (Büttcher et al. 2010) to search via utilized Boolean operators (AND, OR) to refine results and ensure high relevance to the research objectives.

The search model was structured as follows ("Urban growth" OR "Urban expansion") AND ("Duhok" OR "Kurdistan") AND ("Master plan" OR "Vossing Report" OR "Land use") (Büttcher, Clarke, & Cormack, 2010)

3.3 Inclusion and Exclusion Criteria (PRISMA)

This review adheres to the PRISMA 2020 guidelines to ensure transparency in study selection. The following criteria were applied:

- Study Type: Only peer-reviewed journals and published thesis and technical reports that are directly addressing urban growth or the Duhok master plan were included.
- Language: Only studies published in English were selected. The behind this is because majority of global research on strategic urban planning is documented in this language.
- Temporal Scale: While the narrative review covers the history of planning since before 2010 but to provide a comprehensive view the spatiotemporal analysis specifically the author focuses on the 2010–2025 window. (University of North Carolina at Chapel Hill, n.d).

3.4 Spatiotemporal Analysis and Google Earth Engine

The paper objective was supported by utilizing Google Earth Engine (GEE) to analyze high-resolution satellite imagery. In that process we first did a data extraction by Identifying urban boundaries and land-use. Secondly, we did a growth intensity mapping by comparing images from 2010 and 2025 to measure the intensity of urban sprawl against the planned growth trajectories of the planned master plan of the city.

Metric	2010 Value	2025 Value	Absolute Change	Percentage Increase
Total Area	34.78 km²	51.14 km²	+16.36 km²	47.04%
Perimeter	27.85 km	42.82 km	+14.97 km	53.75%
Min. Elevation	474.10 m	471.14 m	-2.96 m	-0.62%
Median Elevation	553.68 m	570.79 m	+17.11 m	3.09%
Max. Elevation	717.98 m	838.88 m	+120.90 m	16.84%

Table 2: Comparative Spatial and Elevation Metrics for Duhok (2010–2025). Source: Created by the author through GEE.

3.5 Data Synthesis and Filtering

As illustrated in the PRISMA Flow Diagram below studies were filtered through three distinct phases initial identification, secondly screening for accessibility (open-access journals only), and final eligibility based on the presence of key terms in the title, abstract, or core paragraphs. This rigorous process ensures that only the most pertinent data points are used to evaluate Duhok's urban evolution. (University of North Carolina at Chapel Hill, n.d)

3.6 Objectives

The primary aim of this study is to evaluate the urban evolution of Duhok City from 2010 to 2025. And answering how external geopolitical pressures influenced the execution of the official master plan.

Phase	*Step*	*Details / Numbers*
Identification	Records identified from:	Databases (n = 1) Registers (n = 265)
	Records removed before screening:	Duplicate records removed (n = 0) Records marked as ineligible by automation tools (n = 0) Records removed for other reasons (n = 0)
Screening	Records screened	(n = 265)
	Records excluded	(n = 65)
	Reports sought for retrieval	(n = 200)
	Reports not retrieved	(n = 0)
	Reports assessed for eligibility	(n = 200)
	Reports excluded	Total: 191 • Reason 1: Not related directly to Duhok • Reason 2: Not related to objective of review • Reason 3: Not English / missing data
Included	Studies included in review	Total items (n = 9) • Primary studies (n = 6) • Reports of included studies (n = 1) • Theses of included studies (n = 2)

Table 3: PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only. Source: University of North Carolina at Chapel Hill. (n.d.). Creating a PRISMA flow diagram PRISMA 2020. LibGuides

4 RESULTS

The Author has used a time series like approach to categorize the urban growth into three-time related category. The first category of growth is pre 2010 followed by intermediate phase which is between 2012 to 2019 and the modern category of urban growth between 2020 and 2025.

4.1 Historical Phase: Pre–2011 (Baseline and Initial Growth)

The city of Duhok has its roots from the very first settlement of the town in the year 1887, in the time of the Ottoman Empire (Hajani 2019). In 1923, Duhok City had transformed into a natural center of 18.6 hectares (Hussein & Al, Jameel 2025; Hajani 2019). During these years, the town had already begun to rely on paper cadastral maps to indicate its development. These maps were produced from the plane table detailed surveys and field surveys were direct on the trace paper (Kattan & Abdulrahman, 2019). The local architecture of Duhok City received a significant incentive in 1969 when Duhok became the provincial capital or in local legal term governorate. The population of Duhok city surged from 5, 621 in 1947 to 212, 469 by 1998 (Hajani 2019). To curb the rapid increase in population the government instituted a practice of free land allocation to public servants of which roughly 23, 000 land parcels were allocated between 1998 and 2011 (Hajani 2019). The city underwent rapid extension to the west during the years 1998 to 2011, characterized by the dominance of the single.

4.2 Intermediate Phase: 2012–2019 (Intensification and Environmental Stress)

The city also suffered from some minor environmental degradation during this period. Furthermore, large gaps existed in the application of the institution framework. By the year 2014 the expansion of the urban area was 5, 763 hectares and dense forest cover had greatly reduced due to clearance of the area for the construction of the city (Khwarahm et al., 2021; Hajani, 2019). The residential areas built during this period such as Masike were good but did not apply the strict international standards of sustainability and the good thing about this was having feature of a low population density of 120 people per hectare, making the area car-dependent (Raswol, 2019a).

As a result of the economic crisis and the ISIS war less than 5% of the proposals of the Duhok City Center Masterplan in 2014 achieved implementation by 2019. The project experienced severe challenges (Saadulla, 2019). Later in 2016, the technical documentation was improved by creating an official land use master plan that was confirmed to be of a very high position accuracy of 1.5 cm (Kattan & Abdulrahman, 2019). The sustainable energy action plan, which was conducted through the 2018 Duhok SEAP, demonstrated that the residential and transport sectors are still the major current anthropogenic sources of greenhouse gas (Duhok Governorate, 2018).

4.3 Modern Phase: 2020–2025 (Governance and Heterogeneity)

Recent studies characterize Duhok as a diverse city that requires the abandonment of the concept of citywide uniformity (Hussein & Al-Jameel, 2025). Planners suggest the development of distinct urban codes for the diverse historic, organically developed core, and the separate, amenity rich modern development zones to foster and protect the local distinctiveness (Hussein & Al-Jameel, 2025). To substitute traditional zoning, Urban Transect Theory has been utilized as a potential regulatory framework to enhance urban and natural systems synergy by using a collection of regulatory frameworks to create and maintain urban areas that are high in density and facilitate walkability (Hussein & Al-Jameel, 2023).

The Duhok governance has been integrating E-management and smart services to minimize time and cost of administrative processes (Duhok Governorate, 2018). The goals for 2025 and beyond include:

- Emissions: Committed to a 40% reduction in emissions by 2030 by implementing energy saving "Green Codes" for building (Duhok Governorate, 2018).
- Urban Growth: Urban footprint is projected to grow by 271% by 2060 compared to 2017, with the majority of the loss of farmland (Khwarahm et al., 2021).
- Policy Innovation: Immediate integration of the Sustainable Development Goals (SDG 11) into the city's urban development framework is imperative to enhance the city's resilience and inclusiveness (Dohok Governorate 2018; Raswol, 2019b).

5 DISCUSSION

The assessment of the urban development of Duhok between the years 2010-2025 shows a city with adaptive capacity and the importance of its geostrategic position. While the spatiotemporal data shows a variation from the original master plan, a more detailed review informs us that Duhok is more likely to have had a master plan that is due to exceptional geopolitical circumstances, was delayed, and thus, why the framework was never completed. It lacked systemic failure.

5.1 Resilience and the Geopolitical Crisis

The 2014 regional crisis is pivotal to understanding Duhok's development trajectory. The 2014 Masterplan was a document of great merit with sophisticated technical features and the use of high precision GPS. However, as a consequence of the ISIS war the governorate's primary focus shifted from urban expansion to humanitarian and security imperative.

Duhok became a safe haven for over hundreds of thousands of internally displaced persons (IDPs) and refugees which meant that housing and land had to be allocated rapidly, and the traditional phased land development sequencing of the Vossing report had to be bypassed. Duhok's ability to maintain its primary urban functions and grow was nothing short of remarkable, and this was a reflection of Duhok's resilience as a city and the supportive governance structure, rather than a reflection of failure of the plan.

5.2 The "Safe Haven" Effect and Urban Vitality

The rapid development of Duhok is a testament to its livability and economic potential. Duhok has become a significant trading and safe haven center within the region's persistent instability. The increasing influx of people and consequent urban sprawl is a problem of success. The city developed because people wanted to live there. While the Masike area and others developed as low-density sprawl they were important to provide shelter during a time of extreme pressure at a national level. The period of modern phase Duhok (2020–2025) and the transition to E-management and Smart Services demonstrate that despite the external challenges of the preceding decade, local government is committed to modernization and efficiency.

5.3 Strategic Pivot Toward Sustainability

The modern phase encapsulates how Duhok is not just growing but changing. The city is changing for the better as shown by the 40 percent emissions reduction pledge by 2030 and the continued inclusion of the SDGs in city planning. City planners in Duhok are developing a world-class city, and they are doing so despite the conflicts that plague the region. The shift from firm zoning regulations to the Urban Transect Theory demonstrates Duhok City planners' appreciation and understanding of the city's physical context. By

designating the historic core as a protected area and designing a high-density walkable core the city is re-booting the Vossing report.

5.4 Synthesis of Potential

The evidence shows that a Smart Green Duhok is within reach. The Master Plan Gap was a product of a necessity that arose from the ISIS war whereby planners were forced to choose from a growing set of maps or the immediate protection of the people. Duhok is now in a unique position to integrate its high-resolution planning data with its innovative digital governance to align with the emerging stability in the region and correct the sprawl that so many cities in the region have experienced.

Factor	Planned Trajectory (Master Plan)	Observed Reality (2010–2025)
Land Use	Managed green belts & agricultural protection	High conversion of land to residential
Density	Sustainable, walkable neighborhoods	Low-density, car-dependent sprawl (e.g., Masike)
Governance	Strict adherence to Vossing plans	Flexibility due to economic/security crises
Environment	Emission reduction & temperature control	Urban Heat Island effects

Table 4: Summary of Discussion Points. Source: Created by the author.

Factor	Strength / Success Indicator	Resilience Context
Technological Base	High accuracy in land use mapping	Maintained despite economic crisis
Social Role	Multicultural trade and humanitarian hub	Absorbed massive migration without city collapse
Modernization	Shift to E-management & Green Codes	Preparing for post-2025 sustainability
Resilience	5% plan implementation with 100% functionality	Survival and growth during the ISIS war

Table 5: Key Strengths of Duhok's Urban Framework. Source: Created by the author.

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion: A City of Resilient Growth

The analysis of Duhok’s development over the years 2010 to 2025 depicts a highly remarkable development of urban fortitude. The analytical data suggests that a tiny portion of Duhok’s Vossing Report and 2014 Masterplan was actually materialized. However, this study interprets the implementation gap differently. It suggests that the gap was not a result of a loss of vision but rather a significant shift in focus that was needed to deal with the unforeseen external stresses. The period of 2014-2019 captures the essence of Duhok’s balancing act as it successfully played out the role of a safe sanctuary for the people during the ISIS crisis providing humanitarian assistance, while, paradoxically, assuming the position of a Regional Economic Element (REE) as a cross-border strategic trading facilitator. The rapid development and subsequent urbanization were a result of a choice by Duhok to be functional and open under difficulties. Duhok has now emerged as a multicultural urban center and is no longer in a state of emergency expansion. Immediate development of digital services, and long-term planning for sustainable development has placed Duhok in a reasonable position for planning additional steps. Current development is based on earlier planning. Technically, this planning is still sound and is now based on a highly precise geospatial foundation for the next generation of smart growth.

6.2 Recommendations

To integrate historical planning with modern realities, the following steps are proposed. Master Plan Update With the original Vossing timeline but extended. The governorate must establish a Duhok 2040 vision with incorporating the current sprawl into a unified urban framework. Enforcement of the green code on new developments with a recorded heat island effect. The city requires the immediate enforcement of building codes aimed at energy conservation. This will support the city’s aim for a 40% emission reduction by 2030. The city needs to shift from large homogeneous zoning to the transect theory in order to retain the gorgeous integrated structure of the old city core and the less of the smart zones with high density and walkable of the newer areas. Utilize Google Earth Engine (GEE) and similar technologies for real-time monitoring of the development of different land uses so that any further settlement on the agricultural land can be identified and managed. In response to the car dependency noted from 2012 to 2019 green corridors and crossable sidewalks that integrate with commercial areas from residential areas must be prioritized in order to facilitate walking.

To further visualize the “Resilience Context” you've established in the discussion, the following table summarizes the city's trajectory:

Feature	The Theoretical Plan	The Resilient Reality (2010–2025)
Land Use	Managed green belts & agricultural protection	Rapid conversion to residential to house growing populations
Urban Density	Compact, walkable neighborhoods	Low-density sprawl due to emergency housing needs
Governance	Strict adherence to Vossing/2014 maps	Adaptive/Flexible governance prioritizing safety and trade
Technology	Standard paper/digital cadastral maps	High-precision GIS (1.5cm accuracy) and E-management

Table 6: The end result of the review (Planning vs. Reality). Source: Created by the author

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reviewed paper

A Stakeholder-Driven Needs Assessment: Identifying Urban Challenges and Requirements for Satellite-Based Services Supporting Climate-Resilient Austrian Cities

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1 ABSTRACT

Cities and municipalities face major challenges in times of climate change. As key actors in the transition towards climate neutrality, they require analysis, planning, decision-making processes and services to help them prioritise and justify the necessary measures and activities.

One option for data-based decision-making is the use of satellite-based services. The Urban Sky research project is therefore collaborating with representatives from Austrian cities of various sizes and structures to identify challenges and needs. This information will be used to develop satellite-based services concepts for urban planning, neighbourhood development, natural hazards, and urban mobility, while taking into account the relevant legal and normative framework conditions.

The project focuses on using freely available data such as that from the Copernicus programme. The aim is to explore the potential of the satellite data, review its feasibility and combine it to create useful services. The project also assesses the added value for cities, the market potential and the research requirements, and categorises and prioritises the services, resulting in actionable recommendations. To achieve this, the following research questions are answered: (1) What challenges do Austrian cities face regarding urban and neighbourhood planning? (2) How can satellite data help to solve these challenges? (3) Taking into account spatial and temporal resolution, what additional data and information is required to use satellite data effectively to overcome these challenges?

Following a literature review, the topics were narrowed down to the following areas: buildings; green spaces and biodiversity; infrastructure; mobility; natural hazards; urban planning; and spatial planning. These areas were further discussed and specified during the first Stakeholderworkshop, which was attended by representatives of several Austrian cities varying in population and structure. Particularly urgent needs were identified focussing e.g. on buildings and potential renovation, solutions to reduce heat energy losses and the potential for redensification. In the field of natural hazards, key topics included small-scale air temperature monitoring and the development of early warning systems for floods or agriculture. In the context of infrastructure, the focus was on the detection of damage after extreme weather events and the analysis of photovoltaic (PV) potential in car parks. In addition, priorities were identified in the following areas: recording of traffic movements and parking space usage (mobility); calculating the degree of greening and tree canopy cover to comply with the EU Nature Restoration Regulation; and smart irrigation management (green spaces). Other priorities included urban heat island monitoring and climate risk analysis (urban planning).

The applications are primarily based on time-series data from optical satellite missions, such as Sentinel-2 and commercial very high-resolution satellites like Pléiades, Synthetic Aperture Radar (SAR) missions (such as Sentinel-1, NISAR, and future ROSE-L), and thermal missions, e.g. TRISHNA, ECOSTRESS, and the upcoming Land Surface Temperature Mission (LSTM) from the European Space Agency (ESA). A key outcome of the Urban Sky project is a structured study on the potential of satellite technology for urban and neighborhood planning. The study identifies and analyses existing satellite applications in cities (both nationally and internationally), and assesses their compatibility with current geodata sources. Based on the

stakeholders‘ requirements, the study proposes ten potential applications to serve as a foundation for further RTI (research, technology, and innovation) initiatives.

Keywords: satellite data, services, stakeholder-driven, urban planning, climate resilience

2 INTRODUCTION

Climate change poses multiple challenges for Austrian cities and municipalities. As the main contributors to greenhouse gas emissions, they are required to implement climate mitigation measures in order to meet both national and international climate goals. However, urgent action is not only required due to legislative requirements; cities are also the most severely affected by the consequences of climate change such as urban heat islands (UHI), heavy rainfall events and biodiversity loss. Therefore, they must develop comprehensive adaptation strategies. This pressure has been further intensified by the European policy framework. While the European Green Deal (European Commission, 2019) established the ambitious ecological targets, its successor, the Clean Industrial Deal, introduced in February 2025 (European Commission, 2024), has shifted the focus towards competitiveness and efficient implementation. Within this new framework, local authorities are not only required to prove ecological compliance (e.g., under the Nature Restoration Regulation (Regulation (EU) 2024/1991)) but are also urged to accelerate planning and permitting processes to foster economic resilience. Recent policy analyses emphasise this pivotal role, arguing that cities act as the 'central architects' of the Clean Industrial Deal, because they directly control critical levers such as land use, transport, and energy systems (C40 Cities, 2025). To fulfil this role and tackle these challenges of 'greening' and 'speeding up,' administrations urgently need scalable, evidence-based decision support systems.

To meet these requirements, urban planning authorities and decision-makers need accurate, up-to-date and comprehensive data. Traditional survey methods (terrestrial surveying, aerial surveys, local sensors) are often costly and updated at intervals that are too long to monitor dynamic changes. Satellite-based services (Earth observation – EO), in particular cost-free data, e.g. as provided by the European Copernicus programme, offer enormous potential in this regard. They provide continuous time series on parameters such as surface temperature, soil moisture and vegetation density. Nevertheless, practical experience shows that this potential has not yet been sufficiently exploited in municipal administration (Murgante et al 2024, Gulyás et al. 2025, Strand et al 2025).

A major obstacle to the integration of EO data is the discrepancy between large urban agglomerations and smaller municipalities. Large cities often have specialised GIS departments and budgets for commercial data, but face the challenge of complex inner-city structures and extreme pressure on land use. Small and medium-sized towns – the majority of Austrian municipalities – are often confronted with limited human resources and municipal finances, resulting in a lack of expertise to process raw data and budget for expensive software solutions. Therefore, the solution must not consist of providing even more raw data, but must lie in the development of tailor-made, cost-efficient services that can be directly integrated into existing administrative processes.

The Urban Sky research project addresses this topic. The aim is to identify the specific needs of stakeholders using a demand-driven approach in order to develop concepts for services supporting their urban challenges. The focus is on freely available data (open data) in order to lower the financial hurdle for local authorities.

This paper presents the results of the stakeholder process and the needs analysis. In order to derive recommendations relevant to action, this article addresses the following research questions:

(1) What challenges do Austrian cities face regarding urban and neighbourhood planning?

(2) How can satellite data help to solve these challenges?

(3) Taking into account spatial and temporal resolution, what additional data and information are required to effectively use satellite data to overcome these challenges?

3 METHODS

An initial literature research and review was conducted to gain an understanding of the field of satellite data and Earth observation for urban planning. The results were used to set up a first online Stakeholderworkshop, which aimed to gather information on the needs of cities´ representatives regarding their goal to become climate neutral cities. During the workshop, the participants were asked to consider

their daily challenges and what they would like to change. The impressive variety of anwers enabled us in various internal workshops to come up with over 15 service concepts which have been prepared with descriptive texts and graphical abstracts and are currently being evaluated by our stakeholders in a comprehensive online survey. Based on the results, the best ranked ideas will be detailed in a second Stakeholderworkshop. For the prioritised ten final results, a roadmap will be developed including an assessment of added value, market potential, future research needs, and feasibility.

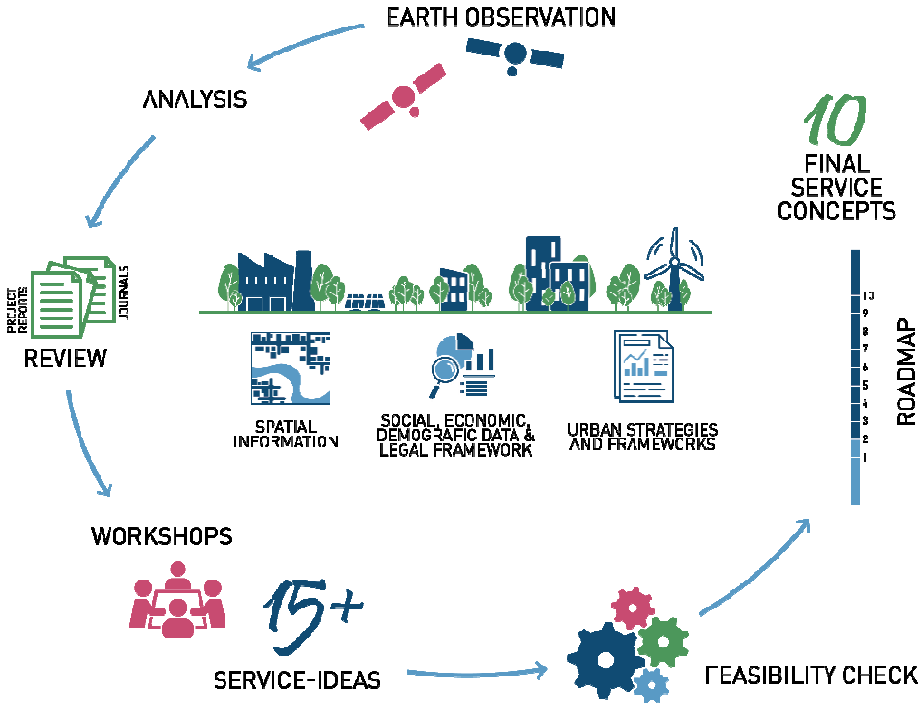


Figure 1: Urban Sky Project Plan © AIT

4 URBAN REQUIREMENTS AND PRIORITY FIELDS IN AUSTRIAN CITIES

Based on the literature review, the topics were clustered in priority fields that were used throughout the stakeholder process. Although there are overlapping areas, the priority fields help to classify and get an overview of most important topics for the cities: Urban Planning & Urban Climate, Buildings & Energy, Green Spaces & Biodiversity & Water management, Natural Hazards, Mobility & Infrastructure. The following section summarises the stakeholder inputs.

4.1 Results of the needs assessment

4.1.1 Priority Field: Urban Planning & Urban Climate

One of the main topics that were discussed during the stakeholder workshop was the field of "Urban Planning and Urban Climate". Throughout the conversations, climate-related risks emerged as a cross-cutting concern that should not be overlooked.

The following topics were highlighted in the discussions:

- The importance of systematic monitoring and assessment of urban heat islands and surface temperatures, with a particular focus on public spaces. Participants discussed the need for city-wide assessments considering perceived temperatures, shading conditions, cold air corridors and monitoring the quality of stay. This information is essential to identify priority areas for heat mitigation and support climate risk analyses at neighbourhood scale.
- The need to identify and reactivate brownfield sites and vacant urban areas including large, sealed surfaces such as parking lots and increasingly also privately-owned sealed green spaces. Sealed surfaces were highlighted as major heat traps and therefore high-priority targets for cooling-oriented reuse and redesign. For the participants it was important to prioritise adaptation, renovation, and climate-sensitive redevelopment over new greenfield construction, as well as monitoring changes in

land use, vacancy and unused spaces over time. Therefore, change detection was considered one interesting topic to be supported by using satellite time-series data.

- Additionally, monitoring of light pollution was discussed as an important topic as the view from above reveals unnecessary electricity use and shows where light can be reduced and energy saved.

4.1.2 Priority Field: Buildings & Energy

The field of Buildings & Energy was one of the central topics discussed during the stakeholder workshop as it is one of the main levers to reach the goal of climate neutrality and energy efficiency in cities. The following topics were discussed:

- Updating and improving existing building inventories, including the identification of conditioned and non-conditioned building areas was seen as essential to support reporting obligations under the revised Energy Efficiency Directive EED III (Directive (EU) 2023/1791), which requires member States to improve the availability and consistency of data on building energy performance.
- Closely linked to this, stakeholders highlighted the need for the detection of thermal energy losses through the building envelope to identify renovation priorities.
- The assessment of rooftop solar potential including shading was identified as crucial to assess seasonal yields to support the usage of renewable energy and strategic energy planning.
- In addition, the monitoring of green roofs was highlighted as an important climate adaptation measure. From an EO perspective, time-series analyses allow vegetation development and vitality to be monitored in a consistent and city-wide manner. This is relevant not only for building owners/tenants to assess, whether green roofs effectively contribute to heat mitigation, but also for city administrations to verify the performance of (potentially) subsidised measures, ensure the effective use of public funding, and support strategic planning and monitoring of urban climate targets.

4.1.3 Priority Field: Green Spaces & Biodiversity & Water management

The stakeholders ranked the priority field “Green spaces, Biodiversity and Water Management” as very important. This was particularly pertinent given the future tasks arising from the implementation and enforcement of the EU Nature Restoration Regulation (Regulation (EU) 2024/1991), a key element of the EU Biodiversity Strategy (European Commission, 2020). The discussions covered the following topics:

- Quantitative and qualitative mapping of tree populations (including tree species, crown diameter/tree canopy cover and height) and changes therein (such as tree health), with the aim of establishing a baseline in accordance with the EU Nature Restoration Regulation.
- Another closely related topic was efficient and sustainable irrigation management (smart irrigation), with a view to preserving tree health and adapting to changes of vegetation period. This included the question of automation.
- Green spaces, particularly trees, were regarded not only as a means of mitigating urban heat, but also as a steppingstone for establishing resilient biodiversity.

4.1.4 Priority Field: Natural Hazards

The topics discussed in the “Natural Hazards” priority field were diverse and naturally overlapped with those in other priority fields. There were overlaps, particularly in the “Green Spaces” priority field.

- The participants prioritised two topics regarding climate change: the small-scale monitoring of inner-city air temperatures, and the identification of areas where cold air forms.
- The monitoring and management of neophytes and invasive species (as a biological natural hazard) currently was mentioned as a contribution to biodiversity. However, the use of EO was questioned and deemed ineffective.
- Stakeholders also identified the assessment (and monitoring) of stormwater events or flooding in urban areas as essential (for assessing the risk situation, for designing danger zones, and for the

identification of gaps and lack of protective measures). However, it was noted that responsibility actually lies with higher levels of administration. The same applies to the topic of mass movements.

4.1.5 Priority Field: Mobility & Infrastructure

The focus area of "Mobility & Infrastructure" was a broadly discussed topic in the stakeholder workshop.

The main topics resulting from the exchange among workshop participants who came from various professional background regarding needs assessment for mobility can be narrowed down:

- Monitoring of commuting and traffic patterns, more specifically a request was to monitor long-term the change rate on the used traffic corridors and streets as well as the frequency of its use and the number and types of vehicles using which road when. This topic was also discussed from the perspective of congestion and traffic frequency, road utilization, peak times, and improvement of traffic flow.
- Monitoring the transit traffic in its amount and main routes used with the aim of developing seasonal deviation roads easing the main routes.
- Monitoring the intensity and frequency of utilization of parking lots by using multi-temporal satellite acquisitions (mornings, middays, evenings and nighttime) over a longer period to detect daily as well as weekly or seasonal patterns.
- Monitoring the traffic of cyclists to raise the share of modal split cyclists. E.g. systems for counting bicycles, traffic flow measurements with smart cameras have been discussed.
- CO_2 and energy accounting of traffic: Especially transport of goods and cargo, but also public transport and general transport of passengers. The assessment of this need focusses on measurement of plausible data instead of a model. The stakeholders mentioned punctual counts of passenger mobility and the use of telecommunication data as well as google analytics, the Google Mobility report or traffic models. The example Vorarlberg was mentioned, where a traffic behavior survey was conducted for the years 2008, 2013, 2017 and 2023 (Herry, 2024).

The focus area "Infrastructure" covered the following topics:

- Detection of infrastructure damages after extreme weather events, including the mapping of economic or monetary damage. Another perspective was the need to detect and prevent damage at an early stage, caused by excessive heat.
- There is a need to gather information on the thickness, density and persistence of snow cover for winter service and snow clearing units. This can be tied to weather and temperature scenarios including the local topography.
- Identification of parking lots which are not covered yet, as possible space for PV installation on roofs.
- Identification of gas leakages or damages along pipelines or power lines that could be caused by landslides, avalanches or storms.
- Mapping and regularly updating construction sites or road closures of each kind. This need includes regular updates on construction progress and compliance with regulations concerning deposit of sewage and construction waste.
- Monitoring the demolition of buildings for reusing its materials, to establish a proper recycling system, interim storage areas would be needed. This poses major difficulties within cities, but remote sensing can help identify brown field/fallow areas.

The following table summarises the five priority fields, and the key urban challenges identified for Austrian cities based on literature and stakeholder input.

Having established the main urban priorities and requirements from Austrian cities, the next step is to examine how current satellite-based applications can address these needs. Chapter 5 presents the key EO application domains identified in literature and international projects, providing a foundation for matching city priorities with usable Earth observation services.

Priority Field	Main Challenges	Typical EO-based use case[1]
Urban Planning & Climate	- Identification and monitoring of urban heat islands and heat stress in public spaces - Assessment of thermal comfort and quality of stay (perceived temperature) - Detection and constant monitoring of vacant areas	- Mapping of surface temperatures using EO data (Landsat, ECOSTRESS) - Identification of potential air corridors using 3D building models in combination with land cover and elevation data (Sentinel-2, LiDAR, DEMs) - Detection of vacant areas through land use classification and time-series analysis of satellite imagery (change detection) - Light pollution
Buildings & Energy	- Updating and improving building inventories - Detection of thermal energy losses to identify renovation needs - Assessment of rooftop solar potential, including shading and energy yield - Monitoring of green roofs	- EO-supported building inventory updates using Sentinel-2 and LiDAR data - Urban heat loss screening with thermal satellites (ECOSTRESS, Landsat) - Roof PV potential assessment combining optical imagery and LiDAR for shading analysis - Green roof monitoring using time-series NDVI (Normalised Difference Vegetation Index) from Sentinel-2
Green Spaces & Biodiversity	- Updating and improving green space/tree inventories - Efficient and sustainable irrigation management (smart irrigation)	- EO-supported green space/tree inventory updates using Sentinel-2 and LiDAR data - Using time-series NDVI for health monitoring of trees for maintenance and irrigation
Natural Hazards	- Small-scale monitoring of inner-city air temperatures - Identification of areas where cold air forms - Mass movement	- Validation with satellite data: ECOSTRESS (daily cycle), Landsat (long-term dynamics) or by future missions e.g. TRISHNA, LSTM - InSAR (Interferometric Synthetic Aperture Radar)
Mobility & Infrastructure	- Monitoring of commuting and traffic patterns (frequency, types of vehicles, peak times, congestion) - Detection of infrastructure damage after extreme weather events - Mapping and updating construction sites or road closures to support traffic management - Monitoring demolition of buildings and brownfield areas for potential material reuse and urban redevelopment	- Traffic pattern and congestion analysis using high-resolution optical imagery and Sentinel-2 time series - Post-event infrastructure damage assessment using Sentinel-1 SAR and optical data - Construction site and road closure monitoring through change detection on optical imagery and aerial photos - Identification of brownfield/fallow areas via high-resolution optical images and land-use data to support recycling and redevelopment initiatives

Table 1: Summary of Priority Fields, Key Urban Challenges and Relevant Earth Observation Data

5 EO-BASED APPLICATION DOMAINS IDENTIFIED IN LITERATURE AND PRACTICE

5.1 Overview of international EO-related urban projects and services

This section presents the main EO application domains identified in the scientific literature and international projects on using satellite data for urban decision-making in the context of climate-resilient cities. A literature analysis has been conducted, screening a total of almost 240 relevant projects and publications from various sources (publication databases, project databases, etc.). These were then clustered and the topics were visualised in a matrix (Figure 2). Among the sources were the FFG project database with a focus on the Austrian Space Application Programme (ASAP). The entire database was screened, and the Horizon Europe project databases were systematically reviewed. The ESA portfolio was also considered, particulary its demonstration projects and thematically relevant projects ("Infrastructure & Smart Cities") which were added to the list. Another source was a collection of ESA services which are continuously updated as a "living document". The "Urban EO Service Catalogue" (ESA, 2025a) lists a total of 17 services on urban heat (private access [11], public access [6]), 37 services on mapping urban areas (private access [29], public access [8]), and 15 services on air quality (private access [9], public access [6]). Recent activities originating from the Horizon project "Space4Cities" (Forum Virium Helsinki, 2025) were also reviewed. At the beginning of 2025, the project launched a €2.87 million call for proposals, and the winners have now been announced. Ten of the 20 selected consortia will now have the opportunity to further develop their solutions to common challenges in European cities, such as flood detection, identifying heat islands, reducing traffic emissions, preventing wildfire risks, protecting cultural heritage sites, locating underground pipe leaks, and monitoring the condition and changes of green spaces, bridges, and roads. The five best prototypes will then be tested in real-life situations in fifteen European cities from July 2026 to February 2027 (Space4cities, 2025).

5.2 Key thematic clusters identified in the literature

The urban planning theme covers projects that develop digital models (e.g. digital twins, 3D models) for analysing urban structures, vegetation areas and thermal properties, and for supporting planning decisions.

[1] Details on satellite technology see chapter 6.

They differ in their specific fields of application, which range from mapping green spaces, analysing the urban heat island effect and solar potential, improving urban resilience and adapt to climate change, optimising urban mobility and parking space utilisation, to automated mapping of land use and land cover (FFG 2026b; ESA, 2026), and supporting visually impaired people in urban areas. Projects in the field of heat islands deal with the combination of satellite data, meteorological information and climate models in order to obtain the most up-to-date or real-time picture possible of urban overheating areas (Cure-Copernicus, n.a; Geoville, 2025; LUP, n.a.; LAND, 2026). Surface temperature maps are created using satellite data or aerial survey data in order to provide cities with a basis for decision-making when planning green and blue infrastructure (Stadt Konstanz, 2025; UrbanFootprint, 2026). Covering the building domain, the creation of digital twins is common, both for individual buildings and for entire neighbourhoods (Buildspace Project, 2026). Projects adressing green spaces aim to monitor and optimise green spaces and their ecological functions (biodiversity, cooling potential, biotope areas, etc.) (BOKU, 2025; GrünStattGrau, 20, FFG 2026c). One project covering many of these aspects is the Green Transition Information Factory (GTIF), an ESA initiative designed to demonstrate the added value of EO. The Austrian GTIF currently covers various narratives tackling the named topics like Heat Risk Maps, High-Resolution Forecasts of Solar Potential and Extreme Temperature, Brownfield Recovery Potential, Wind Atlas, Urban Energy Performance Monitor (GTIF Austria, 2026).

In the field of natural hazards, projects focus on the early detection, monitoring, documentation and prediction of specific hazards such as forest fires or flooding, as well as on the creation of dynamic, comprehensive hazard maps. The projects differ in terms of the natural hazard they address, such as fire, water or mass movements, the level of detail in the analysis (from large-scale monitoring to specific hazard locations such as aquaplaning) and the focus of application (real-time warning, support for authorities, traffic safety, dynamic mapping) (FFG, 2026a; Joanneum, 2025; FFG, 2026d).

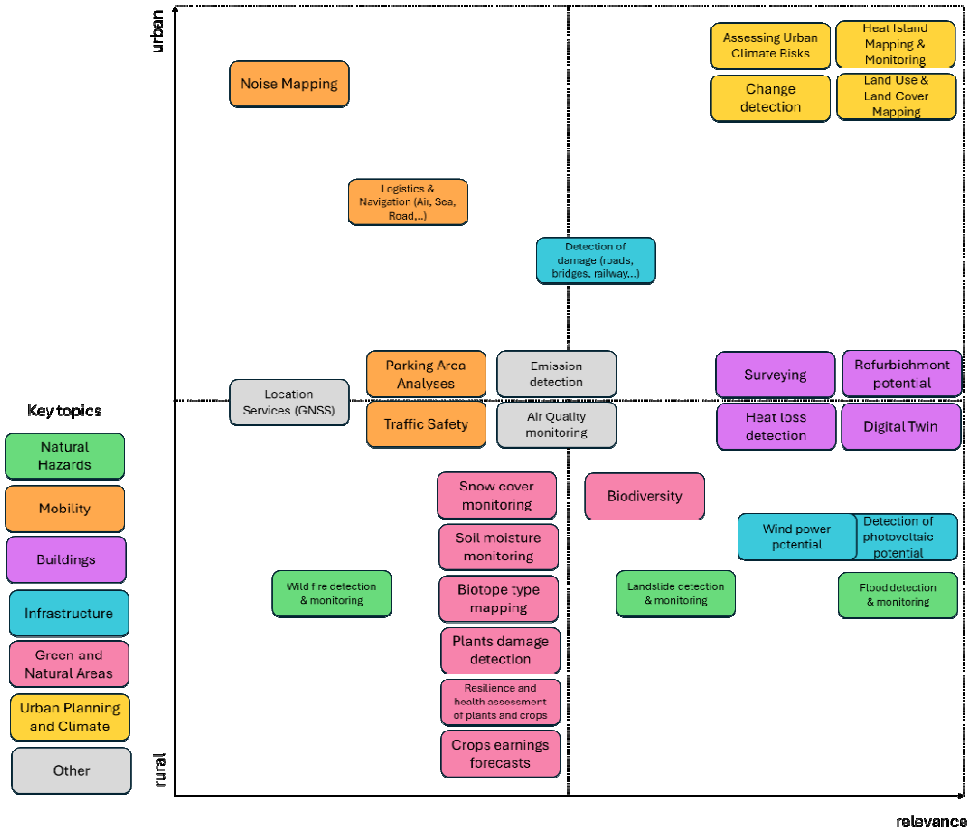


Figure 2: Illustration of the subject areas narrowed down into relevance, rural and urban focal points © AIT

Projects in the field of mobility and infrastructure aim to optimise and secure transport systems and monitor infrastructure. The applications range from high-precision positioning for accident prevention and route optimisation for cyclists to satellite-based detection of available parking spaces and road conditions. Due to space constraints only two of the 22 identified projects covering mobility are quickly mentioned. Firstly, SatPark is a completed FFG project from 2019 covering georeferencing, identification and classification of

vehicles based on satellite data to enable improved parking space analysis and navigation (FFG, 2026e). Secondly, ESERCOM-D is a project concerning the implementation of satellite-based data to support greener and smarter road usage, optimise road maintenance, and enhance traffic safety (EU-Project, 2026). In addition, solutions are being developed for the management of infrastructure assets such as power grids, street lighting and dams in order to improve their maintenance and resilience. In the literature analysis 17 projects and services have been identified that are within the field of infrastructure monitoring. For example, the FFG project RAVEN developed a radar-technology-based methodology for detecting structural and ground movement changes in urban buildings, enabling improved monitoring of infrastructure stability and early warning capabilities (FFG, 2026e).

The literature review confirms a strong alignment between international EO-based urban services and the needs expressed by Austrian cities, particularly in the domains of urban climate, buildings, and natural hazards. However, gaps remain regarding spatial resolution, operational integration into municipal workflows, and long-term sustainability of services.

6 SATELLITE DATA SUPPORTING URBAN DECISION-MAKING

6.1 Relevant satellite data types for urban applications

Optical, radar (SAR) and thermal satellite data each provide unique strengths and are suited for specific applications. To address the complexity of urban planning tasks, they are often combined to facilitate the complementary information content, which they provide.

Due to often limited resources in cities, they need to pay attention to costs. Therefore, for urban applications, it is crucial to distinguish between freely available satellite data and commercial datasets. Open-access Copernicus missions such as Sentinel-1 SAR and Sentinel-2 optical provide consistent, long-term time series with high temporal coverage, making them well suited for continuous monitoring and trend analysis for cities. Thermal open access data such as e.g. ECOSTRESS can be applied to assess urban heat dynamics such as e.g. UHI mapping and heat stress analysis. Commercial datasets such as Pléiades (Airbus, 2026) offer very high spatial resolution and are valuable for detailed analyses at building or object level. Due to higher costs and task-based acquisitions, they are typically used selectively, complementing freely available data where finer spatial detail is required.

6.2 Future satellite missions and their potential for urban applications

While these currently operational satellites already provide valuable data for urban applications, a new generation of satellite missions, both public and commercial, will significantly expand the availability of high-resolution, freely accessible, and near-real-time Earth observation data. These missions will provide a valuable addition to existing satellite missions, thereby offering Austrian cities enhanced capabilities for monitoring, analysis, and decision-making. The main new satellite missions are:

- TRISHNA (Thermal Infra-Red Imaging Satellite for High-Resolution Natural Resource Assessment): A French-Indian mission scheduled for launch in 2026, TRISHNA will provide thermal data at 57 m resolution, bridging the gap until Sentinel-8 LSTM becomes operational. Its focus on water resources and land surface temperature makes it highly relevant for heat stress monitoring (CNES/ISRO, 2025).
- Sentinel-8 LSTM (Land Surface Temperature Monitoring): Planned for launch in 2029, LSTM will deliver land surface temperature data at 30–50 m resolution with revisit times of 1–3 days. These EO data will be crucial for monitoring urban heat islands, energy efficiency, and climate adaptation strategies (ESA, 2025b).
- ROSE-L (Radar Observing System for Europe in L-band): Expected launch in 2028, ROSE-L will operate in the L-band, enabling penetration through vegetation and cloud cover. With 5–10 m resolution and revisit times of 3–6 days, it will support applications such as infrastructure monitoring, flood risk assessment, and land cover monitoring (ESA, 2025b).
- NISAR (NASA-ISRO Synthetic Aperture Radar): already launched in 2025, NISAR offers comparable L-band SAR capabilities as ROSE-L, providing early access to datasets relevant for European urban resilience planning (for details see: NASA, 2025).

- FireSat: Developed by the Earth Fire Alliance with partners including Google Research, FireSat aims to deliver near-real-time global fire detection with a 20-minute revisit cycle when the full constellation is operational. The first protoflight satellite launched in March 2025, and the system will expand in coming years (Earth Fire Alliance, 2025).
- HotSat Constellation (Satellite Vu): Following the HotSat-1 demonstrator (2023), HotSat-2 and HotSat-3 are planned for launch soon. These satellites allow monitoring of heat stress and detection of heat losses in buildings and industrial facilities, supporting energy efficiency measures in cities (SatVu, 2025).
- CO3D (Constellation Optique 3D): Jointly developed by Centre national d´études spatiales (CNES) and Airbus Defence and Space, CO3D was already launched in 2025, and the commercial phase is expected to begin in 2027. It will generate high-resolution 3D surface models, enabling systematic urban morphology analysis and supporting spatial planning. Global coverage is expected within 3–5 years, with annual updates for priority regions (CNES, 2025).

The integration of these missions into Austrian urban planning frameworks offers several opportunities for Urban Climate Resilience:

- Enhanced monitoring of heat islands, water resources, and vegetation.
- Improved early warning systems for floods and fires.
- Detailed 3D urban models for infrastructure resilience and redensification strategies.
- Support for compliance with EU regulations such as the Nature Restoration Regulation.

Together, these missions represent a paradigm shift in satellite-based services, enabling cities to access actionable, high-resolution data for climate-resilient developments. Combined with existing Copernicus datasets and local geodata, this information forms the backbone of future applications and can now be turned into practical services to address municipal priorities, as presented exemplarily in the next chapter.

7 SERVICE DEVELOPMENT

7.1 Translation of requirements into service concepts

Based on the first Stakeholderworkshop, the consortium developed over 15 initial service concepts that directly address the priority fields identified by Austrian cities. The concepts cover a range of urban challenges, including climate resilience, energy efficiency in buildings, mobility and infrastructure, and natural hazard monitoring. These concepts were briefly described with graphical abstracts and evaluated by stakeholders through an online survey providing feedback on relevance, feasibility, and potential impact. This participatory approach ensured that the concepts reflect real municipal needs and priorities. For example, some ideas already highlighted ways to monitor urban heat hotspots or assess rooftop solar potential – practical services that cities could implement. The most promising concepts will be refined in a second workshop and translated into a roadmap, including their potential value, feasibility, and research needs. This process ensures that the resulting services are actionable, relevant, and ready to support decision-making in Austrian cities.

7.2 Legal, regulatory and organizational considerations

Legal, regulatory and organisational aspects play a crucial role in determining whether EO-based services can be operationally adopted by cities. Rather than acting as barriers, these framework conditions define boundary conditions that must be systematically considered during service design, implementation and long-term operation.

Within the Urban Sky project, the legal framework is primarily shaped by European and national regulations governing data protection, data governance, environmental monitoring and the use of geospatial information. A central element is compliance with the General Data Protection Regulation (GDPR), particularly where EO-derived data is combined with auxiliary datasets that could enable the identification of individuals or sensitive urban patterns. Objects or locations captured in very high-resolution imagery that can be linked to specific individuals – such as homes, vehicles, or other personal property – constitute personal data under the GDPR. Although EO data are typically non-personal, downstream processing, data fusion and spatial

resolution must be carefully assessed to avoid indirect personal data inference. Consequently, privacy-by-design and data minimisation principles are integral to the development of Urban Sky services.

In addition, the regulatory environment for spatial data infrastructures plays a significant role. The INSPIRE Directive (Directive 2007/2/EC) establishes common standards for the harmonisation, interoperability and sharing of geospatial data across public authorities within the European Union.

From an environmental and urban governance perspective, EO-based services operate within a framework of sector-specific regulations related to climate adaptation, air quality, land use planning and disaster risk management. In this context, the EU Nature Restoration Regulation (Regulation (EU) 2024/1991), which entered into force in 2024, introduces legally binding targets for the restoration of degraded ecosystems, including those located in urban and peri-urban areas. Organisational considerations are closely intertwined with the legal framework. The adoption of EO-based services requires clear role definitions between data providers, service operators and municipal end users. Responsibilities related to data stewards, quality assurance, liability and long-term maintenance must be contractually defined to ensure sustainability.

In summary, the legal and organisational framework provides a structured environment that shapes service development and deployment. By addressing these conditions proactively, Urban Sky aims to ensure regulatory compliance, institutional acceptance and long-term usability of EO-based services for urban decision-making, thereby supporting their transition from pilot applications to operational tools within city administrations.

7.3 Example Services

While this paper focuses on cities needs and the development and evaluation of the services, an analysis of their potential economic benefits for cities and stakeholders will be addressed in follow-up work. Nevertheless, two example service concepts are briefly described here to provide an idea of the direction.

7.3.1 Heat Dynamics

The service aims at enabling automated recording and analysis of spatio-temporal heat dynamics in urban areas in Austria. It provides cities with detailed insights to assess urban thermal stress and serves as a decision-making aid for urban planning and climate adaptation. The service combines multiple freely available datasets to ensure accurate and actionable results. This includes thermal satellite time series from ECOSTRESS, TRISHNA, Landsat, and in the future ESA-LSTM, calibrated and validated with meteorological station data from GeoSphere Austria. Additionally, Sentinel-2 optical imagery, land use data from zoning plans or the Copernicus Urban Atlas, aerial imagery, and LiDAR-based terrain and vegetation models are integrated to capture the urban landscape in detail. By merging these sources, the service identifies heat hotspots, monitors changes over time, and provides practical guidance for urban planners aiming to reduce thermal stress.

7.3.2 Remote sensing for the implementation of the EU Nature Restoration Regulation in cities

The aim of the service is to assess and support the restoration of urban ecosystems in Austria based on satellite remote sensing. The focus is on implementing Article 8 of EU Nature Restoration Regulation, in particular ensuring "no net loss" of urban green spaces and tree canopy cover by 2030. It integrates multiple freely available datasets to provide accurate and actionable insights. These include Sentinel-2 optical time series, land use data from zoning plans, the Copernicus Urban Atlas, aerial imagery and LiDAR, and the LUCAS land cover inventory (Eurostat, 2026). By combining these sources, the service derives ecological indicators, monitors changes over time, and guides planning and management decisions for greener, healthier urban environments.

8 CONCLUSION AND OUTLOOK

Based on the current findings of this study, satellite-based EO has strong potential to support cities on their way to climate-neutrality by providing consistent and spatially accurate information for planning, monitoring and decision-making. Freely available EO data already enable cities to better assess their key challenges such as heat stress, maintaining green infrastructure, detecting natural hazards, identifying buildings and tracking land use changes over time in a transparent and comparable way.

A key advantage of satellite data lies in the nature of the data itself, which makes it usable by stakeholders from different sectors: Mostly freely available access, automated and frequent updates, a holistic view from top and the ability to visualise continuous areas. This enables satellite data to be applied and transferred to all fields of application that benefit from change detection and continuous monitoring, spatially and temporally. Due to changing legislations on monitoring and reporting obligations, satellite data technology is becoming increasingly relevant.

To maximise the user uptake of the ESA Programme (e.g. Copernicus and Galileo) and address gaps in spatio-temporal resolution, the project is moving towards a multi-modal data fusion strategy for the considered services. This strategy synthesises freely available Copernicus and Galileo data, as well as non-remotely sensed data (e.g. socio-economic and/or environmental data), and considers commercial satellite products. Integrating non-remotely sensed data is essential, because satellite sensors alone cannot provide the services needed to adress cities´ specific needs. Adding, combining and layering data from multiple sources enables the development of services which might allow to monitor rapid, localised events, that would otherwise remain undetectable by single-sensor platforms or single data sources, and to respond to them in a timely manner.

Using satellite data strengthens transdisciplinary collaboration both horizontally across municipal departments and vertically between different administrative units and economic actors. In this context, start-ups and specialised service providers play an important role as experts in providing satellite data understanding and following the fast changes in this rather young technology. Public administration can benefit from the fast advancements of the Earth observation sector in terms of data-based decision-making and completely new perspectives on data collection.

So far, there is still a lack of communication and common ground between data providers, researchers and end users such as in public administration. This means that offered services often do not align with the requirements of public administration and are therefore less likely to be implemented and a fix component of running systems. For this reason, the Urban Sky project plays a valuable role in ensuring the practical applicability of solutions developed using satellite data.

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reviewed paper

A Systematic Living Lab Approach for Community Engagement for Urban Regeneration – the S.M.I.L.E. Methodology

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1 ABSTRACT

Community engagement and feedback has often been pinpointed as the weakest link in sustainable neighbourhood transformations. The living lab approach has been known as a promising methodology for engaging with multi-stakeholder groups in real-life contexts, yet studies have shown that engagement is rarely achieved in practice in many living labs. In this paper, we suggest it is helpful to take a process orientation to cut through the clutter of living lab literature, focusing on the "how" of establishing "living labs". We posit that it is most imperative in this process to put people in focus, foregrounding their specific needs, interaction, and wellbeing and channelling their competences and experiences towards urban regeneration.

Drawing inspiration from the literature that focuses on innovation-oriented living labs and based on a case study of organising and leading six living labs for community engagement in social renovation and energy transition in six European cities from 2022-2025, this paper will advance a methodology for establishing a living lab approach towards community engagement for urban regeneration. We suggest focusing on five phases to get going on the ground with the living lab networking approach– Scope, Map, Implement, Learn and Enhance – the S.M.I.L.E. methodology, What stands out from prevailing living lab approaches is Scope and Map. Scope foregrounds the importance of users (in their various roles) and the community. In this first step, a deep understanding of the citizens and community demographics regards citizens as catalysts of innovation and that their inputs can lead to better informed and robust outcomes in various measures and solutions. Map envisions all the actors relevant for the development of the socio-technical solutions and facilitates the possibility to review the congruence of their interests. Adopting the living lab approach requires thorough understanding of important actors' objectives and drivers, the alignment of operational processes, and establishment of open and collaborative culture. The S.M.I.L.E. methodology provides a pragmatic point of departure for a living lab facilitator responsible for engagement activities, whether newly set up and as an extension of ongoing programmes.

Keywords: Community engagement, Sustainable neighbourhood transformation, Living Lab approach, Stakeholder engagement, Deep renovation

INTRODUCTION

Decarbonising the urban built environment requires integrated innovations and solutions across climate mitigation, large scale renovation and urban greening. To meet the EU's ambitious climate and energy efficiency goals, the rate of deep building renovations must increase. In this regard, the interest in accelerating deep renovations on a neighbourhood scale has arisen as the adequate scale to adopt for essential solutions such as inclusion of renewable energy resources and decentralisation of energy production. In other words, going beyond the limits of the single building has become the more efficient and effective unit to work with. However, it has also been increasingly recognised that working on the larger neighbourhood scale is challenging as it requires integrated innovations and solutions involving multiple actors across different sectors (Sassenou et al. 2024). Indeed, stakeholder involvement, community engagement and feedback has often been pinpointed as the weakest link in sustainable neighbourhood transformations. Concomitantly, living labs have been known as a means to structure stakeholder and user involvement in innovation processes (Leminen et al. 2012, Almirall & Wareham 2011, Rizzo et al. 2021). However, in the rather young living lab research domain, there is no consensus yet regarding supporting theories and frameworks. This has resulted in a proliferation of projects and approaches carried out under the 'living lab' umbrella in a very loose sense that is not reaping the benefits of a living lab approach (Schuurman et al. 2013; Veeckman et al. 2013). In this paper, we distill our experience from planning six living labs for community engagement in social renovation and energy transition in six European cities. We suggest it is helpful to take a process orientation to cut through the clutter of living lab literature, focusing on

the "how" of establishing "living labs" as a promising platform for engaging with multi-stakeholder groups in real-life contexts.

This paper is organised as follows. We start with a review of relevant literature to understand the different types of living labs and specifically foreground the type of living lab focused towards multi-stakeholder collaboration and knowledge sharing. We do so to apply the living lab concept to community engagement efforts within the EU Green Deal project "ARV"[1] (https://greendeal-arv.eu/) which aims to demonstrate and validate attractive, resilient, and affordable solutions for a sustainable neighbourhood concept known as Climate Positive Circular Communities (CPCCs). The paper asks: How can a living lab approach be established for varying ambition levels of community engagement, communication and education towards sustainable neighbourhood transformations? Based on empirical insights from six demonstration communities with the ARV project, we advance a five-phase methodology for establishing a living lab approach towards community engagement for urban regeneration. We then discuss the implications of adopting a process orientation to living labs for research and practice before concluding the paper.

2 THEORY

This sections grounds the understanding of the living lab approach within the living lab literature focused on types of living labs, characteristics and outcomes, highlighting the need to establish a better understanding of how to plan and set up living labs in the practical sense. Based on the literature, the first sub-section presents a living lab typology to help make sense of the many types of living labs out there. Next, we review relevant literature looking for key dimensions that must be clearly defined and planned for when establishing a living lab. The third sub-section highlights variations in ambition levels in terms of community engagement, where metaphors such as "wheel of participation" have been used to characterise them.

2.1 Types of living labs

The living lab has been conceptualized as an environment (Ballon et al., 2005), a methodology or innovation approach (Bergvall-Kåreborn et al., 2009), an organization or an innovation intermediary (Schuurman et al., 2013), a network (Leminen and Westerlund, 2012), and a system (ENoLL – https://enoll.org/living-labs/). This lack of common consensus makes it difficult to advance research focused on living labs. To better understand the different typologies of living labs, a useful starting point is to distinguish between the American vs. European notion of living labs.

The first use of living labs in its present connotation was in MIT. This American notion of Living Labs describes a laboratory environment with all facilities of a regular home, optimized for multi-day or multi-week observational studies of single individuals and constructed to resemble a 'real' home as closely as possible (Schuurman et al., 2025). This American notion of Living Labs sees the Living Lab concept merely as a physical research facility that tries to overcome the artificial lab-context.

In Europe, the living lab movement has been gaining momentum since 2006 with the founding of ENoLL and the number of living labs has been growing (Schuurman et al., 2025). The overall aim of the ENoLL as an international federation of Living Labs is to support the creation of a dynamic innovation system throughout Europe. Two types of living labs can be distinguished within this European notion: living labs supporting context research and co-creation vs. living labs as extensions to testbeds (Følstad 2008). On the one hand, living labs supporting context research and co-creation would be based on an identified problem and focused on developing a solution in close interaction with end-users, or on the iterative finetuning of innovative products or services, tapping into the innovative capacity of test-users. On the other hand, living labs as extensions to testbeds describe testbeds (controlled network environments for test and validation) for e.g. ICT services (see Ballon et al. 2007).

According to Schuurman et al. (2013), a fourth type of living labs can be further distinguished. This final type is more focused towards multi-stakeholder collaboration and knowledge sharing, with less emphasis on developing and testing of new technologies and on deep end-user involvement. This fourth type of living lab are long-term and are intended to involve prolonged engagement with communities.

[1] ARV's meaning in Norwegian: "heritage" or "legacy"

2.2 Key dimensions for establishing an urban living lab

The living lab methodology has become a prominent approach in sustainable neighbourhood planning and development, often referred to as urban living labs.

Juujarvi and Pesso (2013) distinguish three types of urban living labs. First, urban areas can serve as technology-assisted research environments such that the living lab facilitators can collect feedback on products and services through webpages or sensor-based methods. Second, users can co-create urban artifacts and local services, such as communal yards, garden allotments or daycare services. Citizens are viewed as co-creators who contribute to designing and developing local services such as renovation processes. Third, an urban living lab can develop new kinds of urban planning using new tools and processes with the engagement of citizens. The goal is to facilitate vision-making of the area and planning processes, and increase the access and mutual learning of stakeholders. In this manner, the urban living lab can serve as a platform for stakeholders to participate in a neighbourhood's renovation initiatives and decision making.

One strand of living lab research positions living labs as a way to address the complex challenges of sustainable urban transitions and neighbourhood development through citizen engagement. When collecting the varieties of living lab definitions, Steen & Van Bueren (2017) structured them by defining four dimensions that must be clearly defined and planned for when establishing an urban LL:

- aim (a. innovation, b. formal learning for replication, c. for urban Living Labs: increasing urban sustainability)
- activities (a. development, b. co-creation, c. iteration),
- participants (a. public actors, private actors, users, knowledge institutes, b. decision-making power), and
- context (a. real-life use context).

In another study, based on empirical research from four living labs in Belgium and Finland, Veeckman et al. 2013 has discussed the characteristics and outcomes of living labs as a collaborative innovation approach and introduced a living lab pyramid to provide practical guidelines for organising living labs to foster user-centred innovations. The living lab pyramid framework consists of three pillars: living lab environment, living lab approach, and the innovation outcome. While one base of the pyramid anchors the living lab environment, considering technical infrastructure, ecosystem approach, level of openness, community, lifespan, scale, and real-world context, the other base of the pyramid secures the attention to the living lab approach, emphasizing evaluation, context research and user roles. The pinnacle of the pyramid addresses innovation outcomes, linking them to strategic intention, knowledge, resources, and partnerships.

Van Geenhuizen (2018) suggest attention should be given to both intended outcomes and unintended outcomes of living lab processes and results.

- Outcomes in the sense of intended outcomes include a better knowledge of user wishes and speeding up and bringing more solutions to market (e.g. Veeckman et al., 2013).
- Unintended outcomes may also happen. These include the absence of desired outcomes as well as adverse effects, and both are to a certain extent connected with bad predictability of influences and processes.

2.3 Mix of ambition levels for community engagement

Leminen et al. (2012) emphasize that living labs are open-innovation networks. Based on which actor drives the activities, living labs differ from one another in terms of activities, structure, organization, and coordination (Westerlund & Leminen, 2011). For example, living lab activities can be provider-driven when the innovation activities of the living lab aim to develop a solution for participants or other stakeholders, or have an educational purpose. Living lab activities can also enabler-driven, taking a bottom-up approach, when the activities focus on fulfilling the needs of a local community or association like improving the local social development where the living lab is located.

Nowadays, the Living Lab approach can be understood as an attempt to bridge the gap between multiple actors through directly involving them into the process of developing or transforming an urban neighbourhood (Steen & Van Bueren, 2017). However, a key finding of Steen & Van Bueren (2017)'s

review is that half of the living labs did not directly involve users, while the other half organised participation processes. It is apparent that engagement is challenging to achieve in practice in many living labs. Steen & Van Bueren, (2017) point out that the lack of participation may be a result of discrepancies between the methods used in practice and the ambitions of urban living labs defined in an early phase.

Arnstein`s ladder (1969) conceptualizes public involvement in decision-making as a hierarchy ranging from nonparticipation to full citizen involvement. However, studies have also put forth alternative frameworks to Arnstein's (1969) ladder, such as the wheel of participation (Davidson, 1998) as a more appropriate metaphor to deal with different levels of citizen engagement. The wheel promotes the appropriate level of community involvement to achieve clear objectives, without suggesting that the aim is always to climb to the top of the ladder. This wheel metaphor thus beckons the importance of a mix of engagement levels in living lab approaches to effectively channel citizens' experiences and competences.

Summing up

Taken together, to reap the benefits of living labs for collaboration and knowledge support activities, a systematic process orientation to the living lab concept is required. Living Lab facilitators working on the ground are in need of a simple methodology that is practical and easy to apply. Furthermore, a high degree of engagement is not always required to deliver change processes and implement sustainable solutions. The transformative potential of an urban living lab can also be realised with a low level of user involvement. As the literature points out, the 'higher level of engagement, the better' is not the aim. Instead, it is more important to consider the right form of engagement at the right time. This paper asks: How can a living lab approach be established for varying ambition levels of community engagement, communication and education towards sustainable neighbourhood transformations?

3 RESEARCH APPROACH

This section outlines the research approach. It is based on six living labs for community engagement focused on deep renovation. We draw on ongoing results from the EU Green Deal project 'ARV' (https://greendeal-arv.eu/) which aims to demonstrate and validate attractive, resilient, and affordable solutions for a sustainable neighbourhood concept known as "Climate Positive Circular Communities" (CPCCs).

A CPCC in the ARV project is defined as an urban area which aims to achieve net zero greenhouse gas emissions, enables energy flexibility, and promotes a circular economy and social sustainability. This novel concept focuses strongly on the interaction and integration between new and regenerated buildings, users, and energy systems, facilitated by ICT to provide attractive, resilient, and affordable solutions for citizens.

3.1 Purposeful sampling

To better understand the task of establishing a living lab approach for community engagement, purposeful sampling was relied upon. Purposeful sampling, or specifically criterion sampling, is widely used in qualitative research for the identification and selection of information-rich cases related to the phenomenon of interest (Creswell, 2009). A range of diverse strategies that can be used in purposeful sampling in accordance with different objectives (Palinkas et al. 2015).

Two widely used strategies for purposeful sampling include the identification of unusual phenomena from extreme cases as well as the identification of patterns of variation from heterogeneous cases. A third strategy can also include the simplification of the analysis and the emphasis on similarity from homogeneous cases or convenience sampling that emphasise collecting information from willing participants. While the first two strategies focus on describing the variability or dispersion of values, the third is used primarily to reduce the range of variation and identify similarities.

In line with this study's objective of increasing our understanding of how to establish a living lab approach for community engagement, we relied on the third strategy of purposeful sampling. This choice reflects our aim to deepen insight into the complexities of developing a living lab approach across the pilot sites and to provide detailed accounts of their contexts, aims, actors, and activities. This purposeful sampling strategy is particularly interesting where relationships between actors extend both horizontally, between organizations at the same level in the network context, and vertically from state to local stakeholders.

Various activites were carried out to interact, engage and collaborate with the multiple actors in the six demonstration communities in the ARV project during 2022-2025. These activites include, among other

things, stakeholder mapping, one-to-one meetings, workshops and events. Actvities conducted in the six demonstration communities were systematically registered in respective living lab logbooks over the four years. Furthermore, the community engagement activites were described and analysed in reports as a part of the deliverables for the ARV project.

3.2 Overview of cases

For this study, six pilot sites in different climate zones of Europe were used as cases. Within the EU Horizon 2020 project ARV, Climate Positive Circular Communities were designed and implemented in Oslo (Norway), Palma de Mallorca (Spain), Karviná (Czechia), Utrecht (Netherlands), Trento (Italy), and Sønderborg (Denmark), offering diverse contexts for examining living lab approaches to community engagement.

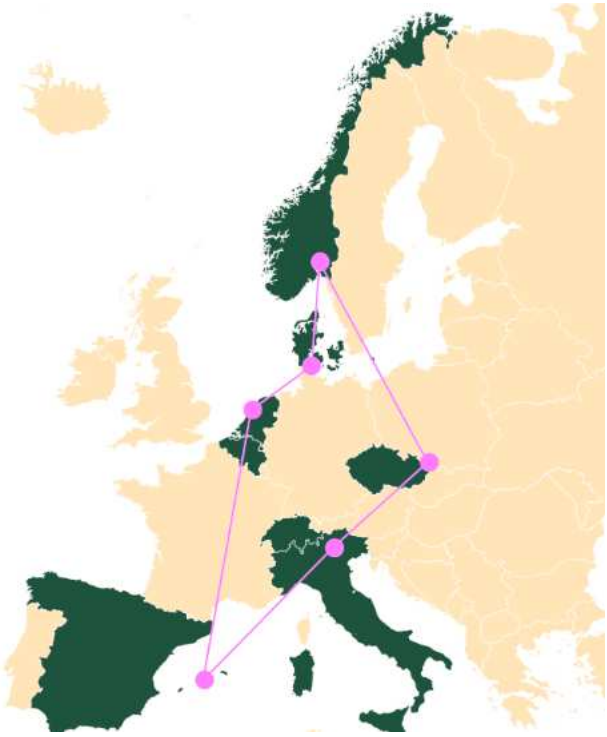


Fig. 1: Map of ARV demonstration sites in Oslo (Norway), Palma de Mallorca (Spain), Karviná (Czechia), Utrecht (Netherlands), Trento (Italy), and Sønderborg (Denmark)

4 FINDINGS

In a nutshell, the pilot sites encompass the development of a plus energy school and cultural area in a former industrial site in Oslo, Norway, energy upgrades of multi-family blocks with district heating in Sønderborg, Denmark, industrialized renovation of social housing in Utrecht, the Netherlands as well as in Trento, Italy, the transformation of an health care centre into a living lab for CPCC in Karvina, Czechia, and urban transformation of a city district in Palma de Mallorca, Spain.

Based on the place-based experiences of establishing a living lab approach for community engagement in the six pilot sites, we distill the most important aspects that stand out in its community engagement activities.

CPCC Demonstration Site (Neighbourhood)	**Understanding social contexts and embeddedness**	**Defining Goals and outcomes (the innovations)**	**Target groups to engage**	**What was learned**	**Enhance (what to do better next time wrt. Community Engagement)**
Oslo (Voldsløkka)	Location of the school bridging east and west Oslo; the need for a non-homogeneous façade appearance, and the highly ambitious energy goal for the building building-attached photovoltaic	Create awareness and understanding and hence acceptance and maintenance of these innovations/solutions BAPV and BIPV	Pupils of the secondary school (Voldsløkka school) and the culture school (Voldsløkka Culture Station) Building professionals	Long presentations on sustainability aspects did not attract the pupils.	Pupils liked contextualized and playful formats – such as climate bootcamps, board game co-creation, and prototyping – which helped translate abstract concepts into tangible understanding.

	(BAPV) and building-integrated photovoltaic (BIPV) panels on the East, West, and South façades, and on the roof. Outdoor stormwater solution.		Municipality planners		
Sonderborg	Cost-optimal design to reduce district heating return temperature[2] from substation systems in multi-flat buildings.	Tenants' usage of heating and radiator thermostats varied very much among apartments; activities were initiated to help the tenants to operate the radiators in an optimal way.	Tenants	Engaging representatives of residents (Green ambas-sadors) to help tenants using energy soluti-ons properly	Representatives of the housing organization visited each household to inform and engage the residents as a substitute for the green ambassador program.
Utrecht (Overvecht)	Social renovation process where the tenants are actively offered help before, during, and after renovation. Diffrent stake-holders were brought together.	These partners simultaneously implemented interventions to improve the tenants' conditions, such as work, mental support, healthcare, housing, social contacts, and finances. reduce renovation stress. Helps establish more trust in institutions and government in the neighbourhood.	Tenants Municipality actors	Multi-disciplinary coordination (housing, welfare and health workers) reduced tenant stress and prevented social issues. But, the colla-boraion needed time and effort, to create a common understanding.	To transfer the competence in the housing coorporation and the collaborative mechanisms among the social partners. In Overvecht, this alignment (multi-disciplinary coordination) has since become more efficient and has resulted in long-term collaboration that extends beyond the social renovation projects themselves.
Trento	End-users' perspectives have been addressed by a noise and dust perception campaign targeting the installation of the 'Renew Wall' kit vs. ETICS.	Cost optimization of the prefab kit vs. business-as-usual solutions	Tenants – elderly	Terminology "indoor comfort" By using existing communication channels and local dialect to communicate with and engage residents, the building manager made the residents to feel more comfortable and reassured and to build trust.	Using familiar means to communicate with tenants (especially when they are elderly people) will be a more effective way to engage them.
Karvina	Renovation of existing health care centre note context: region that has historically been built on coal mining) Health Centre –as an "educational building" (Note presence of vocal groups in the Czech Republic who are strongly opposed to the Green Deal and related sustainability topics)	Getting a building ready for PED development as an educational platform, and to stem outflow of young people	Centred on education and engagement of young citizens, particularly pupils aged 14 to 19. institutional stakeholders such as energy centres, schools, hospitals, and public service providers.	Spark interest in the topics of energy transition and sustainability and to foster a deeper connection between the youth and their region, with the broader ambition of motivating them to stay or return and contribute to local development Identified that long lectures to educate and encourage the youth to gain	To gather diverse perspectives on sustainability and identify potential roles for these institutions in future city projects. Youth: not overly technical tasks, importance of simplifying the content and incorporating more creative, hands-on elements for students to express their ideas. Institutional stakeholders: Projects must have specific, realistic goals,

[2] Reducing the district heating return temperatures from buildings allows the main district heating network to operate with a lower temperature level, which again allows the district heating company to utilize energy sources at a lower temperature level, enhancing the utilisation of energy produced by heat-pumps, excess heat from factories, cooling applications, data centres, etc. In Denmark, building users are economically rewarded if they can reduce the return temperature from their buildings back to the district heating network.

				knowledge on sustainability did not work well.	demonstrate cost-effectiveness, and offer a long-term vision. "The project format" (empowering pupils to shape their learning experience and to become co-creators of the solutions) has been chosen instead of long lectures.
Palma (64 homes initiative)	Attending to the buildings most in need of renovation which are often overlooked and not eligible for subsidy.	Affordability	Architect and engineer volunteers Residents – vulnerable segment	The construction company facilitated self-construction activities by the residents themselves. This has helped reduce costs, increase neighbourhood involvement and make viable a project that would otherwise have been economically unfeasible.	Focusing adequately on empowering residents / users can be beneficial.

Table 1: Components for establishing a living lab approach for community engagement

5 DISCUSSION

In this section, we discuss the type of living labs that best characterise the ARV living labs. We point out the most important components that living lab facilitators work with for establishing living lab activities. In our effort to channel the insights from the empirical material into a practical approach supporting community engagement, communication and education, we advance a five-phase methodology useful for getting community engagement activities up and running (whether new and as an extension of ongoing programmes). At the same time, we also point out the limitations of this methodology.

5.1 Living labs for multi-stakeholder collaboration and knowledge sharing

The ARV living lab activities have been focused on long-term collaboration and knowledge exchange. The activities in the Utrecht and Sonderborg demonstration sites are continuing existing programmes, while those of Oslo, Trento, Karvina and Palma are new programmes.However, long-term collaboration and knowledge exchange is hard to achieve if a living lab is project-based and unless there is a dedicated living lab facilitator.

In ARV, we observe that activities already embedded in stakeholders' established practices evolve quite differently from those introduced solely through the project. For example, Utrecht municipality had some headstart with working with the concept of social renovation and has collaborated with the housing associations prior to ARV. It also has the ambition to continue this work beyond the project period. Likewise, Sonderborg housing association has been working to deepen the trust with its tenants. In contrast, other demonstrations – such as Oslo – set up short term Living Lab activities that were created primarily to meet ARV's requirements. As a result, sustaining long term collaboration becomes challenging when enduring structures and organizational anchoring are not in place. We also observe that it is challenging to keep focus on the innovation outcomes once engagement activities take a life on its own.

Initial learnings point to the importance of identifying and prioritising the target groups to reach out to and establishing a deep understanding of the social context. Regarding target groups, at times, this can be planned such as the elderly residents in Trento. For Palma, the urgency and oppurtunity to reach out the a vulnerable segment of the neighbourhood presented itself when a building was no longer safe enough for pedestrians in its vicinity. As for social context, in Karvina, the understanding that a sizeable segmnet of the population in this region of Czech Republic are strongly opposed to the Green Deal and related sustainability topics is indispensable when planning and putting together the engagement activities.

The stakeholders that could make a difference also have to be systematically mapped out. In the case of Sonderborg, the district heating supplier is an important actor to enable the 'aftercooling concept', working in conjunction with the housing association.

The living lab facilitator is the instrumental actor for sustained interest and coordination of activities. A pragmatic approach to achieve a level of knowledge exchange commensurate with predefined goals makes the wheel metaphor appropriate for ARV living labs.

5.2 Five phase methodology: S.M.I.L.E.

Based on the insights from literature and the on-the-ground realities faced by ARV living labs, we propose a five-phase methodology to get community engagement activities up and running (whether new and as an extension of ongoing programmes). Community engagement is a difficult task, and some tools will be helpful to living lab facilitators and practitioners.

The diversity of the ARV demonstrations and the planned activities across the living labs demanded a coherent and structured approach for the living lab facilitators, practitioners and the researchers. As shown in Figure 2, a systematic process orientation to living labs can use five phases to get community engagement activities off the ground– Scope, Map, Implement, Learn and Enhance – the S.M.I.L.E. methodology. The idea of the SMILE methodology was developed to offer all project participants of ARV a common framework recipe for planning the activities, implementing them and reflecting on the results. Building on the key dimensions of living labs described by Steen and Van Bueren (2017), the S.M.I.L.E. methodology aims to operationalize these dimensions by providing a more concrete, step by step roadmap for designing, conducting, and following up living lab processes.

We outline each phase in more detail:

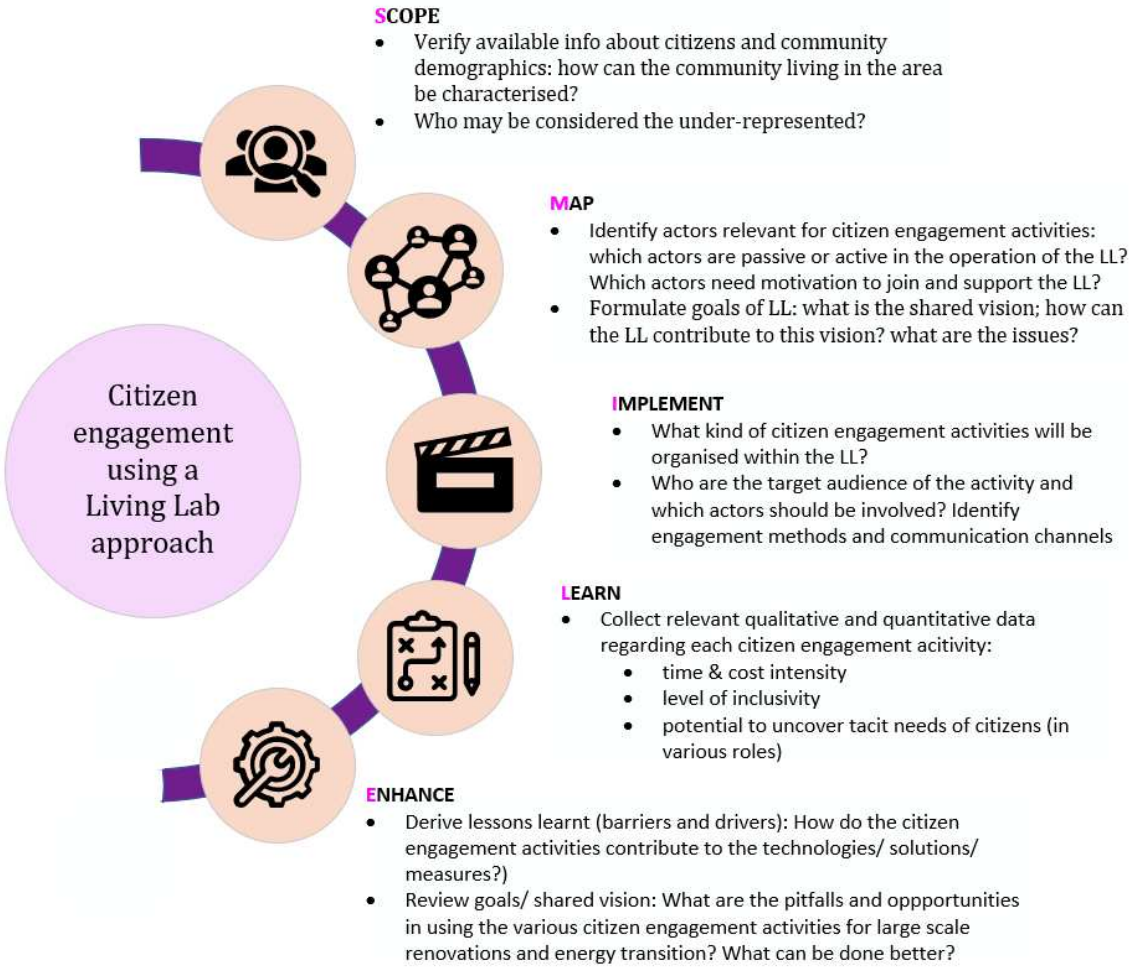


Fig. 2: The 5 phases of the S.M.I.L.E. methodology to reap the benefits of living labs for collaboration and knowledge support activities

Scope: In the first phase, Scope identifies the target groups. This foregrounds the users (in their various roles) and the community and focus the attention on the needs of the target groups within the community. In this first step, a deep understanding of the citizens and community demographics is essential to regard the selected target groups as catalysts of innovation and that their inputs can lead to better informed and robust outcomes in various measures and solutions. In addition, only when the citizens and the community living in the area has been characterized, the question of who may be considered as the under-represented or vulnerable can then be posed.

Map: In the second phase, Map tries to envision all the actors relevant for socio-technical innovation or solution in focus. This entails identifying and mapping out all the actors, their resources and goals. It should be noted that this is a dynamic picture that needs to be regularly reviewed. The Map phase then also involves formulating the goals of the living lab. Based on which actor drives the activities (living lab facilitator), the activities, structure, organization, and coordination can then be outlined. The living lab goals are also dependent on the main actor that drives the engagement activities.

Map allows the possibility to look at the dynamic picture of relevant actors and the goals of the living lab, reviewing their congruence. Afterall, adopting the living labs approach requires thorough understanding of important actors' objectives and drivers, the alignment of operational processes, and establishment of open and collaborative culture (Schaffers and Turkama, 2012).

Implement: In the Implement phase, citizen engagement activities (information-providing activities vs. co-creation activities) are being planned, organised, and rolled out. Various citizen engagement methods and digital tools as well as communication channels may be deployed associated with the activities. The important question to keep asking here is: Who are the target audience of the activity and which actors should be involved? How to gather their insights towards the innovation/solution?

Learn: The Learn phase will be evaluate the engagement activities, the use of various methods and tools (considering the innovation outcomes) and derive lessons.

Enhance: Building on the Learn phase, the Enhance phase will suggest enhancements on the effectiveness and efficiency of the engagement methods. The three important questions here are:

- How can the community engagement activities contribute to the awareness, undersrtanding and acceptance of social and technical solutions and measures related to sustainable transformation of urban communities?
- What are the opportunities (and pitfalls) in using the various citizen engagement tools for large scale renovations and energy transition?
- What can be done better in terms of community engagement, communication and education to increase the awareness and understanding and hence acceptance and maintenance of these solutions?

5.3 Community engagement for sustainable neighbourhood transformations – distinct contribution, limitations and unintended outcomes

Sustainable neighbourhood transformations are long-term initiatives. Working at this larger scale than the building level means involving multiple urban stakeholders such as landscape architects, the user community, making the task more complex and time-consuming. Map envisions all the actors relevant for the development of the socio-technical solutions and facilitates the possibility to review the congruence of their interests. Adopting the living lab approach requires thorough understanding of important actors' objectives and drivers, the alignment of operational processes, and establishment of open and collaborative culture. The S.M.I.L.E. methodology provides a pragmatic point of departure for a living lab facilitator responsible for engagement activities, whether new or an extension of ongoing programmes, towards development of innovations and solutions that support the decarbonisation of the urban built environment.

The S.M.I.L.E. methodology tries to establish a living lab approach that firmly anchors engagement activities in the local environment, considering technical infrastructure, ecosystem approach, level of openness, community, lifespan, scale, and real-world context. Sustainable neighbourhood transformations are local place-based initiatives that require ongoing formulation of challenges in its societal context. It tries to address concerns from researchers such as Roorda et al. (2014) that we should not bracket our research effort towards only focusing on the solutions and innovations while leaving out the context and underlying

systemic challenges and problems. The task of sustainable neighbourhood transformations is fraught with difficulty, and a practical tool like the SMILE methodology can be helpful to discourage working in silos but shape collaboration in a transdisciplinary fashion across topics, allowing for adaptability and reflection to find most effective ways of sharing knowledge, creating awareness and deepening the understanding of neighbourhood-scale interventions and developments.

The distinct contribution of the S.M.I.L.E. methodology is its simple, coherent and structured approach to get all CPCC living labs going in the 6 demo sites. With identifying target groups and their needs coupled with mapping relevant stakeholders at its core, the S.M.I.L.E. methodology can be considered a vital and fundamental preparatory measure for sustainable neighbourhood transformations. It is particularly suited for laying the groundwork for developing CPCCs – places where communities thrive, with low-carbon and energy-efficient building technologies, human-scale architecture, nature-based solutions and green-blue infrastructure, and inclusive public spaces.

However, a novel concept such as CPCCs is related to the notion that durable change has been achieved only when people's hearts and minds, their values and cultural practices, and the quality of relationships they have, are transformed. Engagement activites have both intended and unintended outcomes, and the S.M.I.L.E. methodology can be futher finetuned to address the absence of desired outcomes as well as adverse effects.

6 CONCLUDING REMARKS

This paper has advanced a practical five-phase methodology in order to reap the benefits of a living lab approach towards community engagement, communication and education for urban regeneration. The S.M.I.L.E. methodology puts people in focus, foregrounding their specific needs, interaction, and wellbeing, channelling their experiences to take positive steps towards acceptance of innovations and solutions that can support the decarbonisation of the urban built environment.

As living labs can be broadly interpreted as unique spaces where different types of innovators can interact and thus benefit from synergies, diversity and cross-pollination of ideas, a simple yet practical process-oriented approach can be useful for getting community engagement activities off the ground (whether new or an extension of ongoing place-based programmes). Offering a means to cut through the clutter of projects and approaches carried out under the 'living lab' umbrella, the S.M.I.L.E. methodology is particularly suited for living labs focused towards multi-stakeholder collaboration and knowledge sharing, and for initiatives pursuing the neighbourhood scale in deep renovations.

6.1 Research implications

Depending on the living lab facilitator who drives the activities, living labs differ from one another in terms of goals, activities, structure, organization, and coordination. Deploying engagement methods and tools will have to take this into consideration. Living lab facilitators and researchers contemplating innovation-oriented living labs need to consider the intended inputs and outcomes and reframe their engagement activities accordingly when relying on the S.M.I.L.E. methodology. Varying ambition levels of community engagement should be set to allocate resources accordingly.

6.2 Practical implications

A high degree of citizen engagement is not always required to deliver change processes and implement sustainable solutions. The transformative potential of an urban built environment can also be realised with a low level of user involvement, commensurate with the ambitions set for a particular target group. It is more useful to focus on target groups and their needs, consider their embeddedness, draw out their experiences and competences, and allow these to be channelled to the socio/ technical innovations that support sustainable neighbourhood transformations. Along this vein of thinking, the S.M.I.L.E. methodology can easily be understood and applied by living lab facilitators and practitioners. As the literature points out, the "higher level of engagement, the better" does not always hold true. Instead, it is more important to consider the right form of engagement at the right time for efficient allocation of resources.

7 ACKNOWLEDGEMENTS

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reviewed paper

A Systematic Review of Policy and Legislative Gaps in Advancing Sustainable Human Settlements in Small Rural Towns: A Case of South Africa

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1 ABSTRACT

Despite South Africa's progressive policy and legislative frameworks aimed at transforming human settlements, the unique spatial, social, and economic dynamics of rural towns remain largely marginalised within mainstream planning discourses. As rural development gains prominence in national planning priorities, the question of whether existing policies and laws effectively support sustainable rural human settlements becomes critical. This paper contends that a disconnect exists between the legislative vision and the practical realities of rural settlement development. The study aims to systematically examine South Africa's policy and legislative environment to identify gaps, inconsistencies, and biases that hinder sustainable rural development. The study employs the PRISMA method, focusing on frameworks such as Breaking New Ground (BNG), the Integrated Urban Development Framework (IUDF), the Rural Development Framework, SPLUMA, and other sectoral policies and legislation. Findings indicate that most frameworks adopt an urban-centric approach, offering limited guidance for rural spatial forms, tenure arrangements, or informal settlement upgrading in small towns. Integrated planning is often cited but seldom achieved due to institutional fragmentation and inadequate coordination across governance levels. Moreover, rural development strategies lack enforceable rural-specific standards and actionable instruments. The paper proposes a multi-level governance framework anchored in spatial justice, legislative alignment, and capacity building at local levels. It calls for the localisation of planning tools, legal recognition of rural informality, and enhanced intergovernmental synergy to ensure that rural towns are not left behind in South Africa's human settlements agenda.

Keywords: South Africa, governance, human settlements, policy implementation, rural towns

2 INTRODUCTION

South Africa's post-apartheid policy and legislative architecture have evolved with a stated commitment to address spatial inequality and to enhance sustainable human settlements. Since 2004, the Breaking New Ground (BNG) policy has served as the government's comprehensive strategy for sustainable human settlement development, integrating subsidised, rental, and bonded housing with municipal engineering and mixed-use development principles. However, critiques argue that its implementation has been uneven, particularly in rural settings where small rural towns face entrenched socio-spatial disadvantages that typical urban-biased policies struggle to address effectively (South African Government, n.d.). Spatially, the Spatial Planning and Land Use Management Act (SPLUMA) 16 of 2013 provides a unified legislative framework for spatial planning and land use management across South Africa, aiming to redress past imbalances and promote social and economic inclusion through development principles such as spatial justice and sustainability. SPLUMA mandates wall-to-wall land use schemes and Spatial Development Frameworks (SDFs) at the municipal level, requiring integrated spatial planning that equally considers rural and urban localities (Republic of South Africa, 2013). At the same time, sectoral frameworks such as the Integrated Urban Development Framework (IUDF) stress spatial transformation and integration but are frequently interpreted through an urban lens, with limited tailored guidance for rural towns despite acknowledging rural-urban interdependencies (Department of Cooperative Governance and Traditional Affairs [CoGTA], 2022). Despite these progressive frameworks, significant limitations persist in how rural settlement realities are incorporated into legislative and policy instruments. The limited guidance on rural spatial forms, tenure systems under customary authority, and informal settlement upgrading in small towns reflects broader institutional challenges. Weak intergovernmental coordination, capacity constraints at local levels, and the dominance of urban-centred planning paradigms often undermine meaningful rural integration within national settlement agendas (IUDF, 2020). This review, therefore, situates South Africa's human settlements legislative frameworks within their historical and institutional aspects, intending to identify limitations that impede the advancement of sustainable human settlements in small rural towns.

3 SYSTEMATIC POLICY AND LEGISLATIVE ANALYSIS

The literature on sustainable rural human settlements in South Africa reveals persistent deficiencies in implementation that destabilize efforts to achieve equitable rural development. A significant theme in this body of work is that historical legacies of segregation, land dispossession, and dualistic spatial planning continue to shape rural settlement dynamics, resulting in structural barriers that current policies struggle to overcome. Early analyses of rural development in South Africa highlighted how apartheid land-use regimes produced marginalised rural economies and settlement patterns, reinforcing poverty and limited access to basic services and opportunities across rural localities. These structural factors have been seen not merely as residual "backlogs" but as deeply embedded socio-economic attributes of rural spaces that require setting-sensitive policy frameworks (Makgetla 2010). A growing body of scholarship stresses that government planning instruments tend to replicate urban-centric paradigms that are ill-suited to the complexities of rural areas. For example, traditional urban planning tools embedded in Integrated Development Plans (IDPs) and spatial frameworks often assume service delivery configurations appropriate to urban densities, leading to strained institutional and fiscal capacities when applied to dispersed rural populations. Linked to this is the argument that rural spatial forms are often ignored in dominant planning discourses, which prioritise densification and economic agglomeration as if rural settlements were scaled-down versions of urban centres (South African Local Government Association [SALGA], 2019).

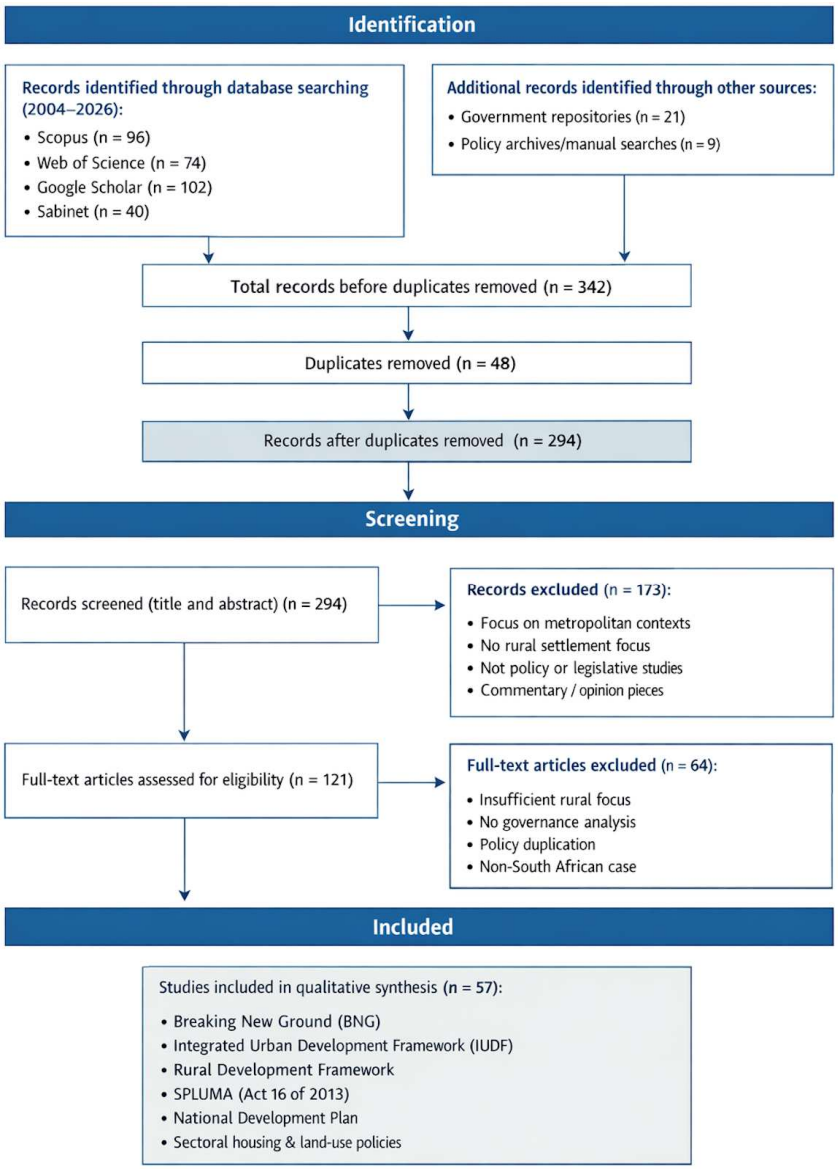


Figure 1: Review Approach

Several scholars also note the limitations of statutory planning instruments in navigating systemic constraints such as insecure land tenure and customary land governance. While SPLUMA provides a unified spatial

planning framework, its normative principles and reliance on formal land-use schemes have been critiqued for insufficiently accounting for rural land tenure heterogeneity, including communal land under traditional authorities. This tension has significant implications for sustainable settlement outcomes in rural towns where customary land rights remain central to social and economic life. In addition, recent research foregrounds the role of governance pluralism in shaping rural development trajectories. Studies advocating for frameworks such as the Rural Development and Governance Initiative (RDGI) argue that effective rural development requires mechanisms that bridge formal local government structures and traditional leadership systems, recognising that traditional authorities continue to wield considerable socio-political influence in rural areas. Such work also highlights capacity constraints and role ambiguities that currently limit the participation of traditional authorities in formal planning and governance processes (Sebola-Samanyanga, 2025). The literature highlights the need to reconceptualise rural development research and practice. Recent reviews argue for interdisciplinary frameworks that engage with rural heterogeneity, spatial justice, and governance dynamics rather than perpetuating simplistic urban–rural dichotomies. Such frameworks aim to better capture setting-specific definitions of 'rural' and integrate place-based development approaches that align policy instruments with lived realities in small rural towns. Overall, these strands of literature collectively point to an enduring policy–practice deficit in South Africa's rural settlement landscape, indicating the need for more adaptiveframeworks to advance sustainable human settlements in rural areas.

4 METHODOLOGY IMPERATIVES

This study employed a systematic qualitative review approach to investigate policy and legislative limitations influencing the development of sustainable human settlements in small rural towns in South Africa. The review was informed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, ensuring transparency, methodological rigour, and replicability in the identification, selection, and analysis of sources. A comprehensive and structured search strategy was implemented across academic databases, government repositories, and policy archives to capture relevant national legislation, policy instruments, and peer-reviewed literature relating to human settlements, spatial planning, and rural development, as shown in Figure 1. The inclusion criteria focused on sources that explicitly engaged with human settlements, spatial planning, land governance, or rural development within the South African setting, while exclusion criteria filtered out materials that did not address rural or small-town settlement dynamics. The selected documents were analysed using thematic content analysis, with attention given to policy objectives, underlying spatial assumptions, implementation mechanisms, and governance arrangements. Essential national frameworks, including Breaking New Ground, the Integrated Urban Development Framework, the Rural Development Framework, and the Spatial Planning and Land Use Management Act (SPLUMA), were examined comparatively to evaluate their coherence, alignment, and applicability to rural settings. This methodological approach was well-suited to interrogating a complex and fragmented policy landscape and enabled the synthesis of insights that underpin a practical, policy-oriented framework for advancing sustainable human settlement development in small rural towns.

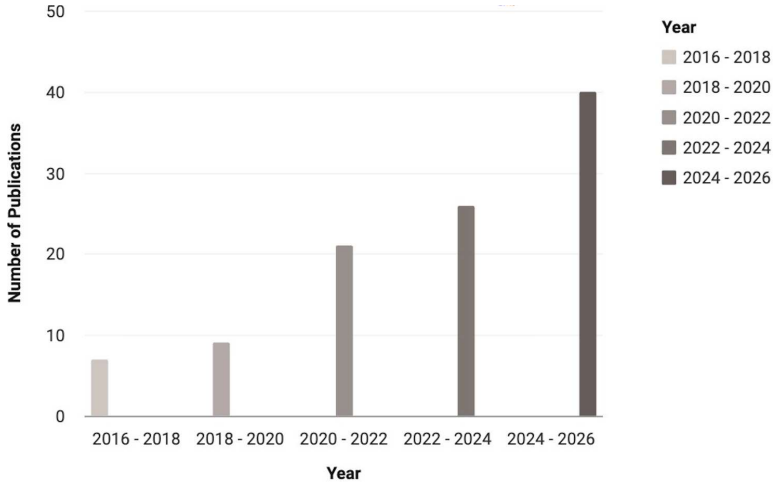


Figure 2: Publication Trend

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5 ANALYSIS AND DISCUSSION

This section presents the results of the bibliometric analysis, highlighting publication trends, dominant themes, and patterns of collaboration related to sustainable human settlements. The analysis provides insight into the conceptual focus and knowledge limitations within the literature, particularly in relation to rural and small-town settuings.

Figure 2 demonstrates a marked and accelerating increase in scholarly output on sustainable human settlements from 2016–2026, with particularly strong growth after 2020. This rise coincides with renewed global and national attention to sustainability, spatial justice, and post-COVID development challenges, especially in the Global South (UN-Habitat, 2020). However, while the quantity of publications has increased, the findings of this review suggest that rural towns remain conceptually peripheral within much of this literature. Many studies framed under "sustainable development" or "human settlements" continue to privilege metropolitan, peri-urban, or informal urban settlements, often treating rural towns as transitional or residual spaces rather than as distinct settlement systems. This pattern mirrors South Africa's policy trajectory. Despite progressive post-apartheid reforms, such as Breaking New Ground (BNG) and the Integrated Urban Development Framework (IUDF), policy attention remains largely urban-centric, with rural towns frequently subsumed under broader rural development narratives or secondary cities, rather than addressed through tailored settlement frameworks.

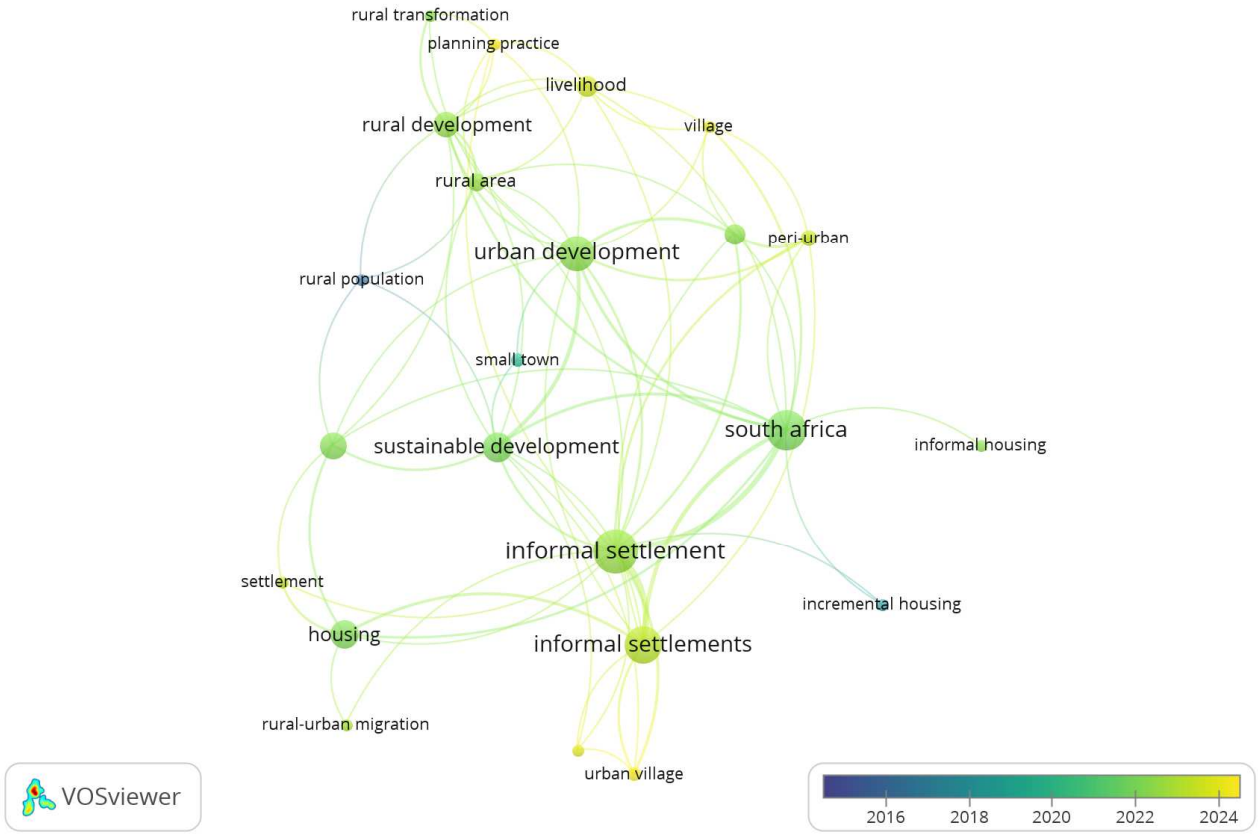


Figure 3: Keywords

Figure 3 provides a keyword co-occurrence network, offering important insights into the dominant thematic orientations shaping scholarly debates. The highly central keywords such as urban development, informal settlement(s), housing, and sustainable development suggest that the literature is primarily anchored in urban theory and practice, even when rural areas are nominally included. Informal settlements emerge as a critical concern, yet they are most often discussed within metropolitan upgrading paradigms, drawing on urban policy tools that are ill-suited to rural spatial forms. This aligns with the study's finding that informality in rural towns is poorly recognised in law and policy. Evidence from South African perspectives further indicates that effective settlement upgrading depends on legislative flexibility, strong community participation, and secure tenure arrangements, rather than solely on formal housing delivery models

(Mndzebele & Gumbo, 2023). Instruments such as SPLUMA (Republic of South Africa, 2013) provide procedural guidance for land-use management but fail to adequately address customary tenure, hybrid land-administration systems, or dispersed settlement patterns common in rural towns.

Keywords such as rural development, small town, livelihood, rural population, and rural transformation appear less central and more weakly connected within the network. This reflects a broader tendency in both scholarship and policy to treat rural towns as support spaces for urban economies, rather than as sites of autonomous development with distinct governance, infrastructure, and tenure challenges. Notably, planning practice appears weakly linked, suggesting a persistent deficit between policy rhetoric and implementation capacity. While integrated planning is repeatedly stressed in frameworks such as the National Development Plan (NDP) and IUDF, empirical studies show that rural municipalities often lack the institutional capacity, financial resources, and technical expertise to operationalise these ambitions.

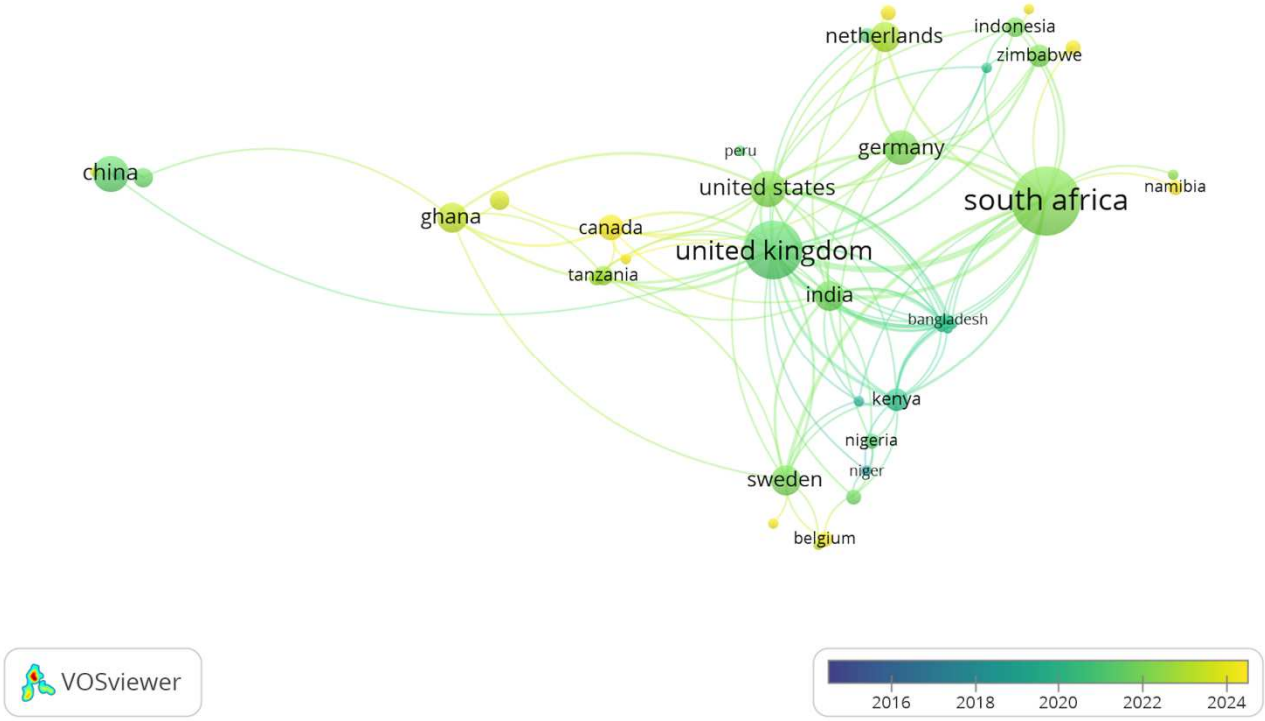


Figure 4: Countries

Figure 4 reveals the country co-authorship network in which South Africa occupies a dominant central position, strongly connected to the United Kingdom, the United States, Germany, and Sweden. This reflects South Africa's role as both a policy laboratory and a focal point for Global South urban and settlement research. While international collaboration has enriched the theoretical depth of South African planning scholarship, the findings suggest a continued reliance on Global North planning paradigms, particularly those rooted in urban sustainability, compact city models, and formalised land markets. This has important implications for rural towns. Planning approaches imported from urban or international contexts often fail to accommodate:

- communal and customary land tenure systems;
- seasonal and livelihood-based settlement patterns;
- incremental and self-built housing processes outside formal subsidy regimes.

As a result, rural towns remain legally and institutionally misaligned with the planning tools intended to guide their development.

6 TOWARDS THE INSTITUTIONAL FRAMEWORK FOR SUSTAINABLE RURAL SETTLEMENT DEVELOPMENT (IFSRSD)

This section converts the study's analytical findings into practical policy and planning recommendations intended to enhance sustainable human settlement development in small rural towns. The recommendations

are presented as an applied framework designed to promote legislative coherence, improve institutional coordination, and enable implementation across different levels of governance.

Framework Dimension	Strategic Recommendation	Primary Implementation Focus
Legislative Alignment	Introduce rural-specific provisions within existing human settlement and spatial planning legislation	Amend SPLUMA regulations, housing codes, and sectoral legislation to explicitly address small rural town contexts
Spatial Justice	Institutionalise spatial justice principles in rural settlement planning	Embed equity-based spatial criteria in SDFs and land-use schemes for rural towns
Planning Instruments	Develop context-sensitive planning tools tailored to rural settlement forms	Localised SDF templates, rural land-use schemes, and flexible zoning mechanisms
Informality Recognition	Formally recognise and regulate rural informal settlements	Legal recognition of incremental housing, customary tenure, and non-standard settlement patterns
Governance Integration	Strengthen intergovernmental coordination across rural development sectors	Clear role delineation between national, provincial, and local government spheres
Municipal Capacity	Enhance planning and implementation capacity in rural municipalities	Targeted technical support, training programmes, and resourced planning units
Policy Localisation	Enable adaptation of national policies to local rural realities	Municipal discretion to contextualise national frameworks without regulatory penalties
Monitoring & Accountability	Introduce enforceable rural development performance indicators	Rural-specific benchmarks, reporting requirements, and compliance mechanisms
Knowledge Production	Promote rural-focused research and planning innovation	Support locally grounded research, pilot projects, and practitioner-led learning
Funding Alignment	Align fiscal instruments with rural settlement priorities	Ring-fenced funding streams for rural town settlement upgrading and infrastructure

Table 1: Institutional Framework for Sustainable Rural Settlement Development (IFSRSD)

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reviewed paper

A Toolbox to Analyse Sustainable Mobility in Land-Use Planning Processes: Methodological Challenges and Approaches for Residential Developments in Rural Areas

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1 ABSTRACT

A major challenge in promoting sustainable mobility behavior in rural areas is the spatial structure. Mapping and modelling the causal interactions between land-use, mobility behavior, and local accessibility is associated with considerable methodolgical complexity. Accessibility analyses have to be linked with tangible applications in order to generate real added value for land-use planning. In the project move.mORe, an approach was developed, building on current research and practical findings, to use accessibility analyses effectively in advising rural municipalities on land-use planning..

Empirical evidence shows that structural parameters such as residential density, mixed land use, accessibility to public transport, and proximity to essential services strongly influence travel behavior. Areas with higher density, diverse land use, and efficient public transport connections exhibit lower car ownership rates and higher shares of walking, cycling, and public transport use. Longitudinal and quasi-experimental studies indicate that changes in the built environment can causally affect mobility behavior, although the extent of these effects is moderated by self-selection processes, whereby individuals choose residential locations aligned with their pre-existing mobility preferences. This poses challenges for researchers and planners seeking to disentangle causality from selection effects.

To address these challenges, the project move.mORe developed a multimethodological toolbox designed to support rural municipalities in evaluating and promoting sustainable mobility within the land-use planning process. The aim of the toolbox is to provide a scientifically grounded impact assessment. This enables municipalities to identify potential traffic-related effects of residential developments already in the early stages of the planning process and to develop evidence-based strategies to support the sustainable mobility of residents. On this basis, site-specific solutions can be developed to promote sustainable mobility. Policy interventions can support sustainable mobility through “pull measures” that enhance the attractiveness of environmentally friendly transport modes, as well as “push measures” that limit car dependency, such as parking management or restricted vehicle access.

The toolbox employs two primary indicators to evaluate the sustainability of the mobility in planned residential developments: traffic-related greenhouse gas emissions and the provided accessibility for residents. Greenhouse gas emissions quantify the ecological impact of transport demand generated by the development area, representing the environmental boundary of sustainability. Accessibility measures the ability of residents to reach essential destinations such as supermarkets, schools, healthcare providers, and public transport nodes within a defined travel time, reflecting the social needs dimension of sustainable mobility. Accessibility analyses within the regions and municipalities of the project area are conducted using weighted destination categories and isochrones based on the concept of “15-minute city” and transferring its ideas and applications to a “15-minute rural region”. The project’s core structure allows the analysis of these cities these “smaller” cities and municipalities in rural regions and explore different use-cases for accessibility analyses.

Keywords: toolbox, accessibility, sustainable mobility, rural areas, land-use planning

2 BUILT ENVIRONMENT AND MOBILITY BEHAVIOUR – THE INTERACTION BETWEEN CAUSALITY AND SELF-SELECTION

The development of mobility and built environment in rural areas can be described as a “vicious circle”. Since the mid-20th century, the increasing prevalence of the automobile and the expansion of car-oriented infrastructure have promoted an increasingly sprawling settlement structure. This leads to longer daily journeys and increased traffic volumes. In order to cover longer trip distances, many people rely on fast modes of transport, especially private cars, which reinforces car dependency. Increased travel speeds reduce

sensitivity to distances, leading to the acceptance of longer journeys and inducing additional car-oriented traffic flows. This in turn encourages people to choose more distant residential locations and exacerbates urban sprawl. In such structures, residents are heavily dependent on motorised individual transport and generate comparatively high greenhouse gas emissions (Holz-Rau and Scheiner 2019; Jarass 2018). This process has not only ecological but also social implications: public services are often only accessible by car, which places a financial burden particulary on low-income households and limits the social participation of people without access to a private car.

It is widely accepted in the literature that the settlement structure plays a significant role in shaping mobility behaviour of the residents and hence changes in the spatial structure can lead to changes in mobility behaviour and promote sustainable mobility (Planersocietät 2012; Holz-Rau and Scheiner 2019).Many authors assume that the mobility behaviour of residents differs depending on various built environment characteristics. Above all, constraints such as residential location, mixed land use, degree of integration into the existing road network, accessibility of daily trip destinations and developments in locations with good public transport connections can influence the mobility behaviour of residents. This is reflected in lower motorisation rates and a high proportion of enviromentally-friendly transport modes in settlement locations with good public transport infrastructure, sharing services and accessibility to daily destinations (see also Beckmann 2020). However, it should not be overlooked that individual parameters such as socio-demographic factors, lifestyles and mobility styles, as well as other structural parameters such as the transport system, also play an important role in shaping mobility behaviour and must therefore not be ignored (Beckmann 2020; Holz-Rau and Scheiner 2019; Jarass 2018).

A study by Christiansen et al. (2017) from Norway, which focuses on commuting, shows that parking availability at work and at home has a significant influence on the choice of transport. The longer the walking distance to parking at home, or if there is no fixed parking space at the workplace the less likely commuters choose the car as their mode of transport. This effect is even more pronounced when there are no parking facilities at the workplace. A combination of limited supply and additional parking fees proves to be particularly effective.

Næss (2011) examined the modal split of commutes in inner-city development projects ("new urbanism development") compared to conventional suburbs in Denver, USA. The results show that, in addition to non-spatial parameters such as transit pass ownership and socio-demographic factors, the availability of free parking at the destination is also correlated with the choice of transport mode.

Schwarze et al. (2025) demonstrate in their empirical study in Germany that walking distance to everyday trip destinations significantly increases the proportion of walking, cycling and public transport use, while reducing car use and the household motorisation levels. Multiple motorisation of households is also less common in residential areas which offer good local accessibility. Interestingly, households in such locations travel more frequently, but their journeys are shorter on average.

The longitudinal study by Bauer et al. (2005) examines the mobility behaviour of households before and after moving within the region of Dresden and shows that moving from the city centre to the surrounding area is often associated with an increase in motorisation level. This study also emphasises the role of car orientation in residential location preferences, so that moving from the city centre to a more peripheral location both requires and promotes car orientation.

Another study by Bauer et al. (2022) examines the influence of mobility concepts in car-reduced new neighbourhoods of Germany on the mobility behaviour of residents. The results show a decline in the degree of motorisation after moving, with less use of private cars in favour of public transport. In addition, the use of car sharing has increased after moving to new neighbourhoods.

A central question in the discussion on the interaction between settlement structure and mobility behaviour concerns, whether observed correlations are causal or whether they result primarily from processes of self-selection. This means that people consciously choose places to live that correspond to their existing mobility behaviour or mobility preferences (Scheiner and Holz-Rau 2007; Bruns 2014; Van de Coevering et al. 2018). Several studies therefore question the thesis that built environment characteristics alone shape mobility behaviour. Bagley and Mokhtarian (2002), for example, emphasise that the influence of built environment characteristics is often overestimated in comparison to socio-demographic variables and lifestyles.

Various methodological approaches have been developed to address the question of causality. Vance and Hedel (2007), for example, analyse variables that correlate with the urban form but are not directly correlated with mobility decisions.

Studies that use longitudinal approach to examine households before and after a move have been able to demonstrate a causal influence of settlement structure changes on mobility behaviour in some cases. A particularly illustrative example is provided by the study by Cao et al. (2019) from Norway, which uses a hybrid method combining a quasi-longitudinal approach and qualitative analysis in the form of interviews. One interviewee reported that after moving from a location close to the city centre to a peripheral location, she purchased a car, even though she had had no intention of buying a car before the move. The reason for this decision was that everyday trips were no longer feasible by public transport. This qualitative observation supports the assumption that the change in mobility behaviour was a consequence of the residential location and the built environment characteristics at the new place of residence and not an expression of pre-existing mobility preferences in the sense of self-selection when choosing a place to live.

Robert Cervero (2017) argues that sustainable mobility depends less on increasing the speed of travel and more on improving accessibility and the ability for people to reach jobs, services, and daily needs efficiently. This shift places land-use planning at the core of transportation policy. Rather than expanding road networks to ease congestion, Cervero advocates for compact, mixed-use, and transit-oriented development patterns that reduce travel distances and automobile dependence. By aligning urban form with high-quality public transit, walkability, and cycling infrastructure, cities can lower greenhouse gas emissions, improve public health, and advance social equity. Sustainable mobility is achieved not simply through cleaner vehicles, but through reshaping urban development to prioritize proximity, accessibility, and people-centered design.

3 LAND-USE PLANNING AS A LEVER FOR SUSTAINABLE MOBILITY IN RURAL AREAS

Despite the ongoing discussion on causality and self-selection there is a broad consensus that both transport mode choice and travel distances vary depending on the built environment characteristics and the spatial context (Jarass 2018; Scheiner 2009). Integrated land-use and transport planning is therefore an important planning approach, particularly with regard to ensuring that everyday destinations can be reached without a private car and creating a healthy and liveable environment (Holz-Rau and Scheiner 2019). Transport planning based on the principles of integrated land-use development forms the basis for promoting sustainable mobility behaviour. Only where suitable built environment structures and appropriate infrastructure conditions are in place do residents actually have the opportunity to adapt their mobility behaviour in favour of environmentally friendly modes of transport.

At the same time, implementing appropriate measures, such as increasing density and mixed land use, improving access to public transport stops or redesigning public spaces, often involves considerable time and financial expenditure once a settlement is developed. This makes it all the more important to consider these aspects at an early stage when planning new settlements. Nevertheless, existing areas also offer certain scope for action. The expansion of infrastructure for eco-friendly transport (e.g. through bicycle and pedestrian infrastructure, better public transport connections) and supplementary measures such as mobility hubs or parking management can provide behavioural incentives.

The spatial planning system in Germany shapes the built environment through a two-stage system of local spatial development planning comprising preparatory land-use plan (Flächennutzungsplan) and binding land-use plan (Bebauungsplan). Preparatory land-use plans define the intended types of land use for the entire municipal territory in accordance with proposed urban development strategies, aiming to address the anticipated needs of the municipality over often a ten- to fifteen-year period. These plans provide the overarching framework and serve as the foundation for binding land-use plans. Binding land-use plans constitute the principal instrument for implementing local government planning. They are developed based on the preparatory plans and contain legally binding provisions that guide and regulate urban development patterns, including the use of land for development and other purposes.

Both types of plans regulate a wide range of measeres that influence the mobility behaviour trough the built environment. For example, the preparatory land use plans affect future traffic volumes, in particular by specifying development sites and their integration into existing infrastructure. A compact, short-distance-oriented settlement structure and the concentration of new developments along high-capacity public transport

corridors can significantly enhance the attractiveness of sustainable modes of transport (SRL-FMV Working Group 2020).

Binding land-use plans adapt these objectives to local conditions and have a direct impact on accessibility and mobility behaviour through regulations on density, mixed land use and the design of public spaces. Requirements for transport facilities such as cycling and pedestrian infrastructures, bicycle parking facilities or car-parking regulations create the structural conditions for sustainable everyday mobility (SRL-FMV Working Group 2020). Once settlement structures have been established, they play a formative role in the mobility behaviour of residents for many years. Land-use planning therefore offers a fundamental opportunity to shape mobility behaviour in the long term and create the basis for sustainable mobility.

Mobility impact assessments for spatial development plans have become increasingly common in recent years, they are often limited to estimating car traffic volumes for the purpose of designing transport infrastructure. Assessing whether an urban development plan promotes or enables sustainable mobility behaviour in the long term is rarely the focus of consideration. The move.mORe project is an IHS-funded transfer project of the Karlsruhe university of applied science and Offenburg university of applied science. (IHS – Innovative Hochschule is a federal-state initiative designed to promote research-based ideas, knowledge and technology transfer).The work package “Region of Short Distances” focuses on the development of a practical toolbox that can be used to assess the extent to which specific measures at the urban land-use planning level will contribute to the development of sustainable mobility in the future. The toolbox builds on existing methodological approaches, which have been systematically combined as a multi-method approach in the project context, further developed and adapted to the specific conditions of rural areas. The adaptation to rural conditions includes the use of data from rural sites as well as the design of the toolbox for application in small not specialized adiminstrations. The aim of the toolbox is to provide a scientifically based impact assessment to support municipalities in rural areas in promoting sustainable mobility. This enables local authorities to identify the potential transport impacts of planned residential developments at an early stage of urban land-use planning and, if necessary, to take countermeasures at an early stage. On this basis, area-specific measures can be derived that promote sustainable development.

4 EXISTING APPROACHES FOR ASSESSING THE IMPACTS OF RESIDENTIAL DEVELOPMENTS ON SUSTAINABLE MOBILITY

A review of existing approaches to assessing the traffic impacts of residential developments is provided, which served as the basis for the development of the toolbox's multi-method approach. These approaches either enable an overall assessment of the plans in terms of their sustainability or focus on individual planning measures and estimate their specific traffic impacts.

4.1 Qualitative checklist: Options for establishing measures for greater climate protection in transport within the framework of binding land-use plan procedures

The Climate Mobility Competence Network (KKM) supports local authorities in promoting climate-friendly transport planning in state of Baden-Württemberg, Germany. It offers local authorities “guidance and advice on possible courses of action, contact persons and funding opportunities” (https://www.klimaschutz-bewegt.de/anlaufstelle/).

One of the KKM's tools is a checklist for the qualitative assessment of climate protection in transport within the framework of binding land-use plan procedures. The aim of this checklist is to support local authorities in avoiding traffic, expanding sustainable transport and strengthening climate-neutral modes of transport.

The checklist takes into account transport-related aspects that can be specified in a binding land-use plan. These include, for example, the location and density of development, the network of bicycle and pedestrian paths, public transport services, mobility hubs and parking management. In addition, supplementary measures that can positively influence mobility behaviour in terms of climate protection are also considered. These can be agreed upon in urban development contracts, e.g. car-sharing services, parking management or mobility consulting services.

The checklist can be applied to development area and analysed using a qualitative evaluation system. This makes it possible to assess the extent to which the planned measures of a development area contribute to

climate protection. The great advantage of this tool is its user-friendliness, which allows local authorities to easily obtain a comprehensive overview of possible specifications for promoting climate-friendly mobility.

4.2 Method for estimating the car ownership in neighbourhoods

The study "Parking space allocation and mobility concepts in residential development" by the Technical University of Hamburg, funded by the "Lebendige Stadt" foundation, uses a statistical method to estimate car ownership in residential areas and determine the necessary parking space requirements (Tahedl 2021). The investigations are based on approximately 900 neighbourhoods in the two major cities of Hamburg and Osnabrück in Germany and focus on the question of which spatial and socio-structural parameters influence car ownership. A small-scale neighbourhood-level analysis is applied.

The identified factors influencing car ownership at the neighbourhood level include: Population density and proportion of residential use in the area, walking distance to local amenities, level of mixed land use, walking distance to bus stops and their service frequency, walking distance to S-Bahn stations and their service frequency, public transport travel time to the city centre, household size or apartment size and houshold income.

Based on the assumption that the availability of parking spaces can influence mobility behaviour and, in particular, car use by residents, the underlying approach emphasises the importance of carefully determining the number of parking spaces required in the context of urban land-use planning. The aim is to contribute to the promotion of sustainable mobility behaviour through conscious control of parking space availability. In this context, it is emphasised that the decision on the number of parking spaces to be actually realised must always be made in the context of the conflicting interests of space availability, costs, requirements for public space and the goals of the mobility transition. The estimation of car ownership serves as a methodological basis. According to Tahedl (2021) it must be determined on a case-by-case basis how many of the forecasted vehicles should be allocated parking spaces and to what extent alternative mobility options can be considered as compensation.

Since the underlying factors are based on empirical data from large cities, the method is suitable for use in metropolitan areas as well as medium-sized and small cities (Tahedl 2021). For application in rural, small-sized municipalities, however, context-specific adjustments of the parameters are necessary.

4.3 Elasticity models for mode choice

Transport mode choice models based on elasticities analyse how much the demand for a particular mode of transport changes when travel time or travel costs change as a result of supply adjustments. They therefore enable an assessment of the extent to which measures that influence travel time or travel costs can change the probability of choosing a particular mode of transport. Examples of such models are the elasticity model for transport mode choice for regional routes in Switzerland developed by ETH Zurich (Vrtic and Axhausen 2000) and the standardised evaluation framework for transport infrastructure investments in local public transport, which is developed based on the empircial data in Germany (Intraplan 2016).

A disadvantage of these statistical models is that they can only take into account measures that can be quantified in terms of changes in time or cost. In addition, spatial conditions and socio-demographic characteristics have a considerable influence on elasticity. As a result, the elasticity values determined vary considerably between different studies. As Vrtic and Axhausen (2000) emphasise, the transfer of such model parameters only makes sense under clearly defined conditions and for comparable supply and demand conditions.

4.4 Estimating traffic volumes for modes of transport in development areas with Ver_Bau

The German tool for estimating traffic volume through urban land-use planning projects (Ver_Bau) serves to estimate the traffic impact of planned development projects within the framework of urban land-use planning. The tool enables a forecast of future traffic volume based on empirical values and data. It takes into account different types of areas such as residential, mixed land use, commercial and special areas, as well as large-scale retail facilities.(Bosserhoff and Vogt 2007).

The tool consists of two parts. In the first part, the structural variables and demand groups of the planned project are estimated on the basis of typical land use parameters (e.g. population density). Based on this, the expected traffic volume in the area is determined in a second step. Based on these values, other traffic-related

indicators such as modal split, travel frequency, domestic traffic shares, car occupancy rates and hourly shares in car traffic can be estimated (Bosserhoff and Vogt 2007).

While the tool can reliably predict the number of trips within an area, it has shortcomings in its assessment of the mode share and can only provide rough estimates. In order to account for the existing uncertainty in traffic generation forecasts, the results are given as ranges. A major advantage of the tool is the comparatively low time required, as the calculations are based on established parameters. Another limitation of the tool is the relatively rough estimate of traffic volume, as location-specific influencing factors are only taken into account to a limited extent. In particular, traffic-influencing factors such as the the mobility concept of the development area, measures to promote environmentally-friendly transport or connections to public transport are not taken into account.

4.5 Transfer of experience from case studies

As the above approaches are often based on studies in urban areas, their transferability to rural contexts is limited. In addition, many statistical approaches have difficulties in reflecting the complexity of real conditions in rural areas. Comparing the study area with relevant case studies can provide additional insights into the actual effects of planned measures.

However, analysing case studies presents several challenges. For example it is often difficult to identify comparable areas with similar conditions. This is particularly true in the case of new or innovative measures that have so far only been implemented in a few cases, especially in rural communities. In addition, the quantitative transferability of the observed effects is problematic, as they are highly context-dependent. Another methodological disadvantage is that, in real-world planning processes, individual measures are rarely implemented in isolation. Instead, bundles of measures are usually implemented, the effects of which influence and overlap with each other. It is therefore difficult to attribute the effects of individual measures within such a package to a specific cause. For these reasons, the uncertainty of assessments based on case studies is high.

5 TOOLBOX FOR LAND-USE PLANNING AND SUSTAINABLE MOBILITY

Despite the diverse approaches presented above, there are limitations to the evaluation of transport measures in spatial development processes. These weaknesses are particularly evident in the analysis of mobility in rural areas. Most existing approaches are primarily geared towards urban contexts and can only be applied to rural structures to a limited extent. In addition, they often focus on regional and community scales, while small-scale effects, for example at the neighbourhood level, have hardly been investigated to date. The developed toolbox addresses the limitations of previous assessment approaches. It aims to minimise the uncertainties existing in previous approaches while at the same time making targeted use of their potential. The toolbox integrates tried and tested elements from the existing approaches. So the multi-method structure of the Klima Mobil competence network checklist is used to structure the scope of the study, while the Ver_Bau tool is used as the data basis. Other approaches are used to assess the transport impacts of specific measures. The toolbox uses data from a comprehensive literature review on the transport impacts of urban land-use planning. In addition, data on mobility in rural areas from Mobility in Germany (nationwide survey of mobility behaviour: https://www.mobilitaet-in-deutschland.de) is used as a reference value.

5.1 Understanding and indicators Sustainable mobility

In order to assess the contribution of land-use planning to sustainable mobility, two indicators are used: accessibility and traffic-related greenhouse gas emissions. These indicators are based on the understanding of sustainability (Ott and Döring 2011) and the definition of sustainable mobility: enabling society to satisfy basic mobility needs while ensuring safety, health, the functioning of ecosystems and justice within and between generations (Gerlach et al. 2015; Eckart et al. 2020). In this context, “transport-related greenhouse gas emissions” (GHG emissions) represent the ecological upper limit of sustainable mobility (other possible ecological issues include air pollutants, noise, ecosystem protection, water and resource consumption), while the indicator “accessibility” marks the minimum social limit (other social issues include road safety, asset maintenance and fairness), thus reflecting the basic need for mobility. The scope for planning sustainable mobility is within these two limits. The following section describes the structure of the toolbox with its two

strands: determining transport-related GHG emissions and the accessibility of the development area (see Figure 1).

5.2 Input values for the assessment

The toolbox is based on a list of measures that influence traffic and can be influenced within the framework of German land-use planning. The toolbox is primarily based on the provisions of the German Building Code and the checklist of the Klima Mobil competence network. The measures considered were verified by an internal expert panel. The measures taken into account include: walking time to the car-parking space at home, walking travel time to the bus station from home, mixed land use, density, distance to the city center and to local amenities e.g.

The toolbox takes into account area-specific inputs, such as the planned number of residential units, the population of the municipality or the spatial typology according to the seven categories of RegioStaR (regional statistical spatial typology of the German federal ministery of transport for mobility and transport research). The input values required for the calculations are based either on data from the national survey Mobility in Germany (https://www.mobilitaet-in-deutschland.de), on the Ver_Bau tool or on user-defined specifications.

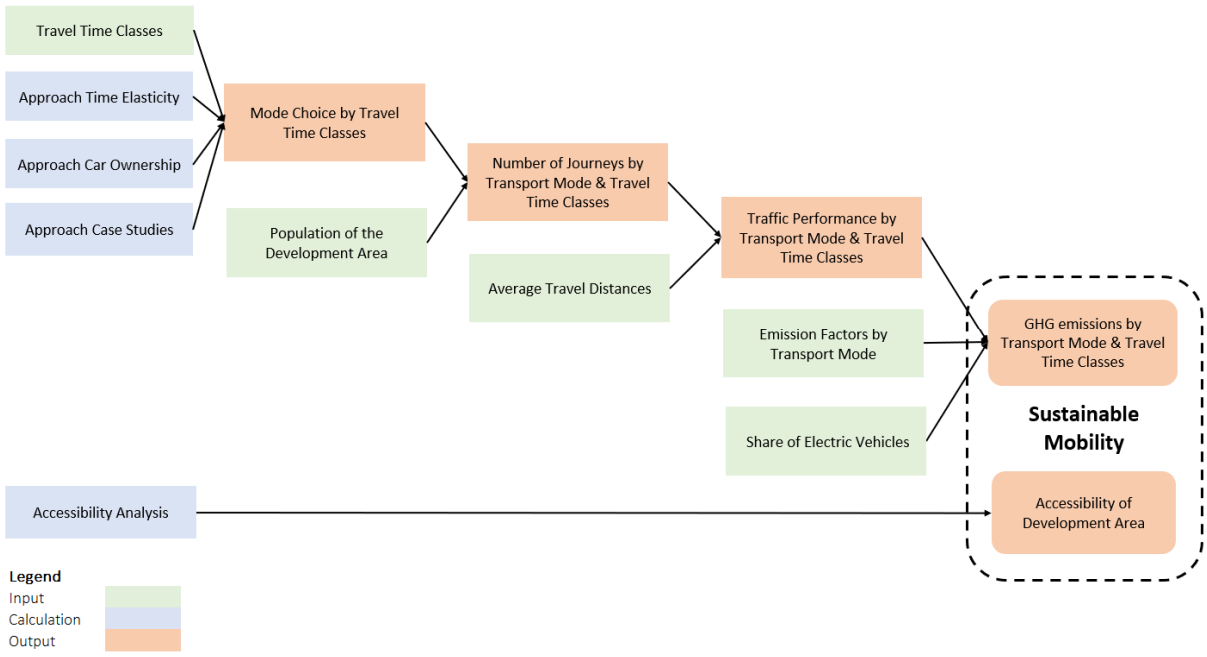


Figure 1: Flow chart of the toolbox

5.3 Determining the choice of transport mode

The modal split is a key factor in assessing the impact of planning on sustainability, as it has a significant influence on transport-related greenhouse gas emissions. Due to the inherent uncertainties of such assessments, the results are presented as ranges. The lower end of the range reflects the more conservative estimates, while the upper end represents the more optimistic effects. The impact of measures in the spatial development plan on the modal split is estimated on the basis of up to three different methodological approaches: car ownership models, time elasticity models or empirically based case studies. The approaches selected are those that are technically suitable for assessing the measure under consideration.

Within the framework of land-use planning, decisions about walking time to the car-parking space at home and walking travel time to the bus station from home are made. Measures such as the location of public transport stops, the location of parking spaces, the mixed land use and accessibility of everyday amenities have a significant influence on mobility behaviour, including the choice of transport mode. The time elasticity model is used to assess these consequences on the modal split. Region-specific boundary conditions that influence elasticity are taken into account when selecting elasticity values.

For measures that influence car ownership, the approach used to estimate the number of cars in neighbourhoods is applied. To ensure a more accurate representation of rural communities, the model was adjusted based on available published data. Due to limited data availability, additional surveys are planned.

The case study approach draws on a pool of empirical examples from the literature research and previous surveys. Suitable case studies are selected based on the measures and context. A forecast for the respective study area is created based on the relative change in the modal split in the selected case study. To calibrate the estimated modal split values, these are compared with empirical data from the project and from previous research in order to refine them and make the forecasts more realistic.

5.4 Greenhouse gas emissions

Based on the estimated range of the modal split, the number and length of trips for each mode of transport and mode-specific emission factors, the greenhouse gas emissions caused by traffic in the development area are calculated on an annual basis. A distinction is made between the emission factors for conventional and electric cars. The result is presented as an indicator of sustainable mobility in terms of the GHG emissions generated by the development area. In order to reflect the uncertainties of such a forecast, the results are presented as a range, with the lower end of the range representing the more conservative values (which will be achieved with a higher certainty), while the upper end represents the possible effects. In addition, qualitative information are provided on the conditions under which the upper or lower end of the range can be expected. It should be noted that the influence of residential self-selection is not taken into account in the toolbox assessments. This methodological limitation can lead to an overestimation of causal relationships between built environemnt and mobility behaviour. Accordingly, a reflective interpretation of the results in the planning context is required.

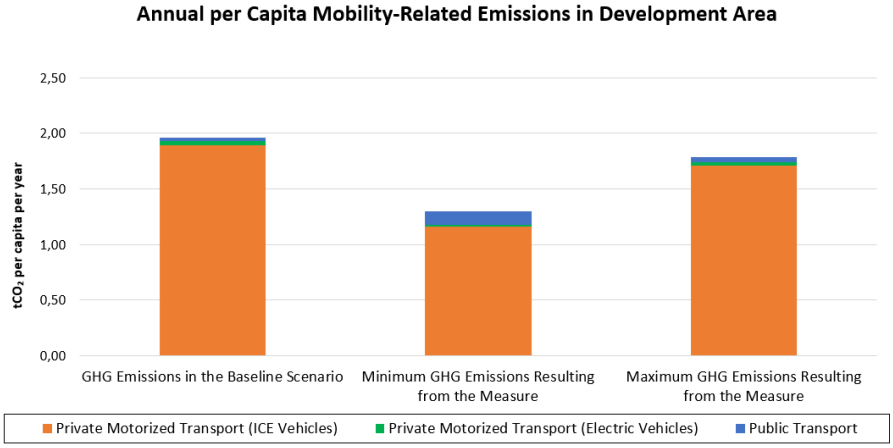


Figure 2: Calculated GHG emissions for a case study

5.5 Accessibility analysis

In parallel the accessibility in the vicinity of the development area is analysed. This is based on the concept of travel time budget indicators for accessibility, which describes how many activities can be reached by a means of transport within a certain travel time (Schwarze 2005). A comprehensive list, containing 24 different everyday activities, is used as a guideline for measuring accessibility (Schwarze 2025). These activities are categorized into four major dimensions: supply, healthcare, education and leisure. These dimensions split into detailed categories like level of schools, different services and types of markets. The toolbox focuses on six categories of everyday activities: supermarket/discount store, daycare centre, primary school, family doctor, pharmacy and local public transport stop. Accessibility of workplaces is not yet part of our categories. The analysis is carried out using a tool developed by the project team based on data from OpenStreetMap and isochrone and travel-time APIs. It determines the number of accessible facilities in each category within a 15-minute walk or bicycle-drive. So the focus are walking, driving by bicycle and in the future also public transport. As results two different indeces are calculated. The first index aims to provide a interpretation of the availability of local everyday destinations. We call it the 15-minute-index. The 15-minute-index describes how many of the twentyfour categories are accessible in 15 minutes by a predetermined mode which makes the most sense for the given category. Respecting the different weights (as

in: schools and supermarkets are heavier weighted than ATMs or repair shops) a percentage between 0 and 100 is the result of the calculation, with 100 meaning every category is reachable within 15 minutes. This index can then be compared with similar regions or residential developments. A second, much more descriptive index, called X-minute-index, describes the accessibility of an area based on the average travel time to destinations of the categories. To calculate this index, the travel time to the next destination and the the weight associated with that category are used. The result is an index that illustrates the average travel time in the context of the categories, meaning for example in a 7-minute-city, the average travel time to the important (highly weighted) categories is relatively short. It does not mean the average travel time to every category is 7 minutes, however the lower the value, the closer the important categories are. This index differs vastly dependent on area, population and destinations. Also different weights can alter the indeces. We plan to iterate on weights and categories depending on use cases.

Finally, the local accessibility values are compared with those of municipalities with comparable spatial typologies in Baden-Württemberg and throughout Germany. This is based on data from INKAR (indicators and maps for spatial and urban development) from the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR). Due to a lack of data in INKAR, daycare centres and family doctors are not included in these comparisons. An expansion of the accessibility analysis is planned. Based on first results with participating cities and urban planners, the details and weightings of certain categories and destinations will be made variable, to offer a more individual approach depending on the planned development.



Figure 3: Flow chart of accessibility analysis

5.6 Integrated assessment of sustainable mobility

For the purpose of advising local authorities and decision-makers, transport-related GHG emissions are presented as an indicator of the ecological limits of sustainability and accessibility as an indicator of the social limits of sustainability. The tool is delibarately limited on two indicators in order to facilitate the communication to decision makers and public. By comparing the two indicators for the development area, the contribution of various transport measures to sustainable mobility in rural areas is illustrated. In addition, the contribution of the measures taken in the development area to achieving German Climate Action Programme 2030 (reduction of 55% of greenhouse gases by 2030) is shown.

5.7 Application and need for further development

The current version of the toolbox is being tested as a tool for policy counceling in two pilot municipalities in order to check its functionality in real-life situations and to further develop the methodology on the basis of practical experience. As the testing is still in process, the results are pending. The current version only allows single measures to be evaluated. An extension for evaluating packages of measures in the form of a combination of qualitative and quantitative assessments is currently under development.

The methodology developed in the project has a high potential to be transferred to other countries, particularly where comparable planning frameworks and objectives exist in the field of sustainable

residential and transport development. Since the core principles of integrated planning such as promoting short distances, mixed land use, and multimodal accessibility are universally relevant for sustainable transport, the toolbox can serve as a conceptual approach in international contexts as well. However, the transfer requires adaptation to country-specific institutional structures (especially regarding approaches for estimating car ownership and the Ver_Bau tool), legal planning instruments, and available data sources (such as the Mobility in Germany dataset). Differences in spatial structure or public transport organization significantly influence the mechanisms through which planned measures have an effect. Therefore, contextualizing the indicators and evaluation criteria is necessary to provide valid assessments of transport-related impacts. Overall the methodology offers a transferable framework that, through appropriate localization of parameters, can provide a basis for sustainable land use and transport planning beyond Germany.

6 CONCLUSION

Due to the interactions between built environment and mobility behaviour, land-use planning influences framework conditions for sustainable mobility. The toolbox developed in the move.mORe project offers a practice-oriented, scientifically approach that supports local authorities in the early assessment of the transport impacts of settlement developments.

The toolbox can help to prioritise measures in urban land-use planning in a targeted manner and make their contribution to sustainable mobility transparent. This strengthens the capacity to act of small and medium-sized municipalities in rural areas, which often have limited technical resources.

Applying ideas from the “15-minute city” concept to rural areas offers a significant improvement in evaluating, comparing and quantifying accessibility, especially in terms of assisting municipalities in decision-making during stages of land-use planning.

To further develop the toolbox it is planned that the data basis for rural areas is to be expanded further and to facilitate the evaluation of packages of measures. Continuous validation in pilot municipalities can additionally increase feasibility and strengthen acceptance in municipal planning practice.

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Accelerating instead of Waiving Planning: Opportunities and Challenges of Digital Building Land Cadastres in Urban Digital Twins

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1 ABSTRACT

Building land registers have the task of providing potential areas for construction activities and developing them for the demand for residential, commercial and open space. They are therefore an essential basis for the ability of municipalities to plan strategically for future land use and to help implement development objectives. The emergence of artificial intelligence, open and free geodata and new technologies in data collection is creating new possibilities and business models for capturing potential areas. The data integration, evaluation and provision of the collected information, in turn, benefits from the development of Urban Digital Twins (UDT). Model projects show that UDTs potentially strengthen cooperation between authorities, the private sector and stakeholders. Existing software solutions already contain relevant data, which makes it easier to design the information model for a UDT.

This article focuses on the adaptation, scaling, and establishment of these solutions in the process management of land management. For this purpose, the current state of development for two common software solutions (ArcGIS Urban©, Urbanistic©) is compared for the requirements of land management. The focus is onthe design of land registers that conforms to the criteria of a new norm on digitals twins for cities and municipalities (DIN SPEC 91607). The results show that methodological approaches are mostly designed as GIS functions and challenging to implement. This learning from our test was further substantiated in discussions with experts, where the seamless integration of benchmarking functions and scenario indicators in UDTis seen as a main requirement for the technical progress and added value for planning. Artificial intelligence is of particular importance in the collection, processing and integration of auxiliary data.

The recommendations in the article conclude that new requirements for information management in urban planning have emerged. They require investments in the development of enhanced land management cadastres which benefit from UDT functions. Their introduction in local planning requires that organizations adapt new process management techniques. The accelerated activation of building land, which has recently been introduced through reforms of the building law in Germany (“Bauturbo”), requires a speedier and more comprehensive evaluation of urban development quality criteria if sustainability criteria are still to play a role. Over time, we expect that UDT technologies will help in this context.

Keywords: Digital Twins, Land management, Infill development, Climate adaptation, Process management

2 BACKGROUND

There is broad support in the literature on sustainable urban development for models and concepts of redensification and infill development (e. g. Heinig 2021; Barton 2016; WBGU 2016). The building land requirements of cities and municipalities should primarily be met within planned inner areas and harmonized with climate adaptation measures and the functional networking of sustainable infrastructures (Umweltbundesamt 2023, see Figure 1).

In planning practice, however, resolving conflicting goals is a challenge. In this context, one author describes the clash of narratives on sustainable urban development as follows:

“The guiding principles [of infill development] are well-founded in each case, and some measures can be implemented without conflict. However, they must enable sustainable socioeconomic development and measurable growth in prosperity. Private investors and project developers are concerned with market-driven utilization concepts, space efficiency, technical constructability, cost-benefit calculations, financial viability,

and marketability. Without a promising business case, no one will invest. Where this understanding cannot prevail, where radical, uncompromising demands from isolated individual interests clash, decisions cannot be made, plans cannot be drawn up, and construction cannot begin, resulting in valuable time being lost" (translated from the German original, see Achilles 2024). In order to bridge this gap, newer approaches focus on a digitally supported flow of information that is specifically practiced between urban development stakeholders (Brade 2025).

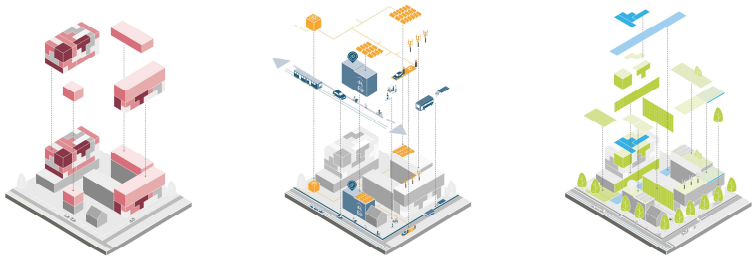


Figure 1: The three challenges of infill development (from left to right: building redensification, sustainable infrastructure, climate adaptation; source: courtesy of Must Städtebau https://must. eu/ [18. 01. 2026]).

UDTs provide new technologies for this purpose. They are currently being introduced in local government as a building block of smart city strategies (Etezadzadeh 2020). In this context, Figure 2 shows two frequent and legally requried tasks in local government for land management which can be supported by UDT technologies in the future:Issuing building permits (left) and setting building regulations through the development of local areaplans (right).

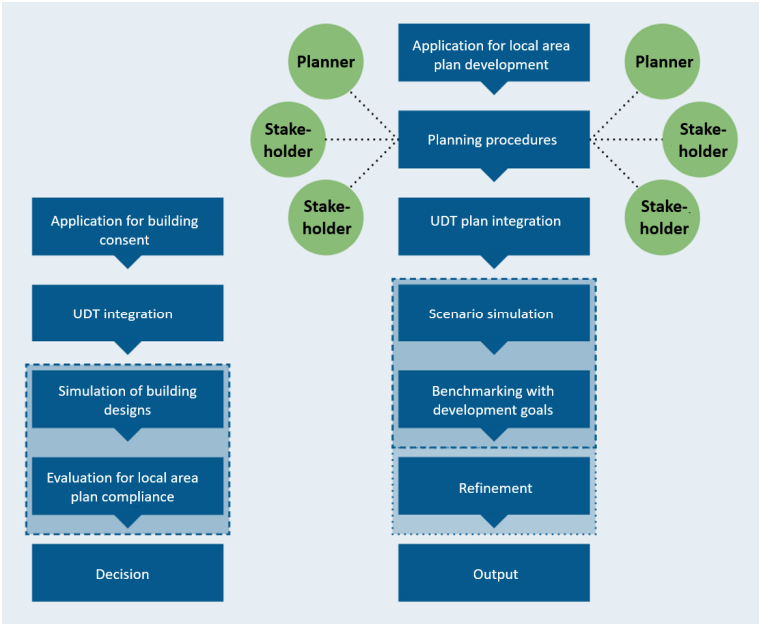


Figure 2: Schematic representation of the process for reviewing a building permit (left) and the process for drawing up a development plan (right) with the support of a digital twin (adapted from BBSR 2025, p. 22).

The workflows depicted in Figure 2 are taken from pilot projects where UDT technologies are currently being introduced (here: City of Kirchheim near Munich). In general, however, there is not much empirical knowledge about UDTusage in planning practice(Guckenbiehl et al. 2021). It is largely unclear what technologies or functionalities constitute a UDT and what makes it unique in comparison to other GIS applications. The term originally comes from industry and is used to create digital representations of products or machines. These serve as virtual replacements for physical prototypes, which can be used to create simulations and analyses (van der Horn and Mahadeva 2021). Applying this concept to the UDT gives cities and municipalities a comprehensive virtual representation of their structural elements and functional networks. This opens up new possibilities for projecting planning goals and building land development designs into the future (Schubbe et al. 2023). Accordingly, a smart city requires a dynamic, digital representation that not only integrates the physical building fabric, infrastructure, urban processes, and

citizen feedback. The intelligent digital image also knows about the business processes (e. g. , informal and formal urban land-use planning), responsibilities (role and user concept), and interfaces to systems at partners that map the state of the city for their needs (Brandt et al. 2023). This means that not only does the city provide the twin with up-to-date information, but the twin can also transmit data and insights from other systems back to the city (Guckenbiehl et al. 2021).

In summary, UDT technologies have the potential to improve land management procedures in planning practice. This comes at a time where remaining infill land potentials in German cities have become more difficult to activate, since many larger potentials have already been developed over the last decades. Interviews with experts in Northrhine-Westphalia explain that remaining potentials are more difficult to activate. Cities like Munster have been successful in the past to direct growth to derelict sites within the urban compound. Now, continued growth pressure forces city planners to develop new suburbs on the outskirts and expand the urban footprint (Fina et al. 2020). In this context, some authors argue that proactive land management needs to focus more on land potentials that are likely to become available in the future and plan for its reuse at an early stage. Newer methodological approaches from pilot studies show that continued urban transformation trends can lead to new obsolete land uses (e. g. petrol stations, car parks, retail and offices, Wenner und Thierstein 2024; Rettich und Tastel 2023). In the past, federal and state research and funding programs have provided valuable impetus to plan for the reuse of such potentials, which has led to improvements in the information base in recent years (BBSR 2022). In planning practice, however, dealing with conflicting planning law objectives in the activation of infill potentials remains a challenge (Preuß und Böhnke 2024).

In 2025, political targets to provide housing for residential use and economic development have led to policy reforms in the building code (“Bauturbo”, i. e. Construction Acceleration Act). Many planning requirements are not required anymore, local planning authorities can or even must provide building consents to applicants without environmental impact assessments or other forms of planning regulation compliance that are usually spelled out in local area plans. This leads to uncertainties about the legal status of building consents in conflicting situations. Many experts predict that such cases will be subject to subsequent legal conflicts that have to be decided in court, counteracting on the target to accelerate land activation. For instance, the tasks of climate protection and climate adaptation and the associated requirements for land use have increasingly being regulated over the last years (Mitschang 2021). It is unclear how the resulting conflicts in legislation can be resolved. Planning asscociations and planning pracitioners warn that the reform falls short from ensuring associated sustainable urban development requirements(SRL 2025). The main line of argument, on one hand, revolves around a large consensus that does support the debureaucratization of planning procedures for faster activation of land potentials. On the other hand, this should not come at the cost of giving up on planning controlsand risk new forms of land speculation(von Lojewski 2025).

Based on this background, we address the question whether (1) UDT technologies can contribute to accelerate the activation of land potentials for infill development and (2) still ensure sustainable development targets at the same time (“accelerating instead of waiving planning”). In the following sections we posit that the emergence of new norms and standards will help to innovate digital planning in urban land management.

3 METHODOLOGY

In the first step, we evaluate these questions based on a review of UDT norms and standards. In the second step, we evaluate two widely used software options (ArcGIS Urban©, Urbanistic©) against criteria taken from the DIN SPEC, focusing on aspects of data interoperability and integration, indicators and benchmarks as well as workflow requirements for planning practice. A special focus is on indicators for climate adaptation. The work was carried out in a third-party funded research project[1] at THA where this perspective is of particular importance.

Our initial findings lead to insights about the importance of digital innovation and process management in local government (Will und Winter 2024). We address this viewpoint in a separate chapter and in the discussion section.

[1] Digital Planning Support for carbon-neutral urban development (DiPukS), https://www. tha. de/Architektur-und-Bauwesen/DiPukS. html [18. 01. 2026].

4 NORMS AND STANDARDS

Since the end of 2024, DIN SPEC 91607 "Digital Twin for Cities and Municipalities" has specified a UDT standard that was developed by municipalities, associations, business, politics, and science in the Connected Urban Twins cooperation project (Munich, Leipzig, Hamburg). In addition to technical issues, the standard also incorporates ecological, economic, and social aspects, including topics such as building permits and sustainable neighborhood development. It defines usage scenarios and methods for accessing and displaying data (Schonowski et al. 2025; DIN SPEC 91607). Another standard, "Municipalities and Digital Transformation – Overview of Fields of Action," serves as a guide for the digital transformation of municipalities. Among other things, DIN identifies digital infrastructures, digital administration, mobility, construction and housing, as well as energy and the environment as areas for action (DIN SPEC 91387).

While developing DIN SPEC 91607, a similar methodology was established to systematically define concrete application cases for the Urban Digital Twin. The approach followed a four-step process to derive use cases addressing municipal needs:

(1) Structuring by establishing initial frameworks through the preliminary identification of application cases

(2) Capturing usage scenarios by collecting input from municipal stakeholders

(3) Grouping application cases according to thematic relevance and alignment with defined fields of action

(4) Developing case profiles to describe selected use cases in detail and to prepare subsequent implementation steps

The resulting set of use cases compiled within DIN SPEC 91607 demonstrates that the five most frequently mentioned municipal needs concerning usage scenarios are similar to DIN SPEC 91387: environment, building and housing, mobility, digital administration, and energy, are all directly linked to spatial and land management. Regardless of the specific use case, the geospatial base twin consistently constitutes the foundational layer and is likewise developed based on a municipal target vision. This process relies on municipally curated datasets in the domain of geospatial base data, including infrastructure and 3D building models, which are implemented using open source data models compliant with OGC standards (e. g. , CityGML, json, gml) as well as XÖV standards (e. g. , XBau, XPlanung). An XÖV standard is a German e-government data exchange standard for interoperable electronic communication between public administrations.

Building upon this foundation, municipal requirements are subsequently integrated in the form of application-oriented use cases as additional modular components of the UDT. Within the domain of digital land management, the digital building permit process plays a decisive role. The current building permitting process requires substantial effort to research, consolidate, and evaluate approval-relevant data from various municipal sources as well as from legal and regulatory frameworks. Delays often occur due to complex coordination among multiple stakeholders and the iterative, human-centred nature of decision-making. UDT technologies address these challenges by digitally supporting all phases of the permitting process. By integrating property and building-related information from public registries, GIS, and BIM data models, the UDT enables partially or fully automated, transparent, and accelerated decision-making. Through the digital representation of legal and regulatory evaluation criteria, formerly analogue workflows can be efficiently parallelized and simplified. Application scenarios include decision support based on indicator-driven data visualization, simulation-based assessment of planned projects, digital communication and collaboration among stakeholders, automated issuance of digital permits, and ongoing digital monitoring and documentation of construction progress. Furthermore, the UDT serves as a training platform for authorities and professionals to build competencies in managing digital permitting processes and assessing construction-related risks.

However, practical implementation examples remain scarce, with current developments largely limited to the application of XÖV standards and the solution DIPlanung that is currently being introduced by state authorities, amongst others in Bavaria (DIPlanung 2026). Following Kaushal (2022), initial international research on application of an UDT in urban planning can be observed. In his work, ArcGIS Urban© is employed in combination with a Spatial Urban Quality Framework that transfers urban quality indicators from first tier to second-tier cities, enabling spatial analyses to support data-driven urban planning. Our own tests with this and alternative software solutions shows that data integration of legally binding district and

local area plans are technically laborious. To date, there is no clear added value of UDT applications for the efficiency of building permitting processes. One main obstacle are the delays in the introduction of the subject-independent and interdisciplinary XÖV standard XPlanung, a data format for use in municipal GIS software solutions for urban land-use planning (Brade 2025). The corresponding legislation for XPlanung was already passed by the federal and state governments in 2017 and should have become the basis for a more direct and cross-system form of cooperation in digital planning by 2023. However, due to implementation problems, interim solutions are currently being pursued which define partial vector capture as a minimum standard in stage 1 of the introduction and only represent the georeferenced scope of a development plan with undefined essential information from a plan in accordance with XPlanung. Only in a later stage 2 will full vector-based recording of all spatial data (e. g. , areas, specifications) as digital objects become mandatory (STMBW 2025). The current data landscape therefore continues to be characterized by formats and tools that are subject to specific domain knowledge and system barriers and create barriers to communication between the actors involved. Land management planning processes will therefore only become fully machine-readable with the delayed introduction of the full range of features in development plans. Furthermore, this regulation only applies to plans that have been drawn up in development planning procedures since 2017. Important planning law indicators that provide decisive information about the permissible extent and scope of development (e. g. , floor area ratio and floor space index) in older plans must therefore continue to be interpreted manually.

In this context, the question arises wether XPlanung-compliant digitization should extent to cover legally binding older development plans. It is mostly in these plans where crucial building regulations for existing development based on the principle of infill developmentcan be found. Efforts to fully digitize these plans require the allocation of considerable time and financial resources within the administration or for the commissioning of service providers. In the process, technical standards with sample directories are being reinterpreted in order to achieve the best possible results for specific urban land-use planning applications, depending on feasibility (cf. NRW. Urban 2021 STMBW 2021). Pilot studies show that artificial intelligence (AI) can be a game changer in this context. A technological leap is being observed in this area, with the use of AI to transfer a new generation of digital building land and brownfield site registers to UDTs. In a pilot study Schwarz (2024) concludes that current AI tools are already capable to interpret text and images in local area plans in high quality. Prerequisites are that the resolution of the documents is high and location specific markers help to interpret map legends and other plan signatures. Additional domain-specific training material is likely to emerge over the coming years to further improve results.

5 EVALUATION OF UDT APPLICATIONS FOR LAND MANAGEMENT

Software tools to capture, store and administer infill potentials in cities have evolved signficantly over the last few years. Initial database and spreadsheet driven approaches have increasingly integrated GIS functionalities to visualize land potentials on maps. Advanced GIS functionalities help to better understand and analyze the geographic context for building land activation, e. g. to inform and provide conditions that enable future usage according to development plans(Fina et al. 2023). Figure 3 shows selected parts of the software interface of the government funded research project KFMplus© (“Kommunales Flächen- und Ressourcenmanagement”, i. e. local planning land and ressource management) for the data-driven assessment of development options for the city of Dachau, Germany. The establishment of such software developments does not necessarily include 3D visualized objects. More importantly, they require interfaces to digitally map infill potentials and auxiliary information on land activation prerequisites, and to supply algorithms for data-driven assessment and visualization technologies. The software design of pilot projects like KFMplus© provided the path for innovations that are currently being rolled out in parts of Germany. One example is the introduction of new land management software with a similar design in the State of Baden-Württemberg.[2]

Sample indicators in the frame on the right of Figure 3(enlarged and translated from the German original) are compiled from a range of geodata inputs and compared between the current situation and a range of development options that the user can select from (in this case “dense built-up”). The Figure focuses on indicators on the acccessiblity of amenities and aspects of climate change. The colour coding of the

[2] https://mlw. baden-wuerttemberg. de/de/landesentwicklung/flaechenmanagement/digitales-flaechenmanagement.

comparison can help to better understand negative and positive effects when implementing a certain development option (shades of red: indicator values show negative effects; yello: neutral; shades of green: indicator values show positive effects). There are also a range of other indicators available in modules on urban amenities ("Daseinsvorsorge") at the location of a selected infill potential, and other important informaton to activate the site for reuse ("Innenentwicklungspotenziale"). The integration of planning regulations is limited to data fields for users to store and manually interpret permissible land use types, the ground area index, the floor area ratio or the building volume ratio. Spatial delineations like construction lines and building delineations are usually only available in linked documents (PDF) and have to be interpreted manually.

More advanced UDTs provide the possibility to integrate such spatial information from standards like XPlanung. Having the corresponding information fully integrated in the application provides possibilities to automatically test designs for building code compliance, in some cases with rule-based tools that deliver compliant design. Indicator-based comparisons of urban development scenarios and public participation to tag and label design and environment features enhance these applications further. In this context, we have tested two software options (1) ESRI's ArcGIS Urban© (supported by ArcGIS Pro/Online and ArcGIS City Engine) and (2) Urbanistic©. Both were used to set up UDT applications for specific use cases in the City of Augsburg in Southern Germany (pop. approx. 300,000). The city has successfully activated former military sites for infill development over the last few years and uses urban planning and architectural competitions to ensure high quality and economically feasible planning.

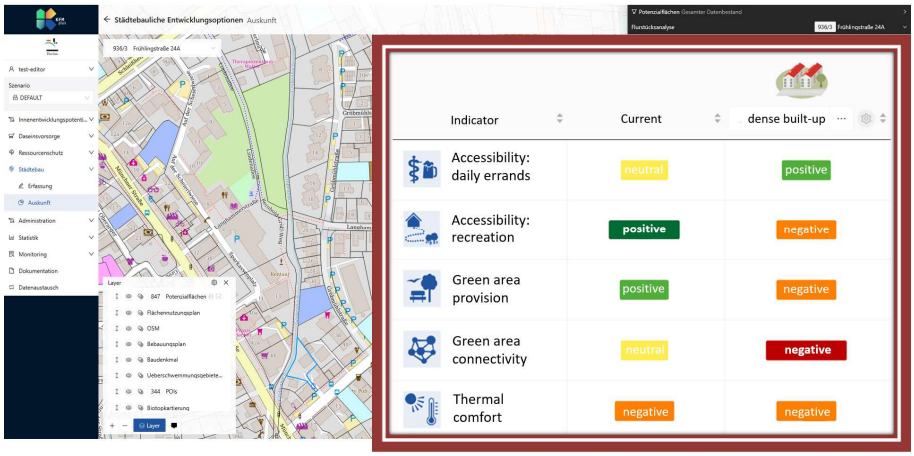


Figure 3: Data-driven assessment of development options in infill development (own design).

Figure 4 shows a UDT with a fully functional building design imported from Autodesk Revit©for the curent situation in an area known as the Prinz Karl area. The area is designated for a new campus for the Faculty of Architecture and Civil Engineering at the University of Applied Science. Results show that setting up the UDT in ArcGIS Urban© with relevant data is time consuming and requires expert knowledge at the interface of geoinformation science and urban planning. The bullet points in Figure 4 depict a summary of the steps in the workflow that need to be managed. After successful data acquisition and integration, the challenge is to harmonize and transform the data into required formats. This applies to context layers like digital elevation models and existing building representations (OpenStreetMap or LoD2 – Level of Detail 2 (LDBV 2026), vegetation and infrastructure. It also applies to the building code imported from XPlanung (if available) or digitized local area plans (Source: City of Augsburg). Architectural designs can currently only be imported as drawings that have to be located manually, with limited accuracy (Source: student projects at THA). Direct imports for object-oriented desing representations (e. g. BIM models in the IFC standard, see Figure 4) cannot be functionally connected to the context layers. In order to achieve this, BIM models have to be duplicated with ArcGIS Urban© modelling techniques.

In the same project, we have evaluated the software option of the Munich-based startup Urbanistic© (Urbanistic 2026). This cloud solution is pre-equipped with data from OpenData BY (LDBV 2026), using API calls for seamless data integration. It has a growing client base in planning practice which values the ease of use for data interoperability between GIS and CAD/BIM software. The graphics performance is higher compared to ArcGIS Urban© and many functionalities address the competencies of CAD/BIM users better than the GIS based software design of ArcGIS Urban©, including building code regulations based on

state legislation (“Landesbauordnung”) and specialized tools to model the land area requirements of fire brigades or emergency services. In contrast to ArcGIS Urban©, the business model of Urbanistic© requires subscriptions for additional data (e. g. local area plans, cadastral data) to be integrated by consultants rather than having a generic software that the user can equip with data from own GIS workflows.



Figure 4: Current situation with a selected new redevelopment design in the Prince Karl area in Augsburg, Germany (own design).



Figure 5: Urbanistic© UDT Prinz Karl, Augsburg (own design, Urbanistic 2026).

Based on the software evaluations of the DiPukS project, one of the authors of this article proceeded to work on an another area development in Augsburg, namely at the former Reese baracks. The Reese development is divided into two separate developments. The southern part has already been subject to an urban design competetion with a winner, the northern part is set to go through the same process in the near future (Stadt Augsburg 2022). As is common in planning practice, the local area plan to regulate building and construction will only be developed once a design has been chosen. As already depicted in Figure 2, UDT applications can be used to inform this process. Figure 6 shows examples for the setup of a UDT for the design of the southern part.

In summary of these learnings, both ArcGIS Urban© and Urbanistic© have the potential to set up UDTs specifically for urban planning. Data integration in ArcGIS Urban© is quite flexible, many datasets can be prepared and integrated. This process is laborious and requires expert knowledge, whereas Urbanistic© is already equipped with many relevant datasets, additional ones require consultant contracting. Both software options work with indicators that can inform planners on design scenarios. We will discuss further insights from this evaluation in the discussion section of this article.

6 INNOVATION AND PROCESS MANAGEMENT

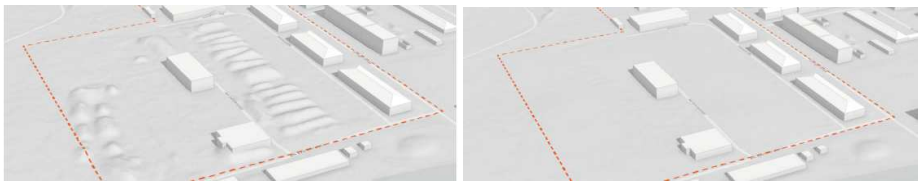
As shown in the previous sections, the handling of new UDT technologies requires specific skillsets to set up, run and maintain the corresponding applications. Organizational structures are needed that support cooperation between administrators, geoinformation officers and urban planners in a range of tasks, including hardware and software provision, data integration and the domain-specific development and usage

of results. Figure 7 provides an overview of the correponding development stages depicted in DIN SPEC 91607.

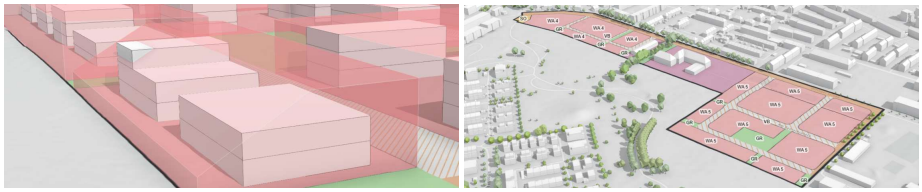
Experience from model projects shows that the interdisciplinary coordination of the underlying digital business processes benefits from professional process management consulting expertise (Schubbe et al. 2023).



1: Building models derived from OpenStreetMap, 2: Level of detail 2 buildings from OpenData BY



2: Digital elevation model from OpenData BY, 3: Modificationsconducted in ArcGIS CityEngine



4: Building envelopes derived from local area plan digitization, 5: Zoning derived from local area plan digitization



6: Building types based on the winning design, 7: Combined tree canopy (existing + planned)



8: Indicators on size, cost, demography, mobility and emissions, 9: Selected shading and viewshed analyses.

Figure 6: Selected steps of a workflow to establish an UDT for the Reese barracks in Augsburg (Finger 2025, unpublished).

The successful adaptation of innovations requires new forms of "digital governance" which not only provides users with digital planning support tools and helps them learn how to use them (Przeybilovicz und Cunha 2024). It is also committed to the sustainable acquisition of knowledge infrastructures in the concrete accomplishment of tasks and establishes new, digitally supported forms of cooperation (Weber und Ziemer 2022).

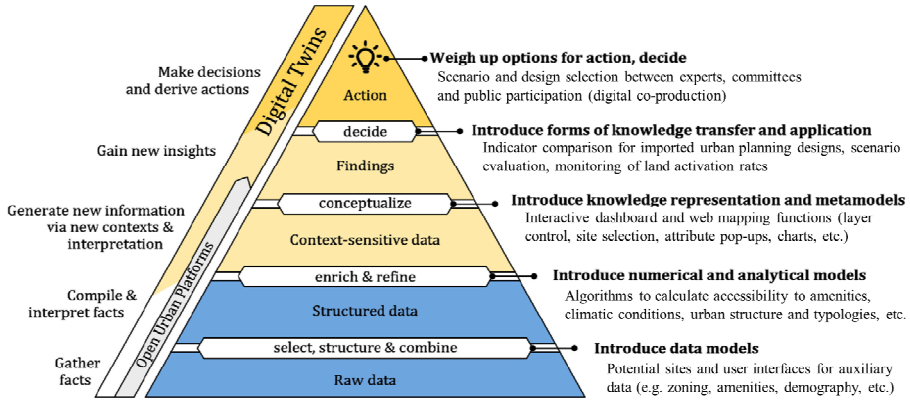


Figure 7: Development stages for UDTs, adapted for land management processes (modified from DIN SPEC 91607, p. 32).

The cooperation requirements are described as an innovation potential that still poses numerous challenges in the transfer and long-term establishment of pilot applications (cf. e. g. Prognos AG 2025). The institutional settings of public authorities with contractors and other stakeholders vary greatly in structure, for example between large, medium-sized, and small cities (Milbert und Fina 2021). Land management and location planning are also subject to urban-rural dynamics, which cause relocation effects to the urban periphery and peripheral locations (Zimmermann et al. 2025). The implementation of UDT technologies to activate infill potentials for sustainable urban development is thereoforealso a challenge for the cooperation between the different departments within one organisation and the cooperation beween neighbouring local governments and planning tiers like regional and state planning authorities. On the technical side, one main hurdle is the interoperability between the different land management systems and the applications of stakeholders, including government organizations, private industry and educational facilities. Data from one stakeholder often cannot be integrated into the platforms of others. This hinders the merging of data and information for joint use, such as analysis or planning. Another problem is the lack of clarity about what data and technical solutions are already available and what they can do. Because projects are often limited to a single sector, cross-sector effects are frequently neglected. The standardization of data structures and content is often inconsistent, which can lead to problems during integration (Donaubauer et al. 2023).

Geoinformation centers often make a cross-cutting contribution in administration to improve the interaction between geobasis data and specialist data from the departments. They are tasked with linking several application-specific UDTs into a “system of systems” during the development of UDTs. Independent data infrastructures and systems thus become a common information platform that supports application-specific scenarios. In addition to tools that allow practical access to available data, access to standardized and up-to-date planning and location data is required. To implement a UDT, data, tasks, and processes from various specialist departments and actors must be integrated. Effective project management organizes clear responsibilities and takes into account the requirements for communication, process planning, and financial resources. It establishes a common understanding of tasks to enable context-oriented communication and citizen participation across different organizational areas (Abt und Hohmann 2025).

The project of developing a UDT is therefore characterized by a high degree of uncertainty of a visionary nature. It can be expected that new requirements will continuously emerge from new usage scenarios that, at the present point in time, are very likely still unknown. Changes in requirements arise, among other factors, from political dynamics, changing climatic conditions, and newly explored technological possibilities in the construction sector. These aspects, together with the resulting complexity of such a project, argue strongly in favor of an agile approach to project execution.

Iterative development means that the development stages for UDT implementation are repeatedly carried out. At the end of each development cycle, a usable increment is produced that contains valuable enhancements compared to the previous version (Schwaber and Sutherland 2020).

Strictly speaking, projects are characterized as unique undertakings with a limited budget and a defined timeframe (“competence-based project managementPM4”,Deutsche Gesellschaft für Projektmanagement e. V. 2019). In view of the expected dynamics in this field, however, UDTs must be developed in such a way that, after project completion, they can be continuously further developed either within follow-up projects or within a permanently established organization.

In cases like land management, the highest stage ('action') of UDT implementation is interpreted as enabling the derivation of adaptive approaches for individual cases of land development activation based on the developed UDT. In industry, this is understood as a reference model from which context individual process models – in this case, checklists – can be derived. This includes the analysis described in Figure 10, but extends beyond it in the following manner. Figure 11 shows how the development stages of fig. 10 can be matched with the objectives of the proposed case. The boxes are placed below the related use symbol (current use, expected use, continuous improvement) they adress.

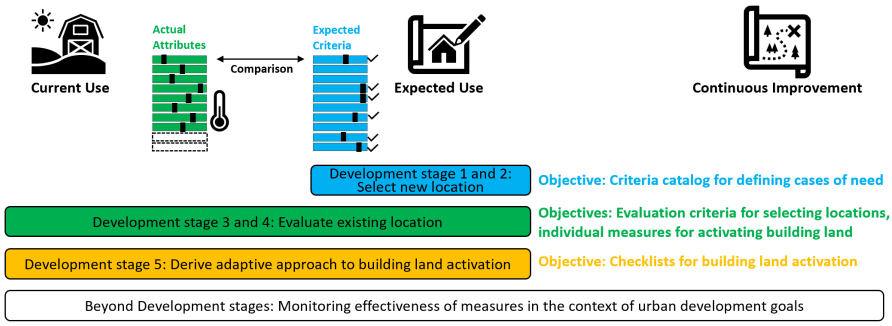


Figure 8: Matching of proposed project with development stages for UTD implementation after DIN SPEC 91607

Within stages 1 and 2 (raw and structured data), profiles consisting of several expected criteria for new development land are identified. These can then be compared to the attributes that describe current usage profiles. Existing UDTs already provide a substantial number of current attributes and their respective characteristics for existing areas (Figure10). However, the number of recorded attributes is not yet sufficiently comprehensive to assess whether the currently anticipated "expected criteria" – profiles are feasible. This goes well beyond a simple evaluation of a site based on predefined criteria (or, speaking in the UDT terminology, indicator values), as profiles made up of multiple criteria must be weighed against one another.

To enable this, in stage 3 (context-sensitive data) the systematic collection of criteria profiles as well as additional evaluation criteria must be consistently pursued. These profiles form the basis for the development of measures for land development activation (stage 4, findings). Building on this, a mechanism can be developed that adaptively derives sets of measures as context-individual approaches from the UDT. The UDT serves as a comprehensive reference model for deriving context-specific approaches(Königbauer 2021). Land development activation can be managed by orchestrating these approaches consisting of individual measures into a context-specific process, which can be understood as a checklist or a project plan(stage 5, action). This approach potentially accelerates planning,especially in more complex cases involving numerous stakeholders and many required individual steps. Such systematic measures have the additional benefit that the effectiveness of individual measures can be consistently recorded. Corresponding optimization measures can then be incorporated into subsequent land development activation projects.

Since neither project management nor UDTs are established practices within public administration, organizational structures must be introduced that support continuous improvement processes over extended periods of time. It cannot be expected that highly committed individuals will drive further development on their own or, in extreme cases, exhaust themselves in the course of implementation. Instead, the commitment of the involved organizations is required, expressed through leadership engagement in combination with subject-matter experts, to ensure that UDTs can evolve into practice-oriented and user-friendly instruments.

7 DISCUSSION AND CONCLUSION

This article discusses the potentials and challenges to implement UDT technologies for more efficient workflows in urban planning in general and sustainable urban land management in particular. Current political trends to waive planning requirements for speedier consenting procedures and critical comments from planning scholars on potential effects set the scene for this requirement: Can UDT technologies help to ensure high quality urban planning without placing new bureaucratic hurdles on the resources of urban planning departments,can they improve and accelerate planning processes in the long run? Are they transferable from piloting local government to a wider range of authorities with limited resources?

Our learnings from document and literature review and our own tests of software options show that norms and standards are urgently needed to provide user orientation. Difficulties to introduce the standards, especially for local area plans ("XPlanung") can potentially be overcome with new initiatives and AI support. The new DIN SPEC 91607 on UDTs is a good starting point to transfer learnings from pilot projects to the community. Available software options like KFMplus©, ArcGIS Urban© or Urbanistic©all run in cloud-based backends and browser-based frontends, but have been designed for different business models (e. g. KFMplus©: open source components, ESRIs ArcGIS© stack of software, Urbanistic©: native application). One main obstacle for easy-to-use UDTs are the requirements of data integration and the establishment of data-driven urban planning indicators. Where KFMplus© provides prefabricated indicator variants for a limited set of typical urban planning typologogies (e. g. densely built up, commercial, open space, etc.), ArcGIS Urban© and Urbanistic© work with variable designs based on building typologies that the user can select from (and, in the case of ArcGIS Urban©, enhance with custom typologies).

Apart from a few very generic indicators (e. g. volume, size, etc.), more advanced indicators require that the user sets up the calculation routines for inputs and outputs. Without going through this effort, the added value of UDT applications seems to be limited. Planning practice needs to know about the number of dwellings or floor area in a new building, derived number of required parking spaces, district heating demand, carbon dioxide emissions, etc. If this information is not available and/or the results are not credible for stakeholders, UDTs cannot reach their full potential for urban planning. We found in our tests that, at this stage, these tasks are laborious if standardized data is not available or supported. Users have to revert to digitizing PDF documents or scans, and subsequently deal with attribute generation, relationship modelling between object classes, and inaccuracies based on manually generated inputs. Interoperability between CAD/BIM on the one hand and GIS on the other needs to be further improved for seamless data exchange, including object-oriented attribution and relationship modelling.

A special focus of our evaluation was on indicators on climate change and climate adaptation, as shown for the software KFMplus©. ArcGIS Urban© can provide information about carbon dioxide emissions or soil sealing for urban planning designs if calculation routines are set up. More domain-specific information (thermal stress, air ventilation, stormwater runoff) is currently not available. New software options like the QGIS plugin Climate Scanner© (an AI trained software tool for climate effect assessments of urban designs) are being developed for UDT integration in emerging new research projects. Their evaluation is the next step in the currently running research project that we reported from in this article.

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reviewed paper

Affordable Housing in Emerging and Developing Economies: Exploring the Role of Urban Planning and Policy in African Countries

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1 ABSTRACT

Housing deprivation remains a pressing global challenge in contemporary urban planning and development, particularly in metropolitan areas and large cities, where unaffordability arises when housing costs exceed a household's financial capacity. Affordable housing – along with related concepts such as low-income housing, public housing, social housing, and subsidized housing – serves as a key government-led solution to mitigate free-market inequalities, enabling low-income and vulnerable groups to access quality housing alongside essential services. Despite growing academic and professional interest in affordable housing, the issue still requires further attention, especially when considering local and contextual conditions. Hence, this study explores affordable housing in emerging and developing economies through the lens of urban planning and policy in African countries. The systematic literature review focuses on a comparative analysis of four distinct approaches in African cities: the state-led rental-sale model in Algiers, Algeria; the facilitated but unaffordable cooperative model in Bahir Dar, Ethiopia; the insurgent prefigurative movement-led model in Cape Town, South Africa; and the informal demand-side adaptation strategies in Lagos, Nigeria. The findings reveal a profound disconnect between top-down policies and on-the-ground realities. The analysis demonstrates that no single, ideologically pure approach is sufficient. Instead, effective strategies must forge a hybrid path that is: (1) empirically grounded in the lived reality and financial capacities of the urban poor; (2) built on an integrated system combining land access with enabling financial mechanisms; (3) reliant on a reimagined state role that moves from rigid provision to responsive partnership; and (4) focused on housing as an act of urbanism, integrating location, services, and liveability. The study concludes that achieving affordable housing in emerging and developing economies including African countries requires a pragmatic, context-sensitive urban planning framework that learns from informal systems, confronts unjust structures, and strategically combines the scale of the state with the agency of its citizens.

Keywords: Affordable housing, Social housing, Sustainable urban development, Urban planning, Urban policy

2 INTRODUCTION

Rapid urbanization and inadequate housing supply have led to increasing demand for affordable housing from low income households with limited financial resources especially in in developing countries (Adigeh & Abebe, 2024). Affordable housing – along with related concepts such as low-income housing, public housing, social housing, and subsidized housing – serves as a key government-led solution to mitigate free-market inequalities, enabling low-income and vulnerable groups to access quality housing alongside essential services. From an urban planning perspective, affordable housing entails habitable units with suitable facilities subsidized/provided by the government, where prices/costs bear a reasonable proportion to income, leaving sufficient funds for other necessities, such as food, clothing, transportation, healthcare, and education (Arbab & Shabani, 2023; Makhloufi, 2025).

Despite growing academic and professional interest in affordable housing, the issue still requires further attention, especially when considering local and contextual conditions. Hence, this study explores affordable housing in emerging and developing economies by a focus on the role of urban planning and policy in African countries. In African cities, rapid urbanization, colonial legacies, and ineffective policies have converged to exclude the majority from accessing decent shelter. As the studies on Ethiopia and Nigeria show, cities overwhelmed by a demand for housing that far outstrips the supply of serviced land, forcing low- and middle-income residents into informal settlements or unaffordable rental markets, despite government programs intended to help them (Adigeh & Abebe, 2024; Akinwande et al., 2024). The top-down interventions often fail, as seen in Nigeria where schemes are frequently unaffordable for their target demographic (Ale, 2025), ignoring the resourceful informal housing strategies – like incremental construction and community finance – that the urban poor already rely on to survive (Akinwande & Hui, 2024). This crisis is further exacerbated by the proliferation of informal settlements lacking basic services, which perpetuates poverty and inequality across the continent (Bhanye et al., 2024). It reveals the profound

disconnect between top-down policies and the on-the-ground realities. The research from Algeria and South Africa demonstrates that studying social housing exposes the multifaceted nature of the challenge, encompassing not just financial and land-access barriers, but also the political battles, the struggle for spatial justice in post-apartheid cities, and the need to critically assess the quality and appropriateness of the housing that is actually delivered (Makhloufi, 2025; Tattersall & Iveson, 2024). Furthermore, sustainable housing solutions must address environmental, social, and economic dimensions simultaneously to create truly inclusive and resilient communities (Bhanye et al., 2024).

3 METHODOLOGY

This study adopts a systematic literature review (SLR) approach to examine social housing in emerging and developing economies, with a particular focus on African cities. Emerging and developing economies encompass nations transitioning from low-income status to advanced industrialization, characterized by rapid GDP growth, increased global trade integration, and maturing financial systems, yet facing challenges such as income inequality and infrastructure deficits. A structured search was conducted using Google Scholar to identify peer-reviewed articles containing the terms “affordable housing” or “housing affordability” in their titles. The search was limited to publications indexed in Web of Science and released by reputable international publishers from 2024 onward. Review articles and studies emphasizing technical, architectural, or psychological dimensions were excluded. The initial screening process identified 40 articles. Following the application of inclusion and exclusion criteria – particularly the removal of studies conducted in advanced economies – the corpus was reduced to 21 articles. A further refinement was made to retain only those studies that included specific city-level case studies with an emphasis on contextual and local dimensions, resulting in a final set of nine articles.

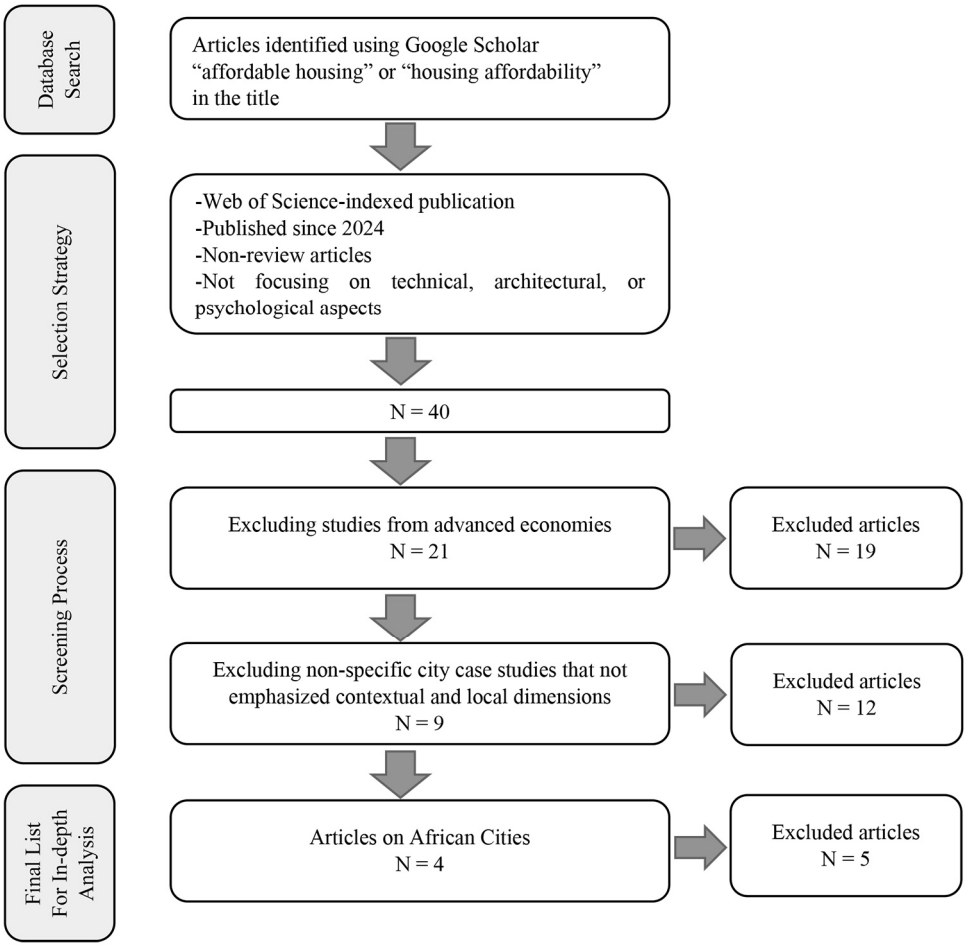


Fig. 1: Literature selection process for systematic literature review (SLR)

The literature selection process is illustrated in Figure 1, and the specifications of the included articles are summarized in Table 1. The selected articles cover a diverse range of cities across the Global South,

including Algiers (Algeria), Bahir Dar (Ethiopia), Cape Town (South Africa), Hangzhou and Shenzhen (China), Ho Chi Minh City (Vietnam), Istanbul (Turkey), Lucknow (India), and Lagos (Nigeria). Given the scope of this review and the need for focused analysis, particular attention was paid to four studies centered on African cities to enable a more in-depth exploration of social housing issues in that context.

Author(s)	Contributing Institution	Research Area	Publisher	Year	Country	City
Adigeh & Abebe, 2024	Addis Ababa University	Urban Land Development	Frontiers in Sustainable Cities	2024	Ethiopia	Bahir Dar
Akinwande et al., 2024	RMIT University	Building and Real Estate	World Development	2024	Nigeria	Lagos
Gao & Hu, 2025	Swinburne University of Technology	Building and Planning	Journal of Urban Management	2025	China	Shenzhen
Huynh & Truong, 2024	Vietnam National University	Economics and Law	Cogent Economics & Finance	2024	Vietnam	Ho Chi Minh City
Makhloufi, 2025	Ecole Polytechnique d'Architecture et d'Urbanisme	Architecture and Urban Planning	Cities	2025	Algeria	Algiers
Ozge Subası & Turk, 2024	Istanbul Technical University	Urban and Regional Planning	Journal of Urban Planning and Development	2024	Turkey	Istanbul
Rao & Biswas, 2025	Indian Institute of Technology Roorkee	Urban and Regional Planning	International Journal of Housing Markets and Analysis	2025	India	Lucknow
Tattersall & Iveson, 2024	University of Sydney	Geosciences	International Journal of Urban and Regional Research	2024	South Africa	Cape Town
Zhao & Zou, 2025	Zhejiang University	Public Affairs	Cities	2025	China	Hangzhou

Table 1: Specifications of the included articles

4 RESULTS

4.1 Algiers, Algeria: The State-Led Rental-Sale Model

Algeria employs a top-down, state-driven model to address its housing shortage. The rental-sale program, managed by the Housing Improvement and Development Agency (AADL), targets middle-income households. It is a structured pathway to homeownership where beneficiaries pay 10% upfront, 15% upon completion, and the remainder in monthly installments over 20 years. This program is part of a broader strategy that includes slum eradication and caters to different income groups (low, middle, high) through various housing types. The new town of Sidi Abdallah, located on the near periphery of Algiers, built with the help of international contractors like China State Construction & Engineering Corporation (CSCEC), is a prime example of this large-scale, industrialized approach.

4.1.1 Strengths

The program's primary strength is its scale and state capacity. It has demonstrably delivered a vast number of housing units and contributed to the near-elimination of slums in major urban areas. The income-graduated system provides a clear, bureaucratic framework for targeting different socioeconomic groups. For middle-income families, it creates a viable, state-backed path to homeownership that the private market may not offer.

4.1.2 Weaknesses/Critique

Quality vs. Quantity: The model prioritizes quantitative output (units built) over qualitative outcomes. As the study's survey reveals, a significant majority of residents (61%) were unsatisfied with their units, citing poor workmanship and construction defects. This highlights a critical gap between housing as a product and a home.

Homogenized Urbanism: The mass production of identical blocks of flats has created monotonous environments lacking the vibrancy and amenities of older neighborhoods. This has led to a spatial mismatch, where residents (20% in the survey) still commute to the city center, 25 km away, for work, healthcare, and social life.

Financial and Data Gaps: The model relies heavily on state oil revenue, making it less replicable in fiscally constrained contexts. Furthermore, its eligibility criteria are based on outdated income data, raising questions about whether the housing remains truly affordable for the intended middle-income group.

4.2 Bahir Dar, Ethiopia: The Facilitated but Unaffordable Cooperative Model

In Ethiopia's state-owned land system, the government in Bahir Dar acts as a facilitator. It provides land at a subsidized benchmark price to self-help housing cooperatives, leveraging collective community action. The policy is detailed in regional regulation 9/2013 to promote affordable housing for low- and middle-income urban residents, outlining cooperative size, member eligibility (e.g., no prior home ownership), land plot sizes (100-150m²), and building standards (G+1 villa house: a building consisting of a ground floor and one additional floor). Between 2014 and 2022, this scheme allocated land to over 31,000 cooperative members.

4.2.1 Strengths

The scheme has been remarkably effective as a land distribution mechanism. It has formally allocated plots to a large number of people, demonstrating the potential of cooperatives to organize demand for housing.

4.2.2 Weaknesses/Critique

Fundamental Unaffordability: The core finding of the study is that the scheme fails the test of affordability. By shifting all financial risks (land compensation, full construction costs, infrastructure) onto the members, and coupling this with the high-cost mandate of a G+1 villa, the policy prices out the very low- and middle-income groups it was designed for. This is a classic case of a policy being designed for affordability but implemented in a way that makes it unaffordable.

Lack of Enabling Environment: The self-help model has become a cost-shifting exercise. Unlike historical Ethiopian models or contemporary examples in Kenya mentioned in the study, there is no government-backed housing finance. Members are left to rely on inadequate personal savings and high-interest informal loans.

Implementation Gaps & Corruption: Municipal delays in providing serviced land (up to 5 years) and corruption in member eligibility screening (using non-digital IDs that confirm the residency in the city for a minimum of 2 years) have severely undermined the program's equity and efficiency. The result is that less than 7,000 of the 31,000 who received land have been able to build homes, forcing many to sell their plots. This is a devastating indictment of the program's effectiveness.

4.3 Cape Town, South Africa: The Insurgent Prefigurative Movement-Led Model

In Cape Town, when formal strategies (through litigation and protest) failed to stop the sale of prime public land for affordable housing, Reclaim the City (RTC), a new social movement of Black working-class and poor communities fighting to reverse apartheid-era spatial segregation, shifted to prefigurative politics. In 2017, they occupied two vacant provincial buildings in the inner city, turning them into live-in models of the affordable housing they demanded. This action was part of a constellation of people power strategies, used alongside legal challenges and mass mobilization.

4.3.1 Strengths

Prefigurative action proved to be a uniquely powerful tactic. It provided immediate, direct relief to those in housing stress, demonstrated concretely that inner-city affordable housing was possible, and created organizing spaces that built community and sustained the movement. The combination of strategies proved effective, leading to the City identifying affordable housing sites and, crucially, a 2020 court ruling that set aside the land sale and affirmed the government's duty to address apartheid spatial planning.

4.3.2 Weaknesses/Critique

This strategy is highly demanding and precarious. Sustaining the occupations required immense effort from residents and institutional backing (from partner NGO Ndifuna Ukwazi which means 'dare to know' and called for the inner-city land to be converted to state-owned public housing rather than the sale). The participatory, non-hierarchical governance model was vulnerable to internal tensions and violent external pressures, including two murdered residents in 2017. The movement's gains are also vulnerable to political shifts, as progress stalled when supportive politicians resigned. While a powerful form of resistance and advocacy, it is not a scalable model for mass housing production on its own. It is most effective as a tactic to force state action, not as a substitute for it.

4.4 Lagos, Nigeria: The Informal Demand-Side Adaptation Strategies

The study of Logos experience takes a radically different approach by analyzing the demand side – the informal strategies of the urban poor themselves. Through interviews in five major Lagos slums, the researchers document how residents house themselves despite state neglect. Key findings include the prevalence of rental housing (82.5%) and shared apartments (7.5%), extremely low and irregular incomes (90% earn < US$30/month), strong economic ties to their settlement location, reliance on community savings groups (87.5% membership), and the use of incremental building.

4.4.1 Strengths

The primary strength of the case of Logos is its empirical grounding in lived reality. By quantifying the actual income and expenditure of the target population, it provides a stark reality check for formal policies. The findings and recommendations – prioritizing rental housing with daily/weekly payments which are more realistic for the urban poor, supporting livelihoods through existent savings group and microcredit institutions, and adopting alternative housing approaches such as incremental housing (by use of cheaper construction materials) and shared housing (as convertible homes and hostels) – are not abstract theories but are derived from proven, working strategies. This experience identifies the raw materials for a genuinely pro-poor housing policy.

4.4.2 Weaknesses/Critique

The study of the Lagos experience is diagnostic and prescriptive but does not deeply explore the complexities of implementation. How can a government institutionalize an informal savings group without destroying its trust-based, flexible nature? How can technical support for incremental building be provided without triggering gentrification? This case successfully identifies what needs to be done but is less detailed on the how – the intricate political and administrative work required to integrate informal systems with formal state structures without breaking them or enabling co-optation.

Aspects/Cases	Algiers, Algeria	Bahir Dar, Ethiopia	Cape Town, South Africa	Lagos, Nigeria
Main Approach	Top-down State-Provision: The state is the primary provider, financier, and developer. It aims at mass production and homeownership for the middle class through a structured formal market mechanism (rental-sale).	State-Enabled Collective Self-Help: Government creates a policy framework (land at benchmark price) for citizens to form cooperatives and help themselves. Places the financial burden and construction risk on the cooperative members.	Bottom-up Insurgent Making: A social movement confronts the state by creating a concrete micro-utopia (housing occupation) to directly challenge exclusionary land use and demand policy change. The approach is pragmatic, using direct action when formal channels fail.	Bottom-up Informal Adaptation: The urban poor are active agents who have developed their own solutions (incremental building, informal finance) outside the formal system. The study advocates for the state to learn from and build upon these strategies.
Role of the State	Primary Provider & Regulator: The central actor in funding, building, and managing the program. The state‘s role is dominant and essential to the model‘s functioning.	Facilitator & Enabler: Provides the policy and land, but shifts the financial burden entirely to members. The state is the gatekeeper of land but fails to provide essential financing or timely delivery.	Adversary & Target: The movement opposes the state‘s (including provincial governments) actions (selling public land) and demands it become a social housing provider. The state is the target of protests, occupations, and litigation.	Absent or Hindering: Formal policies are seen as ineffective or irrelevant. The study argues the state should shift from control/provider to partnership by learning from informal practices.
Target Population & Affordability Definition	Middle-Income: Strictly defined by monthly income bands (1.5 to 6 times the minimum wage). Affordability is about matching a fixed, subsidized price to a fixed income bracket.	Low- & Middle-Income: Targeted by policy, but the critical finding is the scheme is unaffordable for most. High costs of land compensation and construction, coupled with a total lack of accessible housing finance, exclude the intended beneficiaries.	Low-Income & Black Working-Class: Affordability is defined by the lived experience of housing stress, spatial exclusion (apartheid legacy), and the threat of displacement. The movement directly challenges the state and market‘s exclusionary logic.	The Urban Poor: The study reveals their actual affordable threshold is <$9/month, a figure far below any formal scheme. Affordability is defined by extreme income precarity (90% earn <$30/month).
Land Acquisition	State-Allocated: The state provides land for the Housing Improvement and Development Agency (AADL) projects. The cost is integrated into the final price paid by the beneficiary over	Government-Allocated at Benchmark Price: Land is the key state contribution, but members must pay for it indirectly through compensation fees for previous users. A critical	Contentious Occupation: Land is acquired by physically reclaiming vacant public property. This illegal but politically powerful tactic directly challenges the state‘s land use priorities and exposes	Informal & Market-Based: The poor access land in unserviced, hazardous peri-urban areas (swamps, peripheries) because it‘s all they can afford. They have strong economic ties to these locations, living and

Aspects/Cases	Algiers, Algeria	Bahir Dar, Ethiopia	Cape Town, South Africa	Lagos, Nigeria
	20 years. The user doesn't directly negotiate for land.	bottleneck is multi-year delays (up to 5 years) in getting serviced plots.	under-used public assets in the wealthy inner city.	working within them.
Financing & Construction	Structured Long-Term Payment: The state provides a 20-year payment plan. The household pays 25% upfront (10% pre-construction, 15% on completion) and the rest in monthly instalments. Construction is done by large contractors (e.g., China State Construction & Engineering Corporation: CSCEC).	Member-Financed & Built: This is the critical failure point. Members must save 50% of construction costs before getting land and then cover all costs. No state-backed mortgages or affordable finance options exist. This leads to very low construction rates (<7,000 out of 31,596 plot recipients built homes).	Sweat Equity & Community Governance: Residents maintain the building and govern the space themselves. The key output is not just the physical space but a new model of community-led housing governance, which they propose to the city as an alternative to top-down, bureaucratic management.	Incremental & Shared: The poor build in stages (incremental housing) as money allows. They use cheaper materials (wood), share housing with family, and prefer daily/weekly rent. Community savings groups (thrifts, cooperatives) are their primary and most effective financing tool.
Main Challenges	- Poor build quality and monotonous urban design in new towns like Sidi Abdallah. - Balancing the speed of mass production with quality of life for residents. - Financialization of housing potentially undermining broader social goals.	- Policy is fundamentally unaffordable for its target group due to hidden costs (land compensation). - Corruption in member selection. - Extreme delays in delivering serviced land (up to 5 years). - Complete lack of accessible housing finance for members.	- State repression and continuous legal challenges. - Internal conflicts and violence within occupied spaces. - The resource-intensity of sustaining long-term occupations. - Vulnerability to shifts in the political landscape (e.g., resignation of supportive mayor).	- Extreme poverty and income insecurity (90% earn <$30/month). - Mismatch between formal housing products (homeownership) and the needs/capacity of the poor (need rental <$9/month). - Lack of formal finance and secure land tenure.
Outcomes & Effectiveness	High Output, Mixed Satisfaction: Successfully delivered thousands of units, contributing to significant slum reduction. However, resident satisfaction is low (avg. 2.85 of 4) due to quality and design issues. The product is delivered, but is it a good place to live?	Quantitative Success, Qualitative Failure: The policy successfully transferred land to over 31,000 members. However, it failed in its core mission of creating affordable housing. Most plots lie empty, members cannot afford to build, and many are forced to sell.	Political & Policy Wins: The occupation forced the city to identify and zone specific sites for affordable housing. It stalled the sale of large piece of inner-city public land (Tafelberg) and won a court case affirming the state‘s duty to reverse apartheid spatial planning. It created a sustained political force.	Identifies a Viable Policy Alternative: The study provides a powerful demand-side critique. It identifies realistic affordability parameters (rent <$9/month) and highlights the potential of incremental housing and informal savings. It argues for formalizing, not replacing, these strategies.
Critical Analysis	The Commodification vs. Quality Tension: The program successfully financializes housing for the middle class but struggles with the quality of life and urbanism it produces. This shows the limits of a purely quantitative, state-driven production model.	The Policy-Reality Gap: The experience is a stark critique of a well-intentioned policy that is blind to the economic realities of its target group. The self-help model becomes a burden, not a benefit, without financial support. It highlights a profound failure of policy design.	The Inside/Outside Tension: The movement successfully uses "outside" tactics (illegal occupation) to win "inside" concessions (policy changes, court rulings). However, maintaining the internal participatory democracy of the occupation is fraught with conflict and requires significant NGO support, challenging romanticized notions of autonomous movements.	The Formal/Informal Tension: The study makes a powerful case for a paradigm shift from replacing informality to learning from and building upon it. This requires a fundamental reorientation of the state‘s relationship with the poor, from control to partnership.
Reference	Makhloufi, 2025	Adigeh & Abebe, 2024	Tattersall & Iveson, 2024	Akinwande et al., 2024

Table 2: Comparative Analysis of planning and policy on affordable housing in African cities

5 CONCLUSION

The challenge of affordable housing in emerging and developing economies including African countries cannot be resolved by singular, ideologically pure approaches. The diverse experiences of Algiers, Bahir Dar, Cape Town, and Lagos collectively demonstrate that effective strategies must move beyond false dichotomies – state vs. market, formal vs. informal, ownership vs. rental – and instead forge a hybrid path that strategically combines the strengths of multiple actors and processes. This path rests on four following foundational pillars:

(1) Successful approach must be grounded in the lived reality of the urban poor. Policy must begin not with idealized housing standards or financial models, but with a deep, empirical understanding of what the target population can actually afford. As the Lagos study starkly reveals, when formal mechanisms ignore the

precarious, often daily, incomes of the poor (in this case, less than $9 per month for housing), they become fundamentally inaccessible. Policy must therefore recognize and enhance, rather than replace, the sophisticated informal strategies of incremental construction, shared housing, and community-based savings that the poor have already invented.

(2) Land is a necessary but insufficient condition for affordable housing; it must be integrated with enabling financial mechanisms. The Ethiopian experience serves as a tragic cautionary tale: providing land without a concurrent strategy for housing finance is not a policy, but a transfer of unbearable risk. It creates a class of plot-holders who cannot build. In contrast, the Algerian model demonstrates the power of the state to provide structured, long-term finance that aligns with household income, transforming tenants into owners. The critical lesson is that land and finance cannot be siloed; they must be designed as an integrated system.

(3) The state is an inescapable actor whose role must be reimagined, not retreated from. Across all cases, the state is central – as builder (Algiers), enabler (Bahir Dar), target (Cape Town), or absentee (Lagos). No amount of community self-help can substitute for its capacity to act at scale. However, the state must evolve. It must move from imposing rigid, top-down products to supporting housing as a dynamic social process. It must build the capacity for responsive listening, flexible implementation, and accountable partnership with social movements and community organizations. As Cape Town's pragmatic prefiguration shows, an adversarial state can be forced to change through a constellation of people power strategies – combining litigation, mobilization, and the physical demonstration of alternative possibilities.

(4) Housing is fundamentally an act of urbanism, not just shelter provision. The location, quality, and liveability of housing are as important as its existence. The dissatisfaction of residents in Algiers' new towns and the struggle of Cape Town's movement for inner-city land underscore that peripheral housing, no matter how cheap, imposes costs in time, dignity, and opportunity that undermine true affordability. Effective policy must integrate housing with transport, services, employment, and thoughtful urban design.

In conclusion, affordable housing in emerging and developing economies requires a new kind of urban planning – one that is humble enough to learn from the informal, courageous enough to confront unjust structures, and pragmatic enough to combine the scale of the state with the energy of its citizens. The goal is not a blueprint, but a framework: a hybrid approach that empowers the poor, enables the state, and ultimately, reimagines the city as a place of justice and belonging for all.

Future research must move beyond siloed analyses to investigate integrated land-finance policy models, comparing outcomes for households that receive land with and without accompanying financial mechanisms. Researchers should document and analyze informal systems as intelligence, conducting ethnographic studies of incremental building, community savings, and shared housing to understand how these strategies can be enhanced rather than replaced by formal policy. The concept of pragmatic prefiguration requires comparative investigation across housing movements to understand when and how occupations, community experiments, and constellations of people power successfully force state transformation. Multidimensional affordability frameworks must be developed and tested, integrating shelter costs with transportation, employment access, and residential satisfaction. The state's multiplicity of roles demands comparative institutional analysis to explain why some states enable, others obstruct, and still others are forced to change, identifying the conditions under which productive state-society synergy emerges. Finally, longitudinal studies tracking households over time through incremental construction, policy interventions, and movement participation are essential to understand the dynamic processes that determine whether housing strategies succeed or fail – moving beyond static snapshots to capture housing as a temporal process.

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reviewed paper

An Analysis of the Role of Spatial Planning in Enhancing Rural Resilience to Flooding: A Case Study of South Africa

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1 ABSTRACT

In developing countries, human settlements are increasingly becoming more vulnerable to high flood risks and damages, especially those who are situated near rivers, flood-prone areas, and at low elevations. Correspondingly, South Africa is one of the developing countries that often experience devastating impacts of climate-related disasters, such as significantly heavy rainfall-induced flooding. However, floods persist, repeatedly affecting the residents despite the existing mitigation measures such as spatial planning. In addressing these ongoing challenges, this paper aims to analyse the effectiveness of spatial planning in enhancing rural resilience to flooding in South African rural areas and identify opportunities for improvement. Using a mixed methods approach, the role of spatial planning in enhancing rural resilience to flooding is assessed in relation to spatial development and flood risk management of rural areas in South Africa. Findings highlight that spatial planning frameworks in rural areas often lack clear consideration of flood risks, resulting in increased vulnerability. Most rural areas are situated in areas that are vulnerable to flooding, highlighting the necessity for enhanced planning. Limited and poor infrastructure provision in rural areas also hinders rural resilience to flooding. This paper recommends the incorporation of flood risk management into spatial planning frameworks, enhancing green infrastructures, raising awareness among residents about flood risks, and promoting collaborative spatial planning. This paper emphasises the necessity for incorporating spatial planning and flood risk management in rural South Africa, contributing to more rural resilience and sustainable rural development.

Keywords: Flooding, Flood Risk Management, Rural Areas, Rural Resilience, Spatial Planning

2 INTRODUCTION

In developing countries, human settlements are more vulnerable to flood disasters due to the combined consequences of climate change, rapid land-use change, and socioeconomic vulnerabilities (Ananwa, 2023). In South Africa, rural communities located near rivers, low-lying areas, and flood-prone areas are particularly at risk, frequently sustaining repeated flood damage with limited ability to adapt and recover (Chakwizira et al., 2021). Worldwide, flood damages and risks are increasing as climate change increases the frequency and severity of heavy rainfall events, leaving pressure on both urban and rural communities (Raphela, 2025). In South Africa, rural human settlements are increasingly vulnerable to flooding due to inadequate infrastructure delivery, a lack of adaptability, and underfunded institutions (Ampofo et al., 2024). To address the increasing flood risks and damage, researchers and policymakers have devoted substantial focus to flood risk reduction and climate adaptation strategies, notably on governance arrangements and planning tools employed to manage development in areas vulnerable to flooding (Loschner, 2020). Among these planning tools, spatial planning is commonly known as a main mechanism for preparing for flood risk and shaping land use patterns in a way that minimises exposure and long-term vulnerability (Roosimagi, 2021). Spatial planning is a tool that can play a critical role in prevention and transformation in flood risk management through guiding settlements in areas that are feasible for residing, regulating land use, and incorporating environmental challenges into development decision-making (Kodag, 2022). Existing literature largely conceptualises spatial planning as a technical and physical intervention tool, mainly concentrating on spatial design measures such as buffer zones, flood-resistant building standards, and stormwater management systems (Meng, 2020). Although these approaches are essential for flood resilience, they tend to overlook the governance, political, and institutional aspects of planning that shape how such tools are enforced in practice. Consequently, limited focus has been given to how spatial planning systems, decision-making processes, and

institutional capacity influence flood resilience outcomes, especially in areas characterised by poor resources and weak governance. In addition, flood risk management research persistently focuses much on urban areas, with rural areas receiving limited scholarly attention despite facing persistent exposure to flooding, poor infrastructure investment, and poor planning and governance systems. This gap is particularly evident in South Africa, where flooding is the most frequent and damaging natural disaster. Between 2000 and 2016, floods accounted for nearly 42% of all natural disasters worldwide and 35% of those recorded in South Africa (EM-DAT, 2017). In South Africa, rural areas mostly operate under complex land tenure arrangements, poor technical capacity, and fragmented institutional responsibilities, conditions that cater to an urban-centred planning model that cannot address rural areas flood vulnerability.

South Africa exemplifies the aforementioned challenges. The country experiences recurring flood risks and damages due to the combination of climatic stressors, historical spatial planning inequalities, and continuing institutional and governance challenges (Raphela, 2025). Provinces in South Africa, such as Limpopo, KwaZulu-Natal, North West, and the Eastern Cape, are disproportionately affected by more extensive flood risks due to a combination of geographic and government-related weaknesses, and limited adaptation capacity (Munyai et al., 2021). Despite spatial planning being formally known as a vital mechanism for enhancing flood resilience, many rural municipalities struggle to translate planning regulations into efficient flood risk reduction practices due to weak inter-sectoral collaboration and poor incorporation of flood risk consideration into land use decision-making (Munyai et al., 2021). As a result, flooding continues to have impacts on rural settlements repeatedly, raising questions about the effectiveness of existing spatial planning techniques. Despite the growing recognition of spatial planning as the main mechanism for flood risk management, there is limited empirical knowledge about how spatial planning is being implemented in rural South African contexts, the institutional challenges that hinder its effectiveness, and the extent to which current spatial planning frameworks support rural flood resilience. This signifies a vital gap in the literature, especially considering the accelerating climate change impacts and the disproportionate vulnerability in rural human settlements. Addressing these challenges, this study aims to analyse the effectiveness of spatial planning in enhancing rural resilience to flooding in South Africa.

3 LITERATURE REVIEW

3.1 Climate change and flooding in developing countries

Worldwide, flooding is known to be one of the most frequent and catastrophic natural disasters, emerging when water temporarily overwhelms normally dry land due to heavy rainfall, river overflow, or inadequate drainage systems (Ran & Nedovic-Budic, 2016). This statement simply emphasises that globally, floods affect more residents than any other type of natural disaster. UNISDR (2018) reported that floods are the most frequently reported natural disasters, repeatedly affecting a large number of people. According to the United Nations (2015) and Abdrabo et al. (2020), between 1995 and 2015, floods were reported to be 43% of all natural disasters, impacting over half of the residents experiencing any other natural disasters and resulting in more than a quarter of all disaster-related deaths. As mentioned above, climate change continues to increase the flood risks by increasing the frequency and severity of heavy rainfall events, leaving pressure on both urban and rural communities (Raphela, 2025). Worldwide, between 2000 and 2022, floods resulted in inflation-adjusted economic loss equal to US$929 billion, illustrating 3852 floods (Centre for Research on the Epidemiology of Disasters (DRED, 2023). In South Africa, floods and storms are the most frequent natural disasters, resulting in 71.2% of the total disasters in the country (CRED, 2023). In the Global South, flood risks and damages are intensified by structural and socioeconomic aspects, encompassing inadequate infrastructures and weak governmental regulations, and unplanned rural settlements that usually encroach on natural floodplains (Nuissl, 2020). According to Liu (2024), globally from 1990 to 2022, 168 countries experienced 4,713 flood events, impacting more than 3.2 billion residents, resulting in over 218, 000 deaths, and economic losses exceeding $1.3 trillion. Africa continues to be vulnerable to flooding, experiencing the third-highest proportion of global flooding events and associated deaths (Hamidifar and Nones, 2021). In 2024 alone, floods impacted over 8.5 million residents and claimed more than 1,460 lives across 20 countries in West and Central Africa, emphasising the combined impacts of climate variability and inadequate infrastructures (Ramadane, 2024). These flooding statistics highlight that flooding is not only a repeated environmental disaster but also a pressing developmental and governance challenge, especially in areas with limited adaptive capacity.

3.2 Role of spatial planning in flood risk management

Spatial planning is known as a process in which public and private sectors influence the spatial allocation of activities, people, and land uses to guide long-term development outcomes (Roosimagi, 2021). In addition to oversight, spatial planning signifies a coordinated and strategic approach aimed at shaping spatial patterns of settlement growth to enhance resilience, efficiency, sustainability, and safety of human settlements (Thistlethwaite, 2019; Roosimagi, 2021). This has placed spatial planning as a possible vital tool in addressing complex environmental risks and damages, including flooding. Considering flood risk management, spatial planning is known as a preventive tool that can minimise exposure by directing human settlement developments away from areas vulnerable to flooding and incorporating environmental challenges into land use decision-making (Ran, 2016). Spatial planning operates proactively by directing where and how human settlement developments should occur, unlike structural flood control tools such as dams, levees, and drainage systems, which minimise flooding probability but cannot fully stop risks and damages (Sayers et al., 2013; Thistlethwaite, 2019). Therefore, it plays an enhancing role in engineering-based interventions by tackling the fundamental drivers of flood vulnerability. Notwithstanding the recognised capability, the literature repeatedly emphasises major challenges in translating spatial planning principles into successful flood risk management practice. One of the most commonly quoted challenges is the weak collaboration and communication among spatial planning officials and flood risk management institutions, which usually work within incoherent government systems (Ran & Nedovic-Budic, 2017). This institutional disconnect is worsened by varying professional viewpoints, with town planners and flood risk officials mostly holding contrasting perspectives on the role and scope of spatial planning in enhancing flood risk (Solin, 2023). These issues are overlooked and threaten the incorporation of flood risk consideration into spatial development processes and minimise the effectiveness of planning interventions. The mutual reliance between spatial planning and flood risk management highlights the necessity for more integrated mechanisms that correspond to spatial planning, environmental management, and governance processes (Ran, 2016). Effective spatial planning needs to balance environmental, social, and economic aspects while concurrently tackling the current vulnerabilities and hindering the creation of new risks and damages (Thistlethwaite, 2019). Incorporating flood risk management into spatial planning regulations is therefore vital for minimising long-term exposures and enhancing the rural resilience and sustainability of human settlements. These challenges are frequently seen in Africa, where flooding is the most common natural hazard and usually leads to notable loss of lives, property damage, and disturbance of livelihoods (Cilliers, 2019). Under these circumstances, spatial development planning has a vital role in hindering unsuitable settlement development in areas that are vulnerable to flooding and supporting disaster risk reduction efforts. When executed correctly, spatial planning can contribute not only to minimising flood risks and damages but also to addressing social vulnerabilities and reinforcing societal resilience to flooding (Priest et al., 2016; McEwena et al., 2018).

4 APPROACH AND METHODOLOGY

An exploratory research design was adopted in this study to allow for a flexible and in-depth examination of the role of spatial planning in enhancing rural resilience to flooding in South Africa. This design is particularly suitable for gaining new insights, clarifying concepts, and identifying patterns, relationships, or factors influencing complex phenomena (Saunders, Lewis, & Thornhill, 2019). The study employed a mixed-methods research approach, integrating both quantitative and qualitative techniques to provide a comprehensive understanding of the research problem. Mixed methods research is especially valuable for addressing complex issues that cannot be sufficiently explored through a single methodological approach (McLeod, 2024). The quantitative component focused on collecting data related to flood risks, infrastructure availability, and spatial planning indicators, while the qualitative component involved semi-structured interviews with town planners to explore perceptions of flood risk, the effectiveness of spatial planning interventions, and barriers to implementation. A random sampling technique was used to select South African residents for the quantitative survey to ensure representativeness, while purposive sampling was employed to select town planners with relevant expertise for the qualitative interviews. Data analysis involved the use of descriptive statistical tools, including SPSS and Microsoft Excel, for quantitative data, while qualitative data were analysed using thematic analysis to identify recurring themes and patterns. Ethical considerations were rigorously observed throughout the study. Participants were fully informed about the purpose of the research and assured that they would not be deceived in any way. Participation was

entirely voluntary, and respondents were informed of their right to withdraw from the study at any stage without any consequences. To avoid coercion or undue influence, participants were provided with adequate information to make informed decisions and were allowed to ask questions and seek clarification regarding any aspect of the study.

4.1 Data Collection Methods

Data collection refers to the systematic process of gathering, evaluating, and analysing accurate information using established and validated research methods (Mazhar, 2021). This study employed both primary and secondary data sources to ensure a comprehensive and well-rounded analysis of the role of spatial planning in enhancing rural resilience to flooding in South Africa. Primary data were collected through surveys, interviews, and field observations. Secondary data were obtained from policy documents, local government reports, and existing scholarly studies related to spatial planning, flooding and rural resilience.

4.2 Survey Questionnaires

A questionnaire is a research instrument used to collect data through a structured series of questions (Hussain, 2022). In this study, structured survey questionnaires comprising both closed-ended and open-ended questions were used to collect data from South African residents living in rural areas vulnerable to flooding. The mixed question format allowed for the collection of both quantifiable data and contextual insights. A total of 20 questionnaires were distributed to participants residing in flood-prone rural areas. Each questionnaire was designed to take approximately 5–10 minutes to complete.

4.3 Interviews

Interviews are a qualitative data collection method that utilises open-ended questions to obtain in-depth information from participants (George, 2022). Semi-structured interviews were conducted with five town planners, selected due to their role in spatial planning and flood resilience in both rural and urban contexts. The semi-structured format enabled flexibility, allowing participants to elaborate on their experiences, perceptions of flood risk, the effectiveness of spatial planning measures, and challenges in implementation. Each interview was expected to last between 10 and 15 minutes.

4.4 Literature Sources

A comprehensive review of existing literature was conducted to establish a strong theoretical and contextual foundation for the study. This review focused on spatial planning, rural resilience, flooding, land-use planning, and climate change at global, national, and local levels. Key policy documents, including the Spatial Planning and Land Use Management Act (SPLUMA, 2013), Spatial Development Frameworks (SDFs), and Integrated Development Plans (IDPs), were analysed to understand the role of spatial planning in enhancing rural resilience to flooding in South Africa. Additionally, the study was framed within the existing research on theoretical viewpoints in land-use planning, rural resilience, flooding and climate change found in academic literature.

5 RESEARCH FINDINGS

5.1 Flood experience among residents

The findings highlight that flooding is a common experience among most of the participants. The majority of respondents, 83%, stated that they have been exposed to flooding in their communities, while only 17% highlighted that they have not. The absence of “not sure” responses highlights that participants were confident about their responses, emphasising the tangible and memorable nature of flooding events within their communities in South Africa. The majority of affirmative responses emphasise the repeated occurrence of flooding in the study area and confirm that flooding is a common and lived challenge for residents who stay in rural communities. These results further highlight the need for effective flood risk management and spatial planning intervention, as flooding is not a hypothetical risk but a repeated reality impacting most of the residents in rural communities in South Africa, mostly those who reside in areas vulnerable to flooding or low-lying areas.

5.2 Frequency of flood occurrence

The following figure shows that flooding occurs with different regularity in the study area. Half of the participants (50%) reported that they experience flooding every year due to heavy rainfall, highlighting that flooding is a common and recurring event for a significant portion of rural South Africa. About one third of participants (33%) experience flooding occasionally throughout the year, highlighting irregular but still noteworthy exposure to flooding events. 17% reported that they experience flooding rarely, highlighting that a smaller portion of the rural South Africa population faces infrequent flood events. Overall, the data shows that flooding is the most frequent natural disaster in South Africa, with most of the rural communities' residents affected regularly, emphasising the necessity for robust flood risk management and resilience strategies.

5.3 Impacts of flood encountered

The figure below highlights that housing damage during flooding is the most major impact of flooding, affecting 50% of the participants. This emphasises that human settlements in rural areas are highly developed in areas that are vulnerable to flood events, possibly because of weak construction materials used or the location in flood-prone areas and poor infrastructure, such as drainage systems. The loss of crops and livestock is reported to be the second most common impact in rural South Africa, reported by 33.3% of participants. This shows that the negative impacts of flooding on agricultural livelihoods and food security are particularly significant for households that rely on farming and livestock rearing. Displacement of residents affected 16% of the participants, highlighting that fewer households had no choice but to relocate due to flooding, causing damage to living arrangements and community stability. Notably, no participants reported health problems or loss of income (0%). This may highlight effective coping mechanisms and timely evacuation. Overall, the results highlight that flood impacts were primarily physical and livelihood-related, with housing and agriculture being the most affected aspects.

5.4 Challenges of flooding in South Africa

5.4.1 Settlement Patterns in Flood-Prone Areas

The results highlight that settlements developed in areas vulnerable to flooding are strongly affected by land allocation, poor awareness, and weak governmental challenges. All surveyed participants (100%) stated that they were not informed about flood risks and had no idea that they were being placed in flood-prone areas before residing in their respective communities. This shows an urgent gap in risk communication and public awareness about the flood risks, highlighting that flood risk information is not effectively shared with residents before settlement decisions are made. The responses further highlight that the lack of knowledge is a main issue contributing to continued residential development in flood-prone areas. As highlighted by one resident, due to an absence of information pertaining to flood risks, it hinders residents' ability to make informed settlement choices (Resident 16, 2026). This result emphasises that the tribal authorities in rural communities continue to allocate land in areas that are vulnerable to flooding, leaving residents being the ones to experience the challenges. Viewpoints from town planners point to systemic and governmental challenges within spatial planning and human settlement delivery processes. Backlogs in the delivery of properly demarcated and serviced human settlements have resulted in residents settling in available land despite flood risk and damage exposures (Town Planner 1, 2026). This scenario is worsened by repeated housing delays, which drive communities to prioritize having shelters rather than considering their safety. Additionally, it emphasises that municipal planning priorities are more focused on urban areas, leaving rural communities with limited planning support and awareness initiatives. According to Town Planner 3 (2026), weak spatial planning practices in local municipalities, lack of land for development, and poor community awareness programme lead to the continued allocation of stands in flood-prone areas. This shows a broader spatial inequality between rural and urban areas in South Africa. The role of tribal authorities was also mentioned as one of the major aspects influencing settlement patterns in areas that are vulnerable to flooding. Town Planner 4 (2026) emphasised that tribal authorities often lack adequate knowledge of environmental buffers and disaster-prone areas when they allocate stands to residents under their jurisdiction. This emphasises the disconnect among formal spatial planning, disaster risk management regulations, and customary land allocation practices, further exacerbating settlement vulnerability. Overall, this analysis shows that human settlement in flood-prone areas is not solely a result of individual choice but rather a

combination of poor awareness, poor spatial planning, inadequate governmental collaboration, and land scarcity. These results highlight the necessity for improved flood risk communication, stronger coordination among municipalities and tribal authorities, and proactive spatial planning intervention to avoid further human settlement in areas vulnerable to flooding.

5.4.2 Inadequate Integration of Flood Risk into Spatial Planning Frameworks

This paper found that flood risk management is poorly incorporated into rural spatial planning regulations, significantly restricting their effectiveness in minimising flood vulnerability. Spatial Development Frameworks and Land Use Schemes in most rural communities lack comprehensive flood risk assessments, up to flood hazard mapping, and clearly elaborated settlement development guidelines for areas vulnerable to flooding. This absence of risk-informed planning mechanisms leads to human settlement development decisions that do not adequately account for current and potential flood risks and damages. Therefore, spatial planning tools fail to effectively guide human settlement development away from high-risk areas or encourage adaptive land use practices such as controlled development, buffer zones, or flood-resilient human settlement patterns. Instead of spatial planning operating as a proactive and preventive mechanism, spatial planning regulations mostly respond reactively after flood events have already happened. This responsive approach threatens the core objectives of spatial planning in enhancing safety, sustainability, and resilience. Additionally, the results show a disconnect between spatial planning and disaster risk management regulations. Although there is the existence of national and local disaster management frameworks, their principles are not enforced within spatial planning tools at the rural community level. This poor incorporation results in recurrent flood challenges in rural communities, as human settlements continue to be exposed to flood risks without adequate preventive planning mechanisms. Overall, the paper emphasises the immediate necessity for incorporated, risk-sensitive spatial planning approaches that coordinate land use planning with flood risk management and climate change adaptation measures.

5.4.3 Poor Infrastructure Provision and Maintenance

The results of this study confirm that poor infrastructure provision and maintenance significantly challenge rural resilience to flooding. Survey findings highlight that 66.7% of participants have drainage infrastructure to help during flooding, while only 33.3% show the presence of some form of drainage infrastructure. This imbalance emphasises the widespread absence of basic flood mitigation infrastructure in rural areas and underscores the vulnerability of these communities to heavy rainfall events.

Inadequate drainage infrastructures increased flood impacts by allowing stormwater to accumulate within human settlements, exacerbating surface runoff and prolonging inundation periods. These results align with broader observations that infrastructure developments in rural communities commonly lag behind urban areas in both delivery and maintenance. Furthermore, poor infrastructure hinders access to essential services during flooding events in rural communities. Poorly maintained roads and the absence of stormwater systems impede mobility, delay emergency response, and restrict access to healthcare and markets. As a result, flooding not only leaves physical consequences but also threatens socioeconomic status, further minimising the adaptive capacity of rural communities. From spatial planning viewpoints, these results highlight a disconnect between human settlement development and infrastructure planning in rural areas. The absence of incorporated infrastructure planning within SDF undermines long-term sustainability and resilience objectives. Overall, the findings highlight the necessity for enhanced investments in rural drainage and stormwater infrastructure, alongside regular maintenance, to enhance flood resistance in rural areas and support sustainable rural development.

5.4.4 Weak Stakeholder Coordination and Governance

The paper highlighted that poor collaboration between key stakeholders undermines the effectiveness of spatial planning and flood risk management in rural communities. Coordination among town planners, disaster management officials, environmental officials, and local government departments is often weak, leading to fragmented planning processes and poor enforcement of flood resilience mechanisms. The absence of incorporated government structures, formal communication channels, and shared data systems further heightens these impacts, resulting in duplicated efforts in some areas while leaving critical policy gaps in others. This lack of collaboration not only limits the effective execution of flood mitigation strategies but also minimises the capacity of rural communities to benefit from available resources and expertise. For

example, without collaborative planning, disaster management units may enforce emergency approaches that are not aligned with spatial development priorities, while environmental officials may fail to protect natural flood buffers critical for minimising flood challenges. The results emphasize the need for strengthened intergovernmental and cross-sectoral coordination, including the establishment of shared information platforms, joint planning committees, and regular stakeholder engagement forums. By encouraging incorporated governance and cooperative decision-making, rural flood-prone areas can achieve more coherent spatial planning outcomes, enhancing overall community resilience to flooding.

5.4.5 Limited Community Awareness and Participation

Limited community awareness and participation emerged as a significant challenge affecting rural flood resilience. The findings indicate that many residents have insufficient knowledge of flood risks, early warning systems, and appropriate preparedness measures, which reduces their ability to anticipate, respond to, and recover from flood events. The lack of accessible and targeted risk communication in rural areas contributes to this knowledge gap, leaving communities unprepared for recurring flooding. In addition, community involvement in spatial planning processes is often minimal. Residents are seldom actively engaged in decision-making related to land-use planning, settlement development, and disaster risk management. This limited participation restricts opportunities to incorporate local knowledge and lived experiences into planning processes, which are essential for identifying context-specific flood risks and feasible adaptation strategies. When residents are not involved in planning decisions, they are less likely to understand, support, or comply with planning regulations and risk reduction measures. As a result, spatial planning strategies aimed at enhancing flood resilience become less effective and more difficult to sustain over the long term. Overall, the findings highlight the need for participatory and inclusive planning approaches that prioritise community awareness, education, and involvement as central components of rural flood resilience.

6 IMPLICATIONS AND RECOMMENDATIONS

The results of this paper have several implications for spatial planning in rural communities in South Africa. The repeated flood impacts highlight that the existing spatial planning approaches insufficiently consider environmental risks and damages. The town planners and tribal authorities must therefore prioritise flood risk assessment when allocating land uses to residents under their jurisdictions and approving developments, especially in rural and low-lying areas. This paper suggests a necessity for stronger implementation of spatial planning regulation and frameworks. Despite spatial planning regulations, their limited consideration of flood risks and poor enforcement contribute to continued human settlement in areas vulnerable to flooding. Municipal town planners must enhance compliance monitoring and make sure that planning decisions align with disaster risk reduction principles. Exacerbated heavy rainfall variability and extreme weather events require spatial planning regulations and policies that are flexible and responsive to changing climatic conditions. Spatial planning tools such as the Spatial Development Framework and Land Use Schemes should be regularly reviewed and updated to reflect the evolving flood risk and damage. The results suggest that infrastructure planning must be treated as a priority tool for spatial planning, rather than as a split sectoral mechanism. Inadequate infrastructure in rural communities exacerbates vulnerability to flooding, highlighting the necessity for collaborative planning among town planners, engineers, and disaster management officials. Also, the paper emphasises the need for an inclusive and collaborative spatial planning process. Weak community awareness of flood risks and damages shows a gap in public engagement. Spatial planning should then actively collaborate with rural communities to incorporate local knowledge and enhance preparedness and resilience to flooding. The results show that nature-based and green infrastructure resolution should be widely adopted in spatial planning decisions. Protecting wetlands, river buffers, and natural drainage systems can minimise flood risks and damages while supporting sustainable land use and environmental protection. Overall, these implications highlight that spatial planning in rural South Africa must be integrated, proactive, and resilient to effectively minimise flood vulnerability and support rural developments in South Africa.

Flood risk management should be incorporated into rural spatial planning frameworks and policies. SDF and LUS must explicitly identify areas that are vulnerable to flooding and restrict settlement development in high-risk areas. In areas where relocating is unfeasible, spatial planning frameworks and policies must enhance flood-resilient settlement patterns and implement development control measures that minimise

exposure to flood risks and damages. There is a need to enhance infrastructure development in rural communities, especially drainage systems, roads, bridges, and stormwater management infrastructure. Enhanced infrastructure will minimise flood impacts and enhance accessibility during and after flood events, thereby heightening the adaptive capacity of rural communities. Green infrastructure and nature-based solutions should be enhanced as part of spatial planning strategies to minimise flooding in rural communities in South Africa. Tools such as wetland restoration, riparian buffer zones, reforestation, and sustainable land management practices can minimise surface runoff, promote water absorption, and minimise flood risks while supporting environmental sustainability. Rural community residents should be educated about flood risks, early warning systems, and appropriate response strategies, and also enhance community awareness and participation. Participatory spatial planning processes that actively include local communities can enhance local knowledge incorporation and ensure that spatial planning interventions are socially acceptable and contextually relevant. Effective flood resilience needs collaboration among town planners, disaster management authorities, environmental officials, and local governments. Enhanced data sharing and governmental capacity building will support informed decision-making and the enforcement of incorporated flood risk management strategies.

7 CONCLUSION

This paper analysed the role of spatial planning in enhancing rural resilience in South Africa, with particular emphasis on settlement patterns, spatial planning regulation and policies, infrastructure delivery, and community involvement. The results present that flooding continues to be a lived reality for many rural communities in South Africa, with repeated challenges to housing, agriculture, livelihoods, and human settlement stability. Although formal recognition of spatial planning as the main mechanism for flood risk management exist, its practical effectiveness in rural communities remains weak. This paper shows that many rural communities persist in areas that are vulnerable to flooding due to limited awareness of flood risks and damages, poor incorporation of flood risk management into spatial planning regulations and policies and weak governance systems. SDF and LUS in rural local municipalities commonly lack detailed flood risk assessments and hazard mapping, leading to reactive rather than preventative spatial planning approaches. This weakens the capacity of spatial planning to guide safe human settlement development and minimise long-term flood vulnerability. Poor infrastructure delivery and maintenance further increase rural flood risks. The absence of effective drainage systems, inadequate road networks, and poor stormwater management infrastructure exacerbate the frequency and intensity of flood impacts and limit emergency response and recovery. This infrastructural impact shows broader spatial inequality among urban and rural communities and emphasises the necessity for incorporated infrastructure and land use planning.

This paper also identifies the poor collaboration among key stakeholders, including tribal authorities, municipal officials, and environmental and disaster management officials. This poor collaboration weakens the implementation of spatial planning regulations and hinders the effectiveness of flood risk reduction measures. Furthermore, limited community awareness and involvement in the spatial planning process limit local preparedness and weaken the sustainability of planning involvement. Overall, the paper results highlight that spatial planning in rural South Africa has major potential to enhance flood resilience, but it is currently hindered by institutional, infrastructural and governance impacts. Enhancing the incorporation of flood risk management into spatial planning, investing in resilience and green infrastructure, enhancing intergovernmental collaboration, and promoting inclusive and participatory planning processes are important to minimising rural flood vulnerability. By integrating a more proactive, incorporated and risk-sensitive spatial planning approach, rural South Africa can move towards greater resilience, safety, and sustainable human settlement development.

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An Assessment of the Clean Air Zones (CAZ) Implementation in Developing Contexts: Social Equity Report for the City of Johannesburg

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1 ABSTRACT

In the City of Johannesburg (CoJ), the proposed Clean Air Zones (CAZs) initiative, aligned with the C40 framework, promises substantial public health gains through air pollution reduction. However, without equity-centered design, CAZs risk deepening entrenched socio-economic disparities inherited from apartheid-era spatial planning. This study analyzes CAZ implementation pathways and their differential impacts across Johannesburg's seven administrative regions using datasets from the Gauteng City Region Observatory (GCRO), South African Census, and municipal reports. Five regulatory mechanisms comprising vehicle restrictions, solid fuel prohibitions, waste management formalization, industrial emission controls, and charging zones are examined through the lens of income inequality, service access gaps, spatial poverty, and environmental justice indicators. Findings reveal acute vulnerability concentrations: 71% of residents defaulting on utility bills cite unaffordability; 41% of Region G households experience meal-skipping; and declining service coverage (water satisfaction dropped from 79% to 59% between 2020/21-2023/24) compounds policy compliance capacity. A composite regional vulnerability matrix identifies Regions D and G as requiring priority equity interventions, while Regions B, E, and F demonstrate greater adaptive capacity. The study concludes that Johannesburg's CAZs must operationalize through phased geographic implementation, targeted subsidies for clean energy transitions, formalized inclusion of informal waste reclaimers, and participatory policy co-design with marginalized communities. This approach harmonizes environmental sustainability with social justice, advancing SDG commitments while preventing policy-induced displacement.

Keywords: Clean Air Zone (CAZ), Social Equity, C40, Environmental Justice, Vulnerability Assessment.

2 INTRODUCTION

The imperative to combat urban air pollution has mobilized cities globally toward Clean Air Zones (CAZs). Designated areas where vehicle emissions, solid fuel combustion, and industrial pollutants face stringent regulations to protect public health (Altarrazi et al., 2025; Bloss et al., 2025; Mebrahtu et al., 2025). As a C40 Cities member, Johannesburg has committed to implementing CAZs to address deteriorating air quality exacerbated by vehicle congestion, informal solid fuel use, and waste accumulation that undermines its "world-class African city" aspiration. Yet environmental policies designed without socio-economic analysis risk reproducing the very inequalities they claim to transcend (Druckman & Jackson, 2008).

South Africa's persistent inequality, rooted in colonial and apartheid spatial engineering, creates differential vulnerability to environmental regulation (Mashabela et al., 2025). Where European and North American CAZs operate within relatively robust social safety nets, Johannesburg must navigate a context where 48% of households depend on social grants, 11% default on utility payments, and informal economies provide survival mechanisms for populations excluded from formal employment (Götz & Seedat, 2024). In this landscape, policies restricting polluting fuels, informal waste picking, or high-emission transport without viable alternatives do not merely regulate environmental behaviour; they eliminate livelihood pathways and deepen material deprivation.

Recent research by Nabilla et al. (2025) through the Seriti Institute surveyed Johannesburg residents' perceptions of air pollution causes and health impacts, establishing public awareness of the CAZ rationale. However, this polling did not systematically assess households' capacity to comply with anticipated regulations or map vulnerability differentials across the city's socio-economic geography. This gap is critical: effective CAZ implementation requires understanding not whether residents support cleaner air, a near-universal preference, but whether they possess the economic resources, service infrastructure, and social capital to adapt to regulatory changes without catastrophic livelihood disruption.

This paper addresses that gap through socio-economic vulnerability assessment, analyzing how five CAZ regulatory mechanisms, vehicle restrictions, solid fuel prohibitions, waste management formalization, industrial emission controls, and charging zones intersect with Johannesburg's inequality landscape. Drawing on GCRO Quality of Life Survey 7 data (Tshuma et al., 2024), we map spatial patterns of income precarity, service access deficits, transportation dependence, and environmental injustice across the city's seven administrative regions. Our analysis reveals that CAZ regulations, if uniformly imposed, would function as regressive taxation on the urban poor, extracting compliance costs from populations least able to bear them while delivering environmental benefits disproportionately consumed by affluent communities already insulated from pollution exposure (Metheny et al., 2025).

The contribution of this study is threefold. First, we theorize the causal pathways linking CAZ regulations to household-level economic shocks, moving beyond correlation to a mechanism explanation. Second, we develop a composite regional vulnerability matrix synthesizing multiple deprivation indicators to guide geographically differentiated policy rollout. Third, we translate empirical findings into actionable implementation guidelines that harmonize environmental sustainability with social equity, demonstrating that these objectives, often framed as trade-offs, can be mutually reinforced through deliberate institutional design.

The urgency of this analysis extends beyond Johannesburg. As developing-world cities increasingly adopt environmental frameworks designed in Global North contexts, understanding adaptation requirements for settings characterized by informality, service deficits, and entrenched poverty becomes essential. Johannesburg's CAZ implementation will either demonstrate equitable environmental governance or reproduce colonial patterns where regulation serves affluent interests while criminalizing survival strategies of the marginalized. The evidence and framework presented here aim to ensure the former outcome.

3 LITERATURE REVIEW

Investments in environmental policies hold life-supporting potential in contemporary times due to the rapid environmental degradation. Despite their utility, inadequate assessment of their social costs could limit their effectiveness or even lead to social destabilization in societies. As governments strive to ensure that cities support healthy living, they must maintain social justice while doing so.

Cities around the world are implementing Clean Air Zones (CAZs) initiative, an embodiment of the global C40 framework for reducing air pollution and enhancing public health (Altarrazi et al., 2025; Bloss et al., 2025; Mebrahtu et al., 2025). Although this initiative is essential for ensuring urban resilience and environmental sustainability, if it is not properly planned and implemented in conformity with the socio-economic realities of the people, it risks exacerbating existing social inequalities. This is particularly true among South African cities, particularly Joburg, where deep-rooted social disparities continue to shape access to opportunities and resources (Metheny et al., 2025).

In the City of Johannesburg (CoJ), South Africa, the municipal government is trying to enhance city life through the implementation of the CAZ initiative. This need arises from the increasing erosion of public spaces by informal recyclers, homeless people, and the increasing waste accumulation in the city. Clearly, these emerging features negate the aspiration of Johannesburg as “a world-class African city”. To address this trend, public policies, particularly environmental policies in the city, must regulate pollution, waste management, and related urban activities that contribute to the current environmental challenges. While intervening policies in this regard are urgently necessary, such policies must consider the differing socio-economic disparities among the people. As posited by Druckman and Jackson (2008), without this consideration, developing inclusive policies for environmental sustainability and social justice could be difficult.

While the city, through a company, Seriti Institute, conducted a polling survey to aggregate residents' perception of the CAZ initiative (Nabilla et al., 2025), the focus was more on the causes and impacts of air pollution in the city than on the socio-economic realities of the people with the potential to impact the success of the initiative. This study extracts data on socio-economic indicators of people in the city of Johannesburg, mainly from the GCRO datasets, to assess the socio-economic realities of Joburgers and frame the implications of these on CAZ initiative implementation in the city.

4 METHODOLOGY

In conducting a socio-economic assessment of residents in CoJ, this study relied on existing data collected and analyzed by various government bodies in South Africa. Conducting this assessment using primary data could be more comprehensive but also resource-intensive. However, in the absence of budget coverage for this, existing data in documents such as the Gauteng City Region Observatory (GCRO) report (2024), South African Census Report, CoJ reports, etc., were adopted in assessing the prevailing socio-economic status of people living in the city to understand and adequately accommodate their needs and peculiarities in the programs of the city, particularly the implementation of the CAZ inititive. Five indicators relevant to the successful implementation of CAZ, while ensuring social equity and justice, were adopted. These indicators were: income and employment status, access to basic public services, spatial inequity as regards poverty and transportation, waste management, and social inclusion.

5 FINDINGS

5.1 Socio-Economic Indicators

In understanding the socio-economic life patterns of the people of CoJ, the indicators of income & employment, public service access, spatial inequality spread, environmental justice, and digital & social inclusion were adopted. It is based on these indicators that the subsequent sections of the report were discussed.

5.1.1 Income and Employment

Income is strategic to the conditions of living of households as it funds their daily and seasonal needs. Furthermore, it dictates the extent to which paid basic public services can be accessed. In economics, three levels of income earners exist. While there are high- and middle-income earners, there are also low-income earners. In the CoJ, a GCRO QoL Survey 7 explored the percentage of residents with unpaid utility bills (water/electricity) and the reasons for defaulting. In the survey (see Figure 1), it was found that 11% of respondents have unpaid utility accounts, with 71% reporting that they cannot afford to pay. Additionally, 14% respondents reported not knowing whether their household owes money for water or electricity (not shown in the graphs). In addition, the highest percentage of respondents with unpaid bills (22%) was recorded in Region D, highlighting significant affordability challenges in this area. Region B has the lowest proportion, at 4%, indicating fewer payment issues in this region. On average, therefore, 11% of residents in the city have unpaid utility accounts, with 71% of them citing an inability to pay as the reason for the default. This indicated a growing financial incapacity among residents of the city.

This financial condition could be explained by the rate of unemployment in the city (see Figure 2). For instance, 505 of the respondents sampled in the GCRO QoL Survey 7 were unemployed or not working for various reasons. Approximately 2% reported being appointed to a new job they had not started yet. Among those not working, over half (53%) are looking for work, while a quarter (25%) never secured a paying job, with 54% of respondents are retired.

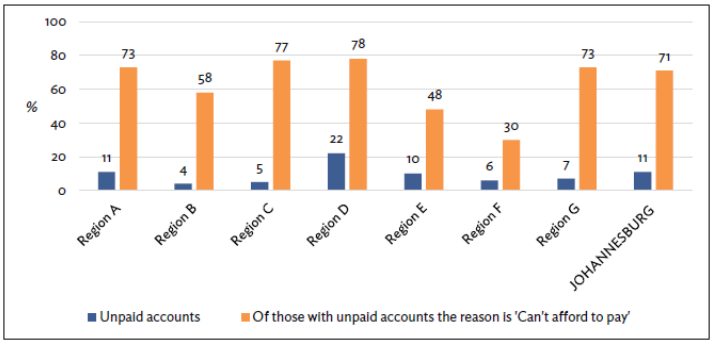


Figure 1: People with unpaid utility accounts (water/electricity) in the CoJ.

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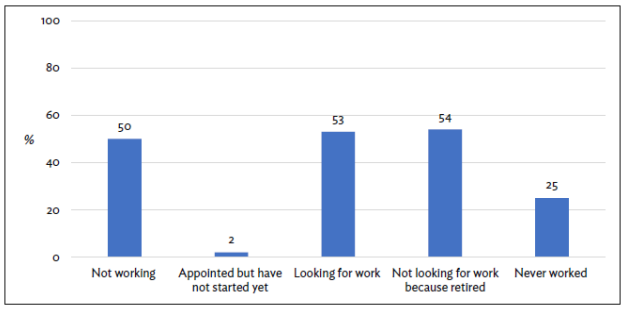


Figure 2: Employment status of GCRO's Survey respondents in CoJ. Source: GCRO's Quality of Life Survey 7 (2023/24) (Tshuma et al., 2024).

Invariably, the majority of Joburg residents are unemployed and lack a steady source of income, resulting in their inability to pay their utility bills. Furthermore, this limits the extent to which people have access to basic public services.

5.1.2 Access to Basic Services

Public service delivery in South Africa has been characterized by widespread dissatisfaction over the years (Götz & Seedat, 2024). Before focusing on the City of Johannesburg, this paper provides an overview of the public service delivery trend in Gauteng province, a broader context for CoJ, as presented in Figure 3.

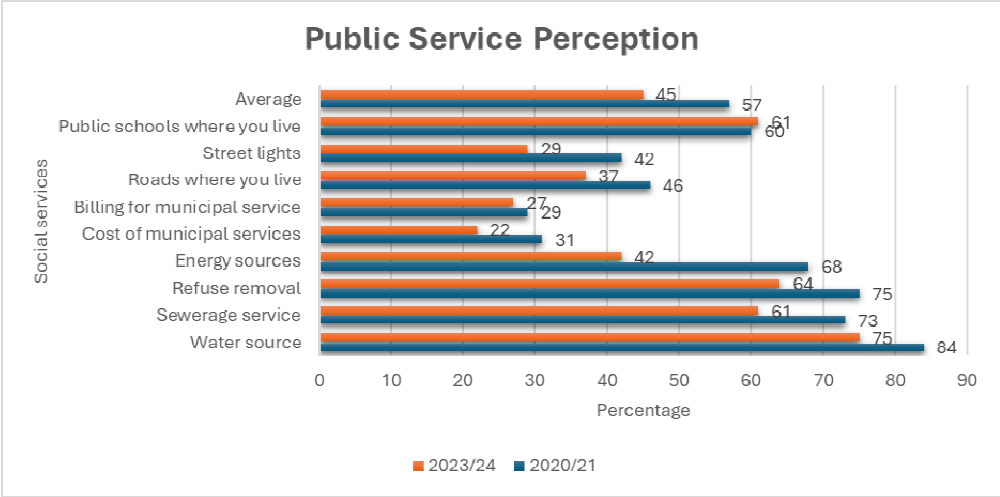


Figure 3: Public satisfaction with basic services in Gauteng. Source: GCRO QoL 7 Survey (Götz & Seedat, 2024).

Indications from Figure 3 suggest that access to public services in Gauteng province has steadily declined over time. In 2020/21, 57% of the population reported satisfaction with service performance; however, by 2023/24, this figure had dropped sharply to 45%, despite a modest increase in the number of public schools in the province. A closer examination of individual cities reveals a similar downward trend.

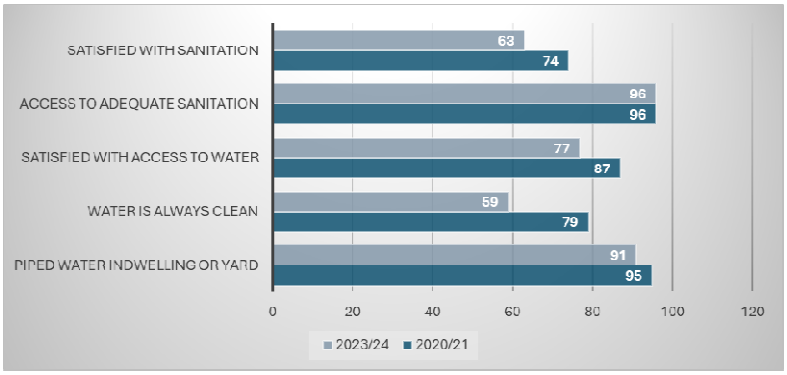


Figure 4: Perception of CoJ residents on water/sanitation service delivery. Source: GCRO's Quality of Life Survey 7 (2023/24) (Tshuma et al., 2024).

In the City of Johannesburg, Figure 4 highlights the situation regarding water and sanitation services. Satisfaction with these essential services has continued to deteriorate. For example, access to piped water within dwellings has declined: in 2020/21, 95% of residents reported access, but this fell by 4% in 2023/24. Likewise, satisfaction with water quality dropped significantly, from 79% in 2020/21 to 59% in 2023/24. Dissatisfaction with overall water service delivery also increased, with 77% of respondents expressing concern in 2023/24, 10% more than in 2020/21. The same pattern is evident in sanitation services, where confidence has continued to erode, even as the proportion of households with adequate sanitation remained unchanged between 2020/21 and 2023/24.

Another important social service that was investigated in the GCRO's QoL Survey 7 was the supply of electricity to the 7 regions in CoJ (see Figure 5). Basically, electricity functions as both a source of lighting and energy. For lighting, between 202/21 and 2023/24, the percentage of residents in the city that relied on it for lighting drops from 94% to 82%, indicating either an increase in loadshedding/interruption or a reduction in the capacity of residents to afford it, thereby switching to alternative light sources such as candles, solar, etc.

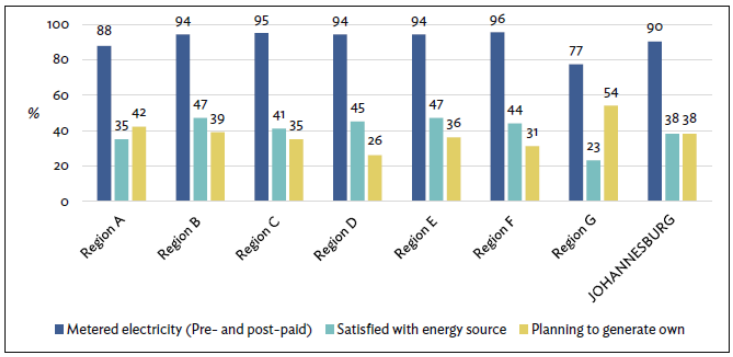


Figure 5: Perception and plans of CoJ residents on electricity supply and consumption. Source: GCRO's Quality of Life Survey 7 (2023/24) (Tshuma et al., 2024).

Access to metered electricity (both pre- and post-paid) is high across all regions, as depicted in Figure 5, with over 90% of households connected to the grid, on average, except in Region G, where the rate is 77%. In Region F, the highest proportion of households (96%) with metered electricity access was recorded, followed by Region C at 95%. Satisfaction with the energy sources varies widely: Regions B, D, E, and F report higher satisfaction levels (44% to 47%) compared to other regions. Region G has the lowest satisfaction at 23%. Notably, 54% of Region G residents plan to generate their own electricity, likely in response to lower access to metered electricity or general dissatisfaction with energy sources.

Healthcare is equally an important social service that governments, at all levels, commit to ensuring unhindered access to. This is given its connection to healthy living and its support for building an agile workforce necessary for achieving economic growth and development. In the City of Johannesburg, access to healthcare facilities is based on proximity, affordability, and belief system. This suggests the availability of three healthcare categories, consisting of public and private healthcare facilities, and traditional/spiritual healers that attract rural dwellers, mostly, given their belief in spirituality. Figure 6 below shows the spread of residents in the city across these healthcare options.

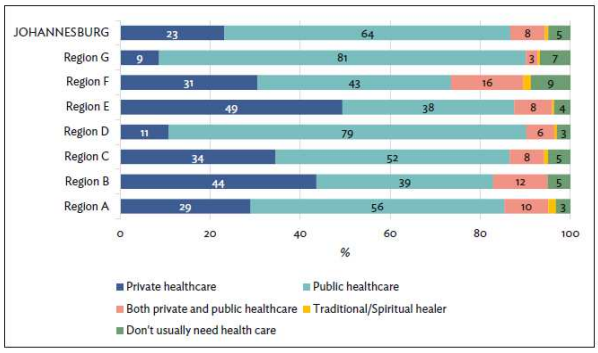


Figure 6: Healthcare service access in CoJ. Source: GCRO's Quality of Life Survey 7 (2023/24) (Tshuma et al., 2024).

In the figure above, while 5% of Johannesburg residents do not patronize any of the healthcare categories, nearly one in four residents access private healthcare facilities, whereas 64% use public healthcare facilities. An additional 8% use a combination of both. The use of private healthcare facilities is highest in Region E and lowest in Region G. Consequently, Region G has the highest reliance on public healthcare, at 81%. This trend suggests that Region E could be a suburb comprising educated and middle-income earners with the capacity to afford orthodox healthcare service, and with the direct opposite in Region G.

Furthermore, the survey provides data explaining the motivation for the growing acceptance of alternative healthcare providers in the city. Basically, the survey showed a decline in the level of satisfaction with the public healthcare services. As presented in Figure 7, a 38% dissatisfaction rate was reported with public healthcare services. This rate becomes significant when converted to the number of people involved. At the individual regional comparison in the city, 77% satisfaction rate, the highest in the city, was observed in Region B, while the lowest, 39%, was reported in Region G. This corroborates the earlier submission of the growth of patronage for alternative/native healthcare systems in Region G.

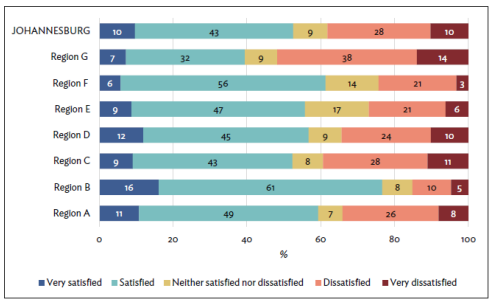


Figure 7: Perception of respondents on public healthcare service access in CoJ.

5.1.3 Spatial Inequity (Poverty & Transportation)

Characteristically, poverty has been explained to be the inability of an individual or group of people to have the wherewithal to provide themselves or their dependents with the necessities of life. These necessities include food, shelter, healthcare, education, transportation, and others. Given the centrality of food/hunger to categorizing poverty, this report, relying on the GCRO data on the prevalence of hunger among Johannesburg residents, presents the spatial poverty spread among regions in the city (see Figure 8).

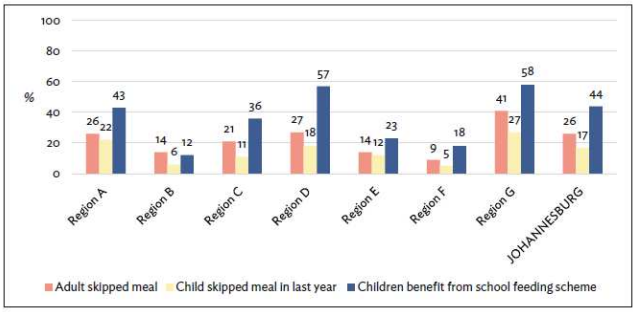


Figure 8: Hunger spread among residents in the CoJ.

In the figure above, the data were based on the criteria of "any member of the household who has skipped meals in the last 12 months owing to inability to afford food," and "the number of children within the household that benefit from a school feeding scheme."

Hunger remains a significant challenge in the CoJ, given the rate of adults (26%) and children (17%) who skipped meals in the last 12 months. Furthermore, Region G has the largest proportion of households where adults have had to skip meals (41%), followed by Regions D and A, at 27% and 26%, respectively. Region F reported the lowest proportion, at 9%. In total, 66% of Johannesburg households have one or more children, with 17% of these skipping at least a meal in the past year due to insufficient money for food. Regional variation is slightly less pronounced compared to households where adults skipped meals. In cushioning the effect of this trend, on average, 44% of Johannesburg households have children benefiting from a school feeding scheme. The highest levels of such support are in Regions D and G, where 57% and 58% of

households with children reported benefiting from these schemes. Region B has the lowest proportion, at 12%.

To further address the spreading hunger and poverty, a social grant scheme to support households facing difficulties was introduced. In Johannesburg, 48% of households have at least one member receiving a social grant (see Figure 9). Additionally, 41% of respondents live in households registered as indigent. In terms of monthly household income, around one in five Johannesburg respondents (22%) live in households with a total monthly income of less than R3,201. In some regions, the proportion of households receiving a social grant aligns closely with the proportion registered as indigent, while there are notable disparities in other regions. For example, in Region D, 67% of households receive a social grant, compared to 46% registered as indigent. In contrast, in Region F, only 26% receive a social grant, with 53% registered as indigent. This disparity may indicate that many households are unaware of how to register as indigent. Overall, these indicators highlight a particular concentration of poverty in Regions D and G.

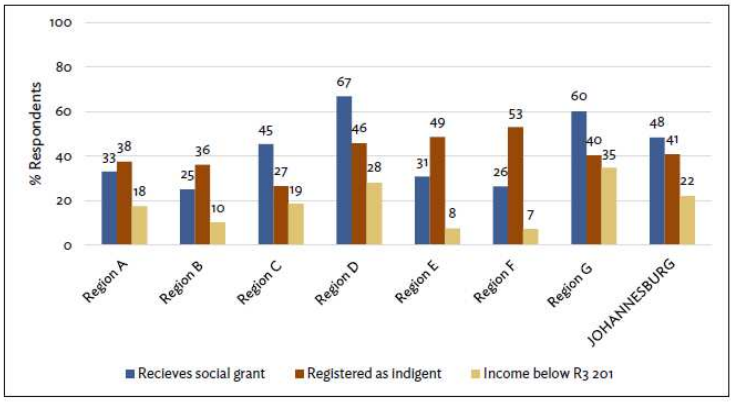


Figure 9: Social grant spread in the CoJ.

In the daily commuting of residents in Johannesburg, there exist many means of transportation, with each indicating the socio-economic status of the people concerned. This is not a clear-cut generalization; rather, it is an attempt to understand the living conditions of the people through their means of transportation on a regular basis. As found in the GCRO's QoL Survey 7 dataset, public transport was the most used mode of transport (47%), followed by cars (33%) and walking (18%) (Figure 10). Cars are more frequently used by respondents in Regions B, E, and F, with over 50% reliance. Public transport usage is highest in Region G, at 62%, while Region D has the highest proportion of respondents who walk, at 25%.

This mobility pattern could explain the socio-economic status of people in the various regions of the city. While residents of Regions B, E, and F with cars as their most frequent mode of transportation could be explained to be of the upper income class, given their ability to afford cars and fuel them, it could also be the absence or inadequacy of public transportation routes in their areas. Understanding this more deeply would require the examination of the public transportation route in the CoJ. Nevertheless, there appears to be a general low socio-economic status among residents of Regions D and G, given their reliance mostly on public transport and walking.

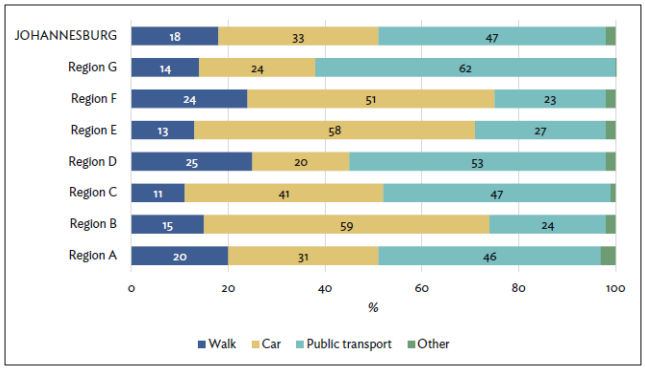


Figure 10: Transportation modes in the CoJ.

5.1.4 Environmental Justice

Regarding the CAZs initiative, waste management is central, given the impact of unsustainable waste management practices on environmental pollution. In the City of Johannesburg, there exists an organized waste collection scheme, and in gauging the frequency of weekly waste collection and the overall satisfaction with the service, GCRO's QoL Survey 2023/24 was conducted (see Table 1). Findings from the survey indicated that in 2020/21, 89% of the surveyed residents confirmed that their household waste was regularly removed on a weekly basis. This figure dropped to 84% in 2023/24, showing a contraction in the service coverage of the waste management body in the city. This service decline justified the reduction in the level of people's satisfaction in the service from 82% in 2020/21 to 80% in 2023/24.

Environmental justice indicators	2020/21	2023/24
Weekly refuse removal	89%	84%
Satisfaction with service	82%	80%

Table 1: Waste management scheme in CoJ. Source: GCRO's Quality of Life Survey 7 (2023/24) (Tshuma et al., 2024).

5.1.5 Digital & Social Inclusion

Access to information is assuming an important right of every individual, given its centrality to accessing opportunities and avoiding danger. In this mix, smartphones occupy a central position. With the increasing mobile applications for varied activities, the level of internet access can be measured using data on smartphone distribution in the City of Johannesburg. In Figure 11, the spatial variation in the proportion of households per ward in Johannesburg with access to a working smartphone is presented. Since most households have access to a smartphone, the spatial pattern does not vary much. Wards with low access (between 36% and 50%) are mostly in south Johannesburg, especially in wards around Soweto and some near the CBD. In the rest of Johannesburg, the proportion of households with access to a working smartphone is much higher (above 90%), with slight variations in and around townships such as Alexandra, and near Ennerdale in the far south.

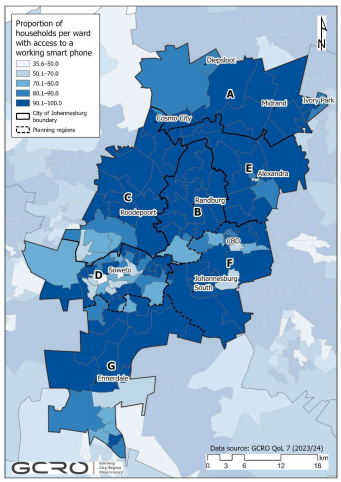


Figure 11: Smartphones spread in the CoJ. Source: GCRO's Quality of Life Survey 7 (2023/24) (Tshuma et al., 2024).

6 DISCUSSION AND POLICY IMPLICATIONS

There are many pathways for operationalizing the Clean Air Zones initiative, with each capable of deepening existing disparities when imposed without equity safeguards (Druckman & Jackson, 2008). Understanding these pathways is critical for Johannesburg, where prolonged inequality creates a differential policy burden (Mashabela et al., 2025).

First, CAZ implementation required restricting high-emission vehicles disproportionately, with possible impact on the travelling experience of low-income commuters and informal transport operators. With 62% of Region G residents relying on public transport and 25% of Region D residents walking (Figure 10), CAZ-induced fare increases from fleet upgrades would compound existing mobility poverty. The 22% of households earning below R3,201 monthly cannot absorb these costs, forcing further service exclusion. Second, restricting cheap energy sources, such as coal and firewood for heating/cooking, directly threatens the 71% of residents unable to pay utility bills (Figure 1). In Regions D and G, where 41% experience adult meal-skipping and electricity satisfaction is lowest (23% in Region G), households depend on polluting fuels

as survival mechanisms, not lifestyle choices. Prohibition without subsidized alternatives forces impossible trade-offs between compliance and basic needs (Götz & Seedat, 2024).

Thirdly, formalizing waste collection threatens informal reclaimers' livelihoods, a population already marginalized by declining municipal service (84% coverage in 2023/24 vs. 89% in 2020/21). With 48% of households receiving social grants and 41% registered as indigent, informal waste picking provides critical income. CAZ restrictions on informal recycling eliminate this safety net without creating formal employment alternatives, exacerbating the unemployment crisis where 53% actively seek work (Figure 2). Furthermore, while regulating industrial emissions is necessary, these regulations impose compliance costs that formal businesses pass to consumers through price increases. For the 67% of Region D households on social grants, even marginal cost increases in essential goods deepen food insecurity and utility payment defaults.

These pathways interact synergistically: a household forced to abandon polluting fuels without affordable alternatives may default on electricity payments, lose waste-picking income from CAZ enforcement, face higher food prices from industrial compliance costs, and experience reduced mobility from transport restrictions, a cascading vulnerability spiral that transforms environmental policy into socio-economic destabilization (Metheny et al., 2025).

To explore the spread of vulnerabilities across the seven regions in the city, Table 2 is presented. The table synthesizes vulnerability indicators across Johannesburg's seven regions, revealing differentiated CAZ impact exposure. Regions are scored on key indicators, with darker shading indicating higher vulnerability.

Indicators/Regions	A	B	C	D	E	F	G
Unpaid utility bills (%)	11	4	9	22	10	8	18
Unemployment rate (%)	Moderate	Low	Moderate	High	Low	Low	High
Adult meal skipping (%)	26	15	18	27	12	9	41
Social grant dependency (%)	45	22	38	67	35	26	65
Public transport reliance (%)	45	28	42	52	32	35	62
Healthcare satisfaction (%)	62	77	68	58	71	65	39
Satisfaction with electricity (%)	38	47	42	44	45	46	23
Access to metered electricity (%)	92	94	95	91	93	96	77
School feeding scheme (%)	38	12	32	57	28	18	58
Composite vulnerability	Medium	Low	Medium	High	Low	Low	Very high

Table 2: Composite Regional Vulnerability to CAZ Implementation. Source: Compiled by the Authors

Table 2 presents the vulnerability spread across regions in the CoJ. Region G exhibits extreme vulnerability across all dimensions, the highest meal-skipping (41%), lowest electricity satisfaction (23%), weakest healthcare access (39%), and greatest transport precarity (62% public reliance). Region D follows with concentrated poverty (67% social grant dependency, 22% utility defaults). Conversely, Regions B, E, and F demonstrate resilience through lower poverty indicators and higher service satisfaction, though no region is immune to CAZ disruption.

This spatial concentration of vulnerability demands geographically differentiated CAZ implementation. Uniform policy enforcement would constitute environmental injustice, imposing disproportionate burdens on communities least equipped to adapt (Druckman & Jackson, 2008). The matrix provides an empirical foundation for a phased, equity-centered rollout that addresses Johannesburg's persistent inequality patterns (Götz & Seedat, 2024) while advancing environmental sustainability.

7 CONCLUSION

Johannesburg stands at a governance crossroads. The Clean Air Zones initiative can either exemplify equitable environmental leadership or reproduce historical patterns where policy serves affluent interests while criminalizing the survival strategies of marginalized communities. This study's evidence compels the former path. Most fundamentally, this study demonstrates that environmental sustainability and social equity are not competing values requiring tragic trade-offs. They are mutually dependent: environmental policies that deepen inequality invite resistance, undermine legitimacy, and ultimately fail to achieve ecological objectives. Conversely, equity-centered environmental governance mobilizes broad coalitions, generates compliance through capacity-building rather than coercion, and produces resilient systems benefiting all residents.

The time for transformative action is now. Johannesburg's CAZ implementation will be observed across the African continent and the Global South as cities navigate the tension between environmental imperatives and development justice. Success requires rejecting the false premise that cities must choose between breathable

air and livable livelihoods. By centering equity, through subsidies, phased rollout, participatory design, and service infrastructure investment, Johannesburg can demonstrate that its "world-class African city" aspiration is achievable precisely by prioritizing those historically excluded from such visions. Environmental resilience and social justice, implemented together, engender the foundation of urban excellence.

8 ACKNOWLEDGEMENT

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An Educational Approach to Planning the Future Spatial Development of a Small Town: The Case of Čakovec, Croatia

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1 ABSTRACT

European policy documents underline the vital contribution of small and medium-sized towns to the urban systems of EU member states. Across several countries, there is a growing intention to equip these towns with new policy instruments that would strategically strengthen their position as drivers of regional development. Common areas of intervention include the regeneration of public buildings, support for business growth and innovation, enhanced regional connectivity, housing improvements, and increased investment in culture, education, and social services.

In the education of urban planners within the course Urban Planning Workshop 1: Settlement Planning at the Graduate Study Program in Architecture and Urban Planning at the Faculty of Architecture, University of Zagreb, small and medium-sized towns hold particular importance. Due to their optimal scale and the complexity of their challenges, they serve as suitable case studies through which students learn the processes of strategic thinking and spatial planning for future urban development. For the purposes of this paper, the example of the small town of Čakovec in northern Croatia was selected. In the academic year 2025/2026, Čakovec served as the workshop assignment for which students were tasked with proposing potential spatial development visions for the town for the period up to 2050.

The aim of this article is to present the educational process in Urban Planning Workshop 1: Settlement Planning, which focuses on planning the long-term future development of a small town. The main objective of the workshop is to formulate a comprehensive vision for the town's spatial development, while also providing a more detailed elaboration of selected areas considered relevant for future transformation and growth.

Keywords: Spatial planning, Small town, Development vision, Education, Čakovec

2 INTRODUCTION

Education in the field of spatial planning is largely shaped by national contexts and the institutional frameworks of individual countries. Janin Rivolin et al. (2025) start from the assumption that the educational process involves the transmission and development of specialized technical knowledge that can be taught through theoretical and practical education, independently of the specific features of national planning systems. They further argue that, although institutional and legal frameworks significantly influence professional practice, they do not fully determine the content and structure of technical knowledge within educational programmes. The authors advocate a clear distinction between spatial planning and urban governance, with the former serving as an instrument for the achievement of the latter. Technical knowledge in spatial planning is most effectively acquired when spatial zoning is established as its foundation and when long-term spatial patterns are identified.

Teaching requires that knowledge be presented to future professionals in a systematic and consistent manner. Due to the specific nature of education in the fields of urbanism and spatial planning, this requirement is less pronounced, as these fields encompass a complex domain of knowledge and practice in which diversity poses increasing challenges (Millard-Ball et al., 2021; Diko et al., 2023).

Understanding complex spatial systems and processes requires specific practical skills as well as theoretical knowledge drawn from multiple scientific disciplines and fields, thereby making the education of spatial planners more comprehensive. AESOP (2024) highlights the need to place particular emphasis on the development of strategic thinking competencies and on strengthening capacities for long-term foresight and spatial planning, whether at the regional or local level.

Since the 1990s, particular attention has been given in Europe to strategic spatial planning as a means of addressing economic, social, and environmental challenges, with the aim of developing a coordinated vision to guide medium- and long-term development (Albrechts & Balducci, 2013; Balducci, Fedeli, & Pasqui, 2011; Albrechts, Healey, & Kunzmann, 2003). Hersperger et al. (2019) point out that strategic spatial plans focus on a combination of development strategies and strategic urban projects. Schmitt and van Well (2016) argue that attention is predominantly directed toward governance processes, while insufficient emphasis is placed on linking these processes to physical transformations in terms of land cover and land-use change. In the implementation of strategic plans, particular attention should be paid to local statutory plans (Mäntysalo, Kangasoja, & Kanninen, 2015; van den Broeck, 2013), as these enable the physical transformation of space.

Small towns represent a particularly suitable context for the education of future spatial planners within the field of spatial planning. European policy documents emphasize their key contribution to the urban systems of EU Member States, and in many countries there is a stated intention to equip them with new policy instruments aimed at strategically strengthening their role as drivers of regional development. ESPON (2024) point out that particular attention should be devoted to development through the renewal of public buildings, support for entrepreneurship and innovation, the enhancement of regional connectivity, improvements in housing, and investments in culture, education, and social services. Within urban systems, such towns constitute spatial systems in which relationships between governance processes and physical spatial transformation are more readily observable and, due to their scale, less complex, thereby facilitating a more comprehensive understanding of space compared to large metropolitan areas.

The aim of this paper is to present the educational process in Urban Planning Workshop 1: Settlement Planning, which focuses on planning the long-term future development of a small town. The main objective of the workshop is to formulate a comprehensive vision for the town's spatial development, while also providing a more detailed elaboration of selected areas considered relevant for future transformation and growth.

3 EDUCATION OF FUTURE SPATIAL PLANNERS ON THE FUTURE DEVELOPMENT OF SMALL TOWNS

3.1 Education of Spatial Planners in the Context of EU Documents

The most significant European documents related to the education of spatial planners are the result of the work of two organizations: the European Council of Spatial Planners (ECTP-CEU) and the Association of European Schools of Planning (AESOP).

During the ECTP-CEU meeting in Athens in 1995, national institutes and professional associations of planners within the European Economic Community signed the International Agreement and Declaration, thereby harmonizing professional standards, ethical principles, and shared objectives for the education and practice of spatial planning in Europe. In the supplement of Appendix B: Education and Training of the Charter, five common cores were highlighted as essential for the education of spatial planners, representing a fundamental part of the planning profession in Europe:

- Environmental Context – Perception and evaluation of the environment; local development; sustainable development; individual needs.
- Theory and Methodology of Planning – History and theory of planning; urban policies; spatial and temporal parameters; methods and research.
- Institutional Framework – Legislation and administration; local economy; interactions at national, regional, and local levels; statistics and resources.
- Professional Practice and Technique – Planning and design; strategies and simulations; interdisciplinary teams; governance and implementation; communication; design and aesthetics.
- Professional Matters – Professional knowledge and competence; responsibility and ethics; guidelines for practice; codes of conduct; promotion of standards.

In its 2013 document, Charter of European Planning, ECTP-CEU points out that research and analysis, advocacy and mediation, and the ability to envision, evaluate, and promote potential future options for urban, spatial, and territorial development constitute the core commitments of planners. In the Guidelines on

Professional Competences in Spatial Planning (2017), ECTP-CEU presented a framework defining the skills, knowledge, and responsibilities that spatial planners should possess in order to practice their profession competently and effectively. The document emphasizes three specific needs for the competences of spatial planners: critical thinking and understanding of the rationale of planning, including its theoretical and legal foundations; an understanding of spatial systems; and the technical and creative competences required to engage in planning practice. These are linked to eight core competences, which are presented in Table 1.

Specific needs for the competences	Core competences
Critical thinking and understanding of the rationale of planning and its theoretical and legal basis	The Rationale of Planning: Spatial planning plays a key role within a market-oriented environment, as it is grounded in the principles of sustainability, social justice, and ethical practice. It balances individual rights with public interest, enabling evidence-based decision-making and the resolution of spatial conflicts. Planners must be aware of the political and ethical dimensions of planning, particularly in relation to the public good, equity, and the fair representation of all stakeholders.
An understanding of the spatial systems	Socio-economic systems: Spatial planning requires an integrated understanding of social and economic systems and their spatial implications. Planners must possess fundamental knowledge of geographic analysis and operational contexts in order to assess political, social, and economic factors, with specialized expertise necessarily linked to local conditions.
	The Built Environment: Spatial planning requires an understanding of the built environment and its impact on quality of life and sustainable development. Particular attention is given to the principles and processes of creating high-quality spaces, the role of urban design, and the evaluation of design. Planners must consider the strategic potential of planning, climate change, challenges in historic contexts, and develop skills for place-making, alongside the ability to engage in interdisciplinary collaboration and mediation to foster inclusive and safe urban environments.
	Spatial planning requires an understanding of physical and biological systems and the effective management of resources, including health, quality of life, and the sustainable use of ecosystems, landscapes, and energy resources. Particular emphasis is placed on the conservation of natural resources and biodiversity, climate change adaptation, heritage protection, the development of renewable energy sources, and the application of planning in maritime areas.
Technical and creative competence needed to engage in planning practice	Planning Techniques: Spatial planning requires both quantitative and qualitative techniques to address spatial challenges and support policy implementation. Planners employ methods to define problems and collaborate within multidisciplinary teams. Planning involves the analysis, assessment, and monitoring of development alternatives and requires specialized knowledge and skills. This includes scenario development and evaluation, visualization of alternatives, land-use and social needs analysis, resource management, assessment of transport impacts, fieldwork, and the application of GIS and other analytical tools. Particular emphasis is placed on interdisciplinary collaboration, urban design, and the capacity for mediation, negotiation, and stakeholder participation.
	Independent Research: A key outcome of education in spatial planning is the development of competencies for independent research, including literature analysis, data collection, application of research methods, and the use of IT tools for analysis and evaluation. Research skills can also be assessed through alternative formats, without the necessity of producing a formal thesis or dissertation.
	Planning Instruments: Spatial planning requires knowledge of institutional and legal frameworks and the application of legal, administrative, and financial instruments. This includes understanding national, European, and international contexts, relevant directives and environmental protection instruments, legislation, and participation systems in planning processes.
	The Planning Product: The outputs of spatial planning include policies, instruments, programs, projects, strategies, and urban and landscape plans at different territorial levels. They encompass strategic frameworks and development visions, thematic strategies for water, energy, and food security, urban regeneration programs, and the integrated use of land, transport, and infrastructure. Planners must combine technical, creative, and personal knowledge and skills, including project management, problem-solving, collaboration, communication, and knowledge transfer, alongside competencies in negotiation, mediation, advocacy, and leadership.

Table 1: ECTP-CEU specific need and core competences defined in Guidelines on Professional Competences in Spatial Planning (2017). Source: Author according to ECTP-CEU, 2017.

The AESOP Core Curriculum (2024) represents an updated version of the Core Requirements for a high-quality European Planning Education (1995) issued as part of AESOP's statement odn European Planning Education. The document has two crucial roles for AESOP: identifying knowledge, competencies and values deemed vital for spatial planners at the beginning of the 21st century; and serving as a 'benchmark' for the evaluation of applications and admission of new member schools and their education programmes.

AESOP core curriculum (2024) of planning programs highlights three essential components – knowledge, practical skills, and values – that planners are expected to acquire or apply in order to carry out their responsibilities in a socially responsible and professionally ethical way. Graduates are expected to understand spatial dynamics across different scales, demonstrating the ability to produce, manage, analyse, interpret, and communicate knowledge relevant to spatial planning. They should also be able to translate this knowledge into practice by designing, evaluating, and implementing spatial interventions that consider multiple stakeholders. Finally, graduates are encouraged to develop a sustainable professional practice by assuming the societal responsibilities inherent to the role of a spatial planner.

In Chapter B, From Knowledge to Action, the development of knowledge is emphasized: regarding the nature, purpose, theory, and methods of planning; its historical evolution as an institution and profession; planning instruments and their adaptation to new challenges; the role of actors and citizens in democratic processes; the political, legal, and cultural context of planning; the application of transformational technologies; and transformative action in the context of sustainable development, climate crises, and spatial injustice.

In addition, the chapter highlights the need to develop practical competencies related to: the assessment and enhancement of the values of natural and built environments; the application of planning concepts, instruments, and measures in practice; the integration of different types of knowledge as well as aesthetic and design dimensions into planning proposals; the development of design and visual representation skills; the preparation of plans, programs, and measures, and participation in their implementation; active collaboration with civil society and stakeholders; and the management of complex governance and transformation processes.

Finally, it stresses the importance of cultivating an appropriate attitude and sense of responsibility, encompassing a conscientious and value-driven approach to planning that acknowledges its ethical implications, the cultural embeddedness of social and collective processes, democratic procedures, and rights such as the "right to the city," with particular attention to social justice, human and environmental rights, and respect for planetary boundaries.

3.2 Urban Planning Workshop 1: Settlement Planning: Case study Čakovec, Croatia

Urban Planning Workshop 1: Settlement Planning (UPW1) is one of the courses in the field of urbanism and spatial planning, offered in the first semester of the Graduate Studies in Architecture and Urbanism at the Faculty of Architecture, University of Zagreb. The main objective of the course is to develop a vision and concept for the spatial development of a small town based on the principles of sustainability. In the academic year 2025/2026, the assignment focused on the case study of the City of Čakovec.

The spatial development vision in UPW1 addresses the administrative area of the local government unit, the City of Čakovec, in the context of its surrounding settlements, with particular attention to the central settlement as well as Mihovljan, Savska Ves, and Ivanovec as potential areas for urban expansion. The task requires students to engage in strategic spatial thinking, assessing the potentials of the area and its acceptable capacities while taking into account spatial specificities and limitations arising from its unique values. Development guided by the principles of sustainability, as a paradigm of contemporary spatial planning, must be integrated into spatial visions and concepts to result in an environment suitable for living, working, and leisure, equipped with all necessary supporting facilities to meet societal standards.

Following analyses of the existing conditions, spatial planning documentation, and strategic development plans, the course assignment is developed on two levels of detail. At the first level, based on the objectives defined in the Spatial Plan of the City of Čakovec and the General Urban Plan of Čakovec, the town's development goals are established, and a vision for the spatial development of Čakovec is proposed and elaborated. At the second level, in accordance with the selected development concept, an optimal development program is proposed for individual areas of Čakovec, including concepts for land use, transportation, and spatial structures, as well as photomontages illustrating possible programmatic, design, and functional arrangements of the selected areas.

The course Urban Planning Workshop 1: Settlement Planning is thematically closely linked to Research Seminar 1: Settlement Planning and is primarily designed to complement and expand the knowledge and insights required to complete the assigned task. The aim of the course is to investigate spatial planning and urban design topics that contribute to the formulation of a spatial vision for the development of the studied small town and to propose a spatial development concept for the selected area. The course has a research-oriented character and culminates in the preparation of a seminar paper on the assigned topic.

At the beginning of the semester, in collaboration with the City of Čakovec and the Association of Architects of Međimurje, a joint site visit and invited lectures were organized for students to provide them with insights into the spatial specificities and local needs, as informed by professionals and residents.

In the summer semester, students will continue working on the Čakovec area within the framework of Urban Planning Workshop 2: Urban Transformation, where, in accordance with their previously developed concept

and development plan, they will create an urban-architectural design for the selected area. The most successful student projects from both courses will be exhibited in Čakovec at the end of the academic year, and a publication will be issued in collaboration with the local government.

3.2.1 City of Čakovec

The City of Čakovec is located in the northern part of the Republic of Croatia, in the central area of Međimurje County, serving as the administrative, governance, and transport center of the region. It covers an area of 73 km² and comprises 14 settlements, including the central urban settlement of Čakovec, which has a population of 15,078, out of a total of 27,122 inhabitants (2021 census). The central settlement of Čakovec is spatially and functionally connected with several surrounding municipalities, while the southern boundary of the City is defined by the Čakovec Hydroelectric Plant reservoir, which also forms the natural border between Međimurje and Varaždin Counties.

The town's favorable geostrategic and transport location has historically influenced its economic and social development. Čakovec is well-connected by international, national, regional, and local road and rail infrastructure. Moreover, the town demonstrates a strong functional link with the City of Varaždin, forming an increasingly integrated urban conurbation. Their shared development area significantly affects migration, transport, and economic patterns in northwestern Croatia. As the largest and most populous town in the county, Čakovec serves as the primary driver of economic, demographic, and infrastructural development in Međimurje and, within a broader spatial context, stands out as a potential contact, transit, and development center with substantial urban capacities. With its natural diversity, rich landscape base, and notable architectural heritage, Čakovec represents a valuable space within the Republic of Croatia, requiring the protection and enhancement of its fundamental spatial, cultural, and environmental values.

3.2.2 Spatial Planning Documents and Strategic Documents

The first document guiding the development of the City of Čakovec was the Directive Regulatory Basis of 1947, prepared by architect Prof. Josip Seissel at the Faculty of Architecture, University of Zagreb. The plan established a new network of major town roads beyond the then town center, introduced new residential neighborhoods for both individual and collective housing, and designated an industrial zone to the northwest of the railway station. The plan was preceded by the preparation of an early form of a regional plan, which examined the spatial and transport connections of settlements in Međimurje and demographic trends, influencing the foundational layout of Čakovec itself (City of Čakovec, 2005; Kranjčević & Pintar, 2017).

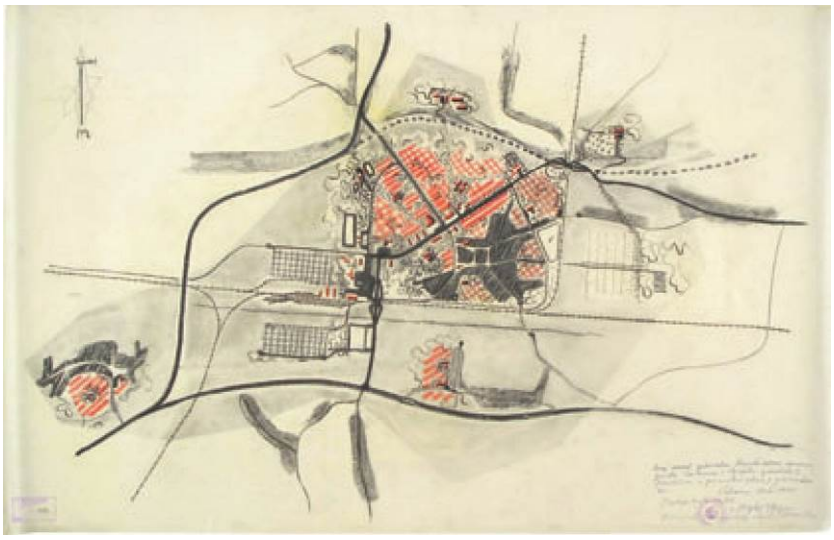


Fig. 1: Directive Regulatory Basis of 1947. Source: Archive of the Department.

The General Urban Plan (GUP) of 1964, prepared by the AR 59 project bureau under the leadership of architect Borisav Vasiljević, represents a revision of the 1947 Directive Regulatory Basis. The plan envisioned the southern expansion of the town beyond the railway line while integrating suburban settlements into the urban fabric. It disregarded the historic urban grid, permitting radical interventions that resulted in the interpolation of residential blocks and the construction of high-rise buildings (City of Čakovec, 2005; Kranjčević & Pintar, 2017).

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In 1978, the General Urban Plan of the City of Čakovec "Čakovec 2000", led by architect Nada Golub-Piližota, established a long-term development concept for the town until the end of the century. The plan defined new residential, industrial, and sports-recreational zones, established a pedestrian zone in the town center, and set the southern boundary of the town with the southern bypass. New residential quarters with distinct identities were created. The plan also implemented the concept of the Eastern Industrial Zone and the Mladost Sports and Recreation Center. Subsequently, the plan was supplemented under the title “General Urban Plan of Čakovec” (led by architect Dragomir Sutlar), which included the construction of the southern bypass and introduced building development restrictions (City of Čakovec, 2005).

The Spatial Plan of the Čakovec Municipality (1978) was the first plan to consider the integrated territory of Međimurje, which at the time constituted the unified Čakovec Municipality (corresponding to the current area of Međimurje County, 729 km²). To ensure conditions for overall social and economic development and to create equitable living and working opportunities for the entire population of the municipality, while adhering to the principles of environmental protection and improvement and rational and efficient spatial management, the plan established the following key objectives: Enable polycentric, efficient, and functional spatial development; Ensure coordinated and purpose-driven land use that supports optimal, stable, and sustainable economic development; Provide a high-quality environment for healthy and humane living while preserving aesthetic and cultural values; Safeguard the territory against potential disasters, hazards, and destruction. The plan proposed a new spatial model of a polycentric settlement system, with Čakovec as the primary center. By connecting settlements with each other and with all parts of the territory, the plan aimed to ensure optimal mobility of the population, accessibility to workplaces, and connectivity of all areas to Čakovec within 30 minutes. This framework was intended to facilitate the gradual restructuring of the population and to free land for intensive agricultural use (Sutlar & Grgan-Makovec, 2017).

The Amendment and Supplement to the Spatial Plan of the Čakovec Municipality (1989) was primarily linked to finding a suitable solution for the alignment of the A4 Budapest–Zagreb highway. When defining the corridor, attention was given to minimizing the impact on valuable agricultural land, avoiding the Murščak protected landscape, and respecting the settlement orientation toward Prelog and Čakovec, so that the highway would not become a barrier within the territory.

The current legislative framework for spatial planning and strategic development at the local level for the town encompasses several types of spatial and strategic development plans, the most significant of which are outlined below.

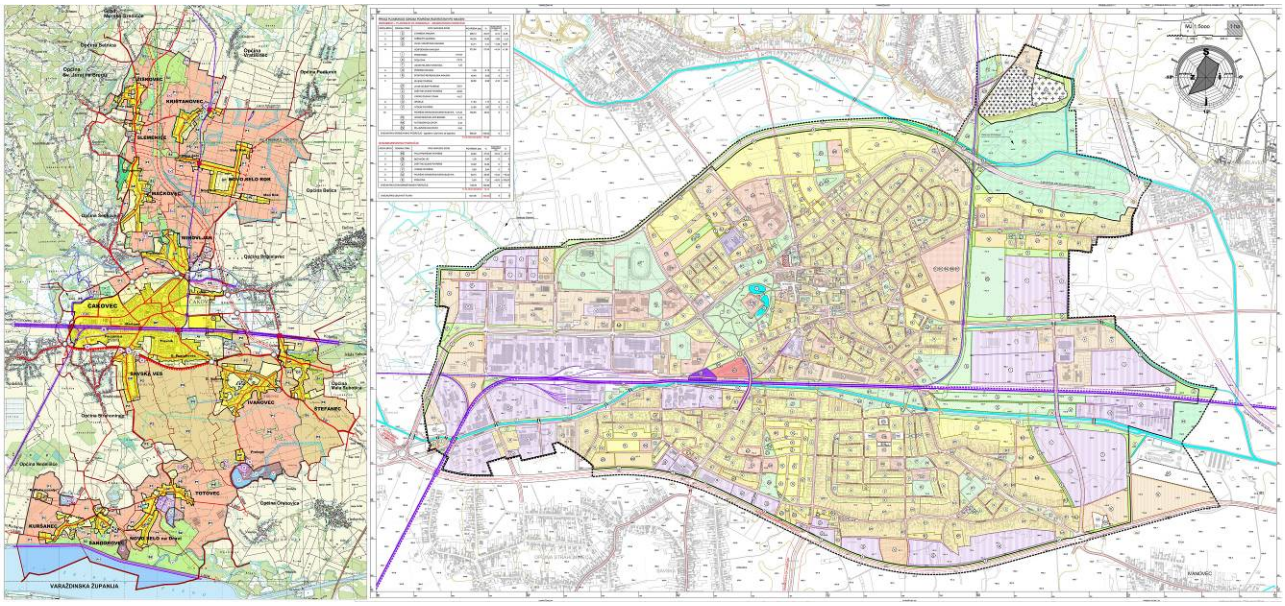


Fig. 2: The Spatial Plan of the City of Čakovec (left) and The General Urban Plan of Čakovec (right). Source: https://www.cakovec.hr/prostorni-planovi-grad-cakovec/

The Spatial Plan of the City of Čakovec (2003) defines the conditions for the development of the urban area, including its purposeful use, land use designation, spatial design, remediation of building and other land, environmental protection, and the protection of cultural heritage and particularly valuable natural areas

within the City's territory, which covers 72.97 km². The plan points out county-level spatial development objectives, including the development of the town and settlements with special functions and infrastructure systems, the rational use of natural resources, and the preservation of ecological stability and valuable environmental components. It also defines town-level spatial development objectives, which include demographic development aimed at promoting stable and sustainable population growth, settlement development, enhancement of social, transport, and utility infrastructure, and the protection of landscape, natural values, and cultural-historical units. Furthermore, the plan sets settlement-level spatial planning objectives within the town, which include the rational use and protection of space by directing land use to meet the town's needs, environmental protection, designation of building areas within settlements, and the improvement of settlement design and utility infrastructure to enhance the quality of life of residents.

The General Urban Plan of Čakovec (2005) establishes the fundamental spatial organization, the protection of natural, cultural, and historical values, and the use and designation of land for the central settlement area, covering 11.27 km². The plan emphasizes that Čakovec, as the county seat, should continue to function as the most important economic, administrative, cultural, educational, and healthcare center, as well as the largest transport hub of Međimurje County.

The plan defines the following key long-term objectives: Preserve the identity and specificity of the urban area; Protect natural and historical values, the environment, and promote sustainable development; Maintain undeveloped areas; Improve the quality of life and living standards of residents; Ensure space and corridors for all infrastructure to connect Čakovec with surrounding settlements, supporting its role as a regional center; Provide the spatial prerequisites for economic development and restructuring relevant to Čakovec and Međimurje County.

The primary goal of the plan is urban regeneration and consolidation of the town's structure. The plan emphasizes the need to: Enhance the spatial structure of the town at a human scale, ensuring good connectivity to all necessary urban functions; Spatially define the existing military zone (training grounds and barracks) and integrate it into the urban fabric with appropriate uses; Achieve urban quality through a system of urban-architectural projects; Use the town's space and environment in a way that prevents irreversible damage, enabling durable and sustainable development.

The plan specifies the following urban planning objectives: Ensure the development of all urban systems; Dimension spaces according to the scale of the town and moderate continuity of development; Promote construction that preserves cultural heritage and natural settings while highlighting urban aesthetics; Protect residents from adverse impacts while utilizing local environmental advantages; Align urban development with socio-economic programs; Ensure construction that supports economic efficiency of infrastructure systems and strengthens the town's economic capacity through functional distribution and overlap of urban functions.

The plan also identifies specific interventions: Expand areas for residential use (single-family and multi-family housing) in the northern parts of the town, Globetka, Sajmište, Martane, and Buzovec; Expand areas for economic, industrial, and business purposes east of Buzovec and on the former military training ground; Form and reconstruct the military barracks area for public and community buildings; Designate new multifunctional green spaces on undeveloped or abandoned agricultural land; Define zones to be regulated through detailed spatial plans; Provide space for the relocation of the bus and railway stations.

For the purposes of sustainable urban planning in line with European Union objectives and regional development criteria, the Čakovec Urban Area (covering 164.85 km²) has been defined, encompassing the City of Čakovec and the surrounding municipalities of Nedelišće, Strahoninec, Pribislavec, and Šenkovec. A Development Strategy for the Čakovec Urban Area has been prepared for the financial period 2021–2027. The medium-term vision for the Čakovec Urban Area emphasizes a resilient, innovative, and sustainable economy, as well as a healthy, educated, and inclusive society that promotes sustainable urban development to ensure a high-quality living environment. The strategy identifies three priority areas of public policy: Sustainable Economy; Healthy and Educated Society; and Pleasant Living Environment. Specific objectives have been established for each priority area: PP1 – Sustainable Economy: Development of entrepreneurship and supportive business infrastructure; strengthening of niche tourism; promotion of green solutions and smart innovations in the economy; PP2 – Healthy and Educated Society: Enhancement of lifelong learning; strengthening of sports infrastructure; improvement of quality of life through increased publicly accessible

amenities; and PP3 – Pleasant Living Environment: Development of cycling and pedestrian infrastructure; enhancement of green infrastructure; improvement and design of public spaces.

The Green Urban Renewal Strategy of the City of Čakovec 2022–2030 is aligned with the Development Strategy of the Čakovec Urban Area, and both documents contribute to achieving the strategic objectives of the National Recovery Strategy 2030 – Ecological and Energy Transition for Climate Neutrality. The strategy defines a vision for the development of green infrastructure in the City of Čakovec, including a development concept for both the wider and immediate urban area. Based on the identified developmental needs and potentials, as well as the established vision, three complementary and synergistic objectives for green infrastructure development have been defined. The strategy also establishes priorities for green urban renewal, specifying measures and proposed projects to be implemented within the town. The main strategic objectives of the strategy are: Increase the efficiency of planning and management of green infrastructure in the town; Improve, expand, and connect easily accessible green infrastructure within the town; and Create livable spaces and enhance the quality of life. By achieving these objectives, the strategy ensures the preservation and enhancement of the green character and identity of Čakovec and guarantees accessible green infrastructure of various types, sizes, and functions for all residents. Given the interconnected nature of the objectives, their implementation will foster a circular process, resulting in a continuous increase in interest and investment in green infrastructure development projects across the town.

3.2.3 Proposals for the Future Development Visions of the City of Čakovec

The following section offers a brief overview of two selected student projects, highlighting the distinct approaches and methodologies adopted by two different menor-led groups.

The project titled “Student Corridor Čakovec – Varaždin” (Figure 3) identifies, through the analysis of the broader spatial context, the need and potential for functional connectivity between the main cities of the neighboring counties, Čakovec and Varaždin. It proposes a joint campus in the eastern industrial zone of Čakovec and aims to enhance transport connectivity through pedestrian and cycling routes linking the two cities, as well as constructing an additional railway track for (inter)urban train services. Considering the concentration of existing higher education institutions and planned urban projects – including the Science Center, redevelopment of the former military barracks into a Creative-Inspirational Center, establishment of a business incubator, and the Međimurje Energy Center – the project proposes repurposing the industrial zone west of the railway into a new urban neighborhood with a student campus. The design envisions a new railway station along the eastern edge of a planned town park, which extends into a central east-west green axis. This axis is flanked by public service zones, such as the new campus with student dormitories, faculties, a primary school, kindergarten, library, and health center, and mixed residential and commercial zones. Peripheral roads in the northern and southern sections are planned for quiet residential areas with family houses, while the central axis culminates in a sports and recreational area forming a buffer zone toward the planned northern town bypass.



Fig. 3: “Student Corridor Čakovec – Varaždin” Vision for Čakovac (students: Petra Kujundžić & Ivan Kukuljević-Sakcinski; mentor: Damir Krajnik, PhD, Full Professor). Source: Archive of the Department.

The student vision entitled “En-park” (Figure 4) identifies multiple (E)layers that strategically aim to affirm Čakovec as a regional research and education center for biodiversity and nature protection, linked to the Mura-Drava Regional Park. The “En” acronym reflects adjectives describing the project’s values: ecological,

energy-resilient, educative, economic, efficient, eccentric, eclectic, experimental, expressive, and more. Students redesigned and integrated existing entrepreneurial zones, adding new educational, touristic, and business functions connected with urban green infrastructure (recreational areas, urban forests, and parks). At the regional level, Međimurje County was analyzed for three potential scenarios: depopulation, stagnation, and demographic growth. The study assessed the potential of built-up zones to become green infrastructure, agricultural land, or to expand. At the local level, the entrepreneurial zone in Čakovec East was planned in detail to integrate all aspects while considering existing and planned major road infrastructure. Integration changes were evaluated using the Space Syntax model, guiding students in selecting the most appropriate traffic solution between two proposed options.

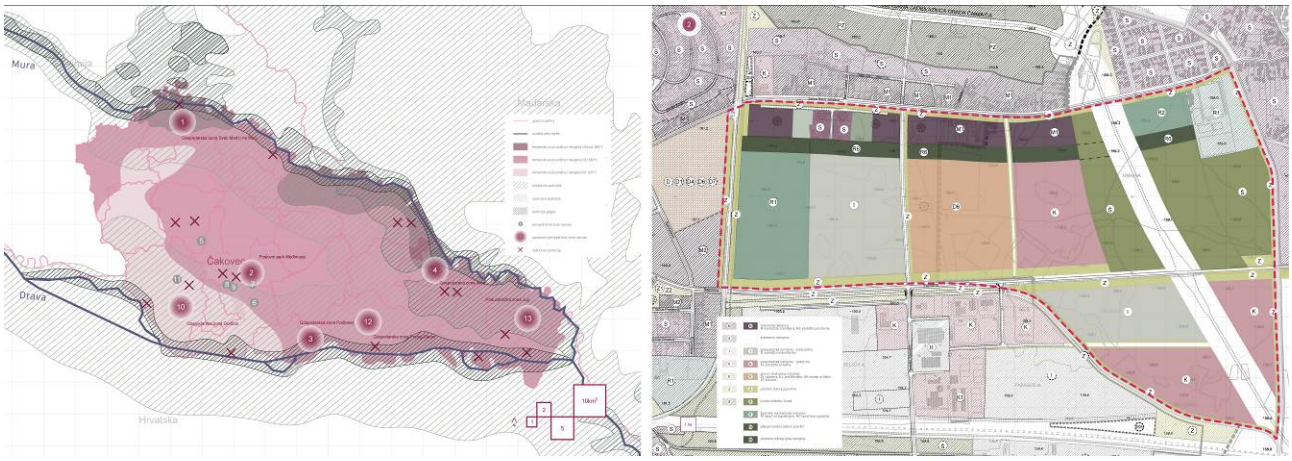


Fig. 4: "En-Park" Vision for Čakovac (students: Lara Prežgaj & Marija Pupovac; mentor: Tamara Zaninović, PhD, Assistant Professor). Source: Archive of the Department.

4 DISCUSSION

Based on the analysis of the most significant ECTP-CEU and AESOP documents related to spatial planning education, a set of comparison criteria was established. These criteria were derived through the synthesis of thematic categories presented in the documents, whereby competency domains and educational objectives were grouped into broader analytical units applicable to the analysis of Urban Planning Workshop 1: Settlement Planning focused on the topic of small towns' spatial vision.

Document analysis demonstrates a strong consensus in understanding the role, scope, and expected outcomes of spatial planning education, despite varying institutional frameworks. While ECTP-CEU approaches planning primarily through the lens of professional competencies and practice standards, AESOP offers an educational framework that integrates theoretical knowledge, practical skills, and the ethical values necessary for socially responsible planning. Within this context, UPW1 serves as a key platform for acquiring both theoretical and applied academic knowledge, simulating professional spatial planning practice.

A central objective of this education is the development of students' ability to integrate spatial, social, economic, and environmental systems, particularly across scales ranging from regional to local. UPW1 functions as a pedagogical instrument that allows students to explore complex spatial dynamics, synthesize knowledge across multiple domains, and translate these insights into foundational visions and concepts for the further development of the selected area.

Research competencies are similarly emphasized across educational frameworks, highlighting the capacity for independent inquiry, critical evaluation, and the translation of research into action and spatial transformation. In addition to the foundational investigations conducted in UPW1, Research Seminar 1 provides an opportunity for deeper, topic-specific research. Students independently explore themes relevant to their chosen area and communicate the entire research process through seminar papers grounded in scientific methodology.

Methodological and technical competencies are also central, with documents underscoring the importance of mastering analytical tools, planning techniques, and legal and institutional instruments, as well as applying them in practice from drafting plans to participating in implementation processes. UPW11 is particularly instrumental in this regard, enabling students to apply analytical methods, employ planning instruments, and

develop the capacity for spatially informed decision-making. Through exercises in strategic thinking, the formulation of development visions, and the proposal of their potential realization using planning tools, students acquire crucial skills for professional practice, making this a pivotal component in the education of future spatial planners.

Both documents recognize the importance of visualization, communication skills, and participation as integral components of planning competence. In this context, UPW1 plays a key role by enabling the integration of analytical work, spatial concepts, and visual presentation into a coherent planning product. Special attention is also given to the creation of a conceptual model to further develop students' abilities to visualize solutions at different scales. Engagement of experts and the local community in the planning process is integrated through organized site visits, guest lectures, presentations, and the curation of exhibitions and publications of selected student works.

Furthermore, both documents strongly emphasize professional ethics, social responsibility, and the value-based dimension of planning. UPW1 can be seen as a didactic space in which the ethical and value-oriented principles of planning are concretized through decisions on spatial priorities, stakeholder involvement, and the interpretation of the public interest in proposed spatial solutions.

While UPW1 primarily focuses on the formulation of spatial visions and planning concepts, real-world spatial planning extends beyond the development of plans to their concrete implementation. The success of planning proposals depends on institutional procedures, financial capacities, and the engagement of public and private development actors, which may significantly reshape initial concepts. Although the workshop setting cannot fully simulate these complex dynamics, students are introduced to existing statutory and strategic frameworks as instruments that shape spatial transformation. A more explicit reflection on implementation conditions and constraints could further strengthen the connection between planning education and professional practice.

The conducted research demonstrates that Čakovec, as a representative small town, possesses a long-standing history of spatial planning. Its further development was already considered in the first half of the 20th century within a broader regional context, underscoring its considerable spatial and economic significance for northern Croatia even at that time. Subsequent interventions in the urban fabric, which substantially transformed the town's character during the second half of the 20th century, were largely driven by modifications in the spatial planning framework. These interventions provide illustrative examples of specific planning practices that warrant critical reflection when envisaging future urban development. Furthermore, strategic planning documents at both the regional and local levels offer a structured basis for analyzing and evaluating previously established development objectives, thereby supporting the formulation and refinement of a coherent vision for the town's future growth.

Student reflections on the future development of Čakovec adopt a variety of approaches, ranging from regional-scale concepts that consider natural and socio-economic characteristics, to site-specific solutions, such as brownfield areas, which have contributed to shaping the broader spatial development framework of the town.

The analysis of student work shows that UPW1 fosters the development of key planning competencies, particularly in the area of integrated spatial and socio-economic processes understanding. The projects are notable for their analytical rigor and synthetic ability, effectively translating spatial analyses into strategic development concepts and urban plans as planning instruments. There is a clear capacity to work across different spatial scales and to integrate environmental considerations and principles of sustainable development into the proposed solutions.

5 CONCLUSIONS

Based on the conducted research, it can be concluded that small towns, such as Čakovec in this study, provide an appropriate context for education in spatial planning. They are large enough to encompass the complexity of spatial, social, and economic processes, yet small enough to remain comprehensible as a whole and analytically manageable.

Towns of this size and position within the hierarchy of spatial systems enable the development of a broad range of competencies as defined by relevant European documents on spatial planning education, while simultaneously providing space for experimentation and innovative planning approaches. The experiences

gained through working on small-town planning within the educational process can serve as a solid foundation for the later application of planning methods and concepts in more complex, larger urban contexts.

In this sense, Urban Planning Workshop 1: Settlement Planning can be interpreted as an integrative learning platform that effectively links theoretical knowledge, planning practice, and the value-based principles of spatial planning. At the same time, spatial planning education should acknowledge that the development of plans represents only one phase of the overall planning process. Their realization depends on implementation mechanisms, financial frameworks, governance structures, and the active engagement of development actors, all of which ultimately shape spatial outcomes. Strengthening students' understanding of these conditions and constraints would therefore further enhance the educational model, enabling a more critical and practice-oriented connection between planning concepts and their real-world implementation.

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Analysing the Logistics Space near Cape Town International Airport in Comparison to the Seaport and Dry Port Environments

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1 ABSTRACT

One focal point on the interconnections between transport and land-use patterns is the concentration of economic activities near airports. However, the literature typically analyses the environs of airports without drawing comparisons with other transhipment zones, such as seaports and inland ports. To contribute towards filling this literature gap, the paper analyses the monthly rental values of warehousing, industrial, retail, and office properties in the vicinity of Cape Town International Airport, compared with those around the Port of Cape Town and Belcon inland/ dry port, South Africa. Property rental data were scraped on 10 December 2025 from the website of Property 24, a leading South African property listing company. Following the cleaning process, the dataset comprised 240 data points: 105 industrial listings, 106 warehouse listings, 25 office listings, and four retail listings across the three transhipment precincts. However, only 186 street addresses were successfully geocoded in Python, forming the foundation for spatial analysis. Using QGIS, RStudio and SPSS for spatial and statistical analysis, the results showed that the mean rental values for industrial, warehouse, and office properties were highest in areas near the airport, followed by those near the port, and lowest around the inland port. The findings provide evidence that, relative to other transhipment precincts analysed, the airport environs may constitute a distinct industrial, warehouse and office property sub-market.

Keywords: Cape Town International Airport, Port of Cape Town, Belcon dry port, transhipment precincts, City of Cape Town

2 INTRODUCTION

One core area of the nexus between transportation technology advancements and land-use patterns is the concentration of economic activities near airports (Mokhele & Geyer, 2018), in line with the normative models of the so-called airport-led development. Proposing the idealised composition and spatial form of urban development near airports, these models are epitomised by the airport city and aerotropolis. Although the airport city conception encompasses various distinct categories (Conway, 1993), it is typically used to promote urban development in the immediate vicinity of airports (Kasarda, 2009). As the airport city evolves, intensifies and matures, urban development is expected to radiate outward, subsequently resulting in the spatial form of the aerotropolis, which could extend to a radius of about 20km from the airport (Kasarda & Lindsay, 2011). Policymakers, spatial planners, airport authorities, and developers across the world use these models to market and strategically guide the economic activity mix and spatial form of urban development, which is understood to be related to the airport's core aviation functions.

Despite its insights, the existing literature on the airport-urban development nexus analyses the environs of airports without comparing them with other transhipment zones within a given territory, particularly seaports and inland/ dry ports. The concept of transhipment points is akin to what Palander (1935) eloquently referred to in his seminal work as transport points connected to other transport points by transport lines. Intermediate transport points, therefore, have special transfer benefits when they are transhipment points or junctions (Hoover, 1948).

Various transhipment nodes are crucial for facilitating logistics processes and global trade amid intensifying globalisation (Chen et al., 2017), and therefore have the potential to shape development patterns and the spatial economy in their territories. Reflecting on the importance of ports, the UN Trade & Development (2025) argues that maritime transport is the backbone of global trade, accounting for over 80% of the volume of goods transported worldwide. Seaborne trade has evolved and gained traction over time, influenced by the increasing containerisation, the growth of developing economies and the shifting global patterns of production and consumption (UN Trade & Development, 2025). In this evolving economic milieu, the concept of an inland or dry port has been used to shift intermodal terminals inland and reduce traffic congestion at seaports (Bayene et al., 2023). While seaports undoubtedly dominate in terms of the volume of goods transported globally, the International Air Transport Association (n.d.) reports that air transport

accounts for approximately 35% of the value of global trade, reflecting the important role airports play in supply chains and logistics. Globally, cargo tonne kilometres increase year on year, reflecting the importance and growth of the air cargo market (International Air Transport Association, 2025).

To contribute towards extending the literature and filling the gap above (i.e., the lack of a comparative analysis of transhipment precincts), the paper analyses the rental value of properties in the vicinity of Cape Town International Airport, South Africa, in comparison to the values around the Port of Cape Town and Belcon inland port. The paper addresses the following research question: Do the environs of the airport represent a unique property sub-market compared to the Port of Cape Town and Belcon inland port? As detailed in the Methods section, the analysis focused on the monthly rental values of warehousing, industrial, retail, and office premises in and around the studied transhipment precincts.

3 LITERATURE REVIEW

As emphasised by Usman et al. (2021), the urban property market is characterised by price variation, which may be influenced by several spatial, social, and physical variables, arguably making it a composite of separate submarkets. Market analysis, therefore, requires segmentation to delineate the property market into distinct groups that are relatively homogenous within themselves, while heterogeneous with others. Sub-markets were introduced as an important analytical tool in the 1950s and 1960s, and the resultant research in property market segmentation has arguably improved the accuracy of property pricing. However, most segmentation studies have focused on the housing market with less attention on the commercial property market. Similar to the housing market, the commercial or non-housing property market is complex and heterogeneous and warrants attention on the market segmentation (Usman et al., 2021).

Aligned with the discussion above, Dunse, Leishman and Watkins (2002) argue that the spatial variation in urban property values is specifically due to the influence of the physical attributes of the property stock across different sections of the city. Two approaches dealing with this variation in property values have been developed. On the one hand, as noted earlier, markets can be interpreted as composed of interrelated sub-markets, each of which may exhibit different price or rental values. On the other hand, price and rental variations can be explained through trade-off theories of locational choice (Dunse, Leishman & Watkins, 2002).

In a study of the office real estate market in Tokyo, Japan, Matsuo et al. (2024) found that the presence or absence of amenities significantly impacted both rent and vacancy rates. Amenities have been perceived and interpreted differently in the literature, with numerous studies classifying them into neighbourhood, on-site, and worker amenities (Sivitanidou, 1995). Neighbourhood amenities include, for instance, the office's proximity to complementary facilities, such as restaurants and retail stores. Neighbourhood amenities are shared among various neighbouring office buildings and thus have a strong public element. By contrast, on-site amenities are private, as their benefits are restricted to tenants in the individual buildings and therefore serve as a differentiating factor from other premises. In this regard, neighbourhood amenities are exogenous, making it difficult for a property owner to directly influence them through capital investment. However, on-site amenities can be directly influenced by the individual property owners (Matsuo et al., 2024).

Sivitanidou (1995) argue that within multi-nodal metropolises, business rent variation across nodes should be attributed not only to differences in their amenity endowments but also to differences in their institutional frameworks. Coupled with a set of firm amenities reflecting traditional demand-side influences (such as access to the central business district, freeways, and airports) and various worker amenities (education quality, levels of crime, access to shopping opportunities, and the ocean), supply-side attributes, such as the availability of appropriately zoned land, and density restrictions, were found to play a crucial role in influencing price variations in office-commercial rents (Sivitanidou, 1995).

In another study, Franco and Cutter (2022) found that, on the one hand, open space, typically an amenity considered to be jointly valuable to firms and households, had either weak or non-robust effects on non-residential property values. On the other hand, the amenities of coastal access, air pollution, weather and crime levels appeared to have stable correlations with property values. In contrast, amenities that are likely valued only by firms, such as accessibility and proximity to concentrations of skilled labour, showed strong and significant correlations with non-residential properties (Franco & Cutter, 2022).

4 STUDY AREA

The study focused on the urban development precincts that are contiguous with the transhipment nodes of Cape Town International Airport, the Port of Cape Town, and the Belcon inland/ dry port in the City of Cape Town municipality, Western Cape province, South Africa. The subject development nodes are Airport Industria/ Airport City, Paarden Eiland, and Parow Industria, respectively (Fig. 1). The studied precincts are considered among the main industrial areas in the City of Cape Town municipality, with varying spatial economic attributes, backgrounds and histories, as highlighted below. It is important to note that the study did not examine areas within the seaport, the inland port, or the airport landholdings.

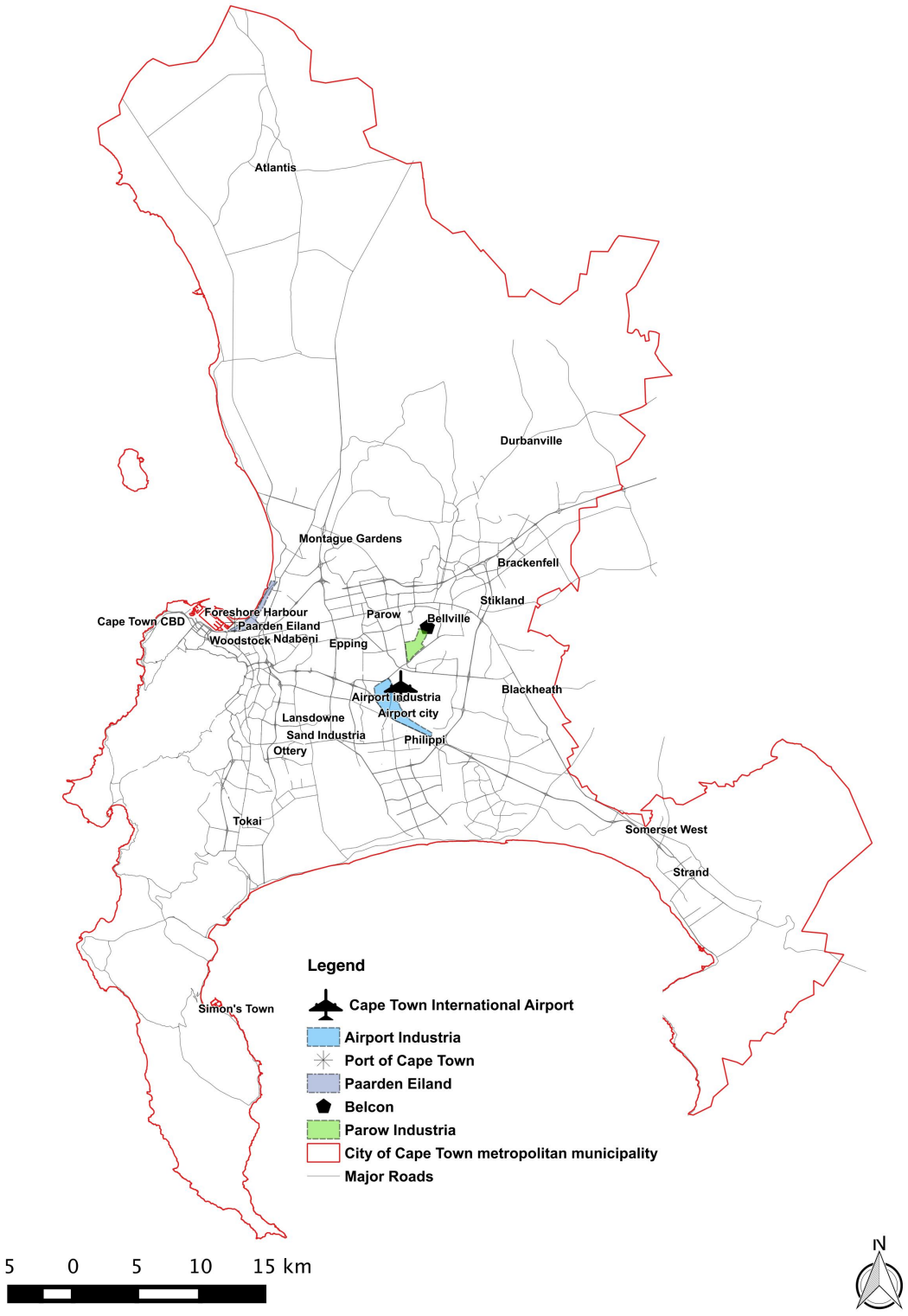


Fig. 1: Location of Cape Town International Airport relative to the surrounding municipalities.

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Established in 1954, Cape Town International Airport is the second-busiest airport in South Africa after OR Tambo International Airport in Gauteng province. It is also the only international airport and one of the two commercial passenger airports in the Western Cape province. Origins of urban development in the vicinity of the airport can be traced to the government's concerted efforts to promote industrial development, where in 1981, about 130 ha of land in this area was zoned for industrial purposes, albeit most of the landholdings were undeveloped at the time (Mokhele, 2017). A trend in the development of warehousing and storage facilities near the airport was particularly evident in the 1990s (City of Cape Town municipality, 2002).

The Port of Cape Town is also the second-largest seaport in South Africa, after the Port of Durban in KwaZulu-Natal province. Paarden Eiland, situated in the environs of the port, has a long spatial economic development history. The literature notes that, with the increasing scale and intensity of manufacturing in Cape Town in the mid-20th century, a search for more expansive and affordable land naturally led to the establishment of new industrial zones in, among other areas, Paarden Eiland. The area was developed mainly in the 1960s (Mokhele & Fisher-Holloway, 2024). In the mid 1990s, Paarden Eiland notably boasted a prime industrial rental rate that was about three percent higher than the municipal average (City of Cape Town municipality, 2002).

The third focus area, Belcon, is a dry port directly connected to the Port of Cape Town via rail. In 2010, Transnet Freight Rail officially opened the Belcon terminal, which serves as an inland port and an extension of the Port of Cape Town, focusing on rail-based container consolidation. Positioned about 30km from the port, this facility allows truckers to increase the number of loads per day by avoiding traffic congestion and delays in and out of the city, as well as congestion at the port itself.[1]

5 RESEARCH DESIGN AND METHODS

This section presents the overarching research design, the units of analysis, and the data collection and analysis methods employed in the study.

5.1 Research design

The study employed a quantitative comparative research design (Iranifard & Roudsari, 2022), using statistical and spatial analysis to compare the monthly rental values of warehousing, industrial, retail, and office properties in the environs of Cape Town International Airport, the Port of Cape Town, and the Belcon inland port.

5.2 Units of analysis

The study's units of analysis were the warehousing, industrial, retail, and office premises advertised for rent in the vicinity of Cape Town International Airport, the Port of Cape Town, and the Belcon inland port. This focus distinguishes the paper from previous related studies (for example, Mokhele, 2025), which used land parcels rather than individual establishments as units of analysis. A key limitation of land parcel-based studies is that they do not account for the potential influence of what Sivitanidou (1995) refers to as on-site amenities, as a single land parcel may accommodate multiple buildings or units with differing amenity provisions and value.

5.3 Data sources

Generally, data on land transactions are scarce in cities, whereas data on rental prices are relatively frequent (Fuss, Koller & Weigand, 2021). Property rental data were scraped on 10 December 2025 from the website of Property 24, a leading South African property listing company. Property 24 was selected because it is a platform widely used by both property agents and individual property owners to advertise properties for sale and rent. The data scraped from Property 24 comprised 361 data points: 218 industrial listings, 114 warehouse listings, 25 office listings, and four retail listings across the three transhipment precincts. To avoid distortions due to the typical conflation of and overlaps between the "industrial" and "warehouse" land-use/ economic activity categories, the industrial listings that did not mention warehouse were categorised under "industrial". In contrast, the industrial listings that mentioned "warehouse" were included under the warehouse category.

[1] https://www.freightnews.co.za/article/belcon-forever-a-white-elephant-or-the-port-of-cape-towns-saviour

The data scraped from the website were cleaned by removing duplicates and entries for which the average monthly rental price per square metre (m2) could not be determined, where, for instance, the monthly rental value or the extent of the property were missing. After discarding 121 entries, the cleaned data comprised 240 data points, as discussed in detail in the results section.

Furthermore, to prepare for the spatial analysis, the street addresses from the web-scraped data were geocoded in Python using the Google Maps application programming interface (API). The total number of geocoded data points was 186, after omitting the entries without accurately formatted street addresses. It is, however, important to note that the omitted data points were still valid and included in the statistical analysis.

5.3.1 Data analysis methods

Statistical and spatial analyses were performed to identify similarities and differences in property rental values across the three transhipment precincts, particularly to determine whether a unique property sub-market existed in the environs of the airport, or by implication, at the other two transhipment precincts.

5.3.2 Statistical analysis

The monthly rental information from the three transhipment precincts was combined into a single Excel spreadsheet and loaded into IBM statistical package for social sciences (SPSS) version 29 for analysis. Basic statistical analysis was then conducted on the 240 data points. The data were split in SPSS to disaggregate the analysis by the transhipment precincts and the four land-use categories analysed.

5.3.3 Spatial analysis

Spatial analysis of the 186 successfully geocoded points was conducted to compare the three transhipment precincts. Because of the relatively small population, the points were analysed at an aggregated level, without distinguishing between the warehouse, industrial, retail and office categories. After obtaining the coordinates through the geocoding process outlined in Section 5.3, the analysis and map visualisation were performed in QGIS and RStudio.

The first tool employed in QGIS, kernel density, estimates the density of features within an area and creates a smoothly tapered surface for each point (ESRI, 2019). In the study, the features whose densities were calculated were the geocoded warehousing, industrial, retail, and office premises advertised for rent across the three transhipment precincts.

Global and local Moran's I were also applied to measure spatial autocorrelation to examine the data's pattern and identify the similarities or discrepancies within the dataset (Yamada, 2024; Chen, 2023; Westerholt, 2022). Moran's I estimates typically range from -1 to +1 (Overmars et al., 2003), where negative values indicate that dissimilar values are closer together and positive values indicate that similar values are clustered. In contrast, a value of zero indicates that the data are randomly distributed. In Moran's I statistics, the p-value indicates statistical significance, where values below 0.05 are statistically significant, implying that the observed pattern is not due to random chance.

6 RESULTS

As noted in Section 5.3 above, the cleaned property rental data comprised 240 data points, including 106 warehouses, 105 industrial properties, 25 office properties and four retail properties across the three transhipment precincts. However, the successfully geocoded data used for spatial analysis comprised 186 points. Against this backdrop, this section presents the results of the statistical and spatial analyses comparing the monthly rental values of warehouse, industrial, retail, and office properties near Cape Town International Airport (Airport Industria/ Airport City), the Port of Cape Town (Paarden Eiland), and the Belcon inland port (Parow Industria).

6.1 Densities and land-use category mix

The kernel density estimations in Fig. 2 identify areas with a high concentration of warehouse, industrial, retail and office premises, where green indicates low-intensity areas and red marks high-intensity zones. Kernel density results show that the high density values were found in the vicinity of the Port of Cape Town, followed by the environs of the airport and Belcon inland port (Fig. 2). Notably, the data points in the environs of the airport were more spatially spread out compared to Parow Industria and Paarden Eiland.

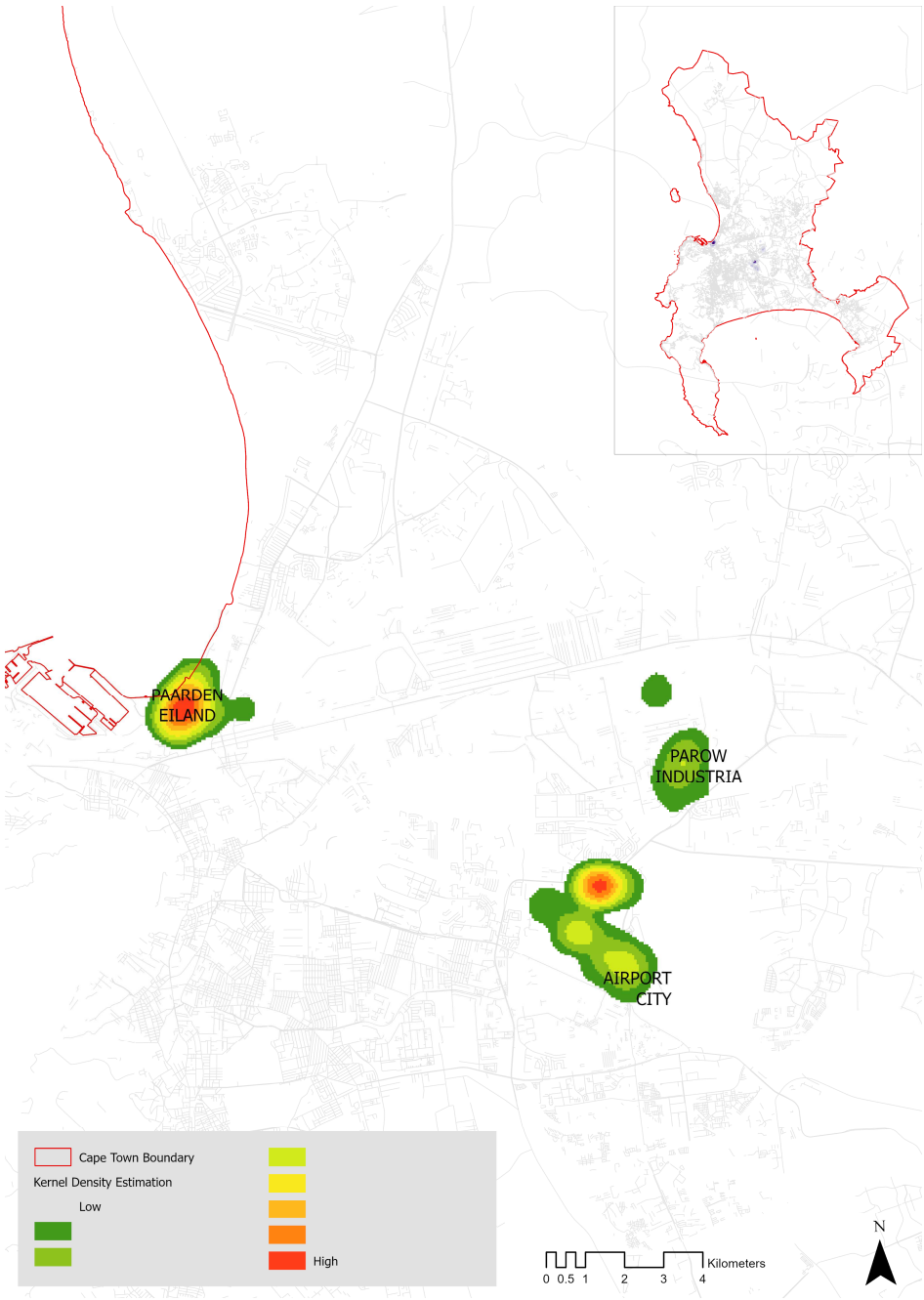


Fig. 2: Kernel density values

Building on the kernel density presentation above, it was also essential to investigate the economic activity or land-use composition across the three transhipment zones. As shown in Fig. 3, in Airport Industria, the majority of the advertised properties were warehouses, followed by industrial and office premises. Notably, no retail properties were advertised for rent near the airport. In Paarden Eiland, the majority were industrial properties, followed by warehousing, office and retail properties. In Parow Industria, most entries were industrial properties, followed by warehousing, office and retail properties. Overall, the number of retail properties was relatively low across the study areas, cementing the transhipment precincts' primary roles as industrial and logistics zones. Only Paarden Eiland reflected a fair number of office properties, albeit still lower than the other land-use categories within the precinct (Fig. 3).

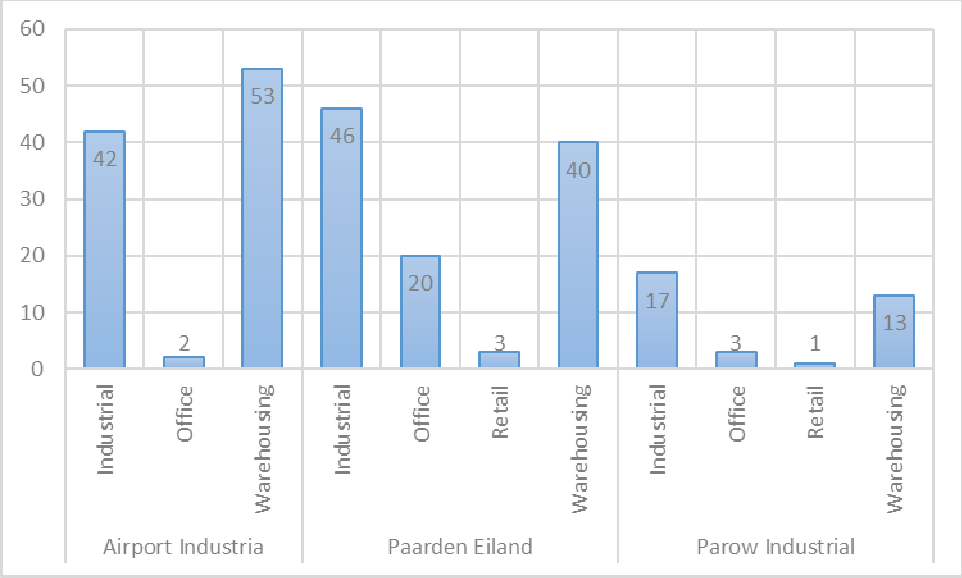


Fig. 3: Number of advertised properties at Airport Industria, Paarden Eiland, and Parow Industria.

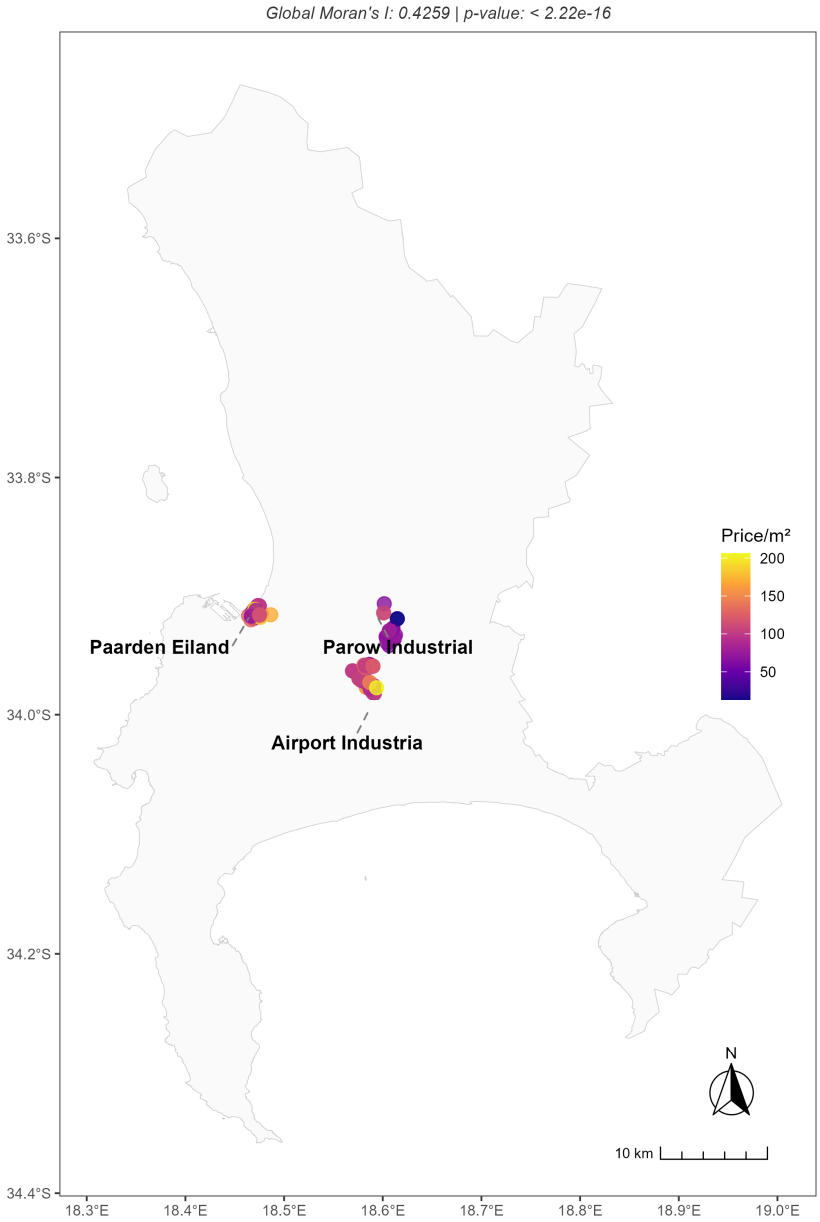


Fig. 4: Geographical distribution of the rental price variation (Global Moran's I)

6.2 Aggregated rental value variations between the transhipment precincts

The Global Moran's *I* yielded a value of 0.4322, indicating spatial clustering within the dataset. This suggests that premises with high rental prices tended to be located close to one another, and that lower-priced properties were similarly clustered. The *p*-value of < 2.22e-16 confirms that the observed pattern is statistically significant and unlikely to have occurred by chance. Fig. 4 shows that properties in Airport Industria near the airport and Paarden Eiland near the port had higher rental prices per m^2. In contrast, Parow Industrial was characterised by medium to low rental prices per m^2.

The Local Moran's *I* statistics are presented in Table 1 below. For Paarden Eiland, Moran's *I* statistic of 0.2158 implies that properties with similar price per m^2 were located near one another. This result is statistically significant, indicating spatial clustering in the area. In Airport Industria, clustering was slightly higher with a value of 0.3774, reflecting the tendency for properties with similar prices to be spatially concentrated. The *p*-value is significant for this location as well. In contrast, Parow Industria recorded a value of -0.0125, which is close to zero, with a *p*-value of 0.39768. This result is not statistically significant, suggesting that the distribution of monthly rental prices per m^2 in Parow Industria was spatially random.

Metric	Location	Moran's *I* Estimate	P-value	Observation Count
Moran's *I* statistic	Paarden Eiland	0.2158	>0.001	79
Moran's *I* statistic 1	Airport Industria	0.3774	>0.001	78
Moran's *I* statistic 2	Parow Industria	-0.0125	0.39768	29

Table 1: Moran's I statistics.

6.3 Disaggregated rental value variations between the transhipment precincts

The descriptive statistics results, disaggregated by transhipment precincts and the four land-use categories, are displayed in Table 2 and discussed in the subsections hereunder. Monthly rental variations within and between the precincts could potentially be influenced by differences in neighbourhood and on-site amenities (Dunse, Leishman & Watkins, 2002). Overall, the highest mean was ZAR177.5/m^2 for two office properties at Airport Industria, followed by ZAR139/m^2 for office premises at Paarden Eiland. The findings show that office properties have a higher rental value than warehousing, industrial, and retail properties across the three transhipment precincts.

Precinct	Category	N	Min	Max	Range	Mean	Std. Dev
Airport Industria	Industrial	42	69.6	204.6	135.0	104.6	24.9
	Office	2	150.0	205.0	55.0	177.5	38.9
	Warehousing	53	67.5	157.1	89.6	109.3	27.7
Paarden Eiland	Industrial	46	66.0	175.7	110.0	98.6	24.4
	Office	20	71.1	206.3	135.1	139.0	40.1
	Retail	3	114.8	116.7	1.9	116.0	1.1
	Warehousing	40	75.0	120.0	45.0	91.9	13.2
Parow Industrial	Industrial	17	12.0	115.0	103.0	65.1	24.6
	Office	3	65.0	80.0	15.0	70.0	8.7
	Retail	1	110.0	110.0	-	110.0	-
	Warehousing	13	60.0	110.0	50.0	74.3	12.3

Table 2: Disaggregated descriptive statistics.

6.3.1 Warehouse rental values

The mean monthly warehouse rental value was highest at Airport Industria (ZAR109.3/m2), near the airport, followed closely by Paarden Eiland at ZAR91.9/m2. The mean value of advertised warehouses was lowest at Parow Industria, at ZAR74.3/m2.

6.3.2 Industrial rental values

The mean industrial monthly rental value was highest at Airport Industria at ZAR104.6/m2, with the widest range at ZAR135/m2, followed by Paarden Eiland at ZAR98.6/m2. The mean industrial value was lowest at Parow Industria at ZAR65.1/m2. The findings indicate that, unlike in the mid 1990s when the industrial rental rate in Paarden Eiland was three percent higher than the municipal average (City of Cape Town municipality, 2002), the November 2025 rental rates were slightly higher in the vicinity of the airport.

6.3.3 Office rental values

The mean office rental value was highest at Airport Industria at ZAR177.5/m2, albeit only two properties were recorded. Paarden Eiland followed with an office rental value of ZAR139/m2. The office mean value was lowest at Parow Industria at ZAR70/m2, with only three properties recorded.

6.3.4 Retail rental values

The mean advertised retail rental value was highest at Paarden Eiland at ZAR116.7/m2, followed closely by Parow Industria at ZAR110/m2. As observed earlier in the paper, no retail property was advertised for rent in the vicinity of the airport.

7 CONCLUSION

The aim of the paper was to analyse the rental value of warehouse, industrial, office and retail properties in the vicinity of Cape Town International Airport, in comparison with values around the Port of Cape Town, and the Belcon inland/ dry port. The specific objective was to ascertain if the airport environs, in contradistinction to the other two transhipment precincts, represented a unique property market. Using QGIS, SPSS and RStudio to analyse the monthly rental data scraped from a prominent property-listing company, the results show that the mean rental values for industrial, warehouse, and office properties were highest near the airport, followed by those in the vicinity of the port, and lowest around the inland port. Global Moran's I showed a stronger clustering of similar rental values in the environs of the airport, followed by Paarden Eiland, while estimates in Parow Industria were not statistically significant.

Despite the densities that are higher in the vicinity of the Port of Cape Town and the absence of retail properties advertised for rent near the airport, the study's findings show that, from the perspective of rental values, it can be argued that airport environs may potentially constitute a distinct warehousing, industrial, and office property sub-market. Spatial planning efforts could leverage this unique position to, among other objectives, appropriately guide the municipality's spatial economy and maximise the agglomeration economies in the vicinity of the airport.

Despite the paper's insights, it has two main limitations. Firstly, the cross-sectional study's main limitation is that rental information was collected at a single point in time (i.e., November 2025) and may not provide a comprehensive picture of the dynamics of property rental value near the airport, relative to the seaport and the inland port environs. Secondly, the study relied on the scraping of a single website.

To address these limitations, it is recommended that future research consider different property listing websites, include sale prices, and scrape data at different times to identify trends and patterns in the warehouse, industrial, office and retail property values in the vicinity of transhipment zones.

8 ACKNOWLEDGEMENT

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reviewed paper

Analysing Urban Development Patterns: A Spatio-Temporal Analysis and Predictive Scenarios around Major Railway Stations/Terminals

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1 ABSTRACT

Rapid urbanisation trends in Southeast Asia are primarily influenced by mass transit systems, however the influence of railways on land use dynamics in India remains unique from global patterns. Unlike contemporary Light Rail Transit (LRT) or Metro systems where Transit-Oriented Development (TOD) is often a planned and post-construction intervention, Indian railway nodes typically predate the very concept of TOD, implying urban areas have integrated organically following railway infrastructure rather than being retrofitted. The study investigates this Railway-induced spatial restructuring in the Indian context, specifically the Southern West Bengal region, a rapidly densifying polycentric system, with the primary objective of determining whether railway proximity naturally fosters efficient development or induces chaotic ribbon sprawl. The methodology incorporates a multi-scalar geospatial framework by employing a 25-year temporal gradient (2000-2025) to analyse the relationship between horizontal densification and vertical building density. Data from remote sensing (Landsat 7/8) was utilised to compute fragmentation metrics using FRAGSTATS to quantify horizontal sprawl, while Google Earth Engine (Open Buildings 2.5D) was utilised to derive the average building height. These morphological outputs were further correlated with Space Syntax Integration values to assess functional connectivity. The analysis established four distinct station typologies regarding the urban form efficiency, namely saturated node, stagnant core, benchmark model and developing node. Moving beyond standard computer simulations, the study predicts future growth by analysing these distinct evolutionary categories and utilising passenger footfall data to forecast passenger and train load transfer. The research concludes that without policy intervention, rapid expansion of these urban areas will overburden infrastructure, highlighting the need for specific policy formulation to mitigate these externalities before they become irreversible.

Keywords: Railway-induced Urban Growth, Transit-oriented Development, Spatial Metrics, Urban Sprawl, Urban Morphology

2 INTRODUCTION

2.1 Background and Research Motivation

The relationship between transport infrastructure and urban form is one of the defining characteristics of the 21st century Asian metropolis (Navalkar et al. 2023). A new global paradigm has emerged focusing on smart, sustainable, and inclusive development, yet the practical application of these concepts in Southeast Asia often faces unique challenges. In India, rapid urbanisation is not merely a function of population growth but is intrinsically linked to mass transit availability (Sekar and Gangopadhyay 2017). Southern West Bengal serves as a paradigmatic case of this phenomenon. As a major rail corridor and economic gateway for Eastern India, the region is witnessing a rapid emergence of peri-urban growth clusters centred around the railway stations. Unlike the planned Transit-Oriented Development (TOD) seen in other cities like Singapore or Hong Kong where density is not organic, the urban growth around Southern West Bengal is organic, historical and mostly chaotic (Mandal et al. 2020).

The motivation for this research arises from a critical observation of the surroundings where the Government of India (through the Ministry of Railways) has allocated significant capital of approximately INR 14,000 crores to upgrade railway infrastructure in West Bengal to support micro-enterprises and regional movement. But investment alone does not guarantee urban transformation. With the absence of evidence-based urban planning, capital investment runs the risk of accelerating “ribbon sprawl” rather than fostering efficient and compact transit nodes. This has led to discussions that investment numbers alone are insufficient, and closer

attention must be paid to the tangible morphological changes they trigger in cities (Ramachandra et al., 2014).

2.2 Problem Statement

The central planning challenge facing the Kolkata Metropolitan Area (KMA) and its hinterlands is the balancing act between infrastructure expansion and sustainable land management. Current frameworks of urban planning often lack the granular data required to understand how railway stations specifically influence the vertical and horizontal dimensions of growth. There is a clear methodological gap, as most existing studies focus only on 2D land-use patterns and overlook the vertical intensity of development (such as building heights), which is essential for understanding densification (Karmarkar, Jana, and Velaga 2024). Along with this, a significant contextual gap persists because international TOD frameworks are seldom tailored to the complex realities of Indian railway towns, where informal settlements and historically evolved urban layouts resist easy incorporation into conventional planning models (Mehra and Vardhan 2025). In these regions, the presence of informal settlements and historical urban forms resists the 'clean' geometry of conventional planning models. While this study establishes a vital baseline for these towns, it also understands that it lacks the socio-economic depth needed to fully capture these physical changes that involve the lives of the people inhabiting them. Consequently, the primary research inquiry stands at "How is railway expansion reshaping patterns of urban development in this dynamic region?" and "Do railway nodes encourage compact, efficient agglomerations, or do they contribute to more fragmented and dispersed urban growth?"

2.3 Aim and Objectives

The primary aim of this study is to investigate the phenomenon of transit-induced spatial restructuring along the Southern West Bengal rail corridor, specifically determining whether railway proximity fosters efficient densification or induces chaotic sprawl. To achieve this, the research examines the spatio-temporal evolution of urban forms around four distinct railway station contexts – Howrah, Shalimar, Santragachi and Uluberia – over a 25-year period (2000 to 2025). This involves a multi-scalar analysis that correlates horizontal fragmentation metrics with vertical building density to establish distinct evolutionary typologies of railway-induced growth. Building upon this morphological classification, the study further seeks to forecast future development trajectories for the active growth nodes by synthesising historical urbanisation trends with passenger ridership shifts.

3 LITERATURE REVIEW

The relationship between rail corridors and urban form has been extensively documented, establishing the fact that mass transit systems are acting as an active agent for densification and spatial restructuring. One of the studies monitored urban growth in Howrah (Mandal et al. 2020). The study used spatial metrics to reveal a distinct pattern of "clumping" in the core city, which is contrasted against rapid outlying growth and high fragmentation at the periphery. This also aligns with the findings of Sekar and Gangopadhyay (Sekar and Gangopadhyay 2017), who analysed land use changes around suburban rail in Chennai using a "concentration index". This index confirms densification has shifted decisively towards railway corridors, thereby altering the city's macro-spatial form. All these studies underscore that while rail proximity acts as a catalyst for growth, the resulting urban morphology varies significantly between compact and fragmented based on local constraints.

However, a significant methodological limitation in current research is the heavy reliance on two-dimensional Land Use Land Cover (LULC) analysis, ignoring the vertical intensity that defines the principle of modern urbanisation. While LULC effectively maps the horizontal expansion, it fails to capture the volumetric capacity of transit nodes. Recent work by Karmarkar (Karmarkar et al. 2024) attempts to bridge this gap by modelling "Volumetric Growth" (2D+3D) around new transit stations. Their work demonstrated that high-rise development correlates strongly with station proximity, yet such studies majorly rely on coarse building height classes or limited field data. There remains a gap of more precise and continuous building height assessments to accurately correlate horizontal with vertical densification, which is addressed by this study by using open-source 2.5D datasets.

While Transit-Oriented Development (TOD) frameworks are well established globally, they are rarely adapted to the specific spatial conditions of historical Indian towns. The assessments often utilise the index-based approaches involving density, diversity and accessibility, as demonstrated in a study by Uddin (Uddin et al. 2023) for the Dhaka MRT and Lin (Lin et al. 2023) for Taipei. However, these frameworks are applied to planned systems where the "railway station area" is a designed zone. The study by Mehra and Vardhan (Mehra and Vardhan 2025) emphasises the necessity of defining TOD typologies specific to the corridor context rather than applying generic metrics, arguing that design and density are the most influential factors in Indian suburban rail corridors. In the absence of such contextualisation, standard TOD principles may fail to address the organic, informal and historical nature of urban growth in the context.

Finally, the approach to forecasting future urban growth around these railway nodes requires re-evaluation. Current predictive models, such as those employing Cellular Automata (CA) and Markov chains by Fu (Fu et al. 2024) or SLEUTH models, have successfully predicted land use changes with high accuracy. However, these mathematical simulations often consider very limited variables, which mostly fail to capture the "messy" socio-economic complexities and historical contexts of Indian railway towns. Consequently, this study proposes shifting from purely mathematical simulations to identifying evolutionary typologies based on historical data and passenger footfall, which is a critical demand variable that is often absent in other research, to forecast future development scenarios more accurately.

4 STUDY AREA

The research focuses on the Southern West Bengal Rail corridor, specifically the South Eastern Railway corridor, which acts as the critical economic and trade gateway for Eastern India. This corridor was also selected for its strategic alignment with the urbanisation priorities and economic policies that were established by the Kolkata Metropolitan Development Authority (KMDA), which functions as a polycentric urban system where the selected railway stations act as anchor points for metropolitan area development. The spatial structure of this region is unique, urban growth is heavily constrained by the Hooghly River and existing infrastructure, forcing a linear north-south expansion pattern along the railway network. This geography of the region makes it an ideal laboratory for analysing "transit-induced spatial restructuring", as the railway line effectively dictates the spine of urban densification. To capture the diverse evolutionary stages of transit nodes, four specific railway stations were selected to represent a gradient of urban development maturity (Fig. 1).

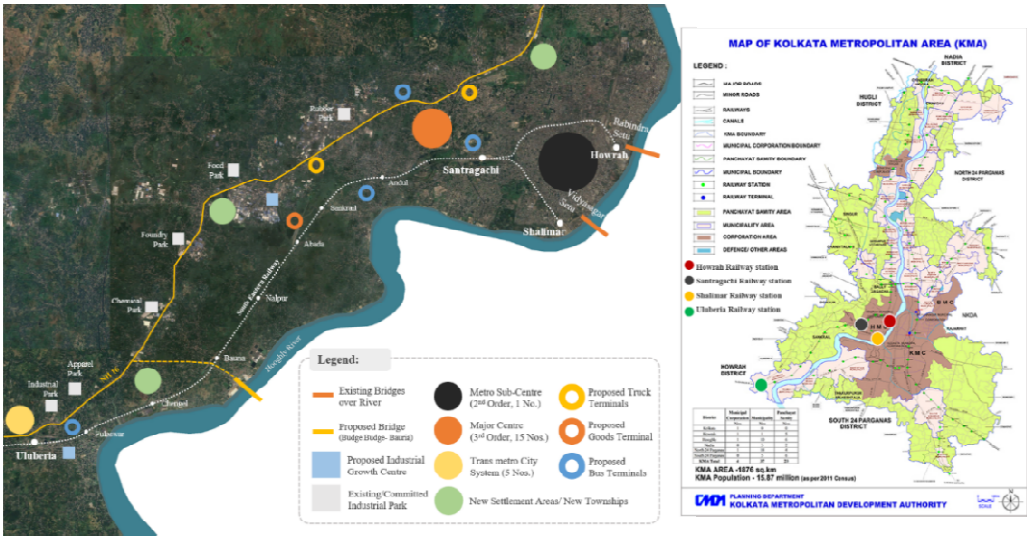


Fig. 1: Map of the Kolkata Metropolitan Area showing the strategic location of Howrah, Santragachi, Shalimar, and Uluberia Railway Stations along the South Eastern Railway Corridor (Source: Adapted from KMDA Comprehensive Mobility Plan, 2008)

- Howrah (The Historic Anchor): Howrah is selected as the primary baseline. It functions as the region's historic terminal and a designated "Metro Sub-Centre", which is providing a fully urbanised and spatially controlled case against which developing nodes can be compared. Currently it serves millions of commuters and also acts as the primary gateway to the Kolkata region .

- Shalimar (The Logistics Hub): Shalimar has a unique spatial dynamic of a specialised logistics and freight-orientated terminal located within the urban core, serving as the case for how heavy freight infrastructure and truck terminals influence immediate neighbourhood development which is distinct from purely passenger-centric hubs.
- Santragachi (The Dual-purpose Node): Santragachi has the strategic role of being a dual-purpose node i.e., functioning simultaneously as a high-volume suburban halt and a major express train terminal with Kona Expressway in close proximity with the railway stations, making it a prime location for analysing the integration of rail infrastructure with the National Highway (NH 16) and its potential as an emerging metropolitan sub-centre.
- Uluberia (The Peri-Urban Periphery): Uluberia represents the metropolitan as well as the corridor's developing edge. This station is designated as a "Trans Metro City" node that acts as a vital intermodal link to the Haldia industrial belt and is also the starting point of the upcoming Varanasi-Ranchi-Kolkata greenfield expressway project, providing a crucial case study for analysing early-stage urbanisation and land-use transformation at the metropolitan fringe.

5 METHODOLOGY

This study adopts an integrated urban development framework that synthesises multi-scalar geospatial analysis with morphological metrics to assess the impact of rail infrastructure on urban form. The methodological approach is subdivided into three distinct phases: urban development analysis, comparative analysis and categorisation, and policy recommendations (Fig. 2).

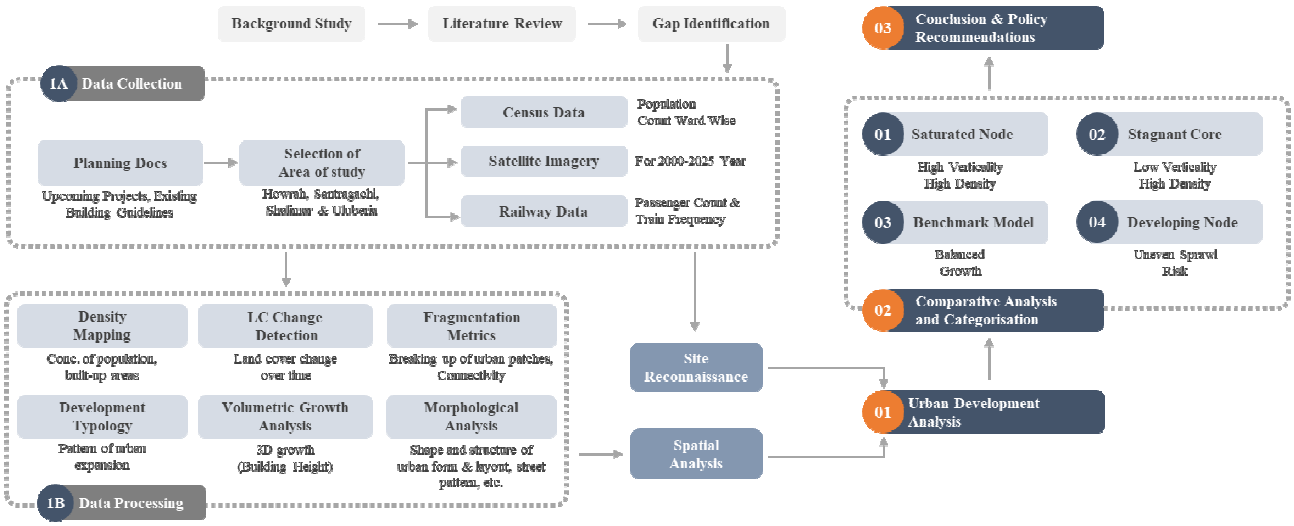


Fig. 2: Methodological Framework Flowchart. (Source: Author)

5.1 Data Collection

For a long-term analysis on transit-induced spatial restructuring, the study integrates diverse secondary sources to create a harmonised dataset spanning 25 years. Land cover changes were monitored using Landsat 7 and 8 satellite imagery (30M resolution) through Google Earth Engine (GEE) for the years 2000 to 2025. To address the critical gap in vertical densification analysis, which is often missed in traditional sprawl studies, building height data was extracted using the "Open Buildings 2.5D" dataset , helping in the calculation of volumetric metrics within the station catchment area. These morphological datasets were complemented by socio-economic layers. These include ward-wise population counts from the Census of India (2001 & 2011) and, crucially, the station-specific passenger footfall and train frequency data sourced from the South Eastern Railway division under Indian Railways. This integration allows for a direct correlation between physical urban form and transit demand.

5.2 Spatial and Morphological Analysis

To quantify the transit-induced spatial restructuring, the study employed a multi-scale buffer analysis. Using the geographic coordinates of each railway station as the geometric centroid, three concentric zones (with radii of 1 km, 3 km and 5 km) were established to capture the influence of railway nodes. The 1 km buffer

represents the immediate pedestrian core (TOD Zone), which assesses the walkability of a typical 10–15-minute walking radius. The 3 km buffer captures the intermediate catchment, which is served by non-motorised transport or para-transit feeds. The 5 km buffer shows the peri-urban interface, which analyses the extent to which the station's urbanisation pressure bleeds into the regional rural hinterland. Within these zones, three primary metrics were calculated.

5.2.1 Fragmentation Analysis (Horizontal Growth)

It measures the urban sprawl of the area. Patch Density (PD) was calculated using FRAGSTATS software as used in previous research by (Mandal et al. 2020; Ramachandra et al. 2014). Patch density is defined as the number of separate built-up patches per unit area. It serves as a robust method for classifying fragmentation versus consolidation. As observed in previous studies, high fragmentation at the periphery contrasts with "clumping" in the core. A greater patch density value signifies that the development is spread out, while a lower value indicates successful urbanisation and horizontal consolidation.

5.2.2 Volumetric Analysis

It fills the gap in traditional studies of urban sprawl. The research correlated Average Building Height (Havg) with the Building Density Index (BDI). This volumetric approach draws on methodologies for predicting the growth around the studied stations, which solidifies the fact that building height is a critical indicator of intensity. The Havg was derived using the Google Earth Engine's (GEE) Open Building 2.5D dataset. Comparing the Havg against the percentage of land cover by buildings (BDI), the analysis distinguishes between various categories of development pattern, thus determining the true 3D capacity of the urban core.

5.2.3 Space Syntax (Network Connectivity):

To evaluate the functional efficiency of the road network, Space Syntax Integration values were calculated. These metrics measure how accessible the street in the various buffer regions is, which serves as the unit for measuring walkability and spatial quality. High integration values indicate a movement economy that supports commercial vitality, while low values suggest isolation. This variable helps to identify whether the station node is effectively integrated or functionally disconnected from its regional hinterland.

5.3 Typology Identification and Predictive Scenarios

The final phase of the framework synthesises the quantitative metrics from section 5.2 to establish a qualitative classification of the railway nodes. These classifications form the basis for forecasting future urban growth (Fig. 2).

5.3.1 Station Typology Framework

A comparative typology matrix was established to measure the urban efficiency of each node. The various metrics used were fragmentation, verticality and connectivity. The first category was the "Saturated" node, which is defined by extreme vertical intensity (high Havg) combined with high spatial congestion, this also represents that a node has reached its physical capacity limits. In contrast, the "Stagnant" node is characterised by high horizontal density (high BDI) but has remarkably low vertical growth (low Havg). This indicates a failure to utilise its central location due to poor connectivity or infrastructure bottlenecks. The third category, the "Benchmark Model", represents the ideal Transit-Oriented Development (TOD) outcome. It is also defined by high horizontal consolidation (low PD) paired with sustained vertical growth, highlighting efficiently managed density. Lastly, low vertical density and moderate horizontal saturation indicate the "Emerging node". This designation represents an early-stage node containing large areas of undeveloped land and significant untapped potential for future densification.

6 RESULTS AND DISCUSSION

6.1 Spatio-Temporal Dynamics: Horizontal Fragmentation vs. Consolidation

The temporal analysis of Patch Density (PD) from 2000 to 2025 reveals two divergent urban growth trajectories along the corridor (Fig. 3). In the mature nodes of Howrah and Santragachi, the PD metric demonstrates a distinct consolidation effect. For Howrah, the PD has remained relatively stable over the last

decade, implying that the urban fabric is saturated and there are no significant spaces left to fill. This results in a contiguous and congested built-up area. Similarly, Santragachi exhibits a decreasing PD trend despite rapid development. This morphological behaviour, where the number of patches decreases while the total built-up area increases, confirms the successful consolidation of the catchment area. It also suggests that new developments are merging with existing clusters rather than isolated development, proving Santragachi's status as a potentially efficient transit node. In contrast to the previous observations, Shalimar exhibits a volatile spike in PD within the 3 km and 5 km buffers. The analysis shows high fragmentation, though the urban footprint is expanding. The quick growth of isolated industrial and residential areas at the periphery shows "ribbon sprawl" caused by speculative land conversion instead of planned transit-oriented densification. This unusual difference in spatial metrics highlights that while rail corridors drive growth, they don't guarantee morphological efficiency without careful planning interventions. Uluberia, on the other hand shows consolidation with PD decreasing gradually with minor spikes in between.

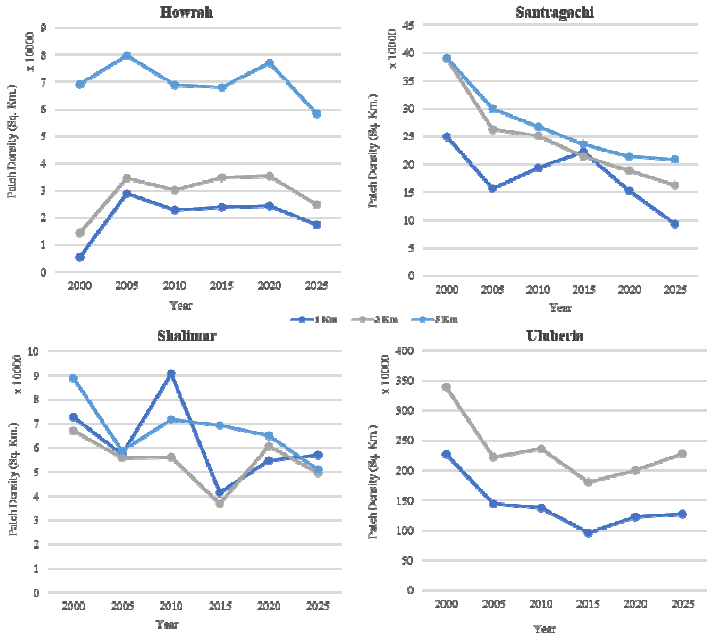


Fig. 3: Temporal variation of Patch Density (Sq.Km.) for Howrah, Santragachi, Shalimar and Uluberia across 1 km, 3 km and 5 km buffers (2000-2025) illustrating the contrast between consolidation (Howrah & Santragachi) and fragmentation (Uluberia). (Source: Author)

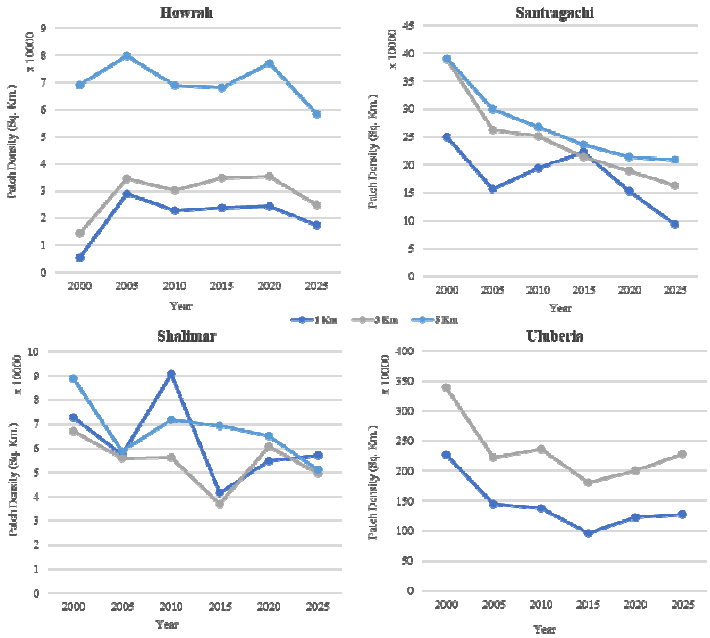


Fig. 4: Spatio-temporal map showing the population density variations for Howrah, Santragachi, Shalimar and Uluberia (2001 & 2011 years), highlighting the demographic shift from the core to the periphery. (Source: Census of India, 2001 & 2011)

6.2 Population Density Gradient and Demographic Shift

The morphological trend is replicated by the demographic pressure on the station areas (Fig. 4). Analysis of ward-wise population density (2001-2011) reveals a clear core-periphery gradient. Howrah exhibits a hyper-dense demographic profile that has stabilised over the last decade, implying that the area has reached its "Carrying capacity", where further population growth is physically constrained by the lack of developable land.

Santragachi and Uluberia demonstrate a sharp growth in population density, signifying a demographic shift where the functional load is moving away from the saturated core into these peri-urban pockets. This rising density perfectly relates to the Patch Density spike observed in section 6.1, confirming that these nodes are the new active fronts of urbanisation and require immediate infrastructure augmentation to prevent the formation of high-density slums.

6.3 Volumetric Analysis

By relating average building height (Havg) with horizontal saturation (BDI), the study identifies the physical efficiency of each station area (Fig. 5). Combined with saturated horizontal density, Howrah records the highest Havg in the studied area. This reinforces the fact that the node has shifted from horizontal expansion to vertical densification. However, the extreme BDI value suggests that this vertical growth is a reaction to land scarcity rather than a planned outcome. A critical finding is the performance of Shalimar. Despite being located within the high-value urban core and comparable in location to Howrah, it exhibits a (low Havg, high BDI) relation. The data shows that while the ground plane is saturated with logistics and low-rise structures, vertical growth is significantly suppressed compared to its neighbour Howrah. This gap defines the "Stagnant Core" typology i.e., a node where conflicting land uses (freight vs. passenger) have artificially capped development potential. The steady rise in Havg parallels its horizontal consolidation, implying that infrastructure upgrades are successfully inducing real estate investment. In contrast, Santragachi shows a balanced morphology where moderate vertical growth goes with horizontal consolidation. This confirms its status as a sustainable benchmark. Meanwhile, Uluberia records the lowest average vertical height, confirming that its rapid expansion is strictly low-rise and sprawling in nature.

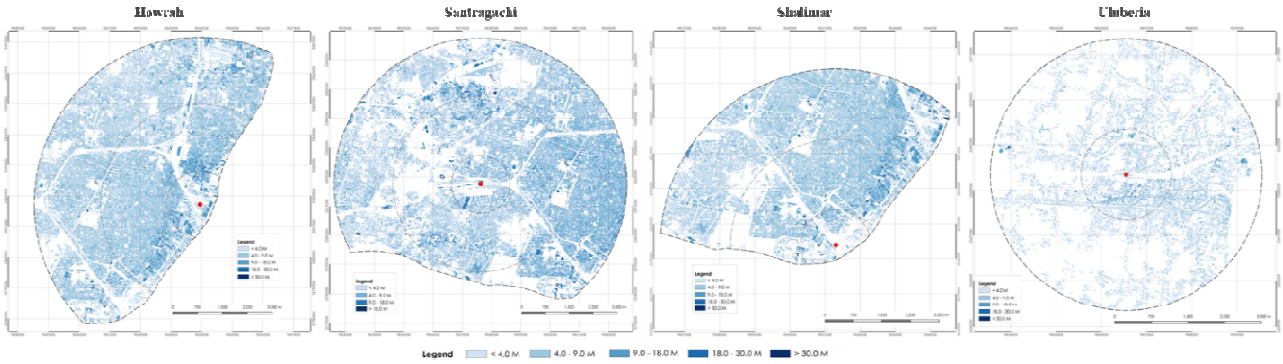


Fig. 5: Building Height Map (2023) visualising the vertical intensity (Havg) across the four station catchment areas (Source: GEE Open Building 2.5D dataset)

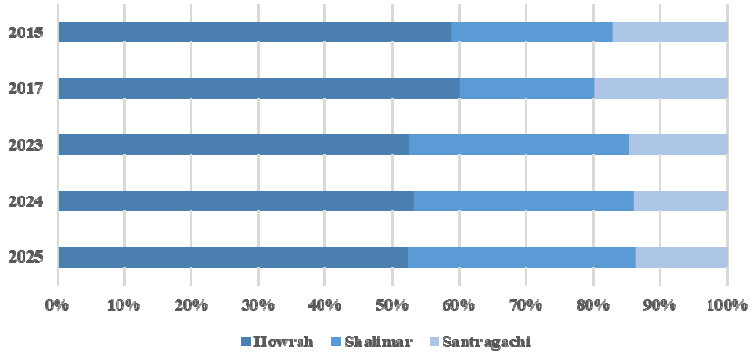


Fig. 6: Year-wise Number of Long-Distance Passenger Trains Originating from Howrah, Shalimar and Santragachi (2015-2025). (Source: South Eastern Railway Division)

6.4 Passenger Ridership Analysis

To support the evidence of urban sprawl, the study analysed station-level passenger footfall data along with express train frequency data for the 2015-2025 period. The data reveal a structural transformation in regional mobility plans, confirming the presence of an active functional load shift from the core to the periphery. In the fiscal year 2017-18, Howrah dominated the corridor with handling 75% of the total passenger volume, while Santragachi and Uluberia accounted for only 10% and 12%, respectively (Fig. 7). However, a sharp break is observed in 2018-19, where Howrah's share dropped to 50%, while Santragachi and Uluberia surged to 21% and 24% respectively. This drastic redistribution shows that satellite nodes are absorbing the exploding suburban demand that the saturated Howrah terminal can no longer accommodate. This supports the fact that the ridership shift is a distinct operational decentralisation of express train services. Analysis of train frequency data highlights functional roles for each terminal (Fig. 6). Howrah remains the primary hub for Western routes (e.g., Mumbai, Tatanagar) handling a total of 68 long-distance trains. In contrast, Shalimar and Santragachi have been tagged as specialised terminals for southern routes (e.g., Chennai, Hyderabad). This strategic diversion of specific long-distance corridors to satellite terminals is a key driver of the patch density spike observed in their hinterlands. These stations evolve from simple halts to major origins/destinations, they trigger immediate and unplanned residential conversion in the surrounding areas to support the new transit economy.

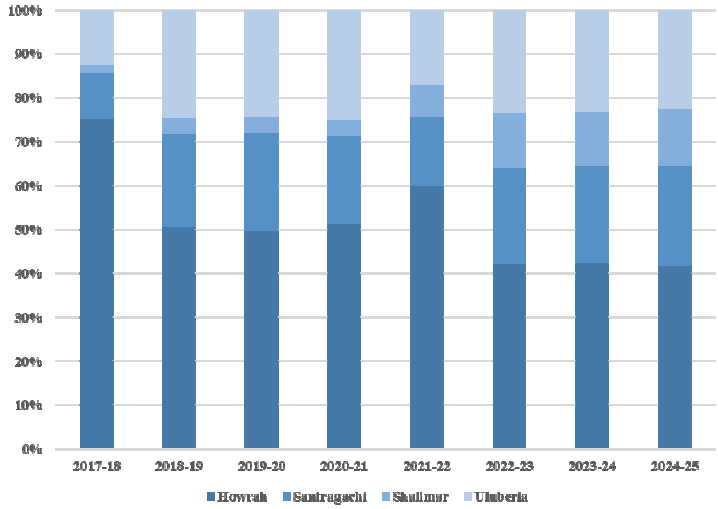


Fig. 7: Year-wise Distribution of Passenger Ridership Share across the Southern West Bengal Rail Corridor (2017-2025), illustrating the functional load shift from Howrah to satellite nodes. (Source: South Eastern Railway Division)

6.5 Operational Efficiency: Traffic Congestion Analysis

To validate the findings from earlier results, the study analysed real-time traffic congestion indices derived from peak-hour movement data (Fig. 8). This analysis serves as a proxy for the functional performance of the street network surrounding the stations. The traffic heatmap reveals that Howrah operates at a severe congestion level, with high indices during peak hours. This confirms the "Saturated Node" typology, where the street network has failed to cope with the vertical densification, resulting in a gridlock pattern that nullifies the benefit of transit proximity. In contrast to this, Santragachi records significantly low congestion indices even during peak windows. This validates its classification as the Benchmark Model. Despite its rising building density, the station area maintains operational fluidity, proving that its urban form (consolidated yet accessible) effectively manages the intermodal transfer of passengers without choking the local road network. This difference provides empirical evidence for the "load shift" strategy i.e., shifting terminal functions to Santragachi is not just a railway capacity decision, but it is an urban relief necessity. Shalimar exhibits a distinct restricted flow pattern. Being a freight terminal, the heavy logistics traffic clashes with passenger movement, effectively cutting the station off from its immediate neighbourhood. Meanwhile, in Uluberia, the outer peripheral roads remain free-flowing. The roads leading directly to the station record a high level of congestion. This specific bottleneck confirms that the unconnected local street network is struggling to cope with the sudden surge in daily commuters.

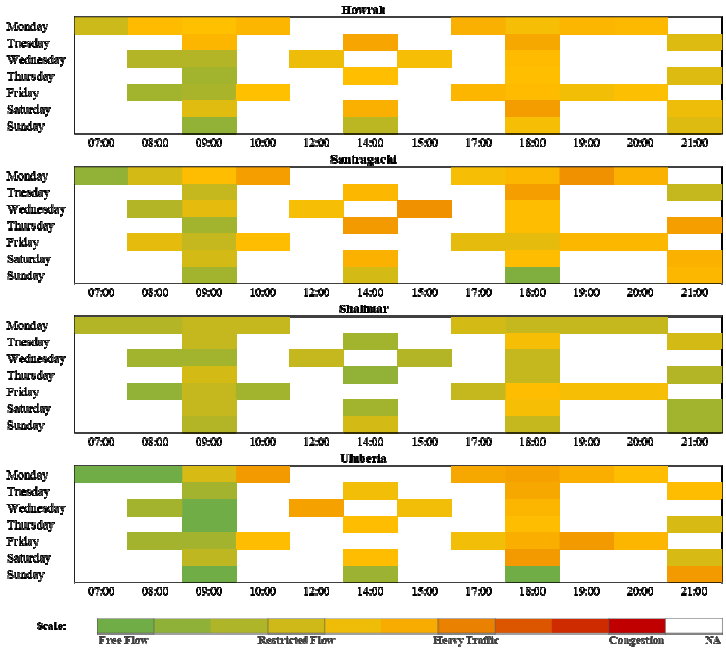


Fig. 8: Comparative Spatio-Temporal Traffic Heatmap (2025) showing congestion indices for peak and off-peak hours across all stations. (Source: Author)

6.6 Morphological Transitional Analysis

The temporal analysis of the spatial footprint across varying building height categories provides a critical indicator for the building transition potential of the station catchment areas (Fig. 9). By correlating the change in low-rise (G+1) versus low-mid-rise (G+4/G+5) built-up shares, the study deduces the probability of organic vertical conversion. In the core area, Howrah demonstrates a "saturation constraint" where the spatial share of the high-rise categories has effectively saturated over the last decade. This suggests the node has reached its morphological limit, and further densification is no longer a function of plot-level upgrading but requires a complex district level development. Conversely, Shalimar shows a stalled conversion trajectory. Despite recording a total built-up coverage comparable to the urban core, the dominance of the low-rise footprint paired with negligible growth in the mid-rise category confirms a deadlock. The functional dominance of freight logistics in this zone appears to suppress the land value aggregation required for residential verticality, effectively trapping the node in a low-rise equilibrium.

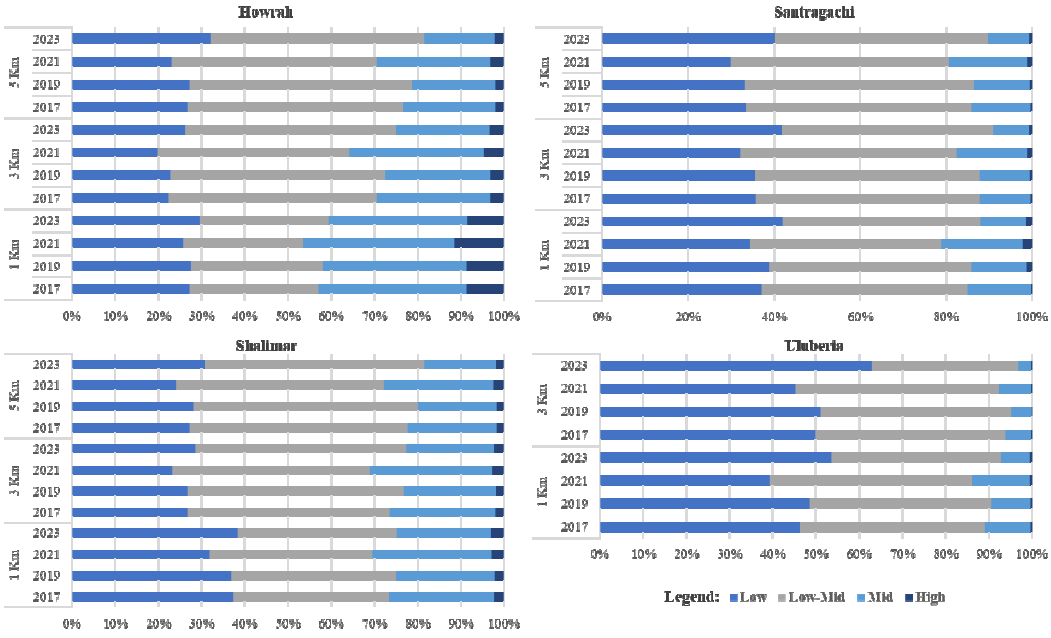


Fig. 9: Temporal Evolution of Building Height Composition (2017-2023) showing the share of low, low-mid, mid, and high-rise structures, indicating the probability of vertical transition. (Source: Google Open Buildings 2.5D Dataset)

Moving towards the periphery, Santragachi emerges as the corridor's active transition zone. The area records a steady increase in the spatial share of low-mid-rise structures relative to the low-rise baseline, which also confirms the high probability of conversion. This indicates that the market is actively responding to the "load shift" by using smaller and fragmented plots to accommodate higher-density housing. In direct contrast, Uluberia displays a probability of diluted conversion. The explosive expansion of the low-rise footprint in this zone far outpaces any transition to mid-rise structures. The data confirms that the market preference here remains skewed toward lateral "ribbon" expansion into the agricultural hinterland rather than vertical densification. As long as the volume of the low-rise construction continues to spike at the periphery, the economic pressure to vertically upgrade the town centre remains minimal. This diverts the growth outwards rather than upwards.

6.7 Comparative Analysis and Categorisation of Station Typologies

Integrating the horizontal, vertical, and other metrics allows for a categorisation of the corridor's urban evolution into four distinct typologies (Fig. 10). Howrah functions as the definitive "Type 1 – Saturated Node", where transit utility is maximised but liveability is compromised by the physical limits of the land. The convergence of peak building height, stabilised patch density and severe traffic congestion metrics indicates that the node has reached a saturation point. The future growth in this area can no longer be accommodated through expansion but is only possible through complex vertical redevelopment. In direct contrast, Shalimar is identified as a "Type 2 – Stagnant Core". Despite its proximity to the urban centre, the low verticality v/s high coverage correlation identifies it as an underperforming asset. The dominance of freight infrastructure and conflicting road networks has created a logistic trap which prevents the station area from transitioning into a modern and mixed-use passenger precinct despite its high land value. Santragachi is confirmed as the "Type 3 – Benchmark Model". The station area demonstrates a rare equilibrium. It absorbs increasing passenger loads and express train traffic while maintaining morphological consolidation (decreasing fragmentation) and low traffic congestion. This balance validates that transit-oriented growth can be sustainable if supported by adequate rail-road integration. Finally, Uluberia is identified as a "Type 4 – Developing Node", which is currently in a critical transition phase. The volatile spike in patch density combined with the massive surge in unreserved ridership indicates that it is rapidly evolving into a town. However, without immediate intervention, its current trajectory of ribbon sprawl suggests it will bypass the efficient "benchmark" stage and degrade directly into a chaotic and low-density agglomeration which mirrors the congestion issues of the core but without its infrastructure capacity.

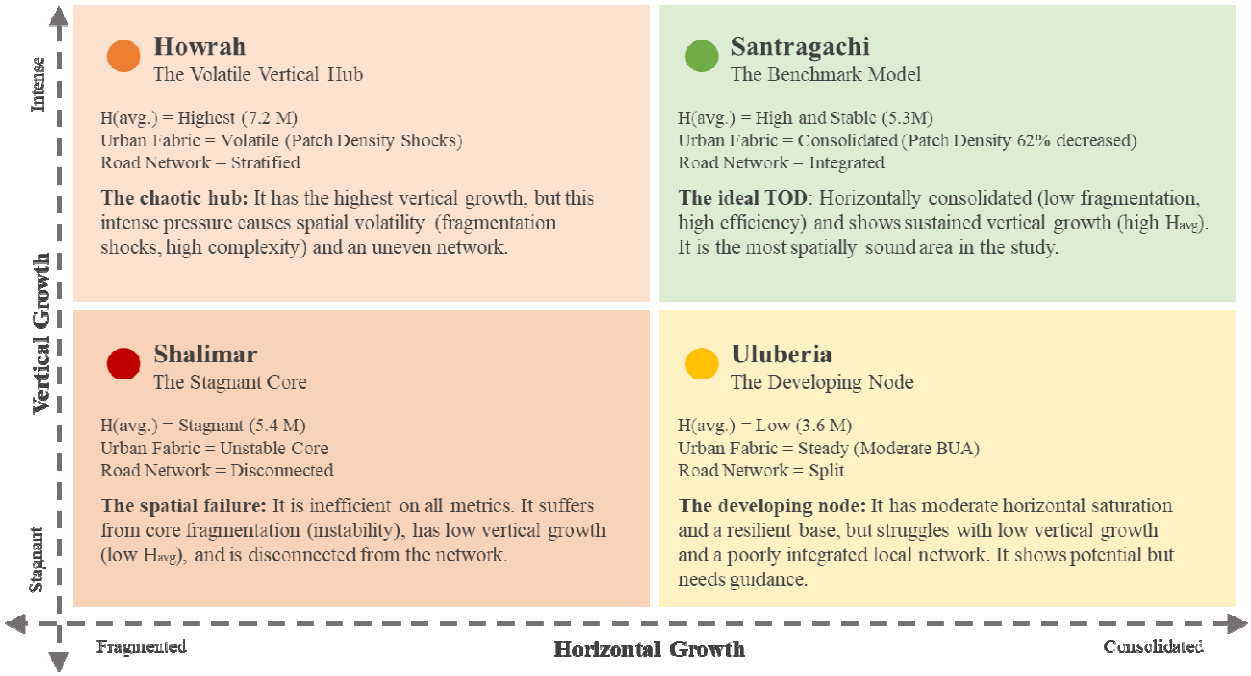


Fig. 10: Comparative Station Typology Matrix illustrating the classification of Howrah, Shalimar, Santragachi and Uluberia based on vertical growth and horizontal saturation. (Source: Author)

7 CONCLUSION AND WAY FORWARD

The study confirms that while railway proximity acts as the primary driver of spatial development, the resulting urban forms are strictly non-uniform. The study identified four distinct evolutionary typologies by considering demographic, operational and morphological data. The saturated node of Howrah has breached the carrying capacity, which is evidenced by a stabilised hyper-dense population and severe traffic congestion indices that nullify its transit advantage. The stagnant core of Shalimar remains paralysed by a "logistics trap" where conflicting land uses suppress vertical conversion despite having high land value. The Benchmark model of Santragachi demonstrates a rare equilibrium which absorbs the surging number of riders while maintaining its low traffic congestion and morphological consolidation. Conversely, the developing node of Uluberia exhibits a hazardous trajectory where an explosive rise in unreserved ridership is fuelling the fragmented "ribbon sprawl" rather than efficient densification.

7.1 Future Scenarios

Excluding the static baselines of Howrah and Shalimar, the study projects divergent trajectories for the two active nodes based on their current capacity to handle the "load shift". Santragachi is projected to follow an optimised densification path.[1] The node's ability to accommodate a 21% share of corridor ridership while maintaining free flow traffic conditions suggests a robust infrastructural baseline. By 2050, it is predicted to evolve into a fully integrated polycentric anchor, which naturally absorbs the demographic spillover from the core through vertical upgrading without suffering the gridlock associated with rapid growth. In contrast, the "business-as-usual" scenario for Uluberia predicts a systemic functional failure. The convergence of three negative trends, such as a massive surge in unreserved commuters, a volatile spike in horizontal patch density and a disconnected local street network, warns of an impending collapse of accessibility. Without proper intervention, the node is projected to bypass the efficient benchmark stage and degrade directly into a "Congested Sprawl Zone". By 2050, the fragmented settlement pattern will render the limited road network incapable of supporting the high-density commuter flow which replicates the worst aspects of Howrah's congestion.

7.2 Policy Recommendations

To align the future trajectory of the corridor with sustainable principles, the study proposes station-specific micro-plans. For Santragachi, where the road network and urban form are currently efficient, policy must focus on developing and retaining this form i.e., implementing transit-supportive mixed-use zoning (500m radius) to formalise commercial density and prioritising "grade separated pedestrianisation" to separate the growing footfall from vehicular traffic, preserving the node's high operational fluidity. For Uluberia, where natural forces favour chaotic expansion, the strategy must focus on restrictive spatial form. This requires a dual approach: establishing a strict urban growth boundary at the 3 km mark to halt ribbon sprawl while simultaneously executing a grid plan in the immediate vicinity to upgrade the local road network. Furthermore, introducing a differential FAR policy i.e., high FAR strictly within 1 km is essential to economically incentivise vertical redevelopment over horizontal expansion, which will prevent the formation of inaccessible settlements. Looking ahead, the next phase of research will focus on layering this morphological data with deeper socio-economic insights to better understand its impact on transit-induced growth. Additionally, future works must find ways to fully ensure that policies like the proposed micro-plans and FAR adjustments serve the entire community rather than just the formal urban fabric. Bridging these physical and human gaps is essential for creating transit nodes that are not just efficient but truly sustainable.

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Architectural Rehabilitation of Charasteen Cave in Duhok: A Locally-Led Accessibility and Heritage Intervention within the UNESCO–EU MADAD Framework with Support from the Kurdistan Regional Government

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1 ABSTRACT

This paper is the result of a successful architectural and heritage intervention at Charsteen (Charasteen) Cave in Kurdistan Region of Iraq, which is a very important cultural and spiritual place for Zoroastrians. In accordance with the framework of the UNESCO-EU MADAD "Support to Livelihoods through Cultural Heritage Development" program and with support from the KRG, the project was implemented using a low impact design approach that made safe access available while protecting the sanctity of the environment and the cultural significance of the cave. As the Head Architect Engineer and Project Coordinator of WADI (a German international organization) the author was responsible for leading the total redesign and implementation of the site's Master Plan; UNESCO experts, as well as the Duhok Directorate of Antiquities and Heritage, the Tourism Department, the Local Workers Union, and the International Labour Organization (ILO) provided the author with the necessary supervisory, coordinating, and technical assistance. The project consisted of a minimal amount of physical intervention with a focus on adaptive reuse, environmental protection, and the use of natural materials. Water supply line additions, a water-recycling system, sewage systems, improved lighting, and the stabilization of circulation pathways were among the infrastructure upgrade actions taken. A workforce consisting of women, persons with disabilities, Syrian refugees, IDPs, and local community members who were employed under ILO-Cash for Work schemes were involved in all aspects of the project. Capacity building activities involving training in heritage conservation, site management, safety, and construction techniques were also conducted to promote increased community involvement in the site's future stewardship. Utilizing an analytical-applied methodology, this paper will detail the entire process of the intervention from analysis/design phase to demolition/re-construction/evaluation phase, and assess the extent to which it achieved a balance of accessibility, heritage protection and community inclusion. Ultimately, the results of this study clearly show that when implemented under international frameworks locally-led, low-impact architectural interventions can be carried out successfully and maintain the highest levels of preservation and sustainability. The project has established a viable model for sustainable and inclusive restoration of vulnerable heritage landscapes in disaster-affected areas.

Keywords: architecture, accessibility, heritage, UNESCO, Kurdistan

2 INTRODUCTION

Cultural Heritage in conflict areas are at risk from Social Displacement, Environmental Deterioration and Economic Instability. In the Kurdistan region of Iraq (KRI) the pressures were increased as a result of the Syrian Crisis that displaced over 227,000 people to Iraq – 96 % of them settled in KRI. This resulted in an increase in population that placed pressure on the infrastructure, depressed wages and also limited employment opportunities especially for Vulnerable Community Groups.

In this sense, the EU-UNESCO MADAD initiative "Supporting Livelihoods through Cultural Heritage Development" is an example of how cultural heritage sites are being protected by creating job opportunities for Syrians and vulnerable people in Iraq using Cash for Work programs in the form of Employment Intensive Schemes. As part of this initiative, Charsteen (Charasteen) Cave a Zoroastrian religious site located near the old Dohuk Pass has been chosen for rehabilitation.

Prior to the intervention, the site presented many problems such as; dangerous walkways, inadequate infrastructure, uncontrolled flow of visitors, poor lighting and environmental damage. On the other hand, because of the sacred nature of the site, and the natural beauty surrounding it, a very particular approach was needed to create a project that would respect the spiritual dimension of the place and the natural environment surrounding it.

In order to carry out this project, the author performed all the architectural analyses, redesigned the master plan, produced the technical details and implemented the works at the site from May 2023 until May 2025. The other actors involved in this project were mainly UNESCO, ILO, Directorate of Antiquities of Duhok, Department of Tourism, and Workers Union that acted in a coordinating role and/or supervising one.

The present document describes the whole process of rehabilitation of the site and shows that with a minimum amount of resources, with an adaptive and inclusive towards the local communities' design, we can protect the heritage sites while providing jobs, training and social values. This study is guided by the following research questions:

- How can minimal-impact architectural interventions enhance accessibility while preserving the spiritual, cultural, and environmental integrity of sacred heritage sites?
- How does a locally led design and implementation approach influence heritage preservation outcomes within internationally supervised frameworks?
- What are the social impacts of employment-intensive heritage rehabilitation?

3 METHODOLOGY

The Charsteen Cave rehabilitation project employed a hybrid analytical applied methodology, integrating architectural assessment, heritage conservation, environmental management, and community development. The approach encompassed several complementary components:

3.1 Broader Urban Context and Long-Term Considerations

The rehabilitation process of Charstein Cave needs to be considered within the context of the broader urban and demographic trends that are impacting Duhok City, as shown in Figure 1. Illustrate the map of Iraq, showing the Kurdistan Region, including the map of Kurdistan Region showing Duhok, and including the map of Duhok showing the Charsteen site location.. For the past decade, the city has been absorbing large numbers of refugee and internally displaced persons, which has exerted considerable strain on the city's infrastructure, housing, and land reserves. While the demographic trend is a positive indicator of the city's capacity to adapt to crises, the urban sprawl that has ensued has led to the city expanding beyond the initially planned urban boundaries, thus leading to the increasing consumption of land reserves, which may otherwise be used for agricultural and forestry activities.

In this context, the heritage site that is Garstein Cave not only provides a sense of urban identity but also becomes a focal point that can be used to inform the urban planning strategies that will be adopted in the future to ensure that Duhok City does not become overly sprawled, thus leading to the degradation of the natural environments that surround the city.



Fig. 1: Location of the charsteen site in Duhok, Kurdistan Region, Iraq.

3.2 Site Analysis and Documentation

The purpose of a thorough site analysis of Charsteen (Charasteen) Cave was to provide an understanding of its historic, environmental, and physical aspects. A comprehensive site analysis was performed through conducting a topographic survey of the site that would include mapping of site features and terrain, a structural assessment to determine the level of hazard or risk involved with the site and to assess the current condition of the site, photography for use as a visual record and/or for comparison in the future, mapping of the site's circulation paths and potential hazards to enable safe passage of visitors to the site, and extensive observations of the site's environment to assess both the climate of the site and the natural characteristics of the site. All of the data collected from this analysis were used as a basis for making decisions regarding the final design of the cave and any interventions made on the site.

3.3 Stakeholder and Institutional Coordination

Coordination was needed at the daily and weekly level to work with the WADI team, UNESCO, the International Labor Organization (ILO), the Duhok Department of Antiquities and Heritage (DHAH), the Duhok Department of Tourism, the Duhok Workers Union, and local community leaders (Department of Media and Information, 2025).

3.4 Minimal-Impact Design Principles

This restoration used a “minimal impact” or reversible design approach that utilized non-invasive methods and natural materials (Lin et al, 2024). The principles for this were used as a guide for placement, construction, and detailing for all new components to match the sites' cultural, archaeological, and environmental attributes according to UNESCO and ICOMOS preservation guidelines (International Committee for the Management of Archaeological Heritage (ICAHM), 1990) (UNESCO, 1972).

3.5 Applied Materials Testing

All construction materials, as well as the technical components planned for installation on-site have been subjected to an extensive evaluation process in order to assure their appropriateness for a highly sensitive cultural-historical heritage environment. Materials used in civil and structural construction (i.e., limestone blocks and dust, steel products, reinforcing steel bars, concrete, sand, soil, wood) were assessed with respect to strength, durability, compatibility with the natural and built environments, and potential long term performance of each material type under the specific climate and geology of the region in which they would be installed. Likewise, the electrical and water supply systems were evaluated to confirm their safe functioning, compatibility with the existing heritage environment, and low-impact design into the heritage environment. Engineers from WADI worked closely with experts from UNESCO and the DoAH to evaluate all materials in accordance with the applicable national building codes, and in compliance with UNESCO/ICOMOS standards for the conservation and restoration of cultural heritage. Through this multi-faceted assessment, it was assured that only those materials meeting structural requirements, environmental considerations, and those most suitable for the heritage environment, were selected for inclusion in the proposed site rehabilitation project.



Fig. 2: Women cleaning the Charsteen’s external surfaces from the grass.

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3.6 Employment-Intensive Approach

The use of an Employment-Intensive approach (in accordance with ILO guidelines) allowed for the involvement of women, refugees, internally displaced persons (IDPs), persons with disabilities and members of the local community through the provision of Cash-for-Work programs (as shown in Figure 2). Manual building techniques enabled social inclusion while allowing for detailed, heritage-specific rehabilitation.

3.7 Continuous Monitoring

The use of a multi-level monitoring system (daily, weekly, monthly, and quarterly inspections) provided oversight of the project through Progress Reports; Site Visits; and Coordination Meetings. Oversight from UNESCO; Department of Antiquities and Heritage (DoAH); International Labour Organization (ILO); Tourism Authorities; and Workers' Unions ensured that all participants were compliant with safety, cultural and labor standards. This methodology brought together high levels of analytical detail; participation from stakeholders; low impact on the cultural resource; validation of materials used; inclusive job creation and systematic monitoring to enable a sustainable and culturally relevant rehabilitation process.

4 SITE CONTEXT AND HERITAGE SIGNIFICANCE

The Charsteen (cave Char-Steen) archaeological site is located in the city of Duhok, in the Kurdistan Region of Iraq. It is near the Duhok dam and is situated where the Dohuk river meets the White Mountain range. Historically, this location served as a sacred Zoroastrian worship place. The site represents a symbolic representation of water, earth, air and fire. “Charsteen” is the Kurdish word for four pillars. Remains found at the archaeological site show evidence that it was used as a fortification during ancient military campaigns. Due to the natural environment and the flow of water, the site requires careful treatment to prevent environmental damage. The site is known as one of the most significant cultural historic sites in the area of Duhok and has been restored through a collaborative effort from UNESCO, the WADI organization, the Directorate of Antiquities and Heritage of Duhok (Government of Kurdistan), and the European Union. The site includes an ancient temple carved out of rock, known as the Charsteen temple (see Figure 3). This temple has been dated thousands of years old and contains four natural rock pillars and a recently restored temple (known to be Zoroastrian) and is thus a major historic and tourism destination. In addition to the cave (temple) the site also includes an Anahita canal, open fire temple, rock fire, fire altar, fire temple, Anahita temple, tomb, cave, tunnel, simiting place, juicer, and is encircled by a fence (Nhili, 2022).



Fig. 3: Entrance of Charsteen cave (4 pillars).

5 NEEDS ASSESSMENT AND PROBLEM DEFINITION

Prior to intervention, a full site assessment was conducted at Charsteen (Charsteen) Cave, and it revealed several challenges related to function, environment, and safety that impacted the site. One key issue was poor condition of pedestrian walkways and handrails which were broken or did not meet compliance requirements. Lighting within the cave was limited and improperly positioned, as shown in Figure 4. Drainage systems failed to address water stagnation which led to rapid erosion of the cave's surface.

Furthermore, there was no control over stormwater run-off, no proper disposal of waste, and no formalized system to manage visitor traffic which posed threats to visitors and to the site's archaeological integrity.



Fig. 4: Pre-existing situation. Unsafe stairs, no stairs, deteriorated handrails, and bins on the west side of the Charsteen Cave.

The assessment found significant quantities of dense vegetative growth throughout circulation paths and on the outside of the cave, as shown in Figure 5. Using characteristics of leaves; growth patterns; and local environmental factors, the primary climbing and groundcover species was identified as Hedera helix (English ivy). While Hedera helix provided positive effects such as improved erosion resistance and microclimate stabilization, it also created negative impacts by obscuring the cave's entrance, signage, and interpretive features thereby limiting visibility and way-finding. This information directly influenced the need to provide for specific clearing and controlled vegetation management efforts and not total removal.



Fig. 5: Hedera helix (English ivy) covers symbolic representation of water, earth, air and fire, and the exterior surfaces of the Charsteen Cave.

6 DESIGN PHILOSOPHY AND MINIMAL INTERVENTION APPROACH

The overall design strategy for the rehabilitation of Charsteen Cave was based on a “minimalist” design philosophy that protected the cave's sacred/cultural/environmental aspects as much as possible. Three main principles were used in developing the architectural decisions of this project: a conservation-first approach to preserve the integrity of all archaeologically-sensitive layers and the spiritual essence of the cave; an environmentally sensitive approach to ensure that the site would be compatible with its natural surroundings; and reversible design elements to allow for the possibility of future modifications or removals without permanently damaging the heritage of the site. Additionally, the design solution incorporated the use of local/natural materials throughout to maintain the site's historic ambiance and create a seamless visual experience. In lieu of introducing new architecture into the cave system, the rehabilitation focused on improving existing circulation paths, consolidating unstable surface areas, and incorporating subtle safety features. This design strategy provided for both enhanced visitor access and safety while maintaining the cave's original authenticity and sanctity.

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ISBN 978-3-9504945-5-6

7 MASTER PLAN REDESIGN

The redesign of the Master Plan was designed to improve circulation, increase the level of safety, protect the Heritage, and ensure that the new infrastructure integrates with the existing infrastructure while maintaining a “minimal impact” philosophy. The redesign of circulation has been addressed by creating stabilized stone walkways, standardized limestone steps, connecting the limestone steps with steel stairs and timber cladding of the existing iron paths to stabilize the rock. Amenities to support the visitors have also been improved, including the inclusion of rest points, an open stage for cultural activities, timber kiosks, seating areas and signs providing interpretation in Kurdish, Arabic and English. Infrastructure components (water supply networks, water recycling systems, sewage pipes, electric wires and lighting) are located away from sensitive archaeological zones as shown in Figure 6. In addition, the deteriorated existing structures have been repurposed via adaptive reuse as maintenance facilities, visitor resting areas and interpretive nodes to extend the useful life of the site. Rehabilitation of the environment has been accomplished through the controlled management of vegetation, the planting of trees, irrigation networks and relocating waterfalls to reduce their impact on the archaeological zones. Overall, the redesign of the master plan has effectively integrated improvements to accessibility, enhancements to the visitor experience and improvements to the existing infrastructure while preserving the site's Heritage, environmental integrity and cultural values.

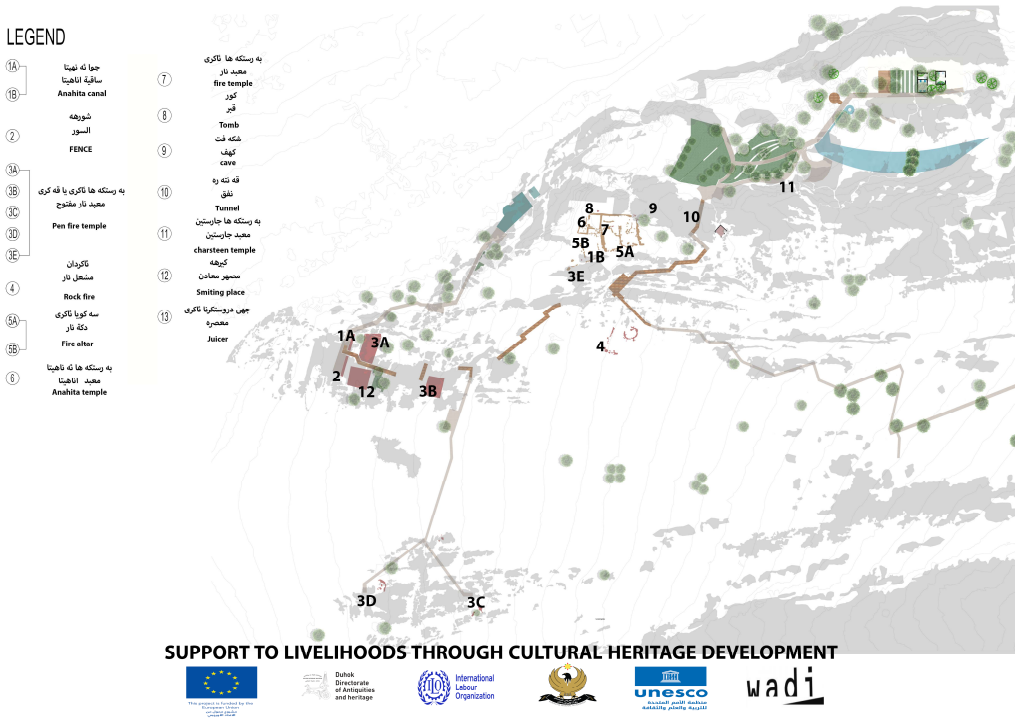


Fig. 6: The designed master plan.

8 IMPLEMENTATION AND CONSTRUCTION PROCESS

The implementation process for the construction of Charsteen Cave involved a series of planned and carefully controlled phases. The phases began with selective demolition and removal of unsafe or deteriorated infrastructure at Charsteen Cave; this was followed by the installation of natural stone staircases, timber-metal handrails, drainage channels and upgraded lighting systems. All the works were designed to provide enhanced accessibility and safety for visitors to the cave while providing the least possible disturbance to its heritage fabric.

The implementation was structured into six primary areas of work: Site Clearance Works; Pavement Works; Steel & Wood Works; Landscaping and Water Systems Works; Electrical and Lighting Installations Works.

Phase One of the project involved clearing the entire site of vegetation, removing grass, roots and all other forms of organic debris from the site, and safely disposing of all biological waste that had been removed from the site. The existing lighting system was carefully disassembled and then stored under close supervision. All deteriorated asphalt, concrete pavement, timber stairs, stone tile finish and parts of the reception building including floor tiles, cladding, ceiling tiles, windows, doors, electrical fittings and air

conditioning units were demolished and removed from the site. Associated services including entrance blocks, toilet facilities and pipe systems, and redundant seating, stairs and handrails were removed to ensure compliance with both heritage protection and safety standards.

The pavement and tiling works were coordinated closely with the Duhok Directorate of Antiquities. A detailed review of the Bills of Quantities (BoQs) against site conditions was undertaken to resolve technical issues and to modify designs where necessary, as can be seen in Figure 7. The excavation, sub-structure construction and installation of durable, safe, and compatible to the heritage fabric pavement systems were completed to provide improved access for visitors to the cave, while preserving the visual and cultural integrity of the cave.



Fig. 7: Stone stairs. The before and after intervention.

Steel works involved the design, manufacture and construction of handrail components, staircase and floor structural framing, benches, waste recycling containers, shade structures, stainless steel safety chain systems and signage systems (Fig. 8), that were constructed in compliance with regulatory requirements regarding both functional performance and safety, while visually being non-obtrusive. The wood works provided functionality and compatibility by installing stair treads, flooring, roofing and gabion-timber elements treated to ensure longevity under various environmental conditions and maintaining their natural appearance.



Fig. 8: Tunnel. The before and after intervention (iron and timber).

Coordinating landscaping, irrigation, and water systems was completed with the help of the Duhok Directorate of Water Resources and the Duhok Directorate of Antiquities. The revised drawings and trenching plans were developed to include galvanized storage tanks, booster pumps and polyethylene piping for drip irrigation for pipeline systems. Planting trees contributed to landscape stabilization, improved microclimate conditions and long term site sustainability, as shown in Figure 9.

The electrical and lighting works were performed together with both Duhok Directorate of Electricity and Duhok Directorate of Antiquities. The Electrical BOQ was reviewed and site visits conducted for optimal routing of trenches and cable path. Where required, design changes were made; all new installations were completed as part of a low-impact, heritage-sensitive approach to enhance both safety, visibility and the overall visitor experience.



Fig. 9: waterfall, ground cover, and shrubs 6. The before and after intervention.

9 INFRASTRUCTURE UPGRADING

Infrastructure improvements for this project included careful planning to protect sensitive areas by creating a new water supply system, sewage, water recycling, and electrical systems. Local and small-scale trenching with materials that are suitable and compatible with the environment/heritage area was done to minimize environmental and heritage impacts, increase durability and enhance visitor comfort and site resilience (Syriacpress, 2025). Materials such as plumbing fixtures, electrical components and construction materials were brought up to the top of the mountain, and a pump booster was utilized in order to cast concrete to build the water tank, as shown in Figure 10.



Fig. 10: Transporting materials and fittings and casting concrete for the water tank using a crane and a pump poster.

10 ADAPTIVE REUSE STRATEGY

The adaptive reuse strategy is about the rehabilitation or repurposing of previously used structures for new uses, with the goal of conserving structural elements while protecting historic architectural characteristics and extending the useful life of the location (Albrifkany et al, 2021). The rehabilitated areas at Charsteen Cave now house rest points for visitors, storage for tools, maintenance facilities, and educational stations. The overall purpose of the project was to have a reduced ecological footprint while increasing usability of the site. This involved creating both covered and uncovered rest places, as shown in Figure 11, as well as an open-platform stage for cultural events utilizing a stone masonry seating platform, timber kiosks and rest areas adjacent to the tunnel, and a complete water distribution system that would provide irrigation to all landscaping elements (shrubs, grasses, etc.). Restrooms are located in the reception area and in proximity to the open-stage. The irregularly shaped natural rock stepways were replaced by a series of regular local limestone stairways and two sets of steel stairways were installed to allow visitors to transition between the archaeological stairway and the limestone stairway. Minimal amounts of steel were utilized in order to minimize intervention to the site and protect it. Several pathways were created utilizing iron and clad with wood to protect the rocky surfaces.



Fig. 11: Creating covered rest places which situates on the west side of the cave (Before and After interventation).

A water collection tank was developed to allow recycled water to be used from artificial waterfalls that had been relocated approximately 100-200 meters away from the cave to further minimize the effects of this aspect of the project, as shown in Figure 12. Ground cover, shrubs, and trees were planted as part of the landscaping aspects of the project. Signs in three languages (Kurdish, Arabic, and English) were also designed and installed as part of the project. All water, sewage, and electric systems were carefully routed away from archaeological areas with approval from Duhok DoAH Supervisors, and documentation was maintained to assist with future maintenance needs. Overall, the adaptive reuse projects at Charsteen Cave have extended the functional life span of the site while preserving its environmental and heritage attributes.



Fig. 12: artificial waterfalls that had been relocated approximately 100-200 meters away from the cave to further minimize the effects of this aspect on the entran cave's surfaces (Before and After interventation).

11 CAPACITY BUILDING AND WORKFORCE INCLUSION

The Charsteen Cave project focused on developing the capacity of and promoting inclusion for workers within the framework of UNESCO and ILO goals that combine heritage preservation with long-term sustainable livelihoods. The project provided training opportunities at all levels of society (community, technical/professional) as well as providing vulnerable populations (women, refugees/IDPs, and members of the host community) direct training through labor-intensive heritage preservation construction/masonry/carpentry/safety and maintenance of infrastructure and environmental practices. At a professional level, the project staff/engineers received specialized training from the EU-MADAD, UNESCO, ICOMOS and ILO that included cultural resource management, conservation techniques, monitoring, site maintenance/tourism planning and additional technical training on the application of B.R.C. Gabion Systems for structural and landscape stabilization of sites. Evaluation and Impact Analysis

The data in the impact evaluation tables confirms that Charsteen Cave has achieved tangible advances in terms of: accessibility; safety; and the preservation of its heritage values by using a low-impact, reversible approach to intervention. In addition to stabilizing key archaeological features at the cave, the project was able to improve environmental conditions in the surrounding area by installing erosion controls and implementing a sustainable irrigation system. Furthermore, the project used local and natural materials which provided an additional layer of compatibility with the heritage characteristics of the site. The project also provided significant social economic returns on investment, providing in excess of 1200 days of employment

opportunities for vulnerable groups; enhancing the technical capacity of local communities; and significantly improving the site's readiness for sustainable cultural tourism; as demonstrated by the information contained within Tables 1 and 2.

	Impact Area	Indicator/ Measure	Baseline	Target/ Goal	Post-Intervention	Measurement Method
1	Accessibility & Safety	Number of stabilized pathways	Informal, uneven paths, erosion, and slip hazards	Safe, continuous pathways	Stone pathways	Site survey, visual inspection
		Number of stairs repaired/constructed	Irregular, unsafe stone steps	Regularized stairs compatible with the heritage	New Limestone stairs constructed	Construction logs, photographs
		Lighting coverage	Limited/ non-functional lighting	Adequate low-impact lighting for safety	Energy-efficient lighting installed along main routes	Site inspection, visitor survey
2	Heritage Conservation	Archaeological structures stabilized	Deterioration and exposure to environmental risks	Stabilized structures with minimal intervention	Key archaeological elements have protected	Expert assessment, site documentation
		Minimal intervention compliance	Risk of intrusive repairs	Compliance with UNESCO / ICOMOS principles	Interventions reversible, non-invasive, and site-sensitive	Project design review
		Adaptive reuse success	Abandoned/ deteriorated structures	Functional reuse without loss of heritage value	Structures reused as rest points, stages, kiosks	Site inspection, photographic record
		Condition of heritage fabric	Weathering and structural decay	Improved structural and visual condition	Heritage fabric preserved and enhanced	Measurement Method

Table 1: Charsteen Cave: Impact Evaluation Table, Accessibility and Safety, and Heritage Conservation.

	Impact Area	Indicator/ Measure	Baseline	Target/ Goal	Post-Intervention	Measurement Method
1	Environmental Resilience	Vegetation coverage managed	Uncontrolled growth affecting structures	Controlled, protective vegetation cover	Vegetation managed and replanted strategically	Site survey, GIS mapping
		Irrigation/water systems functional	Inefficient or absent systems	Sustainable irrigation and water reuse	Irrigation and recycled water systems operational	Functional testing logs
		Erosion/soil stability	Soil erosion near paths and slopes	Reduced erosion and stabilized soil	Gabions, and landscaping reduced erosion	Field measurement, photo monitoring
		Sustainable material use	Use of incompatible or modern materials	Local, natural, sustainable materials	Limestone, timber used	Project materials report
2	Community & Economic Impact	Jobs created	Limited local employment	Inclusive job creation	1200 workdays (women, refugees, IDPs, locals)	HR/project records
		Workforce diversity	Low inclusion of vulnerable groups	Gender and diversity inclusive workforce	Inclusive workforce	Employment records
		Capacity building/training	Limited heritage-related skills	Strengthened technical and conservation skills	On-site and formal training completed	Training reports, attendance
		Community engagement	Limited community involvement	Active local participation	Community leaders and workers engaged	Meeting records, interviews
		Tourism readiness	Site not prepared for visitors	Improved visitor experience	Site ready for cultural and eco-tourism	Visitor surveys, tourism data

Table 2: Charsteen Cave: Impact Evaluation Table, Environmental Resilience, Community and Economic Impact.

The intervention was carried out in accordance with UNESCO and ICOMOS conservation principles, which emphasize minimal intervention, reversibility, respect for authenticity, and sensitivity to the environment. The project also adopted UNESCO's integrated approach to heritage conservation and sustainable development, which emphasizes community involvement in conservation and development work.

12 CONCLUSION

The rehabilitation of Charsteen Cave is a successful example of how to conduct an inclusive, sustainable, and sensitive approach to preserving heritage sites.By using minimum impact design, reusing structures already on-site, protecting the environment through good stewardship practices, and working with the local community, this project was able to preserve the cave's spiritual, cultural and historical importance by making it more accessible and safer for visitors, all without reducing the site's authenticity. This project also contributed to creating jobs and developing the capabilities of the local communities through the use of inclusive and skill based approaches, and produced environmentally friendly infrastructure projects consistent with international preservation standards. Overall, this project demonstrates that if heritage sites are carefully planned, and low-impact design strategies are implemented, the preservation of these sites can be achieved in conjunction with the support of social and economic development, especially in crisis affected areas.

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reviewed paper

Assessing Pedestrian Accessibility to Urban Land Surface Temperature Cold Spots in Bavarian Cities

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1 ABSTRACT

As climate change intensifies, European cities must adapt to increasingly frequent and severe heatwaves. Urban heat is not only an environmental concern but a key challenge for spatial justice, public health, and long-term resilience. For sensible adaptation strategies, planners require spatially detailed and comparable information to understand where heat accumulates, where cooling potential exists, and how equitably these cool spaces are accessible to different population groups. Recent advances in Earth observation and the availability of the German Census data at a spatial gridding of 100-m offer opportunities to integrate high-resolution environmental and demographic data into planning processes in a way that is consistent across cities of very different sizes and spatial configurations.

This study presents a scalable framework that combines satellite-derived Land Surface Temperature (LST) with population data to analyse urban heat patterns and the accessibility of naturally cool areas (cold spots) across all cities in Bavaria, ranging from small historic towns and medium-sized regional centres to large urban municipalities. Multi-year Landsat composites are processed to the harmonised 100-m grid aligned with the national census grid, enabling consistent and methodologically comparable cross-city analyses. Local Getis–Ord Gi* statistics are used to identify spatial clusters of unusually warm and cool surfaces within each city, creating a coherent thermal surface vulnerability indicator which can be compared across different urban systems.

To contextualize the spatial distribution of cold spots, we link them to sociodemographic data from the census grid and to walking-time accessibility. For each city, we derive population-weighted indicators that quantify how well different social groups (such as elderly people, children, and immigrants) can reach cold spots. These indicators reveal how accessibility inequalities vary not only between socio-demographic groups but also between various city sizes. This allows us to identify where targeted planning interventions are needed.

By applying this workflow to the full set of Bavarian cities, the study offers a state-wide, high-resolution comparison of urban heat structures and socially differentiated access to cooling. The results demonstrate how remote sensing, geospatial analyses, and census microdata can strengthen evidence-based planning, support climate-resilient urban design, and contribute to more equitable access to cooling in cities of all sizes.

Keywords: walking accessibility, land surface temperature, climate change, cold spots, Bavaria

2 INTRODUCTION

Climate change represents one of the most pressing societal challenges of the 21st century and its impacts are becoming increasingly evident in urban areas (IPCC, 2022). According to the European State of the Climate Report of the Copernicus Climate Change Service, 2024 was the warmest year on record since the beginning of systematic meteorological observations and the year with the second highest number of heat-stress days in Europe (C3S, 2025).

Currently, approximately 56% of the world's population lives in urban areas (United Nations, 2018), where exposure to extreme weather events such as floods, storms, wildfires, and heatwaves is particularly high (C3S, 2025). Compared to rural regions, the high degree of soil sealing, dense built environments, and limited vegetation in cities significantly reduces the capacity to mitigate the impacts of such events (Stewart & Oke, 2012). Among these hazards, heatwaves affect urban populations more severely than those in surrounding rural areas, as cooling locations are often scarcer and less accessible (Lan, 2022).

Heat has been identified as the most significant and urgent climate-related risk to human health in Europe by the European Climate Risk Assessment of the European Environment Agency (EEA, 2024). A lack of centrally located, easily accessible cool places poses substantial challenges for everyday activities, particularly for vulnerable population groups such as older adults, people with disabilities, and families with young children. Increased thermal stress, adverse health outcomes, and rising heat-related mortality rates are among the major risks associated with increasing temperatures and extreme heat events in Europe (IPCC, 2023). Recent studies suggest that these trends will persist in the future (Taubenböck et al., 2024), with climate change progressing particularly rapidly in European cities (Friesen & Taubenböck, 2025). Projections indicate that under the SSP5-8.5 scenario, average temperatures in European cities could in avaerage increase by 4 °K by the end of the century.

A prerequisite for effective climate adaptation in cities is the availability of up-to-date, spatially detailed temperature data. Satellite observations offer considerable advantages in this regard due to their regular temporal coverage and their retrospective availability dating back to the late 1970s. A widely used indicator for identifying thermally warm and cool urban areas is Land Surface Temperature (LST). LST derived from satellite data allows surface temperatures to be captured at spatial resolutions of up to 30 meters across the entire Earth's surface. It provides valuable insights into where cities tend to heat up most intensely during summer – and, crucially, where comparatively cool areas persist.

Land Surface Temperature (LST) is one of the currently 55 Essential Climate Variables (ECVs) defined by the Global Climate Observing System (GCOS). It describes the thermal radiation emitted by the Earth's surface and constitutes a key indicator for identifying thermal hot and cold spots across both sealed (impervious) and natural surfaces (GCOS, 2025). It is important to note, that LST captures radiative emissions; i.e. it does not capture the near-surface factors that contribute to the heat that is actually experienced by people such as air temperature, humidity, radiation or wind (Oke et al., 2017). However, it has been shown that correlations exist and that under the conditions that one is aware of what LST data shows and what not, it is valuable as a proxy with consistent and area-wide data (e.g. Leichtle et al., 2022). LST is widely applied in studies of the hydrological cycle (Wang, 2009), drought assessment (Karnieli, 2010), and even research on vector-borne diseases (Anyamba, 2014), but it is particularly relevant for analyzing heat-induced stress on urban populations (Malakar et al., 2018; Massaro et al., 2023).

LST can be measured either by in situ meteorological stations, which allow for detailed temporal analyses at fixed locations, or by satellite-based remote sensing. Due to their global coverage, regular revisit times, and high spatial resolution, satellites are the primary data source for LST measurements at regional (Friesen, Leichtle & Taubenböck, 2025) to global scales (Good et al., 2022; Massaro et al., 2023). Using thermal infrared (TIR) sensors, satellite-derived LST captures spatial patterns of urban surface heat and cooling phenomena (Bechtel et al., 2019) and is frequently employed in the literature to characterize the Surface Urban Heat Island (SUHI) effect (e.g., Choi et al., 2012; Isufi et al., 2021; Lemus-Cánovas et al., 2020; Xue et al., 2022).

In recent years, an increasing number of studies have focused on LST cold spots, which represent the thermal counterpart to SUHI hot spots. These areas play a crucial role in enhancing urban climate resilience and supporting climate adaptation strategies due to their cooling effects (Mavrakou et al., 2018; Xue et al., 2022; Choi et al., 2012). Although definitions of cold spots vary across studies, they are consistently characterized by lower surface temperatures relative to their surroundings. Cold spots in cities are most commonly associated with green spaces and water bodies, as well as with areas of low imperviousness, low building density, and good ventilation conditions (Bechtel et al., 2019; Xue et al., 2022; Weng, 2009).

Against this background, this study investigates LST cold spots in Bavarian cities as critical yet underexplored elements of surface urban heat adaptation. While previous research on Bavaria has primarily focused on identifying thermal hot spots and the Surface Urban Heat Island effect (e.g. Heldens et al., 2013;

Leichtle et al., 2023; Friesen, Leichtle & Taubenböck, 2025), comparatively little attention has been paid to the spatial distribution, accessibility, and social context of urban cooling areas. By integrating satellite-derived LST with high-resolution socio-demographic data and pedestrian network information (Weigand et al., 2023; Droin et al., 2024), this study aims to assess not only where LST cold spots are located, but also who can access them. Focusing on all 317 municipalities classified as cities in Bavaria, the central research question is: Which socio-geographical patterns can be identified in the spatial distribution and pedestrian accessibility of land surface temperature cold spots across Bavarian cities? In doing so, the study contributes to a more socially informed understanding of urban cooling potential.

3 CONCEPTUAL FRAMEWORK

This study follows a conceptual framework that links the urban surface thermal environment with pedestrian accessibility and socio-demographic characteristics.

Land surface temperature (LST) patterns within cities give rise to spatially distinct cold spots, which represent areas of comparatively lower surface temperatures and potential cooling benefits. However, the contribution of these cold spots to surface urban heat adaptation depends not only on their presence but also on their spatial distribution and accessibility by foot, i.e. by spatial proximity.

At the same time, socio-demographic characteristics influence heat exposure and vulnerability, shaping who benefits from available cooling opportunities. By jointly considering LST cold spots, pedestrian accessibility, and socio-demographic patterns across Bavarian cities, the framework enables an assessment of spatial inequalities in access to urban cooling and their implications for climate adaptation.

4 STUDY AREA & DATA

This study covers the entire federal state of Bavaria (Germany) and includes all 317 municipalities that are classified as cities according to the official census definition (Fig. 1, left). The spatial extent of each city is defined by its administrative municipal boundary, which serves as the analytical frame for all subsequent processing steps. By considering the complete set of census-defined cities rather than a limited number of case studies, the analysis enables a systematic and comparable assessment of thermal patterns and accessibility conditions across a wide range of urban contexts, including small, medium-sized, and large cities.

To support intra-urban analyses and ensure consistency with population data, each city is represented using a regular grid with a spatial gridding of 100 m × 100 m, clipped to the corresponding administrative boundary. This resolution was chosen to match the spatial structure of the available census grid (Destatis, 2024). All thermal, spatial-statistical, and accessibility indicators are derived and evaluated at this grid-cell level, allowing population-weighted aggregation and cross-city comparisons.

Land Surface Temperature (LST) was derived from Landsat 8 and Landsat 9 thermal infrared observations and processed as a spatially continuous raster dataset covering the entirety of Bavaria at 30 m spatial resolution. Only scenes with a nominal cloud cover below 50% were included in the analysis. Due to frequent cloud contamination over large parts of the study area, shorter time periods were insufficient to obtain robust spatial coverage of all cities. For this reason, the temporal extent of the dataset was expanded to a four-year period from 1 November 2020 to 31 October 2024. This ensures adequate data availability across all municipalities and avoids short-term anomalies by focusing on a long-term trend.

For all eligible scenes within the study period, LST values were aggregated on a per-pixel basis to compute a multi-year temporal mean at 30 m spatial resolution. This aggregation captures long-term average thermal conditions and highlights spatially persistent temperature patterns at the land surface. The temporal mean LST, expressed in degree Celsius, was selected as a robust indicator of urban surface thermal characteristics, as maximum LST values showed strong heterogeneity within cities due to differing acquisition dates of individual satellite scenes. Using the mean reduces artificial temperature discontinuities caused by short-term meteorological variability while preserving meaningful spatial contrasts between warmer and cooler urban areas. The resulting raster thus provides a harmonized representation of urban surface temperatures suitable for comparative analysis across cities.

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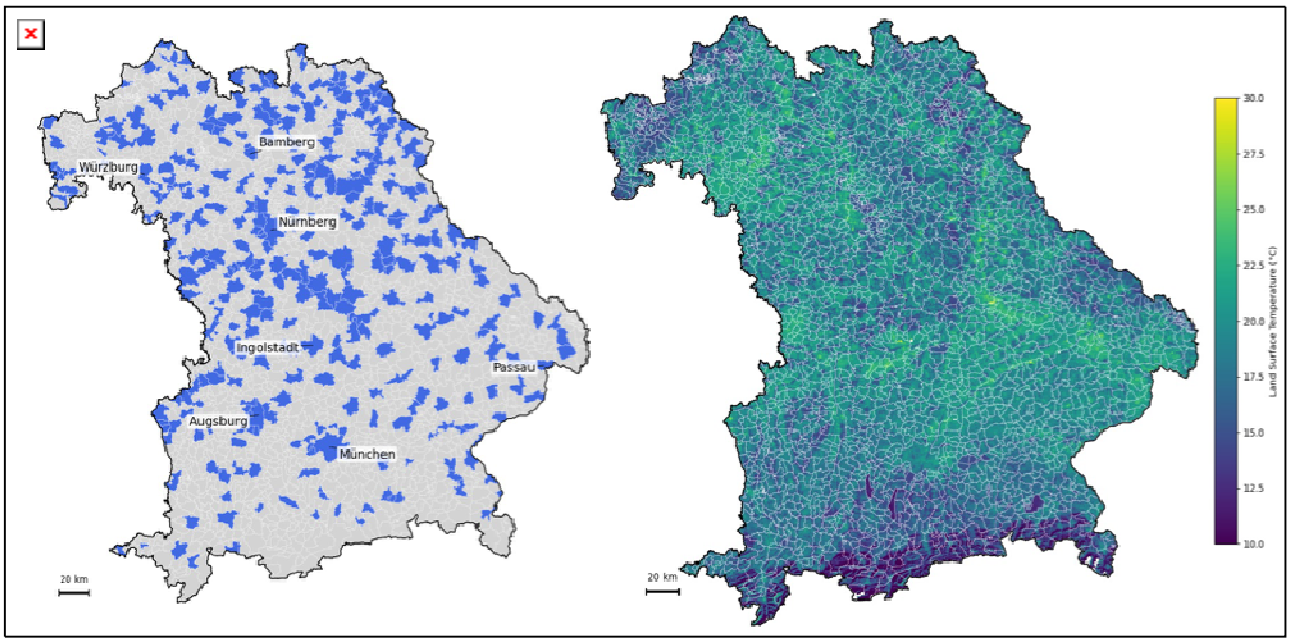


Fig. 1. Left: In blue the analysed municipalities (cities) in Bavaria. Right: Median Land Surface Temperature derived from Landsat 8 and Landsat 9 over four entire years from 2020 to 2024.

5 METHODS

5.1 Grid-based aggregation and identification of thermal hot and cold spots

To enable city-scale and intra-urban analyses, the 30 m land surface temperature (LST) raster was spatially aggregated to the 100 m analysis grid defined for each city (Fig. 2, upper row). Zonal statistics were computed by intersecting the LST raster with the grid-cell polygons and calculating the mean LST value per cell. The resulting grid-based LST values were stored as attributes of the city-specific analysis grids.

Based on the aggregated grid-level LST values, spatial clustering of relatively high and low surface temperatures within each city was assessed using the local Getis–Ord Gi* statistic. This local indicator of spatial association identifies areas where grid cells with similar surface temperature values cluster more strongly than would be expected under spatial randomness. The analysis was conducted separately for each city to account for differences in urban extent, morphology, and thermal variability.

Spatial relationships between grid cells were modeled using a Queen contiguity spatial weights matrix, in which neighboring cells share either an edge or a corner. Only grid cells with valid LST values were included in the analysis.

Rather than applying fixed significance thresholds, a relative, quantile-based classification was used to define thermal hot and cold spots. Grid cells with Gi* z-scores in the lowest 20% of the city-specific distribution were classified as cold spots, while those in the highest 20% were classified as hot spots. This approach facilitates comparison across cities with differing sample sizes and thermal contrasts and ensures a consistent identification of relative thermal surface extremes within each urban system. The resulting binary cold-spot classification forms the primary input for the subsequent pedestrian accessibility analysis.

5.2 Pedestrian accessibility to cold spots

Pedestrian accessibility to thermal cold spots was assessed using a network-based routing approach grounded in OpenStreetMap (OSM) data (Fig. 2, lower row). For each city, a walkable street and path network was extracted using OSMnx. The network was projected to a metric coordinate system, and each edge was assigned a travel time based on its geometric length and an assumed constant walking speed of 4.5 km/h.

Cold spots were represented by the centroids of all grid cells classified as cold spots, which were spatially matched to the nearest nodes in the OSM network. Similarly, centroids of all census grid cells were mapped to their nearest network nodes. To efficiently compute walking times from all populated locations to the nearest cold spot, a multi-source Dijkstra algorithm was applied, treating all cold-spot nodes as simultaneous

sources. This yields the minimum travel time along the pedestrian network from each network node to the closest cold spot.

For each census grid cell, the travel time associated with its nearest network node was extracted and stored in both seconds and minutes. This procedure results in a spatially explicit representation of pedestrian access to cool locations across the entire urban fabric of each city.

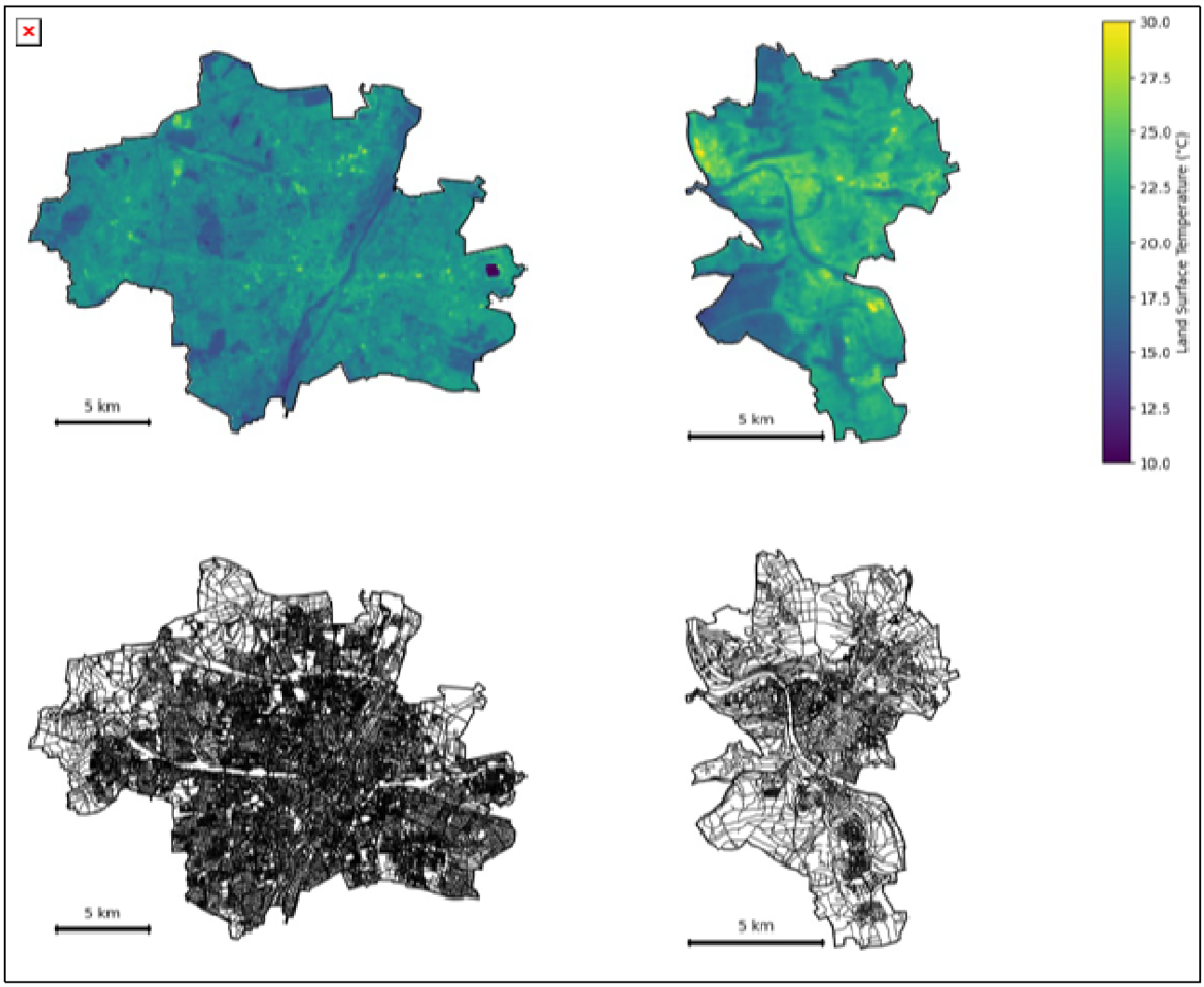


Fig. 2: Upper row: Land surface Temperature for the cities of Munich (left) and Würzburg (right). Lower row: Pedestrian network for the cities of Munich (left) and Würzburg (right)

5.3 Population-weighted exposure and relative risk analysis

Population exposure to limited cold-spot accessibility was evaluated using the 100 m census grid. For each cell, total population counts as well as subgroup attributes (population under 18 years, population aged 65 years and older, and the share of foreign residents) were considered. These groups are considered to suffer most during extreme heat events (Depietri et al., 2013).

Accessibility outcomes were summarized at the city level by calculating the population-weighted share of residents whose walking time to the nearest cold spot exceeds 10, 20, and 30 minutes. These thresholds were selected to reflect increasingly constrained pedestrian access in a particular urban context.

To assess social disparities in access to cooling opportunities, a relative risk (RR) metric was computed for a long-walking-time condition defined as more than 20 minutes to the nearest cold spot. For each population group g, relative risk was calculated as $RR_g = P(t>20|g) / P(t>20|all)$ where $P(t>20|g)$ denotes the proportion of group g living in census cells with walking times exceeding 20 minutes, and $P(t>20|all)$ represents the corresponding proportion for the total population (Friesen, Georganos and Haas, 2025). Values $RR_g > 1$ indicate that a group is disproportionately affected by limited pedestrian access to thermal cold spots compared to the city population as a whole.

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6 RESULTS

6.1 Intra-urban thermal structure: hotspots and coldspots

Across the 317 cities included in the analysis, mean land surface temperatures (LST) show relatively limited variation, with a median of 18.9 °C (Inter quantile range IQR: 18.1–19.9 °C). In contrast, substantial differences emerge when comparing thermally extreme surface areas within cities. Hotspots exhibit a median LST of 21.7 °C (IQR: 21.1–22.6 °C), while coldspots are markedly cooler, with a median of 15.7 °C (IQR: 14.9–16.5 °C).

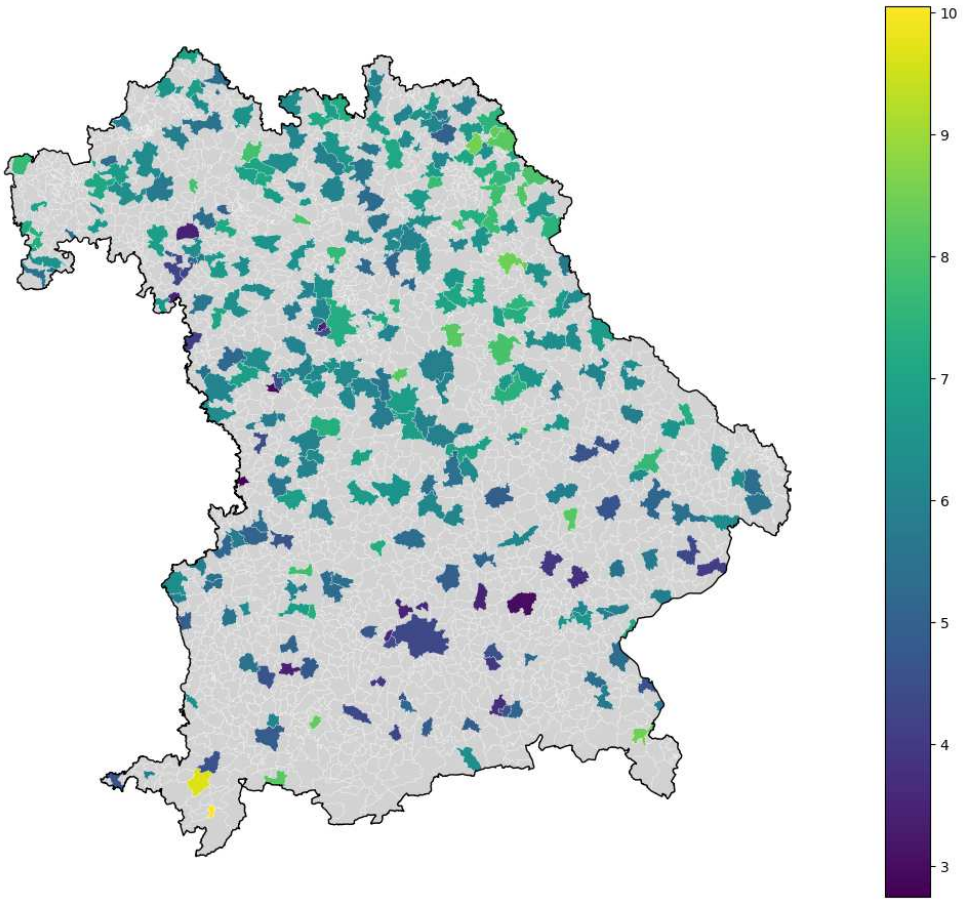


Fig. 3: Temperature differences in °K between hot- and coldspots in Bavarian cities.

The resulting hotspot–coldspot temperature contrast varies considerably across cities and across the state. Cities in the notheastern part show higher temperature differences than cities in the south and west. The median difference amounts to 6.1 °K, with an interquartile range from 5.4 °C to 6.8 °K. At the lower end, some cities show contrasts below 3 °K, indicating relatively homogeneous thermal conditions, whereas others exceed 10 °K, reflecting pronounced thermal segregation.

6.2 Accessibility of cooling areas

Accessibility to coldspots differs strongly both within and across cities. The median walking time to the nearest coldspot is 14.6 minutes (IQR: 11.7–18.9 minutes). It can therefore be stated that at the aggregated city level in Bavaria, the planning idea of the 15-minute city (Allam et al., 2022), i.e. being able to reach central functions for everyday needs on foot in less than 15 minutes, is just about fulfilled for cold spots. But of course there are many places at the intra-urban level that have much better or worse accessibility.

A median of 79.0 % of residents live more than 10 minutes away from the nearest coldspot. For stricter thresholds, the median share of the population living more than 20 minutes away is 32.8 %, while 2.2 % live more than 30 minutes away. However, the upper quartiles reveal much higher exposure levels: in 25 % of cities, more than 55.7 % of the population is located beyond the 20-minute threshold, and in some cities the entire population exceeds this distance.

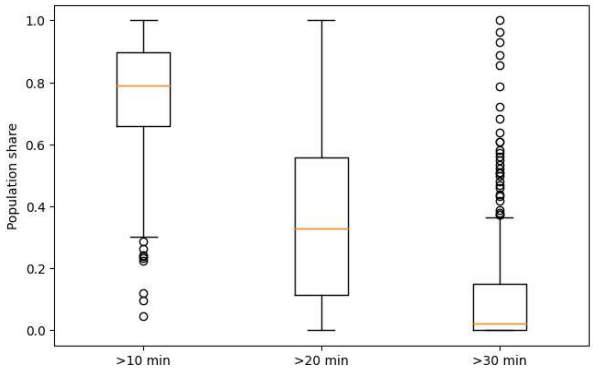


Fig. 4: Boxplots representing the accessibility to coldspots above 10, 20 and 30 minutes for Bavarian cities.

Large cities such as Augsburg illustrate the upper end of this distribution, with 84 % of the population with more than 20 minutes walking time to the next coldspot, whereas more compact cities like Abenberg or Altdorf show substantially shorter travel times for most residents. Nevertheless, similarly high accessibility deficits are also observed in smaller cities with dispersed settlement patterns.

6.3 Coupling of thermal contrast and cooling accessibility

Cities with stronger intra-urban thermal contrasts (Fig. 3) tend to exhibit poorer access to cooling areas. Fig. 5,a highlights, that the hotspot–coldspot LST difference correlates moderately with the share of the population living more than 20 minutes from a coldspot ($\rho = 0.51$).

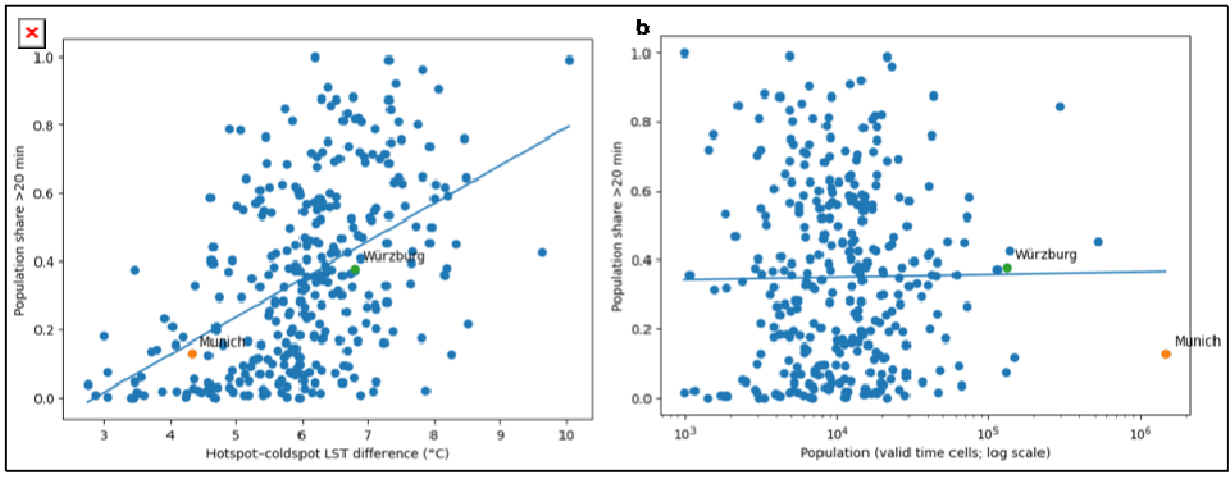


Fig. 5: a: Relationship between population share with more than 20 minutes walking time to cold spots for the analyzed cities. b: Relationship between population share with more than 20 minutes and population within the analyzed city.

While these relationships are intuitively plausible, their consistency across more than 300 cities suggests that they reflect structural characteristics of urban form and land-use configuration rather than isolated local conditions.

In contrast, total city population shows no meaningful correlation (Fig. 5, b) with either thermal contrast or accessibility indicators ($|\rho| < 0.1$). This finding indicates that cooling accessibility challenges are not primarily driven by city size but occur across the full urban hierarchy, from small towns to large regional centers.

6.4 City-level exemples: Munich and Würzburg

The detailed maps of Munich and Würzburg (Fig. 2 and Fig. 6) show how the aggregated patterns illustrated above occur on a city-wide scale. In both cities, coldspots are spatially coherent and closely linked to vegetated areas or bodies of water, while hotspots correspond to densely built-up zones. However, their accessibility patterns differ.

Munich, with moderate hotspot–coldspot thermal contrasts (see Fig. 5, left), exhibits relatively moderate median walking times to coldspots, with a more dispersed pattern of cold and hotspots.

By contrast, Würzburg exhibits a more compact spatial structure, with hotspots in the highly dense structures of the old town and the surrounding highly dense block developments and coldspots on the periphery, near local forests. This, in combination with a less dense network for walking due to topography, leads to localised accessibility deficits. It is important to mention, that some of the city's local parks (e.g. Ringpark in the center of Würzburg) that are supposed to be cold spots do due to our data and threshold approach not appear as cold spots.

6.5 Distributional impacts and relative risks

Relative risk (RR) analysis reveals systematic disparities in cooling accessibility across population groups (Fig. 7) and thus spatial inequality.

For residents with a foreign nationality background, the median RR is 1.07 (IQR: 0.80–1.26). In 59.3 % of cities, RR values exceed 1, indicating that this group is more likely than the general population to live more than 20 minutes from the nearest coldspot. In 25.2 % of cities, RR exceeds 1.25, and in 10.1 % it exceeds 1.5, pointing to substantial overrepresentation in a non-negligible subset of cities. In extreme cases, RR values approach 8, reflecting highly uneven spatial distributions.

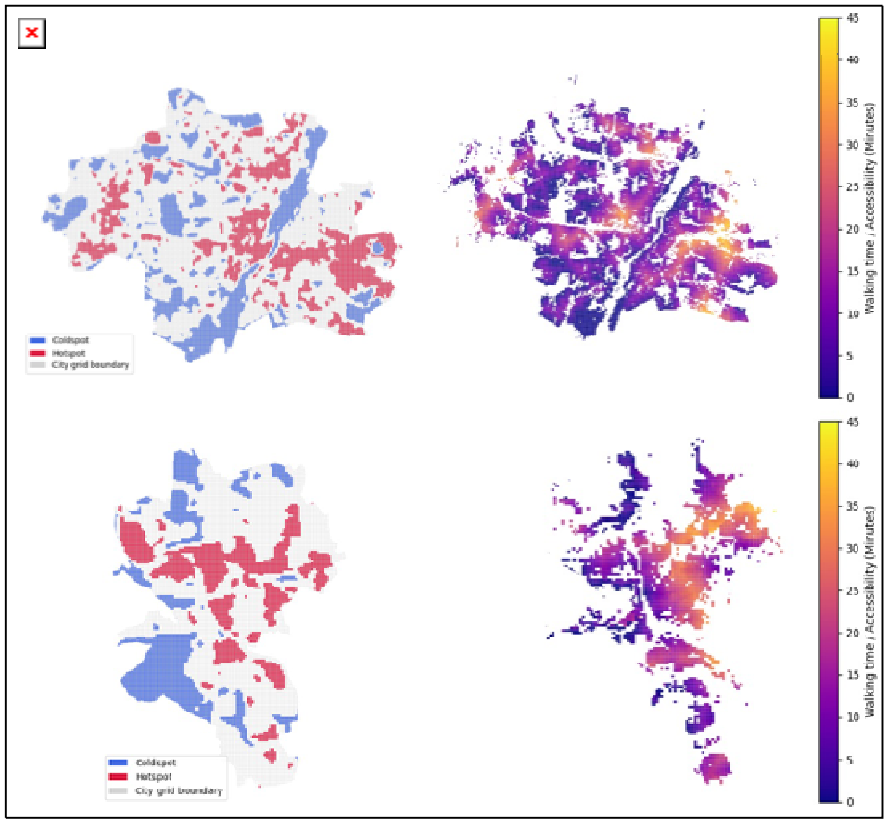


Fig. 6: Spatial distribution of cold- and hotspots (left column) and accessibility (right column) for Munich (upper row) and Würzburg (lower row).

For children and adolescents under 18 years, the median RR is close to parity (1.00, IQR: 0.95–1.06). Although RR values exceed 1 in 52.1 % of cities, stronger disadvantages are uncommon: only 5.7 % of cities exceed an RR of 1.25, and 1.6 % exceed 1.5.

A similar pattern is observed for residents aged 65 years and older. The median RR is 1.00 (IQR: 0.92–1.06), with RR > 1 in 50.2 % of cities. However, elevated values above 1.25 occur in fewer than 5 % of cases, and values above 1.5 are rare.

Comparing across groups, residents with a foreign nationality background consistently exhibit both the highest frequency and the highest magnitude of disadvantage. While slight deviations from parity are common across all groups, pronounced inequities are largely concentrated in this population group.

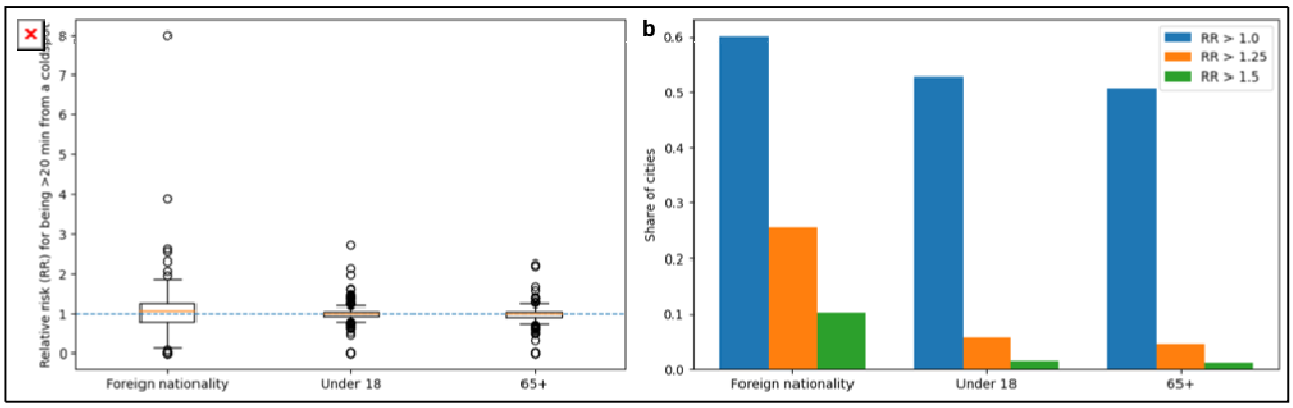


Fig. 7: (a) Relative risk (RR) for different social groups to have worse access to cooling space than the rest of the population and (b) share of cities exceeding a specific threshold of RR. The time threshold used for this analysis is 20 minutes.

7 DISCUSSION

This study demonstrates that pronounced thermal surface heterogeneity is a common feature of cities across Bavaria, extending well beyond large metropolitan areas. Across municipalities, the median difference in land surface temperature (LST) between hotspots and coldspots clusters around approximately 6 °K, with interquartile ranges between roughly 5.4 and 6.8 °K. These magnitudes confirm that even small and medium-sized cities exhibit strongly differentiated internal thermal surface structures rather than spatially uniform surface heat exposure.

The observed intra-urban contrasts are consistent with previous urban heat island research highlighting the role of land cover, vegetation, and impervious surfaces in shaping local thermal environments. Importantly, the lack of association between hotspot–coldspot contrast and total population size suggests that thermal differentiation is driven more by urban form and land-use configuration than by city size per se.

The Bavaria-wide comparison reveals that high thermal surface contrasts are not restricted to large urban centers. Several small and medium-sized municipalities exhibit hotspot–coldspot surface differences comparable to, or even exceeding, those of larger cities. This finding underscores that challenges related to urban surface heat exposure and cooling provision are regionally pervasive and should not be framed solely as metropolitan issues. From a planning perspective, it reinforces the need to consider heat adaptation and cooling infrastructure across the full spectrum of city sizes.

While thermal surface contrasts provide insight into the existence and intensity of coldspots, accessibility metrics reveal how unevenly these cooling resources are distributed relative to residential urban populations. Across cities, a substantial share of residents – around one third at the median – lives more than 20 minutes walking distance from the nearest coldspot, with upper quartiles exceeding 50%. At a more conservative 30-minute threshold, accessibility is given in most cities, indicating that coldspots are generally present but often spatially distant from everyday residential environments.

Another finding of this study is the positive association between hotspot–coldspot thermal surface contrast and poor cooling accessibility. Cities with larger thermal surface differences tend to have a higher proportion of residents living far from coldspots. While this relationship is moderate and not deterministic, it suggests that strong thermal surface heterogeneity may coincide with spatial concentration of cooling resources rather than their integration into the urban fabric. In other words, cities may exhibit substantial cooling potential without providing widespread, walkable access to it.

City-specific patterns illustrate how analytical choices and urban morphology jointly shape these outcomes. In cities such as Augsburg and Würzburg, large forested areas located within administrative boundaries dominate the coldspot classification due to the high temperature differences between the urban forests and the urban fabric. These specifics by the adminsitrative units influence the coldspot classification. For Würzburg this leads to comparatively low accessibility for large parts of the population in our analysis (Fig. 6). These cases highlight that coldspots are not purely physical entities but analytically defined spatial units whose extent and location influence observed accessibility patterns.

Importantly, not all cities with large thermal contrasts exhibit poor accessibility. This variation indicates that urban layout, connectivity, and the spatial distribution of green infrastructure mediate the relationship

between thermal patterns and effective cooling access. Walking networks, permeability (c.f. r.g. Droin et al., 2024), and the placement of small-scale green spaces appear to play a critical role in translating cooling potential into practical heat mitigation benefits.

Beyond average accessibility, the relative risk (RR) analysis reveals systematic but heterogeneous inequities in access to cooling. In approximately 60% of cities, residents with foreign nationality are overrepresented among populations living more than 20 minutes from a coldspot. For children and older adults, the proportion of cities with RR values greater than 1 is slightly above 50%, indicating weaker but still widespread inequities. While median RR values across cities remain close to 1 for all groups, the distribution for residents with foreign nationality shows a pronounced upper tail, with RR values exceeding 1.25 and, in some cases, substantially higher.

These patterns suggest that cooling accessibility inequities are highly context-dependent and shaped by local residential segregation and urban structure. The relative measures (relative risk) mentioned in the study are robust measures for capturing inequality in access to cold spots, as are the absolute values, since, as already indicated above, these are sensitive to the definition of cold spots. As a result, while absolute accessibility measures reflect conditional exposure patterns influenced by analytical choices, the observed relative inequities point to more robust social gradients in access to cooling resources.

Taken together, the findings suggest that surface urban heat adaptation strategies should not focus solely on increasing the total amount of green space or cooling capacity. Cities characterized by large, spatially concentrated coldspots but poor accessibility may benefit more from distributed, small-scale interventions (such as street trees, pocket parks, and shaded pedestrian corridors) than from further expansion of already extensive green areas. Integrating accessibility considerations into urban climate adaptation planning is therefore critical for translating cooling potential into thermal relief.

The observed equity patterns further highlight the importance of evaluating cooling interventions not only in terms of average benefits but also in terms of who gains access. Place-specific diagnostics that combine thermal (surface) patterns, accessibility, and socio-demographic characteristics can help ensure that cooling infrastructure contributes to reducing, rather than reinforcing, existing social inequalities.

Overall, this study should be interpreted as identifying indicative patterns of relative thermal surface exposure and cooling accessibility rather than providing precise estimates of individual-level heat risk. The sensitivity of results to coldspot definitions and boundary choices highlights the need for future work to systematically test the robustness of accessibility and equity patterns across alternative conceptualizations of urban cooling, including absolute temperature thresholds, usability-based criteria, and alternative delineations of urban areas such as functional urban areas. Despite these challenges, the consistent spatial and social patterns observed across cities demonstrate the value of the proposed approach as a comparative framework for understanding how thermal environments, accessibility, and equity intersect in urban heat adaptation.

7.1 Limitations

The following limitations should be considered when interpreting the results of this study, particularly with respect to data sources and modeling assumptions.

First, land surface temperature (LST) estimates were derived from multi-scene Landsat composites using median values. While this approach increases robustness against cloud contamination and scene-specific artifacts, it may underestimate thermal extremes that are most relevant for acute heat-related health impacts. Peak temperatures during extreme heat events are likely higher than the reported values, and their spatial patterns may differ. Although this limitation affects absolute temperature levels, it is less likely to substantially alter relative hotspot–coldspot contrasts within cities, which form the basis of the comparative analysis. It has also to be taken into account, that LST is just a proxy for thermal comfort and further studies on ambient air temperature, humidity radiation or wind (Oke et al., 2027) are needed to better understand to what extent the findings of this study relate to heat stress.

Second, pedestrian accessibility was modeled using OpenStreetMap (OSM) street networks. Despite generally high coverage in urban areas, OSM data quality varies with respect to pedestrian connectivity, access restrictions, and the representation of informal or recently developed pathways. Such inconsistencies may introduce spatial biases in estimated walking times, particularly in areas with complex access

conditions. However, as accessibility calculations were performed consistently across cities, these uncertainties primarily affect absolute values rather than relative comparisons between population groups within the same city.

Third, accessibility modeling assumed a uniform walking speed across all population groups and spatial contexts. This simplification does not account for differences related to age, health status, terrain, or environmental conditions, which may disproportionately affect vulnerable populations such as older adults or individuals with mobility impairments. Consequently, estimated walking times should be interpreted as generalized indicators of spatial proximity rather than precise measures of experienced accessibility.

Fourth, the analysis focused on spatial proximity to coldspots without explicitly accounting for their functional characteristics or usability. Coldspots differ substantially in size, public accessibility, amenities, and their capacity to provide effective thermal relief (e.g., tree canopy density, shaded seating, or water features). The presence of a coldspot within walking distance therefore does not guarantee that it functions as an accessible or effective cooling resource for all residents.

Finally, population characteristics were analyzed at the 100 m grid-cell level using aggregated census attributes. This spatial aggregation may mask intra-cell heterogeneity and does not capture temporal dynamics such as daily mobility, diurnal population shifts, or differences between daytime and nighttime exposure. As a result, the analysis reflects residential accessibility patterns rather than dynamic individual exposure.

Taken together, these limitations suggest that the results should be interpreted as indicative patterns of relative thermal exposure and cooling accessibility rather than precise estimates of individual-level heat risk. Nevertheless, the consistent application of methods across cities and the robustness of relative risk patterns support the validity of the comparative insights and provide a foundation for future studies using more detailed, temporally resolved, or context-specific data.

8 CONCLUSION

This study shows that strong intra-urban thermal surface heterogeneity is a widespread feature of cities across Bavaria, extending well beyond large metropolitan areas. Substantial hotspot–coldspot contrasts are common even in small and medium-sized municipalities. In many cities, a significant share of the population lives at considerable walking distances from coldspots, and stronger thermal contrasts tend to coincide with poorer accessibility. These patterns indicate that urban surface heat risk is shaped not only by the intensity of heating but also by how cooling opportunities are distributed within the urban fabric.

The analysis further reveals context-dependent but systematic social inequities in cooling accessibility, particularly affecting residents with foreign nationality. While absolute accessibility measures are sensitive to analytical choices and urban morphology, relative risk patterns are more robust, highlighting persistent social gradients in who benefits from urban cooling. Together, these findings underscore that effective urban surface heat adaptation requires attention to spatial distribution and walkable access, not only the amount of green space availability. The proposed framework demonstrates the value of integrating thermal data, accessibility analysis, and equity metrics to support more targeted and socially just climate adaptation planning, while also providing a basis for future robustness and sensitivity analyses.

9 ACKNOWLEDGEMENTS

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reviewed paper

Beyond Informality: Middle-Class Urbanisation, Hybrid Governance, and Resilience Challenges in African Peripheries

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1 ABSTRACT

Africa's rapidly expanding peri-urban zones have become critical sites of urban transformation, yet dominant narratives continue to frame these spaces through poverty-centred understandings of informality. This paper challenges these framings by systematically examining the emerging role of the African Middle class in driving self-help housing developments on customary land. It draws on a systematic literature review of 32 peer reviewed studies published between 1994 and 2025, and interrogates the intersection of middle-class investment practices, neo-customary land tenure, hybrid governance arrangements, and the implications of these dynamics for urban resilience. The review reveals four core patterns reshaping the African periphery: the commercialisation and reconfiguration of traditional authority; the emergence of institutional multiplicity and fragmented planning legitimacy; the strategic but spatially fragmented logic of middle-class self-help; and the production of ecological and infrastrucutural vulnerabilities that undermine collective urban resilience. The paper argues for a reconceptualisation of informality that recognizes class-mediated urbanisation as a structurally significant mode of African city-making. It concludes by proposing a resilience-oriented planning paradigm grounded in engaged tenure pluralism, metagovernance, ecological protection and differentiated housing policy responses.

Keywords: Peri-urbanisation, Middle-class self-help housing, hybrid governance, neo-customary land tenure, urban resilience

2 INTRODUCTION

The 21st century is projected to be the African century of urban transformation (UNECA, 2024). Yet, the patterns and processes of this urbanisation defy conventional models, unfolding not just within city cores but explosively across their peripheries. These peri-urban zones, the contested interfaces between the urban and the rural, have become the primary theatres for Africa's urban future, characterised by dynamic complexity, institutional hybridity, and profound socio-ecological change (Sihlongonyane & Sithagu, 2025; El Kahlaoui, 2024). Prevailing policy and research paradigms, often inherited from the Global North, have historically framed urban expansion through a lens of dichotomies: formal versus informal, legal versus illegal, planned versus unplanned. Within this framework, informality is frequently conflated with poverty, marginality, and a state of exception to be remedied through formalisation (De Soto, 2000).However, a significant and growing body of scholarship on African cities reveals a far more nuanced reality. A pivotal and under-acknowledged driver of this peripheral urbanisation is the formally employed, asset-accumulating middle class (Andreasen & Agergaard, 2022; Mercer, 2024). Faced with prohibitively expensive formal housing markets and inadequate state-provided housing schemes, these households are increasingly bypassing traditional governmental and market structures. Instead, they are engaging in self-help housing on customary land, leveraging their economic capital to secure plots and incrementally build homes in peri-urban areas (Ubink & Quan, 2008; Abdulai, 2024). This phenomenon represents a critical intersection of class, tenure, and urbanisation that fundamentally challenges existing narratives.This paper seeks to synthesise and analyse the emerging evidence on this phenomenon. It poses the following central question: How is the growth of middle-class self-help housing on customary land tenure systems reconfiguring governance, spatial forms, and socio-ecological resilience in Africa's peri-urban peripheries?

3 LITERATURE REVIEW

This review synthesises existing scholarship across three intertwined domains: the definition and role of the African middle class, the complexity of the peri-urban condition, and the evolving nature of customary land tenure and informality.

3.1 The African Middle Class: Beyond Income, Towards Asset-Building and Spatial Practice

Lentz (2015) argues that the African middle class is not a monolithic entity, but a social category defined by its "struggle for belonging" and distinction, often achieved through consumption patterns, educational attainment, and investment in housing and property. For these groups, formal employment, often in the public sector or services, provides a degree of economic security, which is then channelled into asset accumulation, primarily through real estate, as a strategy to mitigate pervasive economic precarity (Andreasen & Agergaard, 2022).This asset-building imperative is a key driver of spatial practice. It transcends mere shelter; it is an entrepreneurial act of investment and a claim to social status and urban citizenship. As Mercer (2024) illustrates in Dar es Salaam, the suburban frontier is being constructed by a middle class for whom self-built housing represents a primary strategy for securing economic futures. Their practices represent a form of "upwardly mobile informality" or "informalised modernity," where formal economic resources are deployed within informal institutional and spatial frameworks to achieve security and upward mobility, a phenomenon that reflects the "anxious, insecure and ambiguous" nature of this social stratum that Melber (2016) describes.

3.2 The Peri-Urban as a Zone of Institutional and Ecological Complexity

The peri-urban interface is a dynamic, multi-faceted space characterised by intense social, economic, and environmental interactions. Academically, it is understood as a zone of "fragmented governance" (Sihlongonyane & Sithagu, 2025), "ecological risk" (Mwonzora & Hamunakwadi, 2025), and "institutional multiplicity" (Nchanji & Bellwood-Howard, 2018). Ecologically, peri-urban zones are critical yet vulnerable. They often contain essential ecosystems like wetlands, watersheds, and green corridors that provide vital services for the entire urban region. However, they are also the prime target for urban expansion. The work of Mwonzora and Hamunakwadi (2025) in Harare illustrates the tragic trade-off between "securing a roof" and "securing ecosystems," as middle-class housing encroaches on wetlands, increasing flood vulnerability. Wijesinghe and Thorn (2021) further highlight the governance challenges in managing urban green infrastructure within informal settlements of Windhoek, underscoring the disconnect between ecological value and urban land pressure.

3.3 Customary Land Tenure and the Re-invention of Informality

Customary land tenure, once considered a rural and anachronistic system, has become central to peri-urban transformation. It is not a static relic but a highly adaptive and commoditised system. Due to rising land prices, traditional leaders have been allocating land more in a market-driven manner, creating what scholars refer to as "neo-customary" land tenure (Ubink & Quan, 2008; Abdulai, 2024).This neo-customary system is characterised by the commercialisation of land transactions, often to the detriment of the original communal principles. Sumbo (2022) provides an analysis of this shift in peri-urban Kumasi, showing how the transformation of usufruct rights into marketable commodities leads to the exclusion of indigenous community members. This process creates new social hierarchies and tensions within peri-urban communities. This commodification directly challenges simplistic formal/informal dichotomies. The housing that emerges on this land is "informal" from the perspective of the state (lacking planning permission, title deeds, and compliance with building codes) but is often developed with significant formal economic capital. It represents a "formal-informal hybrid" were salaried incomes fund incremental construction on extra-legal tenure. This is evident in the work of Andreasen and Agergaard (2022), who frame urban property explicitly as a form of security for Africa's growing middle classes, a safe haven for capital investment.

3.4 Synthesising the gaps

While many studies analyse customary tenure, middle-class housing, governance, and environmental risk separately, few systematically integrate all four to investigate their interconnection and cumulative impact on urban resilience.This paper seeks to fill this gap. It argues that understanding the resilience of African cities requires a holistic analysis of how class-driven investment, mediated through hybrid tenure and governance

systems, produces specific spatial forms that either enhance or undermine the capacity of urban peripheries to adapt to social, economic, and environmental shocks. The following sections will undertake this synthesis through a systematic analysis of the literature.

4 METHODOLOGY

This paper employs a systematic literature review methodology to synthesize existing scholarly knowledge on the intersection of customary land tenure, middle-class self-help housing, and urban resilience in Africa's peri-urban contexts. A systematic approach was selected to minimize bias, enhance reproducibility, and provide a comprehensive audit trail of the literature identification and selection process. Search strings combined keywords and synonyms using Boolean operators (AND/OR) within TITLE-ABS-KEY and were restricted to literature focusing on Africa and Sub-Saharan Africa. A full list of search strings and thematic focus areas is provided in Table 1 below.

Theme	Search String (Scopus Advanced Search)	Focus/Rationale
1. Self-help housing and middle class	TITLE-ABS-KEY(("self-help housing" OR "self built housing" OR "self-building" OR "informal housing" OR "incremental housing") AND ("middle class" OR "emerging middle class" OR "formally employed households" OR "asset accumulating households") AND (Africa OR "Sub-Saharan Africa"))	Captures literature on self-help/self-built housing practices by middle-class groups in African contexts.
2. Customary land tenure and housing	TITLE-ABS-KEY(("customary land tenure" OR "traditional authority" OR "communal land" OR "land access" OR "land rights" OR "tenure pluralism") AND ("self-help housing" OR "informal housing" OR "self-built housing") AND (Africa OR "Sub-Saharan Africa"))	Focuses on the role of customary land systems and traditional authorities in enabling or shaping self-help housing.
3. Governance and peri-urban development	TITLE-ABS-KEY(("hybrid governance" OR "customary governance" OR "traditional authority" OR "municipal governance") AND (peri-urban OR "urban periphery" OR "urban fringe" OR "city edge" OR "urban expansion") AND (Africa OR "Sub-Saharan Africa"))	Targets literature on governance arrangements (customary vs. municipal) in peri-urban African contexts.
4. Resilience and peri-urban housing	TITLE-ABS-KEY(("urban resilience" OR "climate resilience" OR "ecological risk" OR "urban sustainability") AND ("self-help housing" OR "informal housing" OR "self-built housing") AND (peri-urban OR "urban periphery" OR "urban fringe") AND (Africa OR "Sub-Saharan Africa"))	Identifies studies linking housing practices in peri-urban areas with urban/climate resilience and ecological risks.
5. Informal urbanism and class dynamics	TITLE-ABS-KEY(("informal urbanism" OR "informal settlement" OR "incremental urbanism") AND ("middle class" OR "emerging middle class") AND (Africa OR "Sub-Saharan Africa"))	Highlights the intersection of class dynamics (middle class) with informal urbanism in African peripheries.

Table 1: Search strings and thematic focus areas (Source: Author's construction, 2025).

4.1 Screening process and PRISMA protocol

The review applied carefully defined inclusion and exclusion criteria to ensure the relevance and quality of the selected studies. Articles were considered eligible if they focused on self-help, informal, or incremental housing within African peri-urban contexts and engaged substantively with issues of customary land tenure, governance, resilience, or middle-class dynamics. Only peer-reviewed journal articles, books and book chapters published between 1994 and 2025 and written in English were included, reflecting both the contemporary relevance of the topic and the need for quality assurance in the sources consulted. Although the date range was set to capture a broad period, the searches ultimately produced articles concentrated within the past two decades, highlighting the relatively recent emergence and growing scholarly attention to middle-class self-help housing on customary land in Africa. Studies were excluded if they were duplicate records, if they fell outside the geographic focus on Africa and Sub-Saharan Africa, or if they did not explicitly engage with housing and land dynamics relevant to the study.

The identification and selection of studies followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which emphasize transparency, reproducibility, and rigor in review methodologies (Page et al., 2021). A total of 92 records were initially retrieved from Scopus across the five thematic search strings. After merging the CSV files and removing duplicates based on titles, DOIs,

and author details, the dataset was reduced to 67 unique records.Ultimately, 32 studies were included in the final review and synthesis. The flow of records through each stage of the process follows an adaptation of the PRISMA 2020 flow diagram template for systematic reviews (Page et al., 2021), which provides a transparent account of how the initial dataset was refined to the final body of literature analysed.

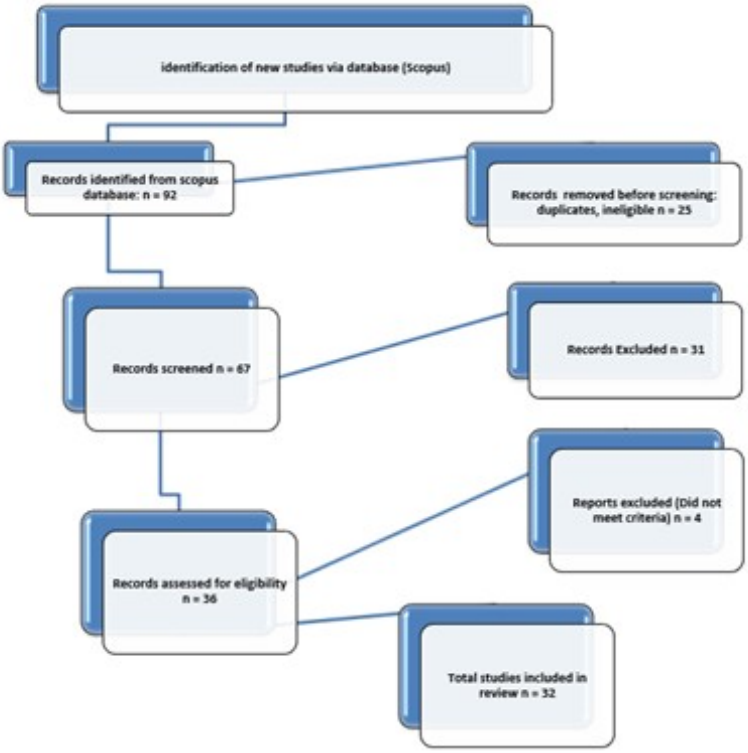


Fig 1: PRISMA Workflow diagram Source; Authors, 2025

5 THEMATIC ANALYSIS

The systematic review of the literature reveals four interconnected thematic domains through which the phenomenon of middle-class self-help housing on customary land unfolds. These themes illustrate the complex reconfiguration of authority, the emergence of hybrid systems, the distinct logics of spatial production, and the consequential challenges to urban resilience.

5.1 The Reconfiguration of Traditional Authority: From Custodians to Land Entrepreneurs

A paramount finding across the literature is the profound transformation of traditional authority structures under the pressures of peri-urbanisation. Customary leaders, once regarded as custodians of communal land heritage, are increasingly functioning as de facto planning authorities and entrepreneurial actors within urban land markets (Ubink & Quan, 2008; Simelane & Sihlongonyane, 2021). This shift is not a simple erosion of tradition but a strategic adaptation, resulting in what scholars' term "neo-customary" land tenure, a system where the outward forms of custom are maintained while the underlying practices become intensely commercialised (Abdulai, 2024; Sumbo, 2022).

In Senegal, Pinard (2021) analyses the contentious consolidation of 'traditional villages' in Pikine, where chiefly legitimacy is constantly negotiated through the control of and access to peri-urban land. Similarly, Sihlongonyane and Sithagu (2025) detail the powerful influence of traditional authorities over territorial governance in Thembisile Hani Municipality, where their role in land allocation creates a parallel planning system with significant spatial implications. This reconfiguration positions traditional leaders not as relics of the past, but as central, albeit contested, figures in the urban development process.

5.2 Hybrid Governance: Institutional Multiplicity and Contested Legitimacy

The collision of traditional land administration with the purported authority of municipal governments generates a state of institutional multiplicity and fragmented sovereignty. This results in hybrid governance arrangements characterised by competing claims to legitimacy, unclear jurisdictional boundaries, and

ultimately, a planning vacuum that is filled by incremental and often contradictory practices (Nchanji & Bellwood-Howard, 2018; Sihlongonyane & Sithagu, 2025). Residents become adept at navigating this complex institutional landscape. Chitengi (2020) examines a potential cooperative model, arguing for partnerships between Lusaka's city council and customary leaders to improve land allocation governance for low-income groups. However, the more common reality is one of strategic negotiation rather than formal integration, as individuals and communities' manoeuvre between systems to secure their claims, as evidenced in the daily practices of land access in peri-urban Ghana and Senegal (Ubink & Quan, 2008; Pinard, 2021).

5.3 The Logic of Middle-Class Self-Help Housing: Security, Investment, and the Production of Fragmented Space

The engagement of the middle class with self-help housing on customary land represents a calculated, albeit often contradictory, spatial strategy. It is a practice born not from a lack of alternatives but from a rational assessment of available pathways to secure a fundamental asset within an uncertain economic landscape. Andreasen and Agergaard (2022) aptly frame this as urban property acting as "security", a bulwark against economic precarity and a tangible store of intergenerational wealth. This logic transcends the mere acquisition of shelter; it is an entrepreneurial venture into real estate, where the house functions as both home and a primary investment portfolio, a finding corroborated by Mercer's (2024) work on the "suburban frontier" in Dar es Salaam, where middle-class construction is a deliberate project of place-making and asset accumulation.

The process is inherently incremental. Unlike state or large-scale private developments, construction occurs plot-by-plot, funded through a combination of savings, formal loans where accessible, and informal financing mechanisms. This incrementalism offers financial flexibility, allowing households to respond to economic fluctuations. However, it systematically prioritises the private dwelling unit over collective urban infrastructure. The result is a distinctly fragmented urban morphology. The city expands through the aggregation of individually rational investments that collectively lack coherence, leading to inefficient land use, a lack of public space, and a critical deficit in shared infrastructure networks for drainage, sanitation, and transportation (Muthama, 2025; Sihlongonyane & Sithagu, 2025). This creates a fundamental paradox: the very act of securing individual household futures through investment in property can actively undermine the collective urban condition, producing a landscape that is ill-equipped to function as a resilient, integrated city.

Furthermore, this process is deeply embedded in social differentiation. The ability to access and develop customary land is not uniform within the broad category of the "middle class." Abdulai (2024) provides a critical lens on this, examining how "emergent neo-customary land tenure" in peri-urban Ghana creates new barriers for non-indigene smallholders. This highlights how the commodification of customary land can reinforce or create new socio-spatial inequalities, privileging those with the right connections, capital, or ethnic belonging, thereby fracturing the notion of a homogeneous middle class and revealing the exclusionary mechanisms embedded within this form of urban expansion.

5.4 Implications for Urban Resilience: Manufactured Risk and the Systemic Adaptation Deficit

The spatial and institutional outcomes described above directly and severely compromise urban resilience, constituting an active process of risk manufacturing rather than a passive vulnerability. Resilience, here, refers to the capacity of urban systems to absorb, adapt, and transform in the face of socio-ecological stresses and shocks. The development patterns driven by middle-class self-help housing systematically degrade this capacity across multiple fronts.

Firstly, the location of these settlements actively manufactures ecological risk. The pursuit of affordable and accessible land directs development towards environmentally sensitive and hazardous zones that are typically avoided by formal, regulated development. Mwonzora and Hamunakwadi (2025) offer a devastating case study of this dynamic in Harare, where the imperative of "securing a roof" for the middle class leads directly to the settlement of vital wetland ecosystems. This not only destroys the ecological functions of these areas (water filtration, flood attenuation, biodiversity habitat) but also places residents in direct harm's way, significantly increasing their exposure to flooding. This is not an unfortunate coincidence

but a direct consequence of a land market and governance system that fails to value and protect ecological infrastructure.

Secondly, the incremental, uncoordinated nature of construction creates a profound infructural vulnerability. The absence of enforceable planning regulations and the plot-by-plot development model prevent the implementation of coordinated, city-scale infrastructure. The consequences are stark: inadequate drainage systems exacerbate flood risk; haphazard road networks impede emergency services; and the lack of formal waste management leads to pollution and public health hazards, as documented by Thakur and Nel (2022) in their study of South African townships. The household-level strategy of incremental upgrading cannot compensate for this initial, systemic deficit in public works. The resilience of a city is rooted in the robustness of its networked infrastructures, and these settlements are characterized by their absence or fragmentation.

Finally, the hybrid governance context creates a critical adaptation deficit. Climate adaptation and disaster risk reduction require coordinated, anticipatory action by a legitimate governing authority. The institutional multiplicity that defines peri-urban areas means there is no single entity with the clear mandate, capacity, or accountability to perform this role. Municipal authorities may disavow responsibility for "illegal" settlements on customary land, while traditional leaders lack the technical and financial capacity for large-scale resilience planning. Wijesinghe and Thorn (2021) explicitly grapple with this governance challenge in their analysis of green infrastructure in Windhoek's informal settlements. This governance void means that even when risks are identified, such as the clear danger of building on a floodplain, there is no effective mechanism to mitigate them, leaving communities dangerously exposed. The result is a systemic failure to adapt, locking these rapidly growing areas into pathways of escalating vulnerability to climate change and other urban stresses.

6 DISCUSSION: RECONCEPTUALISING INFORMALITY FOR RESILIENT FUTURES

The systematic review undertaken in this paper elucidates a profound and complex urban transformation unfolding across Africa’s peri-urban peripheries. The central paradox that emerges is that the very strategies employed by households to achieve economic security through self-built housing on customary land actively manufacture systemic risk and undermine the collective resilience of the urban regions they are joining. This discussion synthesises these findings to argue for a critical reconceptualization of urban informality and to propose a forward-looking framework for planning and policy.

This recency underscores two important points. First, it highlights the novelty of the research agenda, positioning middle-class self-help housing in Africa as an emerging field of inquiry that remains underexplored compared to more established studies on informal settlements and poverty-driven housing. Second, it points to the need for longitudinal and comparative research that can track the evolution of these dynamics over time, given that the bulk of the evidence currently available captures only the initial phases of the phenomenon. In addition to synthesizing current insights, the review highlights the importance of increasing scholarly and policy attention to the intersection of class, land tenure, and resilience in African peri-urban development by placing this paper within the framework of an expanding but still emerging body of literature.

The evidence consistently points to a core contradiction at the heart of middle-class peri-urbanisation. The practices of asset accumulation through self-help housing, while rational and often successful at the household level (Andreasen & Agergaard, 2022; Mercer, 2024), generate significant negative externalities at the city scale. The incremental, plot-based development model precludes integrated planning, leading to a fragmented urban fabric that is inherently inefficient and vulnerable (Muthama, 2025; Sihlongonyane & Sithagu, 2025). Consequently, the middle class, in its attempt to secure its own future, becomes an unwitting agent in the production of risk, ultimately jeopardising the very assets it seeks to build.The hybrid governance arrangements that characterise these zones, while offering flexible pathways to land access, represents thestates limited capacity to steer urban growth sustainably. The coexistence of traditional and municipal authorities often results in a regulatory vacuum where no single entity is accountable for ensuring safety, equity, or sustainability (Nchanji & Bellwood-Howard, 2018; Simelane & Sihlongonyane, 2021). This is not a "governance vacuum" but a governed space. However, it is governed by a logic of commodification and individual transaction (Ubink & Quan, 2008; Sumbo, 2022) rather than one of public welfare and collective resilience.

7 CONCLUSION: TOWARDS A RECONCEPTUALISED PLANNING PARADIGM

The analysis presented herein necessitates a fundamental reconceptualization of urban informality and planning in the African context, where a new, resilience-focused paradigm, one that recognises informality, particularly in its middle-class incarnation as a persistent, complex, and economically significant mode of urban production. This paradigm shift begins with the explicit acknowledgement and strategic engagement with tenure pluralism. The findings suggest a need for policymakers and planners to move beyond the binary of formal versus informal tenure and instead develop frameworks that recognise customary and neo-customary systems as enduring features of the urban landscape. The objective should not be to replace these systems but to regulate them, creating mechanisms for transparency and accountability within traditional land administration to protect against the exclusionary and predatory practices that often accompany commodification, while potentially fostering cooperative partnership models between municipal and traditional authorities.

Building on this foundation of engaged pluralism, the analysis suggests a shift in the role of the state from a direct provider of planning into a facilitator and coordinator of urban development, a role conceptualised as metagovernance. This entails municipal authorities actively engaging with and steering the actions of the diverse actors shaping the peri-urban frontier, including traditional leaders, private developers, community associations, and NGOs. The goal of such metagovernance is to align these often-disparate activities towards achieving common public goals, such as ensuring equitable service provision and, most critically, safeguarding ecological integrity. Indeed, ecological planning must be repositioned from a peripheral concern to the non-negotiable core of urban planning. This requires the assertive use of planning instruments to clearly demarcate and protect ecological no-go zones such as wetlands, steep slopes, and riparian corridors from any form of settlement, a vital step in preventing the manufactured vulnerabilities documented across the literature.

Ultimately, this reconceptualized approach demands a more nuanced and differentiated set of housing policies that respond to the varied drivers of informality. The state's role in relation to the middle class is not necessarily to provide its housing directly but to create an enabling environment that channels its considerable investment potential towards more sustainable and resilient outcomes. This can be achieved by developing and enforcing clear ecological zoning plans, proactively facilitating the provision of bulk infrastructure in developing areas to pre-empt fragmentation, and promoting alternative, affordable formal housing models that can compete with the economic and accessibility allure of customary land. Planning may start to harness the dynamism of middle-class urbanization while firmly minimizing its detrimental externalities by implementing this multidimensional strategy, which prioritizes the environment, embraces pluralism, practices metagovernance, and offers diverse pathways.

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Beyond Municipal Boundaries: Rethinking Public Amenities in Eswatini's Peri-Urban Transformation

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1 ABSTRACT

Across sub-Saharan Africa, the rapid expansion of urban frontiers has blurred the traditional boundaries between urban and rural spaces, resulting in complex peri-urban landscapes that necessitate new spatial planning approaches. In this evolving context, Eswatini's accelerating peri-urban transformation necessitates a spatially responsive re-evaluation of the planning, distribution, and governance of public amenities. The rapid expansion of settlement patterns beyond formal municipal jurisdictions, particularly within the Swazi Nation Land adjoining urban centers such as Manzini, Matsapha, and Mbabane, has generated new functional urban regions that challenge conventional planning regimes. These peri-urban zones have emerged as dynamic nodes of socio-economic activity and demographic growth, yet they remain marginal in the allocation of public infrastructure and social amenities. The persistent unevenness in spatial investment, particularly in youth-oriented facilities such as recreational spaces, libraries, sports fields, and community centers, highlights the structural limitations of a planning system that remains bounded by statutory municipal demarcations. This paper interrogates the spatial inequities and institutional fragmentation that have perpetuated the neglect of peri-urban territories within Eswatini's national development agenda. It contends that the inadequate provision of social infrastructure in these spaces exacerbates spatial injustice, reinforces socio-economic exclusion, and constrains pathways for youth empowerment. Anchored in a qualitative research design, the study synthesizes evidence from policy documents, academic discourse, and institutional reports to analyze prevailing trends, governance challenges, and service delivery deficits in the peri-urban planning landscape. The findings reveal that despite their demographic dynamism, peri-urban areas exhibit severe infrastructure backlogs, overcrowded social spaces, and limited public service accessibility. In response, the paper advances a Peri-Urban Youth Amenities Framework (PUYAF) that advocates for integrated spatial planning, redistributive resource allocation, and multi-level collaborative governance between municipalities, traditional authorities, and communities to promote spatial equity and enhance urban livability beyond municipal boundaries.

Keywords: peri-urban transformation, spatial justice, social infrastructure, youth development, Eswatini

2 INTRODUCTION

The development of peri-urban settlements has generated divergent perspectives within urban planning discourse. Turner (1977) frames these areas as adaptive housing solutions for low-income populations, while others portray them as urban dysfunctions, akin to blighted zones that threaten public health and safety (Amoako and Boamah, 2016). Such perceptions contribute to the marginalization of peri-urban communities, restricting their access to essential infrastructure and services despite rapid urbanization and technological advancement (Winayanti and Lang, 2004). Residents are frequently labeled as "unregulated occupants" and face tenure insecurity, including potential evictions or displacement due to policy changes. Consequently, these areas exemplify spatial inequities where economic and political priorities often overshadow the welfare, rights, and environmental sustainability of inhabitants. Peri-urban communities are commonly characterized by deficiencies in critical urban infrastructure, including potable water, sanitation, drainage systems, road networks, electricity, waste management, and public transport (Tutu and Stoler, 2016). Exclusion from municipal extension programs and urban service networks perpetuates socio-spatial marginalization. This deficit adversely affects residents' health, quality of life, and social well-being. Furthermore, peri-urban areas often lack emergency response services, educational facilities, and healthcare institutions, exacerbating vulnerability during crises such as floods or fires (Ansah and Chigbu, 2020). Housing and service provision in peri-urban areas frequently operate outside formal regulatory frameworks. As a result, activities such as water collection, electricity access, healthcare utilization, and informal commerce are often treated as unregulated. The provision of essential infrastructure is constrained by multiple dimensions, including legal, spatial, social, institutional, political, and economic barriers (Sinharoy

et al., 2019; Allen, 2010). Economic constraints, such as limited household income and insufficient municipal funding, inhibit infrastructure investment, while tenure insecurity undermines the establishment of sustainable service delivery mechanisms (Pierce, 2017).

Building on this argument, this research contends that Eswatini's municipal-centric spatial planning framework has inadequately accommodated the dynamics of peri-urban expansion, resulting in pronounced deficits in youth-oriented urban amenities, including public parks, libraries, sports facilities, and multi-purpose community centers. These infrastructural gaps exacerbate socio-spatial inequities, limiting opportunities for recreation, education, social interaction, and civic engagement among young residents. Through a critical examination of the spatial, institutional, and governance-related determinants of this under-provision, the study contributes to the discourse on inclusive urbanization, equitable infrastructure distribution, and the operationalization of the "right to the city" within peri-urban settings beyond formal municipal boundaries (Lefebvre, 1996; Harvey, 2008).

3 CONCEPTUAL AND THEORETICAL FRAMEWORK

Peri-urbanization is widely understood as a process through which rural land is incrementally absorbed into expanding urban systems, often without corresponding institutional integration (Shaw, van Vliet & Verburg, 2020). In African settings, this process is frequently shaped by customary land tenure, weak regulatory oversight, and fragmented governance structures. Scholars argue that peri-urban areas are not merely transitional spaces but enduring socio-spatial formations that require tailored planning responses (Gonçalves et al., 2017). Failure to recognize this reality results in uneven development outcomes, where residents experience urban densities without urban servicesa phenomenon increasingly described as "infrastructural exclusion". The concept of spatial justice provides a critical lens for understanding the uneven distribution of public amenities across space. Public infrastructure is not neutral; it reflects political priorities and institutional power relations (Solis-Navarrete & Bucio-Mendoza, 2025). In peri-urban Eswatini, youth experience compounded marginalization: spatially excluded from municipal service networks and socially excluded from development opportunities. Public amenities, parks, sports grounds, libraries, and community centers are widely recognized as foundational to social inclusion, crime prevention, and human development (UN-Habitat, 2012). Their absence limits young people's ability to build social capital, access knowledge, and participate meaningfully in community life.

3.1 Problem Statement

Despite the rapid growth and functional urbanization of peri-urban areas in Eswatini, these spaces remain excluded from systematic public amenity provision due to planning frameworks that are institutionally confined within municipal boundaries. This exclusion has resulted in persistent infrastructure backlogs and limited youth-oriented social amenities, reinforcing spatial injustice and socio-economic marginalization. The continued neglect of peri-urban territories raises critical questions about equity, governance, and the sustainability of Eswatini's urban transformation. This paper aims to examine the spatial and institutional factors underpinning the uneven provision of public amenities in Eswatini's peri-urban areas and to propose a framework for youth-centered, equitable service delivery beyond municipal boundaries.

The specific objectives are to:

(1) Examine peri-urban growth patterns and governance arrangements in Eswatini.

(2) Assess the implications of inadequate public amenities for youth development.

(3) Identify institutional and planning gaps contributing to service delivery deficits; and

(4) Propose a Peri-Urban Youth Amenities Framework (PUYAF) to guide inclusive planning and governance.

4 METHODOLOGY IMPERATIVES

The Kingdom of Eswatini has a current population of approximately 1,263,016 people. With a total land area of 17,200 km², the country has a population density of about 73 people per km² (or 189 people per square mile). Eswatini remains predominantly rural, with only 31.26% of the population, around 392,638 people, residing in urban areas, and a median age of 22.5 years (Worldometers, 2026). The median age in Eswatini indicates that the country has a predominantly youthful population, which has direct and significant

implications for this study. In the aspect of peri-urban transformation, this demographic profile means that young people constitute the largest and most affected user group of public amenities.

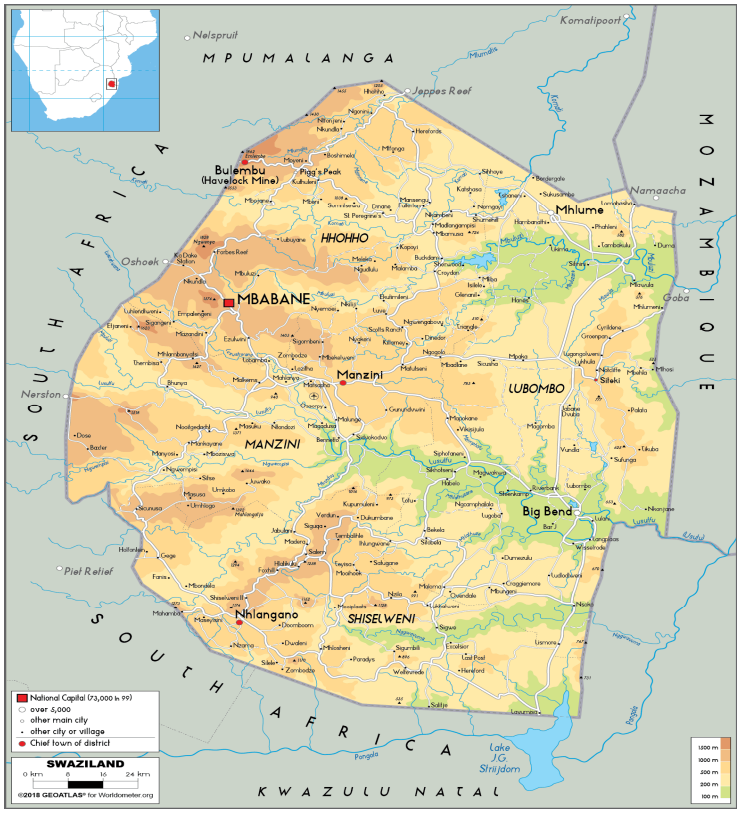


Figure 1: Study Area. Source: Worldometers (2026)

Figure 1 depicts where Eswatini is located. The study employs a qualitative research design grounded solely in secondary data analysis. The data corpus comprises national development strategies and statutory spatial planning frameworks; urban governance and youth-focused policy instruments; peer-reviewed scholarly literature addressing peri-urbanisation, spatial justice, and the provision of public amenities; as well as institutional reports produced by UN-Habitat and other regional development agencies. The use of secondary data analysis is particularly suited to interrogating structural planning constraints and policy discontinuities, especially in settings where primary data collection is limited by institutional barriers and resource constraints (Bowen, 2009). The collected materials were subjected to thematic analysis to distil recurring patterns and analytical themes, notably governance fragmentation, socio-spatial inequality, and the marginalisation of youth within planning and service delivery processes.

5 ANALYSIS AND DISCUSSIONS

A pronounced disparity persists between rural and urban areas in both the extent of infrastructure provision and the quality of infrastructural services available (Eswatini, 2025). The analysis confirms that peri-urban areas in Eswatini have transitioned into functional urban zones, hosting dense populations and diverse economic activities. However, planning instruments continue to conceptualize these spaces as rural, limiting state investment in social infrastructure (UN-Habitat, 2020). The findings indicate acute deficits in youth-focused amenities, such as recreational areas, sports facilities, libraries, and community halls. Where such facilities do exist, they are frequently inadequately maintained, overstretched, or located within school premises, thereby limiting broader public accessibility (Ngwenya, 2024). This lack of infrastructure limits opportunities for structured recreation, learning, and social interaction, increasing youth vulnerability to substance abuse and antisocial behavior (UNODC, 2018). Children born in Khoza, Logoba, Msunduza, Ticantfwini, Nkwalini, Mangwaneni, and surrounding areas have limited spaces to play. Providing public parks would create venues for families to gather, children to enjoy outdoor activities, and communities to come together in celebration (Ngwenya, 2024). However, there are positives concerning per-urban areas, as the Manzini Municipality extends an invitation to all regardless of communities not situated within the jurisdiction of the city (Municipal Council of Manzini, 2022). Fragmented governance among

municipalities, traditional authorities, and the central government is a significant contributor to neglect. The lack of coordinated planning mechanisms creates accountability gaps, leaving public amenities in peri-urban areas without clear institutional responsibility (Watson, 2009).

6 TOWARDS THE PERI-URBAN YOUTH AMENITIES FRAMEWORK (PUYAF)

In response to the findings of the study. The paper proposes the Peri-Urban Youth Amenities Framework (PUYAF), structured around four pillars as shown in Figure 2. The Peri-Urban Youth Amenities Framework (PUYAF) is primarily designed to address the socio-spatial and governance challenges of peri-urban communities in Eswatini, where rapid urban expansion, limited municipal services, and hybrid governance structures involving traditional authorities create pronounced deficits in youth-oriented public amenities. While contextually grounded in Eswatini, the framework's principles, integrated spatial planning, redistributive infrastructure investment, collaborative governance, and youth co-production, are transferable to other peri-urban regions in the Global South that face similar dynamics, such as parts of Malawi, Zambia, and Kenya, where hybrid governance, informal land tenure, and service inequities are prevalent. PUYAF differs from typical Global North frameworks, which generally assume formal municipal governance, established infrastructure networks, and stout service delivery, and often prioritize technological innovation and efficiency over equity and inclusion.

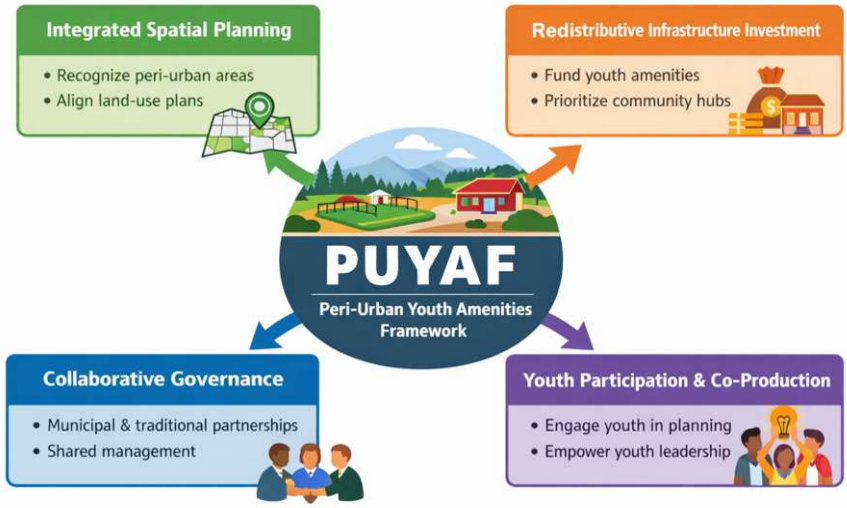


Figure 2: Peri-Urban Youth Amenities Framework (PUYAF).

The proposed Peri-Urban Youth Amenities Framework (PUYAF) responds directly to the persistent misalignment between spatial planning instruments and the lived realities of peri-urban transformation in Eswatini. Despite functioning as urbanized zones with dense populations and complex socio-economic activities, peri-urban areas continue to be framed as rural within statutory planning and development frameworks, resulting in structural exclusion from public investment in social infrastructure (UN-Habitat, 2020). Through formally recognizing peri-urban territories as permanent and integral components of the urban system, PUYAF promotes the integration of national development strategies, municipal spatial development frameworks, and traditional land governance arrangements. This integrated spatial planning approach addresses the fragmentation that has historically constrained coordinated infrastructure delivery in areas such as Khoza, Logoba, and Msunduza, enabling more equitable and efficient allocation of youth-oriented public amenities. Central to this approach is a redistributive logic that prioritizes targeted investment in underserved peri-urban zones, particularly through the development of multi-functional community hubs that expand access beyond school premises, reduce infrastructural overload, and correct spatial imbalances in recreational and learning facilities.

In parallel, PUYAF addresses the institutional and social dimensions of infrastructure deprivation through collaborative governance and youth-centered co-production. The findings reveal that fragmented responsibilities among municipalities, traditional authorities, and the central government have created accountability gaps that undermine the planning, maintenance, and sustainability of public amenities in peri-urban areas. Through formalizing partnerships across governance levels and incorporating civil society

actors, the framework clarifies institutional mandates and builds on inclusive practices such as the Manzini Municipality's open-access provision of recreational facilities (Municipal Council of Manzini, 2022). Embedding youth participation in the design, management, and programming of public spaces further enhances social ownership, ensures contextual relevance, and strengthens community cohesion. This participatory approach responds directly to evidence linking the absence of safe, structured public environments to increased youth vulnerability, substance abuse, and antisocial behavior, positioning youth amenities as preventative social infrastructure rather than discretionary investments. Collectively, PUYAF offers an equity-driven, setting-sensitive planning response that repositions peri-urban youth amenities as a critical component of inclusive and sustainable spatial development in Eswatini.

7 CONCLUSION

This paper has demonstrated that peri-urban areas in Eswatini have evolved into integral components of the national urban system but continue to be marginalized by municipal-bound planning approaches and fragmented governance arrangements. The persistent under-provision of youth-oriented public amenities reflects deeper structural and institutional shortcomings rather than isolated service delivery failures. Through proposing the Peri-Urban Youth Amenities Framework (PUYAF), the study advances a practical and setting-sensitive pathway for reorienting spatial planning, infrastructure investment, and governance toward greater equity and inclusion. Strengthening public amenities for peri-urban youth is not only a matter of service provision but a strategic investment in social cohesion, urban livability, and long-term national development beyond formal municipal boundaries.

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Cherishing Human-Elephant Landscapes with GIS-LBS: A LUCIS-Based Negotiation Framework for Human-Elephant Coexistence in Sri Lanka

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1 ABSTRACT

Conflicts over land and ecological heritage increasingly require planners to treat plans not as fixed blueprints but as negotiated agreements over space, values, and future risk. Collaborative and communicative planning traditions emphasise that durable spatial decisions emerge through iterative bargaining – where maps, scenarios, and design proposals act as shared "boundary objects" that help parties externalise trade-offs and explore mutually beneficial solutions (HEALEY, 2020; BAR-SINAI, 2013). However, while negotiation is widely discussed in planning theory, it is still weakly operationalised in everyday practice, especially in multi-stakeholder settings shaped by power asymmetries, competing mandates, and contested evidence (RUMING, 2012; KARTZIOS et al., 2022).

A further challenge is that many land–ecology conflicts behave as complex systems: outcomes emerge from interacting processes, feedback loops, and adaptation across actors and environments, often producing nonlinear change and shifting hotspots over time. In urban science and complexity perspectives suggest that such contested socio-ecological landscapes require an Urban Informatics stance – integrating big data, sensing, and computing to support dynamic, evidence-updated decision-support systems and applications, rather than relying solely on conventional land-use allocation logic and periodic plan revisions (BATTY, 2013; SHI, GOODCHILD, BATTY et al., 2021).

Methodologically, many planning support tools remain oriented toward spatial optimisation or impact assessment, rather than negotiation itself. Multi-criteria frameworks (e.g., AHP) can formalise stakeholder priorities, yet weights often remain expert-driven and opaque. Game-theoretic approaches offer a complementary lens by representing stakeholders as strategic actors with distinct objectives and utilities, enabling systematic testing of stability (e.g., near-equilibrium outcomes) and efficiency (e.g., Pareto-improving compromises) across alternative spatial strategies (ZARREH & GROGAN, 2025). Importantly, negotiation-oriented modelling must remain participatory and transparent, supporting learning and trust rather than acting as a technocratic "black box" (CUHADAR, 2004).

Human-Elephant Conflict (HEC) in Sri Lanka is a particularly urgent arena for such negotiation-capable, informatics-oriented planning support. HEC is not only a conservation challenge but also a land-use and spatial justice problem in mixed agricultural–settlement landscapes that overlap elephant home ranges and corridors (GUNAWANSA et al., 2023). These landscapes are continuously reshaped by cultivation cycles, settlement expansion, infrastructure, and seasonal resource conditions – interacting with elephant movement to create persistent yet evolving conflict patterns – thereby reinforcing the need for dynamic, evidence-driven planning beyond static master-plan prescriptions. This paper advances a GIS-LBS–enabled negotiation framework that couples (i) LUCIS-based suitability and conflict mapping (CARR & ZWICK, 2007) with (ii) LBS-derived GPS elephant movement as an empirical validation lens, and (iii) game-theoretic analysis to

evaluate negotiated outcomes across three strategy families: coexistence, partial separation, and full separation. By explicitly linking spatial modelling, movement evidence, and negotiation analytics, the framework provides a transparent basis to "cherish heritage" through evidence-based, politically feasible landscape sharing – supported by adaptive, data-informed planning applications – rather than purely separation-oriented interventions.

Keywords: Spatial Planning, Landuse Conflict, Human-Elephant Coexistence, Geographic Information System, Participatory Planning and Negosation

2 METHOD OF STUDY

2.1 Conceptual and Methodological Framework

Across Sri Lanka, the struggle between protecting endangered Asian elephants and sustaining rural livelihoods has become one of the most acute land-use planning challenges. Around 40% of the country's population lives within the elephant home range, where more than half of the land is classified as non-forest wildlife area, including extensive agriculture and dispersed human settlements. Each year, 300–400 elephants and 120–140 people are killed due to Human-Elephant Conflict (HEC), giving Sri Lanka one of the highest per-capita elephant and human death rates from HEC globally.

This study conceptualises HEC not merely as a conservation or law-and-order problem, but as a profound land-use and spatial justice issue situated at the interface of heritage conservation, rural development, and climate-resilient planning. Elephants represent both ecological heritage and cultural identity, while smallholder agriculture and village settlements provide the socio-economic backbone of rural regions. The central question is: how can GIS and Location-Based Services (LBS) – particularly GPS tracking of elephant movement – support planners in negotiating spatially explicit, politically feasible strategies for coexistence?

The study develops an integrated decision-support framework that combines:

- GIS- and LBS-based movement analysis of elephants using GPS records to delineate empirical home ranges and movement corridors;
- A GIS-based land suitability model for elephants, agriculture and human settlements;
- The Land Use Conflict Identification Strategy (LUCIS) to identify compatible uses and conflict zones;
- Stakeholder-driven weighting via Analytic Hierarchy Process (AHP); and
- Game-theoretic negotiation to evaluate coexistence, partial separation and full separation strategies.

The key innovation are i.) the explicit use of LBS-derived GPS elephant tracks not only as an input dataset, but as a validation lens – home ranges extracted from GPS data are compared against modelled suitability, revealing where planning assumptions match or diverge from elephants' actual space-use behaviour – and ii.) the use of game-theoretic negotiation to obtain stakeholder-driven weighting when implementing LUCIS-based scenarios.

2.2 Study Area and Data

The analysis is conducted at national scale in Sri Lanka. The GIS database includes land cover, topography, climate, soils, water bodies, protected areas, vegetation structure and existing infrastructure were obtained from open-source data-based and grovment aginces.

LBS is operationalised through:

- GPS records from collared elephants and field tracking.
- Delineation of home ranges and movement corridors (e.g. kernel density and home-range analysis);
- Overlay of these empirical patterns with the elephant suitability model to refine factor weights and thresholds, and to identify under-protected high-use areas and "misclassified" suitable zones.

2.3 GIS–LBS, LUCIS and Game-Theoretic Negotiation

Following LUCIS, the method unfolds in three phases:

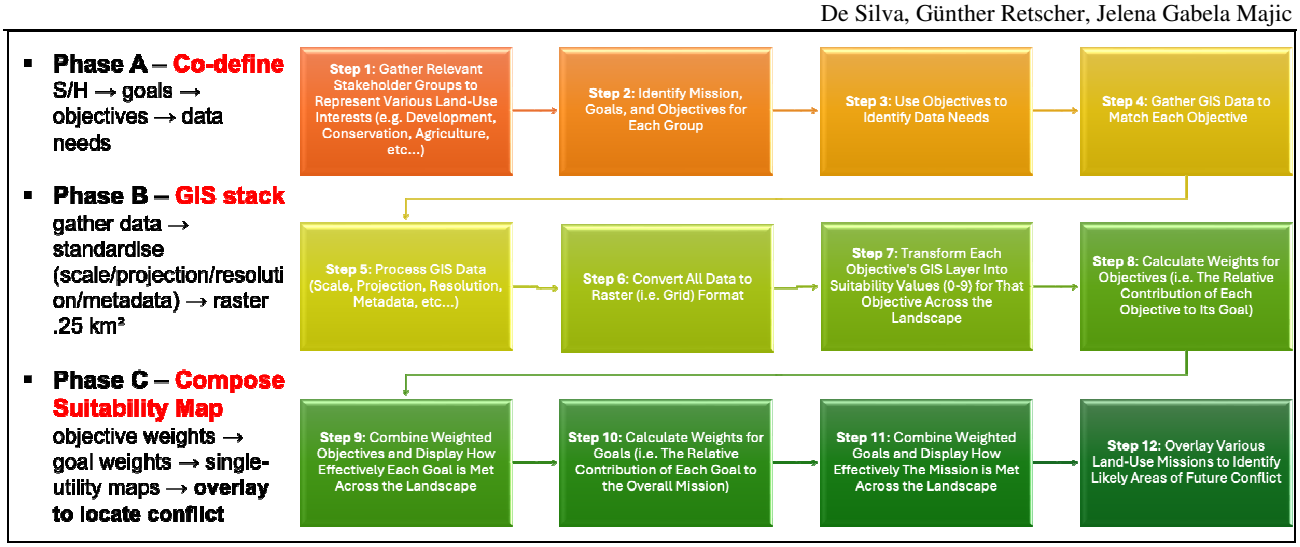


Fig. 1: GIS–LBS–LUCIS negotiation workflow

(1) Co-definition of missions and objectives: Missions such as securing elephant landscapes, safeguarding productive farmland and ensuring safe settlements are decomposed into measurable spatial objectives and indicators.

(2) Suitability mapping with GPS validation: Indicators (e.g. distance to forest, slope, rainfall, access to water, vegetation density, infrastructure) are standardised into 0–9 suitability scores. AHP is used to derive initial weights for objectives and goals for elephants, agriculture and settlements. GPS-based home ranges and corridors are then overlaid on the elephant suitability surface to validate and refine these weights, exposing mismatches between modelled suitability and actual elephant use.

(3) Conflict mapping and game-theoretic negotiation: Composite suitability maps are overlaid to classify land into single-use, compatible multi-use and high-conflict zones. Alternative strategies – coexistence, partial separation, full separation – are spatially implemented. Stakeholder utilities for each strategy, reflecting their weighted objectives, are then analysed using game theory (Nash equilibria and Pareto efficiency) to identify robust compromise solutions. Here, game-theoretic negotiation is used to iteratively adjust and stabilise stakeholder-driven weights and preferences when applying LUCIS.

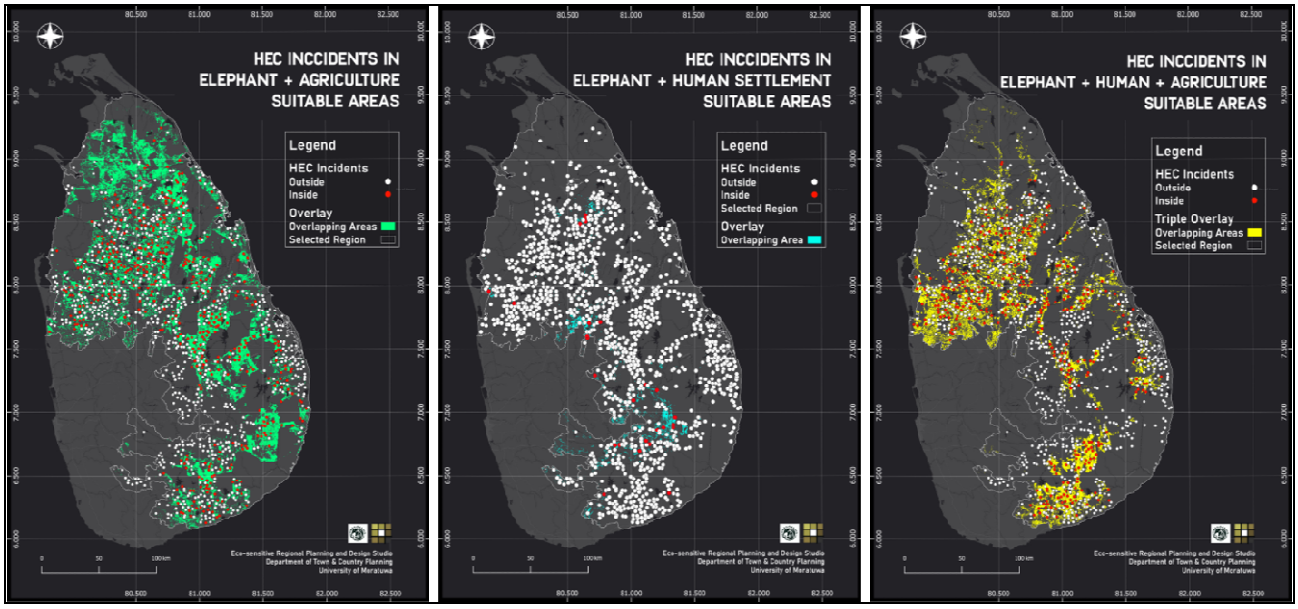


Fig. 2: National-scale overlap of suitability surfaces for elephants, agriculture, and human settlements, highlighting compatible-use zones and high-conflict hotspots where GPS-confirmed elephant use intersects high agricultural/settlement suitability

3 KEY FINDINGS

3.1 GPS–Suitability Compatibility and Conflict Hotspots

GPS-based home ranges confirm that elephants intensively use several zones currently dominated by agriculture or mixed land uses, and highlight high-use areas underrepresented in existing protected networks. Conflict hotspots cluster where:

- GPS-confirmed home ranges intersect areas of high agricultural suitability; and
- Movement corridors are constricted by settlement growth and infrastructure.

Comparing GPS tracks with the suitability model improves habitat prioritisation, helps avoid designating "paper habitats" that elephants seldom use, and sharpens the delineation of critical corridors and buffer zones.

3.2 Planning Strategies and Negotiated Weighting

Three strategy families are tested:

- Full separation (strict elephant/human–agriculture segregation);
- Partial separation (Elephant Conservation Areas allowing seasonal agriculture and eco-tourism);
- Coexistence (habitat restoration, corridor protection, targeted agriculture, compensation and livelihood diversification).

Strategy	Core planning logic	Typical spatial instruments	Governance & livelihood instruments	Expected strengths	Key risks/failure modes
Coexistence	Share landscapes by reducing risk and improving compatibility where overlap is unavoidable	Corridor protection; habitat restoration; buffer zoning; micro-siting of settlements/infrastructure; land-use guidance in mixed mosaics	Compensation/insurance; early warning; crop switching; livelihood diversification; community stewardship	Often higher multi-stakeholder acceptability; flexible and adaptive; can protect "working corridors"	Requires sustained institutions/funding; uneven benefits may trigger distrust; needs strong participation to avoid perceived imposition
Partial separation	Prioritise elephants in defined conservation areas while allowing limited/seasonal compatible use	Elephant Conservation Areas (ECA); controlled agriculture zones; seasonal access rules; corridor widening	Co-management agreements; conditional permits; eco-tourism and benefit-sharing	Clearer spatial structure than coexistence; can reduce peak-risk encounters in hotspots	Boundary disputes; leakage of settlement expansion; may displace risk to edges if enforcement is weak
Full separation	Minimise contact by spatial segregation of humans/agriculture and elephants	Fencing; strict exclusion zones; relocation/resettlement; hard barriers along corridors	Enforcement-heavy management; resettlement packages; strict land controls	Fast visible action in specific sites; may reduce encounters locally if maintained	High social cost and political resistance; barrier maintenance failures; can fragment habitat and intensify conflict at fence lines

Table 1: Summary comparison of HEC strategy families.

Preference elicitation shows overall support for coexistence-oriented options. Game-theoretic negotiation, grounded in stakeholder-driven weights, indicates that GPS-informed coexistence scenarios yield higher combined utilities for farmers, conservationists and state agencies than fencing-only or relocation-centric approaches, and emerge as Pareto-efficient in many settings.

4 DISCUSSION

The proposed GIS–LBS and LUCIS-based framework reshapes Human-Elephant Conflict from a predominantly technical or sectoral problem into a structured arena of spatial negotiation. A central contribution lies in treating LBS-derived GPS elephant tracks not merely as another input layer, but as a validation lens on top of the suitability model. By overlaying empirical home ranges and movement corridors with modelled suitability, the framework forces planners to confront where their assumptions diverge from elephants' actual space-use behaviour. This is particularly important in Sri Lanka, where conservation and land-use decisions have often relied on generalised habitat notions rather than movement-informed landscape functionality. The GPS-based perspective exposes "phantom suitability" areas that look ideal on paper but are rarely used by elephants, as well as overlooked "hot habitats" and corridors that demand higher protection or more sensitive management.

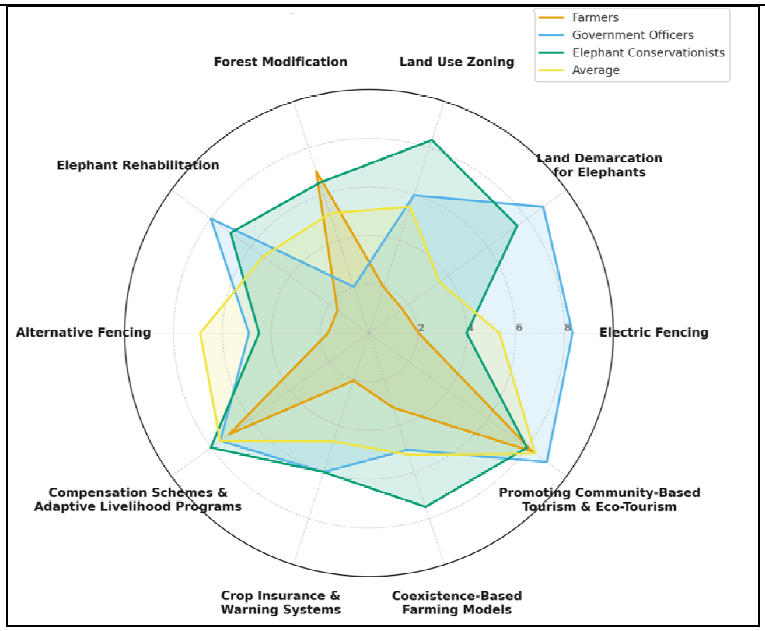


Fig. 3: Stakeholder preference distribution across strategy families (coexistence, partial separation, full separation), summarised by stakeholder group and used to parameterise utility-based scenario comparison.

Equally important is the shift from purely expert-led weighting of criteria towards a game-theoretic, negotiation-centred approach to stakeholder-driven weighting. LUCIS has proven powerful for conflict identification, but in many applications, weights and priorities remain largely in the hands of experts or single institutions. In contrast, this study combines initial AHP-derived weights with an explicit game-theoretic layer, where alternative scenarios – coexistence, partial separation, full separation – are evaluated as strategic options with utilities for farmers, conservationists, and state agencies. Through this, weighting is no longer a hidden technical step: it becomes contested, negotiated, and iteratively adjusted until more stable, Pareto-efficient outcomes emerge. This responds directly to the discourse on whether digital tools and AI truly revolutionise planning: here, technology is not the driver of decisions but an enabler of more transparent bargaining over space, risk, and heritage.

The framework also highlights the promise and the limits of relying on digital evidence in deeply political conflicts. GIS–LBS tools can clarify trade-offs, show where fences or resettlement are unlikely to work, and visualise where coexistence is spatially feasible. Yet they cannot, by themselves, resolve power asymmetries, ensure compensation is fair, or guarantee that communities trust institutions. There is a risk that highly technical models may be used to legitimise predetermined decisions if participation is superficial. Thus, the value of the approach depends on how genuinely stakeholders are engaged in defining missions, interpreting maps, and shaping strategies, rather than merely being shown “finished” products. The work also underscores a broader insight for digital urbanism: AI, LBS and advanced models are most transformative when they illuminate shared problems and create common ground for negotiation, not when they are treated as black-box optimisation engines.

5 CONCLUSION

The GIS–LBS, LUCIS and game-theoretic negotiation framework presented in this study offers a transparent and transferable approach to planning for Human-Elephant coexistence in Sri Lanka. By integrating GPS-based movement data as both input and validation, it grounds conservation and land-use strategies in elephants’ lived geographies, revealing where protected areas, agricultural expansion and settlement growth are misaligned with actual home ranges and corridors. Through LUCIS-based suitability and conflict mapping, it provides a clear spatial language to distinguish compatible-use zones from structural hotspots of conflict. Game-theoretic negotiation adds a governance layer, turning stakeholder preferences and weights into an explicit object of discussion rather than a hidden technical choice. In practical terms, the results indicate that well-designed coexistence strategies – supported by habitat restoration, corridor protection, controlled agriculture, compensation, and livelihood diversification – can deliver higher joint benefits than rigid separation or fencing-and-resettlement approaches alone. More broadly, the study demonstrates the

effectiveness of an Urban Informatics approach – combining complexity science, sensing, data integration, and spatial computing – to support dynamic, evidence-updated planning decisions, in contrast to static land-use master plans that struggle to respond to shifting risk and dayanmics.

Limitations include partial coverage and temporal bias in collaring datasets, sensitivity of suitability outputs to indicator selection and AHP weights, and the coarse national grid that may miss micro-scale barriers and local land-management practices. Future work should: (i) add uncertainty and sensitivity analysis to identify "no-regret" corridors and interventions; (ii) incorporate temporal dynamics (seasonality, crop calendars, rainfall variability) beyond static suitability; (iii) deepen participation through facilitated negotiation workshops to refine utilities, test coalition stability, and address power asymmetries; and (iv) operationalise the framework as an adaptive planning application linked to monitoring, early warning, and compensation targeting. These steps would strengthen robustness and uptake while maintaining transparency and stakeholder ownership.

6 ACKNOWLEDGEMENT

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reviewed paper

Childhood Mobility Socialisation: The Influence of Social Environment, Infrastructure and Perception of the School Route on Active Mobility Modes

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1 ABSTRACT

Mobility patterns established during childhood play an important role in shaping travel behaviour later in life. While transport planning has traditionally focused on infrastructure and spatial accessibility, research on mobility socialisation emphasizes that children's everyday mobility is strongly embedded in social contexts. This study examines how social environment, infrastructural conditions, and route perception relate to active school travel among school-aged children.

The analysis is based on a multi-site survey conducted between November 2024 and January 2025 at six school sites in rural areas and small towns in Styria, Austria. Pupils aged 6 to 14 years and their parents were surveyed. The study combines information on pupils' school travel behavior with indicators of parental and peer influence, subjective assessments of the school route, and basic spatial and sociodemographic characteristics.

Walking to school was analyzed using a logistic regression approach, while wheeled school travel (cycling and scooter use) was examined using descriptive and bivariate methods due to a limited number of cases. The results show that socialization processes are more influential than infrastructural factors. Walking to school is primarily associated with social environments, particularly peer practices and parental orientations, whereas infrastructure and route perceptions do not exert independent effects once social factors are considered. Wheeled school travel is mainly shaped by peer dynamics and age-related autonomy, with infrastructure acting as an enabling rather than determining condition.

Overall, the findings suggest that strategies to promote active school mobility should extend beyond physical infrastructure and more strongly address social contexts, everyday practices, and peer dynamics in which children's mobility is embedded.

Keywords: Mobility socialisation, Active school travel, social environment, infrastructure, route perception

2 INTRODUCTION AND THEORETICAL FRAMEWORK

The transport sector is among the main contributors to greenhouse gas emissions in Austria. Since 1990, emissions have increased by around 40%, largely driven by domestic motorised private transport (Umweltbundesamt 2026). However, the need for a mobility transition extends beyond climate policy. It is also motivated by public health concerns from insufficient physical activity, car-oriented settlement and transport planning, and inequal access to mobility options. Adult mobility behaviour is strongly shaped by routines and habits, the foundations of which are laid early in life. A successful mobility transition should therefore not be reduced to questions of traffic safety or infrastructure design alone, but must also address health-related, ecological and social objectives, as well as issues of autonomy and participation. This places the following question at the centre of the analysis: how is mobility socially shaped during childhood, and which actors and contexts are particularly influential in this process?

2.1 Childhood mobility socialisation

Mobility is a defining feature of today's society and is deeply intertwined with prevailing lifestyles and economic structures. For a long time, mobility was predominantly approached from a technical or economic perspective, with transport planning and policy focusing on infrastructure provision, efficiency and system performance. Over the past two decades, however, increasing attention has been paid to how mobility patterns are embedded in social contexts. As a result, mobility has become a central topic of social-scientific and interdisciplinary research (Ruhrort, 2025) Mobility behavior can be analyzed from different social-scientific perspectives, including lifestyle-oriented approaches, social-psychological models, and supply- or

system-oriented concepts. The mobility socialization approach offers a particular advantage in that it addresses diverse role models and their mutual interrelations.

Socialization refers to the process by which individuals internalize socially shared norms, values and meanings through ongoing interaction with significant others and social institutions across the life course (Berger & Luckmann, 1966; Giddens, 1984). Key socialization agents or contexts include the family, the spatial environment, peers, school and media. These contexts shape mobility-related orientations and contribute to the development of specific mobility lifestyles. Tully and Baier (2018) conceptualize mobility socialization within a three-level framework, distinguishing between societal conditions (such as infrastructure, spatial differentiation and cultural guiding principles), meso-social contexts (including role models, school and peer groups), and individual conditions (such as attitudes, values, age and gender). Mobility is particularly salient during adolescence, as it enables young people to organize increasingly differentiated everyday lives across spatially separated domains such as school, leisure activities and peer networks. At the same time, mobility becomes an expression of autonomy and identity formation, since independent access to places is closely linked to social participation and self-determination.

2.2 Social environment, infrastructure and route perception

Empirical studies show that children's everyday mobility is shaped by the interaction of social and spatial influences. Parents act as primary socialization agents by structuring everyday mobility routines, communicating norms and safety-related expectations, and serving as role models for their children. Parental personal and social norms, as well as habitualized mobility practices within the family, shaped later travel behavior (Haustein et al., 2009). With increasing age, peers become important reference groups, contributing to the adoption of mobility practices through shared routines and social comparison, particularly in the school context. However, the social contexts of family, peers, school, and media do not stand alone but are interrelated contexts in which mobility-related orientations and practices are learned and stabilized (Baslington, 2008).

Another perspective emphasizes the material and spatial context defined by infrastructure. Research on children's independent mobility indicates that parental perceptions of sidewalk and street safety are closely linked to whether children are allowed to travel independently (Santos et al., 2013). Distance and the availability of walking and cycling infrastructure further provide everyday mobility opportunities (De Meester et al., 2014). Infrastructural conditions do not influence behavior directly but are mediated through route perception, that is, subjective evaluations of safety, comfort, and attractiveness by both parents and children. Together, social environment, infrastructure, and route perception provide a coherent analytical framework for examining how children's school travel behavior is shaped in everyday contexts.

2.3 Planning and project practice in school environments

Projects for the redesign of school environments by traffic planners are typically recommended to be carried out in cooperation with the respective local authorities. Problems with traffic management and traffic hazards around the school are usually first reported by parents to the school or directly to the municipality. Teachers are the second most important group of people who identify and report traffic safety problems in the school environment. If there are problems or requests for changes, schools usually contact the responsible local authority. Similar to socialization research, parental mobility practices and transport infrastructure emerge as factors for enabling active mobility by schoolchildren.

If a project is given to a planner, technical considerations are made as to how the situation in front of and around the school can best be resolved in the interest of all road users, with particular focus on the pupils. Not every street is equally suitable for a 'school street', shared space or other structural or design measures. The type of planning intervention must therefore be carefully considered by experts in each individual case.

In the municipality of Frohnleiten, the primary school and secondary school are located in a school complex on the same street. A new housing development was planned for the same street in 2021. In response, the municipality approached the traffic planning company verkehrplus to implement traffic calming measures for the sensitive school area. The aim was to ensure the safety of pupils and the smooth flow of traffic, especially at the beginning and end of the school day. During the planning process, information evenings in cooperation with the local police were held for the teachers. Feedback and suggestions were included in the planning process. Parents were informed by e-mail after the planning had been completed. In other

municipalities, such as in an ongoing project to introduce a school street in Steyregg in Upper Austria, an information evening is planned before the school street is implemented.

The introduction of walking buses or bike buses ('Pedibus' or 'Bicibus') is often initiated by committed parents or teachers. These projects are usually implemented by local authorities, as was the case in Gleisdorf, for example, who may call in experts for advice and implementation.

Experience in various schools has also shown that the exemplary behavior of individuals influences the whole group. For example, a new kiss-and-go zone was set up at the St. Veit primary school in Southern Styria. The zone is located at an alternative entrance to the school away from the courtyard in front of the school, where buses stop and teachers park. The new entrance was only accepted after the headmistress specifically asked the respective parent representatives of the individual classes to use the new kiss-and-go zone and thus set an example for their classes.

3 STUDY DESIGN AND METHODS

3.1 Context and Research Area

The study was conducted as part of the FFG-funded project "Auf vertrauten Wegen" , which aims to promote active mobility by analyzing school routes together with pupils and co-developing context-specific interventions. The project was implemented at three primary and three secondary schools located in rural areas and small towns in the Austrian province of Styria. At each site, pupils' everyday school routes were examined and discussed, forming the basis for the collaborative development of measures to encourage walking and cycling.

The selected schools differ markedly in the characteristics of their immediate school environments. Some sites already feature traffic-calming measures, such as access restrictions for cars or designated 'school streets', while others are characterized by higher levels of traffic and frequent parental drop-offs, hindering active travel to school by foot or bicycle. Prior to the development of interventions, a comprehensive survey of all pupils and their parents was conducted at each of the six school locations to establish a baseline for the subsequent analyses.

3.2 Data Collection and Sample

The multi-site survey was conducted between November 2024 and January 2025. The extended survey period resulted from different start dates and differing implementation schedules across school sites, which were coordinated locally by teachers (pupil surveys) and school administrations (parent surveys). Primary school pupils were surveyed using paper-based questionnaires administered in class, while surveys at secondary schools were conducted digitally during class time under teacher supervision.

The parent survey was more extensive than the pupil questionnaire and was distributed via school-internal communication channels. Online questionnaires were created and administered using the open-source survey software LimeSurvey. To increase response rates, two reminder messages were sent to parents at each site. Following data collection, pupil and parent datasets were merged into a single analytical dataset. This matching procedure reduced the final sample size to n = 235, as each pupil needed to be uniquely linked to one responding parent for inclusion in the multivariate analyses (see table for response rates and site-specific sample sizes).

Municipality	Inhabitants (2025)	School type	Number of pupils	Sample size pupils (n)	Response rate pupils (%)	Sample size parents (n)	Response rate parents (%)
Frohnleiten	6.690	primary	241	187	78	87	36
St.Veit/Südst.	4.426	primary	94	79	84	31	33
Zeltweg	6.993	primary	229	214	93	75	33
Frohnleiten	6.690	secondary	190	131	69	45	24
Gleisdorf	11.533	secondary	350	219	63	127	36
Zeltweg	6.993	secondary	104	88	85	28	27

Table 1: Overview of study sites and survey samples; source: population data Statistik Austria (2025)

3.3 Analytical approach

Building on the theoretical framework, which conceptualizes children's school mobility as the outcome of interactions between social environment, infrastructural conditions, and route perception, this study examines which socialization agents, spatial factors, and distances are associated with pupils' active school

travel. Two binary dependent variables were specified. The first captures whether a child walks to school (1 = walking, 0 = not walking). The second model examines wheeled active travel, combining cycling and scooter use into a single outcome variable (1 = wheeled mode, 0 = not wheeled). Statistical analyses were conducted using SPSS, complemented by additional data procedures in R.

Survey data from parents and pupils were processed using a standardized multi-step procedure. Data preparation included the removal of duplicate cases, incomplete responses, and identifying information, as well as consistency checks of names, school class identifiers, and school information. Variables required for linking parent and pupil records were harmonized across datasets in terms of formatting, spelling, and variable type, and standardized (e.g., uppercase lettering, trimmed spaces). Address information was manually reviewed and supplemented where necessary. Parent and pupil datasets were then merged stepwise using a composite linkage key (first name, school, class, postal code), supported by manual plausibility checks to resolve ambiguous matches. The final analytical dataset included only consistently matched and valid cases.

Descriptive analyses were used to examine modal split patterns for pupils and parents. Reliability analyses and exploratory factor analyses informed the aggregation of similar items to composite variables. Predictors of walking to school were examined using a multivariate Firth-penalized logistic regression model. The regression model for using wheeled modes did not provide robust multivariate estimates because of a skewed distribution in the outcome variable. Wheeled school travel was therefore examined using descriptive and bivariate statistical analyses. The variables used in the analyses are outlined below.

3.3.1 Transport mode choice

Pupils were asked how they usually travel to and from school under good or bad weather conditions. Parents were additionally asked about their mode choice across several everyday trip purposes, including work or education, shopping, errands, escorting children, and leisure activities.

3.3.2 Parental social norms

Parental attitudes and norms related to children's active travel were measured using items capturing perceived social norms and parenting-related orientations. Descriptive and injunctive social norms assessed how strongly parents perceive active school travel to be supported and valued within their social environment. All norm items were recoded so that higher values indicate stronger pro-active-travel norms.

Parenting style items captured a family-centered orientation emphasizing emotional closeness, shared decision-making within the family, and difficulties with letting go. Higher values thus reflect stronger family embeddedness and parental involvement rather than early autonomy support. Exploratory factor and reliability analyses revealed a stable two-factor structure with good internal consistency, distinguishing mobility-related parental social norms (parent_norms_active) from a general family-centered parenting style (parent_family_centered_style).

3.3.3 Peer mobility shares

For each school class (school_class_id), relative peer shares (0–1) were calculated for walking and for wheeled modes (bicycle, scooter, e-scooter), representing the proportion of classmates using each mode on the school trip (peer_walk_share_class, peer_wheeled_share_class).

3.3.4 Parental active mobility share

Based on parents' reported mode choices across all trip purposes, mean shares of active mobility were calculated. Two indicators were derived and included in the models: the proportion of trips made on foot and the combined proportion of trips made by bicycle, scooter or e-scooter, reflecting parents' everyday preference for walking and cycling (parent_walk_share, parent_wheeled_share).

3.3.5 Infrastructure

Objective assessments of walking and cycling infrastructure are excluded because of multicollinearity issues in multivariate models from low variance between the six school sites. Therefore, infrastructure is measured by parents' ratings of sidewalks and bicycle lanes (infra_rating_sidewalks_new, infra_rating_bikelanes_new). Higher values indicate more positively evaluated infrastructure conditions.

3.3.6 Pupils' and parents' route evaluation

Pupils and parents were asked to evaluate the school route by rating a set of statements using a Likert-type scale. Several factor solutions were tested. An eight-item solution was selected as the best compromise between explained variance and informative value. Factor 1 captures parents' and pupils' evaluations of the route with regard to perceived safety, difficulty and overall comfort, including feelings, like fear or perceptions of well-being and ease when using the route (parent_safety_comfort, kids_safety_comfort). Factor 2 captures parents' and pupils' evaluation of the route with regard to presence of nature elements and the perceived novelty of the route (parent_environmental_attractiveness, kids_environmental_attractiveness). All route perception scales are coded so that higher values indicate more negative evaluations (e.g., higher perceived danger, stress, or discomfort), meaning that odd rations below 1 reflect decreasing likelyhoods of active travel with worsening route perceptions.

3.3.7 Distance

Distances to school were calculated based on geocoded home and school locations (straight-line distance). Address data were prepared and standardized in Excel and then geolocated using an automated geocoding service. Where exact house numbers were missing, locations were approximated using street midpoints or central reference points for the respective municipality or district. In cases with ambiguous address information, conservative assumptions were applied and results were manually checked for plausibility. Exemplary geocoding outcomes were manually verified to ensure spatial consistency and reasonable distance estimates.

Age and gender were included as control variables to account for basic socio-demographic differences that may influence pupils' school travel behavior.

4 RESULTS

4.1 Descriptive results – Transport mode choice

A comparison of modal choice by school grade shows that walking is more common among primary school pupils than among secondary school pupils (good weather: 42% vs. 30%; bad weather: 33% vs. 28%). In contrast, secondary school pupils travel to school by wheeled modes substantially more often (14%) than primary school pupils (3%). This difference can partly be explained by the Austrian "Radfahrprüfung", which is typically completed in the fourth year of primary school and grants children permission to cycle independently in traffic. Primary school pupils are also more frequently driven to school by car (good weather: 23%; rainy/cold weather: 40%) compared to pupils in secondary schools (18%; 27%).

The six school sites differ substantially in modal choice. Among primary schools, St. Veit/Südsteiermark shows the lowest share of pupils walking in all categories (including the return trip), with walking shares ranging from 7% to 21%, and the highest share of car use (up to 73%). In contrast, the primary school in Frohnleiten records the highest proportion of pupils walking to school (41–57%). A plausible explanation for this difference lies in the immediate school environment in St. Veit, which is less pedestrian-friendly and was also perceived as unsafe by respondents in the survey – while Frohnleiten shows more favorable conditions for walking.

Among secondary schools, Zeltweg stands out, showing the highest shares of wheeled modes (up to 10% cycling and 3% scooter) and walking (up to 47%). These patterns may be explained by site-specific characteristics. By contrast, in Gleisdorf, the municipality covers a large geographic area and the secondary school attracts pupils with longer travel distances, which in many cases exceed feasible ranges for active mobility. Consequently, a substantial proportion of pupils rely on public transport, with up to 43% traveling by bus and 10% by train.

A comparison between good and rainy/cold weather conditions further indicates that the primary school with the highest car use, St. Veit/Südsteiermark, also exhibits the strongest increase in car-based travel under adverse weather conditions (from 48% to 73%). Generally, pupils are more likely to walk or use wheeled modes under favorable weather conditions, while car use increases when weather conditions worsen.

4.2 Predictors of active school travel

The logistic regression model for walking to school is statistically significant (LR $\chi^2(12) = 105.13$, $p < .001$) and explains substantial variance in pupils' walking behavior. Overall, the results underline the central importance of socialization processes, while infrastructural conditions and route perceptions show no independent effects once social factors are taken into account.

The strongest predictor of walking to school is the mobility behavior of peers (classmates). The class-level share of pupils who walk to school is very strongly associated with individual walking behavior (OR = 156.31, $p < .001$). Walking appears to be a taken-for-granted and socially reinforced practice when it is common within the classroom context. Parental influences also playges a decisive role. Children are more likely to walk when parents perceive active travel as valued within their own social environment (OR = 3.57, $p < .001$). In addition, a family-centered parenting style has a positive effect (OR = 1.73, $p = 0.39$), indicating that more family-centered orientations are associated with higher odds of walking to school. Beyond norms and parenting style, parents' own walking behavior is a significant predictor (OR = 1.04, $p < .001$), highlighting the importance of everyday role modelling and habitual practices within families.

By contrast, infrastructural variables and route perceptions do not show statistically significant effects in the walking model. Neither parents' nor children's assessments of safety, comfort, or environmental attractiveness of the school route are associated with walking once parental and peer norms are included. This indicates that perceived infrastructure quality and route experience may be necessary but not sufficient conditions for walking, and that their effects are largely mediated through social contexts.

Finally, distance to school, age and gender do not exert significant influences. Taken together, the walking model demonstrates that children's walking to school is primarily shaped by their social environments, rather than by infrastructural conditions or route perceptions.

Table 2 reports the results of a Firth-penalized logistic regression model examining social, infrastructural and perceptual predictors of walking to school.

Predictor	β	SE	OR	95%-CI (OR)	p
(Intercept)	-3.20	1.81	0.04	0.0007–1.61	.089
parent_norms_active (social environment)	1.26	0.32	3.57	1.89–7.69	< .001
parent_walk_share (social environment)	0.043	0.013	1.04	1.02–1.08	< .001
parent_family_centered_style (social environment)	0.55	0.26	1.73	1.03–3.12	.039
peer_walk_share_class (social environment)	5.05	1.26	156.31	13.45–2892	< .001
infra_rating_sidewalks_new (infrastructure)	-0.16	0.26	0.86	0.49–1.47	.574
kids_safety_comfort (route perception)	-0.17	0.27	0.84	0.48–1.52	.562
kids_environmental_attractiveness (route perception)	-0.03	0.23	0.97	0.59–1.56	.889
parent_safety_comfort (route perception)	-0.40	0.32	0.67	0.33–1.32	.253
parent_environmental_attractiveness (route perception)	-0.26	0.24	0.77	0.46–1.26	.305
distance	-0.29	0.16	0.75	0.49–1.02	.095
age	0.04	0.11	1.04	0.83–1.31	.722
gender (male)	0.34	0.47	1.41	0.54–3.85	.489

Table 2: Predictors of walking to school, n = 169, LR-Test $\chi^2(12) = 105.13$, $p < .001$; method: Firth-penalized logistic regression); DV: walking to school (1/0). Regression coefficients (β), standard errors (SE), odds ratios (OR), and 95% confidence intervals.

Due to the small total number of pupils using wheeled modes (cycling or scooter), the dependent variable has too little variance for calculating multivariate regression analyses. Consequently, wheeled mobility was examined using descriptive and bivariate analyses, comparing the groups of pupils who do and do not use wheeled modes. The bivariate results highlight a pronounced peer effect. Pupils who travel to school by wheeled modes visit school classes with significantly higher shares of peers also using wheeled modes ($p < .001$). This finding indicates that wheeled mobility is closely linked to shared mobility practices within the classroom, mirroring the strong peer effects observed in walking. Age emerges as another key factor: wheeled users are significantly older than non-users ($p < .001$), reflecting increasing autonomy, cognitive and motor skills, and formal permission to cycle independently with age.

In contrast to walking, parents play a limited role for wheeled mobility. Neither parental mobility-related norms, nor parents' own wheeled travel or parenting style show statistically significant associations. This suggests that wheeled school travel is less embedded in family routines and parental socialization processes and that the influence of peers becomes more salient with age.

With regard to the built environment, pupils using wheeled modes rate the cycling infrastructure more positively ($p < .05$), indicating that infrastructure supports this mode of active travel. At the same time,

wheeled pupils report higher levels of perceived fear and danger along the school route (p = 0.40), suggesting that wheeled mobility is often adopted despite, rather than because of, high subjective safety.

Overall, the wheeled results point to a mobility pattern that is primarily shaped by peer dynamics and age-related autonomy, with infrastructure facilitating this behavior.

Predictor	Mean rank (other)	Mean rank (wheeled)	Test statistic	p
parent_norms_active (social environment)	116.18	85.28	U=1228.5, Z=-1.815	.070
parent_wheeled_share (social environment)	106.13	127.11	U=1125.5, Z=-1.785	.074
parent_family_centered_style (social environment)	113.39	122.03	U=1559.5, Z=-0.507	.612
peer_wheeled_share_class (social environment)	111.06	164.12	U=967, Z=-4.709	<.001
infra_rating_bikelanes_new (infrastructure)	108.47	141.35	U=1218, Z=-2.110	.035
parent_safety_comfort (route perception)	98.22	95.33	U=1310, Z=-0.190	.849
parent_environmental_attractiveness (route perception)	98.37	93.60	U=1284, Z=-0.314	.753
kids_safety_comfort (route perception)	112.46	78.81	U=1125, Z=-2.049	.040
kids_environmental_attractiveness (route perception)	110.87	98.94	U=1447, Z=-0.727	.467
age	111.48	187.18	U=643, Z=-4.495	<.001
gender (male)	–	–	–	.310
distance	118.17	108.94	U=1699, Z=-0.541	.588

Table 3: Correlates of wheeled school travel. n=216, mean ranks; U and Z for Mann-Whitney U test in all predictors except Fisher-test for gender

5 DISCUSSION AND CONCLUSION

5.1 Implications for Planning and Intervention Design

Surveys of parents and pupils as well as the results of workshops in school classes with pupils from 6 to 14 years have shown that children's active travel behavior is strongly influenced by the social norms set by their peers. Schoolmates who jointly walk to school, use the scooter or cycle to school allow children to engage in playing and exploration activities with their friends during the school trip. Parents function as role models and gatekeepers with regards to walking. However, once children have grown older and can safely ride the scooter or the bike, this parental influence diminishes. Infrastructure and route characteristics may provide enabling conditions for active school travel, but their influence is much weaker than the influence of peers and parents.

Projects for redesigning school environments or for school mobility management should therefore target not just children directly, but should also leverage peer or parental dynamics that might emerge once children commence to shift their travel patterns. In particular projects in primary schools should explicitly work not just with children, but should address the parents as well. It must also be taken into account that parents are concerned about the safety of their children. Infrastructure projects in the school environment, such as school streets and shared spaces, can create a safe school environment and, together with the establishment of kiss-and-go zones on the periphery of school areas, make it possible to drop off children safely. However, improving infrastructure alone will most likely yield limited effects unless peers and parents are also engaged in, for instance, competitions or mobility exercises. We thus recommend approaches where schoolchildren are motivated to travel together and where parents are involved to revise their own mobility patterns.

Participation formats in schools make valuable contributions to surveys and polls: on the one hand, playful formats and joint visits allow the motivations of children and young people on the topic to be discovered directly and immediately, and on the other hand, substantial awareness is raised and the students communicate their findings and experiences in their peer groups and families. Role-playing facilitates understanding of different perspectives (parents, teachers, children), and walking to school together allows children to experience the challenges firsthand. With this jointly developed understanding, mobility infrastructures can be planned and implemented in an optimal and needs-based manner.

5.2 Limitations and Outlook

Despite high response rates among pupils (63–93%), the final analytical sample was reduced to N = 235 due to lower response rates in the parent survey (24–36%). As parent-child linkage was required for the multivariate analyses, this imbalance reduced statistical power and limited the applicability of regression models for wheeled school travel.

A further limitation relates to the survey period, which extended from November 2024 to mid-January 2025. Seasonal effects, weather conditions and the timing around the turn of the year may have influenced reported travel behavior. In addition, home-school distances were calculated as straight-line distances. While this approach ensured consistency across sites, it does not fully capture actual route choices or topographical conditions, which may be particularly relevant in rural and small-town regions in Austria.

Looking ahead, the project "Auf vertrauten Wegen" will proceed with the implementation of interventions co-developed with pupils, such as Pedibus stops and routes, cycling training programs or the redesign of a school forecourt. A follow-up survey is planned at the same schools to assess potential changes in mobility behavior and perceptions resulting from both infrastructural and behavior-oriented measures.

Feedback from pupils and parents indicates that the questionnaires were generally well understood and well received. However, the detailed breakdown of parental mobility by multiple trip purposes proved challenging for some respondents and reduced the response rates. Future surveys should therefore aim to balance analytical precision and respondent burden, particularly when addressing children and their parents. Despite these limitations, the consistency of key findings across multiple sites and school levels suggests that the results are robust and informative for schools in rural areas and small towns.

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Co-Creating Urban Resilience by Community Engagement in Central Asia

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1 ABSTRACT

Mountain cities in Central Asia face growing climate-related challenges, including ecosystem degradation, water vulnerability, exposure to natural hazards, and the loss of green infrastructure. Responding to these pressures, the Naryn Urban Resilience Programme (NURP) demonstrates an integrated model of low-carbon, climate-responsive, and community-driven urban development. Drawing on the NURP case, this paper explains how collaborative processes (co-creation) among residents, municipal actors, investors, and technical experts build urban resilience in Naryn.

The NURP introduced multi-level capacity-building programmes for residents, municipal departments, and local businesses, focusing on sustainable landscape design, slope and riverbank stabilisation, public-space management, and the use of climate-resilient local flora. The NURP activities include nature-based solutions (NBS), circular landscape practices, community engagement, and GIS decision-support systems to strengthen Naryn's adaptive capacity. Community engagement activities led to the formation of a local expert group that facilitated co-design, stewardship, and ongoing dialogue between residents and authorities, strengthening social resilience and shared ownership of public spaces. Using NURP cases, the paper analyses which institutional arrangements amplify or inhibit co-created resilience interventions.

The findings show that the combination of participatory greening, native-plant-based NBS, and digital planning technologies creates a practical pathway toward resilient, energy-efficient, and climate-adaptive urban development. The Naryn case highlights the importance of co-governance structures, blended learning approaches, and local ecological knowledge for sustaining NBS in resource-constrained mountain environments. The paper concludes by outlining how lessons learned from the NURP could be applicable across similar urban contexts in Central Asia and beyond.

Keywords: participatory planning, urban resilience, nature-based solution, community engagement, greening

2 INTRODUCTION

Urban areas across Central Asia are becoming increasingly sensitive to climate-induced hazards, including extreme temperature variability, water scarcity, flooding, and ecosystem degradation. These challenges are particularly acute in the remote and mountain cities, where limited institutional capacity and ageing infrastructure intersect with rapid socio-economic transitions. In this context, strengthening urban resilience has emerged as a strategic priority for sustainable urban development. To support the enhancement of resilience in towns/cities across Central Asia, SECO and AKDN agencies have been engaging with the governments of the Kyrgyz Republic and Tajikistan to develop a model aligned with international best practice in the delivery of Urban Resilience Programming in Central Asia. The Naryn Urban Resilience Programme (NURP) aims to build local capacity and implement nature-based and data-informed solutions to strengthen urban resilience in Naryn.

Nature-based solutions (NBS) play a crucial role in enhancing urban resilience by leveraging natural processes to address contemporary environmental challenges. Growing empirical evidence supports the hypothesis that participatory NBS models not only improve sustainability but also enhance acceptance and overall social performance. Puskas, Abunnasr & Naalbandian (2021) have identified that co-created green spaces improve social connectedness and, therefore, better neighbourhood relationships and higher levels of civic participation. In addition to their social effects, NBS projects designed and managed by the community also contribute to long-term environmental sustainability. Ferreira et al. (2020) have argued that projects developed and owned by local stakeholders are more likely to be well-maintained in the long run, thereby reducing the risk of degradation or abandonment. Despite the growing prominence of NBS in urban resilience agendas, a key concern remains that many NBS initiatives are comprehensive engineering interventions that are difficult for local communities to manage or sustain independently. There is a notable scarcity of empirical studies examining how resident engagement can effectively scale NBS down to levels

that are adaptable, usable, and manageable by local communities, with a particular emphasis on capacity building and sustained community participation.

Building on these identified gaps, this paper examines the NURP in Kyrgyzstan as an in-depth case study of co-creating urban resilience through community engagement and nature-based approaches. It investigates how participatory processes embedded within the NURP shape the design, social acceptance, and overall effectiveness of NBS-oriented interventions at the local level. In doing so, the study addresses three interrelated research questions (i) how local community needs drove NBS adoption to increase community engagement, and (ii) which institutional and socio-cultural factors enable or constrain co-creation processes in mountain urban contexts. By systematically addressing these questions, the paper advances the literature on participatory urban planning and community engagement for strengthning resilience, while offering empirically grounded insights for policymakers and practitioners working in Central Asia and other transitional urban environments.

3 LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The involvement of residents in the planning and implementation of nature-based solutions (NBS) is firmly grounded in collaborative governance theories and socio-ecological resilience frameworks, which emphasise the interdependence between institutional structures, local knowledge, and adaptive capacity. Within this literature, scholars conceptualise participation not as a procedural add-on but as a core mechanism that builds trust and delivers long-term resilience outcomes. They argue that when actors operationalise engagement mechanisms in meaningful ways, these mechanisms align interventions more closely with local priorities and everyday practices, thereby increasing both their legitimacy and effectiveness. Empirical studies demonstrate that successful urban greening initiatives increasingly rely on participatory assessment frameworks to evaluate not only environmental performance but also the quality and depth of community engagement, ensuring that local perspectives actively shape project design and implementation rather than merely being consulted ex post (van der Jagt et al., 2022). Therefore, the way participation is structured and enacted is decisive in shaping both trust-building processes and the governance capacity of NBS initiatives, thereby setting the conditions for more advanced and equitable forms of co-creation to emerge.

Co-design and co-implementation models are particularly emphasised as critical pathways for building public confidence in NBS interventions. Ferreira et al. (2020) argue that projects developed in collaboration with local stakeholders are more likely to generate a sense of ownership, which in turn supports sustained maintenance and long-term environmental outcomes. Through such processes, communities move from being passive recipients of top-down policies to becoming active co-producers of urban resilience. Digital participation tools increasingly support this shift by broadening access to planning processes, lowering participation barriers, and enhancing inclusivity across different social groups (Frantzeskaki et al., 2019). Any tools aligned to local communities' actual or developed capacities can strengthen transparency and feedback loops, further reinforcing trust between residents and implementing institutions.

The quality of participation, however, remains uneven across urban contexts mainly because development continues to be imposed from the top by developers or subject experts without careful attention to local circumstances. Arnstein's Ladder of Participation provides a practical analytical framework for distinguishing between symbolic forms of engagement and genuine citizen power, ranging from tokenistic consultation to complete citizen control (Frantzeskaki, 2019). Despite widespread rhetorical commitment to participation, many NBS initiatives remain situated at lower rungs of the ladder, where communities are consulted but retain limited influence over decision-making. This governance imbalance raises critical concerns about equity and inclusivity, particularly in socioeconomically diverse or marginalised urban areas. Tozer et al. (2020) caution that when participatory NBS governance fails to address power asymmetries, it risks reinforcing existing socio-spatial inequalities by systematically excluding disadvantaged groups from meaningful involvement. There is a growing need to move beyond formalised consultation toward creating the institutional conditions necessary for trust, inclusivity, and genuinely community-driven NBS co-creation processes.

Scholars increasingly converge on the argument for embedding inclusivity in the institutional design of NBS governance rather than treating it as a secondary objective. Moving participatory processes beyond symbolic engagement toward material empowerment – where communities can shape priorities, propose interventions, and co-plan implementation – has been shown to enhance both the social acceptance and durability of urban

greening initiatives. Aligning NBS actions with locally articulated needs not only enhances contextual relevance but also fosters trust, a prerequisite for deeper forms of co-creation. Over time, this trust can enable local stakeholders to initiate and lead collective actions, such as the co-planning of green neighbourhoods, thereby strengthening urban resilience through locally grounded, socially legitimate NBS interventions.

Taken together, this body of literature provides the theoretical foundation for a bottom-up analytical framework that integrates collaborative governance, socio-ecological resilience, and participatory planning theories to examine how NBS are co-produced in practice through systematic assessment of those needs, targeted capacity-building, and inclusive engagement mechanisms. Within this framework, local communities are understood not merely as beneficiaries of environmental interventions but as key actors whose knowledge, capacities, and agency are central to the sustainability and resilience of urban systems. Applying this perspective to the Central Asian mountain town case enables an examination of how aligning actions with locally articulated needs can foster trust and enable residents to move beyond passive participation toward the co-development, stewardship, and long-term maintenance of green infrastructure. The study positions bottom-up participation not only as a governance principle but as an operational strategy for embedding NBS within local socio-institutional contexts, thereby enhancing their legitimacy, durability, and contribution to urban resilience outcomes.

4 NARYN CASE STUDY

Naryn town represents a distinctive and analytically valuable case for examining community engagement in nature-based and resilience-oriented urban interventions. Located in the south-eastern part of Kyrgyzstan, the town has an estimated population of 41,681, according to the 2022 Population and Housing Census of the Kyrgyz Republic. Nestled within a high-altitude mountain landscape, Naryn extends as a compact, linear settlement of approximately 25 km along the Naryn River canyon – the largest tributary of the Syr Darya, which flows across multiple Central Asian countries. Its mountainous geography, climatic sensitivity, and physical isolation – approximately 5 hours by road from Bishkek – render Naryn particularly vulnerable to climate change impacts while simultaneously making it a manageable, clearly bounded setting in which to pilot and test community engagement mechanisms.

Naryn is undergoing a period of transition marked by ongoing urban planning activities, development projects, and existing tourism and agricultural economic activities. Recognising both its vulnerabilities and its development potential, several international partners have initiated substantial investments in the town and the wider oblast. Within this context, the Naryn Urban Resilience Programme (NURP) is a five-year planning and proof-of-concept initiative aimed at developing the institutional structures, systems, and local capacities required to transform Naryn into a model resilient mountain town. The programme explicitly links government planning and investment frameworks with initiatives led by communities and national and international partners, creating a platform for bottom-up engagement alongside formal governance processes.

Beyond its physical characteristics, Naryn occupies a unique socio-cultural position within the country. Often referred to as the “original town of the Kyrgyz,” it holds substantial symbolic value for its residents, many of whom express great pride and attachment to their hometown. This strong place-based identity suggests a latent potential for collective action and civic engagement. However, before the initiation of the NURP, observed levels of local activism and organised community participation remained relatively low, highlighting a gap between social attachment and active engagement in urban development processes. This contrast makes Naryn particularly relevant for investigating how trust-building and capacity development can activate community participation in practice.

Naryn’s role as the economic, social, and political hub of the oblast further amplifies the significance of the NURP intervention. The town faces compounded pressures from climate-induced natural hazards and demographic change driven by urbanisation, while also contending with limited economic opportunities. These conditions, combined with its compact urban form, challenging hazard profile, and alignment with ongoing SECO and AKDN initiatives, led to its selection as a showcase for resilient urban planning and development. Recent municipal actions, such as housing and public space projects, improvements to transport and education infrastructure, and reforms such as the acquisition of underutilised industrial land for public use, underscore the town’s readiness to experiment with participatory, community-driven approaches to urban resilience.

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Fig. 1.

4.1 Identifying Local Capacity by Needs Assessments

To operationalise community engagement and align nature-based interventions with local needs, the Naryn Urban Resilience Programme (NURP) adopted an evidence-driven, bottom-up approach centred on systematic surveys and needs assessments. Since its launch in 2022, the programme has conducted a series of citywide and neighbourhood-level assessments to capture residents' lived experiences, risk perceptions, and development aspirations. There are several early diagnostic efforts to inform technical planning but also to create an entry point for dialogue between local communities, municipal actors, and programme implementers, thereby laying the groundwork for trust-building and participatory governance.

A significant milestone in this process was the launch of the Integrated Habitat Assessment (IHA) in 2023. The IHA combined social, economic, and environmental datasets, including multi-hazard exposure, hydrological conditions, geo-botanical characteristics, forestry and soil profiles, demographic trends, and sociological indicators. When analysed in combination, these layered datasets generated a composite spatial index that identified hazard exposure, demographic sensitivity, infrastructure service gaps, and environmental hotspots across Naryn. This integrated analytical framework enabled NURP to translate complex ecological and social risks into spatially explicit insights that could be communicated to both technical experts and residents, strengthening the transparency and relevance of planning decisions.

Building on this analytical foundation, NURP conducted a targeted needs assessment for nature-based solutions between June and August 2024, explicitly linking data-driven risk analysis with community capacity and willingness to engage. Through diagnostic missions and capacity-building sessions, the programme assessed not only local awareness of NBS but also residents' readiness to participate in community, public, and entrepreneurial activities related to urban greening and landscape-based resilience. These engagements introduced participants to basic principles of urban and landscape design while exploring how locally adapted NBS could respond to Naryn's specific environmental and socio-economic conditions.

The findings revealed a critical structural constraint: a severe shortage of highly qualified landscape design professionals and firms with experience in applying NBS, especially those capable of working with native species and mountain ecosystems in Kyrgyzstan. This capacity gap emerged as a key barrier to translating community interest and locally identified needs into high-quality, sustainable interventions. At the same time, the assessment highlighted an opportunity for targeted capacity development, strengthening local skills and knowledge could enable residents and local actors not only to receive externally designed interventions but also to co-develop and maintain green infrastructure. In this sense, the surveys and needs assessments functioned as more than diagnostic tools; they became a central mechanism for aligning NBS actions with local needs, addressing institutional and capacity constraints, and advancing the conditions for meaningful co-creation in Naryn.

4.2 Catalogue of Kyrgyz Flora

The University of Central Asia (UCA) team co-implementing NURP paid dedicated attention to addressing the historical erosion of local flora resulting from Soviet-era urban planning practices, which introduced non-native and often maladapted plant species across Central Asian cities. In Naryn, this legacy has contributed to the gradual displacement of indigenous vegetation that is better suited to the town's harsh mountain climate and fragile ecosystems. Recognising the ecological and cultural significance of restoring locally adapted species, NURP initiated the development of an illustrated catalogue of climate-resilient plants designed to guide both residents and municipal authorities in making informed, context-sensitive planting decisions.

The catalogue responds directly to Naryn's specific climatic conditions and ecological characteristics, while also advancing the notion of a distinctly "Kyrgyz" landscape that reflects local identity, heritage, and environmental knowledge. It documents a carefully curated selection of native and climate-resilient species, including eight tree species, 13 shrubs, 13 grasses, and 2 vines that can thrive in Naryn's urban environment. Beyond their aesthetic value, these species provide measurable ecosystem services, such as reducing dust pollution, improving air quality through carbon sequestration, and enhancing overall urban ecological stability. By foregrounding plants that are both environmentally functional and culturally resonant, the catalogue aligns ecological restoration with place-based identity.

High demand for the catalogue led to its translation into both Kyrgyz and English, underscoring its relevance not only for local communities but also for planners, designers, and external partners involved in urban development. As a participatory tool, the catalogue plays a dual role: it addresses technical knowledge gaps in plant selection while simultaneously empowering residents to engage more actively in urban greening initiatives. By enabling informed choices rooted in local ecology, the resource supports a shift from externally imposed landscaping norms toward community-driven restoration practices. Consistent with existing research, engaging communities in selecting flora has been shown to enhance ecological awareness, foster a sense of ownership, and improve long-term maintenance of public green spaces (Raymond et al., 2021). In the context of Naryn, the catalogue thus functions as both an ecological corrective to historical planning legacies and a trust-building mechanism that anchors nature-based solutions in local knowledge and stewardship.

4.3 Addressing Knowledge Gaps through Targeted Capacity Building

Early engagement activities under the NURP revealed a significant shortage of local knowledge and technical expertise related to urban greening and the use of locally adapted flora. While residents and municipal actors expressed strong interest in improving public spaces and environmental conditions, many lacked practical understanding of landscape design principles, plant selection for mountain climates, and the maintenance requirements of nature-based solutions. This knowledge gap – shaped by decades of externally driven planning practices and limited access to professional training in the region – emerged as a critical constraint on meaningful participation and effective implementation of NBS.

In response, NURP designed a targeted capacity-building strategy aimed at transforming interest into informed and actionable engagement. To overcome barriers related to remoteness, time constraints, and uneven access to formal planning processes, the programme adopted a hybrid engagement model combining face-to-face workshops with online surveys, digital polls, and mobile-based learning tools. Such an approach aligns with participatory NBS governance literature, which emphasizes that strengthening local capacities is a prerequisite for the long-term success and maintenance of urban greening interventions (Kabisch et al., 2016). All online lectures were recorded and made publicly available on YouTube, allowing participants and other residents to revisit the material and extend learning beyond the formal training period.

The capacity-building initiatives targeted municipal officers, forestry personnel, and community members, with the explicit objective of enabling local stakeholders to co-develop, implement, and manage urban greening projects. Launched in 2024 and continuing to date, the training programme covered both foundational and applied topics, including plant grafting, pest and disease management, efficient irrigation techniques, and public space improvement using locally adapted nature-based approaches. By combining technical instruction with hands-on application, the programme operationalized a "learning by doing" approach, which has been shown to be particularly effective in enhancing the performance and confidence of community-based sustainability initiatives (Frantzeskaki et al., 2019).

The practical outcomes of this approach became evident within a relatively short timeframe. After six months of training, participants collectively identified five underutilized open spaces in Naryn and developed site-specific greening proposals, leading to the planting of 60 saplings in two of the town's most environmentally vulnerable locations and the organization of a jointly led tree-planting event formally acknowledged by the Mayor's Office. These outcomes illustrate how targeted capacity building – grounded in local needs and reinforced through practical application – can convert limited initial knowledge into sustained community engagement, strengthen trust between residents and institutions, and establish the foundations for locally driven and maintainable urban greening in Naryn.

4.4 Mudflow Collectors as a Community-EndorsedNBS

The implementation of mudflow collectors in Naryn provides a further illustration of how local stakeholder engagement mechanisms were applied in practice and how NBS-aligned interventions contributed to tangible urban resilience outcomes. Findings from the 2023 Integrated Habitat Assessment (IHA) identified mud and debris flows as one of the most severe natural hazards affecting the town. The assessment mapped seventy-four ravines to the south and six to the north of Naryn that pose direct flood risks to residential areas, roads, and critical urban infrastructure. In total, eighty-eight mudflow sites were classified as high-risk, exposing both human life and property to recurrent hazards. These results were communicated to municipal authorities and local stakeholders, forming the basis for joint prioritisation of intervention sites.

Rather than applying a purely engineering-led response, NURP aligned technical recommendations with local knowledge and institutional capacities. The IHA proposed constructing mudflow baffles, reinforcing channel banks, and developing mudflow storage reservoirs where appropriate. These recommendations were discussed with municipal services, residents of exposed neighbourhoods, and representatives of the Ministry of Emergency Situations, enabling a shared understanding of risk and intervention options. This process contributed to local acceptance and trust, as stakeholders could directly link the proposed actions to the risks identified through participatory assessment.

The resulting implementation at the Mazar-Bulak and Chygysh-Bulak sites in the eastern part of Naryn marked a key programme milestone. The mudflow collectors employed gabion-based structures – wire-mesh containers filled with locally sourced stone – which serve as nature-based solutions by combining natural materials with adaptive engineering. These structures stabilise slopes, slow debris flows, reduce erosion, and enhance flood management while remaining compatible with the surrounding landscape. Their construction not only reduced exposure to recurrent mudflow risks but also strengthened the protection of nearby residential neighbourhoods and critical urban assets.

The intervention demonstrated how NBS can serve as an entry point for co-creation even in technically complex infrastructure projects. Residents acknowledged the works positively, while municipal authorities and the regional subdivision of the Ministry of Emergency Situations emphasised their strategic value, noting that the facilities could benefit approximately 25 per cent of the town's population and significantly reduce the need for costly household resettlement from high-risk zones. In this sense, the mudflow collectors illustrate how aligning NBS actions with locally identified risks and priorities can build institutional trust, enable cross-sectoral collaboration, and deliver resilience outcomes that are both socially legitimate and functionally effective in a mountain urban context.

4.5 Participatory Planning for Urban Greening

The cumulative effects of sustained needs assessments, targeted capacity development, and trust-building engagement under the NURP culminated in a significant governance milestone: an invitation from local government to co-develop the town's future development trajectory. Under the leadership of the First Deputy Governor of Naryn Oblast, a formal Working Group was established to prepare the Green Naryn Five-Year Development Plan. This step reflects what recent studies identify as a critical condition for successful urban greening – namely, the transition from consultative participation toward the meaningful involvement of local populations in decision-making processes, which has been shown to strengthen both project effectiveness and long-term stewardship (Ferreira et al., 2020; Puskas et al., 2021). As part of this initiative, the Government of Naryn formally requested technical and strategic support from the University of Central Asia and the Aga Khan Foundation, recognising the value of expert input aligned with locally articulated priorities.

To ensure balanced representation and coordinated decision-making, the Working Group includes representatives from the Naryn Governor's Office, the Naryn Mayor's Office, the NURP team, and residents. This institutional configuration reflects a deliberate effort to embed community engagement within formal governance structures, thereby addressing the gap between participation in project implementation and participation in strategic planning. Notably, the invitation to co-develop the town's green future emerged from a demonstrated process of capacity building and collaborative action, rather than from symbolic inclusion, signalling increased institutional trust in community-informed planning.

The integration of nature-based solutions into this participatory planning framework further reinforces their role as both ecological and social infrastructure. By involving residents directly in shaping the Green Naryn Five-Year Development Plan, the process aligns NBS interventions with local values, cultural practices, and everyday uses of urban space – factors the literature associates with greater acceptance and sustained maintenance. In this respect, the NURP experience operationalises key insights from participatory NBS research by translating engagement into shared responsibility and long-term commitment.

Through community-based greening projects, structured training programmes, and sustained stakeholder engagement, NURP has enabled residents to move from passive beneficiaries to co-governors of their urban environment. The participatory planning process thus represents both the culmination of earlier engagement mechanisms and the institutionalisation of co-creation, embedding stewardship of green infrastructure within the social and governance fabric of Naryn and laying the foundation for resilient, locally owned urban development in a mountain town context.

5 CONCLUSION

The Naryn case demonstrates that NBS adoption became meaningful and scalable only after aligning interventions explicitly with locally articulated needs, risk perceptions, and capacities. Through iterative needs assessments, participatory diagnostics, and the use of spatial and ecological data, NURP translated abstract resilience goals into locally relevant actions – ranging from native-plant-based urban greening to mudflow risk reduction – thereby strengthening community engagement not as an objective in itself, but as a response to tangible everyday concerns.

The findings further show that engagement deepened as residents moved from consultation to co-development, supported by targeted capacity-building and practical learning. Blended learning approaches – combining digital tools, recorded online lectures, and hands-on field activities – played a critical role in enabling residents to understand, apply, and maintain NBS in a resource-constrained mountain environment. Practical application, mentorship, and site-based experimentation proved especially important in translating theoretical knowledge into durable practice, reinforcing trust and confidence among local stakeholders. In this sense, participation functioned not merely as a governance mechanism but as a learning process through which communities developed the ability to co-create and steward green infrastructure over time.

From an institutional perspective, the Naryn case highlights the importance of co-governance structures in enabling co-creation. The gradual shift from project-level engagement to formalised participatory planning – culminating in the establishment of a multi-stakeholder working group for the Green Naryn Five-Year Development Plan – illustrates how sustained engagement can reconfigure power relations between communities and authorities. Socio-cultural factors, a powerful place-based identity, and local pride in Naryn as a historic Kyrgyz town served as latent enablers of participation. At the same time, initial low levels of civic activism underscored the need for trust-building and capacity development as preconditions for co-creation. Conversely, constraints emerged where technical expertise, financial continuity, or institutional mandates were insufficient to support long-term maintenance, underscoring the need for adaptive management and sustained investment.

Overall, the NURP experience confirms that NBS's success in mountain cities depends as much on social resilience as on environmental design. The combination of participatory greening, native-plant-based NBS, and digital planning technologies created a practical pathway toward resilient, energy-efficient, and climate-adaptive urban development in Naryn. By embedding engagement as a core operational principle rather than a symbolic exercise, the programme enabled residents to transition from passive beneficiaries to active co-creators of their urban environment. As such, Naryn serves as a reference case for how community-driven,

needs-based NBS governance can be operationalised in remote and climatically vulnerable urban contexts, offering transferable lessons for similar towns across Central Asia and beyond.

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Beyond its empirical insights, this study offers both theoretical and practical contributions for cities and towns facing similar environmental, institutional, and socio-economic constraints. Theoretically, it advances the literature on participatory urban resilience and nature-based solutions by demonstrating how needs-driven, bottom-up engagement operationalises co-creation in practice. The Naryn case shows that community engagement becomes transformative when it is anchored in locally articulated needs, supported by capacity development, and embedded within co-governance arrangements. In mountain urban contexts – often characterised by remoteness, limited institutional capacity, and high climate vulnerability – the study highlights the importance of integrating socio-ecological resilience theory with collaborative governance and experiential learning frameworks. It thus contributes a refined understanding of how trust, local ecological knowledge, and institutional openness interact to enable sustained co-creation beyond project cycles.

From a practical perspective, the findings offer a replicable pathway for policymakers, development agencies, and practitioners working in Central Asia and other transitional or resource-constrained regions. Key lessons include the value of combining participatory needs assessments with spatial and ecological data; the effectiveness of blended learning and "learning-by-doing" approaches in building local capacity; and the role of native-plant-based NBS in aligning ecological restoration with cultural identity and community ownership. The Naryn experience underscores that durable NBS outcomes require institutionalisation – through formal working groups, participatory planning frameworks, and long-term investment in training and adaptive management. Taken together, these lessons suggest that cities seeking to scale NBS should move beyond technical replication and instead focus on process replication: aligning interventions with local needs, fostering co-governance, and enabling communities to act as long-term stewards of urban resilience.

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Co-Productive Project Development in Urban and Regional Planning

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1 ABSTRACT

Co-production is gaining prominence, both as an analytical term and as a conceptual framework applied to urban and regional planning, during the last years (Lee et al. 2024:237). There is no single definition, there are various (Valencia et al. 2020; Bandola-Gill et al. 2023). Often the term is used unspecified.

Here, co-production means the collaborative process where citizens, stakeholders and professionals work together to design, develop, and implement projects or policies to "make a city" or transform regions. Therefore, co-production can be a powerful, people-centered approach to urban and regional planning.

Currently, urban planners, who face complex challenges in terms of population and economic development as well as urban renewal in deprived neighbourhoods, are increasingly discussing planning cultures, actor-specific modes of interaction and communication-based goal achievement. New forms of cooperation can be tested and learning effects generated by examining how mutual expectations, participation and trust-building are handled.

Representatives of private-sector, intermediary or civil society interests are no longer merely the recipients of government procedures, programmes and projects. Rather, as co-producers, they actively shape urban spaces and become relevant cooperation partners for urban planning and economic development. They therefore assume control functions and responsibility for space-forming processes themselves.

The findings of this paper are based on research conducted with qualitative analysis of literature review and of semi-structured interviews with municipal stakeholders and business owners. As a result, a research model for the analysis of co-productive value chains was developed. On behalf of analysis of different examples of value-creation-chains of cultural service and manufacturing firms it is shown that co-production needs equal, networked forms of communication and cooperation as well as specific location conditions.

As a result, co-production should not be seen as a planning tool or technique, but as a paradigm shift for future urban development. It enables to integrate different needs and expectations as well as innovations in all phases of spatial project development at eye level by addressing multi-actor involvement differently from established forms of collaborative planning.

Keywords: Governance, co-production, urban design, collaboration, innovation

2 WHAT IS CO-PRODUCTION ?

Co-production is gaining prominence, both as an analytical term and as a conceptual framework applied to urban and regional planning, during the last years (Lee et al. 2024:237). The concept of co-production can therefore be used to examine regional value creation processes. It can also be used as a tool for project development in urban and regional planning.

There is no single definition, there are various (Valencia et al. 2020; Bandola-Gill et al. 2023). Often the term is used unspecified. Here, co-production means the collaborative process where citizens, stakeholders and professionals work together to design, develop, and implement projects or policies to "make a city" or transform regions. This refers to collaborative production processes with reciprocal exchange relationships at a predominantly horizontal level (s. figure 1).

Co-production never proceeds in a linear fashion, but rather involves a wide range of discussions and deliberations, and does not involve any central decision-making positions. As a result, such processes (often) take place outside the formal procedures of urban planning and economic development, which are anchored in building regulations and fiscal policy, among other things.

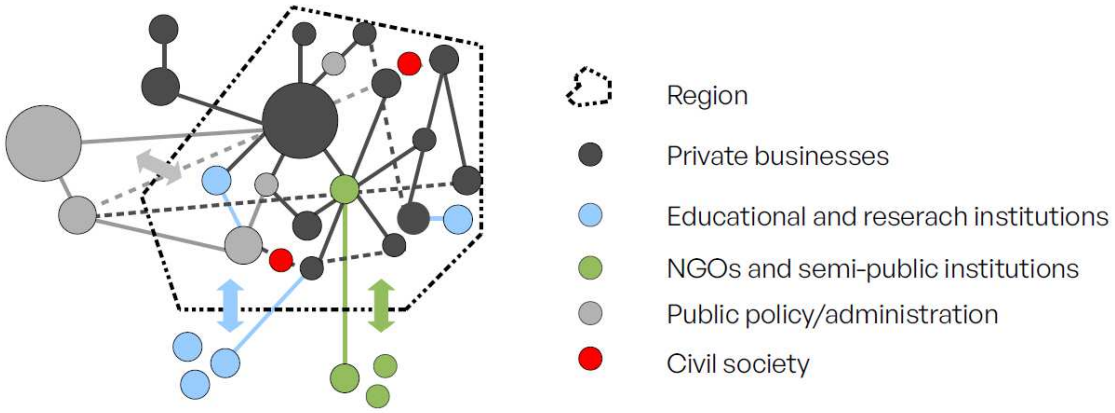


Fig. 1: Reciprocal exchange relationships of various stakeholders within a region (S. Schreiner 2026)

3 THESIS AND RESEARCH METHODS

My thesis is: Co-Production functions different from just participation or strategic urban governance – it involves shared responsibility, shared knowledge, shared infrastructure and shared power to produce sustainable space and shape productive livelihoods. New forms of cooperation and co-production can be tested and learning effects generated by examining how mutual expectations are handled, how participation on an equal footing is achieved, and how trust is built.

If conducted right, co-productive project development can supply integrated, innovative and sustainable solutions for reshaping, restructuring and maintaining urban or regional areas. Aim of this article is to inspire and discuss, how co-production can be more than just participation if it involved shared responsibility, shared knowledge, and shared power.

Findings of this paper are based on research conducted with qualitative analysis of literature review, of case studys and of semi-structured interviews with municipal stakeholders as well as business owners.

4 WHY CO-PRODUCTIVE PROJECT DEVELOPMENT MATTERS FOR URBAN AND REGIONAL PLANNING

Co-production has been considering to play an important role in dealing with various challenges and complex problems (Lee et al. 2024, Matyushkina et al. 2024:721). Therefore the concept of co-production has become increasingly popular across disciplines. The ambiguity of the concept has increased as well.

The term has been researched in different disciplines and areas, e.g. policy management (as a governance concept), public management and administration, healthcare, environmental science and social care (Brandsen et al. 2017; Bandola-Gill 2023). In the field of urban and regional planning there is literature available especially in relation to digital participation, mobility, cultural economic services, urban living labs and also the role of universities (Lee et al. 2024; Valencia 2020:115 ff.).

The concept of co-production had been first mentioned within planning theory around 1970 in the context of citizen involvement in planning processes (Arnstein 1969), but has gained popularity as an transdisciplinary approach to multiactor knowledge production especially during the last ten years (Simon 2021:5). The further development of Arnstein's Ladder of Citizen Participation (Arnstein 1969) focuses today on processes in which professional and civic expertise lead to joint planning outcomes (s. figure 2).

It shows that co-production, as a process of equal and reciprocial partnership and communication, functions differently from established forms of collaborative planning (Lee et al. 2024; Simon 2021). Co-production is based on bottom-up-activities instead of top-down-processes, expert and citizen input instead expert driven, open dialogue instead of limited transperancy, citizens act as co-creators instead of citizens as recipients (s. Matyushkina et al. 2024:722).

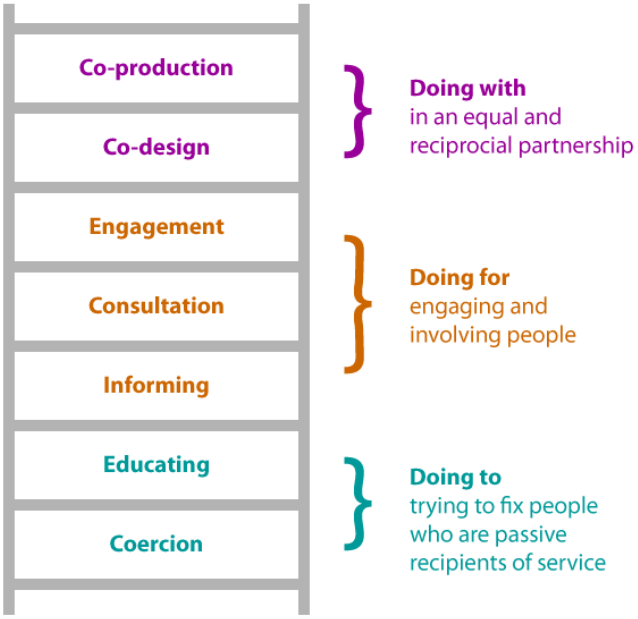


Fig. 2: The co-production ladder (Source: LELAN 2022)

So, co-production shifts planning from a technical task, througouht participation and co-creation as a hybrid governance approach, to a democratic process. That makes the concept of co-poductive project development attractive for urban and regional planning not only in Europe and the United States of America, but also in developing countries. It has been applied by different disciplines and in different contexts, for example, to cope with informal settlements in Asia or lack of water infrastructure in Sub-Sahara Africa (Hoelzel 2024).

Public authorities, from the local to the national level, increasingly expressing their will to integrate participation or co-production into their urban development strategies; they are trying to activate civil society and stakeholders to meet the demand of a changing society and complex spatial problems, especially in urban areas (Brandsen et al. 2017:677). For example, the European "New Leipzig Charta" describes new forms of participation like co-creation and co-design as important aspects for urban development and "productive cities" (BBSR 2020:8). Participation of the public and stakeholders is addressed to "consider their concerns and knowledge" (BBSR 2020:38). Different planning cultures, actor-specific modes of interaction, and communication-based goals come together in planning processes. But, the New Leipzig Charter also acknowledges that there is a "lack of clear and transparent processes, requirements and specific objectives" (BBSR 2020:44) which remains unsolved.

Co-production project development adresses:

- Better fit with local needs
- More inclusive outcomes
- Higher legitimacy and trust
- Greater innovation through diverse perspectives

Threfore, co-productive project development enables groups to take ownership over participatory processes and can foster learning and innovation processes.

This distinguishes co-productive approaches from forms of urban planning and regional governance in which value chains are viewed on the basis of clusters, cultural value creation models or the concept of innovative milieus. Since cooperation activities in clusters are highly institutionalized, they are particularly suited to hierarchical forms of management (s. Porter 2000; Pratt 2015). The cultural value creation model can be used to examine individual activities and actors, their interactions, and inputs and outputs; this allows linear processes to be examined (Canadian Minstry of Industry 2004:13). However, this research model cannot represent exchange and interactions, feedback, and joint product development within spatial context. The concept of innovative milieus allows the innovative power of urban spaces to be examined on the basis of locally networked companies and individuals (Camagni 1991). Personal information exchange and diverse

collaborations lead to collective learning processes; the specific location serves as a resource for innovation. This allows bottom-up processes and interactions to be examined, but they remain diffuse in terms of spatial resources.

5 THE ROLE OF SPACE FOR CO-PRODUCTION

If the concept of co-production shall be applied in urban and regional planning projects, learning processes and stakeholder engagement across phases of co-design, co-implementation and co-assessment need to be enabled and integrated. Outcomes of such projects and processes are difficult to measure because of their immaterial nature. Analyzing the role of space can help to present co-productive project results.

A more concrete analytical model is needed for a systematic empirical investigation of spatially anchored co-production processes. Activities from the private, intermediary, and public sectors should be considered on a region-specific basis in all phases of value creation. Based on literature analysis, and analysis of different examples of value-creation-chains of cultural service and manufacturing firms, I have developed a research model that can be used to visualise and analyse co-productive processes between authorities, companies, intermediary organizations and private individuals – on different spatial scales (s. figure 3).

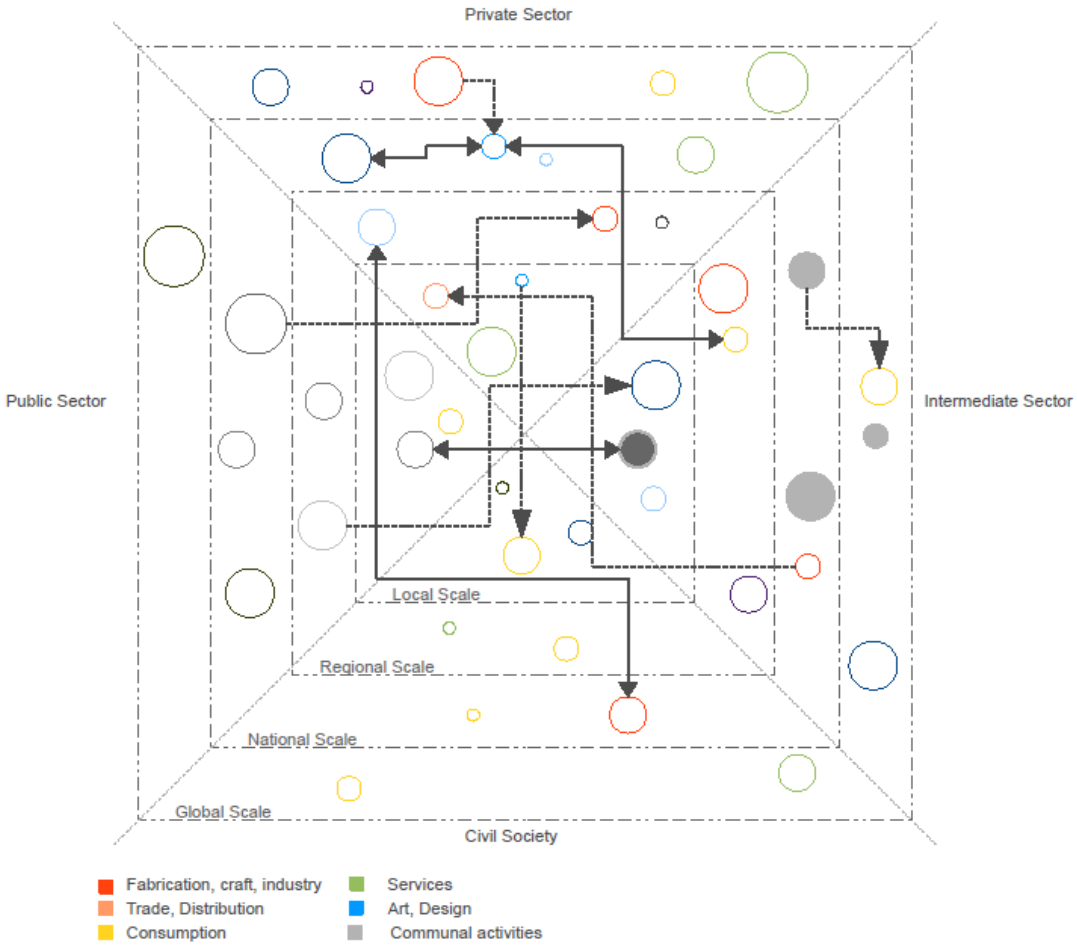


Fig. 3: Research model for the analysis of co-productive value chains (S. Schreiner 2026)

It shows, that the role of space in co-productive project development can be various and needs to be focused on different scales ¬ like the local scale, the regional scale or the global scale:

- Space as a resource (real estate, use of buildings);
- As social and cultural environment where co-production grows;

- As area for innovation processes, like co-creation (as design-construction-distribution as networked communication and production process);
- As arena for discurs or conflicts, e.g. do-it-yourself constructions (e.g. the district of Christiania in Kobenhagen/Danmark as a merely self-organised neighbourhood development processes).

Below, two very different typologies for applying the model are outlined, which were generated from interviews with 30 companies from the fields of architecture, design, planning, craft and industrial production. The companies were anonymised at the request of the interviewees. For each typology, approaches for space-related co-productive project development are outlined.

5.1 Typology: The departing company

The departing company is an typical example of a design company that will relocate its business premises. The reason for this is that their opportunities for local and regional cooperation with industrial manufacturers and craft-based production companies are dwindling. This means that opportunities for cooperation are becoming increasingly limited. In this case, the migrants are a fashion design label with two partners who mainly design unique pieces and small series. They produce the unique pieces themselves. For the production of small series, they cooperate with three freelancers (s. figure 4). For sophisticated collections, they rely on local sewing workshops with several employees as suppliers, who guarantee fast and high-quality production. They rarely need large quantities or intermediate products. Due to lower labour costs, they have these produced in large sewing factories in Poland, the Czech Republic or other international locations. As local cooperation partners for design, production and distribution processes dwindle, those who leave cannot maintain cost-efficient, local manufacturing. As interviews with other entrepreneurs in this field have shown, the comparatively high commercial property prices and labour costs at the company's location lead to high design as well as textile craftsmanship costs. According to the interviewees, this is offset by relatively low acceptance among end customers of the corresponding high end product prices. Since co-productive design and manufacturing processes are important everyday practices for those who are leaving, they are planning to relocate their business to a city with lower commercial property costs. One interviewee said: ‘Actually, it's nonsense to do this just to cover the costs; you might as well not bother.’ To counter this with project development approaches:

This type of business, which combines design, operational organisation, quality control, presentation, sales and the manufacture of fashion products, is particularly suited to studios and lofts with a maximum usable floor space of 100 square metres. The commercial space for this type of business does not need to be centrally located in the city, but should be easily accessible for customers and employees. Dialogue-oriented approaches should focus on expanding contacts and cooperation partners, especially with local craft businesses and small factories, as well as public relations work for expanded distribution channels.

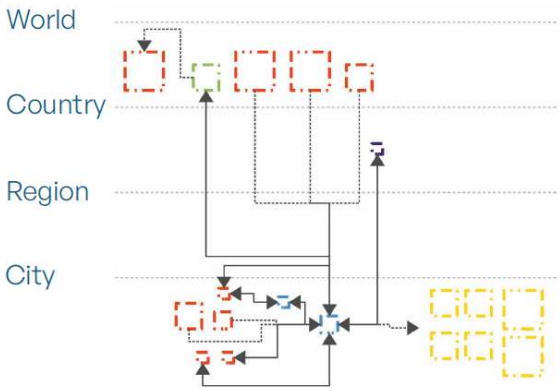


Fig. 4: Co-productive value chains of the departing company (S. Schreiner 2026)

5.2 Typology: The locally embedded company

The typology of those embedded locally develop and implement innovative ideas, themes and technologies from various disciplines of landscape design and horticulture. The city where your company is based always

forms the centre of your activities: ‘We travelled throughout the country, always starting from our office location’ (interview with the owner of the company). However, as there are not enough orders for the company in the region, they also work for clients at various locations throughout Germany. The office is integrated into a diverse network of local, regional and national interactions. The illustration depicts the situation explained in the interview regarding project processing. Creative service providers mainly engage in local and horizontal cooperation (s. figure 5). There is also mutual exchange with a municipal consulting company. Craft businesses mainly act as suppliers at local and regional level. Customers are medium-sized or large companies, city or municipal administrations. The office has been established at its local location for many years. There are no plans to relocate the business, even though there are not enough orders in the region to ensure the economic survival of a company of this size. Accordingly, employees must be mobile and work remotely in order to temporarily work on nationwide projects. This example shows that I can develop a planning company steadily at its location over many years despite difficult local income generation. In this case, this is achieved through constant and diversified exchange relationships: the company operates nationwide and has a wide range of cooperation partners and suppliers from service and craft businesses. This typology also shows that even a micro-enterprise can be sufficiently efficient to handle projects for large end customers in a flexible and professional manner.

Suitable commercial premises for companies such as these are purely office spaces in commercial properties in mixed-use or commercial areas. They should have good transport links. The office space should be available exclusively to a company such as the local embedded company. Shared use of a conference room with other companies in the building is possible (optional). This guarantees short distances for meetings with business partners. Strengthening interdisciplinary contacts supports local stabilisation. Interdisciplinary themed events such as discussion evenings can contribute to this. Specific public relations work tailored to the field of activity can also support local stabilisation as this can promote sales.

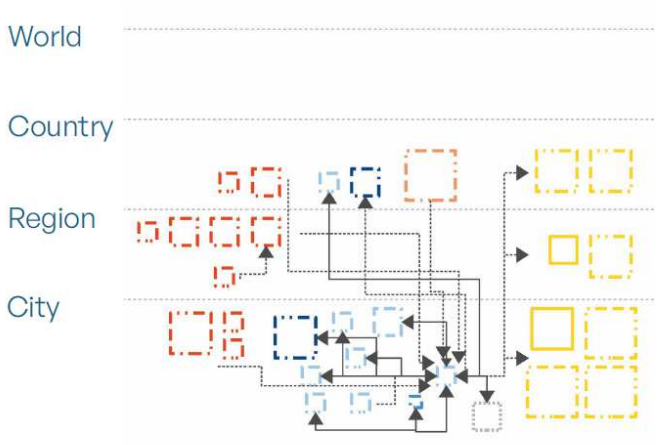


Fig. 5: Co-productive value chains of the locally embedded company (S. Schreiner 2026)

6 PLANNING TOOLS FOR CO-PRODUCTIVE PROJECT DEVELOPMENT

Multi-actor involvement with shared power and responsibility in spatial development projects has to deal with complexity, but can also lead to better outcomes if the right tools are used. Various planning tools can enhance and support co-productive project development in urban and regional planning (s. Matyushkina et al. 2024:733f., Külvik et al. 2021). Recommendations for action to promote co-productive activities, extracted from interviews and literature analysis are as follows:

- Face-to-face communication at community engagement events. Informal communication formats to promote personal contacts and, above all, horizontal cooperation with representatives of companies, government agencies and intermediary organisations;
- Urban (co-)design pilot projects;
- Participatory budgeting of public funds;

- (Digital) Platforms (e.g. citizen portals, online mapping). Establish a national public profile for specific areas of activity in order to improve acceptance and sales of locally developed or manufactured products;
- Affordable real estate;
- Flexible land-use (multi-use options).

Specific cooperation and information events are suitable for supporting the networking of potential business partners and planning stakeholders at a horizontal level. This may require that such activities are not limited to individual sectors, but also involve representatives from trade, industry, commerce, and science on a case-by-case basis.

In this context, planning and funding stakeholders should take on more of a moderating role in order to be able to act on a horizontal level. Their influence should focus on partnership-based cooperation. Local authorities can also support co-productive project development with tools such as building land allocation, flexible land use planning, financial support for certain construction projects, or hands-on support of co-creation processes of public open spaces.

Technology like online mapping tools can enhance co-production, but tech should support – not replace – human interaction. Critics about tech-based planning tools argue that e.g. elderly or marginalised groups might not have resources or knowledge to use such tools (cf. Külvik et al. 2021). Supporters of tech-based planning tools argue instead that it depends on the right type of information, human support and learning opportunities for elderly or marginalised groups to reach digital services and tool. For example, in Estonia online collaboration platforms like TOM/TID+ or Maptionnaire are used by a lot of different citizens, because digital public services are common and spatial data is often used for smarter cooperation.

The integration of digital tools can improve reach and responsiveness. But it can also distract or exclude certain people/groups from project participation.

7 DISCUSSION AND CONCLUSION

In addition to everyday knowledge, co-productive urban development requires a wide range of expertise on the respective planning objectives, as well as mutual trust and openness to new ideas among all those involved. This calls for a specific planning culture that reflects local characteristics, is based on a common language, and is constantly evolving.

Representatives of private sector, intermediary, or civil society interests are no longer merely recipients of government procedures, programs, and projects. Rather, as co-producers, they actively shape urban spaces and become relevant cooperation partners for urban and regional planning. They therefore take on control functions and responsibility for space-creating processes themselves.

Overall, it depends on the project- and location-specific interaction between formal and informal, hierarchical and heterarchical coordination between public and private sector actors. Top-down planning approaches and context-specific control are less suitable for this than bottom-up processes and direct support activities.

Planning tools and resources should be used dynamically, but also complementarily, and should lead to joint decisions. However, this requires intensive coordination across departments and topics. It also requires public sector representatives to question their ability to act on their urban development goals and to take on appropriate roles as mediators, moderators, or co-production partners, or to delegate these tasks to suitable actors.

Co-production should not be seen as a planning tool or technique, but as a paradigm shift for future urban development. It enables to integrate different needs and expectations as well as innovations in all phases of spatial project development at eye level by addressing multi-actor involvement differently from established forms of collaborative planning or urban governance.

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Combining Social Aspects of Climate Change with Urban Heat Stress Modelling – a Case Study from Bremerhaven, Germany

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1 ABSTRACT

The impacts of climate change create interconnected ecological, economic, and health challenges that act as multiple drivers shaping local social conditions in urban areas. While municipal adaptation strategies increasingly address physical risks such as heat, flooding, and drought, the social dimensions of climate change often remain underrepresented. Vulnerability to climate impacts, however, is not evenly distributed. Certain population groups – such as older people, children, people experiencing homelessness, and individuals with low income – are particularly at risk. Moreover, low-income neighborhoods are often disproportionately affected by heat waves. This is partly due to the fact that these areas typically have below-average access to open spaces such as parks or water bodies. Furthermore, the distance to public recreational areas often increases as household income decrease.

Against this background, the paper presents a case study on heat stress modeling in Bremerhaven, Germany. The analysis focuses on the Goethestraße district, which faces significant socio-economic challenges and holds the lowest social index of the city. Bremerhaven itself is characterized by the second-highest unemployment rate and the highest rate of over-indebtedness among all German cities. The case study employs a top-down approach using scientific data – including environmental parameters, weather observations, and regional climate projections – as inputs for model simulations conducted with the "Tygron Platform". This was complemented by a bottom-up approach involving key stakeholders from the city administration to integrate expert knowledge, local perspectives, and community-based assessments. Through this transdisciplinary and co-creative process, all major decisions – like the definition of the current and future climate scenarios to be taken into account, the potential adaptation measures to improve the thermal comfort (mainly the integration of green spaces, urban trees, and water areas), the integration of aditional stakeholders from the city admistration, the future communication of the modeling results – were taken collaboratively and on an equal footing.

Beyond conventional urban climate modeling approaches and indices commonly applied in Germany, the study also incorporates planning principles from the Netherlands, notably the 3-30-300 rule. In addition to presenting modeling results, the paper discusses possible practical adaptation options and first next steps to strengthen socially inclusive climate adaptation strategies.

Keywords: climate change adaptation, co-creation, social aspects of climate change, urban heat stress modeling , urban resilience planning

2 INTRODUCTION

The impacts of climate change pose ecological and economic challenges that are also influencing and interacting with the local social conditions in urban areas (IPCC, 2022). While physical risks such as heat, heavy rainfall, or drought are increasingly considered in municipal adaptation strategies, social aspects often remain underrepresented (EEA, 2025; Teebken, 2024; Teebken & Schipperges, 2024; Juhola et al., 2022). Certain population groups – such as older people, children, the homeless, or individuals with low income – are particularly more vulnerable to climate impacts (Etzel et al., 2024; Prina et al., 2024; Proulx et al., 2024; IPCC, 2022; Swanson, 2021). Especially heatwaves disproportionately affect low-income urban neighborhoods. This is for example because compared to more wealthy neighborhoods, socially disadvantaged ones often show higher proportions of sealed and developed land. In combination with an associated lack of shades from trees or cooling effects of green spaces and water bodies, these districts can heat up more easily. Additionally, housing conditions in these areas tend to exacerbate vulnerability, as buildings are often poorly insulated and overcrowding limits opportunities for retreat during extreme heat events. Therefore residents are often unable to find relief from heat at home or within walking distance of their homes (Yin et al., 2023; IPCC, 2022; Rehling et al., 2021).

These circumstances for example contradict one of the goals of the Federal Climate Adaptation Act (KAnG)[1] – the German regulatory binding framework for climate change adaptation – aiming to prevent the increase of social inequalities caused by the negative impacts of climate change. Additionally, the German Strategy for Adaptation to Climate Change[2] aims to strengthen the resilience and resistance of ecological systems, the economy, and society to create equal living conditions. In this context, impact assessments are key for developing climate adaptation concepts. However, the use of the commonly used models to examine spatial vulnerabilities often focuses solely on identifying hot spots related to land use and building structures, only indirectly addressing social issues. However, it is important to also consider social aspects from the outset, as a one-sided focus on physical exposure can lead to maladaptation.

Against this background, the paper presents a case study of heat stress modeling for the district Goethestraße in Bremerhaven, Germany.[3] The Goethestraße is characterized by significant socio-economic challenges. It has the highest population and building density in Bremerhaven and is marked by high proportions of residents with migration backgrounds as well as children and adolescents, of which about one-half live in households receiving basic income support for job seekers. Overall, the district has the lowest social index in Bremerhaven – a city that itself in 2024 had the second-highest unemployment rate (14.5%) and in 2025 was the city with the highest rate of over-indebtedness (18.3%) in Germany (Creditreform, 2025; Statista, 2025).

To assess current and future heat stress and to estimate the effectiveness of potential adaptation measures, heat exposure and the impacts of various scenarios were simulated for the Goethestraße district using an urban climate module of the “Tygron Platform”. The analysis also focused on testing the applicability of this modeling tool, which relies on simplified process assumptions and is commonly employed in the Netherlands to support the implementation of the 3-30-300 rule in urban planning (Konijnendijk, 2024; 2023; 2021). This guideline stipulates that residents within a neighborhood should: i) be able to see at least three trees from their home or workplace, ii) benefit from a minimum tree canopy cover of 30%, and iii) live no more than 300 meters away from a green space or park suitable for recreation. A secondary objective was to explore, through scenario-based simulations, how local heat stress is projected to evolve under future climate conditions and to what extent different adaptation measures can contribute to improve the thermal comfort.

The case study includes a top-down approach based on scientifc data – containing environmental data, weather observations and results from regional climate projections – as input for the model simulations carried out by the Tauw GmbH using the “Tygron Platform”. This setting was combined with a bottom-up approach involving local key stakeholders to incorporate local expert knowledge, stakeholder perspectives, and community-based assessments. Based on this transdisciplinary and co-creative approach, all key decisions – like the definition of the current and future climate scenarios to be taken into account, the potential adaptation measures to improve the thermal comfort (mainly the integration of green spaces, urban trees, and water areas), the integration of aditional stakeholders from the city admistration, the future communication of the modeling results – were taken collaboratively.

The paper is structured as follows. Section 3 briefly highlights main aspects regarding the current discussion on social aspects of climate change. Section 4 introduces the destrict Goethestraße as the model region as well as the specific heat stress modeling approach. Section 5 presents and discusses the main results for all four scenarios taken into account. Section 6 concludes by summarizing main results, reflecting on the specific indicators used and highlighting possibel next steps.

3 SOCIAL ASPECTS OF CLIMATE ADAPTATION

It is in general well understood that the impacts of climate change affect different population groups with varying intensity. Older people, individuals with pre-existing health conditions, and children are most frequently identified as vulnerable groups. In addition, pregnant women, people experiencing homelessness, and outdoor workers may also face elevated risks. Socio-economic factors such as low income, insufficient

[1] https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Gesetze/kang_en_bf.pdf.
[2] https://www.bundesumweltministerium.de/DL1322-1.
[3] The specific content of the conducted modeling approach is based on the TAUW final report ‘Hitzemodellierung Bremerhaven – Ortsteile Goethequartier und Klushof’ by Zerhusen & Bauer (2025), which was developed as part of a joint project by the Climate Service Center Germany (GERICS), TAUW GmbH, and the City of Bremerhaven to create a new prototype module for the “GERICS Adaptation Toolkit for Cities”.

financial security, language barriers, and limited educational attainment further exacerbate individual vulnerability by constraining adaptive capacity. Given the high level of exposure and comparatively lower adaptive capacities of certain groups, socially equitable adaptation strategies should place particular emphasis on these vulnerable groups (EEA, 2025; Meer, 2025; Etzel et al., 2024; Prina et al., 2024; Proulx et al., 2024; IPCC, 2022; Swanson, 2021).

A key challenge lies in the fact that individual living conditions strongly shape exposure, and multiple vulnerabilities can overlap, making it difficult to derive generalized conclusions. Moreover, significant differences in adaptive capacities and needs exist both across the general population and within the different social groups. Evidence also suggests that insufficient consideration of social dimensions can further exacerbate existing inequalities within society (Spannagel & Brülle, 2024; IPCC, 2022; Swanson, 2021; Barnes et al., 2020).

Climate risk assessments, however, often focus primarily on exposure, overlooking social characteristics that critically influence susceptibility for climate change impacts. For example, Graham et al. (2018) demonstrate that risk assessments which fail to account for social factors may result in the relocation of socially connected, low-income communities without preserving their social networks – an outcome that could increase vulnerability, further marginalize these groups, and negatively affect their motivation to participate in political decision-making processes. Also the European Climate Risk Assessment (EEA, 2024), the European Commission′s Communication on Managing Climate Risks (EC, 2024), the EC′s Climate Action Progress Report (EC, 2023) and most recently the EU Preparedness Union Strategy (EC, 2025) stress the need for adaptation strategies that prioritise and focus on vulnerable populations to ensure that justice is integrated more broadly into efforts towards adaptation and societal preparedness. This highlights the critical importance of integrating socio-economic contexts alongside physical risks in assessment processes, to effectively reduce vulnerability and lower the escalating risk of maladaptation (EEA, 2025; IPCC, 2022; Shi et al., 2016; Ribot, 2014).

Despite these clear insights, recent research on subnational adaptation plans in Europe conducted by the European Environment Agency (EEA, 2025) illustrates for example a significant gap between recognition and implementation of measures with respect to social vulnerability. The study found that socially vulnerable groups are most frequently acknowledged during the early stages of the adaptation policy cycle, particularly in climate impact and risk assessments, with 68% of local adaptation plans including such considerations. However, this attention declines substantially in later stages: only 45% of plans incorporate socially vulnerable groups into specific adaptation actions, 7% monitor progress related to these groups, and 4% directly involve them in the planning process. Furthermore, only 3% of the plans examined include one or more adaptation goals explicitly addressing climate justice.

Interpreting the outcomes of urban climate analyses presents another specific methodological challenge, as these analyses typically rely on anonymized representations of cities, neighborhoods, and buildings without demographic or socioeconomic context. Nevertheless, empirical evidence indicates that heatwaves disproportionately affect socioeconomically disadvantaged urban areas (Yin et al., 2023). Income-based spatial segregation is also increasingly observable in Germany: lower-income households frequently reside in substandard housing conditions (e.g., insufficient thermal insulation, absence of air conditioning) and have limited access to cool refuges during extreme heat events. Furthermore, access to urban green infrastructure exhibits a strong socioeconomic gradient (Schüle et al., 2017; Wüstemann et al., 2017). For instance, the walking distance from residential locations to the nearest public park, tends to increase as household income decreases (Rehling et al., 2021). Overall, neighborhoods characterized by socioeconomic disadvantage demonstrate below-average provision of open spaces (Senatsverwaltung für Mobilität, Verkehr, Klimaschutz und Umwelt Berlin, 2025).

To assess local vulnerability within impact analyses, a top-down approach is commonly applied, using various indicators and local data to determine exposure. However, a key challenge lies in capturing social aspects based on specific and reliable data, as standardized indicators and externally defined descriptions of vulnerability often fail to adequately reflect the root causes and lived realities of vulnerability (Teebken & Schipperges, 2025).

To design effective adaptation and avoid exacerbating social inequalities, it is therefore essential to integrate social dimensions and justice already at the stage of vulnerability assessments. Early and inclusive

stakeholder engagement in planning, design, and implementation is a central component for ensuring socially just climate adaptation (Leuphana University Lüneburg, 2024; Teebken, 2024; Teebken & Schipperges, 2024; Juhola et al., 2022; Breil et al., 2021; Fedele et al., 2019; Shi et al., 2016). Through this bottom-up approach, local knowledge and diverse perspectives can inform the characterization of local vulnerability. Consequently, both approaches – top-down and bottom-up – are crucial for capturing social vulnerability.

4 MODEL REGION AND MODELING APPROACH

4.1 Model region: destrict Goethestraße

The district Goethestraße is predominantly characterized by dense, impervious residential areas with multi-story perimeter block development. In the northwestern section, there are several sealed residential areas with multi-story linear buildings. North of Frenssenstraße, commercial areas and some vacant lots are located. The eastern Hafenstraße features mixed residential areas combined with commercial premises. Within this district, there are vacant multi-family buildings in need of renovation – some of these so-called "junk properties" have been closed for safety reasons. Most residential buildings are privately owned, with owners often residing outside the city.

A site inspection by the project team in May 2025 revealed a significant need for heat protection measures in public recreational spaces. Although some new trees have been planted and older street trees exist along the Goethestraße and adjacent streets, there remains a considerable need to provide adequate shading for pedestrian and cycling paths. This also applies to public recreational areas. For example, the Zollinlandplatz offers only limited shaded areas, and the Leher Pausenhof consists largely of sealed surfaces with a playground lacking sufficient shade.

This need for adaptation is particularly relevant given the district's demographic and social characteristics. The population density in the Goethestraße district is approximately more than ten times higher than the average density in Bremerhaven. As a designated "arrival neighborhood", the proportion of residents with a migration background is around 51% (Magistrat der Stadt Bremerhaven, 2024), significantly exceeding the citywide average of about 17%. The share of children and adolescents is also higher at around 21% compared to the citywide average of 10%, with this group exhibiting a very high need for language support (over 80%). In general, residents of this district are heavily affected by unemployment and debt, with a substantial proportion of the working-age population (approximately 31%) receiving basic income support for job seekers (Proloco Bremen & plan zwei, 2023).

The social vulnerability of the district has been confirmed by recent monitoring efforts. As part of the social area monitoring conducted in 2023 (Magistrat der Stadt Bremerhaven, 2023), Bremerhaven's districts were analyzed and categorized based on their social situation. The classification was derived from an index value calculated using six indicators: i) need for language support, ii) proportion without a high school diploma, iii) child poverty, iv) share of employable residents receiving SGB-II benefits, v) unemployment rate, and vi) proportion of non-voters. The index value indicates the extent to which a district's social status deviates from the citywide average. The district with the lowest status value is Goethestraße, with a calculated value of -1.6. Finally, the interplay between social vulnerability and environmental stress also becomes evident by a comparative analysis of nine-year mean air temperatures (2017–2024) and the social index at the district level carried out as part of the case study. This analysis suggests a tendency for neighborhoods with lower social status to exhibit higher average air temperatures – and thus more heat stress (Klafka, 2025).

4.2 Heat stress modeling approach

To estimate where heat hotspots occur within the city and to learn about the possible effectiveness of adaptation measures, it is common practice to conduct model simulations using urban climate models. Scenario analyses allow the comparison of urban planning and meteorological scenarios based on high-resolution, spatially comprehensive data (Bender et al., 2025). A key criterion considered in these simulations is human thermal comfort, which can be assessed using various indices. These indices help to describe whether a given microclimatic situation is perceived as comfortable or uncomfortable. This perception is primarily determined by the human energy balance (Höppe, 1999), which is calculated using a combination of meteorological parameters (air temperature, humidity, wind speed) and human factors (clothing type, activity level) to quantify heat exchange at the skin surface and heat transfer within the body.

One commonly applied index – also used in this study – is the Physiological Equivalent Temperature (PET), which expresses results in degrees Celsius, thereby facilitating communication (Matzarakis et al., 1999). The classification of PET values is provided in table 1.

PET-Range in °C	Stress level	PET-Range in °C	Stress level
> 41	Extreme heat stress	13 – 18	Slight cold stress
35 – 41	Strong heat stress	8 – 13	Moderate cold stress
29 – 35	Moderate heat stress	4 – 8	Strong cold stress
23 – 29	Slight heat stress	< 4	Extreme cold stress
18 – 23	No thermal stress		

Table 1: Influence of physiologically equivalent temperature (PET) on the modeled temperature stress on humans (based on Matzarakis et al., 1999).

The calculations used the urban climate model of the "Tygron Platform". To assess urban heat stress, the "Tygron Platform Heat Module" in combination with the "Heat Stress Overlay" was utilized. An autochthonous weather pattern at a summer day was selected for the analysis of urban heat exposure. This weather type is characterized by the formation of cold-air flows during nighttime and pronounced diurnal cycles of air temperature, humidity, wind speed, and solar radiation, which amplify the effects of urban climate phenomena (Oke et al., 2017).

The evaluation of urban heat stress was based on the indicators proposed by Kluck et al. (2020): i) PET, ii) walking distance from residential buildings to public recreational areas not affected by heat stress, and iii) the proportion of shaded areas on public traffic surfaces.

The calculation of shaded areas on public traffic surfaces consider terrain elevation and urban morphology. Walking distance was determined through a network analysis of streets, pedestrian paths, and cycle routes at the building level. This analysis incorporated previously calculated PET values, assuming a threshold of 29°C to define heat-unaffected areas – corresponding to the upper limit of slight heat stress according to established classifications. Additionally, a minimum size of 200 m² was set for potential recreational areas. Private spaces and areas outside the model boundaries were not considered in this approach.

In addition, and to assess local heat distribution based on the PET as well as the effectiveness of adaptation measures, the four scenarios defined in table 2 were devoped and used within the modelling framework.

Szenario	Definition
KliStaRef	Representative current summer day as a reference scenario for describing present urban heat stress. The basis is formed by data from the climatological standard normal period (1991–2020) recommended by the World Meteorological Organization.
KliWaMed	Representative average summer day in the near future, based on the median value of regional climate projections for the period 2036–2065, considering the intermediate emissions scenario (RCP4.5).
KliWaMax	Representative extreme summer day in the near future, based on the maximum value of regional climate projections for the period 2036–2065, considering the intermediate emissions scenario (RCP4.5).
HitAnK	Representative current summer day with adaptation measures to describe present urban heat stress while accounting for the effects of potentially implementable adaptation measures (a combination of e.g. green spaces, building greening, urban trees, and reflective surface materials).

Table 2: Simulation scenarios for assessing heat stress.

5 RESULTS

The assessment of urban heat stress in all scenarios is carried out at a pedestrian-relevant height of 2 meters, using the spatial distribution of PET values. To enable a clearer evaluation of the small-scale urban climatic structure, the district was subdivided into smaller subareas representing typical urban design patterns. For the Goethestraße district, the analysis highlights in detail the following elements: (a) linear development („Zeilenbebauung"), (b) wasteland („Brachflächen"), (c) Zollinlandplatz, (d) perimeter block development („Blockrandbebaung"), (e) Leher Pausenhof, and (f) Goethestraße.

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5.1 Current situation – KliStaRef

5.1.1 Heat stress

At 2:00 p.m., the highest PET values (above 45°C) occur in the Goethestraße district between the linear building structures, in the central part of the Leher Pausenhof, as well as along the southern facades of buildings and within densely built street spaces (figure 1). The most favorable comfort conditions, characterized by slight to moderate heat stress (25°C to 35°C), are found on the shaded northern sides of buildings or beneath tall vegetation. Furthermore, the modeling results indicate that perimeter block development with a west–east building orientation generates significantly more shade compared to north–south oriented linear structures. An exception is the north–south oriented Goethestraße itself, where tree shading locally reduces PET values.

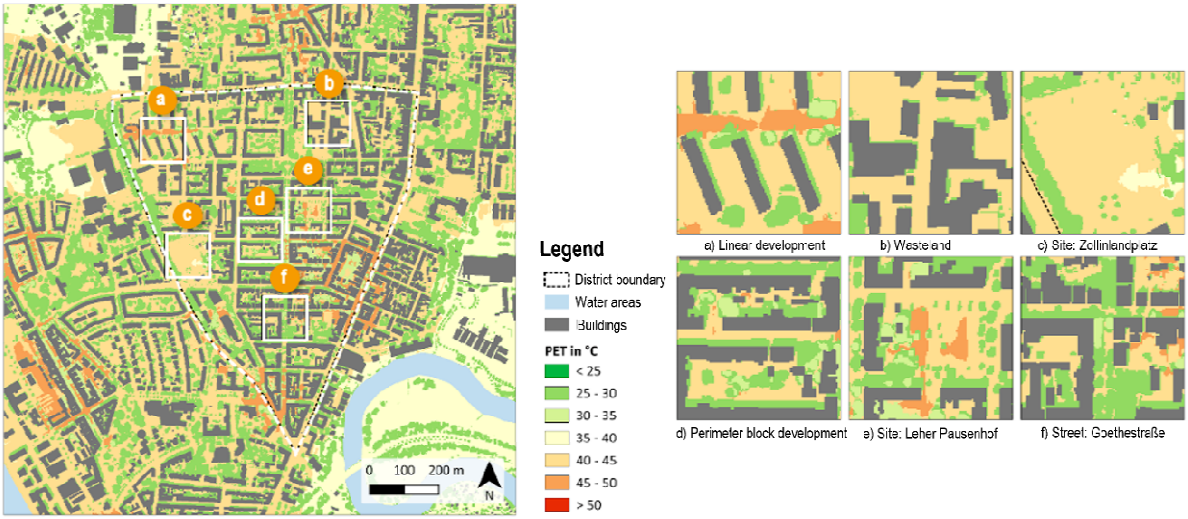


Fig. 1: PET values during the peak heat stress around 2:00 pm in the Goethestraße district for the KliStaRef scenario.

5.1.2 Shaded areas on public traffic surfaces

Between 12:00 p.m. and 6:00 p.m., the proportion of shaded areas on public traffic surfaces in the Goethestraße district varies by subarea, ranging from 41.4% (Goethestraße-North) to 51.2% (Gnesenerstraße). A detailed analysis reveals that areas such as Zollinlandplatz, the central section of the Leher Pausenhof, and many inner courtyards of perimeter block developments lack any shading during this time period (figure 2). Favorable shading characteristics include multi-story buildings, tall urban trees with large crown diameters, and narrow street canyons.

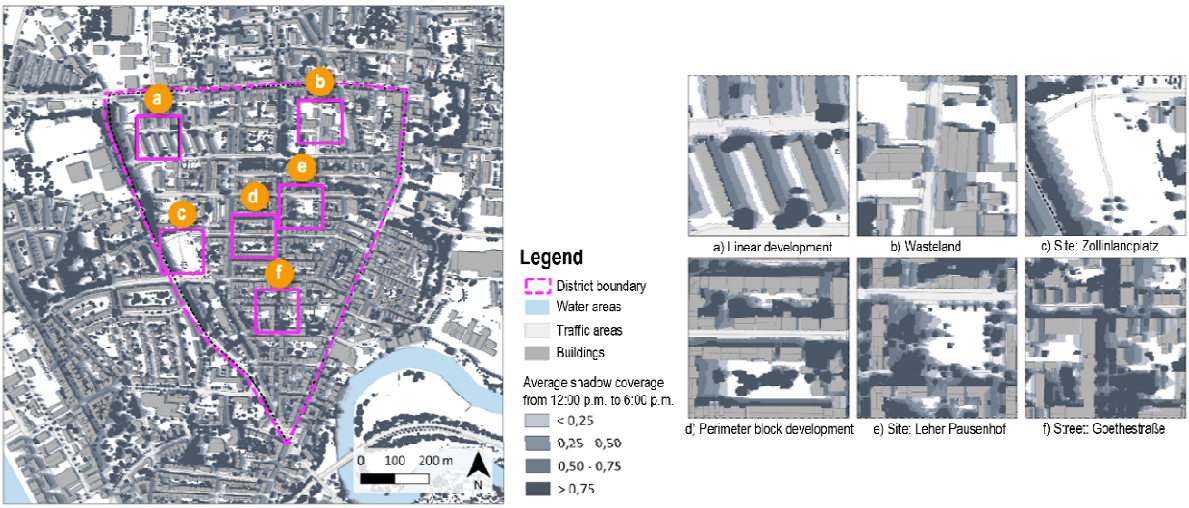


Fig. 2: Share of shaded traffic surfaces between 12:00 p.m. and 6:00 p.m. in the Goethestraße district, scenario KliStaRef.

5.1.3 Walking distance

The modeling of walking distances to heat-unaffected public recreational areas shows that in the Goethestraße district, distances of 400 m or more can occur in the northwestern and southern sections (figure 3). However, this result should be interpreted with caution, as areas with the highest values are located near the model boundaries, making it possible that recreational spaces in adjacent districts could reduce the actual walking distances.

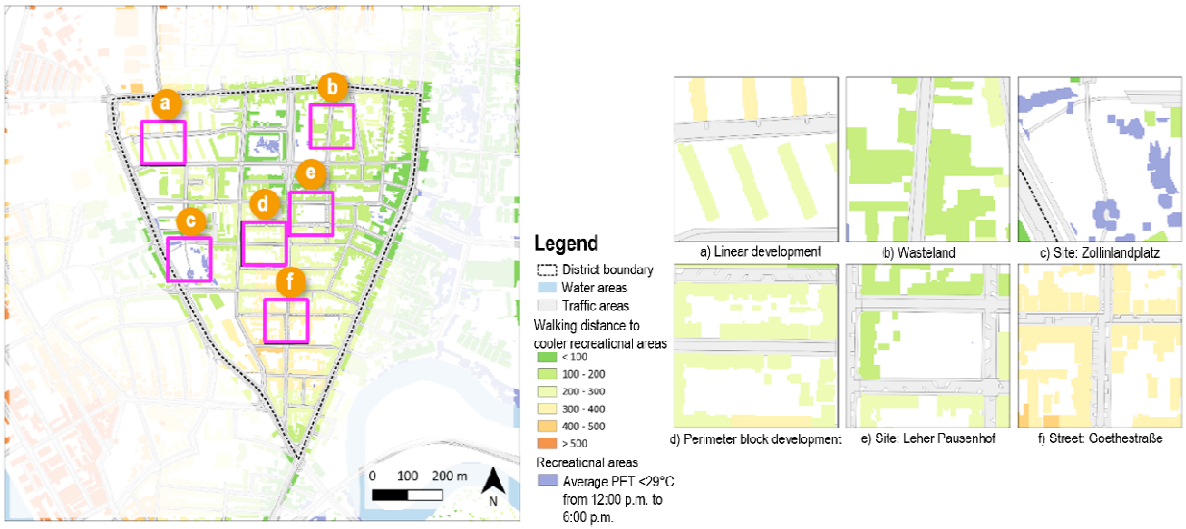


Fig. 3: Walking distance from buildings to heat-unaffected public recreational areas between 12:00 p.m. and 6:00 p.m. in the Goethestraße district, scenario KliStaRef. Areas outside the model boundary have been excluded.

5.2 Future scenarios – KliWaMed und KliWaMax

Both scenarios exhibit a comparable pattern of PET values, although thermal stress is consistently higher than in the reference scenario. Overall, PET values in KliWaMax are approximately 2°C higher compared to KliWaMed. When examining the spatial distribution of PET in the detailed subareas, heat stress in street spaces, inner courtyards, and between buildings increases further under KliWaMed (figure 4) and, in particular, under KliWaMax (figure 5). The contrast between shaded and unshaded surfaces also becomes more pronounced in these scenarios.

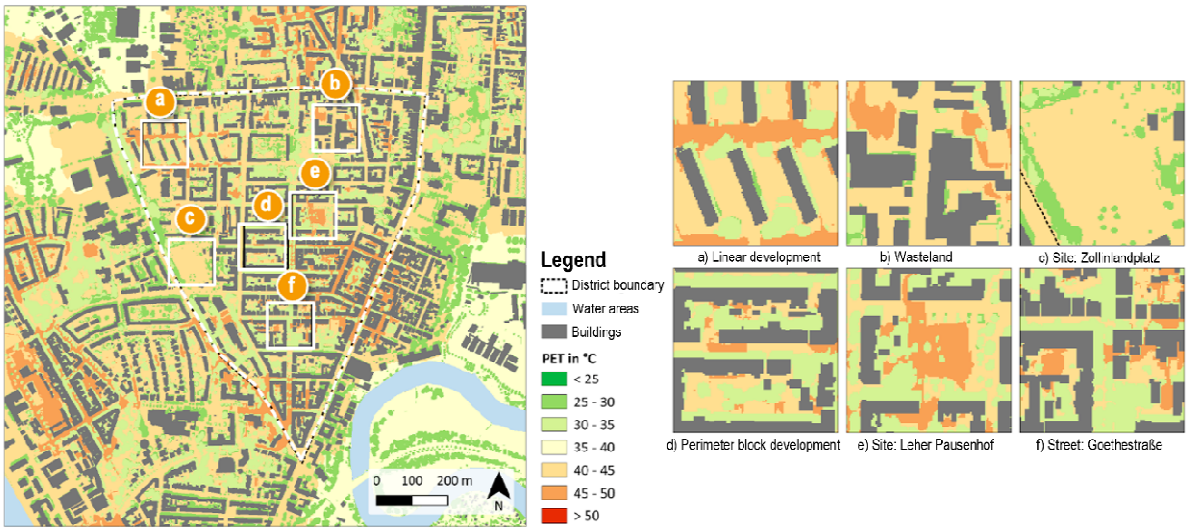


Fig. 4: PET values during peak heat stress around 2:00 pm in the Goethestraße district, scenario KliWaMed.

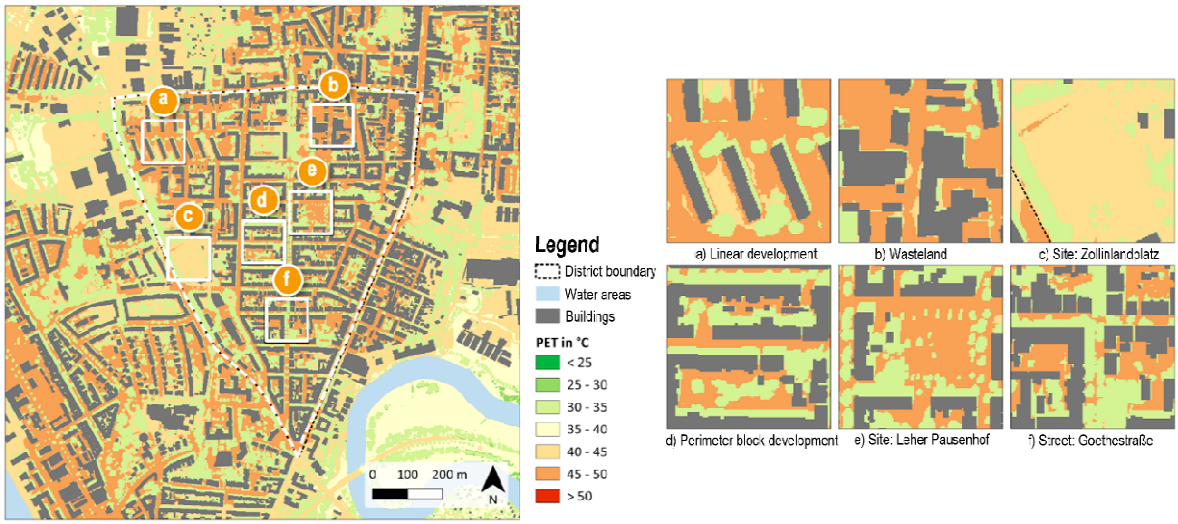


Fig. 5: PET values during peak heat stress around 2:00 pm in the Goethestraße district, scenario KliWaMax.

5.3 Current situation with adaptation measures – HitAnK

This scenario is based on the reference scenario and incorporates adaptation measures that are potentially feasible within the urban area to reduce heat-related impacts. Existing trees, buildings, and traffic surfaces were retained during implementation. Methodologically, the measures were realized by adding various green space configurations in areas such as vacant lots, parking spaces, sealed roadside strips, unused brownfields, sealed commercial fringe areas, and sealed recreational spaces. In some residential sections, tree density was increased (figure 6). In this scenario small trees (10 m height, crown diameter: 5 m), medium trees (15 m height, crown diameter: 10 m), and large trees (20 m height, crown diameter: 15 m) were included, whereas a minimum safety distance of 2.5 m between tree crowns and buildings was maintained. Planting distances were chosen based on two criteria: i) maximizing canopy closure and ii) preserving access points and parking spaces along traffic surfaces. As a measure with theoretically high visibility potential – but currently not beeing feasible in practise –, the former course of the Aue stream in the Goethestraße district was reconstructed in the model using historical city maps. This intervention widened the watercourse to 5 m and added 5 m-wide green strips with scattered tree groups on both sides of the stream. However, it has to be considered, that this model tool cannot calculate PET values above water surfaces, so that positive effects were minimal. In order to obtain a better direct comparison of all measures, another model that can calcluate PET-values over all surfaches has to be used for the modeling.

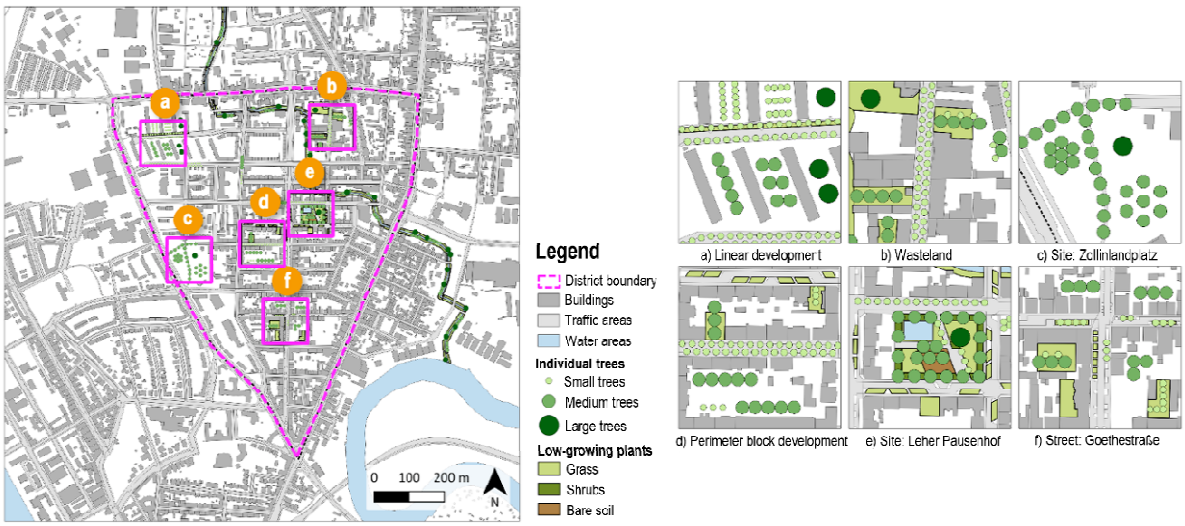


Fig. 6: Structure of the heat adaptation scenario (HitAnK) in the Goethestraße district.

When comparing the current thermal stress with a hypothetical situation in which numerous adaptation measures have been implemented throughout the model area, it becomes immediately apparent that heat stress has decreased by one to two PET classes in many locations. The expansion of shaded areas has

improved conditions between linear and perimeter block developments, in street spaces near wasteland, at Zollinlandplatz, and at the Leher Pausenhof, reducing severe heat stress to moderate or slight levels (figure 7). However, the modeling also reveals that the increased tree cover locally reduces ventilation to such an extent that small areas – such as the wasteland subarea and some southern building façades (e.g., perimeter blocks or Goethestraße) – exhibit a narrowly confined increase in PET values.

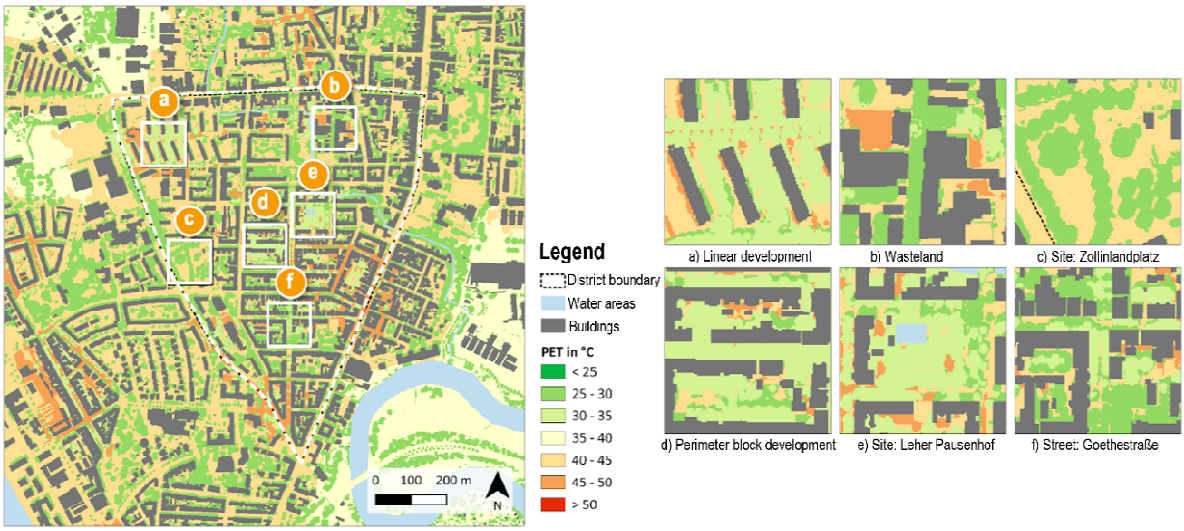


Fig. 7: PET values during peak heat stress around 2:00 p.m. in the heat-adapted Goethestraße district, scenario HitAnK.

The benefits of adaptation measures become evident when examining the difference map (figure 8). At the time of peak heat stress (2:00 p.m.), differences between the reference and adaptation scenarios range from -15.3°C to +2.3°C. Cooling effects in newly greened residential areas with low-growing vegetation reach -1.8°C (e.g., in the northern part of the vacant lots or the southern section of the Leher Pausenhof). In the shade of newly planted trees, PET values decrease up to -15.3°C, and in most cases around -10°C to -15°C. Areas planted with tree groups arranged in an east–west orientation and with close spacing provide more extensive cooling compared to tree groups oriented north–south with wider spacing. In contrast, the reconstructed course of the Aue stream appears to have a limited cooling effect in the Goethestraße district. This – as already mentioned above – can mostly explaint by specific limitation of the model approach.

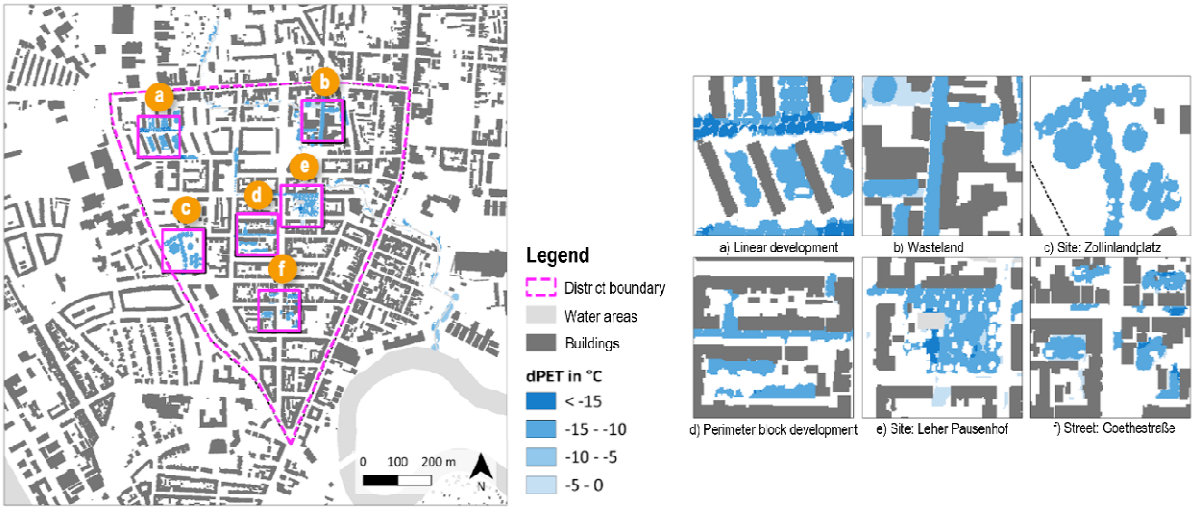


Fig. 8: Difference in PET values between the HitAnK and KliStaRef scenarios in the heat-adapted Goethestraße district during peak heat stress around 2:00 pm.

6 CONCLUSION

The modeling results indicate that the highest PET values occur around 2:00 p.m. on sun-exposed, south-facing sides of buildings or across built-up areas without any significant shading. The most favourable thermal conditions are found where surfaces are permanently – or at least for several hours – extensively shaded. Therefore, adaptation measures should primarily aim to increase shading during the midday and

afternoon hours – especially on sun-exposed facades and roofs of buildings. In addition to the use of large-canopy urban trees and building greening, technical shading elements such as sun sails or parasols can make a valuable contribution.

To provide further cooling, the proportion of shade on public spaces should be examined in more detail by analysing people's usage patterns to answer the following questions: Which traffic areas are used most frequently at which times, and which recreational spaces are primarily visited for leisure activities? From this, one can prioritise the areas and routes that should be addressed first when implementing adaptation measures, in order to improve overall thermal comfort.

As the future scenarios show, heat stress will increase in the absence of adaptation measures. It is therefore advisable to consider improved shading in street space and on public recreational areas, so that these areas can be used during the summer months now and in the future, enabling people to avoid severe and extreme heat stress in other parts of the city. This also includes the routes leading to the recreational areas. It must be taken into account, in particular, that the full benefits of tree shade only materialise once the associated trees have reached the necessary size at the appropriate age, which means that action should start as early as possible.

The spatial distribution of PET values presented here provides initial indications of where high values are to be expected. The computed values are based solely on future changes in input temperatures. Therefore, it must also be assumed that humidity and other PET-relevant variables will change and PET values will additionally shift locally. Regardless of the exact values, however, the results indicate that – and where – increasing the share of shaded surfaces is an effective means of reducing heat stress.

Decisive for the degree of area-wide heat reduction are the planting distances between urban trees and the spatial orientation of tree rows. An east-west orientation has a greater effect than a north–south orientation. Green spaces can also contribute to increasing thermal comfort, but this requires adequate irrigation. Moreover, urban trees and green spaces provide additional ecological and health benefits and help reduce flooding by improving infiltration. To ensure that urban trees can cope with the consequences of climate change in the long term, site-appropriate, climate-resilient (Roloff et al., 2013) and allergy-friendly (Bergmann et al., 2025) tree species should be used. The construction of tree infiltration trenches has proven particularly advantageous, as they retain rainwater and increase water availability for the trees, thereby reducing irrigation effort (Szota et al., 2019).

The indicator "share of shade on public traffic areas" proposed by Kluck et al. (2020) offers, in contrast to the use of thermal indices, a simple approach to assessing heat exposure along streets as well as pedestrian and cycling paths. Its application in combination with an analysis of the time-of-day-dependent use of these areas is a good approach to planning and implementing targeted adaptation measures. By including different scenarios, the effectiveness of individual measures can be made more tangible and communicated more clearly. For this reason, it is recommended to calculate the share of shade not only at the social-area level, but for the entire urban area. It may also be helpful to consider the share of shade on residential buildings at different height levels and with a focus an apartments located under rooftops or with extensive south-facing exposure, frequently experience particularly high indoor temperatures during summer months.

Application of the indicator "walking distance to non-heat-stressed public recreational areas" proposed by Kluck et al. (2020) confirms the need for action identified during the site visit regarding the lack of shading in large recreational spaces, which are of great inportance for vulnerable residents to find cooling outdoors during heatwaves. This means in sum that residents are unable to find relief from heat at home or within walking distance of their homes. As the building-resolved analysis for the Goethestraße neighbourhood shows, there are currently only a few recreational areas with lower heat exposure during the time of day with the greatest heat burden. As a result, walking distances to cooler areas in the north-western and southern parts are in some cases more than 400 m. In particular, these areas should be considered for improving heat protection, including the provision of public buildings that offer thermal relief. The indicator should also be recalculated taking these facilities into account. Additionally, it could be discussed whether free drinking-water stations should be installed at some locations.

Overall, the study shows that the development of joint scenarios and the simulation of heat exposure highlight the necessity of specific adaptation measures for vulnerable groups. Exemplary approaches from the Netherlands can also provide valuable new impulses for planning in Germany. Furthermore, it becomes

clear that the social dimension of climate adaptation must not be treated as an add-on, but should be considered from the outset and be an integral part of all planning phases. This also includes the early integration of social data into impact analyses. Only through the systematic consideration of social issues and the active involvement of vulnerable groups as well as practical decision-makers on site a just and sustainable urban climate adaptation can be achived.

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reviewed paper

Community Perceptions of Municipal Stormwater Management in Durban, KwaZulu-Natal: Evaluating Progress and Challenges

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1 ABSTRACT

In Durban, KwaZulu-Natal, inadequate maintenance and limited capacity of municipal stormwater drainage systems have been repeatedly linked to urban flooding, causing significant property damage, health risks, and public dissatisfaction, particularly in the wake of extreme rainfall events such as the 2022 floods. This study investigates community perceptions and responses to municipal stormwater drainage management in urban and peri-urban areas of the eThekwini region, KwaZulu-Natal, South Africa. In 2024, 200 residents participated in structured surveys, with quantitative data analysed using descriptive and correlation statistics and qualitative responses examined through thematic analysis. Results indicate that public satisfaction is closely linked to perceived municipal effectiveness in maintaining drainage infrastructure and mitigating flooding. Communities reported persistent concerns regarding system performance, delayed interventions, and associated health and safety risks, reflecting limited confidence in municipal progress. The findings align with frameworks of urban resilience and participatory governance, emphasising the importance of responsive and inclusive management strategies. The study concludes by recommending targeted municipal engagement, enhanced monitoring and maintenance, and community education to improve trust, resilience, and adaptive capacity in the face of rapid urbanisation and climate-related flood risks.

Keywords: Community Perception, Municipal Governance, Stormwater Management , Urban Resilience, Urban Flooding

2 INTRODUCTION

2.1 Background

Urban and peri-urban areas in South Africa, particularly in the eThekwini region, face increasing challenges related to stormwater management due to rapid urbanisation, ageing infrastructure, and the impacts of climate change (Grab, 2023). The intensification of extreme weather events, including increased rainfall and flooding, has exposed vulnerabilities in existing drainage systems. These issues are particularly evident in communities such as Umlazi, Wentworth, Amanzimtoti, Isipingo, Umdloti, and Tongaat, which experience recurrent flooding, compromised infrastructure, and health and safety concerns (Grab and Nash, 2023).

2.2 Introduction

This paper presents an in-depth analysis of survey data collected to assess public perceptions, experiences, and expectations related to stormwater drainage systems in urban and peri-urban areas. The findings illuminate critical themes such as infrastructure performance, flooding impacts, health and safety concerns, and public satisfaction. These insights contribute to the development of a robust framework for sustainable urban drainage systems (SUDS) and inform strategies to enhance resilience in the face of urbanisation and climate change.

The survey was conducted in the subject areas of Umlazi, Wentworth, Amanzimtoti, Isipingo, Umdloti and Tongaat, and was shared with public primary schools in the local communities. These public schools then shared the survey with members of the community and the survey link was closed once 200 responses were recorded. All survey responses were collected between February and July 2024, just after the expected rainy period of April in the eThekwini region.

2.2.1 Problem Statement

The rapid urbanisation and increasing frequency of extreme weather events in the eThekwini region have exacerbated challenges related to stormwater management in urban and peri-urban areas. Communities such as Umlazi, Wentworth, Amanzimtoti, Isipingo, Umdloti, and Tongaat frequently experience flooding, infrastructure failures, and associated health and safety risks. Despite these challenges, existing stormwater

drainage systems have not been sufficiently upgraded to cope with intensified rainfall patterns, leaving residents vulnerable to recurring impacts. A critical gap in addressing these issues lies in the lack of a comprehensive understanding of public perceptions, experiences, and expectations regarding stormwater management. Current approaches often fail to incorporate community insights, which are vital for developing effective and sustainable urban drainage systems (SUDS). Furthermore, limited local government interventions and inadequate public education exacerbate the situation, contributing to dissatisfaction and mistrust among affected residents.

2.2.2 Research Questions

(1) What are the public perceptions and experiences related to the performance of stormwater drainage systems in urban and peri-urban areas of the eThekwini region?

(2) How do flooding events impact the health, safety, and daily lives of residents in Umlazi, Wentworth, Amanzimtoti, Isipingo, Umdloti, and Tongaat?

(3) What are the key expectations of local communities for government interventions and public education to improve stormwater management?

3 THE PUBLIC PERCEPTIONS

The findings from the Survey Data are presented in 7 broad categories that inform an in-depth opinion from community members with reference to the current stormwater management system endured in the eThekwini region. The survey covered the following categories: Demographic Context, Awareness of Drainage Systems, Flooding, Healthy and Safety Concerns, Public Satisfaction and Municipal Accountability, Broader Infrastructure Challenges and lastly Community Engagement and Climate Resilience.

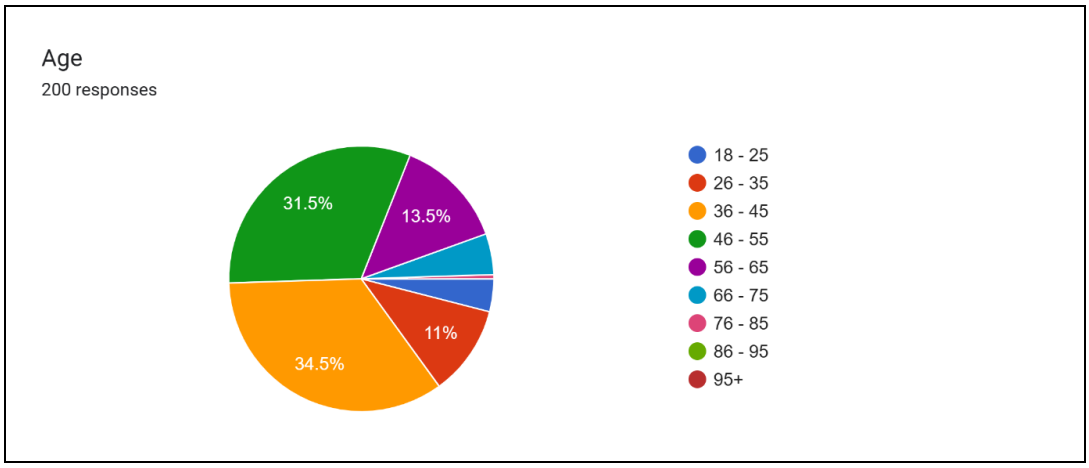


Figure 1: Survey Respondents Age, Moosa (2024)

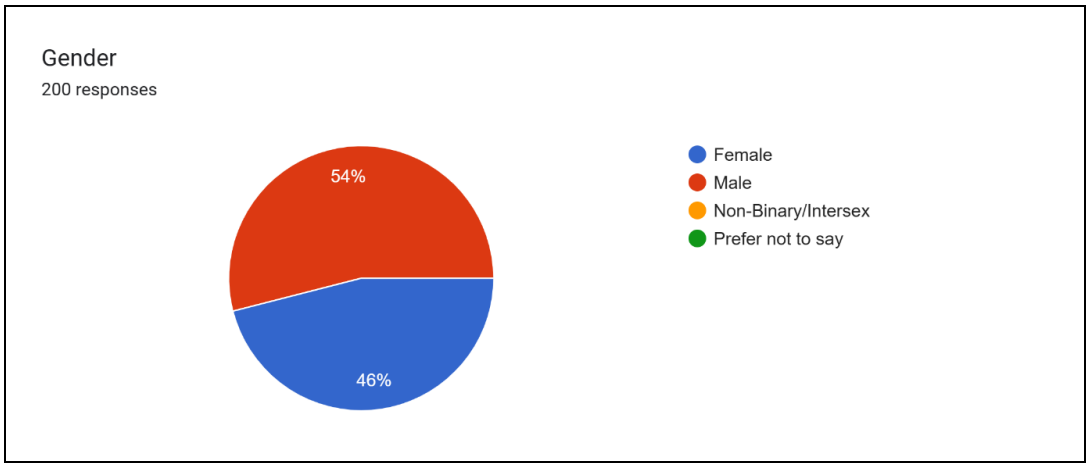


Figure 2: Survey Respondents Gender, Moosa (2024)

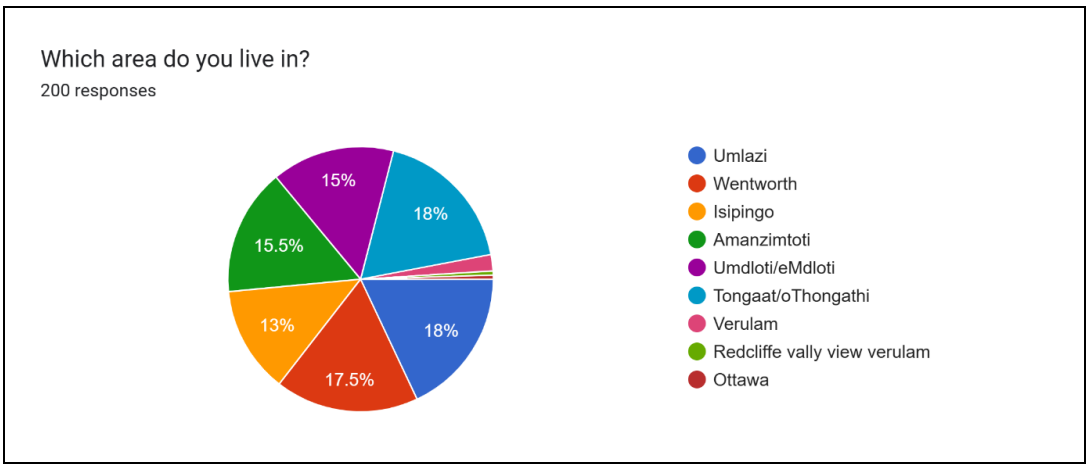


Figure 3: Survey Respondents Area of Residence, Moosa (2024)

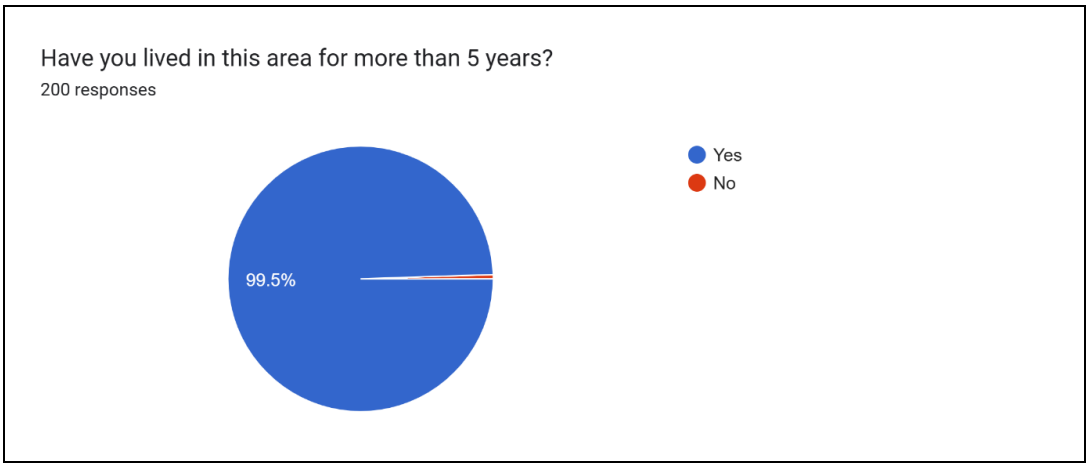


Figure 4: Survey Respondents Length of Stay in Area of Residence, Moosa (2024)

3.1 Demographic Context

The demographic analysis highlights that respondents span a wide age range, with a significant majority (26–55 years) representing active professionals and household decision-makers. Over 90% of respondents have lived in their neighbourhoods for more than five years, reflecting deep familiarity with local environmental and infrastructural conditions. This demographic stability ensures the reliability of responses and provides a longitudinal perspective on drainage system performance.

The above highlights the key demographic indicators to provide reliability to the responses received from the participants, 99.5% have resided in these areas for longer than 5 years, which provides a perspective of familiarity and also a sense of identity which enables accurate reporting. Out of 200 responses, 54% were male, and while the gender marker does not indicate any bias, it can be noted that male respondents were more interested in the infrastructural challenges their communities faced.

3.2 Awareness of Drainage Systems

A substantial portion of respondents (83.5%) reported being aware of the drainage systems in their areas, and 73.5% demonstrated an understanding of how these systems function. This high level of awareness suggests that the community is well-informed and capable of engaging in meaningful discussions about infrastructure improvements. However, the persistence of systemic issues such as flooding and poor maintenance highlights a gap between public awareness and effective municipal action.

The sample revealed that there is a requirement for community based education, improving the education within the public schooling system and improving community awareness related to drainage and stormwater management will improve residents interaction with municipal structures and infrastructure.

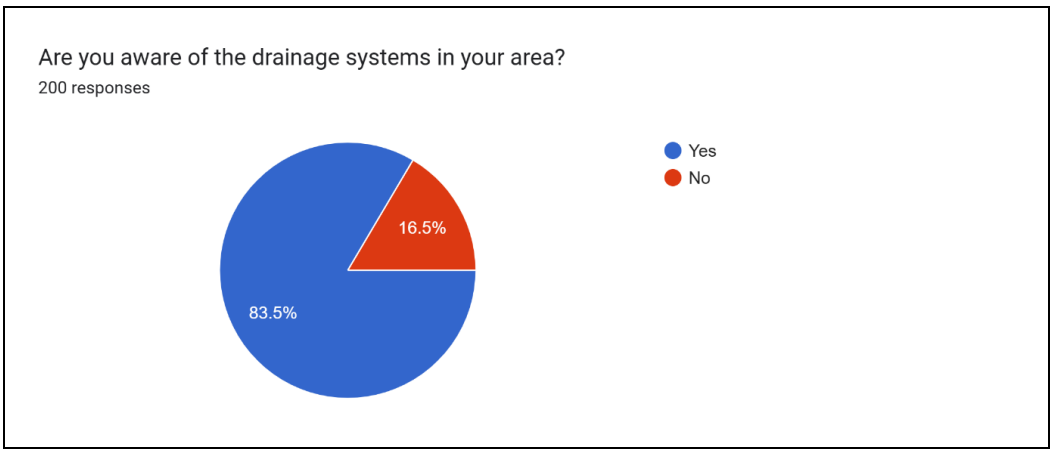


Figure 5: Survey Responses with Drainage System Awareness, Moosa (2024)

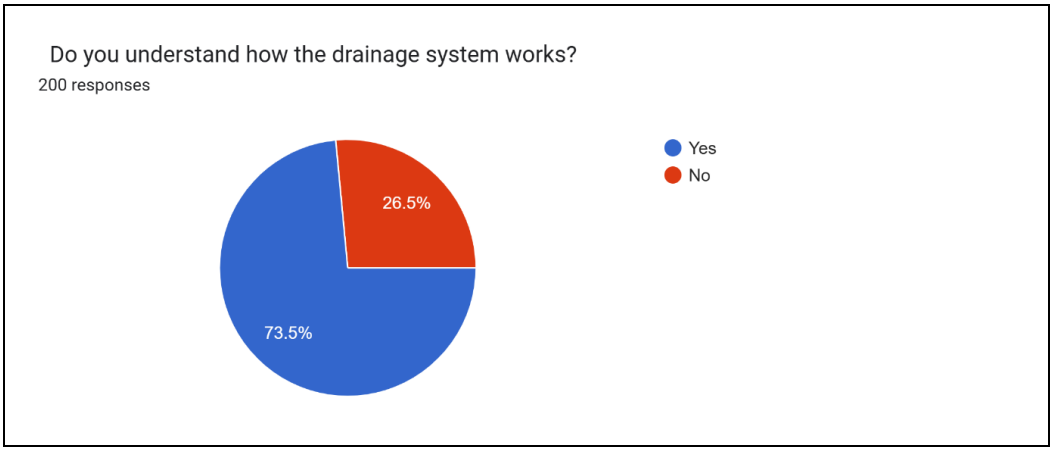


Figure 6: Survey Responses that Understand how Drainage Systems Work, Moosa (2024)

3.3 Flooding and Its Impacts

Flooding is a pervasive issue, with 99% of respondents reporting direct experiences. While some described minor disruptions during rainy weather, others noted severe consequences, including property damage, which affected 25% of respondents. These findings underscore the socio-economic vulnerabilities exacerbated by inadequate stormwater management. Frequent flooding not only disrupts daily life but also imposes financial burdens on households, amplifying the need for resilient infrastructure solutions.

An overwhelming amount of respondents (96.5%) displayed dissatisfaction with the current drainage system in their area – this response clearly depicts a need for improved systems to cope with the needs of the community. While 99% of respondents indicated that they have noticed flooding in their areas during rainy periods, only 25% of respondents have indicated being affected by the consequences of flooding on a daily basis. 25% of respondents expressed that they have experienced property damage due to drainage challenges.

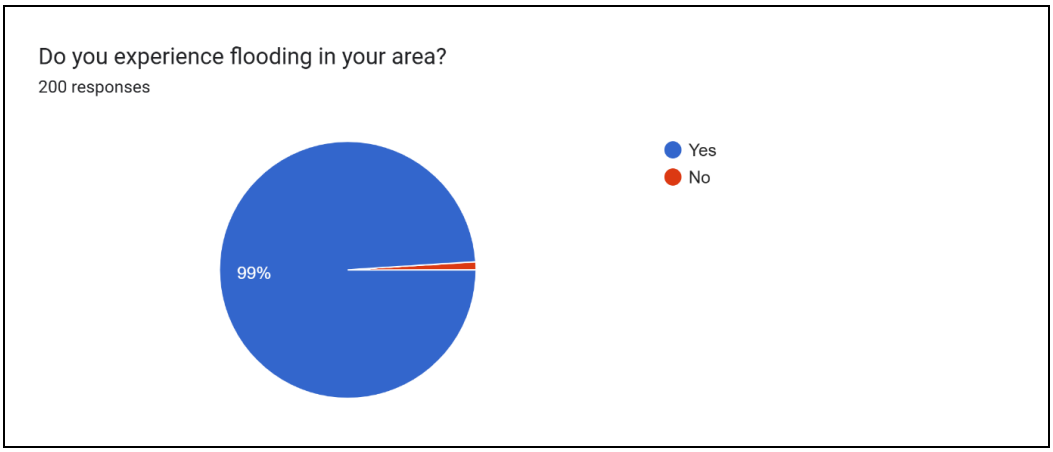


Figure 7: Survey Responses Regarding Flooding Experiences, Moosa (2024)

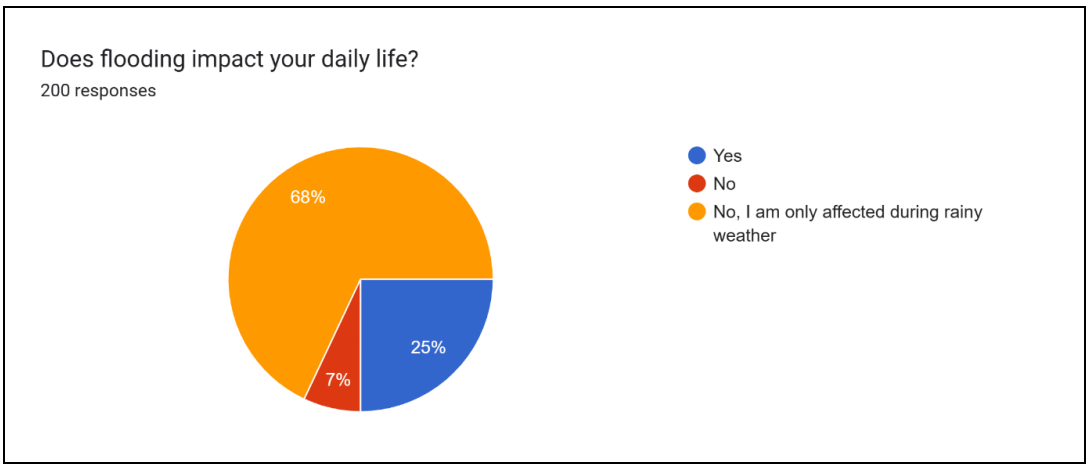


Figure 8: Survey Responses: Daily Life Impact of Flooding, Moosa (2024)

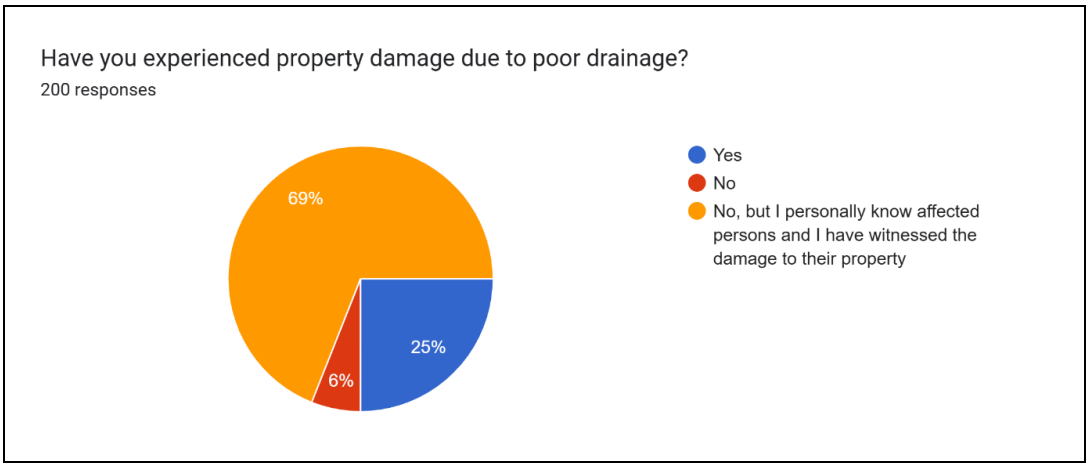


Figure 9: Survey Responses: Experiencing Property Damage due to Flooding, Moosa (2024)

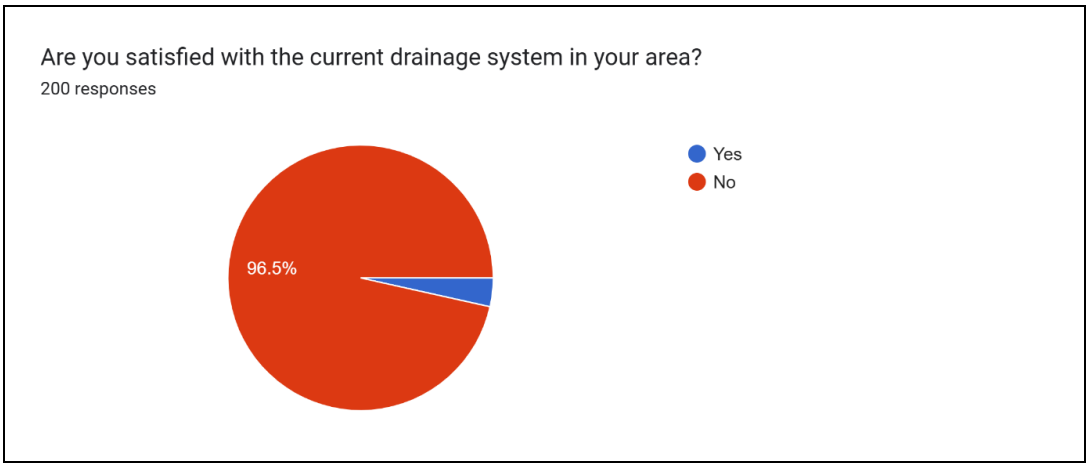


Figure 10: Survey Responses: Current Drainage System Satisfaction, Moosa (2024)

3.4 Health and Safety Concerns

Health risks associated with inadequate drainage were reported by 18% of respondents, while 100% expressed concerns about neighbourhood safety due to poor drainage. Stagnant water was frequently identified as a breeding ground for disease, compounding public health risks in already vulnerable communities. Additionally, flooding creates hazardous conditions, including increased risks of accidents and injuries. These findings highlight the critical intersection of drainage infrastructure, public health, and safety.

An overwhelming 100% of respondents indicated their fear of poor drainage and infrastructure affecting the safety of neighbourhoods. The roadside dumping, overgrown plants and grass impeding walkways and

blocking drains continuously affect the community and impede access to open spaces which should serve as community infrastructure that promote healthy neighbourhoods and safe environments.

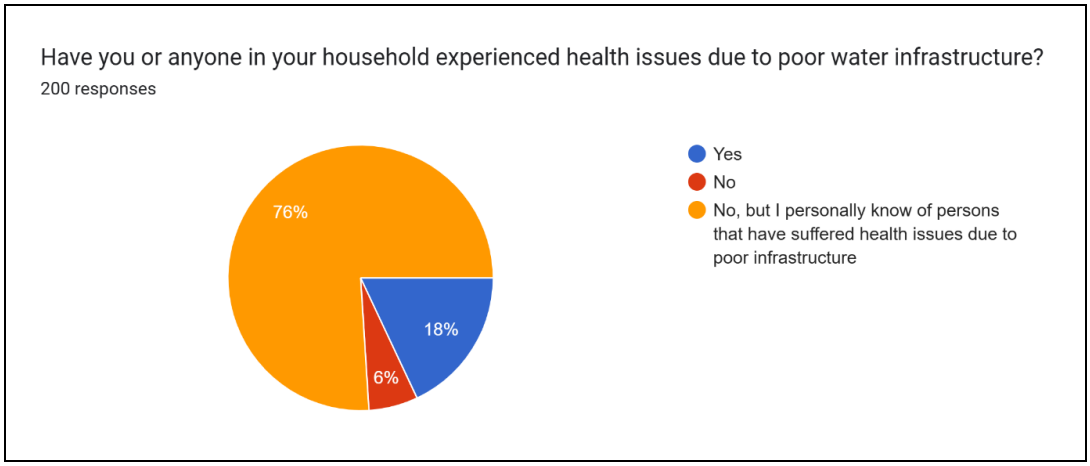


Figure 11: Survey Responses: Health Concerns Related to Flooding, Moosa (2024)

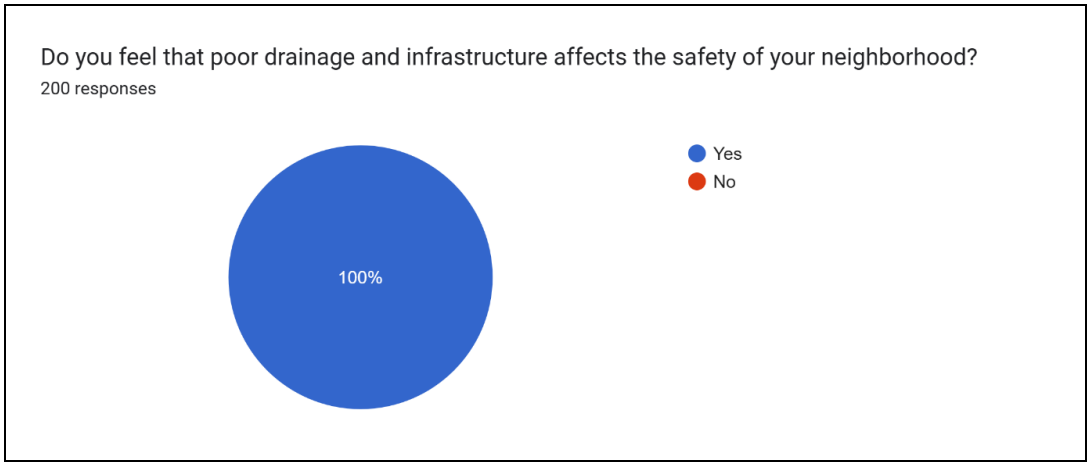


Figure 12: Survey Responses: Neighbourhood Safety due to Poor Drainage, Moosa (2024)

3.5 Public Satisfaction and Municipal Accountability

A striking 86.5% of respondents expressed dissatisfaction with existing drainage systems, citing municipal inefficiency and delayed responses to reported issues as major concerns. This dissatisfaction underscores a growing mistrust in local governance and a perception of systemic neglect. Addressing these concerns requires not only technical improvements but also enhanced governance frameworks that promote transparency, accountability, and public participation.

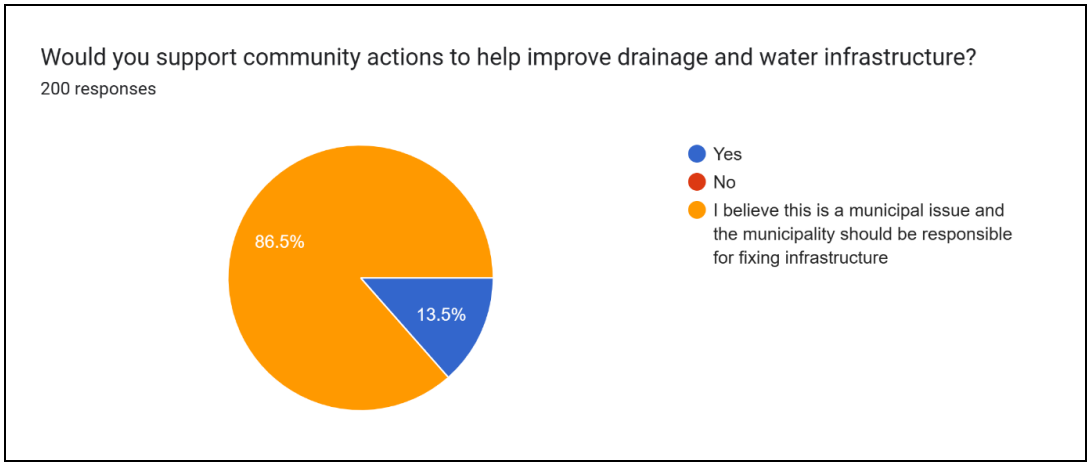


Figure 13: Survey Responses: Responsibility of Improving Drainage and Water Infrastructure, Moosa (2024)

The community sentiments generally indicate that residents believe water infrastructure and drainage systems are the responsibility of the municipality, citing that the community members pay property rates and taxes and expect the municipality to allocate funding for neighbourhood improvement.

4 METHODS

Fife-Schaw (2020) encouraged using a survey to gain insights into key theories within research make for an effective research design and answer the objectives of a study with reliable perspectives from the affected communities. Tomaszewski, Zarestky and Gonzalez (2020) emphasise that survey data should always represent the sample in the most responsible way to ensure high-quality data and insights that reflect the broader community in a considerable way, which holds the researcher to high standards of accountability and accuracy.

The survey was designed to capture quantitative and qualitative data from a diverse demographic of residents across selected study areas. A structured questionnaire focused on key aspects of stormwater management, including awareness, functionality, and community impacts. Participants were drawn from a range of age groups (18–85 years) and socio-economic backgrounds to ensure a representative sample. The data collection process prioritised inclusivity and anonymity, enabling respondents to share candid insights.

The survey was limited to 200 responses from Umlazi, Wentworth, Amanzimtoti, Isipingo, uMdloti and Tongaat – and neighbouring areas. For effective dissemination of the survey, public primary schools were approached within the subject areas and were requested to share the survey with their staff and immediate community. The limitation of 200 responses is intended to complement the findings from on-site observations and provide a reliable foundation for the recommendations made in this study.

The methodology behind the Community Survey on Drainage Systems is designed to gather insights into the impact of drainage systems on the community, contributing to the quality of the findings presented in this study. The survey aimed to assess how drainage systems affect residents, particularly in terms of flooding, property damage, health risks, and overall safety. By collecting this data, the research identified areas where the current systems can be improved and made recommendations for more effective stormwater management.

By targeting residents from specific areas such as Umlazi, Wentworth, Isipingo, Amanzimtoti, Umdloti/eMdloti, and Tongaat/oThongathi. These are regions that are directly impacted by drainage system failure (Grab, 2023), and the survey aims to capture the experiences of those living in these communities. The sampling method used was non-probability sampling, where the focus is on residents who were easily accessible for participation. However, some aspects of stratified sampling were considered to ensure that different demographic groups (such as age, gender, and location) are adequately represented in the data collection process.

To ensure a representative sample, the survey was widely distributed across multiple platforms. It was disseminated through local community networks, neighbourhood social media groups, and with the assistance of public primary schools operating in the subject areas. These groups were instrumental in encouraging participation and provided a platform for sharing the survey link. By leveraging these diverse distribution channels, the survey reached a broad spectrum of the population, including individuals who may not typically engage in municipal consultations or planning discussions.

A total of 200 valid responses were collected, yielding a dataset that included responses from a near-equal distribution of residents from the subject areas. This balanced representation allowed for a comparative analysis of the areas, highlighting any differences in perceptions, experiences, or needs between these communities.

The survey was designed with closed-ended questions that provide clear and quantifiable responses, mainly through "Yes" or "No" answers. This structure allows the identification of trends and patterns in areas like awareness of drainage systems, flooding experiences, property damage, and health issues. Some demographic questions (such as age, gender, and location) were considered to help segment the data for a more detailed analysis. In addition, a few questions allow for additional responses to capture some nuance in the participants' experiences.

Ethical considerations were integral to this study, especially given its focus on community perspectives. The survey was designed to protect respondents' anonymity, and no identifying information was collected to ensure privacy and data confidentiality. Participants were informed about the study's purpose and assured that their responses would be used solely for research purposes. Researchers approached this study with sensitivity toward the community, recognising that flooding is a disruptive issue that may involve traumatic experiences for some residents. Ethical approval was obtained from the University of Johannesburg prior to conducting the survey, ensuring that the study adhered to research ethics guidelines regarding informed consent, confidentiality, and respect for participants.

5 DISCUSSION

The survey findings emphasise the urgent need for policy reforms aimed at addressing governance inefficiencies, particularly in the management of urban infrastructure such as stormwater and drainage systems. Governance inefficiencies often manifest in the form of poor coordination, slow decision-making processes, lack of transparency, and inconsistent service delivery, all of which undermine public confidence and hinder the successful implementation of urban management strategies. These inefficiencies not only result in inadequate infrastructure but also exacerbate social inequalities, as marginalised communities are often the most affected by poor governance and urban planning failures.

To overcome these challenges, it is essential to introduce comprehensive policy reforms that focus on improving the efficiency, transparency, and accountability of municipal governance (Dierkes, Lucke and Helmreich, 2015). These reforms should be aimed at streamlining administrative processes, ensuring that resources are allocated effectively, and increasing responsiveness to community needs (Napier et al., 2018). By introducing more robust frameworks for monitoring and evaluation, municipalities can track progress, identify gaps, and ensure that their actions align with the long-term goals of urban resilience, sustainability, and inclusive development (La Rosa and Pappalardo, 2020).

Policies should encourage the adoption of modern technologies and data-driven decision-making processes that enable better planning, forecasting, and implementation of infrastructure projects (Pappalardo and La Rosa, 2020). Digital tools such as Geographic Information Systems (GIS) and real-time monitoring systems can enhance the ability of municipalities to manage urban drainage, predict flooding events, and allocate resources more effectively (Hoang and Fenner, 2016; Zhang, Wang and Gong, 2024).

The community survey conducted in Durban, KwaZulu-Natal, highlighted significant deficiencies in the current stormwater drainage infrastructure, revealing the widespread impact of flooding on residents' daily lives. Flooding is a frequent occurrence, particularly during periods of heavy rainfall, and has become a persistent challenge in these rapidly urbanising areas. The inadequacy of the existing drainage systems to cope with extreme weather events, compounded by the effects of climate change, has left many residents frustrated and feeling vulnerable to future flooding risks.

The survey analysis provides a comprehensive understanding of the challenges and opportunities in stormwater drainage management within the study areas. The findings illuminate the socio-economic and environmental dimensions of these challenges, offering valuable insights for designing sustainable solutions. This paper contributes to the broader goals of the thesis by bridging empirical evidence with theoretical development and practical implementation, laying the groundwork for resilient and inclusive urban water management frameworks. Although a majority of residents are aware of the stormwater drainage systems, they express dissatisfaction with their capacity and reliability. The ageing infrastructure, coupled with insufficient maintenance, has led to frequent blockages and inefficient water management during storms. This survey also reveals that while residents are aware of these problems, many lack a deep understanding of how stormwater systems function or what role they can play in their maintenance. This underscores the need for public education and greater community involvement in addressing stormwater challenges.

There is an overwhelming consensus among residents on the urgent need for infrastructure improvements. However, the results also show a readiness among the public to collaborate with municipal authorities in finding solutions. Residents are eager to participate in community-driven initiatives, particularly if they receive technical and financial support, indicating a fertile opportunity for partnerships between the community and local government. The survey findings illustrate both the scale of the problem and the potential for community-based solutions. By combining modern infrastructure improvements with public

education and local engagement, eThekwini can take important steps toward building flood-resilient communities that are better equipped to handle the intensifying impacts of climate change.

5.1 Recommendations for Resilient Urban Drainage Systems

The survey findings highlight the critical need for adaptive strategies to mitigate flooding risks and enhance urban sustainability in the face of climate change. Respondents consistently identified frequent and severe flooding as a significant concern, underscoring the strain on existing drainage systems and the vulnerability of urban communities. These insights emphasise that municipalities and urban planners must transition from reactive responses to proactive investments in adaptive and future-proof infrastructure.

Resilient infrastructure is essential for managing the intensified rainfall patterns associated with climate change (Ferdowsi & Behzadian, 2024). Urban drainage systems must be redesigned and reinforced to accommodate extreme weather events while aligning with broader climate adaptation, environmental sustainability, and urban development goals (García & Santamarta, 2022). This includes integrating robust stormwater systems, green infrastructure, and flexible designs capable of addressing both immediate flooding concerns and long-term climate challenges. Green infrastructure solutions, such as permeable pavements, bioswales, and green roofs, are vital components of these adaptive strategies. These natural approaches reduce runoff, improve water infiltration, and provide additional environmental benefits, such as enhanced air quality and recreational spaces. By complementing traditional engineering methods, green infrastructure offers a more sustainable way to manage stormwater and mitigate flooding risks.

Flood resilience in urban planning also plays a crucial role. This involves implementing zoning regulations, identifying flood-prone areas, and promoting flood-resistant construction techniques in vulnerable neighbourhoods. Improving urban landscapes to naturally absorb water and integrating flood resilience into planning processes can prevent urban development from exacerbating flooding risks. Real-time monitoring and forecasting systems further enhance flood preparedness. By tracking rainfall, drainage performance, and flood risks, municipalities can act proactively to address potential issues. Advanced forecasting tools enable early warnings and efficient resource allocation, ensuring that cities are better equipped to handle extreme weather events.

As climate change continues to alter global weather patterns, including more frequent and intense rainfall events, the demand for resilient infrastructure has never been more urgent (Leal Filho et al., 2023). Increasing rainfall intensity and the unpredictability of storm events are putting significant pressure on urban drainage systems, which were often designed based on historical weather patterns that are no longer reflective of current or future conditions (O'Neill et al., 2020). Inadequate infrastructure is not only unable to cope with the heightened frequency and volume of rainfall but also leads to increased flooding, infrastructure failure, and environmental degradation (Wang et al., 2023; He et al., 2024). Resilient infrastructure is critical to reducing the vulnerability of urban areas to these increasingly severe climate impacts (Kourtis and Tsihrintzis, 2021). Poorly managed stormwater systems lead to flooding, contamination, and the spread of waterborne diseases, all of which have far-reaching consequences for both individual and public health (Mukhtarov et al., 2019). Inadequate drainage systems can exacerbate health risks, cause injuries, and result in significant social costs, including loss of life, hospitalizations, and long-term health complications (Nguyen et al., 2024).

Community involvement is another key element of adaptive strategies. Engaging local communities in planning and implementation ensures that solutions align with local needs and priorities. Community-based disaster risk management initiatives can raise public awareness of climate risks, foster collective action, and empower residents to protect their neighbourhoods. Achieving long-term urban sustainability requires integrating climate change adaptation into all aspects of urban planning. This involves prioritising the needs of vulnerable populations, promoting equitable access to resources, and fostering environmental protection. By addressing these challenges holistically, municipalities can create cities that are not only resilient to climate change but also economically and socially sustainable. Ensuring that cities are better prepared for future climate impacts will require a combination of improved infrastructure, adaptive governance, and community involvement, all working in concert to reduce vulnerability and enhance resilience to flooding and other climate-related challenges (Yazdanfar and Sharma, 2015).

6 ACKNOWLEDGEMENTS

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reviewed paper

Condition Assessment of Cycling Infrastructure – A Step towards a Systematised Approach in Austria

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1 ABSTRACT

In Austria, regular condition assessments of roads and civil engineering structures have long been established, while cycling infrastructure has often been neglected. However, an efficient, safe, and continuous cycling infrastructure is an essential prerequisite for promoting cycling and shifting journeys to this mode of transport. There are currently considerable differences between the responsible local authorities in terms of the regularity of condition surveys, the parameters recorded, their level of detail, and the survey methods used. While regular condition assessments are planned for tourist cycle routes, such as EuroVelo routes, there is a lack of uniform and binding specifications for everyday cycling infrastructure.

Regardless of the type of cycling facility, a reliable, up-to-date, and comparable database is essential for planning, maintenance, and quality assurance. It enables the early identification of gaps in the network, infrastructural deficits, and deviations from applicable safety and design guidelines. In addition, continuous updating of the Graph Integration Platform (GIP) as the central reference system for public administration for transport infrastructure data is necessary, which requires structured and regular feedback from the responsible authorities.

Against this backdrop, a research project funded by the Austrian Road Safety Fund (VSF) investigates the development of an efficient, objective, and comparable methodology for recording cycling infrastructure. To this end, online surveys were conducted among cycling officials and GIP representatives in the federal states, and supplementary expert discussions were held. Based on 27 relevant quality and safety parameters identified in the specialist literature, ten key parameters were defined in consultation with an interdisciplinary advisory board. In addition, a concept was developed for uninterrupted, sensor-based condition surveys using a cargo bike, and criteria for a continuous cycling infrastructure were defined. Pilot applications in 2026 will serve to evaluate and further develop the methodology in terms of its practical applicability and significance.

Keywords: cycling infrastructure , condition assessment , Graph Integration Platform (GIP), Austria, mobility

2 PROBLEM STATEMENT

Recording the structural condition of roads and engineering structures on a regular basis is common practice in Austria. The approach being pursued is to use a measurement vehicle to provide a comprehensive and objective assessment of the condition of the road network. The vehicle's sensory system records the roads in flowing traffic without any traffic-restricting measures (AIT 2026). Subsequently, the various road sections are categorized based on current guidelines (IÖB 2023). This approach aims to support administrative and political decision-makers in prioritizing future road maintenance and renewal measures throughout the country. Based on the available data and its classification, it is possible to develop a program for road construction and renovation measures can be scheduled.

In contrast, this approach is only being pursued for motorized transport areas and not for cycling infrastructure. Although the importance of increased bicycle traffic for the mobility transition is recognized, the necessary bicycle infrastructure is often neglected and its condition overlooked. Despite the fact that studies on single-vehicle accidents involving cyclists related to infrastructure in Austria and Germany (Zuser

et al. 2023, Francke et al. 2024, Borsellino 2024) and experiences from Denmark show that "Surfaces for cyclists require high quality maintenance, higher than the road surface, as even a small crack or pot hole can have very serious consequences" (Eriksson 2013: 165). A study by the Transport Research Laboratory shows that infrastructural factors such as limited visibility or insufficient road grip are responsible for 26.3% of traffic accidents, while only 6.7% are attributable to vehicle-related causes (e.g. faulty braking systems) (Eriksson 2013). The vast majority of accidents (91.5%) are attributable to human factors, including excessive speed, the influence of alcohol or drugs, attention deficits and orientation problems (Eriksson 2013).

There are significant differences in terms of the regularity of condition assessment of bicycle infrastructure, the parameters measured, the level of detail of the parameters, and the survey procedure itself (with or without technical assistance) in Austria. The quality of bicycle infrastructure surveys therefore varies depending on the authority responsible and the importance given to the network section of the cycling infrastructure. For tourist cycle routes of European significance (EuroVelo), for example, regular condition assessments are necessary, but there are no generally applicable requirements for the subordinate cycling network or everyday cycling infrastructure.

Regardless of the type of cycling infrastructure, a reliable data basis for planning and maintenance is essential to identify gaps and poor-quality infrastructure (e.g., non-compliance with current road safety guidelines) at an early stage and to be able to take appropriate action. In addition, it is necessary to keep the Graph Integration Platform (GIP), the official reference system for authorities and public administrations for transport infrastructure based on a common data standard, up to date. That also means supporting local authorities in regularly reporting to the GIP officers on changes and innovations in cycling infrastructure.

To collect infrastructure information in Austria efficiently, objectively, and in a comparable manner, the requirements for an efficient infrastructure condition assessment methodology must be determined.

3 METHODOLOGICAL APPROACH AND PRELIMINARY WORK

A three-stage methodological approach was chosen to identify key quality parameters for cycling infrastructure (see Fig. 1). First, preparatory work involved conducting a comprehensive literature review and systematizing relevant quality criteria and characteristics of reported problem areas. Building on this, qualitative data was collected through discussions with stakeholders from various federal states, analysis of measurement methods used, and the involvement of an advisory board. In a third step, the results were quantitatively validated and prioritized using an online survey of 29 experts and used to derive requirements for sensor instruments. The result is a survey catalog with the ten key parameters.

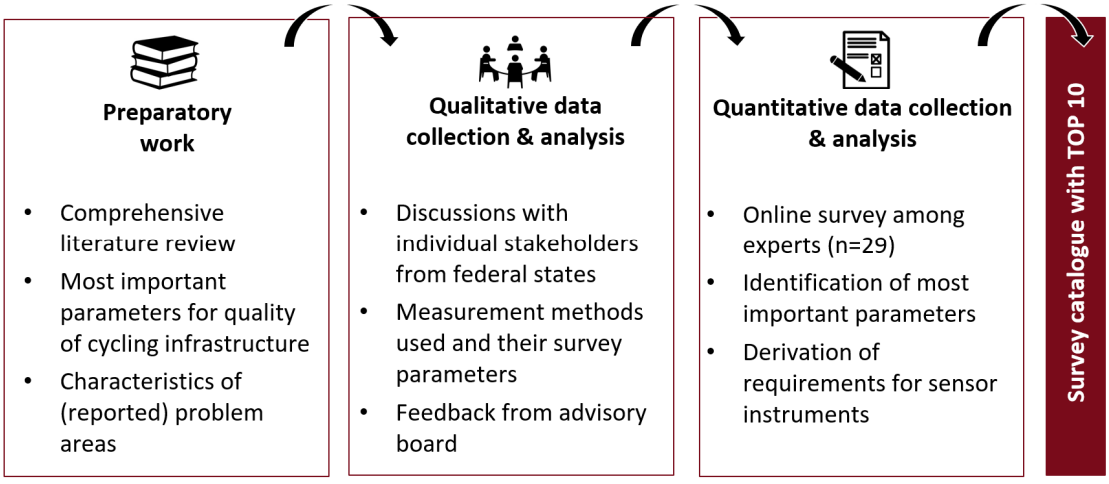


Fig. 1: Methodological approach.

To outline the initial situation, the following paragraphs briefly discuss relevant national and European preparatory work.

In Austria, several studies on the systematic evaluation of cycling infrastructure were carried out at the Institute of Transportation Sciences at the University of Natural Resources and Life Sciences in Vienna. This resulted in standardized survey and evaluation approaches using checklists (Ferstner 2020,

Schnauderer/Vavti 2022), including classification systems and analyses of administrative requirements for app-based reporting systems (Zorzi 2014). The BikeQuality app from Salzburg Research assesses cycling infrastructure based on vibrations, stopping times, and speeds during the ride (Salzburg Research 2021) without providing details on the surface characteristics, signage, markings or clearance.

At the European level, the SABRINA project (Safer Bicycle Routes in the Danube Area) investigated the safety of cycling infrastructure in the Danube region. The results show deficits compared to motorized traffic standards, particularly in terms of equipment and maintenance, and emphasize the added value of bicycle-based inspections (Fischer et al. 2022).

4 STATE-OF-THE ART OF CONDITION ASSESSMENT OF BICYCLE INFRASTRUCTURE

In February 2025, AustriaTech conducted an evaluation of safe cycling networks[1] based on data from the GIP. At the time of the analysis, the cycling network recorded in the GIP covered a total length of 18,724 km. The distribution of lane types by kilometre and federal state shows a clear dominance of roads with a maximum speed limit of ≤ 30 km/h (around 41%), followed by mixed footpaths and cycle paths (around 40%) and roads with access restrictions, except for cycle traffic (around 9.5%) (AustriaTech 2024).

In terms of the percentage distribution of cycling infrastructure across the federal states, Lower Austria leads the way with a share of 18%, followed by Styria and Vienna with 14% each. Vorarlberg is close behind with 13%, followed by Tyrol with 10% and Salzburg and Upper Austria with 9% each. Carinthia and Burgenland have the lowest share with 7% and 6% (AustriaTech 2024). Apart from the high network density in Vienna, which is due in particular to the intensive expansion of inner-city transport connections, Vorarlberg stands out as the second smallest federal state (Statistik Austria 2025) with a comparatively small area, but an above-average level of development of its cycle network.

Although these official figures and a definition of safe cycling infrastructure exist, discussions with the federal states have revealed that the term “cycling infrastructure” is not understood uniformly by the stakeholders. From a legal perspective, the different types of facilities are defined in the Road Traffic Regulations (StVO) and the Road Marking Regulations (BmVO). The guidelines and regulations for road construction (RVS) contain further conceptual distinctions: while cycle facilities comprise all areas where cycling is permitted, cycle lanes refer to those areas for which special usage regulations apply, such as multi-purpose lanes (Radlobby 2024).

It should also be noted that the importance of various cycling facilities varies from one federal state to another. In Tyrol, for example, the focus is on leisure and tourism (see Fig. 2). Accordingly, the characteristics and requirements of cyclists vary depending on whether they are using their bikes for everyday or leisure purposes, as explained in RVS 03.02.13 “Cycling”.

The federal states pursue different approaches to the assessment, expansion, financing and maintenance of cycling infrastructure. While Burgenland, Lower Austria and Tyrol carry out regular condition assessments and inspections, there is no systematic assessment in Upper Austria. Lower Austria, Carinthia and Upper Austria have clear regulations on the distribution of costs between the state and municipalities, especially for supra-regional main routes. Carinthia and Vorarlberg have established supra-regional cycle paths legally and strategically, with Vorarlberg prioritising everyday cycling and using data-based condition assessments. Salzburg and Vorarlberg also focus on everyday traffic, while Tyrol prioritises recreational cycling. Vienna records its cycling infrastructure digitally across the board using its own survey system (Kappazunder). Overall, there are significant differences in terms of responsibilities, quality standards, data bases and the strategic orientation of cycling in the federal states.

[1] A safe cycling network includes the following (cycling) infrastructure: Structured bike paths, bike paths without mandatory use, separate sidewalks and bike paths with and without mandatory use, mixed sidewalks and bike paths with and without mandatory use, bike lanes, bike crossings, multi-purpose lanes, residential streets, shared zones, cycling in pedestrian zones, cycling against one-way traffic ≤ 30 km/h, roads ≤ 30 km/h, driving ban except for bikes ≤ 50 km/h.

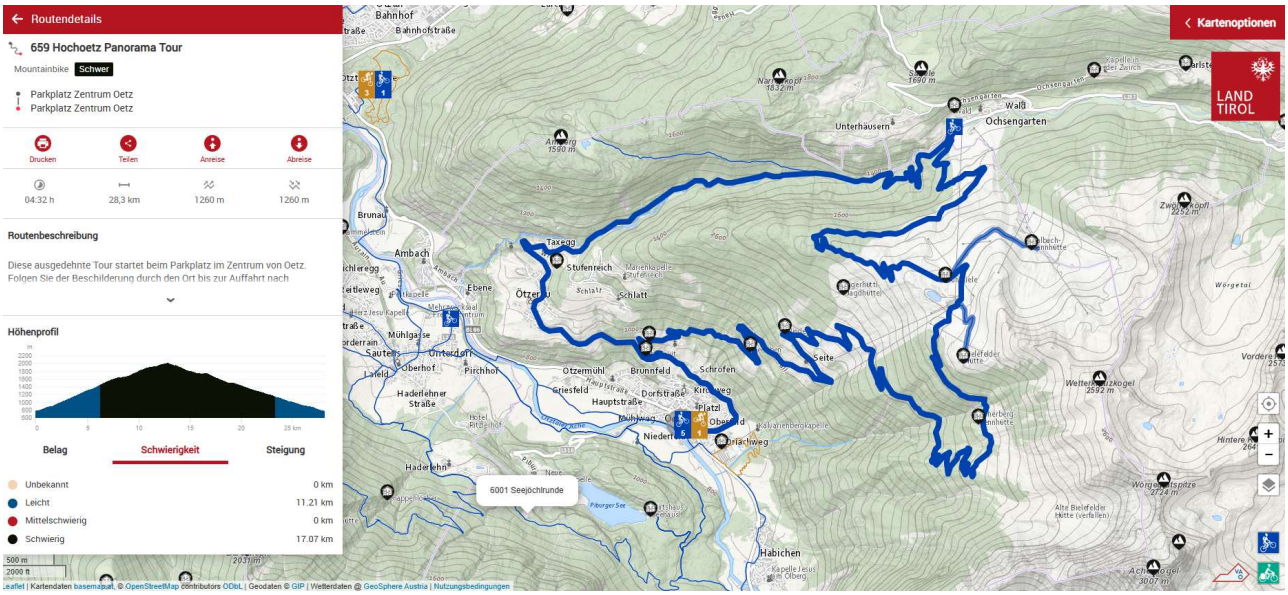


Fig. 2: Tyrol's bike route planner based on GIP data (https://radrouting.tirol/) provides a route description, an elevation profile with information on the surface type and difficulty level as well as travel time and route length.

5 DEVELOPMENT OF A SURVEY CATALOG USING EXPERT FEEDBACK

In addition to discussions with stakeholders, an online survey among experts has been conducted (16 September 2025 to 9 October 2025) to ascertain current access to status surveys of cycling infrastructure and the implementation of data in the GIP. The aim was to identify the most important parameters for condition assessment and to create a survey catalog that allows for systematic inspection of the cycling infrastructure based on these.

A total of 29 questionnaires were evaluated, 22 of which were complete and the remaining six participants answered at least half of the questions. Different questions were asked depending on the job profile, as GIP experts have a different focus than those who collect status data. The complete questionnaire consists of 13 questions. The survey reached experts from all federal states with the following distribution: Vienna – 5 persons, Burgenland – 5 persons, Tyrol – 5 persons, Upper Austria – 4 persons, Lower Austria – 3 persons, Carinthia – 2 persons, Vorarlberg – 2 persons, Styria – 2 persons, Salzburg – 1 person. In terms of the professional orientation of the survey participants, the field of geoinformation (18 mentions) leads the way, followed by bicycle traffic coordination and bicycle traffic planning (with five mentions each). Three respondents mentioned the signage of bicycle facilities, two mentioned the construction of physical facilities, and one mentioned the maintenance of physical facilities.

The survey participants responsible for cycling infrastructure were asked about the current practices for assessing the condition of cycling facilities. The most common response was an inspection without a standardised checklist followed by assessing the condition of cycle facilities by driving along them in a vehicle using a checklist. The evaluation of planning documents, driving along the route in a measuring vehicle, cycling along the route using a checklist and an inspection with a checklist are hardly according to the survey participants. Cycle paths primarily used by tourists are inspected at regular intervals in Austria (every year up to every three years). For everyday cycle paths, the frequency of inspections depends heavily on the responsible authorities and the available budget. However, problem areas are often known and are sometimes reported by the citizens. Responsibilities vary greatly between the federal states. In Vorarlberg, for example, the road maintenance authority is responsible, while in Lower Austria it is the state employees. In some federal states (e.g., Salzburg, Burgenland), it even concerns different stakeholders.

The survey of regularly recorded parameters on the condition of cycle facilities (24 answers) shows a strong focus on basic infrastructural features. A total of 27 parameters from the literature were provided for selection, and the option of entering free text was also offered (Miscellaneous). The most frequently documented aspects are surface type, signage and facility width, while structural condition, road markings and separation from other traffic areas are only taken into account by a small proportion of respondents. Numerous parameters relevant to safety and riding comfort, including gradients, obstacles, drainage, grip and

distances to parked vehicles, are not systematically recorded. In addition, other aspects such as the mere presence of cycle facilities and vegetation in the clearance profile were mentioned in isolated cases. Overall, the evaluation indicates limited and heterogeneous data collection, in which key qualitative and safety-related features are often not taken into account.

Parameter	**Entries**	**Parameter**	**Entries**
Signage (traffic signs in accordance with road traffic regulations and directional signage)	18	Longitudinal gradients	4
Type of surface paving	16	Lighting	4
Separation from other traffic areas (roads, pavements)	15	Clearance	4
Width of the cycle lane	14	Stopping points and stopping times	3
Road markings	11	Metal grilles	3
Changes in road surface	11	Distance to parked vehicles	3
Route images (front, rear and 360° panoramic camera)	11	Driving comfort (vibrations)	3
Obstacles	9	Kerbs lowered at entrances and exits	2
Hazardous areas	8	Cross slopes	2
Structural condition, including type and severity of damage	8	Drainage facilities	2
Uneven surfaces	8	Grip	2
Narrow sections	7	Curve radii	2
Sight lines	5	Miscellaneous	2
Longitudinal edges, kerb edges	5		

Table 1: Survey question “Which parameters are relevant to your daily work (planning, maintenance, transfer to the GIP)?”.

In contrast, respondents were asked which parameters would be relevant for their everyday work (see Table 1). This question was answered by 28 of the 29 respondents. The most frequently mentioned factors were: signage (18 entries), type of surface paving (16), separation from other traffic areas (15) and width of the cycle lane (14). The least frequently mentioned were: cross slopes, kerb ramps, drainage facilities, grip, curve radii, other (2 mentions each). The correct location (in the GIP) was mentioned under the category “Miscellaneous”.

Focussing on the GIP officers among the respondents, the entry of infrastructure data into the GIP was questioned with regard to the information collected as a priority and the frequency of reporting. The survey participants were asked about the types of infrastructure which are primarily included in the GIP (see Fig. 2) and the details on the cycling infrastructure available in the GIP (answered by 15 persons, question “What data is included in the GIP?”).

The minimum standard was mentioned most frequently (12 mentions), followed by “push bike” (8 mentions), “traffic restrictions for cyclists” (7 mentions), and cycle route status (7 mentions). Speed limits were mentioned only five times, difficulty five times, and obstacles twice. Accompanying paths were only an issue for one stakeholder, while details on the experience value and time restrictions for cyclists were each mentioned twice.

To verify the practical suitability of the condition assessment method prior to field testing, an advisory board was established. The advisory board consisted of national and international experts in the fields of cycling infrastructure, cycling safety, and infrastructure data, with national experts from six of Austria’s nine federal states. The ten most important metrics were determined in consultation with the advisory board of which five metrics are to be transferred to the GIP.

(1) Type of surface paving (→ GIP)

(2) Changes in road surface (→ GIP)

(3) Width of the cycle lane (→ GIP)

(4) Road markings quality including pictograms/sharrows or similar

(5) Separation from other traffic areas (roads, pavements) (→ GIP)

(6) Signage (traffic signs in accordance with road traffic regulations and directional signage) (→GIP; a facility type)

(7) Route images

(8) Longitudinal edges, kerb edges

(9) Structural condition including type and extent of damage

(10) Clearance including obstacles

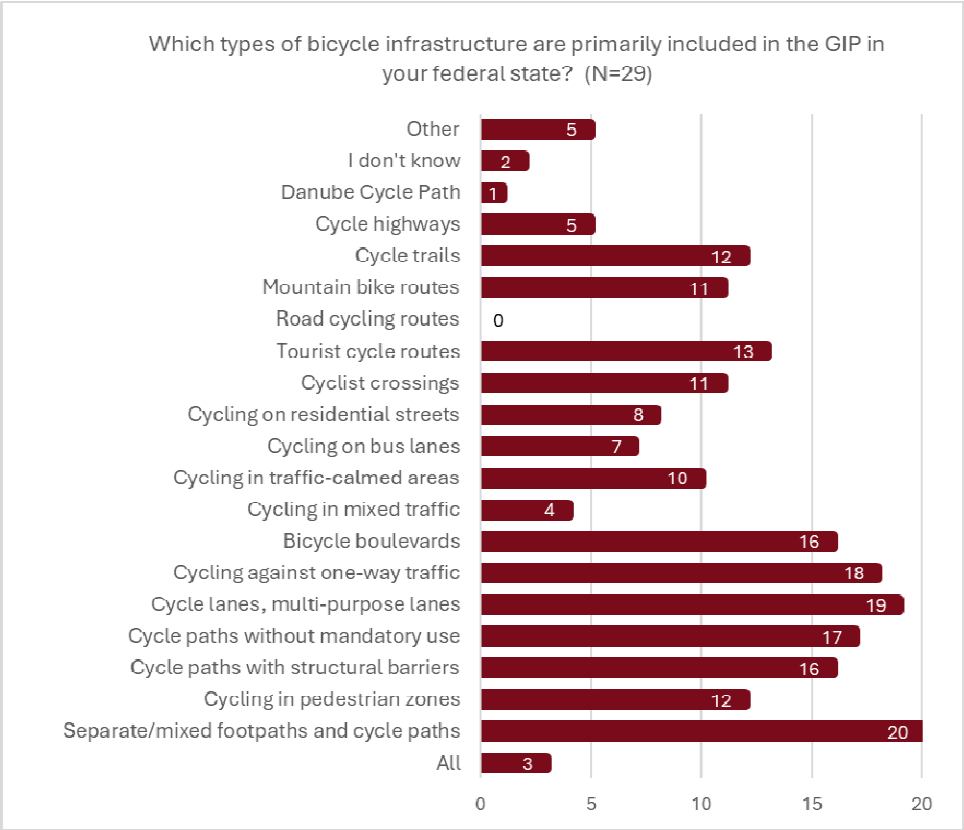


Fig. 3: Survey question "Which types of bicycle infrastructure are primarily included in the GIP in your federal state?".

During the advisory board meeting, it was suggested that on the journey, it should be possible to record signage in both directions, and the side space would also be interesting for obtaining additional information (e.g., signage obscured by vegetation). In addition, curbs and associated vibrations should be recorded at intersections, and with regard to obstacles in urban areas, cars protruding into the bicycle lane would be of interest (percentage evaluation). All elements of the survey catalog must also be described or defined in more detail, and the level of detail of the survey data must be specified.

6 TRANSFER OF SURVEY RESULTS INTO A MEASUREMENT SYSTEM

To record the parameters in a measurement run without interruptions (performed by a cargo bike due to more points of contact with the ground), basic sensor equipment has to be assembled and the level of detail for the condition assessment of cycling infrastructure has to be defined.

A survey of currently existing digitization solutions for bicycle networks shows that camera-based detection systems in combination with GPS are predominantly used. In Germany, Steffen Knab Mobility Consulting offers image-based inventory of cycling infrastructure with a focus on signage (bildbefahrung 2025), while the R4R research project expands on this approach by using additional sensors (including LiDAR and IMU) and automatically merging multimodal data (Laghbani et al. 2025). The Holocene Bike has been developed by Boréal Bikes with the following equipment: GPS, IMU, LiDAR, cameras, on-board computer, interfaces for wireless communication, electric drive (Salzburg Research 2026).

In Denmark, the "ROAD System" has been tested as a comprehensive monitoring tool that records various infrastructure and environmental parameters and visualizes them in a GIS-based dashboard (EIT Urban Mobility 2026). A simplified version uses smartphone images taken from bicycles to automatically detect road damage with high classification and positional accuracy (ROAD SYSTEM™ 2026).

CycleRAP takes a model-based approach, calculating a risk score for cycling regardless of the type of facility by taking into account infrastructure features, accident factors, and, in particular, the distance to motorized traffic (iRAP 2024).

Investigations on sensors available to collect the ten specified parameters resulted in a limitation of basic sensor equipment to the technologies described in Table 2.

Sensors	**Possible measurement parameters**
GPS	Trajectory, curve radius
IMU	Evenness, longitudinal and transverse slope
Stereo cameras	Object positioning, carriageway width, lighting, colour, parking facilities, side distances, cracks/damage
LiDAR	Carriageway width, sight lines, clearance profile, cracks/damage, kerb height, overtaking distances, side distances, speed difference during overtaking manoeuvres
Position sensor (DMU)	Distance travelled
Temperature sensors	Air temperature, carriageway temperature

Table 2: Sensors for recording various parameters.

In addition to selecting the sensory characteristics, the level of detail for the condition assessment had to be determined. The GIP standard description devotes a separate chapter to bicycle traffic and the associated special provisions, which is illustrated with various examples. The most important metrics recorded are the type of cycling infrastructure (cycle path, cycle lane, etc.), the average width, the surface (paved, unpaved, or specification), the type of crossing (intersection area). Apart from that, the assessment of comfort (experience value, difficulty), and regulations according to the StVO (time restrictions for cyclists, speed limits, pushing bikes, restricted through traffic for cyclists), lighting, traffic light control, cycle route status, and obstacles can be implemented in the GIP (ÖVDAT 2021).

The GIP standard description (ÖVDAT 2021) therefore offers a wealth of parameters in the category of bicycle traffic. The definition of road surface characteristics thus comprises 28 options, excluding the option "unknown". The level of detail causes problems when analyzing the data, which is why a simplified approach to data collection is chosen in some cases (see Table 3). In addition to the aspects mentioned in the GIP standard description, other aspects such as gaps in signage and the quality of the road surface, pictograms, and the condition of signs are relevant as well.

Parameter	**Level of detail**
Type of surface paving	Gravel, asphalt, concrete, paving stones, terrain
Changes in road surface	-
Width of the cycle lane	Accurate to ≤ 10 cm
Road markings availability/quality	All markings including pictograms, sharrows; Categories: okay/monitor/replace
Separation from other traffic areas	Infrastructural separation (roads, pavements)
Signage	Existence and condition of signage compliant with traffic regulations and directional signage; Categories: okay/monitor/replace; Identification of gaps in signage
Route images	Front and rear images
Longitudinal edges, kerb edges	Existence and location
Structural condition including type and extent of damage	Identification of cracks etc.; Categories: okay/monitor/replace
Clearance including obstacles	Occurrence and location

Table 3: Level of detail in the collection of various parameters.

Furthermore, criteria were established that a "continuous cycling infrastructure" should meet. This definition incorporated aspects such as adequate directional signage, clear indication of the type of facility through road markings and traffic signage, cycle-specific routing at junctions (cycle crossings, etc.), clear separation/mixing with other road users, and passage (bottlenecks, obstacles). Furthermore, it has been solved from a technical perspective how gaps (e.g., in signage) or bottlenecks (e.g., due to vegetation) are to be dealt with during the inspection.

7 CONCLUSIONS AND OUTLOOK

Safe and attractive cycling infrastructure is a key factor in driving forward the mobility transition. Systematic assessment of the condition of cycling infrastructure is therefore essential. To assist those responsible, the parameters to be collected as standard and the intervals at which they should be collected were identified and this approach was compared with actual requirements. A literature review, an online expert survey as well as discussions with experts and the feedback of an advisory board were used to achieve a systematic approach to assessing the state of cycling infrastructure.

A total of ten parameters were identified that should be collected in order to adequately assess the condition of cycling infrastructure and five of them that provide the necessary data for the GIP implementation: type of surface paving, changes in road surface, width of the cycle lane, road markings quality including pictograms/sharrows or similar, separation from other traffic areas (roads, pavements), signage (traffic signs in accordance with road traffic regulations and directional signage), route images, longitudinal edges/kerb edges, structural condition including type and extent of damage, clearance including obstacles.

Based on the parameters to be collected, suitable sensor technologies were identified and the required level of detail for data collection was determined. As part of sample surveys of various cycling infrastructures starting in Spring 2026, potential weaknesses in the methodology for condition assessment, the sensor technology used, and data processing will be identified. The aim is to verify and ensure the practicality and robustness of the chosen approach to condition assessment.

A total of around 150 km of cycling infrastructure in Austria will be examined. The surveys will be carried out on different types of infrastructure and in several federal states. There is no minimum length for the individual sections; rather, the sections examined should be as diverse as possible in order to comprehensively evaluate the suitability of the measurement methodology and the subsequent data analysis. The collected data will be integrated into the GIP in cooperation with the respective GIP officers of the federal states concerned. The results of the survey will be presented to the advisory board and their feedback will be incorporated into the survey catalog and the list of recommendations for efficient surveying.

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reviewed paper

Constitutional Energy Mandates and Local Governance in Post-Apartheid Spatial Planning

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1 ABSTRACT

South Africa's post apartheid positions municipalities as key actors in the provision of basic services, including electricity. Section 156 and Schedule 4B of the Constitution empower local governments to govern electricity reticulation within their jurisdictions, granting them original authority independent of national or provincial delegation. This legal empowerment has significant implications for spatial planning, especially in historically marginalised regions like De Aar in the Northern Cape. However, the energy governance landscape is populated by multiple institutions with overlapping mandates. The Department of Mineral Resources and Energy (DMRE), though not constitutionally empowered, plays a central role in policy formulation and regulation through the Electricity Regulation Act. Eskom, a state-owned enterprise, dominates generation and transmission, operating under executive mandate and regulatory oversight. These institutional arrangements create tensions between constitutional decentralisation and centralised energy control. This article investigates how constitutional energy mandates are interpreted and operationalised at the municipal level, and how these dynamics shape spatial planning outcomes. Using De Aar as a case study, the research draws on spatial theory, energy justice, and systems theory to analyze the feedback loops between law, infrastructure, and governance. A qualitative methodology is employed, including document analysis of legal frameworks, municipal Integrated Development Plans (IDPs), and interviews with local officials.Findings reveal that while municipalities are legally empowered to provide electricity, their capacity to do so is constrained by technical limitations, fiscal dependency, and regulatory ambiguity. The recent amendments to the Electricity Regulation Act, which allows municipalities to procure power from independent producers, have opened new opportunities but also intensified institutional friction. Municipalities often lack grid access, planning tools, and intergovernmental support needed to translate legal mandates into spatial energy outcomes. The case of De Aar illustrates how constitutional ideals of decentralisation are challenged by systemic bottlenecks and institutional fragmentation. Spatially, this results in uneven infrastructure deployment, limited integration of renewable energy into local development plans, and a disconnect between national energy priorities and local realities. The article argues for a more coherent, capacitated, and collaborative approach to energy governance, one that aligns constitutional mandates with spatial planning and climate adaptation strategies.

Keywords: Constitutional Mandate, Energy Justice, Institutional Tensions, Renewable Energy Transitions, Post Apartheid South Africa

2 INTRODUCTION

South Africa's post-apartheid Constitution, adopted in 1996, enshrines a developmental vision for local government that includes the provision of basic services, promotion of socio-economic development, and facilitation of sustainable human settlements. Section 152 outlines the objectives of local government, while Section 156 and Schedule 4B explicitly empower municipalities to govern electricity reticulation within their jurisdictions (Republic of South Africa, 1996). These provisions grant municipalities original authority, meaning they do not require delegation from national or provincial governments to plan, manage, and deliver electricity services. This constitutional empowerment is particularly significant in the context of South Africa's energy transition, where decentralisation and renewable energy integration are increasingly prioritised. However, the practical realisation of these mandates is shaped by a complex institutional landscape. The Department of Mineral Resources and Energy (DMRE), though not constitutionally empowered, plays a central role in national energy policy and regulation through instruments such as the Integrated Resource Plan (IRP) and the Electricity Regulation Act (2006). Eskom, a state-owned enterprise, retains control over most generation and transmission infrastructure, creating a vertically integrated monopoly that often limits municipal autonomy. The National Energy Regulator of South Africa (NERSA) oversees licensing and tariff regulation, further complicating the governance terrain. These overlapping mandates produce tensions between constitutional decentralization and centralized energy control, particularly in municipalities with limited technical and financial capacity (Ngcobo, 2024; Tyler &

Hochstetler, 2021) Spatial governance, the coordination of land use, infrastructure, and development across space is a critical lens through which to examine these dynamics. In South Africa, spatial planning has historically been used as a tool of exclusion, with apartheid-era policies producing fragmented urban forms and unequal access to services (Harrison et al., 2008). Post-apartheid reforms have sought to redress these legacies through integrated development planning, yet energy infrastructure remains unevenly distributed, especially in arid and rural regions. The integration of renewable energy into municipal spatial plans presents both an opportunity and a challenge: it requires alignment between constitutional mandates, planning instruments, and infrastructure systems. This article investigates how constitutional energy mandates are interpreted and operationalised at the local level, and how these processes shape spatial planning outcomes in the context of South Africa's energy transition. Using De Aar, a small town in the Northern Cape Province as a case study, the research explores the intersection of legal empowerment, institutional coordination, and spatial governance. De Aar is emblematic of many secondary towns in South Africa: it faces infrastructural constraints, socio-economic marginalization, and increasing pressure to participate in climate adaptation and renewable energy initiatives. The central research question guiding this inquiry is: How does the Constitution empower local governments to provide electricity, and how does this shape spatial outcomes in the context of South Africa's energy transition? By integrating spatial theory, energy justice, and systems theory, the article aims to illuminate the feedback loops between law, infrastructure, and governance, and to contribute to a more nuanced understanding of post-apartheid energy planning.

3 LITERATURE REVIEW

3.1 Theoretical Frameworks in Energy and Spatial governance

(a) Spatial Theory: Production and Relationality of Space

Henri Lefebvre's The Production of Space (1991) remains foundational in understanding how space is socially produced through political, economic, and ideological processes. Lefebvre argues that space is not a passive backdrop, but an active medium shaped by power relations and institutional arrangements. His triadic framework: perceived, conceived, and lived space, offers a lens to examine how energy infrastructure reflects and reproduces spatial inequalities (Lefebvre, 1991; Molotch, 1993). In the South African context, energy infrastructure such as grid networks and renewable installations are often deployed in ways that reinforce historical spatial marginalisation, particularly in secondary towns like De Aar. Doreen Massey's relational spatiality complements Lefebvre's work by emphasizing that space is constituted through interactions across scales: local, regional, national, and global. Her concept of "power-geometry" highlights how different actors experience space differently based on their mobility, access, and agency (Massey, 2004; Taylor, 2024). In energy governance, this means that municipalities, despite constitutional empowerment, may be spatially constrained by limited grid access, planning tools, and institutional support. Massey's framework helps unpack how spatial marginality intersects with energy exclusion, reinforcing uneven development and governance asymmetries. Together, Lefebvre and Massey provide a robust theoretical foundation for analyzing how energy infrastructure both shapes and is shaped by spatial planning, governance, and socio-political dynamics.

(b) Energy Justice: Distributive, Procedural, and Recognition Dimensions

Energy justice has emerged as a critical framework for evaluating fairness in energy systems. Sovacool and Dworkin (2015) define energy justice through three core tenets:

- Distributive justice: Ensures equitable access to energy services and infrastructure. In South Africa, this is challenged by affordability barriers, unreliable supply, and geographic disparities in infrastructure deployment.
- Procedural justice: Advocates for inclusive and transparent decision-making processes. Municipalities and communities often lack meaningful participation in national energy planning, undermining democratic governance.
- Recognition justice: Calls for acknowledging the specific needs, identities, and vulnerabilities of marginalised groups. Spatially remote towns like De Aar require tailored governance approaches that reflect their socio-economic and geographic realities (Jenkins et al., 2016; Scholz & Schuppert, 2025).

Energy justice reframes energy transitions not merely as technical or economic challenges, but as ethical and political imperatives. Applying this lens to South Africa reveals systemic gaps between legal empowerment and lived energy outcomes, particularly in historically disadvantaged regions.

(c) Systems Theory: Feedback Loops and Governance Complexity

Systems theory offers a powerful analytical tool to understand the complexity of energy governance. Donella Meadows (2008) describes systems as composed of interconnected elements that produce patterns of behavior over time. Key concepts include feedback loops, delays, leverage points, and resilience. In energy governance, systems theory helps visualize how legal mandates, planning tools, infrastructure deployment, and service delivery interact dynamically, often producing unintended consequences, for an example, a municipality's legal authority to reticulate electricity (input) may be constrained by lack of technical capacity (system bottleneck), resulting in poor service delivery (output) and reinforcing centralised control (feedback). Radtke (2025) expands this by applying systems thinking to institutional design, showing how fragmented mandates and siloed planning inhibit adaptive governance. In De Aar, systems mapping reveals how decentralisation is constrained by technical bottlenecks, fiscal dependency, and fragmented intergovernmental coordination. Systems theory thus enables a holistic understanding of governance complexity and identifies leverage points for reform such as enhancing municipal planning tools or streamlining regulatory processes

3.2 Energy Governance in South Africa: Centralisation, Reform, and Emerging Complexity

South Africa's energy governance has long been characterised by centralised control, with Eskom historically monopolising electricity generation and transmission. Established in 1923, Eskom remains the dominant actor in the energy landscape, responsible for over 90% of electricity generation and the operation of the national grid (Eberhard et al., 2017). This centralisation has contributed to systemic inefficiencies, financial instability, and persistent load shedding, prompting calls for structural reform. The Department of Mineral Resources and Energy (DMRE), though not constitutionally mandated to oversee local electricity reticulation, plays a pivotal role in national energy policy formulation. Its influence is institutionalised through the Electricity Regulation Act No. 4 of 2006, which empowers the Minister to determine new generation capacity and procurement processes (Trollip & Boulle, 2017). The National Energy Regulator of South Africa (NERSA), established under the National Energy Regulator Act of 2004, regulates tariffs, licensing, and compliance, further reinforcing centralised oversight (NERSA, 2024). Recent amendments to the Electricity Regulation Act, most notably the Electricity Regulation Amendment Act No. 38 of 2024 have introduced mechanisms for municipalities to procure electricity directly from Independent Power Producers (IPPs). This reform aims to decentralise procurement authority, enhance competition, and reduce reliance on Eskom (Esterhuizen et al., 2025). However, implementation remains uneven. Municipalities face significant barriers, including limited grid access, technical capacity constraints, and regulatory ambiguity. Eskom retains control over grid infrastructure, and municipalities must navigate complex licensing and compliance procedures through NERSA and DMRE (SALGA, 2024). This institutional arrangement creates a governance paradox: while municipalities are constitutionally empowered under Section 156(1)(a) and Schedule 4B of the Constitution of the Republic of South Africa (1996) to govern electricity reticulation, they remain structurally dependent on national actors for infrastructure, funding, and regulatory approval (De Visser, 2009). The result is a fragmented energy landscape where decentralisation is legally affirmed but practically constrained. Municipalities like De Aar, despite hosting renewable energy projects, struggle to integrate these into local development plans due to limited planning tools and intergovernmental coordination gaps (Tyler & Haysom, 2021; Borchardt, 2023).This complexity underscores the need for a more coherent and capacitated governance framework, one that aligns constitutional mandates with operational realities and supports municipalities in fulfilling their developmental role in energy transitions

3.3 Post-Apartheid Spatial Planning and the Challenge of Integration

Spatial planning in South Africa has been tasked with redressing the entrenched inequalities produced by apartheid-era urban design. Under apartheid, planning was used as a tool of exclusion, systematically segregating communities and concentrating infrastructure investment in historically white urban cores. This resulted in fragmented urban landscapes, peripheral settlements with poor service access, and spatially embedded socio-economic disparities (Harrison et al., 2008; Todes, 2012). In response, post-apartheid

reforms introduced Integrated Development Plans (IDPs) and Spatial Development Frameworks (SDFs) as instruments to coordinate land use, infrastructure investment, and inclusive development. These tools are mandated by the Municipal Systems Act (2000) and are intended to align municipal planning with national development priorities. However, the integration of energy infrastructure, particularly renewable energy into these instruments, remains limited. Municipalities often lack the technical capacity, financial resources, and institutional support to embed energy transitions into spatial planning processes (Van Niekerk et al., 2020; Sutherland et al., 2022).

Secondary towns like De Aar face compounded challenges. These include low revenue bases, limited professional planning staff, and fragmented land governance systems. As a result, municipalities struggle to incorporate renewable energy strategies into their IDPs and SDFs, despite growing pressure to participate in climate adaptation and energy transition initiatives (Gordon et al., 2020; Cartwright et al., 2021). Moreover, national energy priorities such as those articulated in the Integrated Resource Plan (IRP) often bypass local spatial realities. Energy infrastructure projects are typically sited based on technical criteria such as solar irradiance or grid proximity, with limited consideration of local development plans or community needs (Tyler & Hochstetler, 2021). This top-down approach results in spatial mismatches between infrastructure deployment and socio-economic imperatives, undermining the potential for energy transitions to contribute meaningfully to spatial justice. In De Aar, for example, the presence of multiple solar farms has not translated into significant local development benefits. The town continues to experience high unemployment, limited delivery, and infrastructural deficits. The disconnect between energy investment and spatial planning reflects a broader governance gap: while municipalities are constitutionally empowered to govern electricity reticulation, they are rarely included in strategic energy planning processes. This exclusion reinforces historical patterns of marginalisation and limits the transformative potential of energy transitions. Addressing these challenges requires a more integrated and participatory approach to spatial planning, one that aligns constitutional mandates with energy governance frameworks and recognizes the agency of municipalities in shaping climate-resilient futures. It also demands a rethinking of planning instruments to accommodate the complexity of energy transitions, including land use coordination, grid access negotiation, and community engagement.

3.4 Municipal Mandate and the limits of Local Empowerment

The Constitution of the Republic of South Africa (1996) grants municipalities original powers to govern electricity reticulation, positioning them as central actors in service delivery and local development. Section 156(1)(a) and Schedule 4B explicitly assign electricity reticulation to local government, affirming their authority to plan, manage, and deliver electricity services within their jurisdictions (Republic of South Africa, 1996). This legal empowerment reflects the broader post-apartheid commitment to decentralisation and developmental local government. However, the practical realisation of these mandates is often undermined by systemic constraints. Many municipalities operate with limited financial autonomy, relying heavily on national transfers and struggling to generate own revenue through tariffs and property rates (Steytler & De Visser, 2018). Technical capacity is also unevenly distributed, with smaller and rural municipalities lacking the engineering, planning, and legal expertise required to engage in complex energy procurement or infrastructure development (Mosdell, 2016; SALGA, 2021). Institutional fragmentation further complicates implementation, as municipalities must navigate overlapping responsibilities with Eskom, the Department of Mineral Resources and Energy (DMRE), and the National Energy Regulator of South Africa (NERSA). The Presidential Climate Commission's Municipal Just Energy Transition (JET) Support Programme acknowledges these challenges and aims to build municipal capacity for renewable energy integration, climate adaptation, and inclusive development. The programme provides technical assistance, policy guidance, and stakeholder engagement platforms to enable municipalities to participate meaningfully in South Africa's energy transition (Presidential Climate Commission, 2023). However, its success depends on resolving longstanding tensions between municipalities and Eskom, particularly around grid access, infrastructure control, and revenue collection. Eskom's continued dominance in generation and transmission, coupled with its control over distribution in many areas, limits the ability of municipalities to exercise their constitutional authority. Municipalities often face delays in obtaining grid connection approvals, lack visibility into infrastructure planning, and struggle to negotiate equitable power purchase agreements with Independent Power Producers (IPPs) (Mohlakoana & Wolpe, 2023). These tensions are exacerbated by Eskom's financial instability and its reluctance to relinquish control over strategic assets.

Municipalities like De Aar exemplify the disconnect between constitutional authority and operational feasibility. Despite being legally empowered to govern electricity reticulation, De Aar faces infrastructural neglect, limited planning capacity, and exclusion from strategic energy decision-making. The town hosts several solar farms, yet local benefits remain minimal due to weak integration with spatial planning and limited municipal involvement in project design and implementation (Sutherland et al., 2022). This case illustrates how spatial marginalisation and institutional bottlenecks constrain the transformative potential of constitutional mandates. Addressing these challenges requires a multi-pronged approach: strengthening municipal capacity through targeted investment and training; clarifying intergovernmental roles and responsibilities, and reforming regulatory frameworks to enable local energy autonomy. It also demands a shift in governance culture, from top-down control to collaborative, place-based planning that recognizes municipalities as legitimate and capable actors in South Africa's energy future.

3.5 Comparative Reflections: South Africa and Global Experiences in Municipal Energy Governance

The constitutional framework of South Africa bestows municipalities with original authority over electricity reticulation, establishing them as pivotal participants in local energy transitions (Ngcobo, 2024). Nonetheless, as demonstrated by the De Aar case, this legal empowerment is frequently compromised by infrastructural limitations, inadequate planning capabilities, and intergovernmental conflicts (SALGA, 2017). These challenges are not exclusive to South Africa; however, they manifest differently in various global contexts: The European Energy Award (EEA) is a structured framework that supports interdisciplinary planning and continuous improvement in energy and climate policy, which is advantageous to municipalities in Europe. The EEA is a program in which more than 1,800 local authorities in Switzerland, Germany, Austria, and Romania participate, ensuring that local action is in accordance with the climate goals of the EU and the national government (European Energy Award, 2025; SECO, 2020). Cities such as Judenburg in Austria are prime examples of successful multilevel governance. They were able to expand district heating systems and improve spatial energy planning through coordinated planning at the local, regional, and national levels (Dobravec et al., 2021). South Africa's municipal energy landscape is largely devoid of technical advisors, certification mechanisms, and benchmarking tools, which are essential components of these systems. Brazil's 1988 Constitution similarly empowers municipalities, but implementation has been uneven due to fiscal and technical constraints (Souza, 2001). India's Panchayati Raj system decentralises rural governance, yet energy planning remains largely centralised, limiting local agency (Bhattacharyya, 2013). Germany, by contrast, exemplifies successful decentralisation through its Energiewende, where municipalities and citizen cooperatives play active roles in renewable energy deployment (Morris & Jungjohann, 2016). In the Global South, municipalities encounter comparable obstacles, limited capacity, fragmented land governance, and infrastructural deficits, but have responded by implementing adaptive governance and policy innovation. Participatory planning, digital citizen engagement, and localised renewable energy initiatives have been implemented in cities in India, Brazil, and Kenya. These initiatives are frequently supported by transnational networks such as the Global Covenant of Mayors and C40 Cities (Williamson, 2023; Blanc & Cotella, 2023). These strategies prioritise context-sensitive adaptation, community involvement, and flexibility, which are principles that are in alignment with South Africa's requirement for place-based energy governance. South Africa is characterized by the discord between its progressive legal framework and its centralized infrastructural reality. The Constitution establishes a robust basis for municipal autonomy; however, the execution of energy mandates is inconsistent. The contrast with European and Global South experiences underscores the necessity for South Africa to cultivate hybrid governance models that incorporate legal empowerment with institutional support, spatial integration, and systems thinking.

3.6 Gaps in Current Scholarship

Despite a growing body of literature on energy transitions, climate governance, and spatial planning in South Africa, several critical gaps persist particularly in relation to the constitutional role of municipalities and the spatial dynamics of energy infrastructure. These gaps limit the ability of scholars and policymakers to understand and address the uneven geography of energy transitions, especially in secondary towns like De Aar.

(a) Limited Focus on Secondary Towns

Much of the existing scholarship focuses on metropolitan municipalities such as Cape Town, Johannesburg, and eThekwini, which have greater institutional capacity, access to funding, and visibility in national policy debates (Sutherland et al., 2022; Cartwright et al., 2021). These cities have piloted renewable energy projects, developed climate adaptation strategies, and engaged with international networks. In contrast, smaller municipalities, located in arid, and economically marginalised regions, remain under-researched despite facing distinct challenges: limited grid access, fragmented land governance, and constrained planning capacity. De Aar, situated in the Northern Cape, exemplifies these dynamics. It hosts several solar farms under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), yet local development benefits remain minimal. The lack of scholarly attention to such towns obscures the spatial inequalities embedded in South Africa's energy transition and limits the development of place-based policy responses.

(b) Insufficient Integration of Legal and Spatial Analysis

While there is robust legal scholarship on constitutional mandates and municipal autonomy (Steytler & De Visser, 2018; Ngcobo, 2024), and a parallel body of work on spatial planning and infrastructure development (Harrison et al., 2008; Todes, 2012), few studies bridge these domains. This siloed approach overlooks how legal empowerment such as the constitutional authority over electricity reticulation translates into spatial planning outcomes. For instance, municipalities may be legally entitled to govern electricity services, but without integration into spatial development frameworks, these mandates remain abstract. The disconnect between law and spatial practice contributes to fragmented infrastructure deployment, poor alignment with community needs, and missed opportunities for climate adaptation.

(c) Underutilisation of Systems Theory

Systems theory offers a powerful lens for understanding the interdependencies between governance structures, infrastructure networks, and spatial outcomes. It emphasizes feedback loops, emergent properties, and adaptive capacity, concepts highly relevant to energy transitions and climate resilience (von Bertalanffy, 1968; Capra & Luisi, 2014). Yet, its application in South African energy and spatial planning literature remains limited. Most studies adopt sectoral or linear approaches, focusing on policy implementation, technical feasibility, or institutional reform in isolation. This neglects the complex, multi-scalar interactions that shape energy spatiality, such as how national policy filters through provincial structures, interacts with municipal planning tools, and is mediated by infrastructure constraints. Applying systems theory can illuminate these dynamics and support more integrated, adaptive governance models.

Contribution of this article

This article addresses these gaps by offering a place-based analysis of energy governance in De Aar. It integrates constitutional law, spatial planning, and systems theory to illuminate the constructed spatiality of energy transitions in post-apartheid South Africa. By focusing on a secondary town, it foregrounds the lived realities of decentralisation, infrastructural inequality, and institutional tension. It also demonstrates how legal mandates interact with spatial planning instruments and infrastructure systems to produce uneven energy outcomes thereby contributing to both scholarly understanding and policy innovation.

4 METHODLOGY

This study employs a qualitative case study approach to investigate how constitutional energy mandates are interpreted and operationalized at the municipal level, and how these processes shape spatial planning outcomes in the context of South Africa's energy transition. The case of De Aar, a secondary town in the Northern Cape was selected due to its strategic location within the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) and its spatial marginalization within national development frameworks.

4.1 Research Design

A single-case embedded design was adopted, allowing for in-depth exploration of governance dynamics, planning instruments, and institutional interactions within De Aar (Yin, 2018). The study integrates legal analysis, spatial planning review, and stakeholder perspectives to construct a multi-scalar understanding of energy governance.

4.2 Data Collection

The study used document analysis, semi-structured interviews, and systems mapping. Documents included legal frameworks, municipal plans, and energy policy reports to triangulate mandates and institutional roles. Interviews with municipal officials, provincial coordinators, consultants, and community stakeholders explored planning, coordination, and implementation barriers. Systems mapping as shown in figure 1 below, visualized institutional relationships and feedback loops, guiding analysis of multi-scalar governance interactions and spatial outcomes in De Aar.

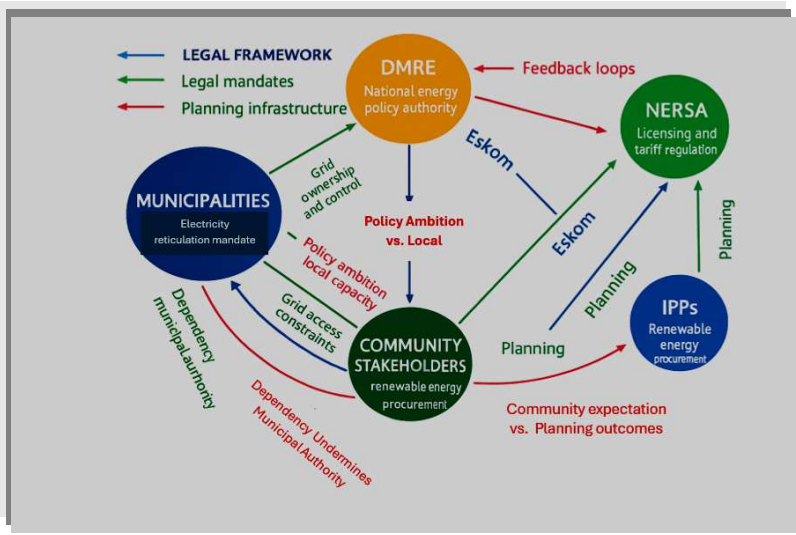


Fig 1: Interactions and feedback loops in South Africa's Local Energy Governance Seystems

Spatial mapping of energy infrastructure and planning zones was conducted using publicly available GIS data and municipal records. Figure to illustrate the spatial mapping of renewable energy around Emthanjeni Local Municipality.

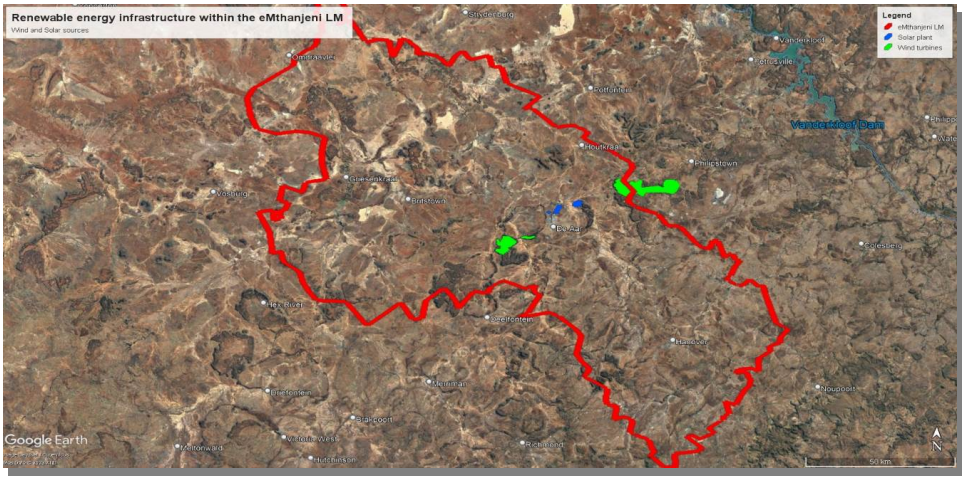


Fig 2: Renewable energy Infrastructure within the Emthanjeni Local Municipality. Source: (Emthanjeni Environmental profile, 2024)

4.3 Data Analysis

The study used thematic coding of interviews and planning documents, supported by NVivo, combining deductive and inductive analysis. Findings show a clear gap between municipal legal authority and operational capacity. Although the Constitution empowers municipalities to manage electricity reticulation, Emthanjeni Municipality lacks the technical skills, financial resources, and planning tools to fulfil this mandate. This reflects deeper institutional weaknesses in South Africa's developmental local government system. Energy governance in De Aar is further constrained by institutional fragmentation. Eskom's control of grid infrastructure and the involvement of multiple national regulators create coordination challenges, regulatory delays, and limited municipal autonomy. While recent legislation allows municipalities to procure electricity independently, practical barriers such as grid access and licensing continue to inhibit implementation. These governance failures have significant spatial and social consequences. Renewable energy projects in De Aar are poorly integrated into local planning and offer limited benefits to local

communities, reinforcing spatial inequality and undermining principles of energy justice. Residents face affordability challenges, unreliable supply, and exclusion from decision-making processes. From a systems perspective, weak alignment between legal mandates, planning instruments, and infrastructure control creates reinforcing feedback loops that entrench centralisation and municipal underperformance. Addressing these systemic bottlenecks requires targeted reforms. Recent policy changes present emerging opportunities, but real decentralisation will depend on strengthened municipal capacity, clearer regulatory roles, improved grid access, and stronger intergovernmental coordination. Without these measures, municipal energy autonomy will remain largely symbolic

5 FINDINGS AND DISCUSSIONS

This section presents the key findings from thematic coding of municipal documents, interviews with local officials, and analysis of planning instruments. It responds to the methodological approach outlined earlier, which combined qualitative document analysis with systems mapping to uncover governance dynamics in De Aar.

5.1 Legal Empowerment vs Operational Reality

The Constitution of South Africa clearly empowers municipalities to govern electricity reticulation under Section 156(1)(a) and Schedule 4B. Emthanjeni Municipality, which governs De Aar, is thus legally entitled to plan and deliver electricity services. However, this empowerment is undermined by operational constraints. Interviews with municipal officials and analysis of the Integrated Development Plan (IDP) reveal that while the municipality acknowledges its mandate, it lacks the technical capacity, financial resources, and planning tools to execute it effectively (Borchardt, 2023; Van Wyk, 2012). The disconnect between legal authority and practical capability reflects what De Visser (2009) calls “institutional fault lines” in developmental local government. Municipalities are expected to be developmental agents, yet they operate within a system that centralises infrastructure control and limits fiscal autonomy.

5.2 Institutional Friction and Fragmentation

The systems mapping of De Aar’s energy governance reveals significant institutional friction. Eskom retains control over grid infrastructure, and municipalities must seek approval from NERSA and DMRE to procure power from Independent Power Producers (IPPs). These actors operate under different mandates and timelines, creating coordination gaps and regulatory ambiguity (Trollip & Boulle, 2017; Tyler & Haysom, 2021). For example, while the Electricity Regulation Amendment Act (2024) allows municipalities to procure power independently, Emthanjeni Municipality struggles to access the grid and navigate licensing procedures. This friction delays project implementation and discourages local innovation. The result is a fragmented governance landscape where decentralisation is legally affirmed but practically constrained.

5.3 Spatial Outcomes and Energy Justice

Spatially, the consequences of this fragmentation are profound. De Aar hosts several large-scale renewable energy projects under REIPPPP, yet these are rarely integrated into local development plans. The municipality has limited influence over project siting, grid connection, or benefit-sharing mechanisms. As a result, energy infrastructure is deployed in ways that bypass local planning and perpetuate spatial inequality (Harrison et al., 2008; SACN, 2015). From an energy justice perspective, this undermines distributive, procedural, and recognition justice. Households in De Aar face affordability barriers, unreliable supply, and exclusion from decision-making. The municipality’s inability to reticulate locally generated renewable energy reflects a broader failure to align infrastructure with community needs and constitutional ideals.

5.4 Feedback Loops and Systemic Bottlenecks

Systems theory helps illuminate the feedback loops that reinforce these challenges. Legal mandates feed into planning tools (IDPs and SDFs), which should guide infrastructure deployment. However, when infrastructure is controlled by external actors, service delivery suffers, and policy feedback is weak. This loop perpetuates underperformance and centralised control. In De Aar, the lack of grid access, technical expertise, and intergovernmental support creates systemic bottlenecks. These are not isolated issues but structural features of South Africa’s energy governance system. Reforming this system requires identifying

leverage points such as enhancing municipal planning capacity, clarifying regulatory roles, and fostering collaborative platforms.

5.5 Emerging Opportunities and Reform Pathways

Despite these challenges, recent reforms offer new opportunities. The Electricity Regulation Amendment Act (2024) and growing interest in distributed generation create space for municipalities to assert their authority. Emthanjeni Municipality could leverage its constitutional mandate to develop local energy strategies, engage IPPs, and integrate energy into spatial planning. However, this requires support. National government must invest in municipal capacity-building, streamline regulatory processes, and facilitate grid access. Intergovernmental forums should be established to align energy and spatial planning across spheres. Without these reforms, decentralisation will remain a constitutional promise rather than a practical reality. Figure 3 below illustrates the systemic interactions in South Africa's local energy governance. It highlights how constitutional mandates for municipal electricity reticulation are undermined by affordability crises and household exclusion (Observed Constraints), while external infrastructure control creates bottlenecks between local planning and implementation (Mandates vs. Local Implementation). The feedback loops visually reinforce the findings in Sections 5.1–5.5, showing how legal empowerment, institutional friction, spatial inequality, and systemic bottlenecks converge to shape energy justice outcomes in De Aar.

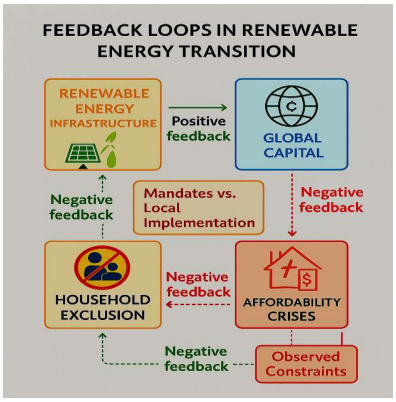


Fig 3: Feedback Loops in Renewable Energy Transition

The diagram provides a unifying visual anchor for findings. In Section 5.1 (Legal Empowerment vs Operational Reality), the annotation "Mandates vs. Local Implementation" illustrates the gap between constitutional authority and municipal capacity, showing how exclusionary feedback loops weaken the execution of electricity reticulation. In Section 5.2 (Institutional Friction and Fragmentation), the negative arrows highlight how external actors such as Eskom, NERSA, and DMRE constrain municipal autonomy, reinforcing the institutional fault lines described in the literature. In Section 5.3 (Spatial Outcomes and Energy Justice), the Household Exclusion loop visually represents distributive and recognition injustices, where affordability crises perpetuate spatial inequality and bypass local planning. In Section 5.4 (Feedback Loops and Systemic Bottlenecks), the diagram itself embodies the systemic bottlenecks: weak policy feedback, affordability barriers, and exclusion cycles that entrench underperformance. Finally, in Section 5.5 (Emerging Opportunities and Reform Pathways), the map highlights leverage points for reform, suggesting that breaking negative loops and strengthening positive ones could enable municipalities like Emthanjeni to align constitutional mandates with practical delivery. By weaving through each subsection, the diagram responds directly to the empirical findings, transforming a methodological tool into a lens for interpreting governance realities and reform pathways.

6 CONCLUSION AND RECOMMENDATIONS

This study has examined how constitutional energy mandates are interpreted and operationalised at the municipal level in post-apartheid South Africa, using De Aar as a case study. Drawing on spatial theory, energy justice, and systems thinking, the research reveals a persistent gap between legal empowerment and practical implementation. While Emthanjeni Local Municipality is constitutionally authorised to govern electricity reticulation, its capacity to do so is constrained by technical limitations, fiscal dependency, regulatory ambiguity, and fragmented intergovernmental coordination. Systems mapping of De Aar demonstrates how these constraints interact across municipal planning, regulatory processes, infrastructure

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deployment, and service delivery, reinforcing feedback loops that allow energy infrastructure to bypass local planning instruments and fail to address community needs. As a result, the transformative intent of post-apartheid spatial planning is undermined, perpetuating uneven development and spatial inequality.

In response, this study recommends a coherent, place-based model of energy governance centred on six interrelated priorities: strengthening municipal capacity, clarifying regulatory roles, enhancing intergovernmental coordination, integrating energy and land-use planning, promoting spatially just energy transitions, and applying systems thinking as an enabling governance approach. Together, these priorities emphasise that meaningful decentralisation requires more than constitutional authority; it depends on institutional capacity, regulatory alignment, and collaborative planning across spheres of government. By situating energy governance within a spatial justice and systems framework, the proposed approach seeks to align constitutional ideals with practical governance mechanisms, enabling more equitable, climate-responsive, and development-oriented energy transitions in De Aar. figure 4 below illustrates six interrelated priorities required to align municipal energy governance with constitutional mandates, spatial justice, and climate-responsive local development.

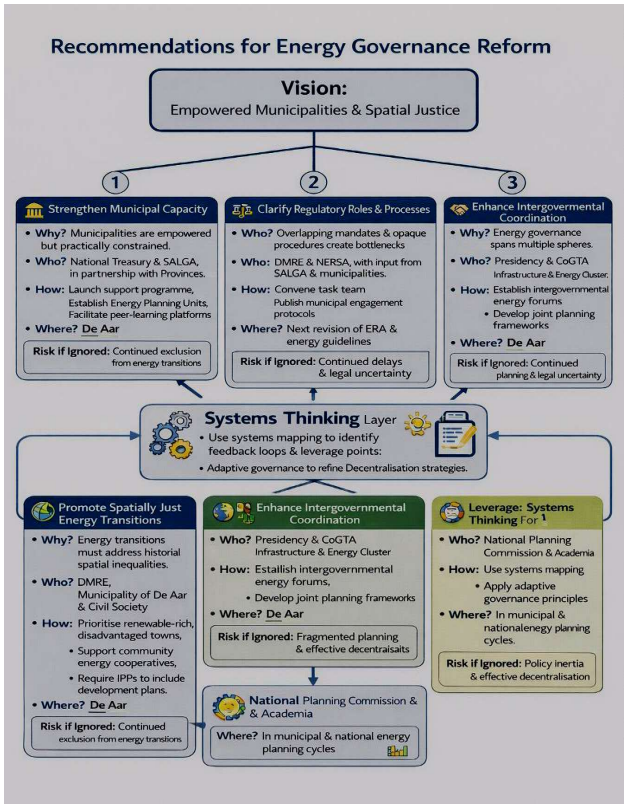


Fig 4: Integrated framework for energy governance reform in De Aar. Source: Author's own compilation based on study findings with diagrammatic assistance from generatie AI (2025)

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Critiquing the Implementation of the New Urban Agenda in Sub-Saharan Africa: A Systematic Review of Housing Policies and the Challenge of Upgrading Informal Settlements

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1 ABSTRACT

Urbanization in Sub-Saharan Africa has brought both opportunities and challenges, with the rapid expansion of informal settlements emerging as a critical issue for sustainable urban development. The New Urban Agenda (NUA), adopted in 2016, provides a global framework for addressing these challenges; however, its implementation in the region remains uneven and fraught with complexities. This research critiques the application of the NUA's principles related to informal settlement upgrading, focusing on housing policies and their alignment with inclusive and sustainable urban development objectives. Despite the NUA's efforts on inclusivity, resilience, and sustainability, informal settlement upgrading in Sub-Saharan Africa is hindered by systemic barriers, including insecure land tenure, inadequate infrastructure, limited financing, and fragmented governance. Using a systematic review methodology, the study synthesises evidence from academic literature, policy documents, and case studies across the region. The analysis framework is guided by the NUA's core principles of inclusivity, sustainability, and resilience. Findings reveal significant limitations in policy implementation, particularly regarding community participation, tenure formalization, infrastructure provision, and resource mobilization. In response, the study proposes the Localised Inclusive Informal Settlement Upgrading Framework (LIISUF), which provides an actionable pathway for aligning informal settlement upgrading practices with NUA principles. Through stressing flexible tenure arrangements, community-led planning, incremental infrastructure provision, innovative financing, and coordinated governance, LIISUF aims to enhance equity, sustainability, and resilience in African urban development, offering practical guidance implement inclusive and locally relevant upgrading initiatives.

Keywords: New Urban Agenda, Sub-Saharan Africa, informal settlements, housing policies, participatory planning

2 INTRODUCTION

The New Urban Agenda (NUA) serves as a catalytic framework for implementing the Sustainable Development Goals (SDGs) within urban and territorial contexts. Since its adoption in 2016, the NUA has been formally endorsed by 167 countries, including a substantial number of African states, signalling broad international commitment to integrated, inclusive, and sustainable urban development. Since 2018, a series of multi-scalar shocks and structural transformations have produced significant, both positive and adverse impacts across the African continent. These include localized manifestations of climate change, the COVID-19 pandemic, the ratification of the African Continental Free Trade Area (AfCFTA), the implementation of regional economic integration frameworks, shifts in national political regimes, and the persistence of violent conflict and insurgency. Collectively, these dynamics have reshaped urban and regional systems, accelerating intra- and cross-border migration flows, particularly among youth, while intensifying socio-economic inequality, precarity, and vulnerability within many African towns and cities (United Nations, 2022). World Bank (2022), Africa accommodates a disproportionate share of the global population living in extreme poverty, with significant implications for urban development, spatial inequality, and the planning and provision of basic services. Even though the NUA is being implemented in African countries, there are still numerous deficits. By 2020, sub-Saharan Africa recorded the highest global incidence of multidimensional poverty, reflecting intersecting deprivations in health, education, housing quality, basic services, livelihood security, personal safety, and exposure to environmentally hazardous locations. An estimated 71.9% of the rural population (approximately 466 million people) and 25.2% of the urban population (around 92 million people) were affected, highlighting stark rural–urban and intra-urban disparities (UNDP, 2020). Furthermore, many African countries remain off-track to achieve the 2030 target of halving multidimensional poverty, thereby constraining progress towards multiple interlinked Sustainable Development Goals (SDGs) and posing significant challenges for inclusive, resilient, and equitable spatial planning (Alkire et al., 2020). The next section outlines the conceptual elements underpinning informal

settlement upgrading in Sub-Saharan Africa, with particular reference to the New Urban Agenda and related housing policy frameworks. This is followed by a description of the systematic review methodology employed, including the search strategy, selection criteria, and analytical approach. The subsequent section presents and discusses the findings of the review, highlighting critical implementation limitations and emerging good practices in informal settlement upgrading. In response to these findings, the research proposes the Localised Inclusive Informal Settlement Upgrading Framework (LIISUF).

3 NORMATIVE FRAMEWORKS AND IMPLEMENTATION REALITIES

The Global Action Plan for Slum Transformation outlines a coordinated, multi-stakeholder framework that promotes a shared vision of inclusive urbanism and "Cities for All," grounded in the principle of leaving no one and no place behind. It is strategically positioned as an implementation accelerator for the Sustainable Development Goals (SDGs) and the New Urban Agenda (NUA), with a specific operational focus on addressing structural inequalities, spatial exclusion, and service deficits within informal settlements and slum environments (Department of Human Settlements, 2022). Across much of sub-Saharan Africa, fewer than 10% of households possess the financial capacity to access mortgage finance, even for the lowest-cost newly constructed formal housing units (CAHF, 2016). Still in the same region, multiple land tenure regimes, often exceeding five distinct systems, frequently coexist within the same spatial context, generating institutional ambiguity, tenure insecurity, and recurrent land-related conflicts. This fragmented land governance landscape significantly constrains formal housing delivery and contributes to the persistent shortage of affordable housing across the region. The conditions described above are in clear contradiction to the principles and normative commitments of the New Urban Agenda. It calls for diversified and accessible housing finance systems, including alternatives to conventional mortgage markets, to accommodate low-income households and those operating within informal economies (UN-Habitat, 2017). These conditions reflect a significant implementation gap between the NUA's equity-oriented, rights-based urban vision and the prevailing housing finance and land governance realities in sub-Saharan Africa, highlighting the need for structural reform rather than incremental policy alignment.

Despite the persistent structural challenges and implementation gaps, UN-Habitat continues to play a pivotal enabling role by supporting Habitat Agenda partners and governments at national, regional, and local levels to advance housing sector reforms. Through technical assistance, policy guidance, and institutional capacity-building, UN-Habitat facilitates the formulation of housing policies, legislative frameworks, and strategic interventions that promote the progressive realization of the right to adequate housing and advance the objectives of inclusive, safe, resilient, and sustainable urban development, in alignment with Sustainable Development Goal 11 and the New Urban Agenda.

4 METHODOLOGY IMPERATIVES

This study employs a systematic review methodology to synthesise evidence from academic literature, policy documents, and case studies on informal settlement upgrading in Sub-Saharan Africa. Systematic reviews are widely recognised as a precise and transparent approach to knowledge synthesis, particularly in policy-oriented and interdisciplinary research contexts where evidence is fragmented across multiple sources and disciplines (Petticrew & Roberts, 2006). Unlike traditional narrative reviews, systematic reviews rely on explicit, replicable, and methodologically structured procedures for identifying, selecting, and analysing relevant literature, thereby reducing selection bias and enhancing the credibility and reproducibility of findings, as shown in Figure 1. The review draws on both peer-reviewed academic literature and grey literature, including reports produced by international and regional organisations such as UN-Habitat and the World Bank. The inclusion of grey literature is methodologically justified, as significant policy-relevant knowledge, particularly in development planning and housing research, is often generated outside academic journals (Adams, Smart & Huff, 2017). Excluding such sources risks overlooking critical insights into policy design, implementation processes, and institutional practices, especially in settings such as Sub-Saharan Africa, where governance frameworks and development interventions are extensively documented through policy reports rather than scholarly publications.

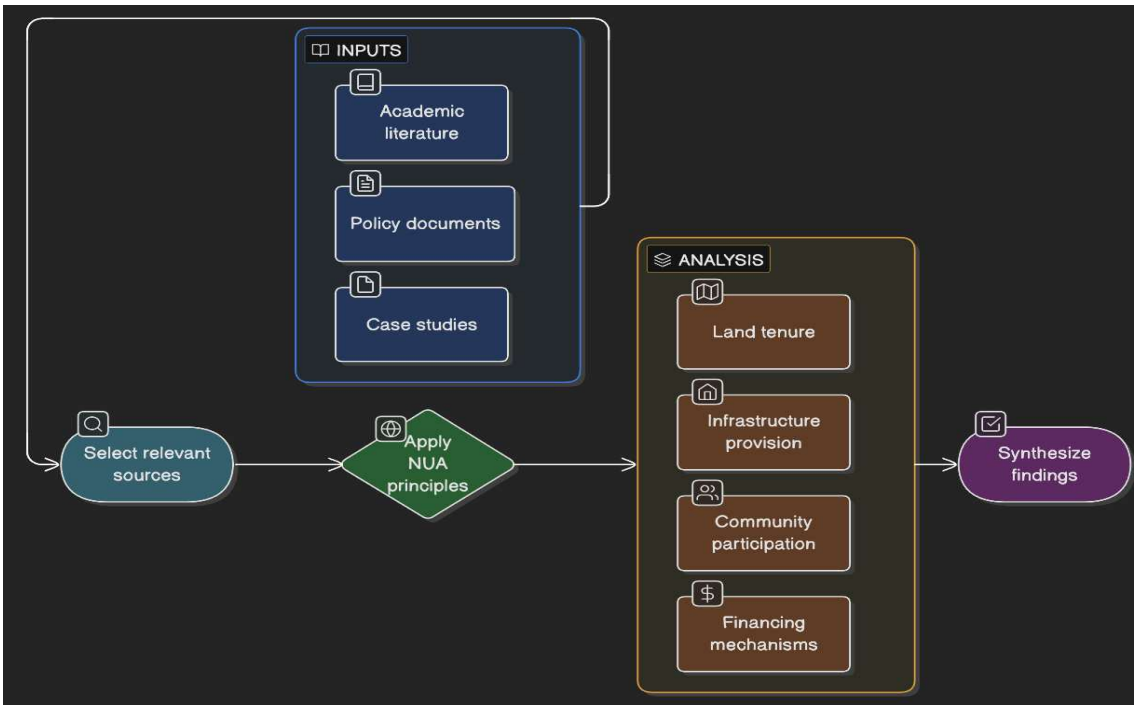


Figure 1: Research Process

To ensure analytical coherence, Figure 1 illustrates that the synthesis of evidence is guided by the core principles of the New Urban Agenda (NUA), namely inclusivity, sustainability, and resilience, which serve as an overarching analytical framework. The use of a predefined conceptual framework is consistent with best practices in systematic review research, as it provides a structured basis for comparing findings across diverse studies and policy texts while maintaining alignment with the study's objectives (Dixon-Woods et al., 2005). This framework enables a critical examination of how global urban development norms are interpreted, localised, and operationalised within housing policies and informal settlement upgrading initiatives in Sub-Saharan Africa. A structured search strategy was developed using predefined keywords related to informal settlement upgrading, housing policy, land tenure, participatory planning, and urban governance. Sources were screened against explicit inclusion and exclusion criteria, focusing on relevance to Sub-Saharan Africa, substantive engagement with informal settlement upgrading, and contribution to policy or empirical understanding. Such systematic screening processes are central to ensuring transparency and methodological defensibility in review-based research (Kitchenham & Charters, 2007; Gough, Oliver & Thomas, 2017). Following selection, data were extracted and synthesised using a thematic synthesis approach, which is particularly suited to systematic reviews in the social sciences where qualitative and mixed-methods evidence predominates (Thomas & Harden, 2008). Through iterative coding and comparison, crucial themes, including land tenure security, infrastructure provision, community participation, and financing mechanisms, were identified and critically examined.

5 ANALYSIS AND DISCUSSIONS

Despite being articulated as core commitments within the New Urban Agenda, the advancement of transparent, inclusive, participatory, and sustainability-oriented urban and territorial spatial planning systems, together with the universalisation of secure land and housing tenure for all socio-economic groups, including women, youth, and other historically marginalised populations, remains a significant implementation deficit. In practice, persistent governance fragmentation, limited participatory depth, weak institutional capacity, and entrenched tenure insecurity continue to undermine these principles, exposing a pronounced limitation between the normative aspirations of the New Urban Agenda and their translation into effective, on-the-ground urban development outcomes (UNECE, 2016). Housing infrastructure is a crucial part of the urban economy. A substantial proportion of the urban population lacks access to, or affordability of, formal housing finance mechanisms necessary for the acquisition or construction of adequate housing (World Cities Report, 2020). Consequently, many households resort to incremental self-provisioning of shelter within informal settlements and slums, located both in inner-city areas and on the urban periphery, often outside formal planning, regulatory, and service delivery frameworks (Bah, Faye & Geh, 2018).

Approximately one quarter of the global urban population residing in slum-like and informal settlement conditions is concentrated in Sub-Saharan Africa, highlighting the region's disproportionate exposure to structural housing deficits, inadequate basic services, and persistent spatial informality within rapidly urbanising cities (World Cities Report, 2020).

The New Urban Agenda (Habitat III, 2016a: 51) elevates spatial planning as a central instrument for steering urban morphology toward more compact, integrated, and efficient spatial configurations. However, this framing insufficiently engages with the empirically established formal–informal continuum that characterises urban development, particularly in rapidly urbanising contexts. The Agenda offers limited operational guidance on how planning systems should meaningfully incorporate existing informally developed areas or address entrenched patterns of unplanned land occupation and informal settlements in Sub-Saharan Africa (Huchzermeyer, 2017). Instead, its normative emphasis implicitly privileges solutions anchored in planned urban extensions and the realisation of economies of scale, thereby underestimating the structural, socio-spatial, and institutional complexities associated with informality and incremental urbanisation. Despite the proliferation of housing programmes aimed at advancing the objectives of the New Urban Agenda (NUA) in South Africa, the national housing deficit continues to widen as sustained rural–urban migration intensifies demand in metropolitan and secondary urban centres. By 2018, the cumulative housing backlog had reached approximately 2.1 million units, underscoring the persistent structural mismatch between housing supply and rapidly growing urban populations (Marutlulle, 2021).

6 TOWARDS A LOCALISED INCLUSIVE INFORMAL SETTLEMENT UPGRADING FRAMEWORK (LIISUF)

The Localised Inclusive Informal Settlement Upgrading Framework (LIISUF) is designed to translate the normative principles of the New Urban Agenda into setting, implementable actions for informal settlement upgrading in Sub-Saharan Africa. The framework responds to the identified limitations between policy commitments and practice, particularly in relation to land tenure insecurity, weak participatory processes, fragmented governance, inadequate infrastructure provision, and limited financing mechanisms. It stresses localisation, institutional coordination, and community-centred implementation as critical enablers of sustainable upgrading.

Challenge Identified	Strategic Focus	Recommended Action	Expected Outcome
Insecure land tenure	Tenure security	Introduce incremental and flexible tenure options (e.g. occupation permits, community land trusts) aligned with local land governance systems	Improved tenure security and reduced risk of displacement
Limited community participation	Inclusive planning	Institutionalise community-led planning and decision-making in upgrading projects	Stronger local ownership and more context-sensitive interventions
Inadequate infrastructure and services	Basic service provision	Prioritise in-situ upgrading with phased provision of water, sanitation, electricity, and access roads	Improved living conditions without forced relocation
Weak localisation of the NUA	Context-sensitive policy alignment	Adapt NUA principles into national and municipal housing and planning policies	Better alignment between global frameworks and local realities
Financial constraints	Innovative financing	Combine public funding, community savings schemes, and private sector partnerships	Increased financial sustainability of upgrading programmes
Fragmented governance and institutions	Coordinated governance	Strengthen intergovernmental and multi-stakeholder coordination mechanisms	More coherent and efficient implementation processes

Table 1: Localised Inclusive Informal Settlement Upgrading Framework (LIISUF)

The Localised Inclusive Informal Settlement Upgrading Framework (LIISUF) in Table 1 proposes a pragmatic approach to advancing the implementation of the New Urban Agenda (NUA) in Sub-Saharan Africa by directly responding to the structural and governance-related constraints identified in the literature. Central to the framework is the recognition that secure land tenure is foundational to sustainable upgrading; however, rather than prioritising full legal titling, the framework supports incremental and flexible tenure arrangements that reflect plural land governance systems common in African cities, including customary and hybrid regimes (Durand-Lasserve, 2015). The framework further stresses community-led and participatory planning, arguing that meaningful resident involvement enhances project legitimacy, improves policy

responsiveness, and aligns with the NUA's "leave no one behind" principle (Habitat III, 2016a). To address persistent service deficits, LIISUF prioritises in-situ upgrading and phased infrastructure provision as a means of improving living conditions while minimising displacement and socio-spatial disruption (Huchzermeyer, 2011; World Bank, 2020). Recognising the difficulty of translating global frameworks into local practice, the framework highlights the importance of localising NUA principles within national and municipal housing and planning policies to ensure contextual relevance and institutional ownership. Given chronic funding limitations, LIISUF advocates for innovative and blended financing mechanisms, including public investment, community savings schemes, and public–private partnerships, which have demonstrated potential to enhance financial sustainability and scale in informal settlement upgrading initiatives (Cities Alliance, 2019). The framework highlights the need for coordinated, multi-level governance, as fragmented institutional arrangements remain a critical barrier to effective implementation across the region. Collectively, LIISUF offers a simplified yet dynamic pathway for aligning informal settlement upgrading practices with the normative commitments of the New Urban Agenda while remaining grounded in the socio-spatial realities of Sub-Saharan African cities.

7 CONCLUSION

This study critically examined the implementation of the New Urban Agenda (NUA) in Sub-Saharan Africa, with a focus on housing policies and informal settlement upgrading. The findings highlight persistent limitations between the NUA's principles of inclusivity, sustainability, and resilience and the realities on the ground, including insecure land tenure, limited community participation, inadequate infrastructure, fragmented governance, and constrained financing mechanisms. These structural and institutional barriers hinder the progressive realisation of adequate, safe, and affordable housing for low-income and marginalised populations. In response, the study proposes the Localised Inclusive Informal Settlement Upgrading Framework (LIISUF), which offers a pragmatic approach to translating NUA commitments into actionable strategies. Through stressing flexible tenure arrangements, participatory planning, in-situ infrastructure upgrading, innovative financing, and coordinated governance, LIISUF provides a pathway for aligning global urban development norms with the socio-spatial realities of African cities. Ultimately, the study highlights that the transformative potential of the NUA in Sub-Saharan Africa depends not only on policy adoption but on its localisation, institutional capacity, and sustained community engagement. Implementing such driven frameworks can enhance equity, resilience, and sustainability in urban development, providing a foundation for more liveable cities across the region.

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reviewed paper

Digital Participatory Rural Appraisal Approach for Smart Sustainable Rural Development

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1 ABSTRACT

Participatory Rural Appraisal (PRA) has long been used in India and globally to enable communities to analyse their own living conditions and co-design development solutions. However, rapid digital transformation, characterized by smartphones, geospatial platforms, IoT sensors, artificial intelligence, and digital public infrastructure, have expanded the scope of PRA into a more powerful, data-driven, and scalable approach, known as Digital Participatory Rural Appraisal (DPRA). DPRA integrates human centred participatory tools with digital technologies to support evidence-based planning, inclusive governance, climate adaptation, and sustainable rural development.

The present article is an attempt to develop a concept for local community participation by the application of digital technologies for preparation of Smart Sustainable Village Development Plan. The paper discusses about the guiding principle and participatory methodology for inclusive digital participation of local community for sustainable village planning and development. In short, the present paper outlines the DPRA framework, methods, implementation model, case applications, and policy directions for Gaindikhata Cluster of villages in Haridwar district of India.

Key words: Digital PRA, Community Participation, Sustainable Development, Village Planning, Smart.

2 INTRODUCTION

Rural development has long been recognized as a cornerstone for equitable and sustainable growth across the globe. It has been a central focus of policy discourse in developing nations, particularly in countries like India, where nearly 65% of the population still resides in rural areas (World Bank, 2023). While traditional approaches have emphasized infrastructure, agriculture, and social welfare, the recent digital revolution has introduced new opportunities for strengthening community participation. Digital technologies, including information and communication technologies (ICTs), mobile applications, social media, e-governance platforms, and artificial intelligence are increasingly being deployed to empower rural communities, improve decision-making, and enhance access to essential services. Conceptualizing Community Participation in the Digital Era refers to the active involvement of local populations in decision-making, planning, and implementation of development initiatives. In the digital context, participation is increasingly mediated through online platforms, digital tools for knowledge sharing, and citizen-led data generation.

Now in the contemporary rural India it is more important to evolve participatory and inclusive rural planning process to understand the rural community needs and over all social and economic development. Seventeen Sustainable Development Goals (SDG) adopted by the United Nations General Assembly in 2015 as '2030 Agenda' representing a comprehensive approach to sustainable rural development. One of the key steps toward achieving higher levels of sustainability and the Sustainable Development Goals (SDGs) is to address economic disparities, climate change, and access to modern technologies and basic infrastructures. The concept of smart rural communities, although somewhat trendy, has gained significant attraction in this regard. While the smart city initiative is well-known, it is complemented by the Indian Smart Village initiative, aimed at leveraging Information and Communication Technology (ICT) to benefit people living in rural areas.

Comprehensively designed smart villages are expected to provide a fundamental framework for rural communities to enhance their participation at the local level, improve their economic, social, and living conditions, and, thereby, increase their resilience. Within the "Digital India" plans, the Indian government envisions a complementary approach, where smart villages not only drive economic growth in rural areas by producing goods and services but also serve as national and international markets. Consequently, there is a pressing need to design and develop villages with strong internal and external connections while preserving their independence in providing employment, services, and a high quality of life.

3 UNDERSTANDING THE CONCEPT OF DIGITAL PARTICIPATORY SMART SUSTAINABLE RURAL DEVELOPMENT.

The development of villages is a crucial factor in the progress of the nation. Therefore, village development should be envisioned in a manner that promotes self-sufficiency in delivering essential services, generating employment opportunities, and fostering strong global connectivity, denoting the concept of a “Smart Model Village”. The term "model" conceptually implies the design of an activity or situation that serves as an exemplary model for replication. In this context, a model village represents a sustainable community capable of generating and sustaining the resources needed to enhance its well-being. This enhancement is achieved by reinforcing the pillars of sustainability, including livelihood, infrastructure, and services. Smart villages rectify social oversights by providing a conducive environment for sustaining family relationships across different generations without disrupting their way of life. The vision behind smart villages is that they can serve as catalysts for development across various domains, including education, health, productive enterprises, clean water and sanitation, environmental sustainability, and participatory democracy. This, in turn, contributes to further progress and improvement. Digital India is a government campaign launched in India with the aim of providing electronic access to government services, improving online infrastructure, enhancing Internet connectivity, and fostering digital empowerment in technology. This initiative encompasses plans to establish high-speed internet networks in rural areas. Digital India revolves around three core components: the development of secure and reliable digital infrastructure, the digital delivery of government services, and the promotion of universal digital literacy.

In the present context the smart dimension of development is more often a sectoral approach. In international as well as in Indian scenario, the present smart approach reveals the piece meal approach of infrastructure development grounded with Information and Communication Technology e.g. Smart Water, Smart Energy, Smart Agriculture etc. A comprehensive approach for analysis of smart initiative and practices integrated with traditional indigenous knowledge-based economy, environment and societal needs fostering innovation of the rural community is missing. “Smart Village Concept” should necessarily be bottom–up integrated approach. The communities should be put behind the steering wheels instead of imposing development paradigms which is incompatible with the community’s desires, their social and cultural environments. An integrated inclusive approach, for felt need, demand and supply is required for making it more sustainable and resilient.

This leads to the basic concept of a smart sustainable rural development. i.e. a process whereby the optimum use of local resources can be sustained over several generations in the context of available technology and skills. To achieve inclusive, smart, and sustainable spatial planning, town planners in India should embrace innovative ideas for public participation. This can be facilitated by harnessing the power of Geographic Information Systems (GIS) and Internet of Things (IOT) technologies. These tools enable more effective and inclusive engagement with the rural community, allowing for the integration of local knowledge and perspectives into planning processes. In today's rapidly changing world, where information and digital technologies are advancing at a remarkable pace and costs are decreasing, leveraging of these technological advancements becomes even more critical. By doing so, town planners can create more dynamic and responsive development strategies that address the evolving needs of rural communities while ensuring the responsible and efficient use of rural resources.

Therefore, the meaning of ‘Smart Villages’ adopted in the paper is identification of local potential, strengths and opportunities of rural communities and to improve resilience through innovative solutions. Present paper frames the process of effective digital participatory model by using IoT technologies. This Model tries to understand and analyze dynamism of a village/ regional ecological-economic cultural system in a participatory approach. Participatory approach adopted in platforms of IoT to be called Digital Participatory Approach. Participatory Rapid Appraisal (PRA) approach, in combination with the use of digital technologies, will lead to empowering rural community by taking the initiative to find practical innovative solutions for both existing complex challenges and appropriate opportunities for sustainable and inclusive rural development. Digital Participatory Rural Appraisal will have to ensure the employment opportunities and skill updation, particularly among the small land holders, the landless labourers, and women to make development inclusive. Conceptually Smart Village Planning Model is an integration of Digital Participatory Inclusive Model and Sustainable Physical Planning Model.

4 SELECTION OF STUDY AREA

In order to identify the idealistic suitable village cluster and also to have true representation of Smart Village Planning Model (SVPM), various types of village ecosystems were studied with the help of Participatory Rural Appraisal (PRA) techniques. Among the various type of village ecosystems studied, Gaindikhata Cluster in Haridwar District, Uttarakhand has been taken as the study area. This cluster is chosen as because of the fact that the Gaindikhata Cluster itself depicts all uniqueness of the village ecosystem. In fact, it is worthwhile to point out here that this cluster itself represents all typical characteristics of different type of village communities (like tribal community, resettlement forest dweller community, advance agricultural community). The present cluster also represents all typical characteristics of physical and geographical setting (like plain, undulating land, hills and mountain topography); the micro-climatic variation, dense forest cover; the various zonation of land-uses in the form of valley zone, above valley zone, semi-arid zone, humid zone. Moreover, located under the shadow of big urban center, Haridwar, this cluster shows cultural cohesiveness and functional linkages. Lastly, the most important characteristic which determined for selecting the cluster is the administratively oneness of the cluster of villages being part of the one Naya Panchayat, one Block, one District

5 METHODOLOGY FOR DPRA

Information technologies in form of IoT have triggered a profound transformation in our way of life in the 21st century. These technologies have not only reshaped human behavior but also have ushered a new lifestyle marked by increased demand for transparency in governance and decision-making processes. The application of IoT Technologies will give planner to analyze the complex rural development problems and issues virtually through development of simulation model of real-world problems providing many options to evaluate the rural development decisions for implementation on the ground. 'Digital Participatory Rural Appraisal (DPRA) through the application of IoT technologies endows sustainable development of rural community by enabling importance for involvement of all levels of community (professional and local) in the process of planning and development leading towards to evolve the 'Digital Smart Participatory Village Planning Model' (DSPVPM). To achieve inclusive, smart, and sustainable rural planning, this innovative approach provides a framework for public participation by leveraging digital tools such as Geographic Information Systems (GIS) and IoT for more effective data collection, analysis, and collaboration among stakeholders. These technologies align with the global trend of rapid changes in information technologies, coupled with cost reduction can be invaluable in enhancing the right decision making for inclusive, smart, sustainable rural development.

The present paper delves into the intricacies of complex smart planning decisions, that are embedded in the procedure for the establishment of a Smart Village Model i.e. 'Smart Participatory Village Planning Model' (SPVPM). Undoubtedly, in the present cybernetics age IoT technologies provide the swiftest means to access, gather, analyze, and disseminate spatial information and also offer innovative and sustainable solutions through digital participatory approaches on the one hand and empowering rural communities and effective governance on the other. However, the adoption of such technologies poses challenges, including technological complexity; high costs, varying literacy levels, societal awareness, and accessibility issues. These challenges contribute to a digital divide, particularly affecting low-income groups. Consequently, the paper endeavors to address the main question of how low income and illiterate society can effectively and democratically access these technologies for participating and providing real-time spatial rural information into digitally tested designs leading into the rural development on the ground.

In overall, the paper frames a "Digital Smart Participatory Village Planning Model' through application of DPRA (intermingling both Geographic Information Systems (GIS) and IoT technologies as a spatial planning tool) to cultivate inclusive, smart and sustainable rural community in Gaindikhata cluster of Haridwar district, Uttarakhand. The central focus of this study revolves around the issue of providing economically disadvantaged sections of the rural community with access to the internet and IoT technologies to enable the effective people's participation in the rural planning and execution of development initiatives.

Indeed, beyond the imperative of achieving sustainable and inclusive development for the Gaindikhata Cluster, there is a pressing need to establish the DPRA with the aid of emerging Information and Communication Technologies (ICTs), such as IoT and GIS. The success of digital model for Gaindikhata Cluster is dependent upon the multiple challenges, like leadership role, skill development, sustainable land-

use planning and fostering a participative and responsive rural community. Gaindikhata cluster faces increasingly complex socio-economic and environmental challenges, especially regarding the competitiveness of the village community for survival. The sensitivity of forest-dwelling communities adds another layer of complexity, underscoring the need for thoughtful and culturally sensitive approaches when applying advanced technologies to address social issues. The establishment of the DPRA offers a pathway to address multifaceted challenges and create a sustainable, responsive, and inclusive future for Gaindikhata cluster and similar rural communities. It requires careful consideration of the local context and active community engagement to ensure the success of these technological advancements in a socially responsible manner.

Recognizing the unique challenges faced by the Gaindikhata Cluster, where a significant portion of the rural community i.e. only 34 % have limited familiarity with internet, smartphones and other digital technologies, thus, it becomes evident that presenting a DPRA in Gaindikhata cluster may not effectively able to connect to local rural community and continue to extend the participatory gap between spatial rural planning and application of IoT technologies. Hence, in Gaindikhata cluster, where planning and governance process evolve within a socially uncertain environment, a more comprehensive "DPRA" is required with collective intelligence, social awareness, and local wisdom of the village community.

To achieve this, a collective intelligence system, by using crowd wisdom is developed with the assistance of IoT technologies in a Common Participative Platform. The Interactive applications is designed to provide rural services and facilitate the implementation of the DPRA. This can then be introduced to the local village communities through smart farming and off-farm activities, efficient rural service delivery, intelligent mobility management systems, streamlined planning processes, and active community participation. Hence, the rural development approach, centers around leveraging the wisdom and collective intelligence of the local community to co-create and implement a Smart Village Planning Model which is not only technically advanced but also socially relevant and inclusive. This encompasses three fundamental elements:

(1) Innovative Technological Solutions: This includes both hard (physical infrastructure and tools) and soft (software, applications, digital platforms) technological innovations.

(2) Local Community: The local community plays a central role. It is characterized by leadership, responsiveness, intelligence, and creative thinking which are essential for active community engagement and contribution to the planning and development process.

(3) Government: The government's role is pivotal in terms of setting policies, rules, governance structures, and demonstrating political will to support and enable the implementation.

This represents a transformation of the smart village planning approach through integrating a social system which empowers the community to create, solve problems, build infrastructure, utilize resources, adapt to changes, secure livelihoods, and more within the context of a ‘Smart Village’ (Figure 1).

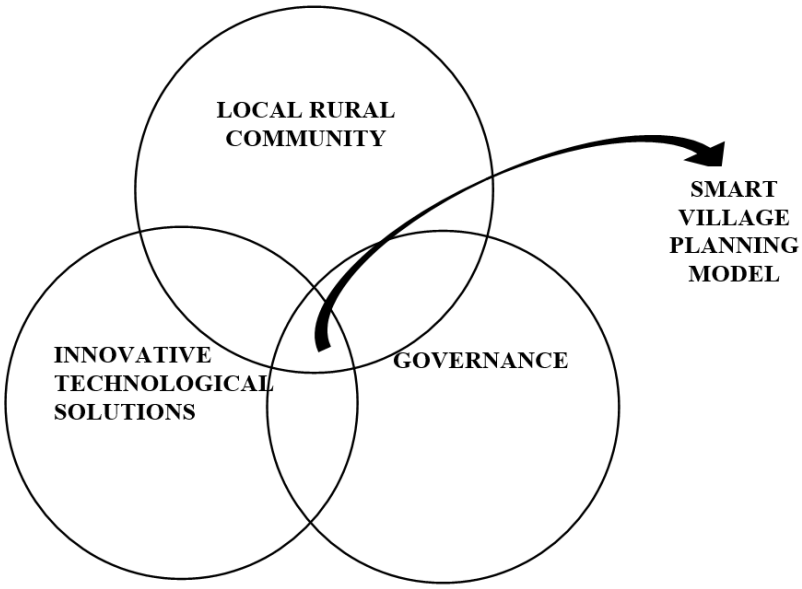


Figure 1: Smart Village Planning Model

In practical terms, the DPRA integrates physical planning and design with the active involvement and influence of the local community, facilitated through a IoT based digital platform This ensures the technologically advanced smart village development process driven by the needs and aspirations of the rural community it serves (Figure 2).

The Gaindikhata cluster system is designed around an input-output model, which serves as a framework for measuring sustainable development and the quality of life within the community. This model encompasses various sub-systems, each contributing to the overall sustainability and well-being of the community. These sub-systems include: Smart Mobility System, Smart E-Governance, Smart Ecological System, Smart Water Management System, Smart Infrastructure System, Smart Community System, Smart Power Management System, Smart Finance Management System, Smart Social Development System, Smart Economic Development System, Smart Environmental Development System, Smart Creative Community Development System etc. These sub-systems collectively contribute to the smart and sustainable development of Gaindikhata cluster and have capability to adapt, repair, and redesign based on the collective intelligence and actions of the community participation. The most important element of the DPRA is the active participation of the local community in governance and the preparation of Smart Participatory Village Development Plan. The crowd-sourcing model, which involves digital participation, plays a pivotal role in this leveraging the wisdom of crowds to generate effective solutions and make collective decisions, ensuring that the planning and development processes are inclusive, responsive, and driven by the insights and needs of the local community.

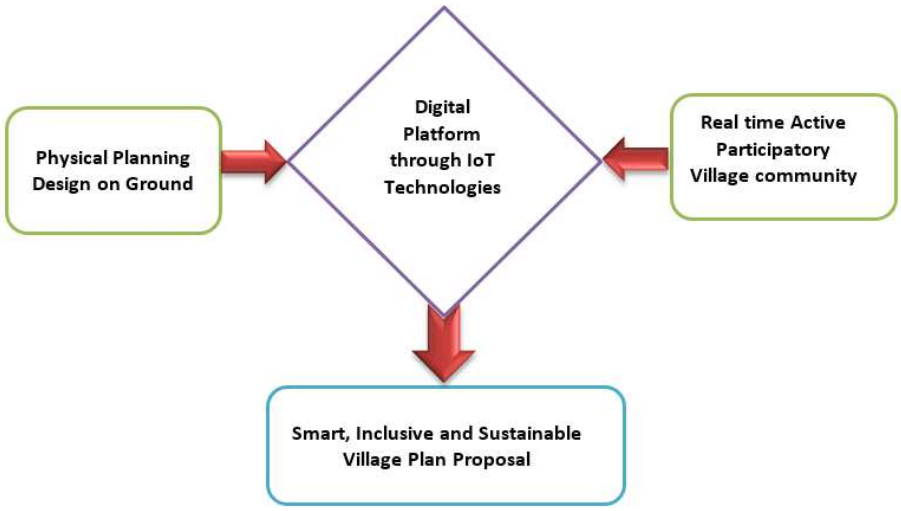


Figure 2: DPRA

6 TECHNOLOGICAL INPUT FOR DPRA

The use of IoT Technologies include social networking sites, like Google Maps Mashups, blogs, YouTube, WhatsApp, and others to disseminate information offering boundless opportunities for social inclusion within the local community, thereafter, transforming rural planning and design into a smart and inclusive process. These technologies encompass participatory web applications that enable villagers to actively participate and create their own content, fostering communication through various mediums such as text, maps, sketches, images, and more. Importantly, these technologies transcend language, culture, and custom differences, making them highly accessible and inclusive and serves as a powerful tool for planners to engage with the local community and vice versa. It facilitates two-way communication and collaboration.

Furthermore, these technologies contribute to transparency in governance by enhancing the interoperability of rural planning processes. It allows greater visibility and understanding in decision-making and resource allocation, ultimately empowering community members to participate effectively in shaping the future of their village. Thus, IoT Technologies in rural planning not only fosters inclusivity but also promotes transparency, enabling active community involvement and collaboration in the planning and development of smart and sustainable villages.

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In essence, this enable the aggregation and analysis of unconventional data sources, offering a wealth of traditional information that can be harnessed to shape smart and sustainable village planning. This data-driven approach enhances the precision and effectiveness of rural development initiatives in the Gaindikhata cluster and similar regions.

Here are some examples of how such data can be leveraged:

(1) Personal Smartphones and Local Cameras

(2) Smartphone Video Recording and Social Networking Sites

(3) GPS-Equipped Vehicles:

(4) Data Mining Techniques

7 CROWDSOURCING FOR DPRA

Establishing the DPRA, especially in a village cluster like Gaindikhata, where only 34 percent of the population has internet access, requires an innovative approach. While the digital divide may pose challenges, it is indeed possible to leverage IoT to establish a Smart Participatory Village Planning Model (SPVPM). To facilitate the effective local community participation, a Core Community Group (CCG) can be formed. Strategy to identify the interested villagers among the least technological savvy village communities who are enthusiastic about supporting the research and to be a part of participatory Core Community Group (CCG) is really a challenging task. These villagers may be referred to as 'LOCAL COMMUNITY FIELDERS' (LCF) at the village level and 'LOCAL COMMUNITY LEADERS' (LCL) at the cluster level. Criteria for selection of LCF and LCL and steps of establishment of SPVM are given below:

(1) Selection of LCF: LCF members should be chosen from various areas within the villages and represent different communities. They should possess smartphones, have a basic level of education, and, most importantly, express a genuine interest in actively participating in the research.

(2) Collaboration: The LCF members will work closely with the researcher. Their role will involve active engagement in analyzing content and solving village-related problems and issues using IoT.

(3) Training and Capacity Building: LCF members are given training for capacity-building and effectively handholding in using IoT applications in their smart phone, for data collection, communication, and disseminating information to the researcher, villagers, planners or managers for further analysis and providing solutions.

(4) Community Engagement: The LCF, in conjunction with the researcher, will engage the broader community to gather insights, share information, and ensure that local perspectives are considered in the research process.

(5) Feedback Loop: A feedback loop should be established to continuously assess the progress, challenges, and outcomes of the research. This iterative process allows for adjustments and improvements based on the experiences of the LCF and the community.

By forming and empowering the LCF and LCL, the research can harness the collective intelligence and involvement of interested villagers to overcome the limitations of internet and smart phone access. This approach enables active participation and ensures that the research benefits from local insights and perspectives, ultimately contributing to the success of the DPRA for achieving the Smart Participatory Village Planning Model (SPVPM).

This digital platform will serve multiple purposes, including:

(a) Access to GIS and Web 2.0 Technology

(b) Information Sharing with Related Agencies.

(c) Storage of Public Information and Databases:

(d) Community Data Analysis

(e) Influence on Decision-Making:

The LCF will feed/ communicate the village development related data to LCL and LCL to planners or village development managers and then planners will upload on common platform or portal. In this way, the digital

platform is managed "by the people," provides information to village planning authorities "for the people," and generates information "from the people." The common platform should be accessible to all members of the local community, ensuring that it empowers individuals with direct access to digital spatial data relevant to the village cluster. LCF and LCL members should be identified for training and access to GIS and IoT technologies, with a particular focus on ensuring the inclusion of marginalized groups such as the poor and women. This approach not only addresses digital exclusion but also reduces the gap between planning professionals and the local public, fostering a more inclusive and participatory approach for inclusive sustainable village development. This Digital Smart Participatory Sustainable Rural Development Planning Approach employs a crowdsourcing IoT platform at all stages of the village planning process, harnessing collective intelligence to create web-based solutions for complex rural problems. The sequence of the DPRA based SPVPM is outlined as follows:

(1) Identification of Problems

(2) Defining Goals

(3) Establishment of e-Platform

(4) Collection of Data through crowdsourcing

(5) Analysis of Data

(6) Solution and Decision Making

(7) Designing Solutions

(8) Implementation of the Plan

(9) Monitoring of the Plan

(10) Evaluating the Plan

In overall, the DPRA led SPVPM for rural development reduces planners' dependency on time and space, gradually transforming traditional planning processes into virtual planning. This approach promotes participatory, transparent, and sustainable village planning that actively involves the local community in problem-solving and decision-making.

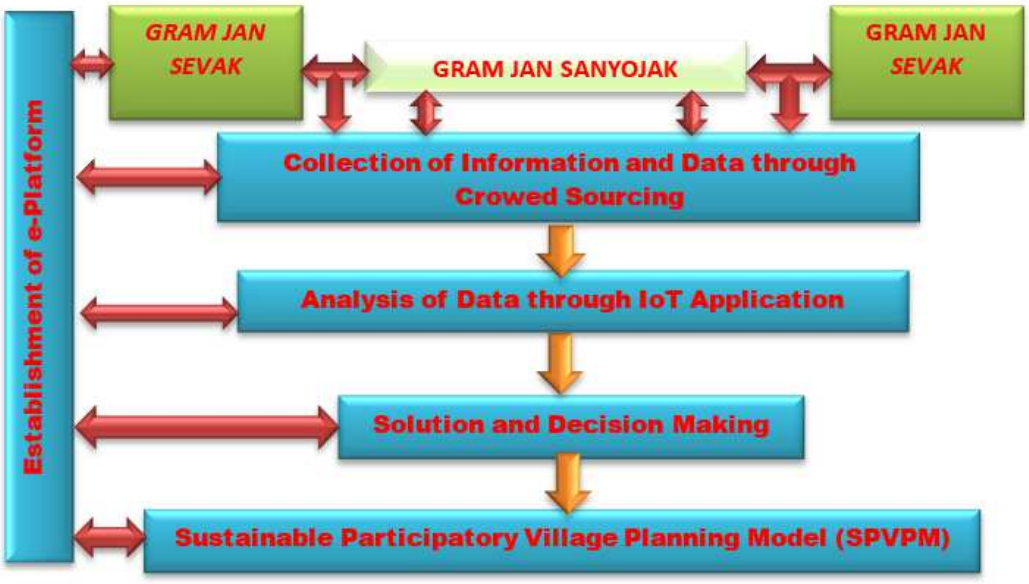


Figure 3: DPRA led Smart Participatory Village Planning Model (SPVPM)

8 CONCLUSION

On the basis of above-mentioned methodology for achieving sustainable, inclusive, integrated, digital participatory spatial planning using DPRA for sustainable development of Gaindikhata cluster, Smart Participatory Village Planning Model tries to understand and analyze dynamism of an existing regional ecological-economic cultural system as an integrated approach on the one hand, and sustainable and inclusive approach adopted on the other. This method aims to overcome digital access barriers. The paper

outlines the functionalities of the digital platform, highlighting its role in accessing, collecting, analyzing, and transferring spatial information. It also emphasizes the platform's role in providing participatory solutions for effective governance and community empowerment. The DPRA approach aims to empower the local village community by giving them the ability to customize the digital platform to meet their specific needs. It enables them to generate and manipulate their own information and spatial data, rather than relying solely on predefined decisions made by higher authorities.

The ultimate goal of DPRA is to make the local community active participants in their village development and planning process. This approach fosters a sense of pride and direct involvement, allowing them to drive their own village's development. the paper appears to propose a noble approach to village planning and development by combining the concept of Smart Village with IoT, ensuring that even communities with limited digital access can actively participate in the process and shape their own development. This approach emphasizes community empowerment and customization of digital tools for local needs.

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🏆 reviewed paper

Digital Systems Audit and Policy Alignment in the City of Johannesburg

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1 ABSTRACT

The City of Johannesburg (CoJ) has articulated an ambitious vision for digital transformation through its Smart City Strategy, Information and Communications Technology (ICT) Policy Framework, and Integrated Development Plan, positioning digitalisation as a key mechanism for improving municipal efficiency, transparency, and citizen engagement. Multiple digital platforms, including e-Joburg, Joburg Connect, the GIS Spatial Portal, and the My Smart City App, have emerged as core components of this strategy. However, the extent to which these systems align with the City's regulatory, strategic and institutional frameworks remains unclear, raising questions about their capacity to support equitable and reliable service delivery. This study conducts a comprehensive digital systems audit and policy alignment review to evaluate the coherence, readiness, and governance compatibility of Johannesburg's digital municipal service ecosystem.

Using a desktop-based analytical approach, the study draws on publicly available municipal policies, digital strategy documents, Auditor-General reports, technical platform descriptions, and legislative instruments governing local e-governance in South Africa. The analysis assesses system functionality, interoperability, data governance arrangements, user accessibility, and alignment with the Municipal Systems Act, National Digital and ICT policies, and 4IR strategic goals. Findings indicate that although Johannesburg possesses a wide range of digital tools, the ecosystem remains fragmented, with limited integration across departments, inconsistent adherence to data governance standards, and uneven alignment with policy objectives relating to inclusivity, public participation, and service accountability. Significant gaps also exist between regulatory intentions and practical implementation capacities.

The study concludes that Johannesburg's digital tools have strong transformative potential but require greater strategic coherence, interoperability, and regulatory alignment to function effectively within a metropolitan governance context. Strengthening platform integration, adopting unified data governance standards, and establishing a coordinated Smart Governance Framework are essential steps toward enhancing the reliability, inclusivity, and long-term sustainability of digital municipal service delivery.

Keywords: Digital systems audit, Policy Alignement, Municipal service delivery, Smart Governance, E-governance

2 INTRODUCTION

Digital transformation has emerged as an important aspect of how cities currently govern themselves. Cities have turned to digital technology to improve the delivery of services through increased efficiency, transparency, accountability, and by engaging their citizens. The Smart City movement frames digital technologies as tools for enhancing institutional capacities, providing opportunities for data-based decision making in the context of rapid urbanization and increasing pressures to deliver services (Meijer & Bolívar, 2016). In addition, the United Nations (2022) describes digitalization in metropolitan governments in the global south as a method for addressing administrative fragmentation and limited resources, and by doing so, improve the responsiveness of governments to their citizens.

Metropolitan municipalities in South Africa are constitutionally mandated to ensure effective and sustainable service delivery and to promote participatory governance, as outlined in Sections 152 and 153 of the Constitution (Republic of South Africa, 1996). The City of Johannesburg, the largest metropolitan municipality in South Africa, is now using digital transformation as a strategic objective for its development and growth through projects like Joburg Connect and e-portal, and a range of spatial information systems, the Geographic Information System (GIS) applications intended to improve planning, administrative, and service coordination (City of Johannesburg, 2022). These projects reflect the South African government's national policy framework to encourage smart government, innovation, and the use of 4IR technology to enhance the ability of the State to function effectively (National Planning Commission, 2012; Department of Cooperative Governance, 2016).

Although the city has made great strides in improving its service delivery, governance is still unstable, and there are ongoing issues of poor coordination within municipal departments as well as among municipal-owned entities (MOE) in Johannesburg. As such, there are several important questions raised regarding whether or not current digital municipal systems have been implemented in a manner that is consistent with the legislation and/or policy frameworks that were developed to govern how they should be implemented. This paper fills the void created by the lack of research on this topic by completing an audit of Johannesburg's digital municipal systems through the use of qualitative desktop analysis methods; and evaluating how well those systems align with applicable governance policies. The paper argues that the City's digital governance challenges stem less from technological inadequacy than from institutional fragmentation and weak policy–systems alignment.

3 CONCEPTUAL AND POLICY FRAMEWORK

3.1 Smart Governance and Digital Municipal Systems

Smart governance encompasses how governments use digital technologies to support better-informed decisions by improving the integration of stakeholders with diverse backgrounds in governance as well as enhancing collaboration among the various components of a government (Meijer & Bolivar, 2016). As opposed to an exclusively technocratic view of smart cities, smart governance focuses on the institutional and legal context in which smart city technologies are applied because smart city technologies function within pre-existing governmental systems and politics (Connolly & Bannister, 2012).

Municipal digital systems such as Service Reporting Platforms, Spatial Information Systems and Performance Dashboards function as governance Infrastructure for the circulation of information in and out of the State and Citizens. Therefore, these systems will be effective not solely based upon their technical sophistication, but also the degree of Interoperability, Institutional Capacity, and Policy Coherence (OECD, 2020) of the systems. As a result, in contexts with inequality and fragmented administration, municipalities' digital systems could create or enhance existing governance failure unless they are specifically designed to reduce it (Parnell & Pieterse, 2010).

3.2 Policy and Legislative Framework Governing Digital Municipal Governance

Johannesburg's digital transformation agenda is embedded within a multi-layered governance framework spanning constitutional, national, and municipal levels.

The Constitution of the Republic of South Africa (1996) establishes local government's developmental mandate, requiring municipalities to provide democratic, accountable, and efficient governance while ensuring sustainable service delivery (Sections 152 and 195). These principles underpin the normative justification for digital systems that promote transparency, responsiveness, and participation. The Municipal Structures Act (Act No. 117 of 1998) defines the political and administrative arrangements of municipalities, shaping the institutional environment within which digital systems are implemented. Complementing this, the Municipal Systems Act (Act No. 32 of 2000) mandates universal access to basic services (Section 73) and community participation in municipal affairs (Section 16), objectives that are increasingly operationalised through digital platforms.

At the national strategic level, the National Development Plan (NDP) 2030 identifies information and communication technologies (ICTs) as key enablers of state capability and service delivery reform (National Planning Commission, 2012). The Integrated Urban Development Framework (IUDF) further promotes smart governance, specifically through Policy Lever 9: Empowered Active Citizens, as an essential component of urban transformation (Department of Cooperative Governance, 2016). This strategic direction is reinforced by the Digital Economy Masterplan, which focuses on modernising public administration through 4IR technologies. Furthermore, the Protection of Personal Information Act (POPIA) (2013) introduces stringent data governance requirements, necessitating that municipal systems such as e-Joburg (for residents and businesses to manage, view, and pay municipal accounts (rates, water, electricity electronically) balance the drive for transparency with robust privacy protections and secure data management protocols.

Integrated Development Plan (IDP) and Digital Transformation Strategy articulate the City's commitment to digital governance, citizen-centred services, and data-informed decision-making (City of Johannesburg,

2022). Collectively, these frameworks provide a strong normative foundation for digital municipal governance, while simultaneously creating complex coordination demands across institutional structures, often resulting in the siloed technical implementations observed in the current digital ecosystem.

At the local level, Johannesburg's digital trajectory is operationalized through three primary strategic instruments:

- Joburg 2040 Growth and Development Strategy (GDS): This serves as the overarching "normative foundation" for the city. It defines Johannesburg's vision as a "World Class African City," providing the high-level, long-term justification for smart governance as a means to achieve social and economic transformation.
- Smart City Strategy (8 Pillars): This strategy provides the technical roadmap for the GDS. It specifically targets "Smart Governance" and "Smart Institutions" as foundational pillars, aiming to institutionalize digital performance across all municipal functions.
- Group Information Communication Technology (GICT) Scorecard: This functions as the City's internal governance and accountability mechanism. Through the scorecard, the City Manager establishes specific, evidence-based Key Performance Indicators (KPIs) for digital transformation. This ensures that high-level IDP goals are translated into measurable technical actions and departmental responsibilities.

3.2.1 Synthesis: The Coordination Challenge

The review of these frameworks reveals a paradoxical landscape. While a "strong normative foundation" exists, supported by constitutional mandates and local strategies, the practical reality is one of "complex coordination demands".

These demands arise because the frameworks originate from disparate sources: national mandates (National Treasury) often clash with local operational realities, while internal city departments (such as Finance vs. Communications) maintain separate reporting lines. This misalignment between multi-layered policy expectations and fragmented departmental structures leads directly to the institutional silos and technical overlaps identified in this audit.

4 RESEARCH METHODOLOGY

This research is designed as a qualitative, desktop-based evaluation of the coherence of Johannesburg's digital municipal system (municipal digital ecosystem). This research examines the gaps in the relationship between the high-level policy vision for the City and the technical implementation through a systematic review of the "paper trail" created by the City's governance practices.

4.1 Data Sourcing and Selection

The data collected for this research will be derived from secondary source data, thereby providing an overview that captures the full range of both the "promises" made by the city, and the "reality" of its systems recorded in the document collection below. The collection of documents referenced above represents the primary documentation that describes the City's systems and practices and therefore provides the best possible insight into the nature of the system.

- Legislative and Regulatory Frameworks: National laws such as the Municipal Systems Act and the Protection of Personal Information Act (POPIA).
- Strategic Municipal Mandates: The City of Johannesburg's Integrated Development Plan (IDP), Smart City Strategy, and Digital Transformation Strategy.
- Accountability and Performance Records: Annual Reports of the City of Johannesburg and the annual reports of the Auditor-General of South Africa to assess technical and financial oversight.
- Platform-Specific Documentation: Publicly accessible technical descriptions and service delivery portals for e-Joburg, Joburg Connect, the GIS Spatial Portal, and the My Smart City App.

4.2 Analytical Procedure: Document Analysis

The data was examined through a Document Analysis Process, a methodical procedure for examining/assessing both paper and electronic materials. The analysis was conducted in accordance with the framework outlined by Bowen (2009), and the documentation was systematically analyzed to determine data that would help establish empirical evidence related to the relationship between Digital Municipal Systems and the intended Policy Outcomes of those Systems.

This process was operationalized by filtering the gathered data through four critical analytical themes:

(1) Institutional Coordination: Examining how different departments and Municipal-Owned Entities (MOEs) collaborate on digital initiatives.

(2) System Interoperability: Auditing the technical capacity of different platforms to share data and function as a unified ecosystem.

(3) Accountability Mechanisms: Evaluating the "digital paper trails" and feedback loops provided by platforms for service delivery oversight.

(4) Inclusion: Assessing the extent to which digital tools accommodate diverse citizen needs and bridge the "digital divide".

4.3 Ethical Considerations

Since this research relied exclusively on publicly accessible data and did not involve interactions with human subjects, it was not necessary to obtain formal ethics approval for the study. This study maintains its integrity as an academic study using official government documents and existing qualitative analytic methodologies.

5 OVERVIEW OF DIGITAL MUNICIPAL SYSTEMS IN JOHANNESBURG

A major contradiction exists at the center of the Municipal Systems Act (2000). While Section 73 requires that all residents have access to their local government's services, the City of Johannesburg is heading toward a digital-first strategy, which may create a "fragmentation gap." In order to provide context for this agenda, this study will provide a brief overview of the digital municipal systems currently being used by the City of Johannesburg. These include e-Joburg, Joburg Connect, etc. These are the City's primary mechanisms for providing citizens with municipal services, facilitating citizen participation in decision-making processes, coordinating administrative activities, and developing spatial plans.

The table below (Table 1) illustrates the primary function(s) of each of the platforms identified above as well as the users of those platforms and the city's policy goals for those platforms. The table also maps these platforms to relevant legislation and strategies and therefore illustrates the City's formal digital infrastructure and establishes a framework to assess the gaps between the city's policy intentions and its operational practices.

Digital System/Platform	Primary Function	Primary User Base	Policy/Governance Alignment
Joburg Connect	Fault reporting & service complaints	Citizens/Residents	Public Participation: Municipal Systems Act
e-Joburg Portal	Billing, accounts, queries	Ratepayers	Transparency: ICT Policy Framework
GIS Spatial Portal	Spatial planning & land management	City Officials/Developers	Evidence-based planning: 4IR Strategic Goals
My Smart City App	Service coordination & citizen engagement	Mobile Users	Inclusivity: National Digital & ICT Policy

Table 1: Overview of Digital Municipal Systems in Johannesburg

The audit revealed that although the city has been successful in developing different platforms to support its departments, there is no one governing body that oversees how all of these platforms are developed or how their data is managed collectively; therefore, the lack of a unifying data governance framework has created many gaps between what the regulations intend and the ability to practically implement those regulations. These gaps are significant to interoperability and the ability to hold services accountable.

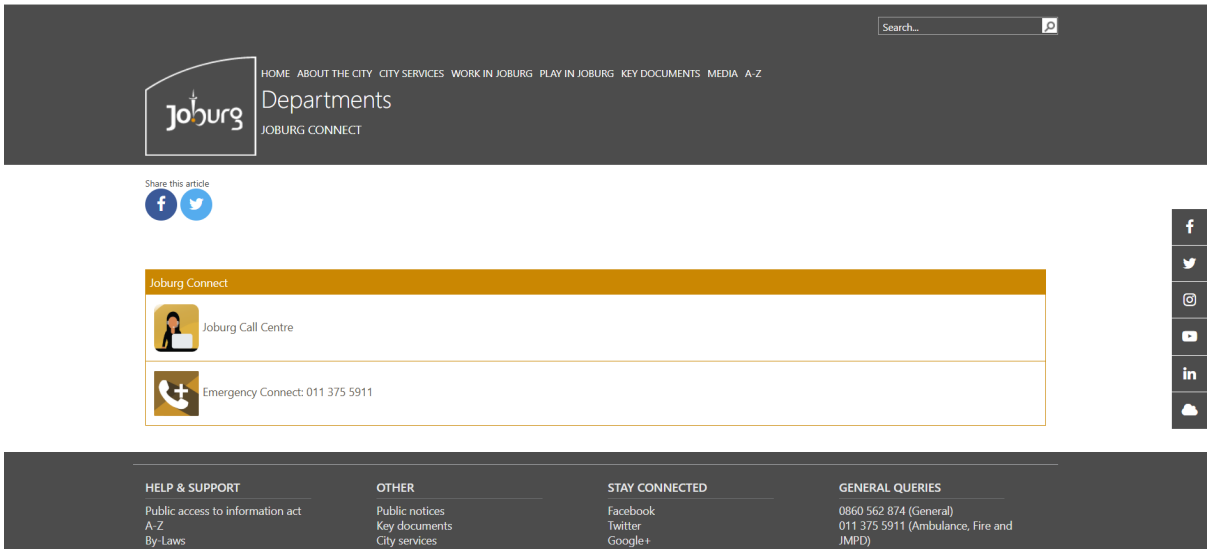


Fig. 1: Joburg Connect.

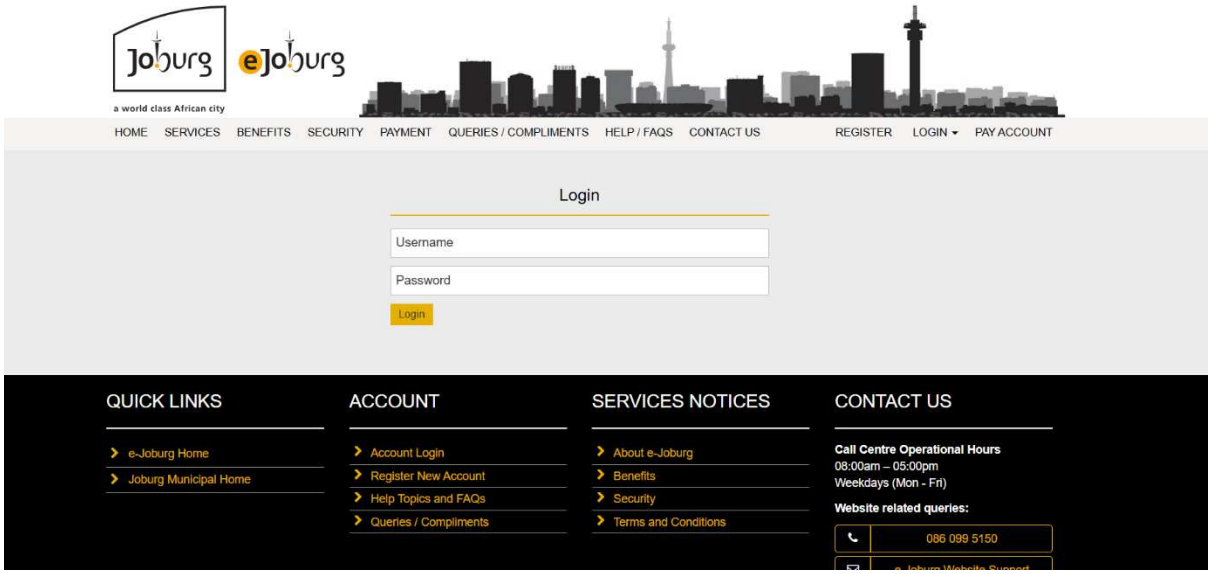


Fig. 2: e-joburg portal.

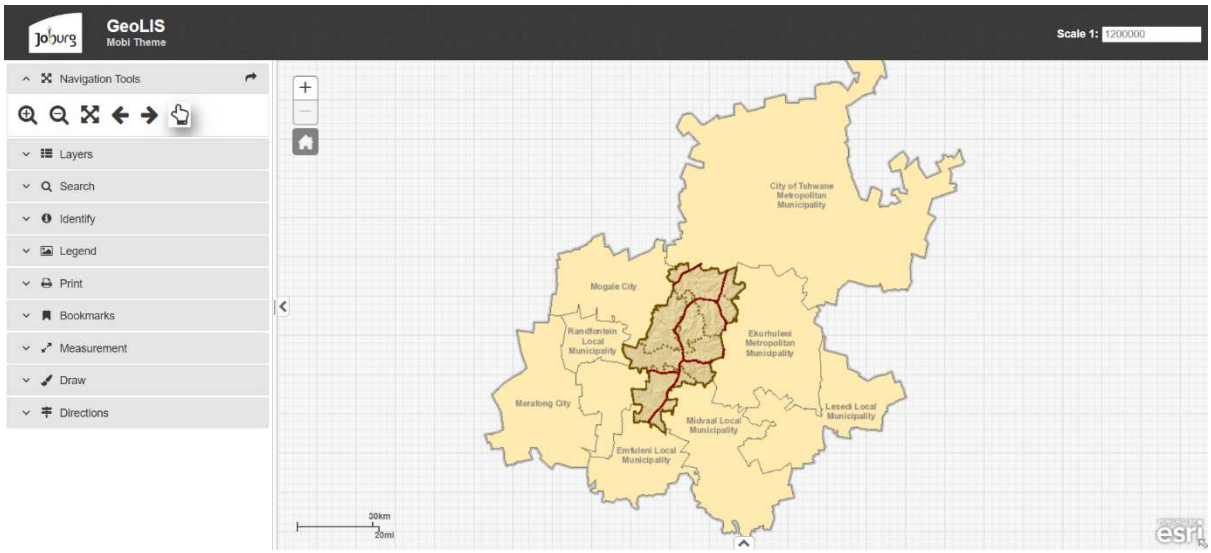


Fig. 3: GIS Spatial Portal.

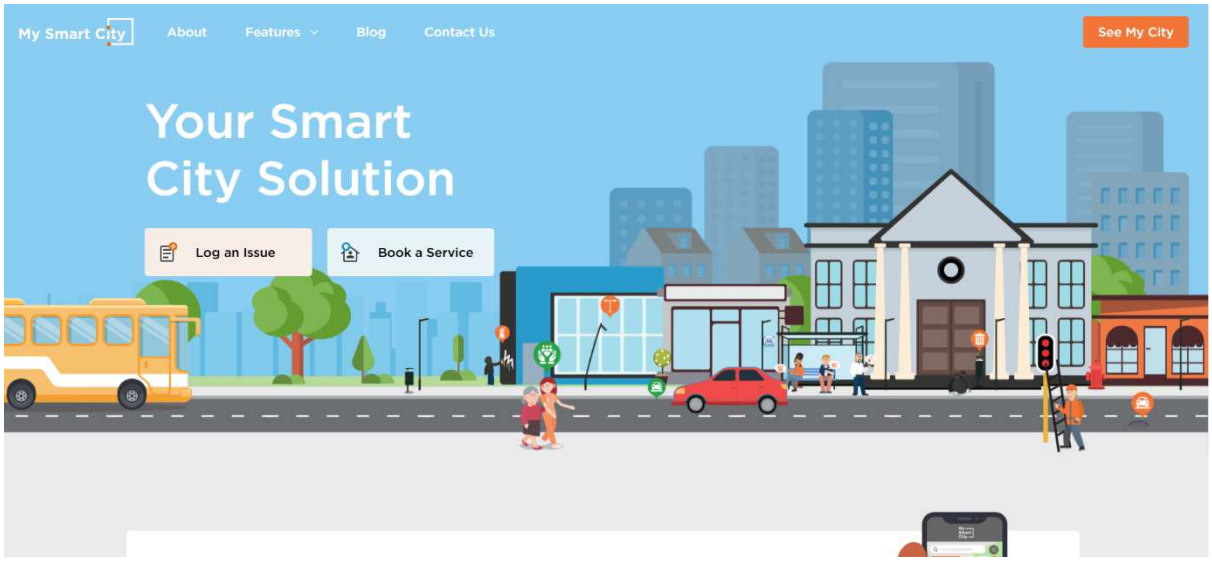


Fig. 4: My Smart City App.

Several digital systems support the operational activities of the City of Johannesburg in various ways. Some examples of these digital systems include; Joburg Connect which allows citizens to report faults with services, the e-Joburg portal that is used to facilitate customer interaction for billing and account management purposes, GIS (geographic information systems), and LIS (land information system) to enable the city's departments to plan for spatial development, and several call center and dash board type systems that are managed on behalf of the city's departments by the city's Metro Offices. While some of the digital systems listed above represent a significant digital investment by the city, the majority of them were developed and are being managed independently of one another at the departmental or entity level. This institutional configuration shapes how digital tools are used and limits their ability to function as integrated metropolitan governance instruments.

6 FINDINGS: DIGITAL MUNICIPAL SYSTEMS AND POLICY ALIGNMENT

6.1 Strategic Alignment with Policy Intent but Weak Operational Integration

The audit shows how, on a conceptual level, Johannesburg's municipal systems digitally support City of Johannesburg (2022), and Department of Co-operative Governance (2016) policy-based mandates around transparency, efficiency, and participation through platforms like Joburg Connect, which represent formal structures for citizens to interact and, in doing so, fulfill the participatory provisions within the Municipal Systems Act.

However, these concepts remain largely theoretical, and there is little empirical evidence of mandatory framework(s) requiring municipalities to ensure digital systems are being used interdepartmentally (MOE), therefore, the translation from policy aspiration to cohesive digital municipal governance practice is only partial.

6.2 Fragmented Digital Governance Across Municipal-Owned Entities

Most of the digital government exists in a fragmented manner among the various MOE's that are responsible for the most important urban service areas (e.g., electricity, water, waste collection, and roads), each of which has its own digital platforms, reporting mechanisms, and data systems, and very little interoperability.

This fragmentation limits the ability of the IUDF to achieve the integrated urban governance it seeks, and limits the city from creating a single, current view of how well services are being delivered (Department of Cooperative Governance, 2016), so that digital systems replicate the existing organizational silos instead of breaking through those silos.

6.3 Uneven Institutional Capacity and Digital Uptake

The audit highlights that there is a wide range in terms of institutional capacity among the different departments and regions. In this respect, while some have developed significant and sophisticated use of

digital dashboards and spatial data, many other departments and regions continue to operate using manual processes or legacy systems. The uneven development and implementation of digital systems and the resulting inability to integrate digital data with strategic decision-making for planning and capital investment are also identified as key barriers (OECD, 2020).

Additionally, the lack of defined digital competences and continuous capacity building initiatives restricts the strategic value of digital systems, which results in their continued use as operational tools and not as governance tools.

6.4 Digital Participation and Data Visibility Bias

While digital platforms have been implemented as a means to enhance citizen engagement opportunities for participation, there is evidence that this opportunity is spatially inequitable. Those locations that have greater internet connectivity and greater digital literacy rates tend to be overrepresented in the digital reporting data generated from the use of digital platforms, whereas informal settlements and peripheral communities are consistently underrepresented in the digital reporting data generated by their use of digital platforms. The result is data visibility bias, which reduces the visibility of digitally marginalized communities to governance systems and may also produce an unbalanced representation in how planners and policymakers make decisions about where resources should be allocated (Parnell & Pieterse, 2010).

6.5 Accountability and Feedback Loop Limitations

The findings indicate a weakness in feedback processes on digital platforms. Citizens may be able to submit complaints about services they are using, but citizens are generally unable to find out when their complaint will be addressed by which department(s) it will be assigned to, or how their complaint will ultimately be resolved. Thus, citizens have little reason to believe that their government is functioning effectively, and therefore, digital technologies cannot provide an effective means for citizens to hold government accountable for its actions (Meijer & Bolivar, 2016).

6.6 Policy Alignment and Fourth Industrial Revolution (4IR) Readiness

The audit also examined how well Johannesburg's digital local government platforms align with the policy and legislative objectives outlined in the Municipal Systems Act (Act No. 32 of 2000), South African national ICT policies, and the overall policy frameworks for the Fourth Industrial Revolution (4IR). Although the City has made significant investments in new digital systems aimed at improving service delivery and administrative processes, the audit's findings indicate that the current configuration of these systems does not provide the transformative governance desired by policy.

The Municipal Systems Act requires municipalities to provide municipal services inclusively by providing all citizens with equal access to these services. The study has found that the current digital platforms for delivering public services have the potential to exclude some residents from accessing municipal services due to a lack of digital technology in their area, low levels of digital literacy among residents, or unreliable digital connectivity in informal settlements and at the periphery of urban areas. If no alternative mechanisms, such as offline or hybrid access, are available to support residents who cannot easily use digital platforms, then they could potentially exacerbate existing social-spatial inequalities rather than alleviate them (United Nations, 2022; Republic of South Africa, 2000).

The policy framework for public participation emphasizes that citizens should be able to have an active role in the development of their local government. The digital platforms available in Johannesburg provide an opportunity for residents to report problems with city services and access information about city programs and policies. However, the current structure of these platforms is primarily used as one-way communications from the city to the resident, limiting opportunities for citizens to engage in deliberative discussions, co-create solutions to municipal issues, and receive feedback on how city policy and/or planning decisions affect them. Therefore, the potential for public participation in the digital governance of the City of Johannesburg is significantly less than what is envisioned by proponents of smart governance and the Fourth Industrial Revolution (Meijer & Bolivar, 2016).

Digital systems can produce "paper trails" for transparency and traceability in terms of service accountability; however, these systems are still not fully integrated to enable monitoring, oversight, or learning within institutions. Although there is a possibility to use digital tools to enhance accountability

through closed-loop feedback, the audit has shown an inability to do so, as there is currently no linkage from citizen input (front-end) to tracking the resolutions to those inputs (back-end).

Overall, it is suggested that Johannesburg has demonstrated partial 4IR-readiness characterized by technology adoption but without sufficient governance integration. A coordinated policy-driven strategy for advancing smart urban management will be required to align the digital system with the objectives of inclusivity, participation, and accountability in South Africa's local government framework.

6.7 Analysis of Audit Findings: The Fragmentation Gap

A substantial gap exists between the City of Johannesburg's strategic vision on how to govern digitally and its day-to-day operations. Although the City's policy debates define digitalization (and its related technological innovations) as an opportunity to make government more efficient, transparent, and to better coordinate services; however, our research finds that the City's digital landscape is a fractured one, limiting the transformative potential of those innovations.

A major barrier to achieving the transformative goals of those technologies is the lack of integration amongst them. The core technology platforms, including the e-Joburg portal, Joburg Connect, and the various geographic information systems operated by different City departments and city-owned entities, are largely incompatible, as they do not interoperate well. The media reports of late responses from the city, duplicated reporting, and unclear responsibilities all demonstrate that there are no integrated city-wide digital coordination tools in place.

Secondly, the study's findings have shown variable levels of governance of data. As a result, weak governance of data has resulted in unreliable, inaccessible, and unsustainable digital services for delivering public services. The lack of data visibility across the city (especially in informal areas) has created governance blind spots, which are likely to reduce the effectiveness of evidence-based planning as well as the ability to intervene at an early stage.

Thirdly, it can be seen that there is a significant gap between the regulatory ambition for enabling urban management through digitally enabled approaches articulated in the City's 4IR and Smart Cities Strategies, and the actual capacity for implementation, which is restricted by unstable governance, fragmented institutional authority, and limited operational integration.

This suggests that the digital challenge facing Johannesburg is less about having the technology and more about the institutional alignment and execution.

Therefore, these three aspects combined indicate that the current state of digital transformation in Johannesburg is characterized by partial adoption with no systemic integration. It is therefore critical to address this "fragmentation gap" to achieve the intended governance, planning, and service delivery benefits for municipalities and the national digital policy framework.

7 FINDINGS: DIGITAL MUNICIPAL SYSTEMS AND POLICY ALIGNMENT

Research suggests that the primary barriers to effective use of digital municipal systems in Johannesburg are largely institutional and governance-related as opposed to technological. The research is consistent with a body of literature from Global South countries, which indicates that digitalisation can only partially compensate for the consequences of a lack of coordination, poor administrative capacity, and fragmentation of authority (United Nations, 2022; Parnell & Pieterse, 2010).

Where digital systems do have some value, it is primarily when there are already high levels of integration and coordination, where they offer considerable opportunities for improved monitoring, planning, and citizen engagement.

7.1 Integrated Synthesis of Policy and Systemic Performance

The findings from the digital systems audit illustrate an extreme disconnect between the City of Johannesburg's "strong normative framework", as defined by the city's strategic frameworks and the actual operationalization of its municipal service delivery system; however, the three key points of tension identified in this synthesis represent the current state of digital governance for the City of Johannesburg.

7.2 The Disconnect Between Strategic Intent and Technical Silos

The audit verifies that "the proliferation of digital systems", including e-Joburg, Joburg Connect, and GIS Spatial Portal, is being developed in departmental silos. In contrast to the vision of an "integrated 'World Class African City'" presented in both the Joburg 2040 GDS and the Smart City Strategy, the current technical state of affairs presents a fragmented system with "little or no inter-departmental integration." Therefore, it can be inferred that the complex coordination demands generated from the overlap of multiple frameworks have resulted in a multitude of departmental function-specific systems (i.e., not integrated into a single, citizen-focused service).

7.3 Legislative Compliance vs. Practical Inclusivity

A contradiction is inherent to the Municipal Systems Act, as it provides for universal access (Section 73); the current "uneven alignment" of digital tools in terms of their inclusiveness does not currently allow for this principle. While platforms such as the My Smart City App are examples of how the community is moving toward Integrated Urban Development Framework (IUDF) Policy Lever 9 (Empowered Active Citizens), they are typically not designed or developed with the "governance compatibility" needed to provide service to all demographics of the city. Without a "coordinated Smart Governance Framework," the transition to digital-first service delivery could create a "digital divide", which would undermine the very purpose of enhancing transparency and citizen participation as provided in the National Development Plan 2030.

7.4 Data Governance as a Barrier to Accountability

The findings of this audit highlight a significant weakness in the City of Johannesburg's (CoJ) Digital Strategy due to an “inconsistent adherence to data governance standards,” as identified by the audit. Although both the Protection of Personal Information Act (POPIA) and the Municipal Finance Management Act (MFMA) require a high level of data integrity and accountability, the absence of “unified data governance standards” across all municipal platforms creates a major obstacle for the CoJ in delivering “reliable service delivery.” Until the GICT Scorecard KPIs advance from platform deployments to evaluate “interoperability” and “system functionality,” the CoJ will struggle to achieve “service accountability” as outlined in its IDP.

7.5 Synthesis Summary: Moving from Platforms to Ecosystems

The evidence presented here illustrates that the digital transformation of Johannesburg is at present platform-heavy; however, it has yet to be "ecosystem light." Therefore, to achieve the "long-term sustainability" described in the Smart City Strategy, the city needs to transition its focus from app development (or individual application) to the creation of an integrated, coordinated smart governance framework. It will require increased "integration of platforms" and "alignment of regulatory frameworks", so that technology acts as a facilitator of effective metropolitan governance, rather than a hindrance.

8 TOWARDS AN INTEGRATED SMART GOVERNANCE FRAMEWORK

To enhance digital municipal governance, this research presents a comprehensive framework to integrate:

(1) centralised digital governance oversight;

(2) enforceable interoperability standards across departments and MOEs;

(3) policy-driven system design aligned with constitutional and legislative mandates;

9 CONCLUSION

This study demonstrates that while Johannesburg has significant digital infrastructure to support governance, it is constrained by institutional fragmentation and poor policy system alignment. Conducting a digital systems audit identifies these problems and further supports the necessity of coordinated, policy-driven approaches to digital governance. To realize the transformative benefits associated with digital local government in cities such as Johannesburg in the Global South, institutional integration and accountability must be strengthened.

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District Sub Centres as Foundational Elements in the Implementation of the 15 Minute City Model: Case Study of Albertfalva

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1 ABSTRACT

The 15-minute city model aims to enable residents to reach the facilities necessary for everyday life within 15 minutes on foot or by bicycle. This study uses the example of Budapest's Albertfalva (sub)district (neighbourhood) to examine how district sub-centres could contribute to the implementation of this model. It was found that, while certain urban functions are present, community and service spaces do not form a real centre. Developing the area surrounding the former market building could fulfil this role. The results emphasise that designating central spaces is not an end in itself, but can be a vital step towards urban decentralisation and sustainability.

Keywords: 15-minute city, neighbourhood centres, urban decentralisation, mixed-use development, Albertfalva

2 INTRODUCTION

The 15-minute city model is predicated on the promotion of a polycentric urban structure, with an emphasis on the organisation of quotidian life around sub-centres and the concentration of essential functions in a decentralised manner.

The relevance of this city model is particularly evident in the context of contemporary issues, particularly those pertaining to sustainability. It presents a "greener" alternative to the reduction of car traffic, traffic jams, and the resultant pollution, which is an overarching objective. This commitment is further underscored by the European Union's allocation of 30% of its planned budget for the 2021-2027 period to the fight against climate change (europa.eu, 2024).

Albertfalva, is a neighbourhood in the 11th district of Budapest. It was selected for case study because previously it was an independent settlement, and with the revitalisation of the remaining (former) settlement centre (Szabó, 2016), it may be suitable for the creation of a sub-centre within 15 minutes' reach by "applying" the "15-minute city" model. Moreover, the neighbourhood is characterised by a diversity of housing typologies, including residential properties with gardens, panel housing estates constructed during the socialist era, and ongoing development of residential parks, thus providing a diversified urban context for the analysis.

After formulating the key planning–urbanistic and sociological questions related to the 15-minute city model, I examine the centre–subcentre context of the area, with particular attention to whether the traditional centre, through deliberate development, can continue to fulfil a central (core) role in the 21st century. The following research questions are linked to this overarching objective:

- The most important central functions are commercial, transport, and institutional functions. Are the basic institutions and services present within the neighbourhood?
- How can the sustainable concept of a 15-minute neighbourhood be implemented in Albertfalva?

3 LITERATURE REVIEW

3.1 The 15 minute city concept

The concept of the 15-minute city was first introduced by Carlos Moreno in 2016. The model under discussion is predicated on the notion that urban planning should be sustainable, and that cities, or in some cases city districts, should be designed in such a way that residents can reach all essential social functions and services within a 15-minute travel time (on foot or by bicycle) from their place of residence. This encompasses domains such as housing, employment, health and social care, education, entertainment, and other recreational activities (Moreno et al., 2021). The model is based on the concepts of neighbourhoods, diversity, density, digitalisation, and ubiquity (Moreno et al., 2021).

The neighbourhood is the smallest, yet arguably the most significant, unit of the urban structure. The concept of the "neighbourhood unit" was initially explored by Clarence Perry in 1923, with a focus on the planning of American suburbs (Szabó, 2016). As Pozoukidou and Chatziyiannaki (2021) argue, this space fulfils a dual function: it serves to meet the basic needs of residents whilst also facilitating community building and facilitating communication between people. It has been demonstrated that this contributes to the early detection of problems, the development of the local community, and the growth of mutual trust. The theoretical framework of neighbourhood units has exerted a significant influence on urban planning practices in Western Europe and within former socialist countries. The necessity to alleviate the burden on historic city centres was identified, and a potential solution was proposed as the creation of areas with neighbourhood unit functions in the outer parts of the city, involving the remaining centres of formerly independent settlements (Szabó, 2016).

The fundamental problem addressed by the 15-minute city concept stems from the increasing reliance on private car use and from cities that have been planned primarily to serve an automobile-oriented society (Moreno et al., 2021; Pozoukidou and Chatziyiannaki, 2021). In European – and thus Hungarian – cities, a key challenge is that they were not originally designed for cars and are therefore unable to cope with the current scale of motorised traffic. This situation may also entail economic consequences, as time lost in traffic congestion can result in productivity losses (Balletto et al., 2021; Forgács et al., 2010). Pollutant emissions constitute a particularly serious problem (Pozoukidou and Chatziyiannaki, 2021), and car-centred urban planning – often at the expense of public transport – negatively affects overall accessibility.

Researchers conceptualise the implementation of the 15-minute city through three main approaches. These include "avoidance," whereby non-walking and non-cycling travel can be reduced through the development of compact urban forms; "shift," referring to a modal shift towards walking and cycling, making shorter distances easily manageable; and the technological "improvement" of transport systems aimed at enhancing energy efficiency (Balletto et al., 2021).

3.2 Community and the city

Within the field of urban studies, organic thinking across generations can be interpreted as a fundamental principle. The present always reshapes its environment according to its own dynamics (Fülep, cit.Vidor 1977). The key concept of this logic is organic decentralisation (Gutkind, 1977). Within this framework, urban planning is understood as a medium- and long-term work process and set of activities through which "dense urban blocks – based on the example of Albertfalva, such as former industrial districts, etc. – may gradually be transformed into groups of separate residential communities, surrounded by green belts and spatially separated from one another" (Gutkind, 1977, p. 207).

Today, however, the prevailing spirit of the age does not necessarily place emphasis on separated and mutually isolated urban areas, as the 15-minute city represents a planning concept and form of implementation in which the emphasis lies on movement and mobility, as well as on equal access to the roles and functions provided by the city. Urban planning can essentially be understood as the aggregate of these preferences – historical traditions, local communities, families (households), commercial and industrial enterprises, as well as public institutions and the environmental expectations adaptable to them (Häussermann and Siebel, 2004).

4 METHODOLOGY

In accordance with the partnership principles of the European Union, it was hypothesised that representatives of institutions, collectives, and professional groups would be deemed experts on the subject in various prominent (elite) studies (Horváth, 2000). However, in the spirit of social consultation methodology (Letenyei, 2010), local residents were also surveyed, with a particular focus on potential individual actions related to the topic. Thirdly, content analysis was conducted using settlement-historical research, development plans, and the mapping services of Google Maps as primary sources.

In the course of the research, six semi-structured expert interviews were conducted with leading professionals and key stakeholders of Albertfalva. My aim was to reach individuals who not only possess substantial professional expertise in the architectural, historical, or sociological (community-related) aspects of urban planning, but who also have in-depth knowledge of the study area itself. The interviewees included the Chief Architect of Budapest's 11th District, the Head of the Urban Planning Department, a staff member

of the Albertfalva Local and School History Museum and former district cultural officer, the municipal representative of the electoral district and former teacher at the (Albertfalva) Petőfi School, as well as the professional officer and cultural programme coordinator of the Albertfalva Community Centre.The findings of the interviews are presented in the form of paraphrases in the relevant section, in relation to the given topic discussed therein.

The survey of local residents was conducted within a closed Facebook group (Albertfalva neighbourhood forum), which functioned as a bounded sampling frame. The collection of data was facilitated by convenience sampling with voluntary participation. The participants were invited to complete a structured questionnaire, which also incorporated open-ended questions. Furthermore, I sought to interview local residents in depth in order to gain insight into the area's history, their personal attachment to the area, patterns of place use, neighbourhood relations, and their future visions, needs, and expectations. A total of 35 respondents completed the questionnaire, and one additional resident participated in a face-to-face interview.As the research is a pilot study aimed at identifying problems, its results cannot be regarded as representative.

5 RESULTS: THE SITUATIONAL ANALYSIS OF ALBERTFALVA

Both writings on the history of the settlement (Virt, 1999; Hoffmann, 1997) and the Integrated Settlement Development Strategy of Újbuda (2022) shows that Albertfalva currently lacks a space that fully serves central functions. The strategy's objectives include the recultivation of Albertfalva's historic centre over several planning cycles. However, despite the potential benefits of such a space, including improved quality of life for the population, enhanced personal relationships and community cohesion, it appears to be a low priority for the district. As posited by several researchers and prominent figures in the field, Albertfalva's peripheral location within the district has resulted in its development being accorded a lower priority (Virt, 1999).

5.1 Demography and spatial structure

According to the 2022 census data of the Hungarian Central Statistical Office (KSH), the population of Albertfalva is 12,840 (KSH, 2023), which is just over 9% of the total population of District XI (this is directly proportional to the district's territorial distribution: Albertfalva covers an area of 3.05 km2, representing 9% of the district's total area (KSH, 2023).

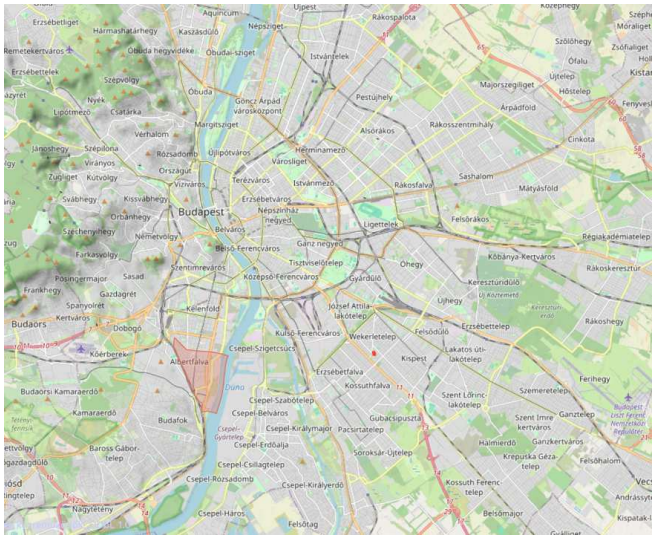


Fig. 1: Location of Albertfalva in Budapest (openstreetmap.org, own ed., 2026)

Researchers from Poland (Techet, 2020) published the capitals of the region in 2015, utilising data from the turn of the millennium. Budapest (primarily Buda) is distinguished by the homogenous appearance of social groups, while Albertfalva is still characterised by the “lower-middle”, “mixed”, and “polarized” category systems (at that time). Thi suggests that while Albertfalva was previously distinguished by its garden-suburban areas with detached houses and the Tisztviselőtelep (Civil Servants' Estate) inhabited by a population of higher social status, the “panel programme” and other mobility processes contributed to the polarisation of the population (Virt, 1999).

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As demonstrated in the National Atlas of Hungary (Kovács and Dövényi, 2021), a further detailed dataset indicating the entrenchment of the middle class in Albertfalva can also be observed (based on 2011 census data).

Despite the decrease in population, there has been a consistent increase in the housing stock. A new wave of housing construction began in the 2000s, with residential parks being built and continue to being built in the area. today in the district. These successive waves of construction have resulted in the establishment of a diversified neighbourhood. The area is characterised by residential properties with gardens, panel housing estates, residential parks and industrial zones. Furthermore, Albertfalva has direct access to the Danube, thereby further enriching the spatial structure of the district (Halabuk, 2000).

5.2 Overview of thearea and functionalanalysis

The objective of this subchapter is twofold: firstly, to examine the necessary functions of the 15-minute neighbourhood based on previous studies and research, and secondly, to attempt to identify these functions in Albertfalva. The categorisation of functions is defined in accordance with the methodology established by Papadopoulos et al. (2023). This categorisation was utilised as a reference in a survey conducted among the population, in which individuals were questioned on their needs and customary land use practices. The following section will present the findings of the research, including the facilities available in the district and the areas in which there are gaps in services.

The 15-minute city model proposed by Moreno does not necessitate the establishment or development of centres; rather, it emphasises density as a fundamental principle, underscoring the importance of optimising spatial utilisation (Moreno et al., 2021). The areas examined (sub-centres of the city) are not intended to concentrate and fulfil all functions in a single point or space; however, due to the size of the settlement (only 3.05 km2) and its spatial structure, I now refer to these as centers for the sake of analytical clarity and practical feasibility. Their long-standing historical development provides a foundation for their emergence as the central functions of everyday life are still evident in the presence of schools, a church, and an old market building. Residents predominantly move within these areas and along the north-south axis of Fehérvári Road, suggesting that the centralisation of key services and facilities in these areas would be a logical approach.

Furthermore, the study places emphasis on the following aspects of accessibility:

- state of the infrastructure: pedestrian walkways, public thoroughfares, the quality of public transport infrastructure, and the condition of cycle paths,
- availability of transport modes: public transport, smart devices such as scooters, bike-sharing and car-sharing
- car related issues: use of parking spaces.

Nevertheless, the involvement of the population – the promotion of participation – is imperative for the development of all these aspects. For this reason, the opinions of local inhabitants were sought with regard to the aforementioned aspects. Beyond these factors, the role of community constitutes a further key element. Putnam (2000) emphasises the importance of social capital, and Clarence Perry's neighbourhood theory also highlights the positive impact of community relations (Perry, cit. Szabó (2016), while identity, as a community-building and neighbourhood-strengthening factor, can also be key to implementing the 15-minute city model. IIn increasingly atomised and alienated societies, there is a clear need for spaces that foster a shared sense of identity. These could include places of worship, cultural institutions (such as community centres, libraries, theatres, cinemas, and to some extent cafes, restaurants, and bars). The Albertfalva case is distinctive in that it is an area with an extremely strong identity, where preserving traditions plays an important role. However, there is a lack of facilities and events in the district that are able to attract young people. The cultural representative of the Albertfalva Community Center also makes this observation, although he considers the ease of access to the inner part of District XI, the Bartók Quarter, to be a positive factor.

5.2.1 Institutions of education

Albertfalva is endowed with institutions providing primary education; however, residents are obliged to travel further beyond the neighbourhood in order to access secondary schools. Early childhood education and

primary schooling are available within the area with adequate spatial coverage, but only one primary school is publicly maintained and serves children primarily from the local community.



Fig. 2: Institutions of education (Google Maps, own ed., 2024)

5.2.2 Healthcare and social careinstitutions

The district is serviced by one adult and one paediatric GP practice, comprising a total of 9 adult and 4 paediatric doctors. According to the responses to the resident questionnaire, 20 and 15 respondents, respectively, consider this to be satisfactory (with an average score of 4.2 and 4.4 on a scale of 1 to 5). This finding is corroborated by personal interviews.

Dental care and other specialist clinics are only available in private practices within the district. While the function and service are provided, the issue of unequal access to these services may be problematic. However, it should be noted that this is not, of course, a deficiency specific to the district.

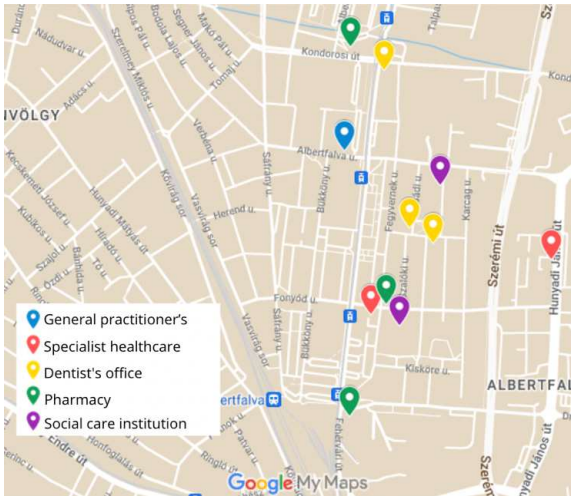


Fig. 3: Healthcare institutions (Google Maps, own ed., 2024)

A positive aspect of the district is the presence of numerous pharmacies, which are dispersed throughout the area.

At present, there are no specialist clinics or hospitals in Albertfalva. In terms of specialised healthcare and hospitals, the nearest facilities are accessible to residents within approximately 20 minutes by public transport.

With regard to social care provisions, the presence of a temporary and day care facility in Albertfalva operated by the Down Foundation is commendable. Despite the presence of a Senior Citizens' Club, it must be noted that the absence of a nursing home within the district constitutes a significant deficiency.

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5.2.3 Administrative institutions

Although several post offices previously operated within the neighbourhood, currently only one is available, located in the shopping centre on the southern periphery of the neighbourhood. Despite the absence of a police station and a fire station in Albertfalva, a district police office was established in the area in 2023. For residents of Albertfalva, administrative procedures cannot be carried out within a 15-minute walking distance; however, in the context of Budapest this limitation is more a matter of administrative organisation than of neighbourhood-level urban planning.

5.2.4 Commercial services

Commercial spaces have functioned as the focal points of urban areas since the early stages of urban development (Vazzoler and Roveroni, 2016). In the case of Albertfalva, it is not the quantity but the quality of commercial services that poses a greater challenge.

The district is home to a substantial shopping centre, which serves as an example of a multifaceted commercial hub. This establishment encompasses not only grocery stores but also a variety of commercial units, restaurants, and a post office, thereby fulfilling its role as a service centre. It was reported by all interviewees that the ability to accomplish multiple tasks simultaneously was a key benefit of the platform in question. The data from the resident questionnaire lends further support to this hypothesis, as it demonstrates that people do indeed use the facility, however, their attitude suggests that they do not consider it a convenient location to “quickly pop into” or “on the way”, but rather consider it a more distant destination.

The survey of the local population revealed that there are currently two supermarkets in Albertfalva (a figure that was three at the time of the survey). In addition to the aforementionedcommercial establishments, there are a number of diminutive retail outlets dispersed throughout the district. However, it is notable that the predominantly single-family residential area is under-served in this respect. Such local shops have the potential to provide a significant degree of support to elderly residents.

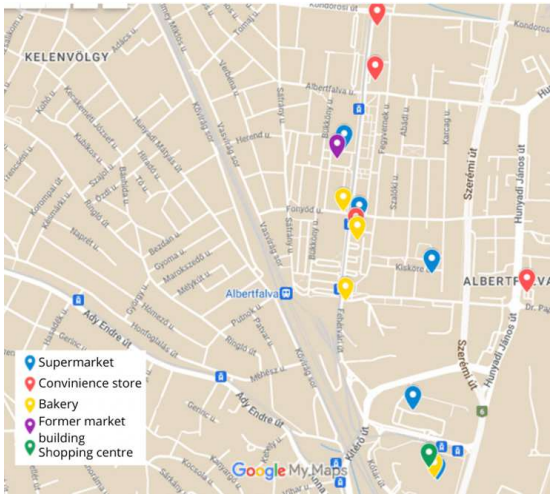


Fig. 4: Commercial services (Google Maps, own ed., 2024)

The inner part of the neighbourhood has a limited number of commercial service providers specialising in non-food items. However, the presence of such professions is shaped by market demand. While they may represent valuable everyday amenities at the local level, they are more commonly concentrated in district-level centres. Consequently, the shopping centre functions as a focal point for a variety of these services. In addition, a variety of smaller commercial enterprises and service providers are located along the northern end of Albertfalva.

5.2.5 Entertainment services

The current situation of hospitality and entertainment venues in Albertfalva presents a distinctive picture. The majority of establishments fulfilling such functions are concentrated along the central “retail strip”. However, the actual usability of these facilities and the quality of the services provided raise several questions. Most restaurants are primarily oriented towards takeaway and delivery services, lack dedicated seating areas or outdoor terraces, or are designed mainly to serve office workers, with opening hours

adjusted accordingly. The place-use patterns reported by residents reflect this situation, as fewer than one third of respondents (ten individuals) visit these establishments on a monthly basis, while the remainder do so even less frequently or not at all.

Albertfalva is a neighbourhood with a single pub, which is currently unable to fulfil its function as a place for civilized social leisure activities or to serve a wide range of age groups. According to the respondents' own statements, 60% of those who completed the questionnaire never attend.

Several interviewees highlighted the absence of a cinema, which could serve as an important venue for entertainment and recreation, particularly given that such a facility had previously existed in the area.

5.2.6 Cultural facilities

The representatives of the Albertfalva Community Center place great emphasis on serving older people and parents with young children, organizing programs, and providing space, however, they find it difficult to reach younger demographics.They agree that it is easier to build on existing communities, and they see the strength of the community center in Albertfalva's strong identity.

The Community Centre organises courses, provides space for civic initiatives and the activities of civil organisations, hosts various interest-based clubs, and serves as a venue for occasional events. Although Albertfalva does not have a theatre, the Petőfi Musical Studio operates within the Community Centre, partially fulfilling this cultural function.

In principle, the Community Centre could be considered one of Albertfalva's main meeting places; however, 40% of respondents to the resident survey reported that they had never visited the facility. At the same time, two respondents indicated that they visit the centre on a weekly basis; both have lived in Albertfalva since birth. These findings are consistent with the observations shared by the interviewees. Furthermore, the neighbourhood is without a public library, a facility that was previously present in Albertfalva.

5.2.7 Religious institutions

In Albertfalva, faith and religion play a significant role as forces of community formation. According to the shared views of the interviewees, the Saint Michael's Church functions as an especially important communal space, particularly for older residents. In the immediate vicinity of the church, a community centre serving the religious congregation has recently been established; this facility supports not only religious activities but also provides space for other organisations and community initiatives.

5.2.8 Recreational areas, parks

Although Albertfalva's suburban character might lead one to conclude that it has a sufficient quantity and quality of green space, the map-based functional assessment does not support this assumption. The assessment concluded that there are seven parks in Albertfalva. According to the assessment, there are seven parks in Albertfalva, but a closer look reveals a different picture: both field observations and residents' opinions indicate that only two of these areas function as genuine recreational spaces. Even in these cases, several shortcomings can be identified, such as limited suitability for all age groups and the lack of complementary functions (e.g. hospitality services or sports facilities). In general, the parks within the neighbourhood tend to be small-scale green areas, in some cases lacking even tree cover.

One interviewee noted the presence of a community garden and a community composting facility in Albertfalva. However, the extent to which the population makes use of the garden located in the garden house area is questionable.

Albertfalva's waterfront location offers untapped opportunities for neighbourhood development, as the area is bordered along its entire eastern side by the Danube. The Árasztó-bank, in particular, represents a high-potential development area due to its direct riverfront connection and its unbuilt character.

Playgrounds are distributed throughout almost all parts of the neighbourhood and are actively used by local residents. They are generally of good quality. These playgrounds play an important role in the life of the local community, as they not only provide a safe and entertaining place for children to play and exercise, but also serve as a meeting point for parents and local residents. This assertion is substantiated by the observation that two respondents who completed the survey regarded the playgrounds as the "heart" of Albertfalva.

The district has a long-standing swimming pool and sports complex, which has recently undergone complete renovation (Albertfalva Local History and School History Museum, 2024).



Fig. 5: Recreational areas, parks (Google Maps, own ed., 2024)

5.2.9 Transportation

Albertfalva is a neighbourhood with strong spatial connectivity and is very well integrated into Budapest's transport network. Several lines of the Buda interlinked tram network pass through the area, including tram lines 17 (connecting Savoya Park and Óbuda), 41 (between Kamaraerdő and Óbuda), 47 and 48 (linking Budafok Centre with Deák Ferenc Square), and 56 (operating along the Budafok–Hűvösvölgy route). In addition, bus line 7 – one of the main east–west corridors crossing the entire city – also runs through Albertfalva, with one of its termini located at Albertfalva railway station and stops at several major transport nodes across Budapest. Bus services connecting Budafok with Móricz Zsigmond Square likewise pass through the neighbourhood.

Albertfalva railway station could also function as an important transport node; however, only a limited number of train services operate from here to Kelenföld railway station or to Kőbánya-Kispest (primarily from the direction of Székesfehérvár). While the rail infrastructure is therefore in place, its more intensive use could represent a further opportunity for improving local and metropolitan mobility.

At the same time, these favourable transport conditions raise questions regarding the feasibility of implementing the 15-minute city model. Several participants in the expert interviews pointed out that Albertfalva's very good accessibility and transport connections may, paradoxically, hinder the development of more locally oriented, proximity-based urban functions.

In my view, strong spatial connectivity should not hinder the emergence and long-term viability of liveable neighbourhoods and accessible local services. Where local transport is supported by appropriate infrastructure – of the kind required for the 15-minute city – residents tend to make natural and routine use of these systems.

A quote from Fred Kent (2005) "If you plan cities for cars and traffic, you get cars and traffic. If you plan for people and places, you get people and places." This principle highlights how the design of infrastructure and urban spaces determines how people use them.

Albertfalva's cycling infrastructure consists of a semi-separated cycling path along the eastern edge of the neighbourhood on a major arterial road, which is located at a distance from the areas most actively used by residents, and a cycling lane running through the low-density residential zone, however, cyclist movement is impeded by cars parked on the lane. The street where tram services operate and the majority of local traffic occurs lacks dedicated cycling infrastructure. This represents a significant development opportunity in implementing the 15-minute city concept. The expansion of the cycling network, particularly in routes connecting residential areas with local amenities, has the potential to enhance the frequency of bicycle use. This has the potential to increase the frequency of bicycle use, which is significant for both environmental sustainability and public health.

The following diagram illustrates the transportation habits of residential respondents. The diagram indicates that walking is the predominant form of transportation in Albertfalva, with cycling being less favoured. The

survey data indicates that the majority the responding local residents primarily utilise public transportation for intra-district and urban mobility. However, in both scenarios, private vehicle usage ranks second.

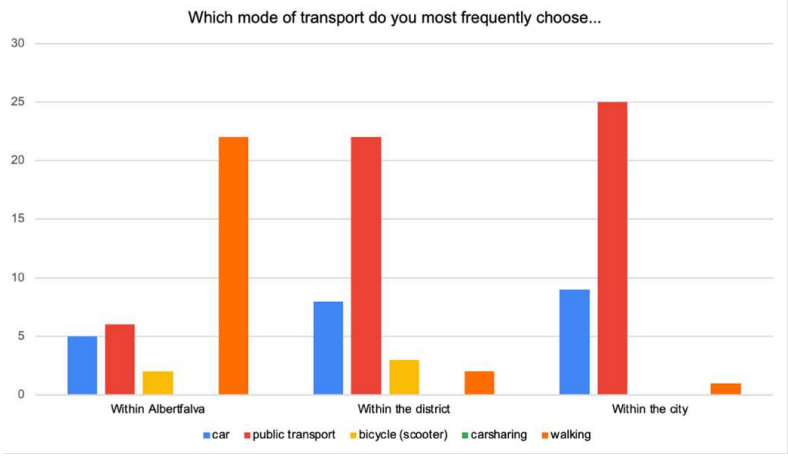


Fig. 6: Mode of transport used by respondents (own ed., 2024)

The concept of the 15-minute city is based on reducing car use, therefore, issues related to automobility warrant particular attention. Several interviewees mentioned the division of parking zones as a problem, as at the time of the data collection Albertfalva lay outside the regulated parking areas and, as a result, the neighbourhood effectively functions as an informal park-and-ride (P+R) area for commuters arriving from the metropolitan agglomeration. This situation implies that parking demand in Albertfalva is shaped not only by local car use but also by the needs of inbound commuters. This trend has a negative impact on the use of space in Albertfalva and the quality of life of its residents in several ways, as the mass presence of cars from the agglomeration increases the demand for parking spaces, making it more difficult for local residents to find free parking spaces near their homes, increased car traffic has adverse environmental impacts and the spatial constraints imposed by increased traffic and the occupation of land by parked cars serve to impede the feasibility of establishing community spaces and green areas, both of which are pivotal components of the 15-minute city concept.

Smart, sharing-based transportation options, such as car-sharing services (e.g., Mol Limo, GreenGo), bike-sharing (e.g. Mol Bubi) or shared scooters (Lime), play a significant role in the future of modern urban mobility. However, it can be observed that the use of these services in Albertfalva is less widespread, based on the fact, that the MOL Bubi system is not currently available within the neighbourhood, on interview reports and the above diagram. However, the integration of these modes of transport contributes to all aspects of sustainability: they are a more environmentally friendly alternative, they can be more cost-effective than owning a car (especially if it is rarely used)and finally, in some cases, they can even have positive social implications, as they encourage community thinking and a culture of sharing. In addition, reducing the number of parking spaces can “give back” space to people.

It is evident that public transport facilitates convenient access to the central areas of District XI and even to the primary centres of Budapest (a direct tram connection between Albertfalva and Deák Ferenc Square). Nevertheless, there is a need for sustainable transport developments within the district that offer local alternatives and aim to ensure a liveable neighbourhood and access to local services (e.g. bike paths and walkable sidewalks).

5.3 Identity and community

Prominent figures in Albertfalva emphasise the profound roots and resilience of the district's identity. According to their interpretation, the origins of this lie in historical factors, as Albertfalva was once an independent settlement with a homogeneous society and significant industrial activity. All this not only evokes the past, but also defines the present identity and cohesion.

They also attribute importance to the fact that in certain areas, such as the Tisztviselőtelep, the population has lived for decades, across generations, in a protected area which, due to building regulations, has been able to preserve its original character and appearance. As a result, the houses still faithfully reflect the former form of this part of the settlement. The strong identity of Albertfalva’s community is further supported by

various tradition-preserving groups and their activities, which play an important role in the preservation and transmission of local culture.

This approach is closely linked to the perspective of the planners and the district chief architect, who emphasise that the past must not be forgotten in the development of the town. They argue that preserving local history is not only about respect for the past, but also about creating a strong and cohesive community.

The interviews and resident questionnaires highlight the importance of community and participation for Albertfalva's residents. The interviewees further emphasize the importance of neighbourly relationships, particularly in the case of the Tisztviselőtelep. Respondents to the residential questionnaire also tend to perceive their neighbourhood relations as rather strong.

The Advent season, for instance, is perhaps the most striking example of this phenomenon. During this period, the houses in Tisztviselőtelep are transformed into a living Advent calendar, and residents gather at the decorated houses.

5.4 Suggestion for a neighbourhood "centre"

So where could a district center emerge that could serve as a starting point for implementing the 15-minute city model? Based on interviews with prominent figures and surveys of residents, this study focuses on the characteristics associated with the traditional centre of the area.

Following the analysis of functions in question, it can be concluded that although Albertfalva does not currently have a clearly defined centre, the most promising area in this respect is Albertfalva Street and its environs, i.e. the historic centre. This area is considered to be in the centre not only in the eyes of the residents but also in spatial terms.

However, Savoya Park should also be mentioned as a new central area defined in terms of architecture and urban planning.

Albertfalva Street and its surroundings were considered the nucleus of old Albertfalva, and even today one can find facilities with a centralising force here (such as a church, schools, and a doctor's office), but by now, several functions have disappeared from the area and thus from the district as well, such as the cinema, restaurants, and pubs. According to one of my interviewees, there were at least ten of the latter (and these services were not separate from each other in Albertfalva's past (Virt, 1999)) in this neighborhood or nearby until 40-50 years ago.

In my view, therefore, if a neighbourhood centre is to be established in this area – which is also geographically located at the heart of the district – or if the emergence of such a centre is to be supported through urban development instruments, particular attention must be given to the reintroduction of community-oriented, recreational, and cultural functions. Not only is there limited space for such functions elsewhere in the neighbourhood, but local traditions and a strong sense of identity also suggest that residents would be most inclined to use these facilities in this location.



Fig. 7: Albertfalva Street and surrounding area: key local functions (Google Maps, own ed., 2025)

At the same time, the mere creation of meeting places (such as cafés or community spaces) is insufficient if these services are not underpinned by appropriate infrastructure. From this perspective, I consider road-

related interventions and traffic restrictions in the surrounding area to be necessary, particularly in the vicinity of the former market. This, however, is complicated by the presence of a supermarket and its associated car park in the immediate proximity of the former market site, as such a large-scale retail facility not only requires substantial space but also generates significant traffic. However, in my assessment, all this only further weakens the former center of social life, whilst reinforcing rapid, task-oriented use, encuraging people to conclude their activities (i.e. shopping) in this location as quickly as possible and depart. In light of this, it is worth to pay attention to various traffic calming (and elimination) measures. The modernisation of the market building, the rehabilitation of its function, and its renovation have the potential to contribute significantly to the enhancement of the quality of life in the district and the promotion of community life.

My interviewees emphasized that the first step would be to modernize the building's heating system so that it could be used all year round. To do this, the local government must attract private investors willing to fund the renovation and operation of the building, contingent upon certain conditions. These include the preservation of the building's original function during the renovation process, thereby ensuring the continuity of operations as a market.

However, the indisputable role of the supermarket can also be approached from another angle. One of my interviewees believes that the proximity of the store would also promote the use of the market and, what is more, would rather revitalize it.

A local government representative from Albertfalva said that the market had never fulfilled its traditional role, and based on this, it was suggested that the building could be treated as a mixed-use area (especially considering that market days do not take place every day), with functions such as a cinema, other retail shops, or various catering establishments, which could have terraces opening from the inside or even outdoor “street-front” spaces (depending on traffic calming/elimination), allowing people to spend their free time in the open air while using the services.

6 CONCLUSION

The 15-minute city model is a potential response to the socio-spatial transformations occurring in contemporary urban spaces. While city centres were once prominent in terms of economic activity and real estate values, today the structure of cities is increasingly being reshaped by a network of decentralised, functionally diverse sub-centres. These areas are capable of functioning independently, but through their rich networks of connections, they become part of the city as a whole – in terms of transportation, services, and community life.

In this study, the role of district centres was examined in the context of the 15-minute city concept, with the Albertfalva neighbourhood serving as a case study. The study revealed that, while the area exhibits certain urban functions, it currently lacks an integrated community and service centre that would be capable of operating in accordance with the principles of the model. The proposed developments are primarily aimed at improving non-motorised transport accessibility, community spaces, and service diversity.

However, it is important to emphasise that the 15-minute city concept is not based solely on the existence or designation of centres. Rather, the model focuses on functional accessibility within the urban fabric, access to services necessary for everyday life, and residents' opportunities to use space. Consequently, the identification of centres is not a prerequisite for the implementation of the 15-minute city, rather the revitalisation of an underutilised area with potential can most effectively become the practical basis for the model.

This pilot study provides a foundation for further, more comprehensive research that extends beyond a single neighbourhood and incorporates multiple urban areas with differing characteristics, in order to examine the feasibility of implementing the 15-minute city model across different urban contexts.

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Earth Observation and Open Geodata for Sustainable Urban Planning – A Practical Case Study from the City of Munich, Germany

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1 ABSTRACT

Cities are hot spots of development and urbanization is a persistently ongoing phenomenon worldwide. Also in Germany, where the urbanization rate is already at the high level of 80%, the ongoing shift towards cities puts increasing pressure on land use and urban planning. The challenge of competing land uses is particularly evident in densely built-up urban areas and their immediate surroundings, where housing, industry, transportation, and open spaces compete for limited space already in the planning phase.

In this study, we investigate a major urban development project by the city of Munich which aims to create a completely new urban district for up to 30,000 new residents. At present, the project has been approved by the city council, and an initial draft plan is already available. This plan is undergoing further review in various areas (e.g., transport, climate, ecology) in order to refine the draft. The practical implementation of the project is scheduled for the 2030s.

To support the ongoing debates on the practical design of the new district, we utilize Earth Observation data with very-high spatial resolution in combination with open geodata to investigate the current status of land use and land cover (LULC) within the study area, as well as the entire city of Munich. On this basis, we focus on the analysis of new urban development areas that were finalized during the past decade in Munich, which serve as practical examples of potential construction in the new district. The effect on LULC is not only illustrated visually but also evaluated quantitatively based on geospatial data. In addition to the analysis of changes in LULC, we also provide a statistical estimate of the resulting living space for the new residents based on Earth Observation and other geodata. Finally, the study examines possible implementations not only of built-up areas, but also developments and potential changes in open spaces.

With this set of data, methods, and geoinformation, this study makes a contribution to the discussion on the design and implementation of new urban development projects. It is applicable to projects at all scales and provides an illustrative view of the impact of planning projects in the targeted area. In addition, it allows to support decision making and also adds to the public debate on competing land uses on limited space, which is particularly crucial in urban areas.

Keywords: Earth Observation, urban planning, land consumption, population estimation, Munich, Germany

2 INTRODUCTION

Urbanization is an ongoing phenomenon worldwide which leads to a persistent demand for housing in cities (Taubenböck et al. 2024). This is accompanied by expansion of cities and continuous development of new districts. However, in many cases around the globe, the construction of new residential districts and the provision of housing do not match the actual demand, resulting in housing shortage and rising prices (van Doorn et al. 2019).

In Germany, with an urbanization rate at the high level of 80% according to official statistics (UN, 2020), urbanization remains steady with a continuous demand for housing (Shahab et al. 2021), especially in economically strong metropolitan areas like Munich (Müther and Waltersbacher 2025). In this context,

targeted and future-oriented land use and urban planning plays an indispensable role not only to meet the demand for housing, but also to preserve the quality of life in cities and enable them for future challenges, e.g. associated with climate change (Gupta et al. 2025).

Earth Observation (EO) has proven a suitable tool for monitoring of land use and land cover (LULC) and to support land use and urban planning (Bielecka et al. 2025). In particular, EO-based data and derived information with very-high spatial resolution (VHR) offer a suitable basis for application in urban environments, where diverse objects and land cover are concentrated in a highly dynamic manner at small spatial scale, and thus, sufficient spatial resolution to capture all details is essential. This allows not only the detailed assessment of LULC and its changes to date within the area under study, but also scenario simulations and relative comparisons across locations for quantification of the impact of planning decisions (Wang et al. 2021). In addition, EO in combination with open geodata facilitates population estimation beyond official census data or planning estimates, providing consistent and area-wide information (Leichtle et al. 2019, Stevens et al. 2015). Finally, EO- and Geographic Information System (GIS)-based methods support the illustration and elaboration of the effect of LULC changes as a result of planning decisions and urbanization on a specific area (Wellmann et al. 2020).

In this study, we demonstrate the potential of VHR EO and open geodata for application in the context of a major urban development project in Munich, Germany. This work aims at the illustration and quantification of potential LULC changes as a result of planning, while also considering different scenarios in an early stage of planning. In particular, we focus on the assessment of residential housing capacity, which is crucial with regard to overcoming the shortage of housing today and in the future.

3 STUDY AREA & DATA

The study area is located in the city of Munich, which covers an administrative area of 310 km² and represents one of the most dynamic metropolitan areas in Germany. At the end of the year 2024, Munich housed around 1.60 million inhabitants, while this number is estimated to increase to 1.83 million in 2045 (Landeshauptstadt München, 2025a). The projected population growth of 14.1 % over the next two decades underlines the urgent need for adequate urban planning in order to meet the housing demand and to ensure sustainable urban development.

3.1 A New Urban District in Northeast Munich

As part of the general urban development plan of the city of Munich, an area of 600 ha in northeast Munich represents one of the major urban development projects of the coming decades (https://stadt.muenchen.de/infos/zukunftsquartier-muenchner-nordosten.html). In this area, it is planned to establish a new urban district for up to 30,000 new residents. At present, the project has been approved by the city council and an initial draft plan is available as a result of an idea competition. It delineates areas of different land use, including built-up areas, green spaces, natural green areas, and activity areas, as well as an initial plan for public and private transport (Figure 1). The initial plan is currently undergoing further review in various sub-areas (e.g., transport, climate, ecology) in order to refine the draft. The practical implementation of the project is scheduled for the decade after 2030.

3.2 Earth Observation and Open Geodata

In this study, we use different sources of geospatial data in order to conduct a comprehensive assessment across multiple dimesnions.

VHR EO data is collected by the WorldView mission with a pixel size up to 30 cm. For Munich, a cloud free WorldView-3 scene covering eight spectral bands is used, which was acquired on 04.07.2019 and provided by European Space Imaging (EUSI, www.euspaceimaging.com). Height information is included through a normalized Digital Surface Model (nDSM) with a spatial resolution of 50cm provided by the city of Munich. In addition, data from Open Street Map (OSM) covering the same time period is employed. Building envelopes are obtained as Open Data from the Free State of Bavaria.[1] For visualization and illustration purposes, aerial imagery from the Open Data Portal of Bavaria are used.

[1] https://geodaten.bayern.de/opengeodata/

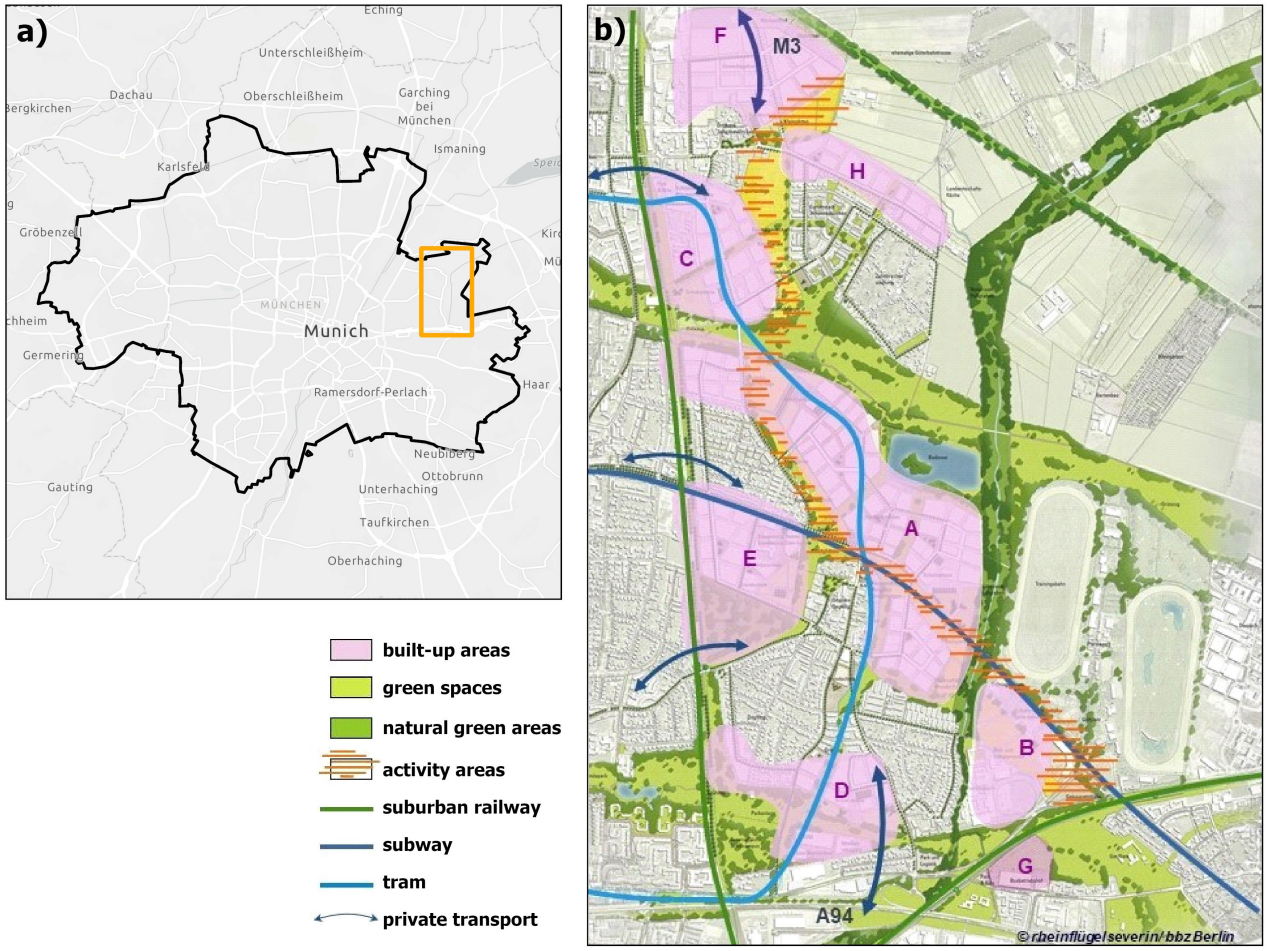


Fig. 1: Location of the study area within the city of Munich (a) and initial draft plan of the new district in northeast Munich (b).

4 METHODOLOGY

The methodology of this work consists of four main steps which are described in the following.

First, in order to derive a spatially consistent data basis on the current situation of LULC, an object-based classification approach based on the methodological foundations introduced in Taubenböck et al. (2010) and Wurm et al. (2011) is implemented. This approach relies on the WorldView-3 imagery, the VHR nDSM, OSM data, and the building envelopes. Target classes include “buildings”, “impervious surfaces”, “bare soil”, “trees”, “low vegetation”, and “water”. The quantitative evaluation of classifiaction accuracy is realized through visual collection of reference samples at randomly distributed locations.

Second, practical examples of existing residential built-up areas and open spaces across Munich are used for evaluating potential realizations of residential construction or types of open spaces in the new district. These are collected across the entire city of Munich, covering open spaces as well as built-up areas. Reference areas for open spaces (i.e. green spaces, natural green areas, and activity areas) are collected regardless of their construction date throughout the city. For built-up areas, we select three new urban developments in Munich that were finalized during the past decade, in order to take current architectural concepts and trends into account.

Third, for the assessment of the potential effects of the new development in northeast Munich, the current land cover of open spaces and built-up areas according to the draft plan is determined based on the EO-based land cover classification. This is compared to the statistical distributions of the land cover classes from the reference areas, i.e. open spaces as well as the three examples of residential built-up areas.

Finally, we conduct a statistical estimation of avaiable living space for the three existing types of residential construction that serve as practical examples of new urban development in Munich. For each individual building, the number of floors is multiplied with the building area to derive floor area per building (Leichtle et al. 2019). The number of floors in each of the three reference areas is assessed by manual inspection and

extrapolated according to built-up areas in the draft plan of the new district in northeast Munich. To account for uninhabited areas within buildings, such as balconies or stairwells, a uniform 10% of the living space per building is deducted (Landeshauptstadt München, 2025b). Based on the available living space, the potential population is calculated using an average living space of 39.5 m² per person (Landeshauptstadt München, 2025b).

5 RESULTS

5.1 Land Cover Classification

Figure 2 shows the result of the object-based classification of land cover using VHR remote sensing. Besides the WorldView-3 imagery acquired on 04.07.2019, the VHR nDSM, OSM data, and building envelopes are considered in this approach. Accuracy assessment based on visual inspection of randomly distributed points within the study area resulted in 88% overall accuracy. For further analysis in this work, the original land cover classes are aggregated as shown in Figure 2.

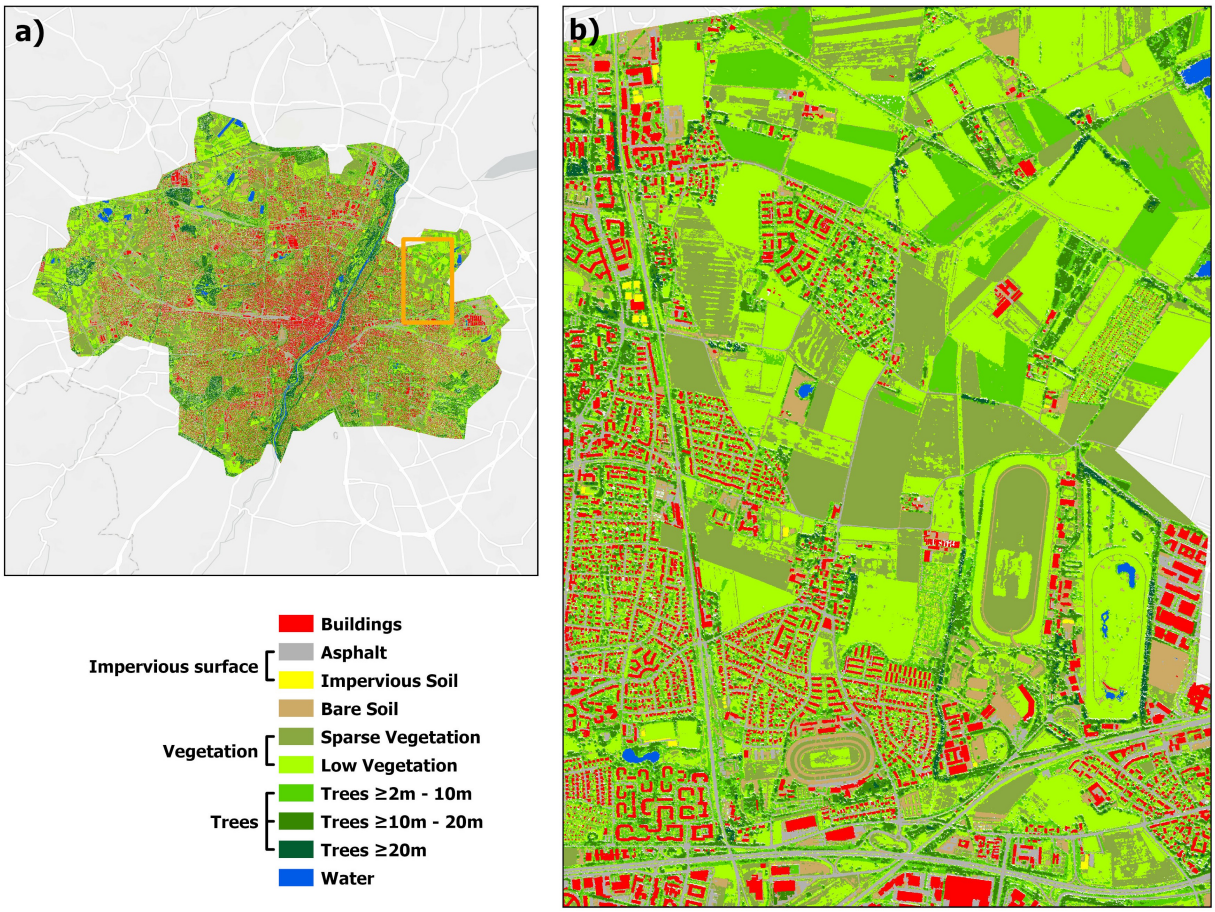


Fig. 2: Land Cover classification based on the WorldView-3 imagery acquired on 04.07.2019, the VHR nDSM, OSM data, and building envelopes. Overview of the city of Munich (a) and detailed view of the new district in northeast Munich (b).

5.2 Collection of Reference Areas

Since the design and implementation of open spaces as well as the type of development on built-up areas in the new district are not yet determined in the early planning phase, reference areas across the entire city of Munich serve as examples of potential realizations. The locations of reference areas for built-up areas, green spaces, natural green areas, and activity areas are illustrated in Figure 3. For built-up areas, three new urban developments that were finalized during the past decade were selected.

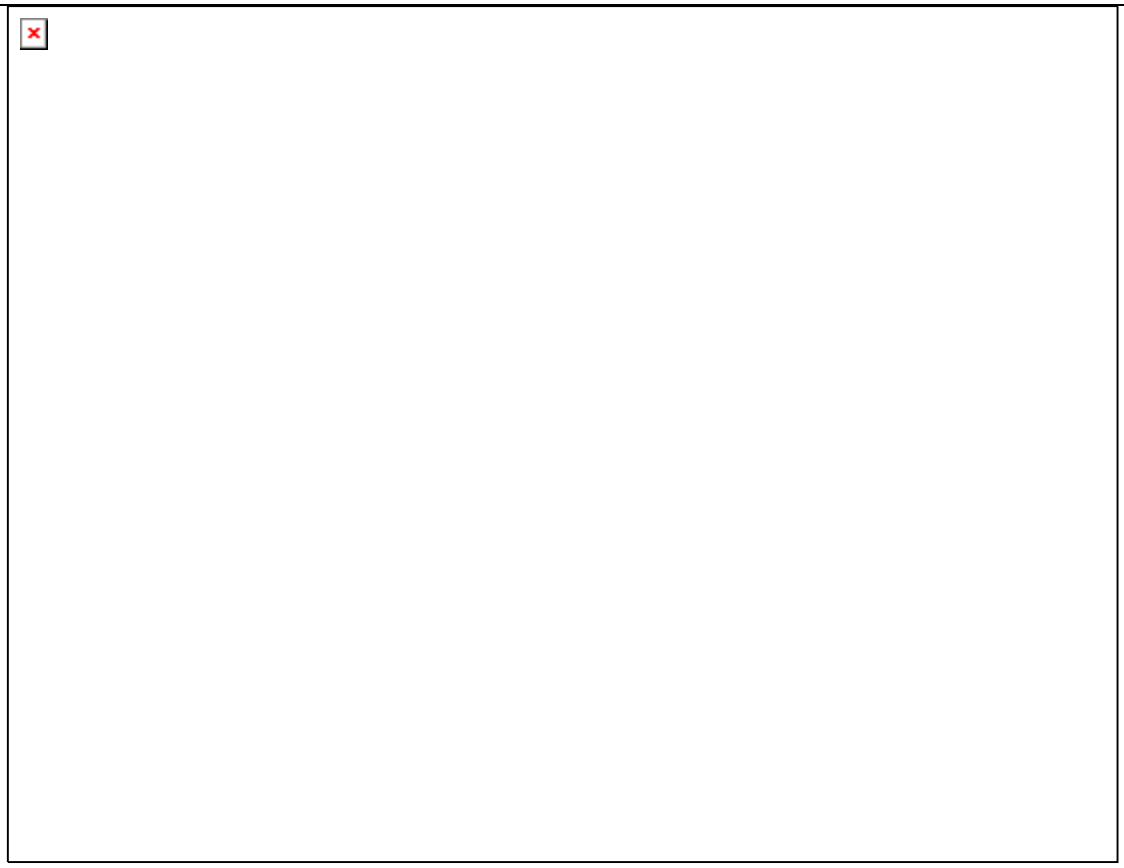


Fig. 3: Location of reference areas for residential built-up areas (new urban developments from the past decade), green spaces, natural green areas, and activity areas within the city of Munich.

Aerial views, spatial statistics of land cover, and illustrations of the three selected new urban developments are summarized in Figure 4.

The first example, “Siemenswerke Obersendling” (Figure 4, left), is a new development in the south of Munich with five high-rise buildings with 15 floors each, which are surrounded by peripheral development with four to five floors. This development was completed in 2014 and features a car-free design with access and parking spaces via the surrounding streets. The land cover of this example has the highest share of vegetation of 51%, with the fewest trees, while building density as well as impervious surfaces are the lowest among the three examples.

The second example, “Neue Gärten Giesing” (Figure 4, middle), is located southeast of the city center and represents a relatively central location within Munich, which was completed in 2014. This development is implemented in a car-free design and features dense residential development with four to seven floors. The land cover of this development features the highest tree density of 8% with medium vegetation cover. Building density of 27% and impervious surfaces of 15% are in the medium range compared to the other examples.

The third example, “Mein Aubing” (Figure 4, right) in the west of Munich, is designed in a conventional layout (i.e. access through motorized individual transport) with buildings of two to three floors. The location of this development can be characterized as a traditional suburban setting; its construction was completed in 2015/16. Due to the presence of roads, this development has the highest share of impervious surfaces of 24% and low values of vegetation and tree cover with 27% and 5%, respectively. Building density of 31% is the highest among the three examples.



Fig. 4: Aerial views (a), spatial statistics of land cover (b), and illustrations (c) of the three exemplary new urban developments. For locations of these areas refer to Figure 3.

5.3 Effects of new development

For the analysis of potential effects of the new development, we use the collected reference areas of open spaces as well as the three selected examples of residential construction to evaluate the impact on the new district.

For the estimation of the effects of planning in open spaces, we assume that tall (>20m) and medium-tall (≥10m-20m) trees are retained, while other areas are altered according to the distibution of land cover in the reference areas. The resulting potential realizations for green spaces, natural green areas, and activity areas are depicted in Figure 5. Overall, vegetation and trees account for the majority of LULC in all three types of open areas. In green spaces (Figure 5a&d), vegetation and trees represent 63.6 and 19.1% of land cover, respectively. In addition, water makes up 10.8% of the total area, which is included through the recreational lake in the center of the planning area (Figure 1b). For natural green areas (Figure 5b&d), vegetation and

trees are more evenly distributed with 52.0 and 37.9%, respectively. As excepted, these areas can be characterized as the most natural, with lowest shares of impervious surfaces and buildings, and highest shares of green space. Finally, activity areas (Figure 5c&d) possess similar distributions of vegetation and trees as green spaces with 62.0 and 16.0%, repsectively. The most pronounced difference are notable shares of buildings (3.8%) and impervious surfaces (9.2%), as well as bare soil (6.8%). Obviously, this is explained by new construction of infrastructure for pedestrian and bicycle traffic as well as areas for sports and leisure activities, which, depending on their use, include both buildings and impervious surfaces. In addition, activity areas also comprise areas for playgrounds, seating, relaxation, and recreation.

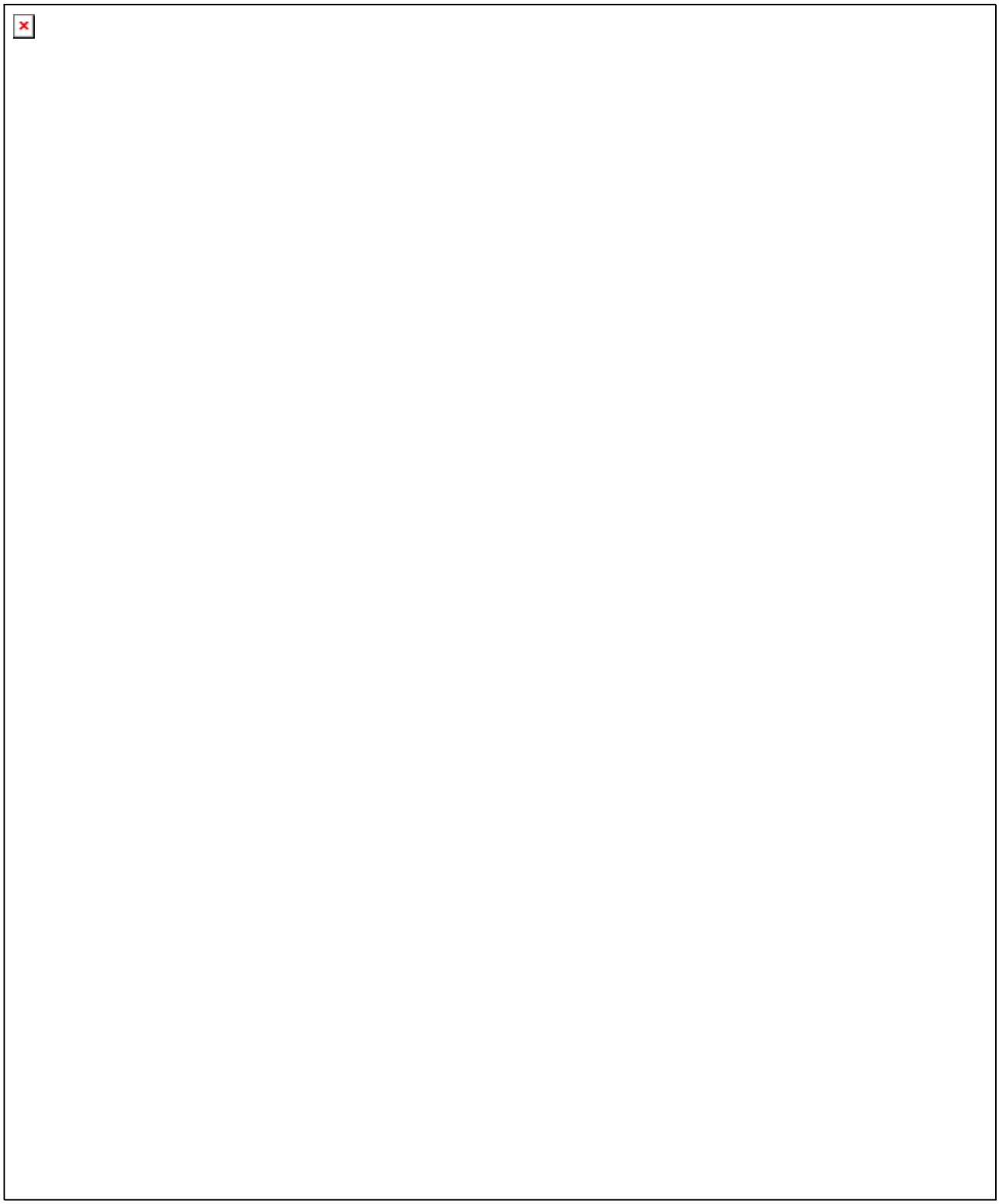


Fig. 5: Potential change per land cover class for green spaces, natural green areas, and activity areas in the new district in northeast Munich.

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For built-up areas, the potential effect of the three exemplary new urban developments is illustrated in Figure 6. On the one hand, new development is accompanied by a loss of natural and near-natural areas, as evidenced by the loss of trees, vegetation, and water bodies in all three examplary new urban developments. On the other hand, new development results in an increase in buildings and impervious surfaces, with the magnitude differing significantly for the three different construction types. The lowest land consumption through built-up areas can be observed for the first example (Siemenswerke), which is very space-efficient based on the high-rise buildings. This is accompanied by a high amount of open space in between the buildings, which is covered by vegetation in this example, resulting in the relatively lowest loss of vegetation. The second example (Giesing) is characterized by a moderate land consumption by buildings and impervious surfaces, whereas the loss of trees is lowest in this example. Finally, the third example (Aubing) of new urban development exhibits the highest building density as well as the highest degree of imperviousness, which can be attributed to the inclusion of motorized private transport and the corresponding space requirements of associated infrastructure.

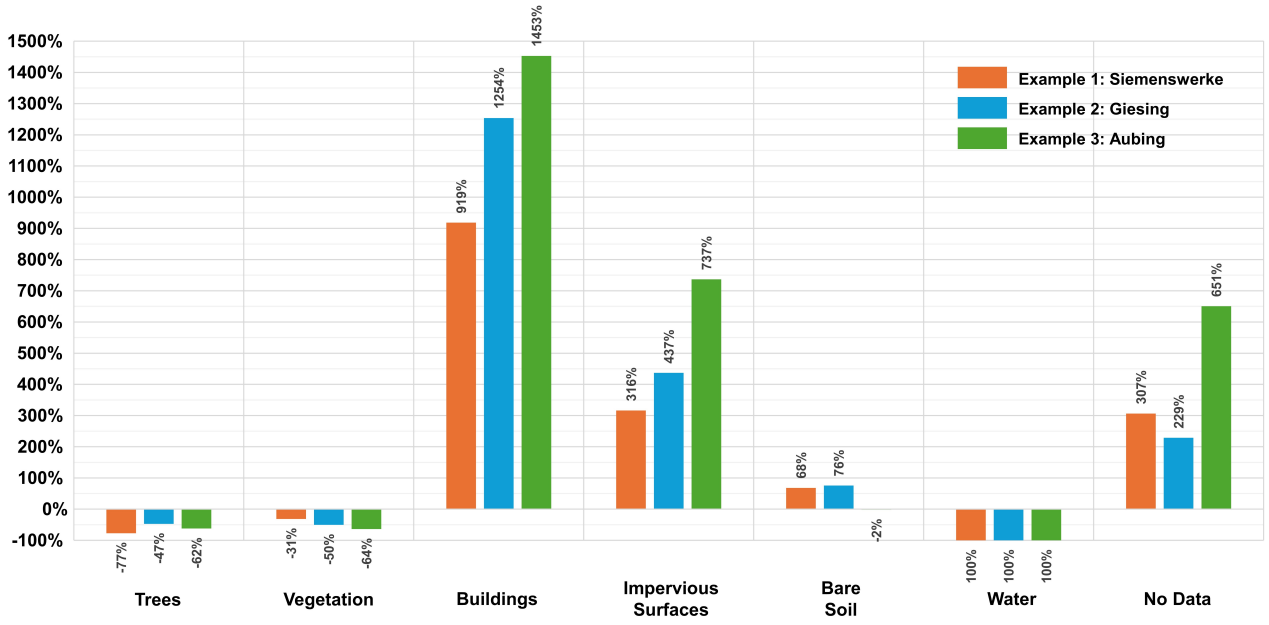


Fig. 6: Potential change per land cover class for built-up areas based on the three exemplary new urban developments in the new district in northeast Munich.

5.4 Estimation of Living Space

The statistical estimation of the potential population capacity based on an average living space of 39.5 m² per person is presented in Figure 7.

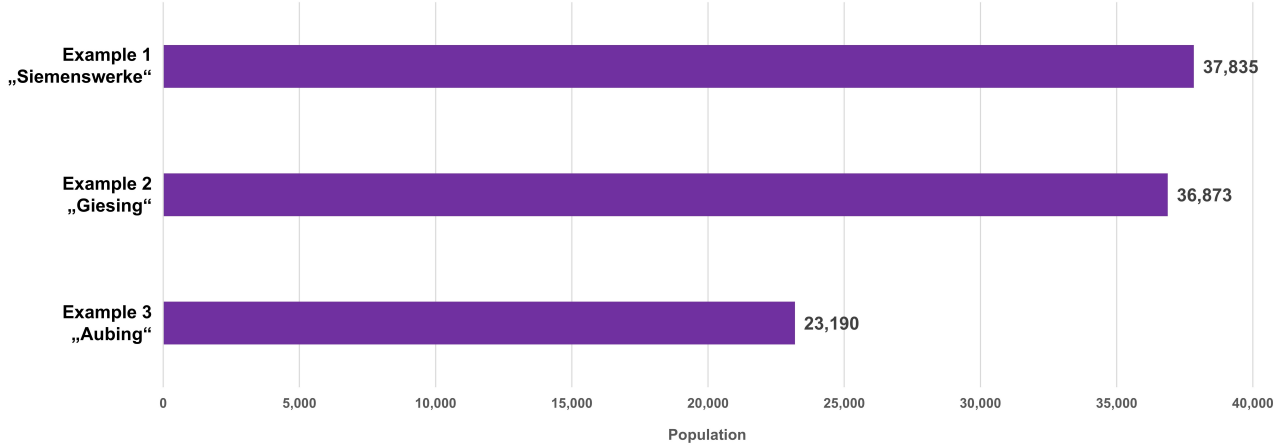


Fig. 7: Potential population capacity for the three exemplary new urban developments in the new district in northeast Munich.

Based on the avaiable areas for built-up development in the new district in northeast Munich, the estimation for the third example “Aubing” is significantly lower, while the other two examples are significantly above

the envisaged population capacity of 30,000 inhabitants from the draft plan. While the estimated population capacities of the first and second examples are close, the two types of construction show clear differences in terms of building density and height, and consequently different possibilities for open space design between the buildings (also see Figure 4). Overall, these results illustrate the potential variation of up to 15,000 inhabitants dependent of different conceptualizations of new urban development, i.e. by implementation of a car-free design and/or construction of high-rise buildings.

6 DISCUSSION

This work demonstrates the capabilities of EO and open geodata for illustration and quantification of potential effects of LULC change as a result of urban planning. According to the draft plan of a major development project in northeast Munich, we demonstrate potential LULC changes differentiated by open spaces and built-up areas, whereas for the latter, three specific of recent residential developments in Munich and their different impacts are examined. In addition, not only the impact on land consumption but also the provision of housing in terms of residential living space is examined.

Compared to existing research on urban land management and planning, the utilized VHR EO data and open geodata was rarely used to date (Bielecka et al. 2025). While VHR satellite imagery – like the WorldView data employed in this study – is usually not freely available and requires some processing effort (Wurm et al. 2011), the derived information is highly valuable to support urban planning. However, despite very-high resolution information, not all aspects can be resolved, e.g. small water bodies or impervious surfaces that are topped by tree crowns and thus, become invisible from a satellite view. In addition, VHR remote sensing classification results usually have a remaining error in the order of 10%, which also entails a certain degree of uncertainty. However, in general, the VHR data basis offers good transferability and applicability to different areas and thus, is a valuable source of information for applications in urban planning.

Overall, the estimated LULC changes in this work are highly dependent on the choice and selection of reference areas that are used to project the effects of planning in the target area. With regard to open spaces, we aimed to collect a high number of different areas across the entire city of Munich in order to reach a sufficient degree of representativeness. Activity areas can take a variety of different forms, combining infrastructure for pedestrian and bicycle traffic with areas for sports and leisure activities, including various proportions and combinations of buildings, impervious surfaces, and bare soil. However, due to their wide range of possible configurations, the specific characteristics of activity areas are difficult to foresee for specific study cases, and individual implementations may vary considerably. With regard to built-up areas, the derived LULC changes are consistent with our expectations, i.e. loss of vegetation and tree cover accompanied by an increase of impervious surfaces and buildings. The three examples of new urban developments in Munich were chosen to serve a range of residential development characteristics; however, their practical feasibility was not assessed within the scope of this work. However, our approach highlights the bandwidth of building density and impervious surface, as well as consequently different shares of vegetation and trees in the neighborhoods that will be constructed. In addition, the estimation of potential living space and population capacity facilitates the illustration of the impact of planning decisions by presenting them in tangible figures not only for experts but also for the general public. This quantification not only shows the potential of variation, but also offers practical perspectives for discussions about possibilities for urban development and design during the planning phase.

In general, planning decisions are often highly influenced by practical and political factors that were not considered in this work. Especially the political aspect of planning decisions is hard to take into account, which is also closely tied to the role of public sentiment and citizen participation (Mitlin 2021). However, it was proven that geospatial data and GIS methods improve public participation in the planning process (Kahila-Tani et al. 2019). From a practical perspective, the feasibility and cost of different realizations for new developments can vary considerably (Hu & Skibniewski 2021), which was not considered in this study. Sustainable urban planning was included from the perspective of housing provision, which plays an important role, particularly in dynamic urban environments such as the city of Munich. However, future research should include other aspects of sustainable urban planning, such as renewable energy, sustainable building materials, and the provision of green spaces. Particularly in view of advancing climate change, aspects of the urban climate and urban green infrastructure will be crucial for urban planning in order to ensure sustainable development and maintain the quality of life in cities.

7 CONCLUSION

This study illustrates and quantifies the potential impacts of a new urban development in northeast Munich. Based on EO and open geodata, we highlight land consumption in different areas of the currently available draft plan of the planning area. This work particularly focuses on built-up areas, where not only the impact of three different exemplary realizations of residential development is demonstrated, but also their population capacity is estimated in order to address the aspect of housing provision.

This work supports the discussion on adequate provision of living space and the demand for housing in urbanized areas of Germany and beyond. Furthermore, our selection of geospatial data, methods and derived information is well-suited to illustrate and elaborate the effect of planning decisions beyond subjective perception, in order to objectify the debate and explain the context and implications also to non-experts.

8 ACKNOWLEDGEMENTS

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reviewed paper

Enhanced Communication Systems with Reconfigurable Intelligent Surfaces in Smart Cities: Bridging Wireless Connectivity and Urban Sustainability

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1 ABSTRACT

The growing need for communication systems in urban areas working at high-speed and energy-efficient has led to developing smart city infrastructures. This article exploits the incorporation of Reconfigurable Intelligent Surfaces (RIS), as a sustainable approach, into urban environments to enhance the connectivity and the energy efficiency of the wireless communication, while exploring their architectural and engineering integration into the fabric of smart cities. Unlike previous approaches, which have traditionally focused on electromagnetic optimizations, this paper proposes RIS as an innovative architectural component that has the potential for integrating wireless communication and sustainability into smart cities. The approach utilizes a multi-step methodology, beginning with an analysis of architectural, structural, and communication needs for designing criteria for implementation. Additionally, this paper proposes a co-design approach for designing geometry and RIS implementation at the same time, which will focus on functional efficiency and aesthetic consistency. Optimization of RIS placement and orientation will be optimized using simulation analysis, taking into consideration signal propagation, energy efficiency, in addition to urban context constraints. The specific RIS modules will be integrated into façade panels and architectural elements using material, structural, and visual strategies. Finally, implementation of this integrated solution will then be assessed for performance on communication, energy efficiency, and aesthetic implementation. By the intelligent reflection of the electromagnetic waves, RIS can transform conventional architectural structures into active communication elements to bridge the gap between wireless connectivity and sustainable urban development. The results aid in the development of future intelligent, energy-efficient, and aesthetically pleasing of future cities.

Keywords: Urban Sustainability, Reconfigurable Intelligent Surfaces , Enhanced Communication Systems , Smart Cities, Urban Planning

2 INTRODUCTION

The rapid growth of cities with urban populations and the increasing demand for high-capacity wireless communication systems have made cities to be smart and data-driven environments (Ouafiq, et al., 2022; Sharma, et al., 2024). To provide real-time services, smart cities need seamless wireless connectivity. This includes smart transportation, environmental monitoring, and sustainable energy management. However, the congested architectural landscape and urban environment can lead to significant signal obstructions, multipath fading, and inadequate energy utilization, which makes modern wireless networks less reliable and less efficient (Akyildiz, et al., 2020)(He, et al., 2024).

In the last years, Reconfigurable Intelligent Surfaces (RIS) have become a promising technology for improving communication performance. RIS can turn passive structures like building façades and walls into active surfaces that improve wireless communication by changing the phase of the reflected electromagnetic waves intelligently. This ability makes RIS an appropriate choice to be used in smart cities, where buildings redesigned to include RIS (Alhafid, et al., 2024; Kisseleff, et al., 2020). In addition to RIS functionalities of improving wireless performance and resources optimizing, it is passive and operates at low-energy, so it has a lot of potential for making cities more sustainable and can satisfy the principle of green infrastructure (Amin, et al., 2023; Salim et al., 2025).

From the perspective of architectural engineering and sustainable urban design, it is important to emphasize the role of communications technologies in the built environment. Accordingly, this paper investigates the alignment of wireless communication engineering and urban sustainability through the architectural

integration of RIS. It proposes a framework of integrating RIS into smart city to improve data transmission and facilitate sustainable urban cites, also emphasizes the collaborative aspects of this approach by encouraging communication engineers, architects, and urban planners from different fields to work together to create the promised future sustainable cities.

3 LITERATURE REVIEW

The use of advanced communication technologies in urban infrastructures has emerged as a fundamental aspect of smart city evolution. Researchers over the past decade have investigated and studied many techniques to improve wireless performance in densely populated cities. Some of these studies include massive MIMO technology, high-frequency communication technology (such as millimeter-waves), and network densification. But these solutions often exhibit energy consumption, and require complex deployment, which makes them less useful for sustainable city models.

To mitigate these challenges, RIS has been proposed as a revolutionary paradigm for next-generation wireless communications. Early works, such as (Kisseleff, et al., 2020) and (Bjornson, et al., 2022), proved that RIS can be leveraged to improve signal-strength and coverage in non-line-of-sight (NLoS) urban areas by intelligently adapting the EM reflections. Other works, such as (Basar, et al., 2021) and (Du, et al., 2021), proved that RIS-assisted communications can provide a considerable enhancement in spectral and energy efficiency over other conventional methods such as relaying and beamforming. Recent works have explored the application of RIS for smart city and urban communications. For instance, the work presented in proposed the wireless environment as a service paradigm through RIS that can be embedded in buildings to optimize the wireless environment. Also, the work presented in (Sang, et al., 2024) explored the application of RIS-equipped buildings for filling coverage gaps in urban areas. On the other hand, works (Alhafid, et al., 2024) and (Alhafid, et al.,2023) explored the application of RIS-assisted localization for near-field localization and proposed new methods using multi-RIS configurations and efficient beam sweeping strategies, respectively. Even with these improvements, most of the research is still focused on communications technologies rather than integrating RISs into architecture or urban planning.

From the sustainability and intelligent design principles point of view, the subject of the built environment has become an important issue in modern architectural engineering studies (Ahmed, et al., 2025; Ahmed, et al.,2024). The authors in reference (Kadhim, et al., 2025) prove that adaptive façade systems improve the energy efficiency of buildings based on weather changes and therefore improve the comfort and energy efficiency of buildings. The authors further argue that smart materials and new ideas in quantum energy can improve the adaptability and efficiency of façades and therefore support adaptive façades as a sustainable solution in architectural engineering. The authors in reference (Corti, et al.,2023) investigate photovoltaic shading systems and argue that such systems can be an effective solution in preventing overheating and allowing for renewable energy implementation. The authors further argue that studies on this subject are still limited. In (Fathi, et al., 2025), the authors conduct a comprehensive analysis and indicate that active and passive smart materials for façades can be an effective solution in improving energy efficiency and preventing overheating in buildings. The authors (Almeida, et al.,2023) investigate a dynamic thermal insulation system and argue that such a system can easily and quickly alternate between different insulation values and therefore can be an effective solution in preventing overheating and ensuring comfortable temperature inside buildings.

Despite the increasing research on RIS, most current research on this subject is largely focused on electromagnetic optimization and network-level performance, overlooking the architectural integration and spatial design potential of RIS in the urban context built environment. At the same time, research on architectural design concepts on building façades is largely concentrated on sustainable design, efficiency, and current design trends, often without taking into consideration wireless connectivity needs. This state of affairs points to a significant research gap, since there is currently no comprehensive framework integrating wireless communication performance, architectural design, and sustainable urban development, a necessary synthesis for developing intelligent, efficient, and interconnected smart cities in the future. Building façades, and public structures have a vast number of surfaces that are geometrically varied and extensive, making them an excellent fit for the application of RIS to increase coverage, facilitate sensing capabilities, and lower transmission power. However, studies on RIS applications have rarely investigated their application through the lens of architectural design concepts, material characteristics, and urban aesthetics. To the best of our

knowledge, this issue has not yet been directly treated by current research on this subject. Based on this research gap, this paper proposes to consider RIS applications through an architectural design lens, thus diverging from an exclusively electronic design approach to integrating applications of RIS into urban planning and sustainable development goals, thus promoting a multidisciplinary approach to next-generation smart city design.

4 THE PROPOSED METHODOLOGY

The proposed multi-stage methodological framework in this research combines RIS into building façades in a smart sustainable urban environment. To begin, there is an initial stage where architectural, structural, and wireless communication requirements are considered collectively in setting common design principles. Next, there is a stage where a co-design strategy is employed, where geometric design of façades and RIS are done simultaneously. Third, there is an RIS placement stage where simulations are done based on position, orientation, signal propagation, and urban environment constraints. Fourth, there is a stage where RIS modules are integrated into façades using material, structural, and visual models. Finally, there is an RIS-integrated façade system assessment stage where communication, energy, and architectural design are considered. This multi-stage methodological framework makes it possible to fully integrate RIS technology into sustainable architectural design principles. The overall process of this multi-stage methodological framework is shown in Figure 1.

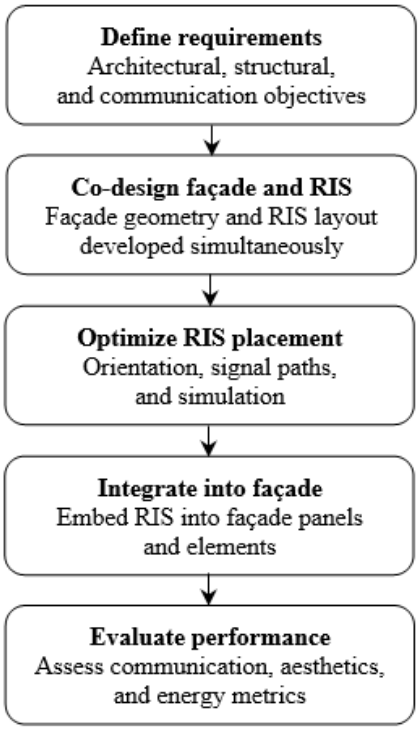


Figure 1 The proposed multi-stage methodology framework

4.1 Development of Urban Geometry Models

In order to properly assess the mutual impact of RIS and the surrounding environment, models of urban geometry can be developed to describe the physical and spatial features of the realistic urban areas for accurate wireless propagation and integration. A typical urban environment (like residential areas, streets, etc.) is first described, with buildings, roads, open spaces, and other environmental features included which can influence the signal behavior. The buildings' geometry is then developed with parameters of footprint, height, and interval between buildings. The façades of the buildings can be specifically described with consideration of their orientation angle, and architectural details like recesses, balconies, and shading. The developed façades are then divided into candidate regions for RIS placement. The regions are described with parameters of orientation angle, height from ground level, surface area, and accessibility. The properties of each surface material for each façade region are described with consideration for surface reflectivity, roughness, and other electromagnetic properties. The regions for deployment of RIS are determined based on their integration with buildings' architecture and relevance to regions with deficient coverage and blocked

areas of urban regions. The process of deployment of urban model for placement of RIS is described with illustrations of each step as depicted in Figure 2.



Figure 2 RIS placement development in urban model

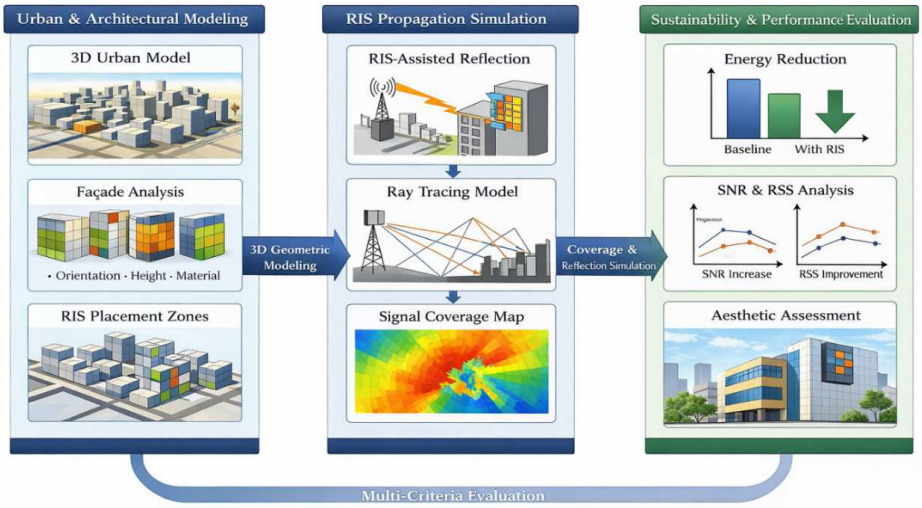


Figure 3 RIS integration in urban environments

4.2 Evaluation of RIS Coverage and Reflection Performancer

Subsequent to the creation of the urban model, the performance of RIS-assisted wireless communication is simulated and evaluated by incorporating the geometric model of the urban environment and communication performance to determine the effect of architectural design on the efficiency of RIS- assisted communication performance. The performance of the communication channel without RIS, which is the baseline propagation scenario, would be simulated first to determine the areas of poor coverage and the non-line of sight (NLoS) areas created by urban structures. The RIS panels would then be virtually placed on the selected areas of the façades, and the panel dimensions, position, and orientation can be varied to determine the effect of the panels on signal redirection behavior. Each RIS would simulate phase and amplitude modulation of the reflected electromagnetic waves to provide beam steering toward desired areas, especially areas with poor coverage in the NLoS region. The performance of the communication system would be measured based on indicators such as the received signal strength (RSS), signal-to-noise ratio (SNR), coverage, and improvement if energy efficiency compared to the baseline scenario. Several scenarios would then be

compared to determine the best approaches for RIS panels placing. Figure 3 illustrates the design and evaluation procedure for incorporating RIS into urban architecture through a multidisciplinary design and evaluation approach.

5 ARCHITECTURAL AND ENVIRONMENTAL INTEGRATION OF RIS-ENABLED FAÇADES

In order for RISs to be incorporated into the façade of buildings, it is essential that these be designed to optimize not only the performance of wireless communication but also take into account architectural and environmental aspects, such as those related to solar exposure and thermal performance of the façade of buildings. Because RISs installed on the façade of buildings are inherently exposed to solar radiation, the angle of installation, size of the RIS panel, height of installation, and material properties will simultaneously impact the efficiency of electromagnetic reflection and may the demand of buildings cooling. Hence, the deployment of RISs can be treated as a multi-objective optimization problem that aims to maximize a combination of communication performance (such as SNR, coverage, and beam steering) and architectural requirements, as listed in Table 1.

From an architectural perspective, RIS panels may be seen as multi-functional façade systems that function similarly to external solar shading systems, perforated metal screens, or double skin façade layers. As such, RIS components may be utilized to mitigate solar gain in highly exposed façades, control glare, and function as a thermal buffer while also re-radiating wireless signals into dense urban environments, as shown in Table 2. At a larger urban scale, dual-functionality provides a means by which buildings may interact with and influence both climates and electromagnetic environments, thus lowering cooling demands, improving pedestrian thermal comfort, and increasing the reliability of outdoor wireless communications. The complete process flow for façade system modeling and placement with awareness of RIS components within urban environment is shown in Figure 4.

Aspect	Communication Perspective	Architectural Perspective	Integrated Outcome
Façade orientation	Determines reflection direction and coverage	Controls solar exposure and heat gain	Orientation-aware RIS placement
RIS surface area	Affects beamforming gain	Influences shaded façade area	Balanced panel sizing
Material selection	Improves LoS and NLoS coverage	Alters solar incidence patterns	Optimized vertical positioning
Phase configuration	Impacts reflection efficiency	Affects absorptance and transmittance	Material-aware RIS design
Solar gain constraint	Maximizes SNR at users	No direct solar impact	Independent control variable
Optimization objective	Not considered in classical RIS	Limits overheating risk	Thermal-safe RIS deployment
Material selection	Maximize SNR / coverage	Minimize cooling load	Multi-objective optimization

Table 1 Communication and architectural criteria for RIS placement

RIS Architectural Role	Solar / Thermal Effect	Architectural Benefit	Wireless Communication Function
External shading element	Reduces direct solar heat gain on exposed façades	Improves thermal comfort and wireless coverage	Redirects signals into non-line-of-sight urban areas
Perforated façade screen	Controls glare and limit solar penetration	Enhances façade articulation and aesthetics	Enables controlled signal reflection and scattering
Double-skin façade layer	Provides shading and thermal buffering	Enables discreet RIS integration	Creates optimized signal reflection paths
Adaptive façade component	Responds dynamically to solar conditions	Facilitates smart building operation	Supports reconfigurable beam steering
Urban infrastructure surface	Reduces cooling demand at district scale	Contributes to smart city resilience	Improves street-level connectivity

Table 2 Architectural and communication functions of RIS-integrated façades

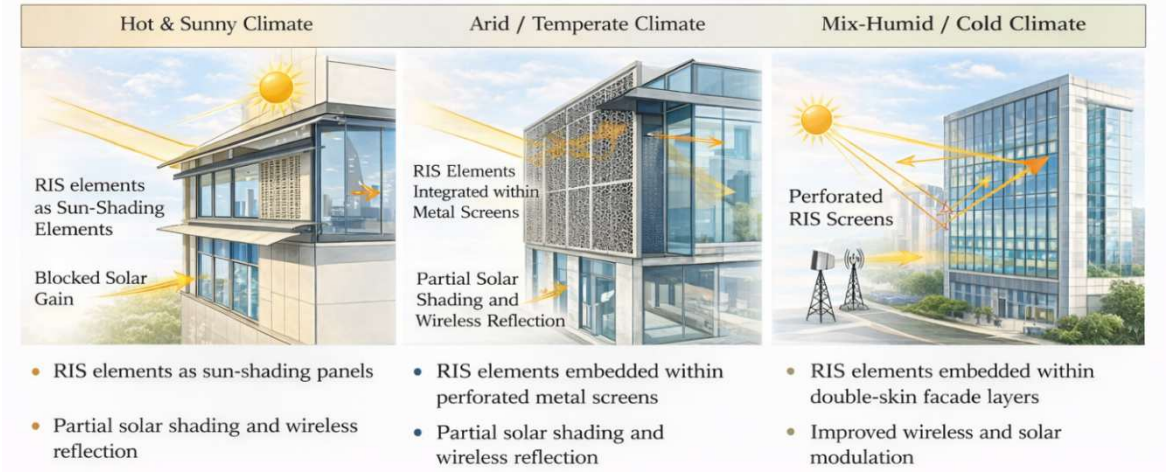


Figure 4 RIS as façade solutions

6 SYSTEM MODEL AND SIMULATION SETUP

The considered system model describes a two-dimensional urban communication scenario, as depicted in Figure 5, where a single BS transmits signals to multiple user equipment (UE) distributed in an area with several building blocks that cause LoS and NLoS propagation scenarios. A set of candidate RIS positions are pre-defined on building walls and urban infrastructure components, considering practical architectural constraints of RIS deployment. Based on this set, two RISs (K=2) are chosen to meet the optimum performance objectives. Three communication scenarios are investigated: (i) a baseline system without RIS, (ii) an RIS-based system with non-optimized RIS positions, where RIS are randomly chosen from the predefined set, and (iii) an RIS-based system with optimized RIS positions, where both RIS positions are exhaustively searched to achieve maximum performance gains. Each RIS is made of certain number of passive elements and employs different phase shift configurations, such as random, quantized, and ideal beams teering schemes. For RIS-based communication systems, received signal powers are calculated considering joint BS-RIS and RIS-UE channels with reflection efficiency, and effects of partial blockages.

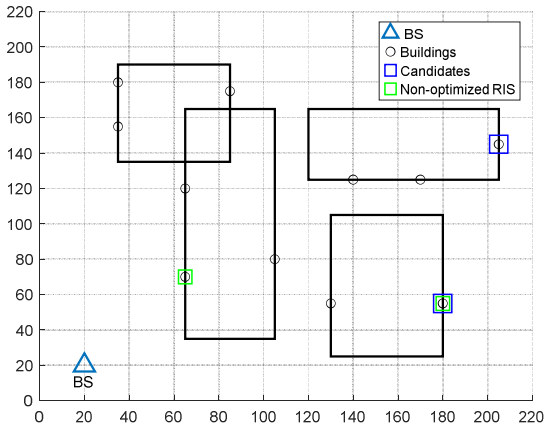


Figure 5 The Considered System Model

The number of RIS elements is assumed to be N elements and $n = 1,2,\ldots N$ is the sequence of each element. System performance metrics are measured by average SNR and spatial SNR heatmaps, as well as by improvements in SNR and in energy efficiency, allowing an overall performance comparison of baseline, non-optimized, and optimized RIS deployment schemes. The received signal observed by the UE can be represented as in (Alhafid, et al., 2023; Alhafid, A.K., Mohammed Ali, et al.,2023):

$$y = h^d x + \sum_{n=1}^{N} Y_n \left(h^f h^b\right) x + n \qquad (1)$$

where h^d is the direct channel between the BS and the UE, x is the known transmitted signal, $h^f$is the channel from the BS to the RIS. $h^b$is the channel from the RIS to the UE, $\Upsilon_n$is the reflection coefficient of the n^{th} element where $n \in \{1,2,\dots N\}$ and $n$is an additive Gaussian Noise.

The reflection coefficient of the n^{th} element possesses an amplitude of Υ and a phase of ψ, which is configured according to the designed profile, so,

$$\Upsilon_n = \Upsilon e^{j\psi} \tag{2}$$

Noting that the channel from the BS to the UE through the RIS is cascaded channel consist of forward $h^f$and backward coefficient h^b.

7 RESULTS AND DISCUSSION

The results shown in Figures 6–9 illustrate the key importance of RIS placement optimization, number of RIS elements, (i.e. RIS size), and phase shift configuration on system performance for dense urban scenarios. As shown in Figure 6, the optimized RIS placement always yields better performance compared to the non-optimized (candidate) placement for all RIS sizes. This highlights that only increasing RIS size is insufficient without appropriate spatial RIS placement, and improper placement is responsible for restricting the possible gain and the beamforming of the reflected signal. Figure 7 further reinforces this observation by showing that optimized RIS placement is responsible for providing significant SNR within the regions of low coverage and NLoS, while the corresponding regions for the baseline case are dominated by the low SNR values due to the blockages created by the buildings.

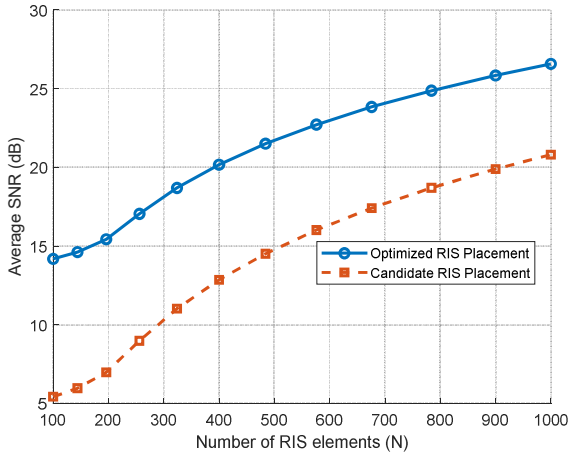


Figure 6 Average SNR versus number of RIS elements for optimized and candidate RIS placement

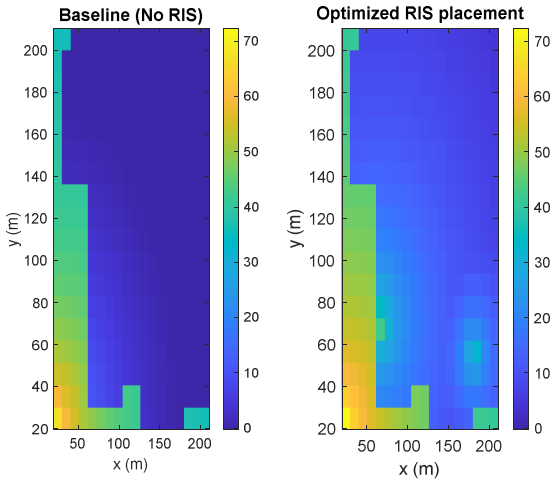


Figure 7 SNR heatmaps for baseline and optimized RIS-assisted communication

The impact of RIS phase profile is then investigated in Figure 8, where ideal beam-steering RIS phase profile provides best SNR gains. Followed by the quantized phase profile which offers a good trade-off between performance and hardware complexity. On the other hand, random phase profile provides little or negligible

performance benefit, emphasizing the need for phase optimization. Finally, it is shown in Figure 9 that properly designed and optimized RIS systems can provide considerable power savings (may reach 60%) for larger RIS sizes. According to these results, communication systems utilizing RISs can significantly enhance SNR, improve coverage, and make energy efficiency better conditioned by the size, placement, and phase profile configuration of the RIS are optimally calibrated.

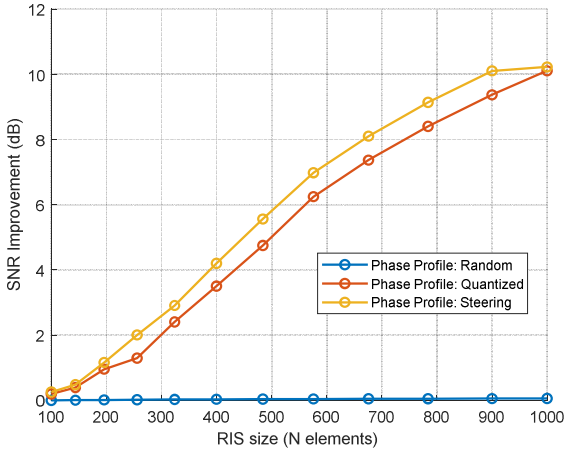


Figure 8 SNR improvement versus RIS size under different RIS phase profiles.

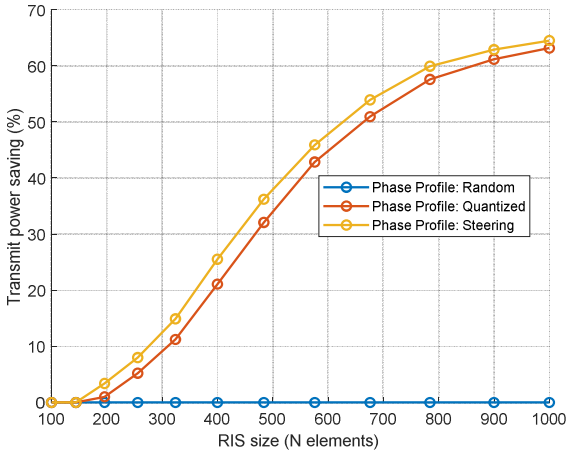


Figure 9 Power saving versus RIS size for different RIS phase profiles

8 CONCLUSION

This paper explored the inclusion of RIS in urban areas from a unified wireless communication and architectural engineering point of view. Unlike most RIS-related research that focuses exclusively on communication optimization techniques, this study considered RIS to have a multifunctional role in façades that could contribute to simultaneous improvements in wireless communication performance and environmentally responsive architecture. A comprehensive framework has been proposed for integrating architectural modeling, geometric of urban areas, and communication optimization. Various RIS placement strategies have been analyzed by simulation. These strategies include communication without RIS, non-optimized RIS placement, and optimized RIS placement by exhaustive search. The results have shown that optimized RIS placement strategies outperform non-optimized strategies significantly, especially for NLoS areas of urban regions. In addition, increasing the number of RIS elements with beam-steering or quantized RIS phase profile has led to considerable improvements in SNR, coverage, and energy efficiencies. The results have shown that RIS are effective in overcoming urban blockage issues while providing considerable energy savings. RIS are thus highly appropriate for sustainable wireless communication. From the architectural engineering point of view, RIS have been found to be integratable with existing architectural façades such as shading devices, perforated screens, or double-skin façades. In conclusion, RIS are identified here as a vital enabling technology for future smart cities where buildings are active participants in wireless communications and environmental regulation. Future works can extend this framework to more practical

urban scenarios, and real-world architectural constraints, as well as explore experimental validation within smart and sustainable city ecosystems.

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reviewed paper

Enhancing Safety Perception for Disabled Users of BRT System through Closed-Circuit Television Cameras in Johannesburg

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1 ABSTRACT

In 2025, the city of Johannesburg has been classified among the ten world most dangerous metropolitan cities. This notion is supported by the city's crime index of 80.8% in mid-year 2025. The modern epoch of transportation planning directs more focus and resources towards implementing smart, effective and efficient bus rapid transit systems to commute urban communities. However, there has been evidence of low ridership of bus rapid transits especially by people with disabilities and the root cause is traced to poor safety perceptions catalysed by criminal and violent activities in and around the bus rapid transit systems. The analysis of this effect is not perceived a massive threat in undermining efforts of smart city initiatives particularly where mass surveillances are implemented in the urban built environment. It is common cause that every development in the city attracts opportunists who poses direct threat towards elimination of innovative strategies. This study adopts a descriptive case study approach to investigate the effect of closed-circuit television cameras in improving the safety perception of disabled users of Rea Vaya BRT system in Johannesburg. Furthermore, the study intends to advocate for the popularization of closed-circuit television (CCTV) networks to combat crime activities in and around bus rapid transit network.

Keywords: Closed-circuit television, bus rapid transit, safety, disabled-users, smart city

2 INTRODUCTION

The implementation of closed-circuit television (CCTV) surveillance cameras in public spaces is common in South African metropolitan cities. In Johannesburg, the installation of CCTV surveillance cameras is pivotal in highways, public transport systems, city centre, malls, common places, and private residence (Gorpi, 2018). The high prevalence of CCTV surveillance is influenced by growing concerns over public safety and security, the protection of essential asserts and property. The current legislation of South Africa does not regulate CCTV cameras in public spaces, and such has been identified for rectification because of abuse by individuals, corporates or the state. It is common knowledge that in Johannesburg, the CCTV surveillance cameras rolled out by private security providers are without clear guidelines on how to bridge balance between public safety and security essentials with interest to rights to privacy. To date, efforts have been made for disclaimers arguing compliance with privacy regulations including Protection of Personal Information (POPI) Act of 2013, which has not yet fully realised operational imperatives. People with disability form segment of the vulnerable society that relies heavily on public transport due to affordable fares and convenience, however, they tussle with increasing criminal and violent activities that are prevailing in and around public transport zones. In terms of Rea Vaya BRT system particularly in Ellis Park, efforts have been made to install CCTV cameras to serve as security features and limit criminal activities in and around the BRT station. The implementation of CCTV cameras has been greatly improved and of assistance to disabled persons as they are able to manoeuvrer with ease and without fear of crime (PSIRA, 2019).

3 HISTORICAL CONTEXT OF CCTV AND BRT IN JOHANNESBURG

The implementation of CCTV surveillance cameras in Johannesburg is not a relative new concept however, it is still growing trend in comparison to metropolitan cities in Western countries such as the United States, United Kingdom and Canada (Lukacs, 2016). However, there is popularization of CCTV systems driven by the state, private sector and private security companies in South Africa. This initiative is sometimes drawn back by the fear notion led by civil society and researchers that the growing demand for surveillance will impede on the right to privacy. According to Minnaar (2015), the implementation of CCTV in South African cities can be tracked back to the early 1970s when the mining industry dealing with diamond and gold refineries invented them to prevent the smuggling and stealing of minerals. However, in the early 1990s and early 2000s, the utilization of CCTV surveillance gained popularity in the central business districts (CBDs)

of many cities where retailers initiated the installation of CCTV surveillance to detect, prevent, deviate and manage criminal activities. This notion is supported by the growing evidence of high volumes of CCTV camera systems in the private sector such as banks, warehouses, retailers and residential estates. During the 2010 World cup soccer tournament in South African, concerns around safety and security of tourists enhanced the fresh push that influenced the public-funded extension of CCTV surveillance on sports facilities, highways, city centres and shopping complexes (Meyersfield &Nyembe, 2016). Moreover, this period has seen public transport systems investing trunk of funds towards installing CCTV cameras in their transport facilities especially the public transport system. The bus rapid transit system in Johannesburg extended more facilities around their stations and inside the fleets to combat, control and deter criminal activities. In 2011, Rea Vaya bus rapid transit system at least installed CCTV cameras in more than 50% of their fleets and stations fully fitted with cameras.

4 CONCEPTUAL AND THEORETICAL FRAMEWORK

The concept of CCTV system relates to surveillance abilities that serves primarily as a security force multiplier, enabling surveillance for greater range of an area, more often than it would be possible for security personnel alone (Minnaar, 2012). CCTV system is sued to provide support the comprehensive security cluster by integrating video coverage and security alarm detectors for detection, barriers and control access. This concept is not a new concept around the world; it may be traced back to the early 1950s. CCTV systems are complex and encompasses various components with multi-faceted functions, specifications and features. The most prominent components include but not limited to lenses, cameras, power, lighting, and data distribution centres. CCTV systems regularly undergo feature upgrades to enhance performance in extents such as data storage, digital equipment options, wireless communications, component reduction and automated picture analysis (Moatshe, 2018). This study is grounded on the rational choice theory which perceive views that people intend to achieve results aligned with their goals to amplify their self-interest. Also, when alternative options are made available, individuals resort to the route that maximizes benefit and satisfaction. In this case, this theory is relevant to the study to provided basis for argument that people with disabilities are more likely to use BRT systems when presented with various options for public mode of transportation because security measures are enforced and prioritised for passengers as compared to other modes of public transit. Thus, the proliferation of CCTV cameras in BRT system enhances the amount of ridership of persons with disabilities as they project the feeling of safe mobility options.

5 METHODOLOGY

This study adopts a qualitative research approach to derive an in-depth understanding of how CCTV surveillance enhances safety perception for disabled persons who commute through BRT system in Johannesburg. The research integrates (interviews with municipal transport officials and residents in the city) and secondary data (municipal reports, academic literature and municipal integrated development plans) that are directly related with sustainable public transit and development goals. In a broader context, this research relies extensively on previous arguments and data results which are synced to a dialogue amongst themselves to derive common conclusions on broadened perspectives. Purposive sampling techniques were adopted to guide the study with the target population limited to a total of 30 respondents who responded to structured interviews. Data collection procedures were observed through key informant and stakeholder interviews such as municipal departments (Spatial planning and economic development department; Environmental affairs and Transport department). Secondary data sources consisted of public transport sector plans, annual reports, policies, scholarly publications and spatial development frameworks. Furthermore, thematic approach was adopted to analyse data collected which aimed on outlining key thematic areas, trends and patterns linked to bus rapid transit and CCTV surveillance cameras.

6 THE LEGAL IMPERATIVES OF CCTV SURVELLIANCES IN SOUTH AFRICA

To derive in-depth understanding of techniques which CCTV surveillance dialects to the right to privacy, there is a broader need to envision the notion of privacy and its imperatives. The right to privacy is a basic human right recognised around the world as one of the concepts of modernity which is set to have a universal common underpinning of definition. The call for the right to privacy remains a global phenomenon, but its foundation is rooted in differential interpretation depending to the prevailing community traits, culture and economic power of the time. South Africa builds its legislative mandate on reference to global legal trends;

in which there have been multifaceted trials at deriving a uniform definition of what the concept 'privacy' constitute. Under international law, the right to privacy is recognised by Article 12 of the Universal Declaration of Human Rights (UDHR) together with Article 17 of the International Covenant on Civil and Political Rights (ICCPR) (Meyersfield & Nyembe, 2016). On the other hand, the South African constitution and common law protect the right to privacy which is listed in Section 14 of the 1996 Constitution outlined as: Everyone has the right to privacy.

The overarching law in South Africa discourage interference with the private communication channels of the people. A detailed comprehensive protection of the right to privacy (digitally) is listed in the POPI Act which is not yet fully adopted and implemented (Van Jaarsveld & Minnaar, 2012). The POPI Act outlines that 'Personal information should only be obtained under specific, explicitly confined and lawful circumstances in relation to a function or works of the responsible party'. In the scenario involving the case of CCTV surveillance, such surveillance should not be carried out in a discriminatory system. It should be regulated, legitimate, lawful and should pass limitation test like any other justification for restriction of fundamental human rights in a democratic society. Furthermore, the deployment of CCTV surveillance cameras should be portioned equally to the legal purpose of pursuit. Along with should be a proportionality test which creates a necessary logical intersection between the extent (CCTV surveillance) and the desired outcome (crime detection, prevention and safety) (PSIRA, 2019).

7 PROFILING CCTV SURVELLIANCE IMPACT IN VARIOUS STATIONS OF REA VAYA BRT SYSTEM

Across the city of Johannesburg many serious violent crime categories have been profiled between 2020 and 2025. These violent crimes have targeted the vulnerable societal members in the city centre and spiralling out to the outskirts. These criminal activities include armed robberies, phone snatching, murder, attempted murder, serious assaults and kidnappings. While there were significant decreases in sexual offenses and common assaults; evidence records that violent crime rate for the city is recorded as 1 424 crimes per 100 000 population which is 25% higher than the national crime average. This incline is characterized by 15.5% increase in the number of aggravated robberies in 2024/25 around economic activities of the city. Table 1 depicts the highest number of violent crime incidents in Johannesburg per station identified.

Station Name	2020/2023	2023/2025	Annual change	Rate
Johannesburg Central	4665	5001	4.5%	8654
Hillbrow	4599	4577	-1%	2786
Soweto	2260	2100	-2.1%	1311
Alexandra	3001	2900	8%	1656
Roodepoort	2535	1800	9%	1604
Auckland Park	800	650	10%	1606
Parktown	401	390	15%	998
Sandton	80	65	20%	600
Midrand	100	101	½%	1789
Honeydew	2804	2888	4%	8654

Table 1.

8 REA VAYA BRT USER PERCEPTIONS OF SAFETY IN JOHANNESBURG

The Rea Vaya BRT user safety perceptions of safety or the lack thereof has incrementally shaped user travelling behaviour while contributing to further decline in ridership of Rea Vaya BRT system in Johannesburg- while also contributing further to a decrease in safety (given changes, for example in the way in which people utilize public transit system). Figure 1 below presents the safety perceptions held by Rea Vaya BRT users across the City of Johannesburg.

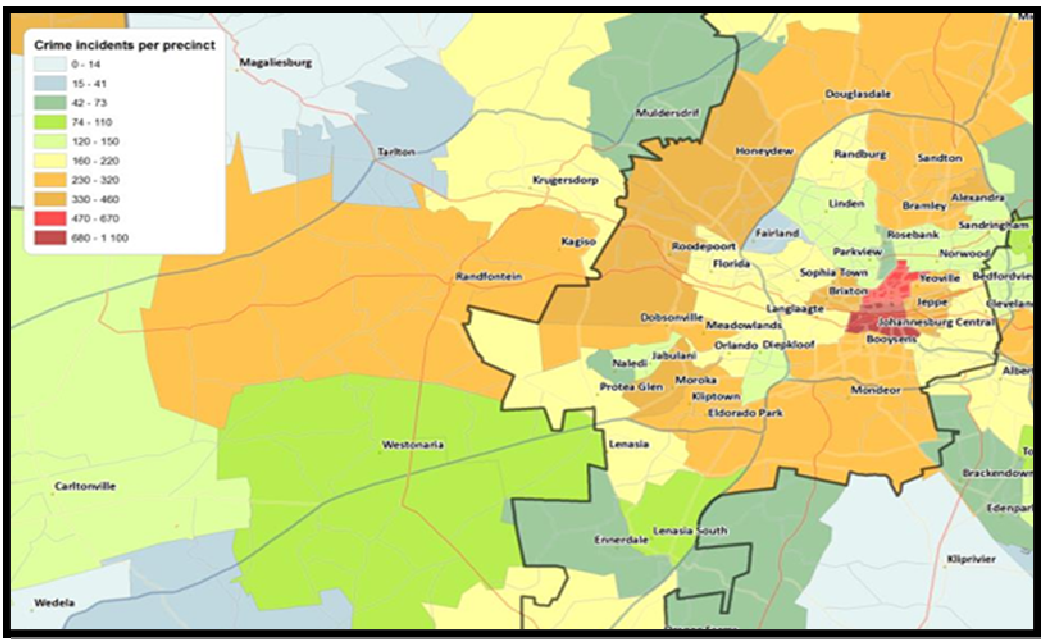


Figure 1: BRT user safety perceptions across the city of Johannesburg

9 AREAS FOR FUTURE RESEARCH

The current legislative frameworks on CCTV surveillance were formulated and adopted in a pre-digital time in which the systems and technologies to detect, monitor and record or appreciate surveillance data was not vigorous. In the current times, societies have made progress with appreciating the role of digital and information technology; not downplaying the huge investments made by those who practise crime activities in digital information and systems. In order to combat crime activities and enhance safety perceptions for the vulnerable communities in city centres it is crucial to invest and encourage extensive research on surveillance data which is intercepted from sensors such as cameras, smartphones and social media. Furthermore, to combat crime in Johannesburg, it is important to adopt legal system that put strong emphasis on public surveillance in every street and public infrastructure.

10 CONCLUSION

The systematic review emphasizes the importance of balancing the legal system imperatives with human safety methods in the city of Johannesburg. In-depth review in this paper, detected that there is a certain degree of overall constitutional framework and urban planning by-laws in Johannesburg that protects human rights while compromising the acknowledgment of public realities in the city. The findings outline that the Rea Vaya BRT user safety perceptions of safety or the lack thereof has incrementally shaped user travelling behaviour while contributing to further decline in ridership of Rea Vaya BRT system in Johannesburg- while also contributing further to a decrease in safety. In order to derive in-depth understanding of techniques which CCTV surveillance dialects to the right to privacy, there is a broader need to envision the notion of privacy and its imperatives. The right to privacy is a basic human right recognised around the world as one of the concepts of modernity which is set to have a universal common underpinning of definition. The call for the right to privacy remains a global phenomenon, but its foundation is rooted in differential interpretation depending to the prevailing community traits, culture and economic power of the time. South Africa builds its legislative mandate on reference to global legal trends; in which there have been multifaceted trials at deriving a uniform definition of what the concept ‘privacy’ constitute

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reviewed paper

Evaluating the Effectiveness of SDG 11 Monitoring and Implementation Frameworks at City Level: A Case Study of Mbabane, Eswatini

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1 ABSTRACT

Sustainable Development Goal 11 (SDG 11) aims to make cities inclusive, safe, resilient, and sustainable, yet implementation at the local level remains inconsistent, particularly in rapidly urbanizing contexts of the Global South. This study evaluates the progress of the City of Mbabane, Eswatini, toward achieving SDG 11 by assessing the effectiveness of existing monitoring and implementation frameworks. Employing a mixed-methods case study design, the research integrates spatial analysis, household surveys, and qualitative interviews with key stakeholders to examine housing adequacy, disaster vulnerability, institutional capacity, and participatory governance. Findings reveal that while Mbabane has integrated sustainability concepts into strategic planning documents, practical execution is hindered by limited data localization, institutional fragmentation, and insufficient community engagement. Informal settlements in flood-prone areas highlight the city's vulnerability and the need for risk-informed spatial planning. Moreover, the absence of a city-level SDG tracking mechanism and misalignment between global indicators and local realities challenge effective monitoring. Drawing lessons from peer African cities, the study proposes a suite of contextually appropriate reforms, including GIS-based monitoring tools, participatory planning mechanisms, and dedicated urban SDG units. These recommendations aim to strengthen institutional resilience and foster inclusive urban development in Mbabane and similar contexts. The research contributes to the discourse on localized SDG implementation by bridging theoretical frameworks with grounded, actionable insights for urban sustainability.

Keywords: Sustainable Development Goal 11 (SDG 11), Urban Resilience, Monitoring and Evaluation Frameworks, Informal Settlements, Sustainability

2 INTRODUCTION

2.1 Background Information on Why the Area of Interest

The journey toward sustainable development can be traced back to the Millennium Development Goals (MDGs), which comprised eight development objectives aimed at reducing income poverty, improving access to clean water and sanitation, reducing child mortality, and enhancing maternal health. The MDGs also played a critical role in promoting universal primary education and significantly advanced the global response to HIV/AIDS, malaria, and tuberculosis (UNDP, 2022). However, evaluations of MDG implementation revealed that approximately 46% of developing countries were off-track in meeting their targets, according to official UN and World Bank assessments (Samman, 2015). This shortfall catalyzed the adoption of a more comprehensive framework: the Sustainable Development Goals (SDGs), launched to ensure that no country is left behind.

In September 2015, the world leaders pledged support for sustainable action around a universally agreed policy agenda (Agenda 2030). This agenda comprises 17 Sustainable Development Goals (SDGs) with 169 specific targets that set out quantitative objectives associated with the social, economic, and environmental dimensions of sustainability to be achieved by 2030, and among these SDGs is SDG11, which focuses on sustainable cities (Osman et al., 2021).

Cities account for most of the global resource consumption and act as critical social, economic, and political hubs. With more than half the global population residing in urban areas, cities are essential actors in the pursuit of sustainability. This is explicitly recognized in SDG 11, which aims to make cities inclusive, safe, resilient, and sustainable (Adamec, Holzinger, & Franz, 2017). SDG 11 states that cities should ensure access to safe and affordable housing, access to public transportation, and public green spaces. It states that cities should be resilient to natural disasters and protect those in vulnerable situations while also minimizing economic loss (National Geographic Society, 2020).

The SDGs offer a structured framework that enables governments to develop and monitor policies aimed at achieving sustainability by 2030. Each goal includes measurable targets – monitored through 232 global indicators – coordinated by the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs) (Fritz, 2019). African cities are forecast to be home to an extra 950 million people by 2050; thus, when considering the projected increase in urban population in Africa, cities must be sustainable and a safe place to stay (Marchant, 2021). Eswatini has two officially recognized cities, with Mbabane serving as the capital and administrative center. It has a night-time population of approximately 62,630 (Population Hub, 2020) and a daytime population reaching 76,218 (World Population Review, 2022). The city hosts key government institutions, foreign missions, and a wide range of commercial activities, making it central to national development (Integrated Development Plan, 2019).

Despite its strategic importance, Mbabane faces several urban challenges. Recurrent flooding, limited access to affordable housing, and the expansion of informal settlements have strained urban infrastructure and service delivery. These issues are particularly relevant to SDG 11 targets, such as 11.1 (adequate housing) and 11.5 (disaster risk reduction). As the capital city of Eswatini, Mbabane needs to be one of the leading sustainable environments in the country. Its state of progress also needs to be known to ensure public resources are aligned with effective strategies that genuinely advance SDG 11 targets, rather than wasted on misaligned or reactive interventions. This study aims to track the progress made by the Mbabane City Council towards achieving SDG11 of the United Nations.

3 PROBLEM STATEMENT TO BE EXPLORED

Globally, cities have acknowledged the importance of SDG 11 and are implementing policies to promote urban sustainability. Yet, urban areas continue to grapple with challenges such as extreme poverty, inequality, and environmental degradation. Although cities generate about 80% of global GDP, they are also major contributors to climate change and unsustainable resource use (Osman et al., 2021). Mbabane, like many urban centers in sub-Saharan Africa, is experiencing rapid population growth, primarily due to rural-urban migration. This trend, if left unmanaged, can accelerate environmental degradation and strain essential services such as water supply, energy, housing, and waste management (Vaidya & Chatterji, 2020). Such problems put the urban population at risk and raise a question about whether the city has plans in place to curb these problems and make the city a safe place.

Eswatini is one of the countries under the United Nations that has signed an agreement to the Agenda 2030 Sustainable Goals (Ndongo-Seh, 2020). Thus, as a country, we have a responsibility to consistently check if we are still falling in line with the targets set under the goals, particularly in making cities sustainable (SDG 11). If Mbabane continues unsustainable development pathways, the consequences could be severe, ranging from increased vulnerability to disasters to inefficient use of public resources. Yet, there is a lack of documented information evaluating whether the city is effectively progressing toward SDG 11, which presents a critical knowledge gap. Lack of such crucial information will make the city pursue unsustainable development paths, which will not only put the urban population at risk but also result in a waste of resources due to the reconstruction of damaged urban structures, which are less resilient to threatening urban disasters such as flooding, in the context of Mbabane city.

This study seeks to bridge the existing information gap by assessing Mbabane's progress toward achieving SDG 11. A better understanding of the city's trajectory will not only inform policy and planning but also serve as a model for other urban centers in Eswatini and across the Global South.

4 AIMS AND OBJECTIVES

Aim

This study aims to evaluate the progress made by the City of Mbabane toward achieving Sustainable Development Goal 11, with a focus on assessing the effectiveness of existing monitoring and implementation frameworks.

Objectives

- To assess the current progress made by Mbabane in achieving SDG 11.

- To identify and evaluate the existing frameworks used in Eswatini for SDG monitoring and evaluation.
- To analyze key challenges hindering effective SDG 11 implementation in Mbabane.
- To propose practical frameworks or tools – drawn from successful African city experiences – that could enhance Mbabane's progress toward SDG 11.

5 RESEARCH QUESTIONS

(1) What measurable progress has been made toward achieving SDG 11 in Mbabane?

(2) What are the existing frameworks in Eswatini for conducting SDG evaluation?

(3) What are the existing problems that hinder the progress of Mbabane to get to the desired outcome for SDG11?

(4) What monitoring and implementation frameworks from other African cities could be adapted to strengthen SDG 11 performance in Mbabane?

6 JUSTIFICATION

This research is justified on multiple grounds. Firstly, it seeks to document Eswatini's progress in implementing SDG 11, providing a reference point for comparative studies across the region. Secondly, it aims to address the knowledge gap on how Global South cities, such as Mbabane, are responding to the challenges of sustainable urban development. Lastly, the study will offer insights for policymakers and urban planners, supporting data-driven decision-making to improve urban quality of life in line with SDG.

7 LITERATURE REVIEW

7.1 Global Discourse on SDG 11 and Urban Sustainability

Sustainable Development Goal 11 (SDG 11) aims to "make cities and human settlements inclusive, safe, resilient, and sustainable," acknowledging the crucial role of urban centers in addressing global sustainability challenges (UN-Habitat, 2022). The importance of SDG 11 lies in the fact that cities, despite occupying only 3% of the Earth's surface, contribute to over 70% of global carbon emissions and consume 60–80% of energy (Aquilino et al., 2020). Urbanization is accelerating, particularly in the Global South, where weak institutional structures and informality exacerbate inequality and vulnerability (Ulbrich, 2021).

Although the SDGs offer a comprehensive framework, there are implementation challenges, particularly regarding SDG 11. Research by Thomas, Hsu, and Weinfurter (2020) found that the overabundance of urban sustainability indicators – 484 identified from 40 indexes – lacks consistency, equity focus, and measurable benchmarks, especially in low-income contexts. This poses a serious barrier to tracking real progress.

Monitoring and Implementation Frameworks for SDG 11

Monitoring SDG 11 requires integrating global frameworks with localized urban planning and data systems. However, current frameworks often rely on aggregate, top-down indicators that obscure intra-urban disparities. As Ulbrich (2021) notes in his PhD thesis on Medellín, the disconnect between centralized monitoring and local realities leads to poor representation of marginalized communities in official reports.

Aquilino et al. (2021, 2023) developed and tested improved dasymetric mapping methods to disaggregate population and infrastructure data at the intra-urban level. This approach allows local governments to monitor indicators such as SDG 11.1.1 (access to adequate housing) or SDG 11.3.1 (land-use efficiency) at the neighborhood scale. Similar methodologies are particularly valuable in cities like Mbabane, where spatial data is limited and informal settlements are prevalent.

Koch and Krellenberg (2018), focusing on Germany, emphasize the importance of contextualizing global indicators to national and sub-national planning systems. Their work shows that even in well-resourced contexts, SDG 11 must be translated to the specific urban governance structures, a lesson highly applicable to developing cities.

7.2 African and Global South Experiences: Successes and Gaps

Several African cities are experimenting with various mechanisms to implement SDG 11, yet the outcomes are mixed. For example, in Durban, Ebhuoma et al. (2024) documented how early-warning systems for floods failed due to the municipality's poor communication with vulnerable populations, highlighting the disconnect between technology and local needs.

In contrast, the peer-reviewed study by Letebele et al. (2024) across 14 SADC cities emphasizes the value of risk-informed development (RID) frameworks. This approach integrates hazard data into urban planning, yielding resilient infrastructure investment and governance practices. Given Mbabane's vulnerability to flooding and informal settlement growth, adopting RID principles could enhance its alignment with SDG 11.5, particularly by integrating resilience into infrastructure and spatial planning.

A key lesson from Adamec et al. (2020), who evaluated civil society-driven projects in Hamburg, Vienna, and Prague, is the transformative potential of grassroots initiatives. Their findings underscore that SDG 11 implementation thrives when citizen participation, flexible governance, and cross-sectoral collaboration are encouraged.

Moreover, Metaxas and Metaxas (2022) note the transition from MDGs to SDGs represented a shift from quantitative service access metrics to qualitative outcomes such as inclusion, resilience, and safety. However, most African cities, including Mbabane, are still operating with legacy planning instruments from the MDG era, impeding localized implementation of SDG 11 targets.

8 THEORETICAL AND ANALYTICAL FRAMEWORK

This study draws on two interlinked theoretical frameworks:

a) Participatory Urban Governance

Participatory governance is essential to inclusive urban sustainability. As noted by Muhamad Khair et al. (2020), community-based monitoring can empower residents to influence planning processes, contributing to SDG 11's inclusive targets (e.g., 11.3 and 11.7). When urban planning processes include marginalized voices, policies are more aligned with community realities and needs.

b) Risk-Informed and Adaptive Planning

The Risk-Informed Development framework (Letebele et al., 2024) integrates hazard, socio-economic, and environmental data into city-level planning. This theory emphasizes adaptive capacity, aligning closely with SDG 11.5 on disaster resilience. For Mbabane, this means embedding flood risk data and informal settlement vulnerability assessments into its Integrated Development Plan.

8.1 Key Lessons for Mbabane's Context

- Data Localization is Critical: Mbabane must adopt localized, high-resolution monitoring tools similar to the dasymetric mapping used in Bari and Hainan (Aquilino et al., 2020; Zhang et al., 2021).
- Institutional Reform is Necessary: As Nabiyeva et al. (2023) argue, without public-sector leadership and institutional clarity, SDG 11 becomes symbolic rather than transformative.
- Learning from Peers Works: Mbabane can adapt practical tools from cities like Guilin, Durban, or Vienna, especially those enhancing participatory planning, spatial data integration, and climate risk mapping.

8.2 Research Methodology

This study adopts a case study phenomenological research design, suitable for capturing the lived urban development realities in Mbabane and interpreting them in the context of SDG 11 progress. The choice of this design stems from the need to engage with both policy-level data and community-level experiences, acknowledging that sustainable urban development is inherently multi-scalar and experiential (Yin, 2018).

The research follows a mixed-methods approach, integrating quantitative, qualitative, and spatial analysis techniques. This triangulation allows for a holistic exploration of the subject by complementing statistical

evaluations of SDG indicators with qualitative insights from stakeholders and geospatial assessments of urban resilience.

8.3 Research Design

The case study phenomenological design focuses on Mbabane as a single, bounded unit of analysis. The rationale is to explore how existing monitoring and implementation frameworks for SDG 11 operate in practice, and to capture contextual intricacies such as informal settlement patterns, flooding vulnerabilities, and urban planning mechanisms. According to Creswell (2014), a phenomenological design is particularly useful when the aim is to describe and interpret experiences around a phenomenon – in this case, sustainable urban development in Mbabane.

8.4 Research Approach

This study utilizes a mixed-methods approach, which integrates quantitative and qualitative data to enable robust cross-validation. Quantitative data includes statistical reports on SDG 11 indicators (e.g., housing adequacy, land-use efficiency, disaster impact records), while qualitative data emerges from semi-structured interviews, focus groups, and participatory mapping exercises with community members, municipal planners, and local NGOs.

Spatial data will be analyzed using geospatial tools, specifically GIS-based risk mapping and dasymetric population modeling, inspired by methods applied in Hainan and Bari (Aquilino et al., 2023). This helps visualize spatial inequities and track urban vulnerabilities such as informal settlement expansion and disaster exposure.

8.5 Sampling Design

The study employs both probability and non-probability sampling techniques to ensure representativeness and depth. A stratified random sampling approach will be used to select residents from various urban zones (formal, peri-urban, and informal), ensuring spatial diversity. Meanwhile, purposive sampling will be applied to key informants such as municipal officials, planners, and NGO representatives who are directly involved in urban governance and SDG monitoring.

A sample size of approximately 100 residents will be targeted for household surveys, supplemented by 15–20 key informant interviews to gain policy insights. The household sample will reflect demographic and socio-economic diversity, ensuring the inclusion of vulnerable groups such as informal settlers, women-headed households, and youth.

8.6 Data Collection Methods

The study will collect primary and secondary data. Primary data includes:

- Household surveys to gauge citizens' access to basic services and perceptions of urban safety and inclusivity.
- Key informant interviews to explore institutional frameworks, capacity gaps, and monitoring practices.
- Focus group discussions (FGDs) to foster participatory dialogue and community reflections on SDG 11 targets.
- Participatory GIS mapping to localize urban vulnerabilities.

Secondary data sources include:

- Municipal development plans (e.g., Integrated Development Plan, 2019)
- UN SDG indicator reports and Eswatini's Voluntary National Review (VNR)
- Urban demographic datasets and Eswatini Bureau of Statistics reports

8.7 Data Analysis Techniques

Quantitative data will be analyzed using SPSS or Stata for descriptive and inferential statistics (e.g., correlation between settlement type and housing adequacy). Qualitative data will undergo thematic analysis using NVivo software to identify recurring policy themes, governance gaps, and stakeholder concerns.

Spatial data will be processed using ArcGIS Pro. Techniques such as overlay analysis, risk zoning, and dasymetric redistribution will visualize informal settlements, flood-prone zones, and service accessibility. These results will directly inform SDG 11.1 and 11.5 progress assessments.

8.8 Research Reliability and Validity

To enhance validity, data triangulation will be used by cross-verifying findings across surveys, interviews, and spatial data. The design ensures internal validity through consistent question framing and piloted instruments, while external validity is supported by comparing Mbabane with similar cities using regional case studies (Letebele et al., 2024).

Reliability will be upheld through standardized data collection tools, detailed documentation of procedures, and researcher reflexivity to minimize interpretation bias. Peer debriefing and member checks will also be employed in the qualitative phases.

8.9 Ethical Considerations

Ethical clearance will be obtained from the University's Research Ethics Committee. All participants will provide informed consent, and their anonymity will be maintained throughout the research process. Data will be securely stored and used exclusively for academic purposes.

Efforts will be made to ensure inclusivity and non-exploitation, particularly in engagements with marginalized communities. The research adheres to the principles of do not harm, respecting both cultural sensitivities and participant autonomy.

9 FINDINGS AND RESULTS

This section presents the findings of the study based on the mixed-methods approach, triangulating quantitative household surveys, qualitative interviews and focus group discussions, and geospatial analysis. The data reveal both structural and operational strengths and gaps in Mbabane's pursuit of Sustainable Development Goal 11 (SDG 11), with a particular emphasis on inclusivity, resilience, and sustainability.

9.1 Progress Towards SDG 11 Targets in Mbabane

Household survey data and city documents (e.g., IDP 2019) show that Mbabane has begun integrating SDG 11 themes – such as housing and environmental management – into its plans. However, these commitments have not consistently translated into on-the-ground action, and many objectives remain aspirational due to implementation gaps.

Regarding Target 11.1 (access to adequate, safe, and affordable housing), 68% of survey respondents reported living in informal or semi-formal dwellings, citing high land prices and inadequate mortgage systems as major barriers to formal housing. A significant number of residents (42%) live in flood-prone areas, indicating a direct linkage between housing inadequacy and exposure to environmental risk, an area where Target 11.5 (disaster risk reduction) becomes highly relevant.

Figure 1 illustrates disparities in access to basic services between formal and informal settlements. While over 90% of residents in formal areas report access to potable water, only 54% of those in informal settlements do. Similar gaps are observed in sanitation, transport, and waste services, emphasizing the spatial inequality in urban infrastructure provision. These gaps underscore the city's underperformance on SDG 11.2 (transport) and 11.6 (waste management and environmental quality), particularly in informal zones.

Spatial analysis corroborated these findings. Using GIS-based risk mapping, informal settlements were found to be disproportionately located in low-lying zones along the Mbabane River, which are especially vulnerable to seasonal flooding. These results confirm observations from the Municipal Environmental Management Strategy (2020), which identified growing informal settlements as a critical urban pressure point.

9.2 Institutional and Policy Frameworks for SDG Monitoring

Key informant interviews with city officials, planners, and national policy actors revealed that Eswatini lacks a fully operational, city-level SDG monitoring system. While the National Development Strategy and Vision

2022 broadly align with the SDGs, including SDG 11, there is no dedicated institutional mechanism within the Mbabane City Council (MCC) for disaggregated indicator tracking.

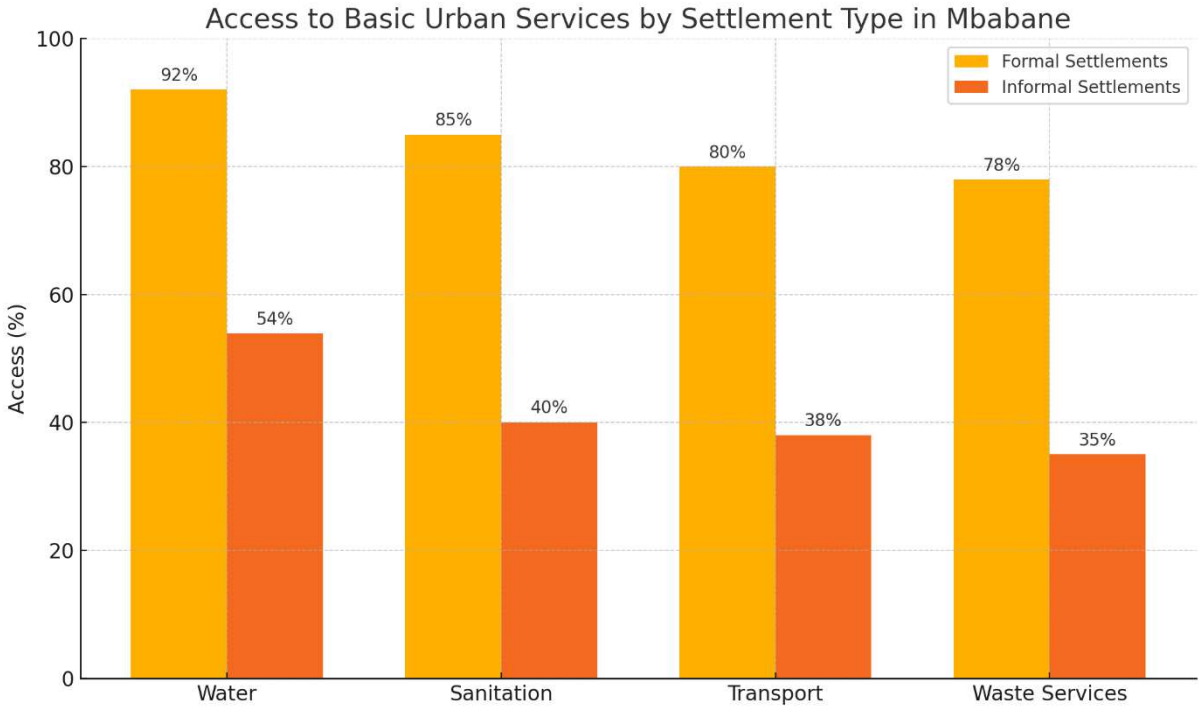


Figure 1: Access to Basic Urban Services by Settlement Type in Mbabane

Respondents from the Ministry of Housing and Urban Development acknowledged that although Eswatini participated in the Voluntary National Reviews (VNRs) of 2019 and 2022, city-level data were minimal or generalized. The absence of subnational dashboards or spatially localized indicators limits the ability of municipalities to operationalize the SDGs effectively. One senior planner noted that “most of the monitoring is reactive; it’s triggered by donor or national government reporting timelines rather than proactive urban policy design.”

Furthermore, there is a misalignment between global indicators and local data systems. For example, SDG Indicator 11.1.1, which requires measurement of the proportion of urban population living in slums or inadequate housing, is not systematically tracked by Mbabane authorities due to data limitations and definitional inconsistencies.

9.3 Stakeholder Perceptions and Challenges in Urban Sustainability

Thematic analysis of focus group discussions with residents from Mangwaneni, Msunduza, and Sidwashini settlements highlighted widespread frustration with service delivery and limited participation in planning processes. Focus group participants expressed frustration over being excluded from municipal planning and budgeting processes, underscoring a disconnect between policy rhetoric and participatory practice (Khair et al., 2020).

Moreover, 73% of respondents indicated that municipal consultations, when they occur, are often symbolic rather than substantive. This resonates with participatory governance literature, which warns of "consultation fatigue" where community input is rarely translated into policy decisions (Adamec et al., 2020).

On the institutional side, MCC officials pointed to chronic budget constraints and a lack of technical capacity to implement integrated planning tools. Planners highlighted that while risk assessments exist, they are not embedded into zoning laws or housing permits. Consequently, informal expansion continues unchecked in environmentally sensitive zones.

9.3.1 Comparative Lessons from Other African Cities

The findings also draw on comparisons with other African cities that have implemented innovative SDG monitoring frameworks. For example, Letebele et al. (2024) describe how Lilongwe and Gaborone have begun integrating climate risk data into land-use planning using the Risk-Informed Development (RID)

framework. These cities have adopted cross-sectoral data hubs that combine demographic, hazard, and infrastructure datasets into dynamic planning dashboards. Mbabane lacks such systems, but officials expressed interest in piloting similar models, particularly to manage risks associated with flooding and informal settlements.

Notably, in contrast to Mbabane's reactive policy environment, cities like Kigali and Cape Town have formalized annual urban sustainability reports aligned to SDG 11 targets. These reports are supported by dedicated monitoring units and participatory review boards. The absence of such structures in Mbabane reflects broader systemic weaknesses in urban governance and underscores the need for institutional reforms.

9.3.2 Spatial Inequities and Vulnerability Mapping

GIS-based analysis revealed sharp intra-urban inequalities in access to services and environmental risk exposure. Informal settlements in Mbabane's peripheral areas demonstrated significantly lower proximity to key services such as potable water, public transport, and emergency services. This pattern aligns with SDG Target 11.2 (access to safe, affordable, and sustainable transport systems), which remains underperforming.

Risk zoning maps indicate that more than 35% of the city's informal settlement areas fall within moderate-to-high flood risk zones, especially along the Mzimnene and Mbabane river corridors. These findings emphasize the urgent need for risk-informed spatial planning tools. If left unaddressed, these vulnerabilities could become exacerbated under climate change scenarios.

9.4 Integration of Local Knowledge and Policy Gaps

One of the most striking findings is the disconnection between local knowledge and official planning instruments. Community-based knowledge on flood-prone areas, infrastructure gaps, and coping strategies is rarely documented or used in formal processes. This disconnect undermines the inclusive ethos of SDG 11, particularly Targets 11.3 and 11.7, which advocate for participatory planning and universal access to public spaces.

When asked to evaluate municipal responsiveness, community respondents rated it an average of 4.1 out of 10. In contrast, municipal officials rated their own responsiveness at 7.5 out of 10. This perceptual gap further illustrates the urgent need for strengthened communication, trust-building, and shared accountability mechanisms.

10 MAIN CONTRIBUTIONS, IMPLICATIONS, AND LESSONS LEARNT

This section synthesizes the key contributions of the study to academic knowledge, policy discourse, and practical urban governance in the context of Sustainable Development Goal 11 (SDG 11). It also articulates the broader implications of the findings and distills actionable lessons that can guide future efforts in sustainable urban development, particularly in rapidly urbanizing cities of the Global South such as Mbabane.

10.1 Academic and Theoretical Contributions

The study advances the scholarly understanding of localized SDG implementation by demonstrating how global sustainability frameworks interact with on-the-ground urban realities in a small but strategically important African capital. Through the application of participatory governance theory (Khair et al., 2020) and the Risk-Informed Development (RID) framework (Letebele et al., 2024), the research bridges a theoretical gap between abstract global sustainability targets and their lived urban manifestations.

Furthermore, the study contributes to the growing body of literature that critiques the top-down nature of global urban sustainability monitoring systems. It affirms the argument by Ulbrich (2021) that disaggregated, high-resolution, and community-informed data are essential to avoid masking inequalities and to ensure truly inclusive urban development. The spatial and qualitative findings from Mbabane validate these theoretical positions and reinforce the importance of locally grounded methodologies in urban SDG research.

10.2 Policy and Institutional Contributions

At the policy level, the research reveals significant gaps in institutional capacity, data systems, and participatory mechanisms that undermine effective SDG 11 implementation in Mbabane. The city's reliance

on generalized, national-level reports for SDG tracking limits its ability to respond to context-specific challenges, such as the expansion of informal settlements in flood-prone areas.

This study highlights the urgent need for subnational SDG monitoring systems that align with urban planning tools like the Integrated Development Plan (IDP) and municipal zoning schemes. Drawing lessons from cities such as Kigali and Gaborone, the study advocates for the establishment of dedicated municipal SDG units and annual sustainability reporting practices at the city level.

Moreover, the research emphasizes the need for institutional reforms to support integrated data collection, storage, and use across government departments. It supports Nabiyeva et al.'s (2023) assertion that without clarity in institutional roles and investment in human and technical capacity, SDG 11 risks remaining aspirational rather than actionable.

10.3 Practical Lessons for Mbabane and Similar Cities

The case of Mbabane yields several practical lessons that have broader applicability for urban planning in other medium-sized African cities:

10.3.1 Data Localization and Integration are Non-Negotiable

The absence of localized, spatially disaggregated data in Mbabane severely hampers evidence-based decision-making. The study shows that leveraging tools such as GIS-based risk mapping and dasymetric analysis is not merely technical – it is foundational to planning for resilience, housing adequacy, and land-use efficiency. Without localized indicators, vulnerable populations remain invisible in planning processes.

10.3.2 Participatory Planning Must Move Beyond Tokenism

Community voices in Mbabane are currently underrepresented in formal urban governance structures. The study illustrates that participatory mechanisms, when they exist, are often symbolic rather than transformative. Implementing structured participatory tools – such as community scorecards, participatory budgeting, and neighborhood SDG audits – can significantly improve legitimacy, responsiveness, and equity in planning outcomes.

10.3.3 Resilience Must Be Embedded, Not Appended

As cities become more vulnerable to climate-related and socio-economic shocks, resilience cannot be treated as an add-on to existing plans. The study shows that in Mbabane, flood risk is spatially concentrated in informal settlements, yet current planning tools do not integrate vulnerability assessments. Incorporating RID principles into zoning codes, housing programs, and infrastructure design can institutionalize resilience at every level of urban policy.

10.3.4 Learning from Regional Peers is a Viable Strategy

Mbabane does not need to reinvent urban sustainability frameworks from scratch. Cities such as Durban, Lilongwe, and Nairobi offer tested models in early-warning systems, community mapping, and integrated transport planning. Knowledge-sharing networks and South-South cooperation – especially within SADC – can facilitate the transfer of innovations that are contextually appropriate and scalable.

10.3.5 Institutional Continuity and Political Will are Critical

One of the persistent challenges identified in interviews was the discontinuity of urban sustainability initiatives due to staff turnover, budget reallocations, and shifting political priorities. Establishing legally mandated SDG tracking units within city structures and embedding sustainability into statutory planning instruments can safeguard against these discontinuities.

10.4 Implications for Future Research and Planning

The findings suggest that sustainable urban development cannot be delinked from questions of governance, equity, and institutional design. Future research should prioritize longitudinal studies to track changes over time and explore the intersection between SDG 11 and other goals, such as SDG 6 (water and sanitation), SDG 13 (climate action), and SDG 16 (peace, justice, and strong institutions).

Additionally, there is scope for piloting community-driven monitoring frameworks using mobile technologies, crowdsourced spatial data, and participatory GIS platforms. Such innovations can empower residents, enhance accountability, and provide real-time feedback loops to city planners and policymakers.

11 CONCLUSIONS AND RECOMMENDATIONS

This study assessed Mbabane's progress toward Sustainable Development Goal 11, focusing on how the city monitors and implements sustainability initiatives. While the city has made some policy strides, actual progress remains limited. Informal settlements continue to grow in high-risk areas, and planning decisions are not supported by localized or disaggregated data. Without clear indicators and spatial tools, the city struggles to track or respond to urban challenges effectively.

Institutional weaknesses further limit implementation. Departments often work in isolation, with poor coordination and limited technical capacity. Planning documents mention sustainability, but these are not backed by strong systems or consistent action. Community participation is minimal, and when it occurs, it often lacks real influence. This undermines the goal of inclusive urban development.

Despite these gaps, there is room for improvement. Mbabane can adapt practical tools used in other African cities, including GIS-based risk mapping, participatory planning, and localized monitoring systems. The city should establish a framework to track SDG 11 indicators at the local level, invest in staff training, and ensure risk data informs planning.

Reforms should also include formal mechanisms for community engagement and learning exchanges with peer cities. With better coordination, stronger data systems, and inclusive governance, Mbabane can take meaningful steps toward becoming a more sustainable, resilient city.

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🏆 reviewed paper

Exploring The Impact of Intelligent Transportation Systems on Johannesburg Park Station and Transit-Oriented Development

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1 ABSTRACT

The efficacy of transportation systems generally relies on the pillars of intelligent transportation systems (ITS) and strategically located transit-oriented development (TOD). Moreover, this study examines the impact of ITS on the operations of Johannesburg Park Station within the framework of its TOD. The paper explores how it optimizes passenger flow within the station by leveraging various transportation modes, improved multimodal transfers, and enhanced TOD. The study uses a case study research design to investigate traffic management and passenger flow. Additionally, the study adopts both quantitative and qualitative research methods to gather relevant data. Interviews and questionnaires were used as tools to collect data. The preliminary findings reveal that it significantly contributes to Johannesburg Park Station by improving efficiency, accessibility, and the transportation network within the Gauteng region. The study concludes that it is data-driven and serves as a key tool for a thriving transportation ecosystem.

Keywords: Multimodal Transportation, Intelligent Transportation Systems, Johannesburg Park Station, Transit-Oriented Development, Spatial planning

2 INTRODUCTION

Contemporary cities, particularly in developing countries, face concerns regarding the efficacy and accessibility of public transport systems. The efficacy of transport systems generally rests on the pillars of intelligent transportation systems (ITS) and strategically positioned transit-oriented development (TOD). As such, there has been growing research on ensuring the sustainability of public transport systems (Balasubramaniam et al., 2017; Khazraeian and Hadi, 2019; Tran et al., 2023). This global shift has prompted various countries to adopt context-specific approaches to improving their transport systems. In China, for example, efforts have focused specifically on improving transportation infrastructure and advancing IT (Bešinović, 2020). These improvements have been driven by increased investment in the traffic management system, resulting in more efficient, convenient, safe, and intelligent public transport. The ultimate goal is to upgrade the current conventional cities into more intelligent, ecologically friendly, and economical cities.

On the other hand, Jimenez (2018) noted that many developing countries are falling behind in installing new transportation infrastructure in their cities, a concern that Gumbo et al. (2022) concurs with. To keep up with global advances in ITS technology, developing countries need to develop well-established transport policies to facilitate the rollout of innovative public transport systems (Gumbo et al., 2022). This would enhance the management and operation in a cost-effective manner. Similarly, Oeschger et al. (2020) argued that integrating new public transport modes could enhance accessibility and lead to modal shifts away from private vehicle use. To assess this potential for TOD, it is important to study these new modes in the context of access and egress trips to and from public transport, as several time-varying components affect optimal operation.

Haggag (2022),Hörcher & Tirachini (2021),& Ceder (2021) contend that previous studieshave investigated interdependent infrastructures as dynamic systems and connectivity for sustainability. Hörcher & Tirachini (2021) observe that empirical studies on ITS's role in enhancing public transport hub operations, specifically in TOD settings within the context of developing urban spaces, remain limited.To address this gap, the study proposes a hybrid ITS-TOD framework for up-and-coming urban hubs, where ITS data-driven tools (e.g., optimised AI scheduling) improve TOD diversity and density, at the same time accounting for local challenges such as spatial inequality. This framework complements Bešinović (2020)'s findings by incorporating resilience metrics for multimodal disruption in Gauteng.

3 RELATED WORK

Public transport system authorities require strategies to inform investments aimed at improving operations and services, both to retain current commuters and attract more users. Globally, there has been an increase in studies on TOD strategies and principles. The '6Ds' have been used to integrate urban development and transport by promoting higher density, encouraging land-use diversity, enhancing urban design, improving access to key destinations, reducing travel distances, and implementing demand management strategies. These seek to inform land types and densities along a transport corridor. Sung and Oh (2011) found that transit ridership is positively affected by the business and residential density and land-use mix index. Later, Ewing et al. (2021) evaluated the benefits of TOD and joint development throughout the United States. The study noted that a higher transit proximity premium of housing prices is most likely to occur in places with more mixed land use. While Ali et al. (2021) assessed the air quality across regions with urban areas. The study noted that transit-oriented development is linked with better air quality.

Modern communities face serious challenges in transportation systems, including accessibility, safety, and pollution. ITS has gained increasing attention and importance in TOD strategies and principles. By seamlessly integrating vehicles and sensing devices, cities can build smart, intelligent transportation systems. A study by Qureshi and Abdullah (2013) found that ITS is not limited to traffic research; it also provides hardware, positioning systems, sensor technologies, and services, and is implemented in navigation systems, air transport telecommunications, data processing, virtual operations, and systems. Due to such complexity, many developing countries are yet to fully realise the merits of ITS. Moreover, the implementation of ITS in these contexts is frequently constrained to pilot projects, hindering its ability to transform public transport systems at scale. In developed countries, local authorities are installing roadside infrastructure, such as cameras and sensors, to collect data on ecological and traffic conditions. These advances in ITS and Information and Communication Technologies (ICT) have led to sustainable transportation systems in these contexts (Guerrero-Ibáñez et al., 2018).

4 METHODOLOGY

This study adopted a mixed-methods approach, combining both qualitative and quantitative data collection techniques to yield a comprehensive understanding of the impact of Intelligent Transportation Systems (ITS) on Johannesburg Park Station and transit-oriented development (TOD). The study also included semi-structured interviews with four officials from CoJ's Department of Transportation, including two from the Johannesburg Road Agency, and 20 daily commuters. Both officials and commuters were selected purposively to ensure relevant and diverse perspectives. The quantitative data complemented the qualitative data from the interviews through structured interviews, which gathered comprehensive insights into the effectiveness and use of the ITS and TOD at Johannesburg Park Station. This methodology expedited a yield analysis of how ITS contributes to multimodal transfers and efficient passenger flow, supporting the overall efficacy of the transportation network and the TOD in Johannesburg.

5 RESULTS

5.1 ITS Impact on Passenger Flow and Multimodal Transfers in Johannesburg Park Station

The implementation of the ITS at Johannesburg Park Station has remarkably enhanced passenger flow within the public transit hub in the TOD vicinity of the station. The questionnaire data from 20 daily commuters indicated an average of 35% reduction in observed congestion during peak hours. 65% of participants reported that waiting times for multimodal transfers were under 5 minutes, compared to pre-ITS levels of 10-15 minutes (City of Johannesburg, 2023). 40% of daily commuters indicated that the nucleation of taxi ranks is the root cause of localised bottlenecks.

The public transit hub in Johannesburg Park Station includes Metrorail, the Wanderers long-distance taxi rank, the Bridge local Taxi rank, the Gautrain rail station, Gaubus, the MTN taxi rank, the public bus station (local, long-distance, and international), Rea Vaya, and E-hailing services (Uber and Bolt). Data collected from daily commuters indicate that rail transit hubs have reduced congestion during peak hours through real-time information displays and ticketing systems. Furthermore, the collected data indicate congestion during peak hours due to clustering of taxi ranks, as Johannesburg Park Station is the main TOD in the City of Johannesburg. The rail systems at Johannesburg Park Station form part of the ITS; these features streamline

passenger movement by providing timely updates on train (Gautrain and Metrorail) and bus schedules. This system allows commuters to make well-informed decisions, facilitating smooth passenger flow in the TOD vicinity of Johannesburg Park station.

Electronic ticketing has also improved the commuter experience, with users reporting faster, more predictable transit arrival and departure times, with mean reported boarding times decreasing from 4.2. minutes to 2.8 minutes. The seamless, comprehensive integration of various transport modes, enabled by the ITS, has also improved the efficiency of multimodal transfers, particularly at Johannesburg Park Station. The Johannesburg Park Station serves as a pivotal junction for multiple transportation services. The ITS solutions, such as coordinated transfer points and scheduling, have been instrumental in foreshortening transfer time between these modes. For clarity, Real-time coordination between Gautrain, Metrorail, MTN taxi rank, Bridge taxi rank, Rea Vaya, Metrobus, Gaubus, and e-hailing services ensures minimal wait time for passengers transferring between modes. Subsequently, the Johannesburg Park Station is a complex area; however, real-time directional signage helped commuters navigate the station with ease, reducing confusion and improving the overall effectiveness of multimodal transfers.

Additionally, interviews with CoJ and Johannesburg Road Agency officials, as well as daily commuters, have underscored the significant role of ITS in promoting a more user-friendly, accessible transit environment. The officials have adequately highlighted the strategic merits of ITS in-traffic management, noting that data-driven insights enable the optimization of service schedules and the allocation of services to meet passenger needs. Commuters, on the other hand, have indicated appreciation for the ITS, noting that the transition between various transport modes is now smoother and that they experience fewer significant delays. This synergy between TOD and ITS principles has not only enhanced the operational efficacy of Johannesburg Park Station but also contributed to a more integrated and sustainable urban transportation network in the CoJ.

5.1.1 Transport modes at Johannesburg Park Station ITS

The Johannesburg Park Station serves as an essential hub for various transport modes, all seamlessly integrated through ITS. This station is not only the biggest in Gauteng but also accommodates a variety of transport services including Metrorail for regional train travel, Gautrain for high-speed connections to key economic zones, Bus Rapid Transit (Rea Vaya) for swift urban commuters, taxis (The Bridge and MTN taxi rank) to connect to local townships and e-hailing services such as Uber and Bolt for flexible and shared rides. The ITS therefore simplifies efficient multimodal transfers by synchronizing schedules, providing transportation information and updates, and ensuring easy navigation via digital signage. This interconnection not only enhances the overall commuting experience but also fosters the use of public transportation by making it more accessible, user-friendly, and reliable. The following figures show images of various transportation modes at the Johannesburg Park station ITS.



Fig. 1: MTN Taxi Rank [Source: The Author (2025)]: The images show the MTN taxi rank during the day at peak hours.



Fig. 2: The Bridge Taxi Rank [Source: The Author (2025)]



Fig. 3: Wanderers Taxi Rank [Source: The Author (2025)]

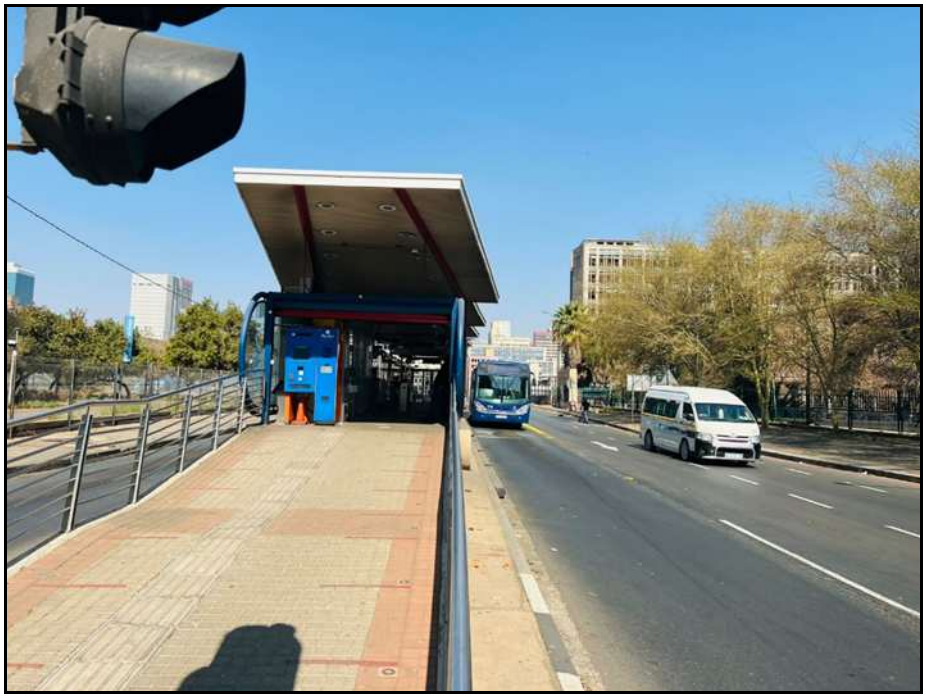


Fig. 4: Bus Rapid Transit (Rea Vaya) [Source: The Author (2025)]

There are three taxi ranks within the vicinity of Johannesburg Park Station's ITS. These are MTN Taxi Rank, The Bridge Taxi Rank, and Wanderers Taxi Rank as depicted in figures 1, 2, and 3, respectively. The MTN taxi rank is well known for connecting the local township with the city centre. These include taxis to areas in the north of Johannesburg, such as Alexandra township, Thembisa, Sandton, etc. The Bridge Taxi Rank connects daily commuters from the South of Johannesburg, such as Soweto, Zola, Dobsonville, and Meadowlands, to the Central Business District of Johannesburg. This network transports commuters into economic activities. The Wanderers Taxi Rank connects commuters to all the provinces in the country. It is also known to service international neighbouring countries such as Malawi, Zimbabwe, Botswana, etc. The ITS at Johannesburg Park Station also includes Bus Rapid Transit (BRT), in particular the Reya Vaya BRT, as depicted in the figure below.

The Rea Vaya is a swift transport that is the lifeblood of Johannesburg's Corridors of Freedom. As one of the first BRT systems implemented in Sub-Saharan Africa, Rea Vaya represents a strategic intervention to address the spatial fragmentation inherited from apartheid-era planning (Togo, 2016). It moves commuters from spaces like the Soweto corridors to the Johannesburg Park Station.



Fig.5: Metrorail [Source: The Author (2025)]

In the Johannesburg Park Station ITS, there are two rail transportation systems. These are the Metrorail and the Gautrain, as shown in Figures 6 and 7, respectively. The Metrorail is the lifeblood of Johannesburg Park Station. This rail transportation not only connects the 7 regions of Johannesburg, but also connects to the provincial regions such as Pretoria, Vereeniging, Germiston, and Springs. The Gautrain, on the other hand, is a high-speed rail offering an efficient and fast option for long-distance travel in the 3 metro cities. It connects OR Tambo International Airport, Pretoria, and Johannesburg. Complementing the Gautrain service is the Gaubus, a feeder and distribution network that extends the rail system's reach. It extends the train's reach, integrating rail and road transport.



Fig.6: Gautrain and Gaubus [Source: City of Johannesburg (2025)]

Figure 8 below is a Sankey diagram that uses width arrows proportional to the flow quantity to visualise how volumes move and distribute through various phases of the system. In this case, it specifically underpins

seamless integration at Park Station by indicating the scale of passenger transitions from primary rail lines to various last-mile transport modes.

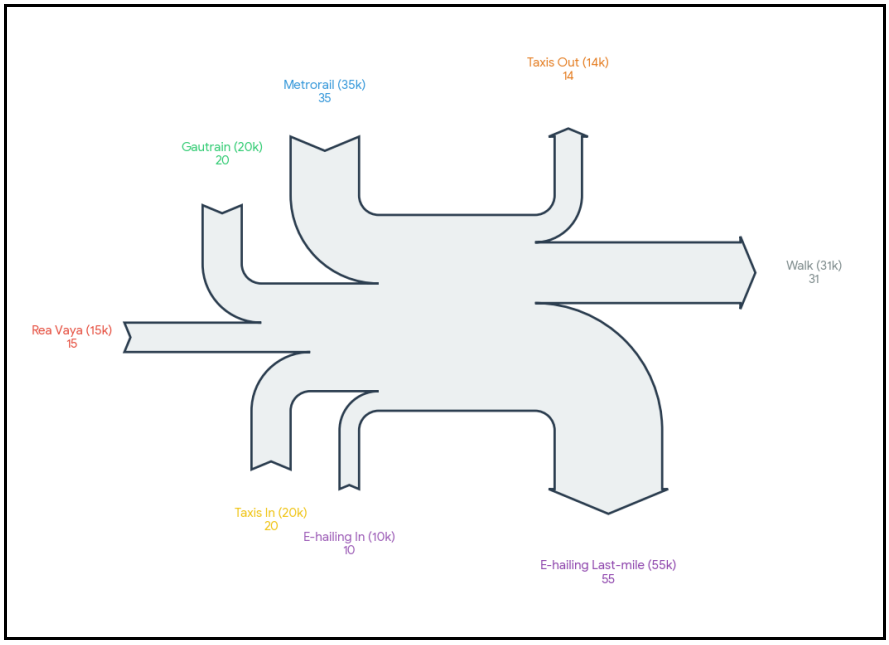


Fig.7: Passenger flow and seamless integration (Sankey Diagram)

5.2 ITS Contribution to TOD Success in Johannesburg Park Station

The ITS has adequately reinforced the success of the TOD at Johannesburg Park Station by improving the overall effectiveness and accessibility of the transportation network. The successful integration of the ITS solution, including the real-time tracking of Gautrain and Metrorail and automated ticketing, has developed a more elegant and user-friendly transit environment. However, the daily commuters indicate that the Johannesburg Park Station precinct is more transit-oriented. Moreover, interviews with daily commuters have indicated that these adjustments have provided them with public transportation options for daily commuting. Subsequently, supporting the core objectives of the TOD, which aim to adequately reduce the reliance on private transportation and encourage urban mobility and sustainable urban development. The data collected indicated that by enhancing the reliability and convenience of multimodal transportation options, the ITS has adequately contributed the role of promoting higher ridership levels and fostering a shift towards more sustainable commuting habits.

The implementation of ITS in Johannesburg Park Station has also catered to better urban development and land use in the vicinity. City of Johannesburg officials and daily commuters have also indicated that, with enhanced transportation services, the vicinity has experienced evident overcrowding and traffic congestion. This has emanated from business attractions and fostering the residential development within walking distance of the station. The principles of TOD align with the densification of ITS, which advocates mixed-use development integrating recreational, residential, and commercial spaces within a walkable distance of transit hubs. It is remarkable that this ITS has enabled efficient accommodation and management of increased passenger flow and volumes. This reinforces Johannesburg's transportation infrastructure to support the growing demand without compromising service quality. The economic vitality and liveability of the surrounding areas are also enhanced by improvements in ITS accessibility, reinforcing the TOD framework.

Subsequently, ITS has enabled a more data-driven approach to transportation management in Johannesburg and to the city's urban planning, both of which are vital to the long-term success of TOD initiatives. Passenger behaviour, transit system performance, and peak usage time have been analysed using real-time data collected via ITS applications; moreover, this data is processed by Gautrain, Gaubus, and Metrorail. Withal, urban planners and policymakers can utilise this available data to make sound, informed decisions about future development, service, and infrastructure investment. This proactive approach ensures transportation networks remain responsive and adaptable to the evolving needs of the urban population. By supporting sustainable and efficient transportation solutions, ITS has improved the operation of

Johannesburg Park Station and reinforced TOD goals, contributing to a more integrated and sustainable urban future for Johannesburg.

5.3 Commuters' Perceptions and Satisfaction with ITS

User feedback on the proficiency and reliability of ITS features at Johannesburg Park Station has been positive among daily commuters. The daily commuters have adequately demonstrated that the ITS provides the convenience of real-time information display, particularly at the Gautrain, Metrorail, Rea Vaya, and the local and long-distance buses. This feature has adequately minimised the stress and unreliability associated with waiting for public transportation. Daily users have also expressed positive sentiment toward the automated ticketing systems used by Gautrain, Gaubus, Metrorail, and Rea Vaya. This feature has also enhanced the efficacy of public transport, allowing commuters to swiftly purchase tickets and avoid long queues.

This study also reveals remarkable input through a comparison of satisfaction levels before and after the implementation of ITS, which improved commuters' movement and perceptions. Prior to the deployment of ITS, many daily commuters and CoJ officials reported frustration stemming from delayed services, inefficient transfer processes, and a lack of information. Recent data indicate that commuters have confidence in public transportation. Subsequently, the statistical analysis also supports a decrease in average waiting time for the next transportation and a reduction in the frequency of missing connections due to the provision of transportation information. The ITS has contributed to a more predictable and smoother commuting experience. These improvements have not only fostered higher ridership but also enhanced individual satisfaction by integrating e-hailing services, supporting the aims of TOD.

The key themes from the qualitative interviews with daily commuters have provided deeper insights into the lived experience of using the ITS at Johannesburg Park Station. Daily commuters have also indicated the value of planning journeys more effectively through real-time updates. It is noteworthy that the daily users reported that the ITS has also made it easier to coordinate transfers between different modes of transport, such as Rea Vaya, Gautrain, Gaubus, Metrorail, and taxis. Further, daily commuters noted that there are various transport modes at the Johannesburg Park Station ITS; these options offer diverse options for commuters.

Table 1 and Figure 8 below compare the Pre and Post ITS Data to demonstrate the historic performance and the current impact.

Metric	Pre-ITS (Baseline)	Post-ITS (Current)	% Improvement
Average Wait Time (min)	12.5	7.2	42%
Satisfaction Score (1-5)	2.8	4.1	46%
Daily Ridership (000s)	150	210	40%
Missed Connections (%)	18	7	61%

Table 1: Sources: Derived from questionnaire data and supplemented by Gautrain Annual Report (2024) and CoJ Transport Stats (2023)

6 DISCUSSIONS

The study's findings underscore the significance of ITS in enhancing TOD. In practice, the study found that the essence of ITS at Johannesburg Park Station has led to remarkable improvements in multimodal transfers and passenger flow. This implementation has reduced waiting times and increased commuters' satisfaction, thereby enhancing the appeal and efficiency of public transportation. The positive impact on urban development and land use around the station, particularly, underpins the strategic value of ITS in supporting the objectives of TOD. These practices paved the way for urban planners and policymakers in other cities seeking to adopt a similar system in their transportation planning. The collected data provides a nuanced understanding of how ITS contributes to the operational success of the transit hub and the TOD objective. The study underscores the significance of real-time data and automated systems in enhancing the reliability and convenience of public transport by boosting ridership and reducing reliance on private vehicles. Subsequently, the study identifies critical areas for future research, such as the long-term sustainability of ITS investments. By identifying and bridging the gap between practice and theory, this study proffers

invaluable contributions to the ongoing discourse on sustainable urban transportation and the role of modern technology in shaping future cities.

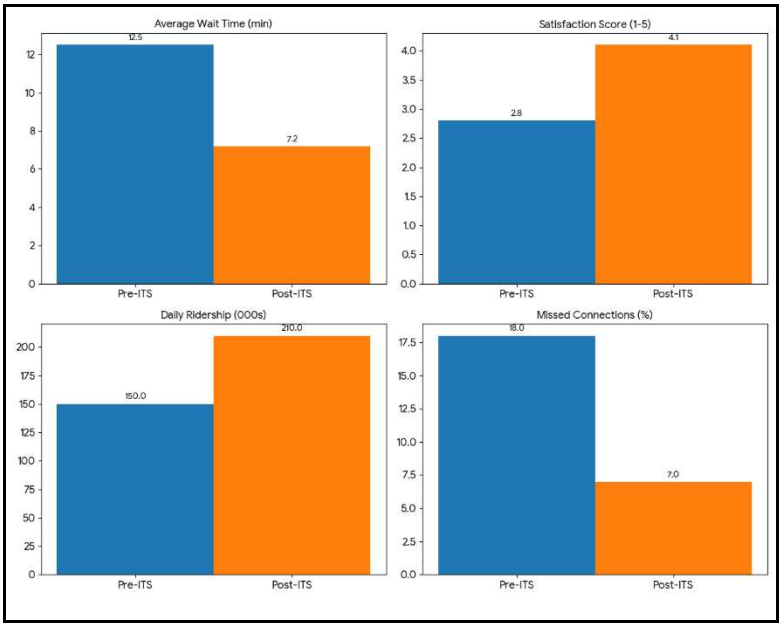


Fig.8 Pre and Post ITS performancemetrics at Johannesburg Park Station

The findings of this study make a significant contribution to both the theoretical understanding and the practical implementation of ITS in the context of TOD. The practical implications are vividly evident in the enhanced passenger flow and multimodal transfer efficiency at Johannesburg Park Station. This has adequately reduced waiting time and increased commuter satisfaction. For that, the study recommends integrating this initiative into land-use planning to enhance safety and security at Johannesburg Park Station, as the station is overcrowded and unsafe.

7 CONCLUSION

The study has highlighted the implementation of ITS at Johannesburg Park Station, as it has enhanced accessibility to the CBD and fostered the effectiveness of the TOD in the vicinity. The study has surfaced that ITS has not only improved multimodal transfer but has also optimised passenger flow. The ITS has significantly improved the integration of the vicinity of Johannesburg Park Station and enhanced the user-friendly public transportation network. The findings underscore the significance of data-driven solutions in contemporary urban planning, helping develop a more sustainable and efficient transportation ecosystem in Johannesburg. The study also revealed that the benefits of ITS are clear; however, it underscores the need for ongoing investments to improve safety and security in the vicinity, particularly in overcrowded areas. Withal, future research can focus on the long-term sustainability of ITS and its wider impact on sustainable urban development.

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reviewed paper

Framing Spatial Decision Support Systems – A Multidisciplinary Perspective on Digital Decision Making in Spatial Planning

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1 ABSTRACT

Spatial planning must resolve increasingly complex land-use conflicts that arise from competing demands on land and space (Hersperger et al. 2015, p. 6, Danielzyk and Münter 2018, p. 1932). These divergent interests stem from heterogeneous stakeholder groups involved in spatial development processes, resulting in multidimensional planning concepts that must integrate socioeconomic, ecological, cultural, technical and ethical dimensions (Bottero et al. 2019, p. 1).

Ongoing digitalization in spatial planning (cf. van Winden and Carvalho 2017, p. 3; Pallagst et al. 2022) is accelerating the adoption of Spatial Decision Support Systems (SDSS), which promise not only faster but also more transparent and evidence-based decision-making within planning processes (Crossland et al. 1995, p. 226). Yet, despite their increasing relevance, SDSS remain insufficiently conceptualized with regard to their decision logic, technological architectures, and underlying data foundations. Ghattas (2018) suggested that further research is needed to better understand the various assessment tools available in sustainable spatial planning.

This contribution deals with the first integrative systematization of SDSS by linking theory on decision making in spatial planning with data and software engineering. Within the research project Ageing Smart – Designing Spaces Intelligently, researchers from various disciplines have collaboratively designed a classification framework through iterative workshops, in-depth research on theory and learnings from selected SDSS samples that merge theoretical insights from planning decision processes with perspectives on functionality, technology and data. This allows for a revised perspective and understanding, empowering researchers to better assess the significance and possibilities of digital tools in planning in the future.

Keywords: Spatial decision support systems, SDSS, decision making in spatial planning, stakeholder in spatial planning, data basis

2 INTRODUCTION

Spatial planning is engaged with coordinating different and often conflicting types of land uses to be allocated in a particular planning situation. From a governance perspective, it also operates as a public task being interdisciplinary, cross-section-oriented, and integrated in a multilevel system (Danielzyk and Münter 2018, p. 1932). It must be understood as a decision-making process. The development of space involves a multitude of different perspectives and concepts from various stakeholders and specialized disciplines, which means that the development and planning of space might be confronted with strong conflicts of interest and the planning solution can strongly vary (Pinson 2004, p. 509). To arrive at a decision that considers and balances the various interests, spatial planners use various intuitive as well as more analytical assessment methods (Scholles 2018, pp. 222-223).

The megatrend of digitalization as a global and multi-disciplinary phenomenon has also arrived in spatial planning (Van Winden and De Carvalho 2017, p. 3; Pallagst and Liggesmeyer 2022). On one hand, this creates challenges for spatial planning, and, on the other hand, it opens many new opportunities that have the potential to provide planners with new methods to improve planning tasks. One of these opportunities addresses the already mentioned complexity of the planning tasks and actors involved, which requires a reliable and comprehensible decision-making process. Digitalization is moving us to digital solutions such as a Spatial Decision Support System (SDSS). An SDSS is a tool to facilitate these day-to-day decisions by digital means (Sugumaran and Degroote 2010, p. 14). It combines different types of spatial and non-spatial data, performs analyses and visualizations, and can thus suggest possible solutions (Keenan and Jankowski 2019, p. 64). SDSS can make processes more efficient and enable decision-makers to make better decisions

faster (Crossland et al. 1995, p. 226). One prerequisite for the efficient use of SDSS is the availability of qualitatively suitable data. Thus, the technologies, functionalities, and data types employed vary significantly. This, at times, also affects the type and quality of the benefits derived from a SDSS for spatial planning. Furthermore, it is crucial to distinguish which user groups are utilizing the program to discern whether it constitutes an expert tool or rather an application designed for a broader user base. However, practice shows that the term SDSS is not always easy to systemize and categorize.

To gain knowledge about the types of SDSS at hand in spatial planning and their application in practice as regards best practice examples, this contribution provides a suggestion for a classification of SDSS used in spatial planning. Various technical, data-related, and spatial planning-related aspects are applied to formulate different assessment criteria. The research on this topic emerged in connection with the interdisciplinary research project Ageing Smart – Designing Spaces Intelligently and it aims at developing a systematized research grid for comparative case studies in this field.The authors have provided a detailed description of the derivation of the classification model in Pauly et al. (2026) and, in Pauly et al. (2025), ventured an exploratory comparison of different SDSSs using the classification model as a methodological approach. The most important findings from this research are now compiled and described in this contribution.

When selecting the appropriate methodology for the investigations, the authors placed great emphasis on ensuring that the various areas of expertise could be utilized to the greatest possible extent due to the different professional backgrounds. However, when different scientific disciplines come together, conflicts can inevitably arise, e.g., with regard to methodological approaches, understanding of terms, and lines of argumentation. Therefore, iterative workshops were chosen as the core methodology for the research, in which the various perspectives on SDSS were shared and discussed without any predetermined conclusions. This allowed for a sharpening of conceptual understandings and the exploration of possibilities for developing a taxonomy-like model that would enable SDSS to be classified using categories that were as precisely defined as possible. In addition to the workshops, however, the research is also based on an in-depth investigation of existing theories, from which key content was compiled to help create the classification model for SDSS.

The next three sections of this article deal with the three different areas that were used to derive the classification model. First, we look at which decisions are made in spatial planning by which stakeholders and where SDSS can come into play. Next, we look at the various technologies and functionalities that are necessary to provide decision support and that can be found in SDSS. Finally, the third area examined is the topic of databases, which have a significant influence on the possibilities for decision support. The classification model resulting from the findings in the above areas is then presented and explained. The researchers' findings that need to be considered for the further development of the model are described.

3 DECISION MAKING IN SPATIAL PLANNING

3.1 Different interests and conflicts of land use

Based on the understanding that spatial planning is a public task that aims to coordinate different demands for the use of a defined space or land (Fürst und Mäding 2011, p. 11; Danielzyk und Münter 2018, p. 1932), the underlying consideration here is that the existence of a space or land is, by its very nature, also a problem. Spatial planning is therefore in the role of problem solver. Hersperger et al. (2015) specifies the problem mentioned and discusses a conflict that arises from the fact that land is a scarce resource. There are different perspectives on a defined land, which ensure that there are different ideas, proposals and claims as to what should happen to it and what function it should take on in the structure of the larger context, e.g. a city or a region. The resolution of this conflict is therefore described by Hersperger et al. (2015, p. 6) as conflict negotiation and thus also defines the goal of land use planning. It is further explained that planning processes therefore also mean conflict anticipation. From a governance perspective, however, it should be noted that planning processes, as the main action carried out in spatial planning, are interdisciplinary, cross-sectional and integrated into a multi-level system (Danielzyk und Münter 2018, 1932). This specifies the problem of the conflict of use and clarifies the dimension of the different perspectives from which the various interests emerge. According to Bottero et al. (2019, p. 1), these have their origin in various actors involved in planning processes, resulting in multidimensional concepts, e.g. from socio-economic, ecological, cultural, technical and ethical perspectives. Bottero et al. (2019) refers to the aforementioned

problems in spatial development as decision problems. This makes it clear that spatial planning implies having to make decisions.

However, the observations on planning that coordinates and anticipates conflicts must be relativized to some extent by the fact that spatial planning and the associated governance structures are conceptualized differently in each country and are shaped by different planning cultures within the meaning of (Knieling und Othengrafen 2016). If one wants to compare these possible conceptualizations according to categories such as planning instruments, administrative levels, regulatory frameworks and their material content, one can speak of planning systems or models of spatial planning (Pallagst 2018, p. 1762; Dühr et al. 2010, p. 35). The understanding of spatial planning as a coordinator and conflict solver can be linked particularly well with the "Comprehensive Integrated" planning system category proposed by Dühr et al. (2010). However, it is clear that the other categories, especially "Land Use Management", but also "Regional Economic" and "Urbanism", are also based on the coordination of land use demands. Even in the countries mentioned by Pallagst (2018, p. 1768) of the Global South, in which spatial development is largely characterized by informal settlement activity, fundamental decisions on the use of a particular land must be the basis, even if there may not always be a balanced consideration of different interests. In general, it can therefore be said relatively universally that spatial planning as a public task deals with land use conflicts and considers and coordinates different interests in order to find solutions. The statement that spatial planning means that decisions are made about the development of an area can also be generalized.

3.2 Planning process

Planning processes depict the processes of coordinating, finding a solution and making a decision and how they interlock. In order to understand the handling of conflicts in spatial planning in depth, a planning process model must be used to operationalize the procedures (Hersperger et al. 2015, p. 7). Also models of planning processes are strongly conditioned by the prevailing planning system. Nevertheless, there are also general aspects that can be operationalized and in reality may have modifications in sequence or other details depending on the country. Hersperger et al. (2015, pp. 7-8) proposes the model of Steiner (2008) for this purpose. This has its origins in landscape planning, but is adapted slightly by Hersperger et al. (2015, pp.7-8) and applied to spatial planning processes in general.

Steiner (2008, pp. 10-11) proposes a process flow with eleven steps. The process starts with the first step, the identification of problems or opportunities, and is completed with the last step, the administration and monitoring of the final plan. After the second step, in which the goal is defined and established in order to address the problem, various steps follow in which inventories, analyses and detailed studies are carried out. Based on this, concrete concepts and options are developed, which then lead to the development of a first plan. This is followed by the citizen involvement step. The plan is then concretized through detailed designs and then implemented in step 10. It is noticeable that the various steps can occur in a different order in the reality of spatial planning depending on the planning system, which can even be regulated by law in some cases. One example of this is the citizen involvement. Hersperger et al. (2015, p. 8) have therefore placed public participation at the center, which makes it clear that on the one hand it is independent of the steps of the planning process and at the same time can be involved in all steps. Another important modification is that Hersperger et al. (2015, p. 8) turn the process into a cycle. This makes it clear that the administration and evaluation at the end of planning also identify problems and opportunities that initiate new planning. It is also made clear that conflict anticipation and conflict resolution are integral parts of the planning process.

3.3 Decisions within the planning process

From the considerations on planning processes and the task of spatial planning to resolve conflicts, conclusions can be drawn about the types of decisions that take place in spatial planning. In the planning processes proposed by Steiner (2008) and Hersperger et al. (2015), the initial point is the identification of problems and opportunities and the resulting planning objectives. Further on, after various studies and consideration of different aspects, there is then the point of creating planning concepts and a concrete design. This means that, particularly at the beginning of the process, attention is initially focused on the option to act and finally the decision to act on the basis of observations and monitoring with the identification step. Later, a decision must be made in order to define planning concepts and develop a concrete design. As planning can

also change during the course of a process by taking other perspectives into account, the same type of decision also applies to the development of any preliminary planning alternatives.

In addition to the perspective of planning processes on decisions in spatial planning, the perspective of planning barriers can also be taken. For this purpose, the execution of planning must be understood as a creative act. However, the creative act of planning is limited by barriers (Schoen 2018, pp. 20-21). The planning system in Germany should serve as an example of this. Here, there are normative regulations with regard to planning limitations that are anchored in construction and planning law. These are the requirement of necessity ("Gebot der Erforderlichkeit"), the weighing-up for balancing requirement ("Abwägungsgebot") and the mandatory legal principles ("zwingende Rechtssätze") (Schoen 2018, pp. 21-22). The requirement of necessity states that planning must take place insofar as the circumstances make this necessary. It therefore describes the start of planning within the planning process. It is therefore the normative equivalent of the identification of problems and opportunities and the planning objectives formed from this as described by Steiner (2008) and Hersperger et al. (2015). The weighing-up for balancing requirement obliges planners to resolve the conflict arising from the different interests and to weigh up the various interests in a meaningful way. This is now the normative equivalent of Steiner's (2008) and Hersperger's et al. (2015) creation of planning concepts and a concrete design. This makes it clear that the two decision typologies already derived from the perspective of planning processes also arise from the perspective of planning barriers: The decision to act and the decision on a detailed design and planning alternatives.

In contrast, the third planning barrier from the example from Germany, the mandatory legal principles, is not a type of decision. Mandatory legal principles are about necessary knowledge of legally binding regulations that restrict the freedom of planners. Rather than a decision, it is therefore a type of consideration that can and must be one of many bases for deciding on a detailed design and planning alternatives. The other considerations proposed by Steiner (2008) and Hersperger et al. (2015) on which planning is based – in particular inventory, studies and citizen involvement – must therefore be extended to include consideration of legal barriers.

Further necessary additions result from the considerations on the influence of the planning culture context and from the fact that land use conflicts arise from different interests. In this respect, the consideration of the different interests of actors, the consideration of different technical interests and the consideration of existing norms and convictions must also be added.

In summary, it can be said that there are two core tyspes of decisions within planning processes that planners have to make: (1.) Decision to take action and (2.) decision about detailed design and planning alternatives.

At this point, however, it is important to note that this classification can only be considered a broad abstraction. Many different decisions made in spatial planning can be assigned to the categories mentioned above. The decision to act, for example, is accompanied by many questions that require a large number of proper sub-decisions: Should an intervention take place at a specific location? What are the objectives? Would it be worth the investment? Does the outcome compensate for the cost and effort? Decisions about detailed design and planning alternatives also raise procedural questions that require sub-decisions: Are there alternative locations, and what criteria are decisive in identifying the best location? What size, dimensions, scale, etc. are necessary? What exactly is the spatial distribution? In conceptual design projects, every single line sketched is ultimately also an independent decision.

However, when considering planning process models and planning barriers for derivation, it is not possible to achieve such a detailed breakdown and meaningful sorting of decision topologies. This would require independent in-depth basic research. However, since this article focuses on the systematization of SDSS, the authors have deliberately chosen to accept the abstraction based on two core decision types in planning processes.

The two decision typologies are framed by different considerations that serve as the basis for decision-making. Fig. 1 illustrates this approach.

The findings on the decision typologies within planning processes shape our understanding of which decisions can be supported by SDSS. At the same time, however, it must be made clear at this point that the two typologies of decisions considered only refer to the core of a planning process. Political decisions on planning, which are made by legislative bodies, for example, and can also be normatively demanded as part of spatial planning, are deliberately not considered. In addition, even after a planning process has been

completed, decisions are made by potential stakeholders about whether or not to make use of the opportunities made possible by the planning. This makes it clear that our understanding of SDSS refers to a tool that addresses the core of spatial planning and its planning processes and probably mostly serves to support planners.

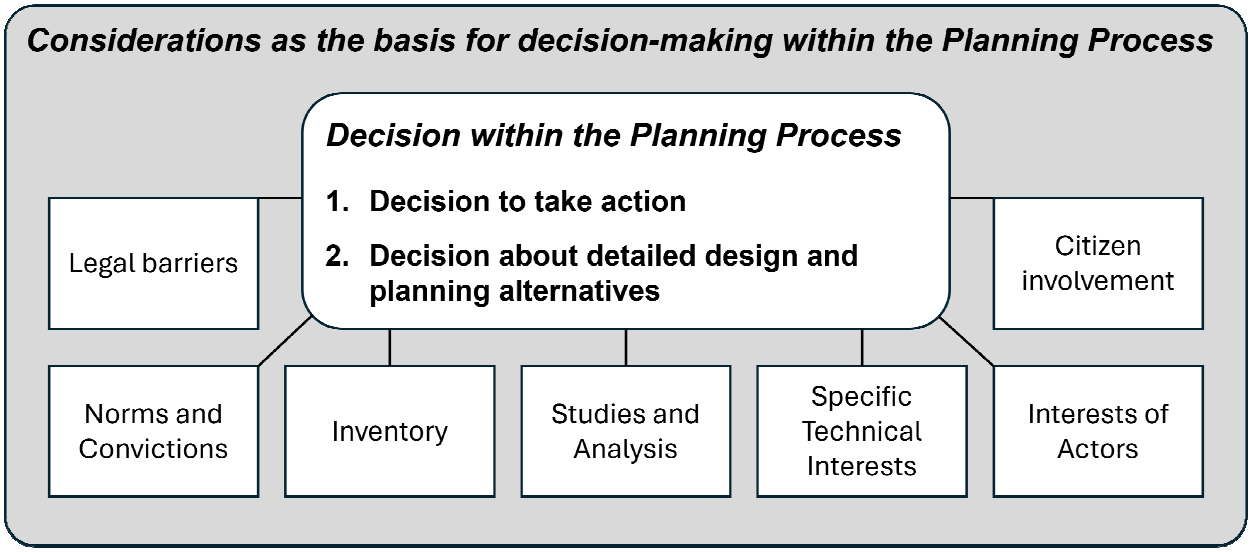


Fig. 1: Decision Typologies in Spatial Planning (translated from Pauly et al. 2026, p. 263)

3.4 Stakeholder in Spatial Planning

When focusing purely on the actors involved in planning processes, it becomes clear that the aforementioned differing interests originate from them, are rooted in them, and are articulated by them. Since planning processes require a solution, but differing interests clash, some form of cooperation is inevitable. The various participants have relationships with each other that are defined by conflict. During cooperation, relationships can be positively influenced if authentic dialogue takes place (Innes and Booher 2010, p. 37). This makes it clear that there must be certain factors, such as specific participation and moderation formats, that enable the best possible compromise to be reached. Ultimately, however, it remains the task of spatial planners to coordinate and weigh up conflicting demands. A decision is then made on the basis of intuitive and analytical evaluation methods (Scholles 2018, pp. 222–223). In order to gain a better understanding of the various actors involved in planning processes, two studies were examined which, for the purposes of their investigations, provide an overview of those involved in planning and their interconnections.

Hölzl and Nuissl (2014) examine urban governance structures in Santiago de Chile and divide the stakeholders into public, private, and civil society groups. They assign influence indices to these groups to illustrate their importance for urban governance. In the public sector, the authors name the responsible ministry, municipalities, the central government with other relevant ministries, regional secretariats, and the regional government. In the private sector, real estate developers, infrastructure companies, the Chilean Chamber of Construction, and other private stakeholders are named. In the civil society sector, individual politicians and universities are mentioned in addition to citizens. The allocation of the influence index is irrelevant at this point, as the influence and role of the various stakeholders can vary greatly depending on the context of the country under consideration. This also applies in part to the allocation of individual stakeholders to the categories proposed by the authors.

Källström and Smith (2023) scientifically accompanied the planning process for regional planning in a Swedish county through several workshops and other events and conducted qualitative interviews. The authors list the actors involved and divide them into ‘internal’, ‘primary’ and ‘secondary’ stakeholders, as well as citizens as a further group of actors. The ‘internal’ stakeholders include a ‘county politician’, the chair of the ‘regional development committee’, the regional planning manager, the project manager, the project team, and the chairs of the thematic working groups. The ‘primary’ stakeholders are listed as the municipality politicians, the members of the ‘regional planning council’, the managers of a municipal association, and the ‘public officials’ of the participating municipalities. National authorities and other secondary participants are listed as ‘secondary’ stakeholders. The group of citizens is not further subdivided. It should also be noted in this example that the proposed structure is strongly influenced by the given

context. However, sorting according to the degree of participation in the process can be very useful, as it allows the role of stakeholders in the planning process to be better classified.

Public/Private: **Spatial planner / Project manager**	*internal*	*Strategic core decisions*
Public Sector: **Executive and legislative bodies with decision-making power**	*primary*	*Political decisions*
Public Sector: **Other by planning activity affected executive and legislative bodies**	*secondary*	*Expression of interest (/vetos)*
Private Sector: **Real estate/Private individual developer and others**		*Economical decisions*
Private Sector: **By planning activity affected organizations and companies**		*Expression of interest (/vetos)*
Civil Society: **Citizens**		*Participation*
Civil Society *(can be additionally public or private sector as well)*: **Universities and other driving forces**		*Participation and expertise*

Fig. 2: Stakeholder within Spatial Planning and their types of decisions (translated from Pauly et al. 2026, p. 265)

These considerations were taken up and resulted in a proposal for the classification of stakeholders in spatial planning (see Fig. 2). A distinction is made between 'internal', 'primary' and 'secondary' actors. These categories define the degree of participation in the planning process. The right-hand column shows the decision typologies. It is clear that the core decisions in spatial planning – the decision to act and the decision on specific planning content – are mainly made by the top group of actors. This underlines our understanding of an SDSS as a support system for planners. However, it is also obvious that planners' decisions can be accompanied by other types of decisions from the primary and secondary stakeholder groups in the planning process. This makes it necessary to also classify an SDSS based on the decisive stakeholder group.

4 TECHNOLOGIES AND FUNCTIONALITIES USED IN SDSS

In addition to looking at SDSS from the perspective of spatial planning and which decisions are made by whom, it is also important to examine the underlying technologies that can result in different functionalities and represent another dimension for classifying SDSS.

In general, available data can be used in various ways in spatial planning. This includes different types of data and also different data sources (sensors, statistical data, etc.). It is obvious that the origin and frequency of data collection have therefore a massive impact on meaningful technologies.

From statistical data to Information and Communication Technologie (ICT) to big data applications, there are dozens of digital concepts and tools that could be considered. For the purpose of decision-making, however, real-time data can be disregarded, as only longer planning horizons are considered in spatial planning.

Other aspects that should be taken into account are the digital skills of planners and their digital environment. End users should have at least basic digital skills, and the underlying digital infrastructure should be provided. Another aspect is certainly the question of how often a digital tool is used. Since this is not static, usage would have to be tracked over time. Since such data is usually not available, this point is not taken into account here. Finally, it could be relevant to what extent end users were involved in the development of the tool. However, this is not easy to determine, which is why it is neglected in the following.

When talking about technology here, a distinction must be made between software and hardware. Since hardware usually plays a subordinate role from the user's point of view, the following analysis focuses on the software aspects of SDSS, whereby the following points can be used to classify SDSS:

Application type	Examples of application types can be smartphone apps, desktop apps or a web-based system. As the questions for spatial planning are usually complex, we assume it is very likely to have tools on a desktop PC, laptop, or maybe tablet PC.
Code ownership	The question if a tool is an open-source product is important. Sometimes, even the programming language (and which libraries are used) can have a massive impact on the usage of the tool. Obviously, an open-source tool usually has a larger community for development and extensions of the tool.
Extendibility	Usually, a new tool is not developed from scratch, that means existing tools or building blocks are taken and extended. From a spatial planning perspective, it might be interesting to discuss the extendibility of the tool. New features might be desired so the question is if they can be added to an existing tool might be of interest.
GUI design	The tool can contain different information in form of text, tables, graphs, and maps. The style and complexity of the tool (number of tables, charts, …) can vary and might be of interest for a comparison.
Interactivity	For a tool, you need to consider if the user can interact with the tool. In other words, the question is if the tool only displays values, tables and charts or if the city planner can set different values as input to obtain different results. Hence, we can classify the tool in interactive tools and static tools.
Analysis	We can group the different analysis methods in terms of classical machine learning methods, wich can be sub-goruped in a) supervised learning, b) unsupervised learning or c) semi-supervised learning. More details and more examples in the context of resilience of interdependent critical infrastructure systems can be found in (Alkhaleel, 2024, p. 3-6). In supervised learning, you usually have labelled data, meaning each dataset has a pre-defined output and the goal is to find an accurate prediction of new data, based on the data labels of known data. In other words, supervised learning usually covers aspects like classification, prediction, or regression. Most important examples are image classifier or prediction tasks (e.g. weather forecast or stock market prices). Typical algorithms are for example decision trees, support vector machines, different regression techniques or artificial neural networks. It should be mentioned that a simple statistical regression is a very basic but supervised learning technique. Unsupervised learning has, in comparison to supervised learning, no labels. In other words, you try to find patterns or structures in the data. The most prominent task is clustering where data points are put into clusters based on their similarities. An example for an unsupervised learning application would be the clustering of people according to their web surfing behaviour, to provide individual advertising. Typical algorithms are K-means clustering or dimensionality reduction techniques like principal component analysis. Semi-supervised learning is a mixture of supervised and unsupervised learning: the labels of the data are only available for parts or a subset of the data. In this case, special generative methods create artificial labels which can be used to adjust the machine learning model.

Tab. 1: Categories to classify technologies used in SDSS in terms of software aspects, own representation

5 DATABASE USED IN SDSS

The quality of the output and results of an SDSS is strongly determined by the quality of the underlying data, whether used directly or through models derived from it. The data should adequately represent and model the addressed spatial problem and contextual factors in such a way that the SDSS can make effective use of all relevant information to achieve optimal results. Understanding the underlying database is therefore a central aspect of classifying an SDSS. Data can be evaluated and categorized according to various criteria, including content domain, publisher, and technical aspects (Van Nuffelen 2024). Depending on the investigator and use case, different aspects may be given more weight. Such assessments can be carried out at varying level of detail; however, this degree of granularity is beyond the scope of this report. The choice of data-relevant dimensions for classifying an SDSS involves balancing the aim of a simple and clearly comprehensible classification structure against the inherent complexity of data and metadata, especially in a broad and multifaceted application domain such as planning.

5.1 Transparency

Is there a website, manual or similar source that provides information on the data used in the SDSS? In the absence of such documentation, it might be difficult to answer most of the following questions correctly.

5.2 Implicit data

Implicit data refers to information that is not explicitly stated or directly provided. Does the system use statistical parameters that have been derived from data or does it employ AI models that have been trained on training data?

5.3 Domains

Demography and socioeconomics	This data might include population statistics (e.g. age distribution and gender ratio), household data, and employment statistics.
Land use and spatial planning	This includes official planning documents, including development plans, land-use plans and zoning plans.
Infrastructure and supply	These datasets include utility network information such as electricity grids, water supply networks, and gas pipelines, service data like maintenance records and outage reports, and transportation infrastructure data.
Transportation and mobility	Relevant data may include traffic flow information such as vehicle counts and congestion levels, public transport data including bus and train schedules, as well as user mobility data such as bicycle-sharing and car-sharing usage patterns and pedestrian counts. This can be considered dynamical information about the usage of infrastructure.
Environment and climate	This domain covers data on air quality, weather data including temperature, precipitation, and humidity, and information on green spaces like the locations and sizes of parks and urban forests.
Health and safety	This domain includes health statistics such as disease incidence rates and hospital admissions, safety data like crime rates and emergency response times, and health service accessibility.
Economy	Economic data might encompass business information such as the number of businesses and types of industries and employment data including job vacancies and wage levels.
Education and culture	Relevant data include school data such as enrollment numbers and graduation rates, information on cultural institutions like museums and theaters, and data on cultural events.
Housing	Housing data can include information on housing stock such as the number and types of housing units and occupancy rates, real estate data like property values and rental prices, and assessments of housing conditions including the age of buildings and renovation needs.
Public services	This domain involves data on the location and availability of public facilities such as hospitals, schools, and libraries.

Tab. 2: Different possible domains of data used in SDSS, own representation

5.4 Data types

The term ‘data type’ is used here to provide a technical overview of the data used without delving into the details of specific data formats. While satellite data, for instance, also falls within the scope of geodata, this type of classification specifically highlights special cases that are of particular relevance for an SDSS investigation.

Geodata	Various spatial structures are used in SDSS. Those contain administrative regions like federal states, municipal borders and districts. Relevant points of interest might be doctors or schools. Detailed maps of infrastructure such as roads and supply lines might also be included.
Sensor data	Air quality, noise and temperature sensors are among the most used sensors in cities. There are also sensors in public transportation and to control traffic.
Remote sensing data	This includes LIDAR data, satellite images, radar data and aerial imagery.
Statistical data	All qualitative and quantitative information that is collected und saved in a structured way like census data.
Images and videos	This could contain surveillance footage, aerial imagery and photographs of public spaces.
Text documents	Any kind of accompanying documents like protocols or documentations
User generated content	This refers to any form of content – text, images, videos, reviews, and other forms of media – that is created and shared by individuals rather than by professional content creators or organizations. This content is typically made publicly available through online platforms, social media, websites, and other digital channels.

Tab. 3: Different possible data types used in SDSS, own representation

5.5 Origin, openness and legal matters

The license under which a data set is made available defines the terms and conditions for its use, sharing, modification and redistribution. Of particular interest is whether the data is openly accessible and therefore freely usable. On the other hand, it must be considered separately whether sensitive data is being used that warrants special protection.

5.6 Timeliness

For some applications, the quality of the results depends on the timeliness of the data used. Are regular updates available, or are there options to update the data? Additionally, is real-time data being used?

5.7 Linking, integrationand export

Of interest is to determine whether users are able to upload or input their own data. Additionally, the availability of interfaces, such as connections to open data portals or other applications, that facilitate data integration is a relevant consideration. Moreover, it is crucial to ascertain whether the system supports the export of results or provides direct connections to other tools for further use of the results.

6 RESULTS

6.1 Classification model for SDSS

Based on the above, a classification according to three overarching categories of indicators is proposed:

(1) Type of decision

(2) Technology an functionalities used

(3) Data basis

The three higher-level categories contain indicators that describe the central characteristics of an SDSS. However, the indicators differ in terms of their response modality. Based on an application to be examined that is classified as an SDSS, the indicators require a binary, descriptive, or nominal response. An example of a bionary indicator is the decision to act, which can be classified as either given/applicable or not given/not applicable. In contrast, the indicator analysis is a descriptive modality, since no choice from predefined categories would be conceivable here, but rather a case-by-case description is required. The situation is different with the nominal modality, where it is expected that an assignment to a predefined selection of categories is possible. An example of this is the data type indicator.

Regardless of the response modality, however, the indicators serve taxonomic-like purposes, enabling SDSS to be classified. For the sake of better understanding and content-related organization, however, we recommend following the order of the three superordinate categories.

The following figure combines the most important findings on the classification of SDSS in spatial planning.

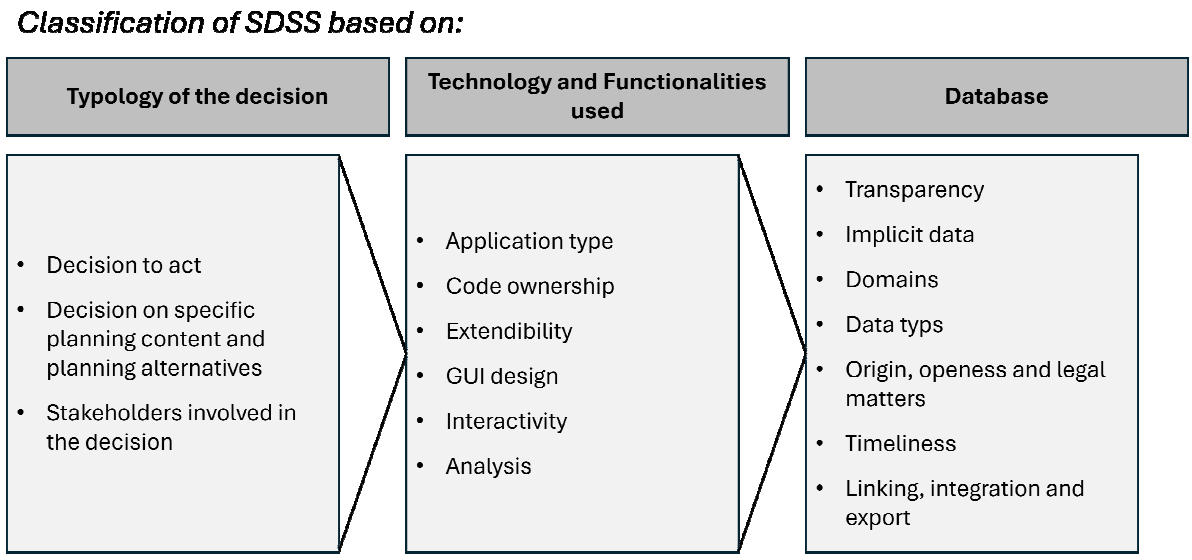


Fig. 3: SDSS-classifying indicators (translated from Pauly et al. 2026, p. 273)

The typology of decisions provides information about which specific decisions are made. Based on the authors' research, these are core decisions within planning processes. On the one hand, the use of SDSS can make users aware of planning needs that were previously unknown. This can lead to the decision to take action. On the other hand, the decision to take action may already have been made as a starting point. In this case, SDSS can make it easier to make decisions about specific planning content and planning alternatives. Furthermore, the group of actors who are supported in their decision-making is another important feature of SDSS. Although it has already been made clear that the core decisions are actually only made by internal actors, political decisions by primary actors could also play a role, for example, if applicable in a given application.

The technologies and functionalities used in SDSS represent a further step toward classification. SDSS can differ in terms of their type of application, code ownership, expandability, GUI design, interaction, and analysis options.

As a final step, classification according to the database is proposed. The database is so important in SDSS because it provides the basis for all functionalities. The quality of the entire SDSS also depends on the quality of the data. In terms of the database, SDSS can differ in terms of data transparency, implicitness, domains, data types, origin, openness, legal aspects, data currency, and data linking, integration, and export.

6.2 First attempts of an application

In Pauly et al. (2025), the authors conducted a study in which they tested the classification model as a method for comparing four selected SDSS. The aim was, on the one hand, to validate the defined indicators and, on the other hand, to identify initial patterns that could indicate certain regularities in SDSS. When selecting the four SDSSs to be compared, care was taken to ensure that they differed from each other as much as possible, particularly in terms of their basic usage concept, in order to enable a differentiated analysis. So, the four SDSS were deliberately selected for their heterogeneity in application domain and methodological approach.These are described in the following paragraphs.

Urbanist AI was developed by two private companies that combine expertise in the fields of software development and spatial development. The basic idea behind Urbanist AI is to highlight alternative design options, particularly for public spaces, thereby identifying areas where action is needed, which can ultimately support decision-making. To this end, the software generates images of the space using AI technology (Toretei S.R.L., SPINUNIT Lab OY, SPINUNIT OÜ, n.d.).

Daviplan was developed by the company Gertz Gutsche Rümenapp Stadtentwicklung und Mobilität. The application was commissioned and provided by the Federal Institute for Research on Building, Urban Affairs, and Spatial Development (BBSR) and the Federal Ministry of the Interior in Germany. The idea behind Daviplan is to analyse the location and supply structures of public services using map-based visualizations, thereby providing targeted support for spatial development decisions (Gertz Gutsche Rümenapp Stadtentwicklung und Mobilität GbR, n.d.; Gertz Gutsche Rümenapp Stadtentwicklung und Mobilität GbR and BBSR, 2023).

Maptionnaire was originally developed in the academic sector, which ultimately led to the founding of a private company (Mapita Oy, n.d). The developers themselves describe Maptionnaire as a geographic information system (GIS) for public participation. The basic idea is to allow the population to generate data on specific topics in which they are involved, which can then be used by planners. This highlights areas where action is needed, which can serve as a decision-making support for those responsible (Mapita Oy, n.d.b).

HEC-RAS was developed by the Hydrologic Engineering Center, part of the United States Army Corps of Engineers. However, the application is also made available for civilian use. The software calculates water flows and visualizes them for flood scenarios (USACE Hydrologic Engineering Center, n.d.).

Now a short summery of the outcomes of the comparison will be given: With regard to the decision-making criteria, it was found that all four applications fundamentally support the decision to act by highlighting deficiencies in the current situation. While Daviplan, Maptionnaire, and HEC-RAS point out these deficiencies directly, UrbanistAI does so more indirectly through idealized representations that do not necessarily correspond to real planning conditions.Daviplan and HEC-RAS in particular provide support for decisions on specific planning content and alternatives, as scenarios are a central component of these

applications. Depending on how it is used, Maptionnaire can be used both for pure deficit assessment and for evaluating planning options. UrbanistAI, on the other hand, is primarily used to visualize imaginary possibilities and does not support realistic planning decisions.All applications are primarily aimed at internal, strategic decisions by spatial planners. Daviplan is more suited to supra-local planning, while HEC-RAS is typically used in specialist planning. In addition, all tools can support political decision-making processes. Maptionnaire plays a special role here, as it involves residents who do not make decisions themselves, but support planning considerations through their input.

In terms of technology and functionality, the applications differ in their technical implementation and accessibility. While HEC-RAS must be installed as a desktop application, UrbanistAI, Daviplan, and Maptionnaire are browser-based, with Daviplan requiring a one-time Docker installation. The licensing model also varies: UrbanistAI and Maptionnaire require a license, HEC-RAS is free of charge, and Daviplan is available as open-source software, which is the only application that allows for extensibility. All tools offer cartographic visualizations. In addition, UrbanistAI displays generated images, Daviplan displays tables and diagrams, and HEC-RAS additionally displays hydrological parameters such as water flows or elevation profiles. The interaction options range from importing your own photos (UrbanistAI) to integrating POIs for accessibility analysis (Daviplan), creating participation questionnaires (Maptionnaire), and parameterizing complex water flow models (HEC-RAS). Methodologically, UrbanistAI uses generative AI, Daviplan uses accessibility models and forecasts, Maptionnaire primarily uses cartographic visualization of user-generated data, and HEC-RAS uses simulation-based hydrological models.

In the area of databases, transparency was examined first. Only limited information is available for UrbanistAI and Maptionnaire, as no detailed documentation is available. In contrast, Daviplan and HEC-RAS offer comprehensive manuals that provide insights into the data used and model assumptions. UrbanistAI does not disclose any information on the training or background data for its AI, andMaptionnairesimilarly does not allow any statements on this subject. Daviplanoperates without implicit data assumptions, whereasHEC-RAS is based on a water flow model with corresponding assumptions. In terms of content, the applications cover different domains, including land use, environment, infrastructure, demographics, mobility, and health, Maptionnaire poteappears capable to integrate all urban topics. All SDSSs utilize with geodata; in addition, photographs and texts (UrbanistAI), statistical data (Daviplan), user-generated content (Maptionnaire), and model-based hydrological data (HEC-RAS) are used. Users can import their own data into all applications. However, statements regarding openness, timeliness, and data protection aspects remain largely unclear, with the exception of Daviplan, which partially relies on openly accessible official statistical data.

6.3 Outlook

The comparison of the four SDSS UrbanistAI, Daviplan, Maptionnaire, and HEC-RAS reveals the diversity of possibilities offered by data-based decision support in spatial planning. It became clear that SDSS are difficult to conceptualize in a general understanding due to this heterogeneity. One reason for this is that their possible applications differ greatly from one another. Applying the SDSS typology clearly shows where the differences lie and how they influence its use as a spatial planning tool.

Since existing SDSSs are found in very different contexts, it is necessary to use a methodology that enables comparative analysis and maps the core characteristics. In this respect, it can be said that the classification approach proposed here offers a good opportunity to gain a better understanding of SDSSs.

Exploring further classification options could expand this understanding even further. For example, the introduction of defined SDSS subject areas would be conceivable. In addition, the development of maturity criteria could add an evaluation level to the typology.

It is striking that for some criteria, such as the ‘openness’ or ‘legal aspects’ of the database, no statement could be made for all or a majority of the applications examined due to a lack of information. This could be due to the selection of the four SDSS and must be critically examined. In further investigation, an expansion of the methodology, in particular through qualitative interviews with the developers, would be conceivable.

All in all, the contribution shows that research into the classification of SDSS helps to better understand their growing importance for spatial planning. New digital tools are increasingly being used in the context of spatial planning, leading to changes in the working methods of spatial planners. Data-based decision support

systems are designed to make them more efficient and have the potential to contribute to better and faster decisions in spatial planning, thereby supporting the planning process.

We could learn, that SDSS mediate spatial thinking by structuring how geographic information is represented, analyzed, and visualized. Importantly, SDSS do not introduce fundamentally new types of spatial decisions; rather, they operationalize and support existing decision-making processes by structuring complex spatial information and, in some cases, lowering the threshold for non-specialist users to engage with spatial decisions making. Research on the classification of SDSS promotes understanding in this area.

The purpose of this contribution is to provide a framework for future research into questions surrounding the potential, benefits, and possible areas of application of emerging digital tools designed to support decision-making in spatial planning. Comparative case study analyses using the framework proposed here appear to be suitable for this purpose.

The findings on decision typologies in spatial planning processes should be understood as a by-product of this contribution. The authors see this as a worthwhile starting point for conducting in-depth basic research in order to better conceptualize decision typologies in the future.

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reviewed paper

From Crisis to Growth: Pre-Disaster Planning as a Catalyst for Sustainable Innovation and Circular Economy in European Cities

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1 ABSTRACT

The proposed contribution analyses how short- and long-term strategies in urban planning can foster urban resilience and a circular economy by comparing technological measures, nature-based solutions and integrative communication processes. In examining how authorities engage the public to address emerging hazards, this study demonstrates the role of pre-disaster planning in catalysing sustainable innovation. We highlight communication as the key driver for inclusive, resilient long-term policy.

Our case studies include Graz (AT) and Ljubljana (SLO). Though confronted with similar ecological and socio-demographic challenges, the two cities address these challenges in markedly different ways, reflecting culturally biased divergent policy priorities and communication strategies. Using Graf et al.'s 2026 introduced Aware–Prepare–Act (APA) lens as a heuristic, the paper conducts a comparative policy analysis of two contrasting urban governance models. The paper tests the thesis that technological upgrades (e.g., expanding tram networks, cycling infrastructure, digital tools and AI) only produce urban resilience when anchored in sustained communication and participatory processes, a relationship made visible through an overarching APA lens on prevailing practices. In addition, inclusive, participatory formats are crucial for the achievement of a Social Licence to Operate, needed for boosting involved stakeholders' acceptance to redesign cities for enhanced biodiversity, integrate green infrastructure, and organizational learning on all levels.

Keywords: Urban resilience, Participatory Urban Planning, Communication Strategies, Circular Economy, Nature-Based and Technological Solutions

2 INTRODUCTION

European cities are increasingly exposed to compound and cascading risks arising from climate change, demographic shifts, and infrastructural ageing. Heatwaves, flooding, biodiversity loss, and energy insecurity challenge established urban development models and strain institutional capacities. In this context, disasters are no longer isolated events but manifestations of long-term structural vulnerabilities. Urban governance has often been characterized by a predominant focus on response and recovery. Recent research increasingly emphasizes anticipatory and preventive approaches to disaster risk management, highlighting the need to reduce vulnerability before hazardous events occur (Botzen & van den Bergh, 2009). These approaches embed disaster risk reduction within broader sustainability objectives, as articulated in the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR, 2015). Analyses of the Sendai Framework further interpret this shift as a move toward risk-informed and preventive governance that extends beyond reactive disaster management (Kelman & Glantz, 2015). Beyond climate-related hazards, urban mobility systems constitute a persistent and underestimated risk domain in European cities. According to the DEKRA Road Safety Report 2025, road traffic remains one of the leading sources of preventable fatalities in urban environments, with vulnerable road users accounting for a growing share of deaths, particularly in cities undergoing rapid mobility transitions. The report emphasizes that technological upgrades alone (such as digital traffic management or vehicle automation) do not reduce systemic risk unless accompanied by behavioural change, governance coordination, and sustained public communication (DEKRA Verkehrssicherheitsreport 2025).

Pre-disaster planning has emerged as a governance arena where risk anticipation, infrastructural investment, and institutional learning intersect. This paper builds on this premise, thus asks: How does pre-disaster planning shape the relationship between risk communication, circular economy strategies, and urban resilience? To address this question, the paper compares Graz (Austria) and Ljubljana (Slovenia), two

medium-sized European cities facing comparable ecological and socio-demographic challenges but pursuing markedly different governance and communication strategies. The analysis draws on the Aware–Prepare–Act (APA) lens as a supportive conceptual heuristic, which supports the comparative interpretation to how communicative purposes (awareness-building, preparedness-oriented communication, and action-oriented signals) and temporal orientations are articulated across policy domains (Graf et al., forthcoming). By focusing on communication and participation, the paper advances the argument that technological and infrastructural innovation only becomes transformative when socially embedded and publicly legitimised.

Demographic comparison of Graz and Ljubljana			
Indicator	Graz	Ljubljana	
Country	Austria	Slovenia	
Settlement type	regional city (mid-sized)	capital city (mid-sized)	
Area (total)	127.58 km²	163.8 km²	
Population (most recent value stated)	345.391	301.268	45,983 (total Ljubljana)
of which EU citizens	52.563	5.686 (Osrednjeslovenska region)	
of which non-EU citizens	50.092	no data	
Population density	2. 707,25/km²	1. 839,24/km²	

Table 1. While 15.3% of Ljubljana's inhabitants are foreign nationals, the specific breakdown for EU citizens is only designated at the regional level for Osrednjeslovenska (SiStat 2026a, 2026b). Numbers are considered most recent (01.01.2026 for Austria, Second Half Year 2025 for Slovenia).

The demographic profile of Graz consists of 50.55% female and 49.45% male residents, with the 25–30 age bracket representing the most prominent cohort across both genders. In contrast, Ljubljana's demographic structure is older, with the 40–44 age group being the most populous, while the 25–30 bracket ranks fourth, accounting for approximately 13% of the total population (SiStat 2026). These demographic characteristics are relevant insofar as they shape participation potentials and legitimacy structures in urban mobility governance. Statistically, members of Gen Z and Millennials are more inclined to adopt digital and shared mobility solutions, which generally fosters more sustainable urban transport systems (Arsovski et al. 2025; Little 2024). Demographic change further amplifies the relevance of inclusive mobility planning. OECD analyses show that ageing societies require adaptive transport systems that integrate accessibility, safety, and participation, reinforcing the need for anticipatory governance in urban mobility transitions (OECD, 2001).

Despite these demographic potentials, a critical disparity arises regarding political agency. In Graz, 29.7% of inhabitants lack Austrian citizenship, and only 15.2% of this group (those holding EU citizenship) possess municipal voting rights (Stadt Graz 2026). This exclusionary framework significantly impacts local governance and social cohesion (Statistik Austria 2025). The restrictive nature of the Austrian franchise becomes particularly evident when compared to the Slovenian model. While Graz excludes third-country nationals from local elections, Slovenia grants municipal voting rights to all foreign residents with permanent residency, regardless of their country of origin. Furthermore, Slovenia's National Council facilitates "functional representation", allowing foreign workers to participate in interest-based elections (Waldrauch 2022).

Finally, urban safety remains a critical metric for both cities. In 2024, Graz recorded 1,655 traffic accidents involving personal injury, resulting in 2,003 casualties and 7 fatalities (Statistik Austria 2026). Though there are no final numbers for Ljubljana 2025, it had zero road fatalities in 2024 (DEKRA Verkehrssicherheitsreport 2025).

3 THEORETICAL FRAMEWORK

3.1 Urban Resilience and Circular Economy

Urban resilience has evolved from a predominantly technical concept concerned with robustness and recovery toward a socio-ecological framework that integrates governance, participation, and learning. Contemporary resilience research emphasizes adaptability, transformability, and the capacity of urban systems to reorganise in response to long-term stressors. Parallel to this development, the circular economy paradigm has gained prominence as a sustainability framework aiming to decouple economic activity from resource consumption through reuse, regeneration, and closed material loops.

Resilience and circular economy approaches both challenge linear planning models and highlight the need for cross-sectoral coordination. In urban contexts, circular economy strategies often materialise through mobility transitions, green infrastructure, energy systems, and waste management. Their success, however,

depends not only on technological feasibility but also on governance arrangements and public acceptance. Recent research highlights that transitions toward circular urban systems critically depend on everyday practices and lifestyles. Studies focusing on urban communities demonstrate that circular economy strategies are only effective when infrastructural change is accompanied by shifts in consumption patterns, mobility behavior, and social norms, reinforcing the role of communication and participation in enabling systemic transformation (Szabó et al. 2024).

Recent mobility research further demonstrates that circular economy strategies in transport systems simultaneously reduce environmental pressure and systemic risk exposure. A large-scale review of urban mobility transitions shows that cities integrating reuse-oriented mobility services, shared infrastructure, and demand-management instruments experience lower rebound effects and higher system robustness than cities focusing exclusively on electrification or digital optimisation (Zhang et al., 2023). A systematic synthesis of circular economy strategies in the transport sector shows that interventions focusing on reuse-oriented services, shared infrastructure, and lifecycle optimization tend to produce broader environmental and operational benefits than narrow electrification or digital optimisation strategies (He et al. 2023). Recent scoping reviews of urban mobility literature highlight that integrated planning for sustainability and resilience, especially through multimodal systems and redundancy, enhances both environmental outcomes and systemic robustness in the face of disruptions (Sassaron et al. 2025).

3.2 Pre-Disaster Planning as a Transformative Bridge – from Participation to Social Licence to Operate

Pre-disaster planning has evolved from reactive emergency management into a transformative governance space that reshapes development trajectories before disasters impose urgent constraints. It functions as a temporal bridge, aligning short-term risk awareness – defined by the interaction of hazard, exposure, and vulnerability (UNDRR 2017) – with long-term infrastructure cycles. The ETSC PIN Annual Report (2025) validates this by showing that sustained safety gains result from institutionalised preventive governance and public engagement rather than isolated technical investments. Thus, anticipatory planning serves as a risk governance mechanism that synchronizes safety, sustainability, and behavioral adaptation (ETSC 2025).

Securing an SLO is critical for sustainable transformation, requiring both capable institutions and active stakeholder involvement to develop legitimate solutions (Borrás et al. 2025, Wenander 2024). Within the spectrum of participation, cities must move beyond a one-sided transfer of information (where experts define goals) towards the co-production of knowledge based on joint problem definitions (Schneider et al. 2018). This shift is essential for implementing the demand-side measures and lifestyle changes that the IPCC (2022) identifies as central leverage points for mitigating climate risks in urban mobility and infrastructure systems.

3.2 The Aware-Prepare-Act Lens

The conceptual foundations of the APA lens build on empirical insights from a systematic scoping review of risk and crisis communication research, which identified persistent fragmentation between short-term warning-oriented communication and long-term adaptation-oriented approaches (Graf et al. 2026).

Building on these empirical findings, the APA lens was subsequently developed as a conceptual heuristic through iterative analytical synthesis and interdisciplinary expert consultation (Graf et al. forthcoming). It distinguishes three interrelated communicative purposes: awareness-building, preparedness, and action.

Awareness refers to the communication of risks, uncertainties, and long-term challenges to diverse publics. Preparedness encompasses planning instruments, institutional capacities, and resource allocation.Action refers to communication related to concrete measures and infrastructure interventions as they are presented in policy documents, without implying an assessment of their implementation or effectiveness. s. The analytical value of the APA lens lies in its capacity to make patterns of emphasis and potential communicative gaps analytically visible, particularly situations in which technical planning advances without corresponding social engagement, as well as configurations where participatory communication reinforces policy coherence and legitimacy.

3.3 Social Licence to Operate in urban transformation

Originally developed in the context of extractive industries, the concept of Social Licence to Operate (SLO) has gained relevance in urban governance. Large-scale transformations, such as mobility transitions or the reallocation of public space, often generate social conflict and resistance. Formal legal approval alone is

insufficient to ensure long-term legitimacy. In urban contexts, SLO refers to the ongoing acceptance of policies and projects by affected communities. It is generated through trust, transparency, and meaningful participation. This paper adopts SLO as an analytical bridge between risk communication and pre-disaster planning, arguing that anticipatory governance can strengthen legitimacy by involving publics before crises escalate.

4 METHODOLOGY

The paper follows a qualitative comparative case study design. Graz and Ljubljana were selected due to their comparable size, regional context, and exposure to climate-related risks, combined with divergent governance and communication approaches. Primary sources include urban development strategies, sustainable urban mobility plans as issued by the respective cities, environmental indicators, and institutional publications. In order to achieve comparability the selected document are mobility plans and strategies of the respective cities that aimed for a vision 2020 and 2040, respectively. This choice allows the APA lens to render long-term goals set in the earlier document in context of the later (Graf et al. 2026). Due to the separated publication of the Graz documents, the mobility plan as well as connected documents such as the plan's measures and goals are added. This is true for both Styrian policy documents. The following table provides a overview of the used sources. Document analysis was complemented by a qualitative content analysis. A coding manual was developed based on a semi-deductive, semi-inductive approach. The deductive perspective was structured using the theoretical Aware-Prepare-Act lens. Furthermore, coding focused on three analytical dimensions: (1) technological measures and infrastructural interventions, (2) nature-based solutions (NBS) and circular economy (CE) elements, and (3) communication strategies and participatory formats.

In a first step, the main coding categories were derived deductively from the research questions and relevant literature on urban governance, risk and crisis communication, disaster risk reduction, and sustainability planning (Fereday & Muir-Cochrane, 2006; Mayring, 2014, Ellen MacArthur Foundation 2017; CE Center | Circular Economy Policy Research Center 2019).

This initial framework was subsequently discussed and critically reflected in an interdisciplinary expert round involving four researchers with backgrounds in trauma studies, sociology, linguistics, environmental systems sciences, psychology, and history. The purpose of this exchange was to assess conceptual clarity, identify overlaps or gaps, and ensure the analytical applicability of the coding categories across disciplinary perspectives. In a second step, the coding scheme was iteratively refined through inductive engagement with the empirical material during pilot coding of selected policy documents, resulting in the specification of category definitions, inclusion and exclusion criteria, and illustrative examples.

The APA lens was subsequently applied as a comparative analytical framework to examine how awareness-building, preparedness, and action are aligned or decoupled across the coded policy domains. The comparative approach allows for identifying patterns of alignment and misalignment between planning, communication, and implementation. This study remains mindful of the potential for verification bias. Following Popper's principle of falsification (1963), the framework is employed not merely to confirm the necessity of participatory communication, but as a diagnostic tool to identify where these assumptions might fail or where technological excellence, as seen in the Graz case, partially compensates for communicative gaps. The comparative design specifically looks for 'disconfirming evidence' – instances where resilient outcomes occur despite a lack of integrated participation.

5 CASE STUDY: GRAZ

5.1 Governance context

Graz positions itself as a regional innovation hub with a strategic emphasis on climate mitigation and sustainable mobility. However, the city's governance landscape is characterized by structural fragmentation, with policy responsibilities dispersed across multiple municipal departments. While high-level strategic documents articulate ambitious sustainability targets, the lack of cross-sectoral coordination often hinders the translation of these goals into a cohesive urban vision.

5.2 Technological measures and circularity

Technological interventions in Graz are robust, focusing on the expansion of the tramway network, significant investments in cycling infrastructure, and the deployment of digital traffic management systems. These measures are effective in driving a modal shift and reducing emissions. Nevertheless, circular economy principles remain weakly institutionalized, surfacing primarily as isolated, sector-specific initiatives rather than as an integrated pillar of urban resilience.

5.3 Communication and participation

The analysis of the Graz Mobility Plan underscores the systematic, dialogue-oriented integration of the Climate Advisory Council into action planning, aiming to incorporate long-term climate-related considerations. In the so-called district dialogues, held over three evenings, there was a clear match between what people wanted and the action plan presented. The mobility dialogue, attended by 300 participants, was rated as uncritical and positive, suggesting approval of the existing concept. At the same time, there is a high level of interest in participation on the part of the population, who want to have a say and be actively informed. However, the selection of target groups and stakeholders is not described transparently in the plan. It also remains unclear how the results of the online mobility survey, which had around 3000 participants, will be integrated into the further development of the concepts. Although the survey provides valuable information on preferences and needs, it does not explain how these findings will be incorporated into concrete measures.

Compared to earlier concepts such as the Graz Mobility Concept 2020, there has been clear progress: these predecessors contain virtually no references to citizen participation or stakeholder involvement. Only the city of Graz's mobility strategy mentions the need to raise awareness, but it does not specify how this should be achieved. For the city of Graz, it also remains essential to coordinate transport policy objectives and planning measures with higher-level planning authorities (the province of Styria, the federal government, ÖBB, and the EU). This serves to protect urban interests and requires targeted lobbying to address overarching problems in the transport sector. Overall, the Mobility Plan 2040 shows a significant increase in consultation elements, especially in the integration of stakeholders and expert committees, but there is still room for improvement in systematically integrating survey results and in the transparent selection of stakeholders.

A primary example for bridging academic research and municipal practice is the city’s involvement in the FLOODPREP project (a pre-disaster planning instrument), which targets extreme weather and heavy rainfall management through the development of advanced planning tools and high-resolution hazard simulations (Stadtportal der Landeshauptstadt Graz, 2025).

5.4 Circular Economy Measures in Mobility Assessment

Austria's Mobility sector has decreasing GHG emissions by 17% in comparing the years 2022 and 2023 considering the whole of the sector. In detail the reduction is due to the decrease in heavy commercial vehicles (WKÖ 2024). The UBA reports the same trend for 2024 with a reduction of 2,7% of emissions in the mobility sector, mainly due to decline in diesel sales, particularly in freight transport). In personal mobility the numbers of use have risen. In 2024 still 19,5 Mio. tons of CO2-eq are attributed to the mobility sector (Environment Agency Austria 2026). 12.3% more cars newly registered than in 2024, leading to 5.29 million passenger cars registered in Austria closing 2025 (Statistik Austria 2026). In Slovenia, the number of newly registered cars rose to 6% compared to the previous year. (Statistics Slovenia 2025). In 2023 Slovenia’s emissions linked to the mobility sector comprised the biggest share (37%, 5,4 CO2-eq) of the countries emissions, which totalled at 14,6 CO2-eq. (European Commission 2024).

To sum, the mobility sector has reduced emissions but not in personal mobility. Mobility services consume resources as well as energy, which need to be reduced in a climate friendly mobility system Based on the principles of circular economy (CE). The VCÖ has put forward a version of the 9Rs circular economy to better mobility's environmental balance (VCÖ 2022). Within the scope of this paper the version has been tailored to the CE measures that apply to cities and their governmental scope. As stated by the Ellen MacArthur foundation cities can plan a major role in implementing CE measures in the fields of urban planning, the design of mobility offers as well as infrastructure (Ellen MacArthur Foundation 2017).

To assess how the selected urban mobility plans incorporated an innovative circular economy perspective literature research concerning mobility measures was conducted. From these categories of CE measures

suitable for urban policies was derived. Subsequently, the documents were screened for the defined categories. Studying the VCÖ report it becomes apparent that the cites leverage in CE application in urban mobility is among the first Rs, focusing on intelligent use and production of infrastructure

Prominence is given to measures within the scope of urban policies. Measures targeting R4 (reuse) and higher were not observed as cities do not have high leverage to influence these factors. Instead, a focus was given to R1 refuse, R2 rethink, and R3 reuse (see fig. 1).

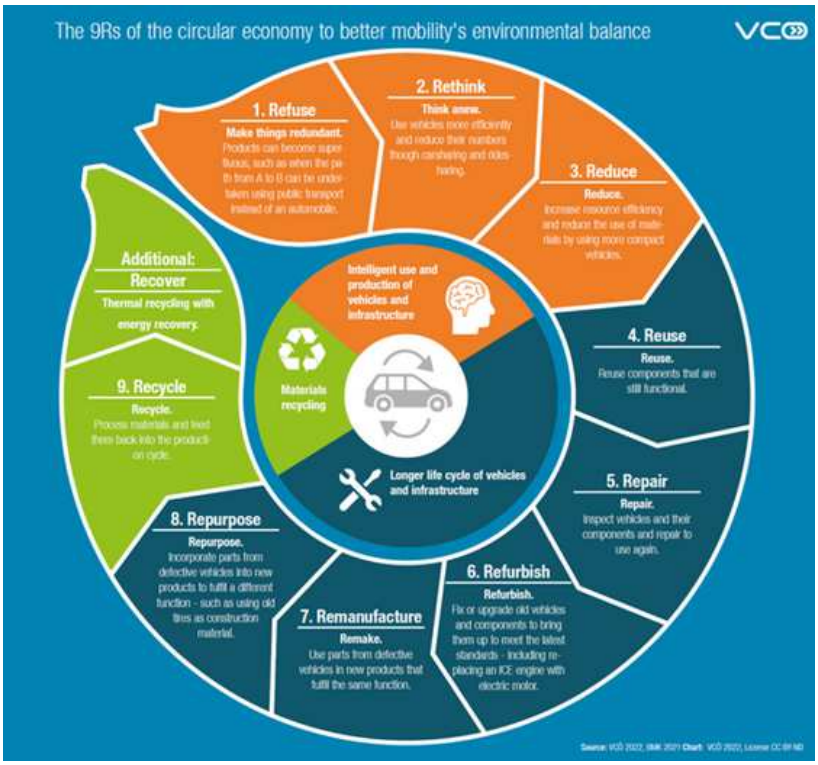


Figure 1: Measures targeting R4 (reuse) and higher were not observed as cities do not have high leverage to influence these factors. Instead, a focus was given to R1 refuse, R2 rethink, and R3 reuse. Illustration from VCÖ.

A non-exhaustive list of mobility measures implementing a circular economy follows and is used as criteria for the assessment of the selected policy documents:

- Cars (car-sharing, rental, carpooling park and ride, etc)
- Cycling (rental, storage, etc.)
- Public transport (micro-public transport / small buses /on-demand buses etc.)
- Walking (pavements, connection of mobility services, pedestrian etc.
- Monitoring (of traditional public transport, walking measures such are.

(Ellen MacArthur Foundation 2017; CE Center | Circular Economy Policy Research Center 2019)

These measures will serve as categories for the Table of Circular Economy Measures (in the Appendix). The results of the policy document assessment and a comparison is found

5.5 APA assessment

The Graz mobility governance portfolios are dominantly structured by preparedness and implementation logics. Awareness-building is present, but its integration varies across instruments. Analytically, the case comprises two policy strands: The Mobility Strategy 2020 is an integrated package (GZ-MOB-2ABC: guideline, targets, and measures), while the Mobilitätsplan Graz 2040 (GZ-MOB-01) is a consolidated long-term strategy document.

The APA profile shows that the dominant purposes for the GZ-MOB-1ABC package are to Prepare and Act. Preparedness is established through planning standards, measurable targets, and steering logics. Action is embedded in a structured implementation measures program. Awareness remains supportive and focuses on the upstream guideline component through normative framing and behavior-oriented messaging. The

package is clearly long-term focused, using hybrid implementation pathways, including phased roll-out of measures. Communication occurs mainly through information and consultation, with little explicit evidence of feedback loops covering the whole portfolio.

GZ-MOB-01 outlines a scenario-based approach, long-term targets, and institutionalized evaluation cycles as the path forward. Awareness serves as legitimizing framing, presenting mobility transition as a shared societal challenge. Action is carried out through implementation pathways and downstream measures programs. Participation formats, such as consultation, workshops, and co-creation, are more explicitly documented than in the 2020 package. This supports the interpretation that participatory elements in the planning cycle are gradually strengthening. Both Graz policy papers show the focus is on Prepare and Act. Awareness-building is included, but not always in every public relations activity. Initiatives such as FLOODPREP illustrate Graz's high institutional preparedness capacity: hazard knowledge is systematically translated into planning instruments through expert-driven collaboration, reinforcing a strong 'Prepare' logic within the APA profile, while post-event social recovery and circular innovation remain weakly addressed.

6 CASE STUDY: LJUBLJANA

6.1 Governance context

Ljubljana follows an integrative governance model that treats sustainability as an inseparable component of its long-term urban identity. Environmental objectives are strategically framed as quality-of-life improvements, a narrative shift that facilitates political continuity and seamless cross-sectoral coordination. Ljubljana's integrative governance approach is reflected in its long-term socio-demographic and mobility indicators. Official municipal statistics show comparatively lower population density pressures and a stable modal shift towards public transport and active mobility, which the city explicitly links to quality-of-life narratives rather than risk avoidance alone (City of Ljubljana, Ljubljana v številkah 2025).

6.2 Technological and nature-based solutions

The city views sustainable mobility, green corridors, and biodiversity-sensitive design as interconnected facets of a singular urban metabolism. In Ljubljana, technological upgrades are intentionally paired with NBS, creating a redundant and adaptive infrastructure that enhances systemic resilience.

6.3 Communication and participation

While the mobility plans of the City of Ljubljana include consultative elements, these remain largely expert- and institution-driven. The plans refer to workshops involving more than 300 experts and other stakeholders, as well as coordination processes with municipalities, ministries, and specialised institutions. Alignment with parallel planning instruments, such as the regional spatial development plan, is also highlighted. The resulting dialogue partnerships are therefore primarily oriented toward formal actors and expert communities. The role of the general public is largely confined to receiving information and fostering acceptance. Participation primarily serves to gather expert knowledge, provide feedback on predefined concepts, and build consensus within institutional frameworks. There is no evidence of joint problem definition with the population, nor of shared decision-making power. Long-term co-governance structures involving users, or forms of equitable knowledge co-production, are not established.

Problem framing, scenario development, and modelling logics remain consistently expert-defined. Public input is advisory rather than binding. Although the documents normatively emphasise the need for active participation of the general public, they do not specify concrete mechanisms for joint decision-making, such as co-design processes, citizens' panels, or participatory decision formats. Consequently, participation in practice ranges from passive information provision to consultation: input is collected, but decision-making authority remains with institutional actors. Co-creation is conceived exclusively within the circle of professional stakeholders, while citizens and the wider public are not actively involved in shaping outcomes. Recent sustainability research further indicates that participatory urban governance enhances policy coherence and long-term system resilience, particularly when mobility and environmental strategies are framed as shared societal projects rather than sector-specific interventions (Abujder Ochoa et al. 2025).

6.4 APA assessment

The mobility governance portfolios of Ljubljana are dominated by preparedness logics. It is evident that awareness-building and action are embedded as supportive elements across the policy instruments. The case is clear: there are two policy strands. The first is the regional guideline and project brochure Public Transport in the Ljubljana Urban Region (LJ-MOB-01). The second is the Sustainable Urban Mobility Plan of the Ljubljana Urban Region (SUMP) (LJ-MOB-02). This is a long-term strategic planning document (anticipatory/pre-disaster logic).

The primary purpose of the Policy guideline "Public Transport in the Ljubljana Urban Region" is to prepare, primarily through expert guidance, long-term regional planning instruments and to institutionalise coordination and harmonisation across governance structures (e.g. ticketing systems, timetables and regulations). Awareness-building is a key part of the solution to the structural problem framing of unsustainable mobility (traffic congestion, air pollution, CO2 emissions, noise, and quality-of-life impacts). This legitimises coordinated regional action. Action is included through concrete public transport improvements and infrastructure modernisation measures. These are described as planned and phased steps that depend on institutional and financial conditions. LJ-MOB-01 is long-term oriented, combining long-term governance coordination with hybrid implementation trajectories.

LJ-MOB-02 clearly shows a more balanced configuration. Preparedness remains dominant through its strong emphasis on regional coordination mechanisms, institutional capacity-building across municipalities, and integration of climate and mobility objectives into long-term planning frameworks. Awareness-building is explicitly documented and functions as a guiding narrative by framing sustainability and mobility transition as a shared regional responsibility linked to quality of life. Action is operationalised mainly through strategic priority initiatives and implementation pathways. These are delegated to follow-up programmes and stepwise realisation. Participation formats, including workshops, interviews, online surveys and GIS-based input formats, are explicitly integrated and accompanied by iterative monitoring and evaluation elements. This indicates a comparatively strong learning- and feedback-oriented governance logic.

7 COMPARATIVE ANALYSIS: GOVERNANCE CULTURES AND CE-INTEGRATION

The comparison of mobility policies in Graz and Ljubljana demonstrates that technological capacity alone is insufficient for resilience. Instead, the governance culture determines how pre-disaster planning translates into sustainable innovation. While both cities share a multimodal technical baseline, their strategic execution reveals distinct approaches to the APA-Lens:

- Ljubljana: Risk-Aware Integration. Ljubljana's strategy (LJ-MOB-01) is unique in its explicit consideration of failure. By including scenarios for unsuccessful measures, the city demonstrates a high level of Awareness regarding implementation risks. This transparency, combined with radical measures like city-center access restrictions, suggests an integrative communication style that prioritizes long-term legitimacy over quick technical wins.
- Graz: Developer-Led Preparedness. Graz focuses heavily on the Prepare phase by institutionalizing the "City of Short Distances" and contracting private developers to provide decentralized mobility hubs (car-sharing, bike services). While technically advanced, this decentralized "action" lacks the centralized, high-visibility communication seen in Ljubljana, potentially leading to a fragmented perception of resilience.

The CE is silent: A key finding is the total absence of Circular Economy as a term, despite the systematic use of CE-strategies (R1-Refuse through access restrictions; R2-Rethink through short distances). Both cities fail to leverage the CE-paradigm as a marketing or narrative tool to secure an SLO. This indicates that while the technical Action is circular, the Awareness phase remains disconnected from the broader sustainability discourse, leaving a significant potential for public engagement untapped.

7.1 APA

This section compares the governance logics underlying urban mobility planning in Graz and Ljubljana. It summarises the results of the qualitative content analysis conducted using the APA lens (see Chapter 4). The comparison matrix summarises the APA-based coding results by aggregating the communication purposes and their temporal orientations.

As shown in Figure 2, the analysed Ljubljana policy documents (LJ-MOB-01, 2010; LJ-MOB-02, 2019) are characterised by a dominance of preparedness-oriented communication in the long-term temporal horizon. In both documents, awareness-raising is coded as present and supportive, accompanying preparedness-oriented communication across long-term planning horizons. Action-oriented communication is coded as supportive and predominantly hybrid, indicating the co-existence of short-term measures and long-term infrastructure development as articulated in the documents. Across both Ljubljana documents, awareness-raising and preparedness-oriented communication precede and accompany action-oriented communication in terms of temporal positioning.

The Graz documents display a different distribution of communicative purposes (Figure 2). In the aggregated policy package GZ-MOB-01-ABC (2010/2012), preparedness-oriented and action-oriented communication are coded as dominant in the long-term horizon, while awareness-raising is coded as supportive and is primarily located within the strategic guideline component. In the later document GZ-MOB-02 (2025), awareness-raising is coded with increased prominence in the long-term horizon, reflected in explicit narrative framing within the policy text. Preparedness-oriented communication remains dominant, structured through scenario-based planning instruments and evaluation cycles. Action-oriented communication in GZ-MOB-02 is coded as hybrid, combining references to immediate measures with long-term infrastructure development.

To summarize, the documents differ in the distribution and temporal positioning of awareness-raising, preparedness-oriented communication, and action-oriented communication across the analysed policy documents. These differences reflect document-level patterns of communicative purpose and temporal orientation within pre-disaster urban mobility planning.

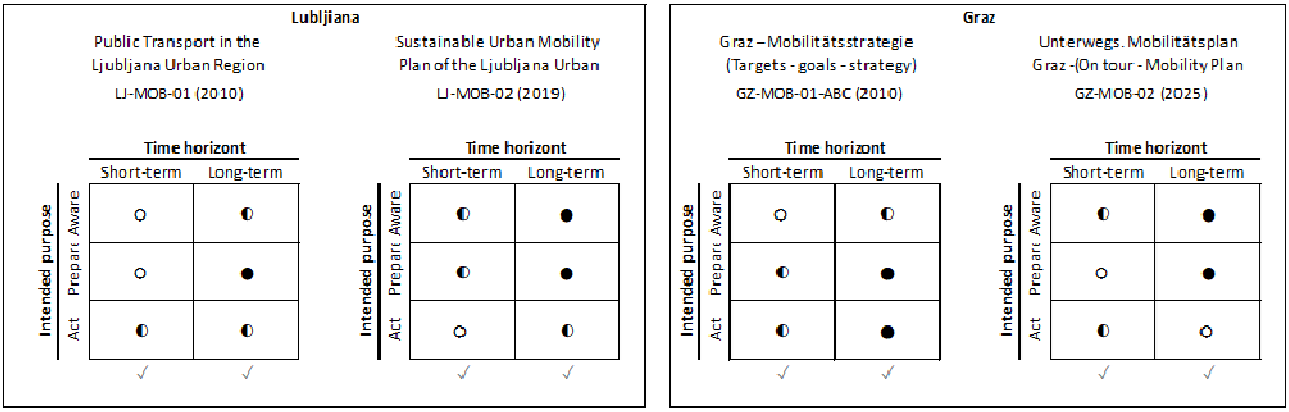


Figure 2 Comparative APA-based matrix of communicative purposes and temporal orientations in urban mobility policy documents for Ljubljana and Graz.

The matrix summarises the results of the qualitative content analysis by mapping the dominance of awareness-raising, preparedness-oriented communication, and action-oriented communication across short-term, long-term, and hybrid time horizons for each analysed policy document.

8 DISCUSSION: PRE-DISASTER PLANNING BEYOND URBAN POLICY

The findings underscore that pre-disaster planning operates as a cross-sectoral logic rather than a localized, city-specific practice. In comparing Graz and Ljubljana, it becomes evident that the efficacy of anticipatory governance depends on whether communication is treated as a technical add-on or a foundational infrastructure. Their instruments function as pre-disaster planning mechanisms, embedding long-term risk anticipation into everyday urban governance rather than treating disasters as exceptional events.

In Graz, the policy documents from the Abteilung für Verkehrsplanung and the city's Klima- und Umweltstrategien demonstrate a high level of technical proficiency in areas such as emissions reduction and digital traffic management. However, the discussion points to a communicative rupture. While the Graz Museum project Becoming Urban: Stadtentwicklung sehen und verstehen attempts to bridge the gap by making urban development visible and understandable, the participation model remains largely consultative. This top-down approach, focused on informing rather than co-creating, often fails to secure the SLO necessary for radical shifts, such as the reallocation of public space for green infrastructure. From a future-oriented perspective, global mobility foresight studies caution against a purely technology-centric transition

pathway. The Arthur D. Little Future of Mobility 5.0 Report stresses that without strong social acceptance, governance legitimacy, and behavioural alignment, digitalisation and electrification may even amplify systemic vulnerabilities by increasing complexity and dependency. This reinforces the paper's core argument that Social Licence to Operate constitutes a critical precondition for resilient and circular urban mobility systems (Little 2025).

Conversely, Ljubljana exemplifies a balanced APA configuration where communication is an enabling infrastructure. The Regionalni razvojni program (Regional Development Programme) and the Strategija prostorskega razvoja (Spatial Development Strategy) of the City of Ljubljana do not treat risk as an isolated hazard but embed it within a broader narrative of urban metabolism. As evidenced in the Ljubljana public transport – Brochure, environmental objectives are strategically framed as quality-of-life issues, fostering trust and collective learning. This integrative approach reinforces the argument that anticipatory governance is most effective when it transcends sector-specific silos.

Furthermore, these parallels are not confined to city governance alone. Comparable anticipatory strategies are observable in broader European research, such as the Interreg Europe Good Practices initiatives, which emphasize that technological infrastructure must be paired with inclusive public discourse to succeed. As highlighted by Graf et al. (2026), the transition from short-term hazard warnings to long-term adaptation requires a fundamental shift in how institutional knowledge is shared with the public.

Ultimately, this discussion reinforces that anticipatory governance, transparent communication, and resource efficiency constitute a broader transformation paradigm. SLO is not a static permit but an ongoing process of social learning and trust-building. These findings suggest that for European cities to move from crisis management to sustainable growth, they must align their technical Action with deeply embedded Awareness and Preparedness strategies. While the results largely support the APA-logic, a Popperian perspective invites us to consider potential falsifications. One might ask: Could a city like Graz achieve sufficient resilience through purely technical and institutional 'Preparedness' (e.g., FLOODPREP) without broad public co-creation? Our findings suggests that while technical 'Action' provides immediate protection, the long-term SLO, essential for the CE, remains the point where purely technical models are most likely to be falsified in practice. The implementation of CE in both cities primarily targets the higher levels of the 9R hierarchy, specifically R1 (Refuse), R2 (Rethink), and R3 (Reduce).

- R1 & R2 : Graz's City of Short Distances model and Ljubljana's access restrictions in the city center effectively encourage citizens to refuse private car use in favor of shared or active mobility.
- R3: Both cities emphasize a reduction in GHG emissions through modal shifts, though personal mobility remains a challenge as car registrations continue to rise in both Austria and Slovenia.
- Gaps in R4-R9: Strategies for higher-order R-measures, such as R4 or R9, are largely absent from urban policy documents as municipal authorities have less leverage over the industrial lifecycles of vehicles.

The analysis reveals a critical disconnect between technical implementation and strategic communication. While both Graz and Ljubljana are successfully operationalizing the higher-order 9R strategies (specifically R2 through modal shifts and R3 through optimized infrastructure) these are often framed as isolated transport projects rather than a systemic transition toward a CE. The analysis of Graz reveals a critical tension: although technical excellence in projects like FLOODPREP and tram expansions provides high-performance Action within the APA framework, it functions as a fragile buffer rather than a sustainable foundation. Without integrated Awareness and co-creation, a communicative rupture emerges that threatens the SLO. Consequently, technical success becomes a systemic risk: It secures immediate hazard mitigation but fails to foster the public trust and behavioral alignment essential for radical CE transformations. As demonstrated by Ljubljana's more integrative approach, true resilience requires that technical measures be harmonized with, or even secondary to, foundational communicative processes.

9 CONCLUSION

This paper has shown that pre-disaster planning can catalyse CE transitions and urban resilience when technological measures are embedded in participatory governance and effective risk communication. By anchoring the comparative analysis in externally documented safety, mobility, and governance risks, the study confirms that pre-disaster planning is not merely a preparatory instrument but a decisive leverage point

for preventing cumulative socio-technical failures in urban systems. Using the APA lens, the study demonstrates that communication is a critical infrastructure of transformation rather than a supplementary activity. The comparative analysis of Graz and Ljubljana highlights the importance of securing an SLO for anticipatory urban policies. For European cities facing increasing climate risks, integrating pre-disaster planning with circular innovation and inclusive communication offers a viable pathway from crisis management to sustainable growth. Future research could test the APA lens across additional urban contexts to further explore its applicability beyond mobility governance.

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11 APPENDIX

Circular economy mobility concepts						
CODE	Title	Car (Car-sharing, car-pooling, etc.)	Cycling (Sharing, rental, etc.)	Public Transport	Walking	Monitoring
GZ-MOB-01	Unterwegs. Mobilitätsplan Graz 2040	carsharing since 2016, by 2023 31 stations in the city; carpooling not centralised but with corporate mobility management of regional employers	rental not in place, middle to long term perspective to install; new infrastructure investments	planned to extend the existing services of on demand transportation o of GUST, FLUX and VOmobil, new tram tracks, P+R, busses with more passenger capacity, punctuality, bicycle storage at stations	PediBus campaign for walking, establishing walking zones in front of schools	modal split, data on the degree of motorization, number of bicycle parking facilities, vehicle parking permits, public transport service area, passenger numbers, or the area of pedestrian and shared spaces
LJ-MOB-01	Public Transport in the Ljubljana Urban Region	Car sharing connected to a park and pool sharing model, P & R scheme (car parks, arrangement of bus stops, comprehensive, information system); concentration of services; smart card system, vending machines	bicycle storage facilities, bicycle rental service and network of bicycle rental shops; ensuring safe cycling routes primarily in the city centre (more friendly, urban traffic regulation for cyclists involving cycle zones, areas closed to motorised traffic, and low speed motorised traffic in other parts of the city centre); carriage of bicycles on buses	enhanced carrying capacity of buses; low-floor vehicles, comprehensive information system; safe footways (wide pavements), signalisation giving priority to pedestrians, arrangement of bus stops (shelter, seating, quietness, cleanliness etc.) offer of additional services (shops) external accessibility to public transport by walking and non-motorised transport modes such as bicycles, and P+R	new urban green spaces, walking paths and parks; pedestrian routes primarily in the city centre (more friendly, urban traffic regulation for pedestrians, pedestrian zones, areas closed to motorised traffic, and low speed motorised traffic in other parts of the city centre);	scenarios to reduce GHG emissions, modal split
LJ-MOB-02	Sustainable Urban Mobility Plan of the Ljubljana Urban Region (for the people and space in an innovative and advanced region)	Avant2Go rent service of exclusively electric cars; comprehensive study of the P+R network; smart planning and allocation of surfaces for stationary traffic; enable the development of public transport or encourage the forms of carpooling and car sharing	construction of adequate infrastructure at the destination (bicycle storage facilities, charging stations for electric bikes, etc.) The adaptation of cycling routes for a faster journey (wider cycle paths, flatter ramps, etc.); The connection of rail passenger transport and cycling	co-modality of bike and public transport; Renovation of existing and establishment of new public transport stations and stops, The extension of existing public transport routes and the introduction of clock-phased timetable; The introduction of an integrated public transport ticket for all users	access to intermodal points with safe and comfortable walking paths; improved intermodal points for pedestrians; introducing access restrictions to the urban centre (e.g. walking zones, environmental zones with special access regimes)	modal spilt, implementation of the needs analyses
GZ-MOB-2A-C	Leitlinien – Mobilitäts-strategie der Stadt Graz – Verkehrspolitische Leitlinie 2020 / Handlungsfelder & Maßnahmen / Ziele	property developer contracted to implement (e.g. car sharing offers, bicycle service, public transport departure displays, information material); Car-sharing concepts	Infrastructure as well as traffic organization to implement measures for cycling; city of short distances	extension of bus stop system and development of new areas; punctuality strategy,	priority to ensure accessibility of densely used areas (city centre, residential areas, leisure and educational facilities); city of short distances	modal split, additional indicators such as walking distance to public transport, air quality and environmental quality, number of people in cars, road safety

reviewed paper

From Field Surveys to Climate Mitigation Support: Scaling Regional Hedgerow Carbon Estimates via Multi-Resolution Remote Sensing

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1 ABSTRACT

Hedgerows provide a variety of essential ecosystem services, acting as a major tool for carbon sequestration to counteract the impacts of climate change. However, determining the amount of carbon stored in hedgerows at a regional level has been challenging. Field surveys can be precise but are time-consuming and labor-intensive, primarily deriving biomass from stem measurements under the canopy. Whereas remote sensing technologies can cover large geographic scales, they often lack the ability to estimate the detailed sub-canopy structure of linear woody features at the local scale. To bridge this gap and calibrate remote sensing models using local field data, a method was developed in this study to estimate hedgerow carbon storage by integrating field survey data with canopy height model (CHM) volume estimation for the Salzlandkreis region in central Germany.

Field sampling was conducted across three study sites, where diameter at breast height (DBH) and height were measured for 4,382 woody plants (diameter > 3.5 cm). Based on this data, forestry form-factor equations were used to calculate individual tree volumes, and above-ground biomass was subsequently estimated based on species-specific wood density. To generalize these localized measurements to the regional scale, volume-to-biomass ratios (VBR) were established. These VBR values were derived from correlations between field-measured biomass and volumes obtained from multi-resolution remote sensing datasets.

By multiplying the converted woody biomass by the canopy volume, the regional estimates of hedgerow above-ground carbon storage ranged from 96,538 to 104,341 Mg C (354,294 –382,931 Mg CO_2e). This corresponds to carbon densities ranging from 57 to 70 Mg C ha^{-1} when normalized to the total hedgerow area in Salzlandkreis.

This research demonstrates that moderate-resolution state datasets, when properly calibrated and validated against field measurements and high-resolution UAV data, can produce regional-scale carbon estimates, which would be impossible through field-only approaches. This study provides a framework for integrating remote sensing data with varying spatial resolutions and field validations, supporting evidence-based regional carbon estimation.

Keywords: Hedgerow carbon storage, Multi-resolution remote sensing, Volume to biomass ratio, Field-remote sensing integration, Regional carbon estimation

2 INTRODUCTION

Hedgerows serve many important functions in terms of providing ecosystem services. These services include carbon sequestration, provision of habitat for biodiversity, protection against soil erosion, regulation of water flow, and natural pest management (Heath et al., 2017; Montgomery et al., 2020). Specifically, their role in carbon sequestration is especially relevant as this is considered an essential tool to mitigate the local and global effects of climate change (Drexler et al., 2021).

Biffi et al. (2023) estimated that 3- to 6-year-old hedgerow stands contained approximately 8.34 Mg C ha^{-1}(megagrams of carbon per hectare), whereas mature stands (>39 years old) contained approximately 40.42 Mg C ha^{-1}. Additionally, studies conducted in Germany indicate much higher totals, with an average biomass carbon stock of approximately 105 ± 11 Mg C ha^{-1}, of which approximately 40% was stored in the root system (Drexler et al., 2023). Drexler et al. (2021) reported that the average amount of aboveground biomass present in hedgerows is about 47 ± 29 Mg C ha^{-1}.

In order to accurately determine the carbon sequestration potential of hedgerows across all regions, in terms of both location and extent, species composition and health condition, extensive assessments over broad areas will need to be conducted (Staley et al., 2023). Traditional on-the-ground survey methods, however,

are labor-intensive, expensive and often impractical or unable to be applied at large scales such as a regional or national level. Given these constraints, there is currently increasing interest in using remotely-sensed data from technologies such as unmanned aerial vehicles (UAVs) equipped with high-resolution cameras (Broughton et al., 2025).

UAV-based photogrammetry can generate centimeter-scale digital surface models (DSMs), Orthomosaics and point-cloud based 3-D models of individual hedgerows enabling precise measurements of their structural properties including height, width and volume. On the other hand, state aerial imagery data generally offers lower spatial resolutions, typically ranging between 20 cm and 1 m per pixel (ground sampling distance), when compared to the near range capabilities of UAVs; however, it enables the creation of large-scale topographic information through digital terrain models (DTMs) and DSMs which can be used to create canopy height models (CHMs) for biomass estimations (Bazzo et al., 2023). By integrating fieldwork data (ground truth data) and high-resolution UAV data for calibration and medium-resolution state datasets for regional coverage, a scalable framework for hedgerow carbon storage estimation becomes achievable.

This study has two objectives: 1) to provide a remote sensing methodology to extend those estimates to larger areas by using canopy height model (CHM), and 2) to provide an estimation of the carbon stored in hedgerows across Salzlandkreis, Saxony-Anhalt, Germany. Through this approach, this study demonstrates the potential of combining high accuracy field sampling with broad area remote sensing analyses, which could provide the policy relevant information concerning the ecosystem services carbon storage estimation provided by hedgerows, supporting data-driven climate action and landscape planning.

3 MATERIALS AND METHODS

The multi-stage methods applied in this study comprised two distinct components: field surveys using multi-resolution remote sensing and biomass estimation; and remote sensing data acquisition and processing.

(1) Field Surveys and Biomass Calculation: In order to determine hedgerow characteristics (type of tree, diameter, height, and width) field surveys were conducted at three sample sites in Salzlandkreis. These characteristics were then used to determine carbon storage.

(2) Remote Sensing Data for Volume Calculation: Multi-resolution Remote Sensing data were collected, including digital surface model data obtained from a drone system (6 cm / pixel resolution), high resolution aerial data that are part of the iDSM (image-based DSM; 20cm / pixel resolution), and medium resolution aerial data that are part of the DSM (1 m / pixel resolution). From the DSMs the volumes of hedgerows were calculated.

(3) Correlation Coefficient: In this step, a correlation coefficient was calculated to quantify the relationship between the field-determined biomass (Step 1) and the Remote Sensing-determined hedgerow volumes (Step 2).

(4) Regional Scale Quantification : A CHM was created from the DSM and iDSM data to calculate the volume of all hedgerows in Salzlandkreis. The total carbon storage for the entire region was then calculated by multiplying the total volume of hedgerows by the correlation coefficient established in Step 3.

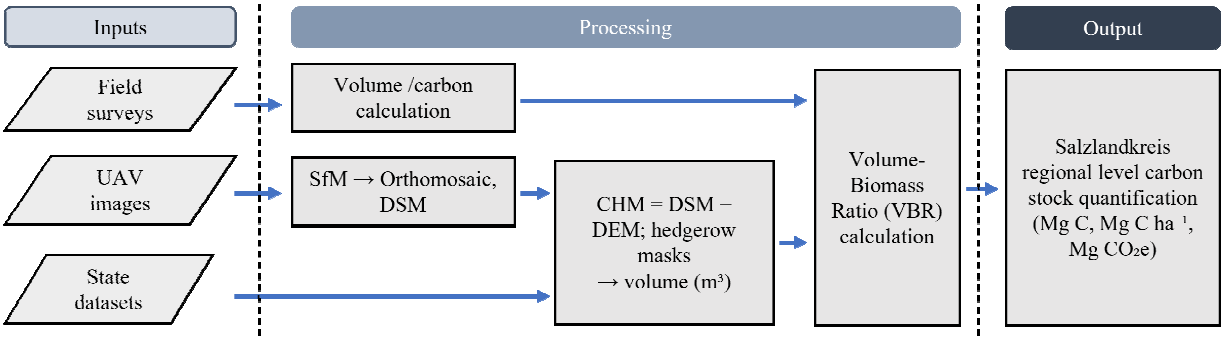


Fig. 1: Research workflow.

3.1 Study Area

The Salzlandkreis (Salzland district; total area: 1,427 km²) is located in central Saxony-Anhalt, Germany, and is characterized by an agricultural landscape typical of the North German Lowlands, representing

intensive agricultural landscapes in this region. In this study, researchers initially identified six locations with a high density of hedgerows within the Salzlandkreis through the application of ArcGIS Pro's Density analysis tools. Subsequently, through site visits, researchers ultimately selected three sample research area (1.5km x 1.5km/each) from those six candidate study sites (see figure 2 and 3).

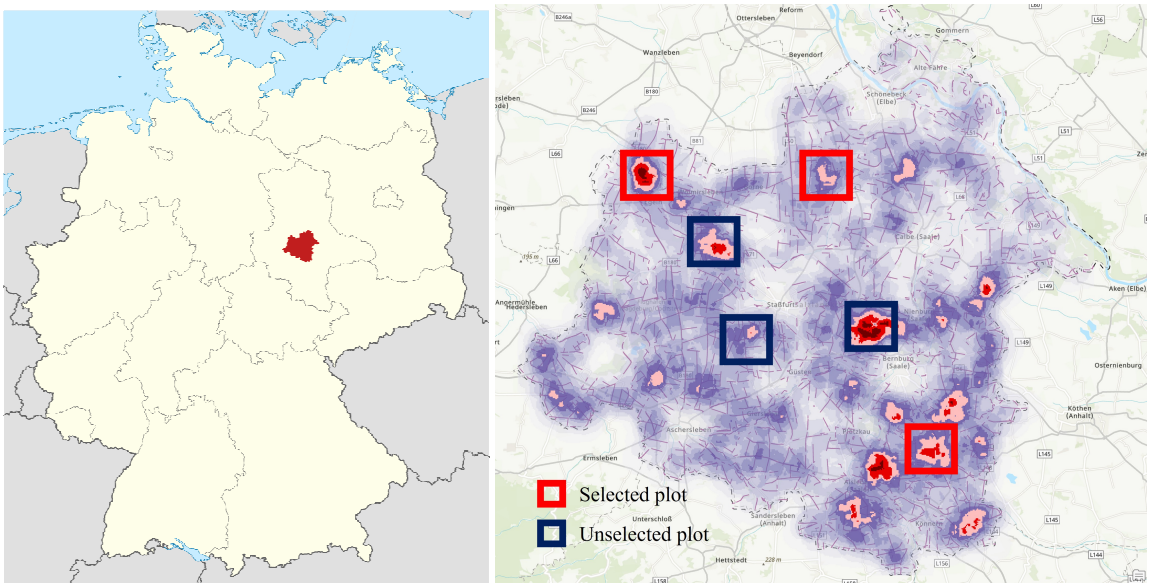


Fig. 2: Location of Salzlandkreis in Germany (left) and three selected research plots (red) in Salzlandkreis (right).



Fig. 3: The three selected research plots (located in Westeregeln, Unseburg, and Peissen from the top to bottom).

3.2 Methods

3.2.1 Field Survey and Biomass Measurement

At three research sites, tree-species-specific values for the calculation of CO_2 potential and standing biomass were recorded for 4,382 woody plants. For this, all woody plants (diameter > 3.5 cm) were measured using Nikon Forestry Pro rangefinder which is a tree height measuring device ranging of 7.5 to 1600 m and a

diameter tape measure. Relevant parameters such as tree species, tree height (h), diameter at breast height (DBH), and nature conservation-relevant characteristics were recorded in a mapping sheet. The calculations of the comparison values for carbon storage and gross carbon were carried out with the software I-Tree Eco (USDA forest service software suite), taking into account the characteristics measured in the field for each woody plant. The calculation of the tree volume was carried out using a form-factor-based volume estimation formula as applied in forest inventory. Only the stem volume without branches and roots is considered here (see Figure 4). The form factor (f) describes the deviation of the stem shape of a tree from a perfect cylinder. Depending on location and tree species, the form factor lies between 0.45–0.52. For the calculations, this was uniformly set to 0.5. The individual tree volume was calculated as follows:

$$V\,[m^3] = \left(\frac{DBH\,[cm]}{200}\right)^2 \cdot \pi \cdot h\,[m] \cdot f$$

where:

V = individual tree volume without branches and roots

DBH = diameter at breast height (1.3 m above ground)

h = tree height

f = form factor (species-dependent correction value)

For the calculation of biomass B [kg], the individual tree volume V [m³] is multiplied by the species-specific basic density WD [kg/m³] for each tree species (see Table 1), according to the following formula:

$$B\,[kg] = V\,[m^3] \cdot WD\,[kg/m^3]$$

where:

B = biomass

V = individual tree volume

WD = wood density

Species	Wood Density (kg/m³) at 12-15% Moisture Content
Populus x canadensis	410
Fraxinus excelsior	650
Tilia platyphyllos	490
Acer platanoides	590

Table 1: Examples of average raw densities of selected wood species (Source: Grabner, 2017; Steuer, 1985; Kollmann, 1982).

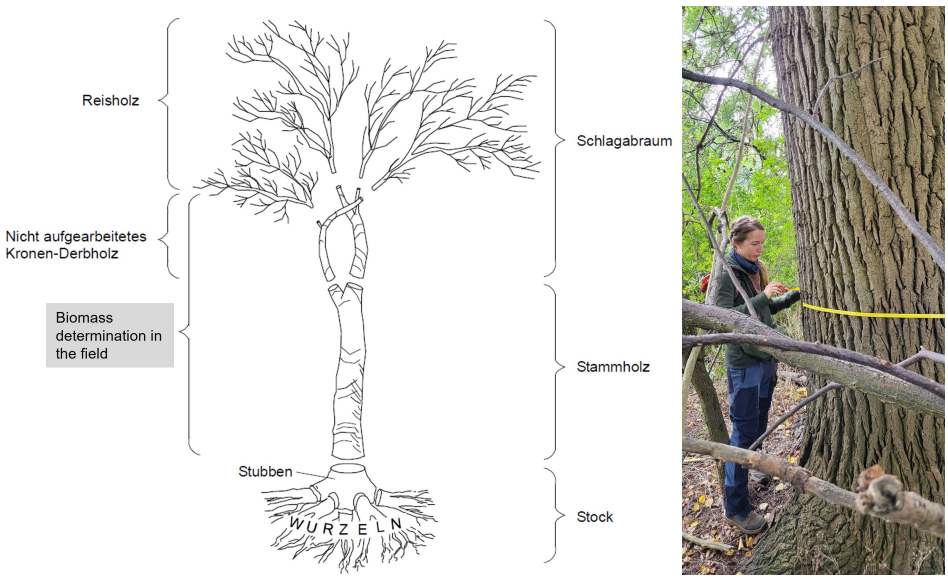


Fig. 4: Field survey and biomass measurement (the figure on the left source: Englert, H et al., 2009).

3.2.2 Remote Sensing Data Acquisition and Processing

High-resolution aerial imagery was acquired at three research sites using a DJI Mavic 3 Enterprise RTK (Real Time Kinematic) drone with a 20M pixels RGB sensor. Flights were conducted at 50 m above ground level (AGL) from multiple viewing angles with 75% forward and 75% side overlap to support 3D reconstruction. Structure-from-Motion (SfM) photogrammetry was applied to generate a 6 cm/pixel resolution digital surface model (DSM) and a 3 cm/pixel resolution orthomosaic. These products enabled precise measurement of hedgerow structural attributes. Official state aerial datasets were used: DSM1 (1 m resolution) and iDSM20 (0.2 m resolution), provided by the State Office for Surveying and Geoinformation of Saxony-Anhalt (Landesamt für Vermessung und Geoinformation Sachsen-Anhalt, LVermGeo). The DSM1 was provided as GeoTIFF to be used directly and the iDSM20 was provided as compressed point clouds (LAZ). Those were converted to LAS format. They were then rasterized to GeoTIFF for analysis. These multi-resolution datasets (DSM1, iDSM) were jointly used to derive hedgerow volumes at scale, with UAV dataset calibrating and validating volume–biomass relationships for regional application.

3.2.3 Calculation of Volume-Biomass Ratio (VBR)

The use of line features provided by the State and manually added in the creation of hedgerow mapping areas that were extended with 20 m radius buffer in order to identify the analysis zones. The canopy height model (CHM) was made through the CHM = DSM – DTM equation (see Fig. 5). The threshold was increased from 1.2 meters to 2.2 meters because of adjacent tall crop fields (such as sunflower fields) that are unrelated to hedgerow vegetation. Hedgerow volumes were obtained by calculating the canopy height over pixels multiplied by pixel area, using zonal statistics in ArcGIS Pro Raster Calculator according to:

$$V_i = \sum_{j=1}^{n} (h_{ij} \times A_{\text{pixel}})$$

where:

V_i = total canopy volume of hedgerow i in Salzlandkreis (m³)

n = total number of pixels within the buffer zone where CHM ≥ 2.2 m

j=1 = no sub-divisions (the object consists of one element)

h_{ij} = canopy height at pixel (i, j) above 2.2 m threshold (m)

A_{pixel} = pixel area (1 m² for DSM1; 0.04 m² for iDSM20)

Biomass was calculated by multiplying the volume of each zone by the Volume-Biomass Ratios that derived from the three-test site analysis for each data.



Fig. 5: Canopy height model (CHM) at Westregeln study area using DSM1, iDSM20 and UAV data sets (from left). DSM1, DSM20, DTM source: State Office for Surveying and Geoinformation of Saxony-Anhalt (LVermGeo).

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4 RESULTS

Using the methods discussed previously, conversion factors for converting remote sensing volume to biomass at a number of resolutions were developed. The conversion factors are summarized in Table 2 as both the volume-biomass ratio (VBR), and as biomass density (kg m^{-3}). Results indicated that the high-resolution UAV data set had the lowest Volume Biomass Ratio (0.6) and correspondingly the highest biomass density (1.66 kg m^{-3}).

	DSM1	iDSM20	UAV
Volume-Biomasse Ratio (VBR)	0.97	0.78	0.60
Woody Biomass (kg/m³) in Field Vegetation	1.03 kg m^{-3}	1.29 kg m^{-3}	1.66 kg m^{-3}

Table 2: Average values of the volume-biomass ratio (VBR) for DSM1 (1 m spatial resolution), iDSM20 (0.2 m spatial resolution), and UAV (0.06 m spatial resolution), and mean value, woody biomass in kg per 1 m³ of field vegetation.

Table 3 presents total aboveground hedgerow carbon stock estimates for the 1,427 km² Salzlandkreis area using both DSM1 (1m spatial resolution) and iDSM20 (0.2 m spatial resolution). Aboveground total carbon stock ranges were 96,538 – 104,341 Mg C (equivalent to 354,294 – 382,931 Mg CO_2e).

Category	DSM1 (1 m)	iDSM20 (0.2 m)	Unit
Salzlandkreis Area	1,427 km² = 142,700 ha		–
Hedgerow Area	1,690	1,484	ha
Total Hedgerow Volume (≥ 2.2 m)	187,452,364	161,768,729	m³
Total Hedgerow Biomass	193,076	208,682	Mg dry weight
Total Hedgerow Carbon Storage	96,538	104,341	Mg C
Total Carbon Sequestration Potential	354,294	382,931	Mg CO_2e
Carbon Density	57	70	Mg C ha^{-1}
Total Carbon Sequestration Density	210	258	Mg CO_2e ha^{-1}

Table 3: Total Salzlandkreis aboveground hedgerow carbon stock estimates.

On this basis, the carbon storage capacity (and corresponding CO_2 equivalents) of specific hedgerow structures can be determined and evaluated at specific areas. Beyond carbon, integrating these results with other ecosystem service metrics enables a holistic evaluation of individual structure for planning purposes. The derived volumetric estimates also provide a baseline for exploring hedgerow biomass as a potential resource; however, determining sustainable extraction levels would require additional research on growth rates, species composition, and ecosystem service impacts. Consequently, these carbon assessments would provide a foundation for enhancing nature conservation planning. In combination with agroforestry systems, sustainable regional utilization concepts for biomass can be developed and implemented.

5 CONCLUSION AND OUTLOOK

This research demonstrated a feasible and applicable approach for estimating hedgerow carbon content in the Salzlandkreis region using DSM with resolutions of 1 m and iDSM 20 cm, in combination with empirical biomass-volume relationships for calibrating biomass estimates from aerial data including UAV high resolution data.

Utilizing this process, estimated regional above ground carbon stock density for mapped hedgerows were found to be in the range of 96,538 – 104,341 Mg C (equivalent to 354,294 –382,931 Mg CO_2e). This corresponds to carbon densities of 57 to 70 Mg C ha^{-1} when normalized to the total hedgerow area in Salzlandkreis, representing a difference of approximately 23% deviation between the two difference types of data: iDSM20 and DSM1.

There are several limitations to the findings of the current study. For example, the estimates represent only the above-ground woody biomass of the hedgerows; therefore, the below-ground biomass and soil organic carbon (substantial components of mature central European hedgerows) have not been accounted for in the estimates. Additionally, the CHM threshold may need to be site-specifically calibrated based on other land

types and regions. Furthermore, the age and management of the hedgerows, which would both affect biomass and carbon stock estimates were not considered as part of the estimation using the remote sensing method. Finally, this study reveals how data resolution affects results: low-resolution data may smooth canopy features, which can lead to vegetation volume underestimation. Conversely, fine-scale data, including UAV data, can capture temporal seasonal changes, which would affect the regional aggregation of estimates.

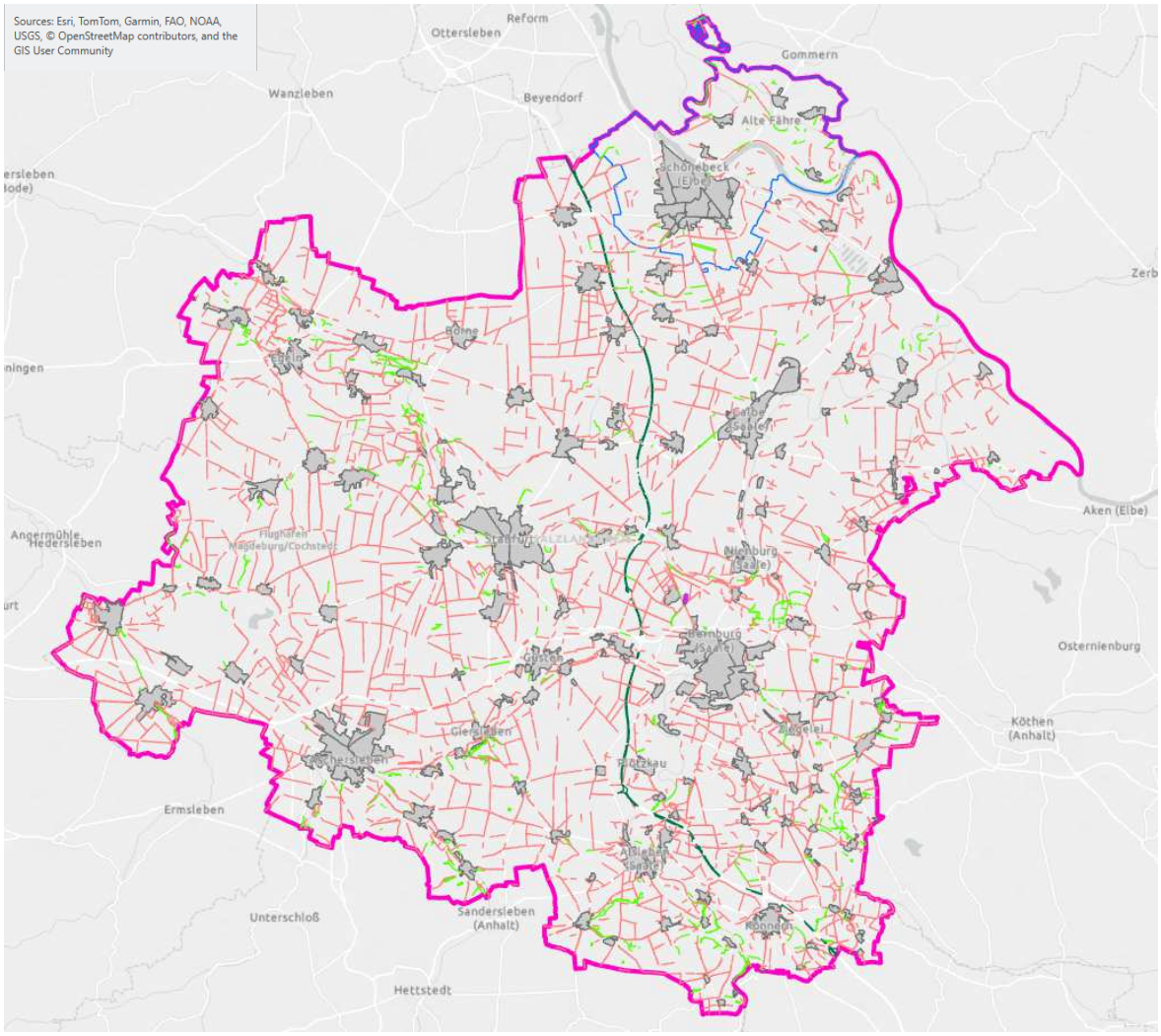


Fig. 6: Hedgerows in Salzlandkreis, Map base: ESRI. Data sources: basic-DLM, manual digitizing and administrative boundaries.

Future research should expand upon the current study by incorporating additional carbon pools (such as below-ground biomass and soils) into the framework to estimate the total carbon content of the hedgerows. The results of this study could also have a substantial impact on the spatial management of resources by providing high-resolution, decision-based information for identifying valuable regions for conservation purposes, allocating optimal use of land for agricultural and urban development, and creating hedgerow-based networks to assist with climate adaptation in rural areas. Additionally, future studies should focus on analyzing the temporal changes of these carbon stocks over time and comparing data across different vegetation zones and countries to establish standardized global baselines.

The spatial data generated in this study provide a foundation for evaluating a wide range of ecosystem services at the regional level, such as: hedgerow health mapping; assessing agroforestry potential; quantifying sustainable harvestable biomass; and creating multi-year carbon balances. Co-development of management and utilization concepts with agricultural and municipal stakeholders will facilitate the conversion of the hedgerow carbon stock estimates into practical mitigation strategies and regional bio-economy opportunities.

6 ACKNOWLEDGEMENTS

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reviewed paper

From Smart City to Meaningful City: A Results-Oriented Perspective on Urban Experience Quality, Governance, and Sustainable Value Creation

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1 ABSTRACT

Despite significant progress in urban planning, smart city initiatives, and city branding, many cities still struggle to translate strategic goals into a sustainably experienced urban quality of life. Early work in urban sociology, environmental psychology, and governance research pointed to shortcomings regarding social cohesion, autonomy, trust, and integrated sustainability. Current research (2023–2026) confirms that these aspects remain inadequately addressed despite technological innovations, data-driven management approaches, and institutional reforms. This article revisits this persistent issue and conceptualizes cities as complex service and value creation systems. It systematizes four key areas of tension in urban development: efficiency versus experiential quality, governance versus autonomy, technology versus trust, and sustainability as an external service versus integrated urban logic and provides an integrated framework.

Keywords: Smart City, Urban Experience, Governance, Urban Planning, City Branding

2 THE LIMITS OF FUNCTIONAL URBAN EXCELLENCE

Cities today face the challenge of reconciling increasing demands for efficiency, sustainability, and competitiveness with their residents' expectations of quality of life and identification with their community. For several decades, research in urban sociology, environmental psychology, and governance has indicated that functional optimization and technological performance alone are insufficient to create vibrant and attractive cities in the long term (Jacobs, 1961; Lynch, 1960; Arnstein, 1969). Nevertheless, smart city strategies, data-driven governance approaches, and city branding concepts continue to shape the urban agenda. These instruments have undoubtedly contributed to efficiency gains and improved governance. However, recent reviews and case studies show that key aspects such as social connectedness, perceived agency, trust in institutions, and an integrated sustainability logic continue to be insufficiently addressed (Hollands, 2008; OECD, 2023; Rasoulzadeh Aghdam et al., 2025).

This discrepancy between functional performance and experienced urban reality points to a central question of this article: Why don't functionally optimized cities automatically become places where people like to live, get involved, and invest long-term? Hence, the described shortcomings are not new findings, but rather persistent problems that, despite years of theoretical grounding and numerous practical initiatives, have not yet been systematically translated into integrated implementation models. This article therefore aims to conceptually address this integration gap.

2.1 Research gap and knowledge contribution

Smart city research has expanded considerably in recent years, addressing key topics such as digitalization, efficiency improvements, and data-driven management of urban systems (Hollands, 2008; Datta, 2015). In parallel, city branding literature emphasizes the importance of identity, narratives, and the coherence of diverse stakeholder groups for the long-term attractiveness of cities (Kavaratzis & Hatch, 2013; Kaufmann and Durst, 2008).

Despite these conceptual advancements, recent reviews and empirical studies show that key challenges of urban development persist and are currently addressed only inadequately in an integrated manner (OECD, 2023; Rasoulzadeh Aghdam et al., 2025). This identified integration gap also provides a clear starting point for further academic research, particularly regarding conceptual modeling, empirical validation, and comparative analyses of urban implementation models. Three key shortcomings can be identified that mark a persistent research gap:

2.1.1 Fragmentation of Analysis Levels

Efficiency, participation, technology, and sustainability are often viewed as separate fields of action, even though they are systemically intertwined in everyday urban life. This sectoral perspective was identified

early on as a key weakness of urban governance (Bulkeley & Betsill, 2005). Current studies confirm that fragmented responsibilities, siloed programs, and a lack of horizontal integration continue to limit the effectiveness of integrated urban development strategies (Yu et al., 2023; European Parliament, 2025).

2.1.2 Lack of an Outcome-Oriented Perspective

Urban performance is still predominantly measured using functional, technical, and process-related indicators, while perceived quality of life, trust, identification, and a sense of responsibility are only marginally considered. This problem was already addressed in early work on perception and environmental psychology (Lynch, 1960; Evans & McCoy, 1998).

Current policy-oriented analyses confirm that outcome-oriented measurement and management approaches are still insufficiently established in urban development (OECD, 2023; Osei-Kyei & Ampratwum, 2025).

2.1.3 Lack of Integrated Implementation Models

While numerous strategic visions, target systems, and pilot projects for urban development exist, consistent models that systematically translate these objectives into everyday urban experiences are lacking. This gap has already been described in the context of New Public Governance (Osborne, 2006).

More recent studies show that living lab approaches and co-creative formats often remain project-based and are not sustainably embedded in overarching governance and value creation logics (Almeida et al., 2025; Sofronievska et al., 2025).

This article addresses these shortcomings and the resulting integration gap by conceptualizing cities as complex service and value creation systems. Building on this, four key areas of tension in urban development are identified, in which the shortcomings manifest themselves in the interplay of efficiency, governance, technology, and sustainability. In addition, an integrated implementation framework is proposed that combines outcome-oriented logic with living lab approaches and provides a starting point for further academic research as well as for empirical and comparative analyses of urban development approaches.

3 THEORETICAL FUNDAMENTS

3.1 Human experience, connectedness and scope for action

Neuroscience and motivational psychology research show that human well-being, learning ability, and engagement are significantly influenced by two factors: social connectedness and perceived self-efficacy or autonomy (Deci & Ryan, 2000; Hüther, 2015). When these elements are lacking, a demonstrable increase in the risk of withdrawal, aggression, and social disintegration (Evans & McCoy, 1998) occurs.

Current interdisciplinary studies confirm these correlations for the urban context as well and show that perceived social isolation, lack of influence, and lack of identification with one's living environment have negative effects on trust, sense of security, and social engagement (OECD, 2023; Rasoulzadeh Aghdam et al., 2025). Applied to cities, this means that urban design and administrative interaction should not only be functional, but rather relationship- and experience-oriented. Classic works in urban sociology point out that a lack of social integration, poor quality of life, and anonymous spaces can promote perceptions of insecurity and contribute to social fragmentation (Jacobs, 1961; Newman, 1972). Recent studies confirm that participatory design approaches, transparent administrative processes, and tangible participation sustainably strengthen perceptions of safety, belonging, and responsibility (Gjørtzvang et al., 2025).

3.2 The city as a service and value creation system

Service-dominant logic understands value creation not as the result of isolated service provision, but as the result of interaction and co-creation between actors within a system (Vargo & Lusch, 2004). Applied to cities, this means that urban quality is not created solely through planning, regulation, or infrastructure, but through the interaction of diverse stakeholders in everyday urban life. This perspective is supported by approaches of New Public Governance, which regard public organizations not primarily as rule-setters, but as coordinators of complex service ecosystems (Osborne, 2006). Current governance research confirms that cities are increasingly acting as platforms where public, private, and civil society actors jointly create value for different stakeholders (Almulhim, 2025; OECD, 2023). The key urban stakeholders include in particular:

- Citizens,

- Local businesses and employers,
- Visitors and commuters,
- Employees of the administration and municipal enterprises,
- Institutional and private partners.

Against this backdrop, results-oriented urban development requires clarity about which services are to be provided to which stakeholder groups and with what intended effect. Recent studies show that a lack of clarity of objectives and insufficient coordination between stakeholder groups can significantly impair the effectiveness of urban strategies (Shao et al., 2025).

4 FOUR KEY AREAS OF TENSION IN URBAN DEVELOPMENT

4.1 Efficiency versus experience quality

Increasing efficiency has long been considered a central goal of urban planning and administration. Smart city initiatives, digital administrative processes, and data-driven control systems primarily aim to optimize processes, use resources efficiently, and provide services in a scalable manner (Hollands, 2008; Datta, 2015). This perspective has undoubtedly led to measurable improvements in areas such as infrastructure management, mobility, and administrative processes. Additionally, studies on service experience show that perceived quality does not depend solely on functional performance but is significantly shaped by comprehensibility, relationship-building, and personal accessibility (Berry & Carbone, 2007). Early urban sociological studies already indicated that efficiency without a conscious design of interaction can lead to distance, loss of trust, and declining acceptance (Lynch, 1960; Jacobs, 1961).

Current research confirms these tensions and shows that digital solutions without accompanying consideration of user experience, quality of stay and social inclusion often cause acceptance problems and weaken trust in public institutions (OECD, 2023; Rasoulzadeh Aghdam et al., 2025).

4.2 Control versus scope for action

Urban development is largely shaped by governance logics. Planning, regulation, standards, and controlling form the basis for the reliability, legal certainty, and coordination of complex urban systems. Smart city approaches, in particular, increasingly rely on data-driven decision support and centralized control mechanisms to design urban processes efficiently and consistently (Datta, 2015; OECD, 2023). However, early work on participation already indicates that formal participation processes alone are insufficient to enable genuine co-creation and the assumption of responsibility. Arnstein (1969) demonstrated that many participation formats are largely symbolic and offer limited opportunities for real influence. Without a perceived sense of agency, identification with, engagement with, and trust in institutional actors decline.

Recent studies confirm these findings and show that while technology-based participation tools increase transparency and reach, they are often not linked to genuine decision-making authority or verifiable feedback (Gjørtzvang et al., 2025). In such situations, a discrepancy arises between formal participation and perceived effectiveness, which can lead to frustration, withdrawal, or political disengagement. At the same time, newer governance approaches indicate that cities become more resilient and effective where spaces for shaping the future are deliberately created and responsibility is shared. Co-creative processes, participatory decision-making formats, and transparent negotiation mechanisms not only strengthen the quality of decisions but also the sense of responsibility among the participating actors (OECD, 2023; Rasoulzadeh Aghdam et al., 2025).

4.3 Technology versus Trust

Digital technologies form a central basis for contemporary urban development. Sensors, data platforms, AI-supported analyses, and networked infrastructures promise more efficient processes, better decision-making, and new forms of urban services. Accordingly, technological solutions play a key role in smart city strategies (Datta, 2015; OECD, 2023). At the same time, social science and information systems studies have long shown that technological capability alone does not guarantee acceptance. Trust is not created by technology itself, but by transparency, traceability, and fair governance structures. If these prerequisites are lacking, digital systems are perceived as opaque, controlling, or externally controlled (Gefen et al., 2003).

Recent studies confirm that data-driven applications in urban areas in particular raise sensitive questions about data protection, algorithmic decision-making logic, and institutional responsibility. If these questions are not addressed openly, this can undermine trust in public institutions and have a lasting negative impact on the use of digital services (OECD, 2023; Almulhim, 2025). At the same time, studies show that transparent data practices, clear responsibilities, and understandable communication can significantly increase the acceptance of technological solutions (Rasoulzadeh Aghdam et al., 2025).

Against this backdrop, it becomes clear that technology and trust are in a state of mutual tension. Digital innovations only have an impact when they are embedded in trust-building governance structures and remain comprehensible to different stakeholder groups.

4.4 Sustainability: External services versus integrated urban logic

Sustainability has become a central guiding principle of urban development. Climate protection, resource efficiency, circular economy, and social sustainability shape strategies, programs, and funding logic at the municipal, national, and international levels. In practice, however, sustainability is often treated as a separate field of activity and implemented through specialized programs, external service providers, or project-related initiatives (Elkington, 1997; Bulkeley & Betsill, 2005). This outsourcing of sustainability-related tasks often leads to ecological and social goals being perceived as additional cost factors, existing alongside performance and efficiency logics. Current studies show that while sustainability measures can achieve short-term effects under such conditions, they lose their impact in the long term if they are not integrated into the core logic of urban value creation (OECD, 2023; Shao et al., 2025).

Recent governance and urban economics research indicates that sustainability is effective where it is understood as an integral component of urban service and value creation systems. Approaches to the urban circular economy, local energy and resource systems, and community-based service models demonstrate that ecological objectives are compatible with economic attractiveness when value creation is locally anchored and considered systemically (Almulhim, 2025; European Environment Agency, 2024).

Against this backdrop, a tension emerges between sustainability as an externally purchased service and sustainability as an integrated component of urban logic. Cities that understand sustainability not as an additional task, but as a structural principle of their service, investment, and governance models, unlock new potential for economic resilience, innovation, and long-term attractiveness as a business location. The four key areas of tension in urban development are summarized in Figure 1. The figure categorizes the four key areas of tension in urban development identified in this article. It demonstrates that urban quality and long-term attractiveness do not arise from optimizing individual dimensions, but rather from consciously balancing equally important, interwoven areas of tension at the organizational, governance-related, socio-technical, and structural-economic levels. Figure 2 illustrates the integrated implementation framework, which will be explained in more detail in the next chapter.



Figure 1: Key areas of tension in urban development: an overview.

The diagram illustrates the proposed integrated implementation framework, which combines outcome logic with living lab principles. The framework serves to operationalize the four identified areas of tension in real urban contexts by linking co-creation, iterative learning processes, and transparent governance with clear outcome dimensions.

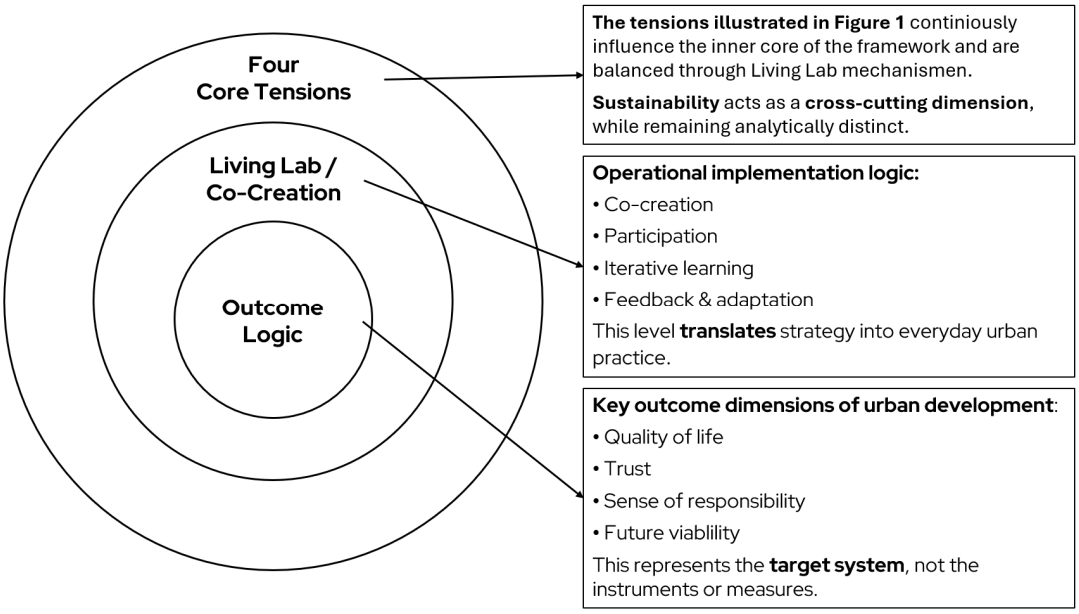


Figure 2: Integrated implementation framework for operationalizing urban tension areas

5 INTEGRATIVE IMPLEMENTATION FRAMEWORK: RESULTS LOGIC AND LIVING LABS

The implementation framework proposed here is based on a results-oriented perspective that evaluates urban development not primarily in terms of the instruments or measures used, but in terms of their intended and perceived effects. The focus is in particular on perceived quality of life, trust in institutions, sense of responsibility, and long-term identification with the urban environment. These outcome measures form the connecting reference point for the planning, implementation, and evaluation of urban development processes.

To operationalize this outcome logic, living lab approaches are a suitable option, and are discussed in current urban research as an effective bridge between strategy and everyday practice. Living labs make it possible to test new solutions under real-world conditions together with diverse stakeholders, to develop them iteratively, and to evaluate them systematically (Schuurman, 2016; OECD, 2023). They create a protected space in which efficiency, design options, technology use, and sustainability are not negotiated abstractly, but rather experienced and reflected upon concretely. Efficiency is linked to experiential quality, governance is connected to real design options, technological innovation is embedded in trust-building governance structures, and sustainability is understood as an integral component of urban value creation.

6 CONCLUSION AND OUTLOOK

This paper has shown that key challenges of urban development have been known for decades, yet persist despite technological advances, data-driven governance approaches, and diverse sustainability initiatives. The analysis clarifies that this persistence is less due to a lack of theoretical knowledge than to a failure to integrate this knowledge into consistent, results-oriented implementation logics. By conceptualizing cities as service and value creation systems and identifying four key areas of tension, an analytical framework is provided that systematically integrates functional, social, technological, and sustainability-related perspectives. The proposed integrated implementation framework connects this analysis with a results-oriented logic and living lab approaches, thus opening a path to translating strategic objectives into tangible urban practice. This article offers conceptual added value to smart city, governance, and city branding research by explicitly highlighting a hitherto insufficiently addressed integration gap and proposing a structured approach to addressing it. At the same time, it demonstrates that urban performance cannot be measured solely by efficiency or technological maturity, but is essentially manifested in experienced quality of life, trust, and long-term identification. Several starting points emerge for future research. These include the empirical validation of the identified areas of tension in different urban contexts, comparative analyses of outcome-oriented management approaches, and the further development of measurement and evaluation instruments that systematically capture experienced urban impacts. Furthermore, living lab formats offer a promising field for transdisciplinary research in which theoretical concepts can be further developed and tested under real-world conditions.

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Gender-Inclusive School Architecture: An International Comparison

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1 ABSTRACT

Gender-inclusive school architecture seeks to design educational environments in which all genders – girls, boys, non-binary, trans and intersex people – are equally considered, feel safe and addressed, and have access to the same spatial opportunities. Drawing on a decolonial, queer and intersectional feminist perspective, this paper analyzes how architectural decisions and spatial configurations can either reinforce or challenge social power relations. Intersectionality provides the analytical lens to understand how discrimination based on gender, body norms, origin or social position operates simultaneously and interactively. This framework highlights the ongoing influence of historical, colonial and normative structures that continue to shape school architecture.

The study is grounded in a broad dataset collected between 2021 and 2024. Through qualitative methods such as interviews, drawings, questionnaires and participatory workshops, more than 460 children and adolescents aged 6 to 16 were included across school and extracurricular settings. This mixed-methods approach captures a wide range of spatial needs and experiences. From the analysis, four core dimensions of gender planning in school construction emerged: (1) safety, security and well-being; (2) movement spaces; (3) retreat spaces; and (4) toilets. These dimensions emphasize the tight interrelation between spatial design, participation, visibility, privacy and psychological safety.

A European comparison underscores Vienna's pioneering role in gender-inclusive planning. Building upon Carla Schwaderer's dissertation „Gender Planning in School Architecture", a comprehensive guide for gender-inclusive school architecture has been developed. Its principles are reflected in several Austrian best-practice projects, including the Konrad-Lorenz-Gymnasium in Gänserndorf, the NMS Mittelweiherburg in Hard and the Pestalozzi Education Centre in Leoben. Complementary examples from other European contexts broaden the analytical scope: Learning Landscapes in Basel, the Reggio School in Madrid and the TORNHØJ HALL in Aalborg Øst in Denmark.

Across Europe, cities and countries pursue different strategies, yet the comparative analysis reveals shared priorities: participatory planning processes, adaptable spatial structures, and safe, inclusive sanitary, movement and retreat areas. These elements form the basis of successful gender-inclusive school construction. The study concludes by reflecting on what can be learned from international examples for future European planning practices and how decolonial and queer-feminist perspectives can be embedded more systematically in architectural practice and educational policy.

Keywords: gender , inclusion, school architecture, intersectionality, planning

2 GENDER-INCLUSIVE SCHOOL ARCHITECTURE AS AN INTERDISCIPLINARY FIELD OF RESEARCH

2.1 Theoretical foundations and social relevance

Girls and young women, as well as other groups affected by discrimination (e.g., based on class, origin, etc.), have long been denied unrestricted access to education in Europe and have been systematically excluded at the institutional level (Jakobi, 2013; Kleinau & Opitz, 1996). Although this has improved in recent years, it is still noticeable in school buildings. Like all buildings, school buildings are mainly designed by male planners according to male needs, which means, among other things, that they are geared towards the "male" body (Criado-Perez, 2020), which differs from the average size, mass, and weight, and has different requirements, for example, in terms of room temperature (Chang & Kajackaite, 2019). The following section will outline the theoretical foundations of gender planning and its social relevance.

2.1.1 Gender, space, and education: A feminist-intersectional perspective

Gender-inclusive school construction refers to a planning and design-oriented approach that aims to design school buildings and spaces in such a way that students of all gender identities feel safe, respected, and included.

This approach takes into account not only binary gender categories, but also non-binary and other gender identities (such as inter, trans, etc.). The relevance of this approach stems from the central role that educational institutions play in the everyday lives of children and young people: Since they spend a significant amount of their time in schools, school spaces function not only as places of learning, but also as social living spaces with a significant influence on individual development processes (Friedrich, 2008, p. 24; Seydel, 2023, p. 19).

The topic of gender-inclusive school architecture is located at the intersection of gender studies, architecture, and education. While gender studies analyze social gender relations, power structures, and mechanisms of discrimination (Butler, 2025; Ahmed, 2024), architecture deals with the material and spatial organization and design of school environments (Kühn & ÖISS, 2025; Rieger-Ladich & Ricken, 2009, p. 197). Pedagogy, in turn, examines educational processes, social interactions, and the institutional framework of learning (Rosenberger 2023). Only through the intertwining of these three disciplines does it become apparent how spatial design, pedagogical practice, and gender attributions influence each other.

Schools are central social institutions in which all children and young people, regardless of their gender, should have access to safety, belonging, and support. Gender-inclusive architecture can help reduce experiences of discrimination, conflict, and insecurity, thereby supporting a supportive school climate. Furthermore, it enables more equitable learning and development opportunities by challenging stereotypical attributions of use, removing spatial barriers, strengthening user privacy, and designing flexible usage structures (Schwaderer, 2025b).

Gender-inclusive school architecture aims to create spatial conditions that ensure safety, well-being, and equal participation for all students. Key criteria here are accessibility, privacy protection, and multifunctional and adaptable spatial concepts. In this context, the term gender is understood as social gender and encompasses socially constructed role models, expectations, behaviors, and normative attributions associated with different gender identities. This is to be distinguished from biological sex, which refers to physical and physiological characteristics used to classify individuals at birth. Feminist spatial theories analyze the extent to which social norms and power relations structure the perception, appropriation, and use of spaces without using biological differences as an explanatory starting point.

The examination of gender-inclusive school architecture is approached from a decolonial, queer, and intersectional feminist perspective (Ahmed, 2024; Crenshaw, 1989). Decolonial approaches problematize historically grown power and knowledge orders that have emerged from colonial contexts and advocate for a pluralization of knowledge beyond Eurocentric norms (Roig, 2024). Intersectional perspectives analyze the interaction of various axes of discrimination – such as gender, origin, social class, disability, or sexual orientation – and reveal how they reinforce each other (hooks, 2000 [1984]; Lorde, 2007 [1984]; Lorde 2017). The feminist approach focuses in particular on structural inequalities and disadvantages faced by FLINTA* individuals and aims to eliminate them.

More than half of students in Austria can be assigned to at least one category of discrimination. Since spatial structures both promote and restrict social practices, the design of school buildings is of central importance.

Architectural decisions have a significant influence on whether experiences of discrimination are reproduced or reduced in the school context and thus contribute significantly to the creation or reduction of social inequalities in the educational space (Goffman, 2001 [1994]).

In addition, the discussion is based on inclusive and user-oriented research approaches that actively involve those groups that are often marginalized in planning and decision-making processes. These include people with disabilities, members of discriminated groups, and people with limited access to resources (Schwaderer, 2024). By systematically incorporating their perspectives as experts in their own lives, research and design processes are made participatory and oriented toward the actual needs, experiences, and everyday practices of the future users, i.e., the students, educators, teachers, and school administrators.

2.1.2 Research gap

Although there has been growing interest in issues of gender equality, inclusion, and diversity in the discourse on school construction in recent years, systematic engagement with gender-inclusive school architecture has remained fragmentary. While educational research often examines social dynamics, experiences of discrimination, and institutional conditions in everyday school life (Heinrich Böll Foundation

2022), architectural discourse increasingly focuses on accessibility, functional flexibility, or gender inclusivity in relation to the school's outdoor space (Diketmüller & Studer 2007; Hottenträger, 2005; Studer, 2002; Federal Ministry of Education, Science and Research, 2019; University of Vienna & tilia, 2007), there is a lack of integrative approaches that consistently combine spatial design, educational practice, and gender-theoretical perspectives.

In particular, there is a lack of empirically based studies that analyze the concrete impact of spatial design decisions on the use, perception, and appropriation of school spaces in relation to gender. Questions about how gender-inclusive planning approaches affect the sense of security, social participation, or well-being of different user groups in the long term have not yet been sufficiently researched.

Furthermore, there is a clear gap in the institutional and procedural anchoring of gender planning in school construction. In existing school construction guidelines, competition procedures, and planning processes, gender aspects are often only considered implicitly or selectively (MA56 – Schools, 2021; MA56 – Schools, 2023; ÖISS, 2021). There is a lack of binding guidelines for establishing clear responsibilities, for example in the form of gender coordinators within construction and planning projects, who would ensure the continuous integration of gender-related issues across all project phases.

Last but not least, there is a research gap regarding the political and legal embedding of gender-inclusive school architecture. Although there are equality, anti-discrimination, and inclusion laws at the national and international level, their spatial implications for school construction have hardly been analyzed and even less frequently translated into concrete building standards. The interactions between legal requirements, political objectives, and architectural practice thus remain largely underexposed.

2.1.3 Research relevance

Against this background, the scientific examination of gender-inclusive school architecture is of great social, political, and planning relevance. Schools are central places of socialization where spatial structures not only enable learning processes but can also reproduce or challenge social norms, power relations, and affiliations.

The study of school spaces from a gender, spatial, and educational theory perspective therefore makes a significant contribution to understanding structural inequalities in education.

This research is particularly relevant because it has the potential to establish gender planning as a binding component of school building guidelines. Such anchoring makes it possible to no longer treat gender equality as a voluntary additional service or individual commitment of individual actors, but to define it as a structural requirement in school architecture.

At the same time, the research provides a basis for argumentation for decision-makers in politics, administration, and planning to legitimize gender planning in school construction in a sustainable manner, secure it financially, and anchor it institutionally.

Overall, the examination of gender-inclusive school architecture closes a central research gap at the interface of gender studies, architecture, and education. It contributes to the further development of discrimination-sensitive, socially just, and sustainable educational construction and opens up new perspectives for planning practices that understand spatial design as an active component of gender equality policy.

2.1.4 Research question

Against this background, this paper takes a comparative international approach and addresses the following research question:

How do different cities and countries in Europe deal with gender-inclusive planning in school architecture, and what can be learned from their analysis for future innovative gender-inclusive school architecture?

2.2 Methods

The empirical data for this study was collected between January 26, 2022, and November 11, 2024, at public compulsory schools in Vienna. The focus of the study was on elementary and middle schools, as these represent a central stage in the socialization of children and young people and are therefore particularly relevant for the analysis of gender-related perceptions of space and experiences of use.

Data collection was primarily carried out in participatory workshops with children and young people. The aim of these workshops was to record subjective perceptions, experiences, and needs with regard to school spaces and to make these visible from the perspective of the actual users. The collected material comprises a total of 32 guided interviews with 53 students, 110 drawings, 111 completed task sheets, 145 written responses from workshop sequences, and 45 standardized questionnaires. The diversity of the survey formats enabled a multidimensional approach to the research field and helped to take into account the different forms of expression and communication of the participating children and young people (Vogl, 2015, p. 69).

All participating students were of compulsory school age at the time of the survey and were between 6 and 16 years old. The deliberate inclusion of this age group takes into account the fact that children and young people perceive and use school spaces differently and that gender-related attributions and spatial appropriation processes already take effect in early stages of life.

The data collected from the students as the central focus group of the study was supplemented by a total of 15 expert interviews. Experts from the fields of architecture, pedagogy, education and urban policy, city administration, and gender studies were interviewed. These interviews served to contextualize the institutional, planning, and political framework conditions of school construction and to triangulate the students' perspectives with expert assessments from various disciplines.

The interviews were recorded as audio files using mobile devices and then transcribed in full. The entire qualitative data material was evaluated using Mayring's summary qualitative content analysis (Mayring, 2015, p. 69-70). This evaluation method enabled a systematic reduction and structuring of the material as well as the identification of central thematic categories, patterns, and connections in relation to gender-inclusive spatial perception, experiences of use, and institutional conditions of school construction.

Research ethics principles were consistently taken into account when conducting the empirical survey, especially with regard to working with minors as a particularly vulnerable research group. Participation in the study was entirely voluntary. Before data collection began, both the legal guardians and the participating children and young people were informed in an age-appropriate manner about the aim, procedure, and content of the research. The consent of the legal guardians and the informed assent of the students were obtained prior to participation (Vogl, 2015, p. 88-89).

2.3 Four Core Dimensions

As already described, gender-inclusive school architecture aims to design spatial structures in such a way that they do not reproduce gender-related inequalities, but actively contribute to equal opportunities, participation, and social justice. The starting point is the recognition that spaces are not neutral, but can materialize and reinforce social norms, power relations, and role models. Gender-inclusive school architecture therefore takes into account the diverse needs, perceptions, and ways of appropriating space of students in all their diversity and avoids binary attributions or stereotypical space allocations (Schwaderer, 2023).

Key principles include the equality of all users, the flexibility and ambiguity of spaces, accessibility, transparency in planning decisions, and the institutional anchoring of gender competence in all phases of the design and planning process. Gender planning thus understands school architecture as an interdisciplinary task that integrates architectural, educational, and social science perspectives and views spatial design as an integral part of education and equality policy. Against this background, four core dimensions can be identified that are of particular importance for gender-inclusive school architecture.

2.3.1 Safety, security, and well-being

Safety, security, and subjective well-being are fundamental prerequisites for successful learning and social participation in the school context. Gender-inclusive school architecture takes into account not only objective safety aspects, but also, in particular, the subjective sense of safety of different user groups. Studies show that perceptions of insecurity can be strongly gender-dependent and that girls, non-binary, and gender-nonconforming students in particular are more likely to identify spaces that cause fear or insecurity (Schuster, 2012; Schwaderer, 2025b).

In this context, architecturally relevant features include clear spatial structures, easily visible traffic areas, clear orientation systems, and a balance between openness and protection. Dark, remote, or poorly visible

areas – such as long corridors, stairwells, or outdoor spaces – can increase feelings of insecurity and promote social exclusion mechanisms. Gender-inclusive planning therefore aims to minimize areas that cause fear and to create an atmosphere of transparency through design, lighting, and choice of materials, without placing the emphasis on surveillance or discipline.

Furthermore, well-being is closely linked to emotional and social security. School rooms should enable identification, make diversity visible, and give students the feeling that they are welcome. This can be supported by flexible furniture, age- and user-friendly design, and the opportunity to participate in the design process (Montag Stiftung Jugend und Gesellschaft, 2017, p. 191). Architecture that promotes security contributes significantly to reducing stress, withdrawal from everyday school life, and gender-specific exclusion.

2.3.2 Movement spaces

Movement spaces play a central role in everyday school life, as they not only enable physical activity, but also make social interactions, power dynamics, and gender-specific appropriation processes visible (Ostermann, 2009). In many schools, large-scale, competition-oriented exercise facilities – such as soccer fields or gyms – dominate, and these are often used more by certain groups, mostly boys. Other students are implicitly excluded or withdraw as a result (Schwaderer, 2025c).

Gender-inclusive school architecture challenges these one-sided spatial offerings and strives for a variety of movement spaces that enable different forms of movement, play, and physical expression. In addition to classic sports areas, this includes informal movement zones, small-scale offerings, multifunctional outdoor spaces, and transition zones that promote spontaneous, non-performance-oriented activities. It is crucial that no form of use is hierarchized or normatively evaluated (Women in Sport, 2022).

The design of movement spaces should also ensure social safety and accessibility. Clear zoning, flexible usability, and transparent rules can help enable all students to participate equally. From a gender-inclusive perspective, exercise spaces are therefore not only places for physical activity, but also central venues for social negotiation processes that can be specifically influenced by architecture (Derecik, 2015, p. 59).

2.3.3 Retreat areas

Retreat areas are an essential element of gender-inclusive school architecture, as they take into account the different needs for quiet, privacy, and emotional relief (Eichler, 2021). Everyday school life is often characterized by high social density, noise, and constant visibility, which can be particularly stressful for marginalized or more sensitive students. Gender-specific expectations regarding presence, assertiveness, or conformity further exacerbate this pressure.

Gender-inclusive planning recognizes retreat not as a deficit, but as a legitimate and necessary strategy for self-regulation. Retreat spaces can take various forms, such as small lounges, niches, reading corners, or sheltered outdoor areas. It is crucial that they are easily accessible, do not have a stigmatizing effect, and can be used by all students without having to justify or legitimize their use.

Architecturally relevant aspects include acoustic shielding, visual separation, flexible furniture, and a pleasant atmosphere. Retreat areas not only contribute to individual well-being, but also promote social sustainability by reducing potential for conflict and enabling self-determined use of space (Derecik, 2015). In gender-inclusive school concepts, they are therefore not an additional offering, but an integral part of the spatial program.

2.3.4 Toilets

Sanitary facilities are a particularly sensitive area of school architecture, as they are closely linked to issues of intimacy, physicality, gender, and social control (Schwaderer, 2025a; Schreiber, 2019). Traditionally binary school toilets can be a significant source of stress for trans*, non-binary, or gender-nonconforming students, leading to insecurity, avoidance, or discrimination. At the same time, toilets are often places of bullying, assault, or social exclusion.

Gender-inclusive school architecture aims to design toilet facilities in such a way that they guarantee safety, privacy, and dignity for all users. Key design principles include lockable individual cubicles, ceiling- and floor-to-ceiling partitions, clearly visible entrance areas, and a clear separation of washing and toilet areas.

Gender-neutral or all-gender toilets should be an important addition or alternative to binary options, provided they are integrated into the room concept in an equal, visible, and natural way (Schwaderer, 2025a).

In addition, the location of toilets in the school building is important. Good accessibility, social integration, and the avoidance of spaces that cause anxiety are crucial for reducing barriers to use. Toilet facilities are therefore not only functional infrastructure elements, but also key indicators of the extent to which a school recognizes and spatially supports gender diversity (ibid.).

3 EXAMPLES FROM PRACTICE

The aim of Carla Schwaderer's dissertation entitled "Gender Planning in School Construction. A Guide to Gender-Inclusive School Architecture" is to develop a guide that will be compiled in cooperation with the Austrian Institute for School and Sports Facility Construction (ÖISS) and published in spring 2026. Research conducted as part of the dissertation shows that, although there are specifications and guidelines for tenders and architectural competitions for school buildings in Vienna, some of these are binding and some are merely recommendations (Plattform schulUMbau, 2010; ÖISS, 2023; City of Vienna, 2023). However, these are mainly limited to general references to gender-inclusive planning, without providing specific instructions or design principles for gender-inclusive implementation. This gap is to be closed in the future by the guidelines developed as part of the dissertation.

An international comparison based on extensive research also shows that Vienna occupies a special position in the international context: Vienna is the only one of the regions studied that explicitly stipulates gender-equitable school spaces in its school building guidelines. In other countries – including Denmark, Sweden, Switzerland, Norway, Spain, Italy, Japan, the USA, and Canada – gender equity has not played a comparable role, at least at the level of guidelines, even though individual projects that have been implemented can certainly be classified as gender-inclusive – as we will discuss in chapter 3.2 International Examples.

3.1 Examples from Austria

With its early feminist urban planning, which was already influenced by Eva Kail (Kail, 2002) in the 1990s, Vienna has generally played a pioneering role in gender planning and can point to a long history of gender-sensitive planning (Knoll & Szalai, 2010; City of Vienna, 2007).

3.1.1 Konrad-Lorenz-Gymnasium, Gäserdorf

The Konrad-Lorenz-Gymnasium in Gänserndorf is a contemporary example of a school that goes beyond mere functional renovation and creates spatial qualities that take into account both the educational and social aspects of school. The building was completed in 2022 after the architectects Franz&Sue ZT GmbH won a Europe-wide competition for the renovation and expansion. The school serves as the main school location for around 1,000 students and integrates existing buildings with a new connecting structure to form an open, hierarchy-free ensemble (Franz&Sue, 2026; ZAB, 2026).

The architectural intervention responds to the structural deficits of the former, strongly linear and spatially segregated corridor school by focusing on central meeting and orientation spaces. The open auditorium in the middle of the building serves as an identity-forming center and connects different levels with wide seating steps. Floods of daylight, attractive seating areas, and a direct visual connection to neighboring open spaces enhance both the communicative use and social accessibility of the space. This communicative core supports an atmosphere in which different groups and social identities can overlap, thus contributing to a school environment that embraces diversity as a constructive element (Austria Architects, 2026).

The cluster structure of the classrooms around this central space creates manageable yet interconnected learning units that facilitate orientation and shorten distances. The deliberate structure promotes the self-organization of learning groups and minimizes areas of uncertainty, which can have different psychological effects on students, especially in larger building complexes (Kühn & Schwaderer, 2025). Color concepts and a visual guidance system also provide intuitive orientation that is not bound to traditional, strictly functional hierarchies, but opens up opportunities for identification through differentiated visual addresses.

Another feature is the integration of indoor and outdoor spaces, which allows views from the classroom into a variety of open areas. The schoolyards and school garden are designed so that they not only function as pure break areas, but also invite different forms of use – from exercise and informal encounters to quiet

retreat areas. This spatial diversity addresses key requirements of gender-inclusive school architecture, as it enables different forms of movement, lingering, and appropriation and promotes social participation among multiple user groups (ibid.).

The choice of materials and the design of the façade also reflect an approach to aesthetic identification and tactile quality: a delicate wooden slat façade lends the building liveliness and warmth, which, beyond functional requirements, can support a feeling of belonging and well-being.

Particularly noteworthy is the range of movement options in the intermediate zones of the school building, which can be considered exemplary for gender-inclusive school construction. Instead of a strict separation between learning, traffic, and movement areas, access areas, stairwells, and lounge areas are deliberately designed as informal spaces for movement and appropriation (Schwaderer, 2025c).

Seating steps, spacious staircases, and open transitions enable spontaneous, low-threshold forms of movement that are not performance-oriented and are not associated with any specific sports culture. This creates alternatives to classic, often gender-dominated exercise spaces such as gyms or sports fields. These informal movement opportunities promote diverse use by different groups of students, reduce mechanisms of exclusion, and support self-determined, gender-independent appropriation of the school space. The integration of movement into everyday routes and lounge areas thus contributes significantly to an inclusive, stress-reducing, and socially balanced school day (ibid.).

As a whole, the Konrad-Lorenz-Gymnasium shows how spatial structures beyond purely functional logic can enable social experiences, orientation, encounters, and identification. These qualities are central elements of gender-inclusive architecture, as they aim to allow for differentiated uses and to spatially accommodate heterogeneous realities of life in everyday school life. Through its combination of open communication spaces, differentiated learning clusters, designed outdoor areas, and an integrative color and orientation system, the building can be considered a model that supports spatial openness, social accessibility, and heterogeneous modes of appropriation in the spirit of contemporary school architecture.

3.1.2 NMS Mittelweiherburg, Hard

The Neue Mittelschule (NMS) Mittelweiherburg in Hard is an exemplary example of the contemporary approach to school interior design in the context of educational and social requirements. Originally opened in 1978, the school building underwent a comprehensive renovation, which was completed in April 2022, and was given a new focus in terms of content and space. The renovation was planned by the architects gruber locher architekten ZT GmbH from Bregenz, which was tasked with transforming the existing qualities of the school building while implementing modern standards of educational interior design (Daibau Magazine, 2026; gruber locher architekten, 2023).

As part of the renovation, the building was not only technically and energetically upgraded, but also structurally redesigned and given a new spatial logic. The aim was to transform the school building from a 1970s school typology often perceived as a “bunker” into an open, communicative, and flexible learning environment that allows for a variety of uses (Schlocker, 2023).

A central design element is the atrium at the intersection of the two wings of the building, which was designed as a vertical meeting zone and distribution area across all floors. This open hall serves not only as a spatial center, but also as a social mediator between formal teaching, informal encounters, and informal learning processes. The original solid steel railings have been replaced by transparent glass balustrades, significantly improving sightlines, permeability, and spatial orientation. This removes boundaries between the levels and allows spaces to be experienced as interconnected social places.

The cluster structure of the learning areas, in which three classrooms are grouped around a semi-open learning area, promotes communication, cooperation, and self-organization among the students. Such spatial constellations support heterogeneous forms of learning that have an integrative effect and enable different learning styles and social interactions. This flexibilisation of learning spaces is in line with gender-inclusive planning principles, as it breaks down stereotypical usage boundaries and creates learning environments that can be used and shaped equally by different groups (Nextroom, 2026).

Another aspect that sets the project apart in terms of gender-inclusive school construction is its use of materials, colors, and atmosphere. Whereas the school used to be characterized by brutal exposed concrete surfaces and garish colors, a coordinated material and color concept now creates a pleasant, diverse room

atmosphere that allows for both visual calm and acoustic differentiation. The use of wood, warm colors, and differentiated flooring materials contributes to the school's functional and emotional appeal, which supports the well-being and identification of all users, regardless of gender identity or personal preferences.

In addition, the renovation made the school barrier-free and equipped it with an elevator, which ensures physical accessibility and enables equal use of all school areas by students with different motor skills. This dimension of accessibility is a central component of gender-inclusive architecture, as it takes multiple differences into account and not only proclaims inclusive participation, but also realizes it spatially.

Finally, communal areas such as the auditorium, library, and modern lounge areas are an integral part of the spatial program, supporting both formal and informal uses. The combination of learning, lounge, and meeting areas promotes social interaction beyond formal teaching situations and fosters an atmosphere of openness that is important for diverse spaces of identity and experience.

As a whole, the NMS Mittelweiherburg shows how an existing school building can be transformed through careful but consistent pedagogically and socially oriented architecture. The combination of transparent spatial structure, flexible learning landscapes, differentiated materiality, and barrier-free access creates a spatial environment that not only tolerates diversity but enables it. This school building project thus makes an important contribution to an architecture of learning that follows gender-inclusive planning principles and translates them into concrete spatial qualities (Weber, 2025).

3.1.3 Pestalozzi Education Center, Leoben

The Pestalozzi Education Center in Leoben-Donawitz is considered one of the most innovative school construction projects in the country. The comprehensive renovation and reorganization of the existing Pestalozzi school complex was completed in 2016, after which the building was put into operation at the beginning of the 2016/17 school year. The Graz-based architectural office nonconform, in cooperation with schuleRAUMkultur/Michael Zinner from the University of Art and Design Linz, was responsible for the planning and implementation, jointly developing an integrative and participatory process management approach (Kühn, 2025).

The project brings together three different types of compulsory schools under one roof – elementary school, new middle school, and polytechnic school – and transforms the building into an open, shared educational center that serves as a model for other regions. The spatial reorganization aimed to break down barriers between traditional functional units and enable diverse forms of use. Participation processes with students, teachers, parents, and other user groups formed the basis for a spatial concept that is not characterized by rigid hierarchies, but focuses on social interaction, communication, and appropriation (nonconform, 2026).

An essential element of this gender-inclusive approach is the transparency and permeability of the spatial structure: classrooms open onto corridors and communal areas that serve as informal learning and meeting spaces. The spatial interaction between formal teaching and open communication spaces promotes heterogeneous modes of learning, facilitates social orientation, and minimizes isolating spatial forms. In this way, the architecture responds to the different needs of students and addresses differences in perception and use across genders, age groups, and learning preferences (ibid.).

Another characteristic feature of the education center is the integration of different age groups and school types into a common spatial logic. The resulting “interstitial spaces” between the units enable informal encounters that promote social exchange across institutional boundaries. Such intermediate zones offer a variety of opportunities for expression and movement: they serve as informal learning spaces, lounge areas, and informal meeting places that are not normatively defined for a specific use. This spatial openness supports a gender-inclusive appropriation of the school space by allowing for multiple identities and social practices equally, rather than reproducing traditional functional assignments.

In this context, the project's participatory planning strategy is relevant not only in terms of process but also in terms of architecture: the involvement of the school community in the design and appropriation phases has helped to ensure that spaces are not “imposed” but respond to actual everyday needs and can be flexibly developed. This form of participation – which goes beyond a mere survey of usage – strengthens the sense of shared responsibility and co-creation, which has a positive effect on subjective security, belonging, and well-being.

Finally, the importance of the Pestalozzi Education Center is also evident in the fact that it is perceived as a best-practice example of integrative school space design in both educational and architectural discourse. Professional recognition, participatory approaches, open spatial logic, and consciously promoted informal usage practices make the project a model that not only addresses gender-inclusive planning in school construction in theory, but also implements it in concrete spatial qualities.

3.2 International examples

This text focuses on Europe, as the regulations here are most comparable to our own context and to the guidelines in Austria; therefore, the learning effect is greater.

In a non-European context, gender planning in school architecture – for example in African countries – may instead emphasize aspects such as safe routes to school, sanitary facilities, and hygiene measures.

3.2.1 Learning landscapes at the St. Johann elementary school in Basel (Switzerland)

The learning landscapes at St. Johann Elementary School in Basel represent an exemplary approach in contemporary school construction, combining spatial qualities and educational requirements into an integrative spatial concept. The redesign of the school rooms was completed in 2019 and was carried out by the Basel-based architectural office ZMIK GmbH, which was able to develop new spatial structures in a participatory process with students and teachers (ZMIK, 2019).

Originally, the long corridors of the historic school building served merely as access zones for teaching purposes. In the context of the renovation, ZMIK transformed these linear spaces into multifunctional learning and recreation areas that combine informal learning, social interaction, and physical activity. The planning followed an intensive participatory process in which the perspectives of the actual users – especially the children – served as the conceptual basis, which promoted a high level of identification with the final spatial concept (ibid.).

Architecturally, the three main rooms of the school building are divided into three differently usable zones: cloakroom, learning landscape, and central movement and meeting area. This zonal structure not only enables functional differentiation, but also supports a variety of ways of using the space. Terraced and variably usable elements are arranged along the window side, serving both as work surfaces for individual or collaborative activities and as informal retreat and communication areas.

Particularly noteworthy is the hybrid character of the learning landscapes: instead of rigid classrooms or functional hallway structures, spatial niches such as “caves” and “hides” have been created that allow for different modes of use – concentrated work, playful discovery, retreat, or informal interaction. Elements such as slides, balance beams, and bouncing balls promote a concept of “active learning” that sees physical activity as an integral part of everyday school life (Schwaderer, 2025c).

From a gender-inclusive perspective, this project is exemplary because it breaks down traditional binary attributions of space and creates types of space that are not tied to specific roles, behaviors, or normative expectations of use. The learning landscapes thus promote the equal participation of all students – regardless of gender identity, learning style, or physical preferences – by offering different forms of access to learning and social interaction. The spatial structure allows for individual self-determination, supports cross-group communication, and creates a variety of opportunities for spending time together that are not evaluated hierarchically.

In addition, the integration of natural materials, differentiated acoustic solutions, and a graduated color palette has a psychosocially supportive effect: it promotes well-being and orientation, reduces stress factors, and creates an atmosphere that encourages positive social exchange. The proximity to the historic building and the acceptance of the existing building as a material basis underscore that gender-inclusive design can be effectively realized not only in new buildings, but also in the careful transformation of existing school buildings.

As a whole, the St. Johann elementary school shows how participatory planning, diverse spatial offerings, and flexible appropriation options can result in a school building that not only supports educational innovation but also creates a multi-layered, socially inclusive, and gender-inclusive learning and living space.

3.2.2 Reggio School in Madrid (Spain)

The Reggio School building in Madrid (El Encinar de los Reyes) was designed by architect Andrés Jaque and the Office for Political Innovation (OFFPOLINN) and completed at the end of 2022. The design is based on the educational principles of Reggio Emilia pedagogy, which views children as active designers of their own learning processes. This educational approach has a direct impact on the architectural concept and makes the school a remarkable example of gender-inclusive school construction (iqd, 2022).

Architecturally, the Reggio School is designed as a vertically organized, open ecosystem that deliberately avoids rigid functional divisions. The spatial organization follows the principle that the learning environment itself – alongside teachers and peers – acts as a "third educator" and thus actively participates in learning processes. Rooms are designed to allow for diverse, self-directed forms of acquisition and interaction. This diversity of possible uses is a central aspect of gender-inclusive planning, as it accommodates different learning styles, modes of expression, and physical needs without reproducing conventional attributions of use.

A striking example of this openness is the central, more than 8-meter-high common room, which serves as a multifunctional agora. This large, light-filled hall can be used as a space for movement, a meeting place, a teaching area, or a social gathering place, and is deliberately not zoned hierarchically. It functions as a social hub that promotes exchange across age groups, interests, and gender boundaries – a spatial counterpart to inclusive educational relationships.

The Reggio School largely dispenses with traditional corridors and instead creates flowing transitions between learning, play, and recreation rooms. These fluid transitions allow students to flexibly cross spatial boundaries and experience the school space in their own way, breaking down stereotypical patterns of use and enabling diverse forms of appropriation (Baunetzwissen, 2022).

Another important aspect is the design of the materials and space, which combines transparency, rawness, and ecological sensitivity. Visible technical systems, exposed pipes, and the consistent integration of natural elements such as courtyards and green spaces create a non-hierarchical, exploratory learning environment in which students of all genders are equally motivated to explore their surroundings and use them interactively.

The vertical staggering of the building – younger children on the lower levels, older children on the upper levels – supports age-differentiated but at the same time permeable use of space. This organization allows for the creation of autonomous spaces for experience without building social barriers, and creates spaces for experience that can be shared by heterogeneous groups (Metalocus & Dragoeva, 2022).

As a whole, the Reggio School combines architectural diversity, pedagogical openness, and ecological responsibility to create a spatial structure that implements gender-inclusive school construction not only as a normative goal, but as a concrete spatial practice. The school creates spaces that equally enable exploration, cooperation, social interaction, and self-directed learning, thus minimizing barriers between different users, age groups, and social identities, both thematically and spatially.

3.2.3 TORNHØJ HALL in Aalborg Øst (Denmark)

Completed in 2012, Tornhøj Hall is a motor skills-based extension of the sports hall at Tornhøjskolen in Aalborg Øst and was designed and built by the Danish architectural office Keingart (in collaboration with technical planning partner Kærsgaard & Andersen). The design responds to the conversion of an existing, traditionally organized hall structure and transforms it into an open, versatile environment for exercise and recreation (Keingart Space Activator, 2012).

Although it is not formally a classic new school building, the project is closely linked to the school context in terms of its functional and social impact: the hall is an integral part of Tornhøjskolen and is not only used for physical education, but also functions as a social, sporting, and interactive center for students of all ages, genders, and social backgrounds. This allows the hall to be seen as an example of gender-inclusive planning in the broader context of school interior design.

The basic architectural concept consists of opening up, connecting, and differentiating spaces for movement and interaction (Schwaderer, 2025c). The long, formerly dark sports hall has been made more permeable; corridors and access areas have been transformed into movement-promoting landscapes that spiral through the building and invite a variety of physical activities: from climbing and balancing facilities to free play and

movement zones to retreat and relaxation niches. This spatial openness and diversity of use promotes spontaneous, non-hierarchical forms of movement that are not bound by traditional performance or gender norms.

Particularly relevant in terms of gender-inclusive aspects is the integration of movement and social spaces: instead of a strict functional separation between sports and recreation areas, intermediate zones are created in which all students – regardless of gender, athletic ability, or physical characteristics – can move and interact independently. This corresponds to a planning concept that breaks down stereotypical patterns of use and offers space for diverse ways of appropriation. The small-scale nature of the facilities, in combination with the open spaces, creates a low-threshold participation structure in which different groups can participate on an equal footing (Keingart Space Activator, 2012).

Furthermore, opening up the hall to the school and the public space has created a strong connection between everyday school life and communal use. The newly created café and lounge areas function as social threshold spaces that enable informal encounters and exchanges before and after class or outside of organized sports activities. This spatial coupling promotes social cohesion and reduces barriers between user groups, which is a central concern of gender-inclusive planning.

The project is also notable for its understanding of physical activity not only as a cognitive or performance-related discipline, but as a social and everyday process of interaction. This perspective supports different forms of expression of movement and reduces normative attributions – an approach that, beyond its specific use, can serve as a reference for gender-inclusive school architecture by showing how spaces open up potential for movement, encounter, and appropriation for all users equally (ibid.).

4 CONCLUSION

The present analysis shows that gender-inclusive school architecture goes far beyond questions of individual room types or design details. It should be understood as an interdisciplinary field of action in which architecture, pedagogy, and gender studies jointly contribute to understanding school spaces as social, political, and pedagogical spheres of influence. School buildings are not neutral containers of learning, but rather materialize social norms, power relations, and ideas of belonging – and thus have the potential to either reproduce inequalities or actively dismantle them.

The theoretical approaches, empirical findings, and practical examples examined illustrate that gender-inclusive planning is effective when it is structurally, procedurally, and spatially anchored. Safety, opportunities for physical activity, places of retreat, and sanitary facilities prove to be central sites of negotiation for gender participation, where social dynamics manifest themselves particularly clearly. At the same time, international and national examples show that gender-inclusive school architecture is not a singular design model, but is characterized by flexible, context-related, and participatory solutions.

This makes it clear that gender planning in school architecture is not an optional addition, but a central prerequisite for sustainable educational architecture. Only when gender equality is understood as a cross-cutting issue in planning and is translated into binding guidelines, processes, and built spaces can schools become learning and living spaces that not only allow for diversity but actively support it.

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Geosystem Services and Subsurface Planning – Case Studies in Two Swedish Municipalities

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1 ABSTRACT

The strategic significance of geological resources for sustainable development and the security of European societies is well established. Nevertheless, the subsurface resources are often not systematically assessed in spatial planning at the municipal level. In cities, there is a variety of increasing demands and land-use conflicts, but these issues are also relevant for smaller municipalities. The absence of strategic prioritisation results in suboptimal utilisation of subsurface resources. Accordingly, a multidisciplinary research project (UNDER) is developing novel methods to incorporate subsurface considerations into spatial planning. This work is being carried out in close collaboration with spatial planners at the City of Malmö (a medium-sized city) and at the municipality of Askersund (a small municipality) in Sweden.

The geosystem services concept has been put forward as a concept that could support the efficient use of subsurface resources and improve systematic planning of the subsurface (e.g., Lundin Frisk, 2025). Geosystem services, analogous to ecosystem services, describe goods and services delivering benefits to humans either derived from the subsurface (van Ree & van Beukering, 2016) or the geosphere (Gray, 2011), often referred to as abiotic nature in this context). Similar to the classification of ecosystem services, geosystem services are categorised into supporting, provisioning, regulating, and cultural services. For instance, groundwater as a supply resource constitutes a provisioning geosystem service, whereas water quality regulation is considered a regulating service. The service perspective is holistic in the sense that it takes into account potentially conflicting uses of the subsurface and highlights a broader range of services and goods than typically included in spatial planning. In order to operationalise the concept, an indicator-based framework for assessing different geosystem services has been developed (Lundin Frisk et al., 2025).

The City of Malmö in southern Sweden (≈370,000 inhabitants) is currently developing a climate resilience plan. To support this effort, the research project has developed seven thematic GIS maps of geosystem services, including stormwater infiltration and retention capacity and access to subsurface space (Lundin-Frisk et al., 2026). The municipality of Askersund (≈11,500 inhabitants) is simultaneously preparing its comprehensive plan. Within Askersund municipality, diverse subsurface resources, such as a zinc mine and mineral resources, groundwater reserves, and geological construction materials (gravel and sand) are present, alongside underground transport infrastructure. Five thematic GIS maps of geosystem services have been developed, including maps for erosion resistance and the access to bedrock with quality suitable for aggregate production (Gustafsson, in prep.).

The thematic maps were presented in workshops with urban planners in Malmö and Askersund. Workshop feedback supported the relevance of geosystem services in supporting planning decisions and suggested future development needs for such maps. In Malmö, maps on stormwater infiltration and geoenergy were viewed as particularly valuable. In Askersund, participants emphasised that geosystem services provide a useful framework for communicating with non-experts, including decision-makers.

Keywords: Subsurface planning, Geosystem services, Strategic planning, Case study, Resilience

2 ABSTRACT (DEUTSCH)

Die strategische Bedeutung geologischer Ressourcen für eine nachhaltige Entwicklung und für die Sicherheit europäischer Gesellschaften ist längst anerkannt. Trotzdem spielen unterirdische Verhältnisse eine

untergeordnete Rolle in der räumlichen Planung auf der kommunalen Ebene. In den größten Städten gibt es eine Vielfalt von steigenden Ansprüchen und Nutzungskonflikten, aber diese Fragen sind auch für kleinere

Gemeinden relevant. Das Fehlen einer strategischen Priorisierung führt zu einer suboptimalen Nutzung der unterirdischen Ressourcen. Deshalb entwickelt ein interdisziplinäres Forschungsprojekt neue Methoden, um unterirdische Fragestellungen in die Raumplanung einzubeziehen. Diese Arbeit wird in engem Austausch mit Malmö (mittelgroße Stadt) und Askersund (kleine Gemeinde) in Schweden betrieben.

Um unterirdische Ressourcen effizienter zu nutzen und die Planung des unterirdischen Raums zu verbessern, wird der Begriff Geosystemdienstleistungen entwickelt (z.B. Lundin Frisk, 2025). Geosystemdienstleistungen ähneln den Ökosystemdienstleistungen und beschreiben Vorteile für den Menschen, unterscheiden sich jedoch durch ihre Fokussierung auf unterirdische Ressourcen und dass sie potenziell konfliktierende Nutzungen berücksichtigt. Ein indikatorbasiertes System zur Bewertung verschiedener Geosystemdienstleistungen ist entwickelt worden (Lundin Frisk et al., 2025). Ähnlich wie Ökosystemdienstleistungen werden auch Geosystemdienstleistungen in unterstützende, bereitstellende, regulierende und kulturelle Dienste aufgeteilt.

Die mittelgroße Stadt im südlichen Schweden Malmö (etwa 370.000 Einwohner) arbeitet derzeit an der Entwicklung eines Klimaresilienzplans. Zur Unterstützung wurden im Forschungsprojekt verschiedene thematische Karten zu Geosystemdienstleistungen mit GIS entwickelt, z.B. für Kapazität des Bodens Regenwasserversickerung (Lundin-Frisk et al., 2026). Die kleine Gemeinde Askersund (etwa 11.000 Einwohner) entwickelt derzeit ihren Masterplan. Innerhalb der Gemeinde gibt es eine Vielfalt unterirdischer Ressourcen inkl. eine Zinkgrube, Grundwasserressourcen, Baustoffen (Kies und Sand), gleichzeitig gibt es auch unterirdische Transportinfrastruktur. Für Askersund wurden thematische Karten entwickelt, beispielsweise zur Erosionsbeständigkeit und zum Zugang zu Gebirgsarealen für Gesteinskörnungen (Gustafsson, 2026).

Die thematischen Karten wurden in verschiedenen Workshops mit Stadtplaner(innen) in Malmö und Askersund präsentiert. Die Rückmeldungen aus den Workshops unterstreichen, dass Geosystemdienstleistungen einen wesentlichen Beitrag zur planerischen Entscheidungsunterstützung leisten. Für Malmö wurden besonders die thematischen Karten zur Regenwasserversickerung und Geoenergie als wichtig beachtet. In den Workshops mit Askersund haben die Teilnehmenden zum Ausdruck gebracht, dass Geosystemdienstleistungen ein wichtiger Begriff in der Kommunikation mit Nicht-Fachleuten, z. B. Entscheidungsträgern, sein kann.

3 INTRODUCTION

This paper presents results from an ongoing research project aimed at investigating the role of geosystem services to support integration of the subsurface in spatial planning. The research is case study-driven, focusing on planning cases in the cities of Malmö and Gothenburg, and the rural municipality of Askersund. For Malmö and Askersund, a similar approach for the dialogue with municipal planning professionals was used, and this paper presents results from this process.

3.1 Background: Geosystem services and subsurface planning

The subsurface plays a significant yet often overlooked role in urban development by providing critical services – such as stormwater infiltration to mitigate flooding, geothermal energy, and groundwater resources (Erlström et al., 2016). However, its potential is frequently neglected in planning, primarily due to limited awareness and understanding of subsurface data and functions (Dick et al., 2017; Finesso & van Ree, 2022). The concept of geosystem services bridges this gap by framing geological information in terms of societal benefits, extending the ecosystem services framework to include the subsurface and abiotic nature (van Ree & van Beukering, 2016; Gray, 2011; Lundin-Frisk, 2025). Lundin-Frisk et al. (2025) identify 39 such services, some of which were applied in the two case studies presented in this paper.

Geosystem services are defined, in this paper, as the contributions provided by the subsurface to human wellbeing, although there are alternative definitions (e.g., Fox et al., 2020; Gray, 2011; Lundin-Frisk et al., 2022; van Ree & van Beukering, 2016). As a parallel to ecosystem services, geosystem services are divided into provisioning, regulating, supporting, and cultural services, and many identified services are presented in Figure 1 (Lundin-Frisk, 2025). For a systematic description, presentation, and analysis of different

geosystem services in a certain geophysical setting, indicators and capacity classes for assessing and visualise the potential for delivering different services have been developed (Lundin-Frisk et al., 2025).

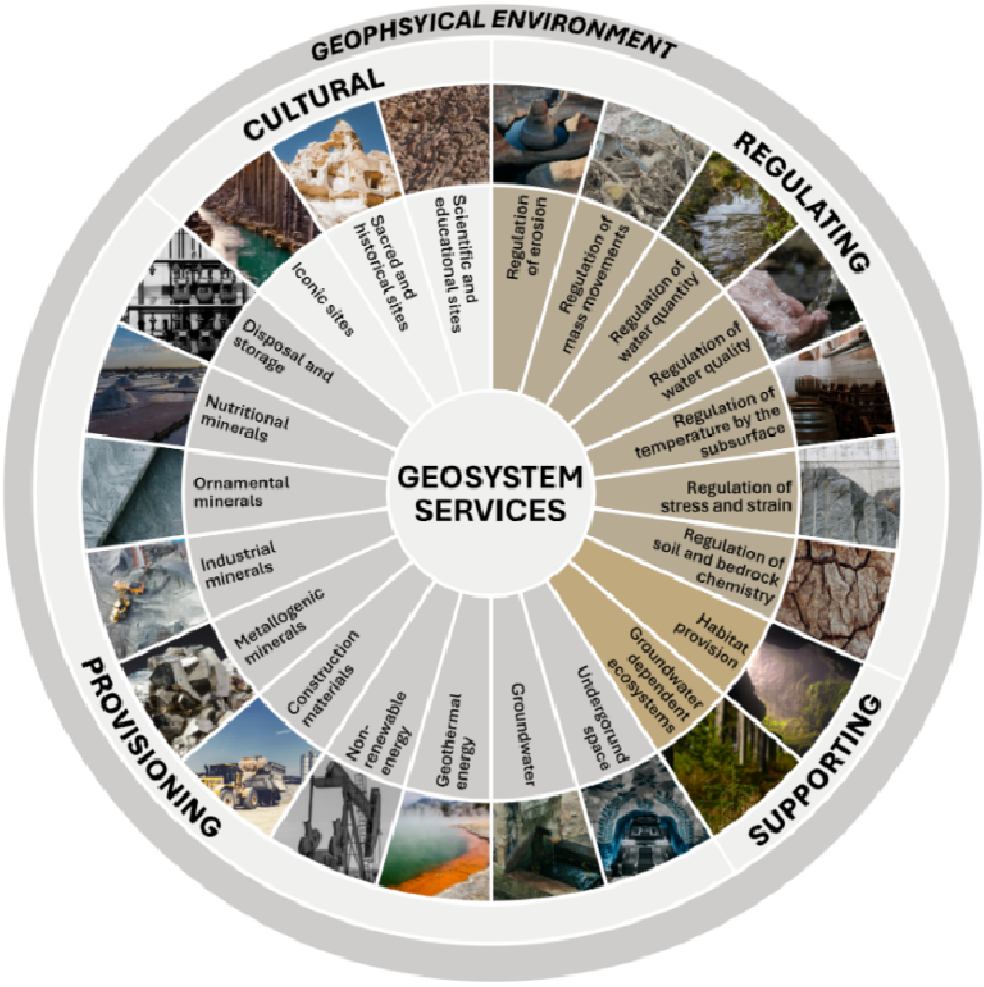


Fig. 1: Geosystem services are systematically divided into provisioning, supporting, cultural, and regulating services (from Lundin-Frisk, 2025)

Previously and in parallel with the ongoing development of the geosystem services concept, other related concepts and definitions – such as nature-based solutions (NBS), geodiversity, geoheritage, geodesign, and geoconservation – have been proposed or established. Steinitz (2012) introduced geodesign as an iterative, collaborative, and multidisciplinary approach applicable across scales, from landscape architecture to comprehensive planning. While geodesign may incorporate georesources and the underground, its primary focus remains on surface planning rather than the subsurface. NBS leverage natural processes and systems to address environmental and societal challenges, such as maintaining biodiversity, flood mitigation, and climate adaptation. Furthermore, NBS generally connects to ecosystem services, but already in its current useage extends to geosystem services such as regulation of water quantity (Kabisch et al., 2022). Previously established or proposed concepts insufficiently include the subsurface, and only ecosystem services have been successfully implemented in Sweden. Therefore, the inclusion of geosystem services in spatial planning is considered important.

3.2 Aim and objectives

This study is part of a collaborative effort of researchers from the UNDER-project, property developers, and civil servants from the Malmö municipality, as well as civil servants of the Askersund municipality, to explore the role of the subsurface in urban planning.

Primary Aim: To explore how geosystem services can enhance urban climate resilience planning in Malmö and for the development of an updated comprehensive plan for the municipality of Askersund. The two municipalities have been studied individually by Gustafsson (2026) and Lundin-Frisk et al. (2026), whereas this paper presents a combined discussion and joint conclusions of the two different studies.

4 CASE STUDIES

The two municipalities for the case studies, the city of Malmö and the municipality of Askersund, were selected because of the importance of the underground, ongoing planning processes, and their openness to exchange with the research project.

4.1 Case study 1: City of Malmö

Malmö is located in the south of Sweden and is the country's third-largest city, and currently has approximately 365,000 inhabitants. The city's rapid population growth, coupled with its coastal location, makes it vulnerable to the impacts of emerging climate change (Malmö stad, 2016; Persson et al., 2012; Sonesson et al., 2024). The surrounding areas comprise a flat landscape with a mixture of suburbs and agricultural land. The municipality is densely populated, considering its 334 km² area. Consequently, civil servants in Malmö are working to improve the city's climate resilience, particularly in response to four anticipated effects of climate change: (1) rising sea levels, (2) more frequent and intense rainfalls, (3) more frequent and severe heatwaves, and (4) more prolonged periods of drought.

4.2 Case Study 2: Municipality of Askersund

The municipality of Askersund has a population of about 11,500 and is located on the northern shore of Lake Vättern, about halfway between the two largest cities in Sweden: Gothenburg and Stockholm. The administrative centre is Askersund town, which has a small-town character. The municipality covers about 1,020 km², and approximately 4,700 inhabitants live in Askersund town, approx. 4,000 in smaller communities and 2,500 in rural areas. Demographic trends indicate a growing proportion of elderly citizens relative to the working-age population (Statistics Sweden, 2025).

Within the municipality of Askersund, there are important geosystem services that may be relevant for spatial planning. These include those assigned as national interest (for mineral resources), and there is an active underground mine, there is underground transport infrastructure with rail tunnels, groundwater resources, a planned drinking water tunnel, as well as areas prone to instability and erosion. A significant share of the coastal area along Lake Vättern is subject to environmental protection, whereas there is a preference to establish new housing in the vicinity of the lake.

5 METHODS

As a part of the UNDER-project, geosystem service maps were developed as presented in Lundin-Frisk et al. (2026) and in Gustafsson (2026). The process to select the geosystem services to be mapped was similar for the two cases, with feedback from the two different municipalities.

Repeated exchange between UNDER-project researchers, property developers, and Malmö municipality civil servants occurred (Lundin-Frisk et al., 2026). For the Askersund case, the exchange was limited to the UNDER-project and civil servants of the municipality (Gustafsson, 2026).

Methodological Steps:

- Exchange with stakeholders/municipality:
    - Malmö: Introduce the geosystem services concept at a workshop, investigate current subsurface use, and match uses with geosystem services. A discussion focusing on what services are assessed to be of the highest importance.
    - Askersund: Workshop/meeting/webinar with civil servants involved in spatial planning to discuss and select the most important geosystem services for the comprehensive plan.
- Map Development: This work with the development of thematic maps is presented in more detail in Lundin-Frisk et al. (2026) and Gustafsson (2026). A selection of geosystem services is presented in Table 1, and indicators are based on Lundin-Frisk et al. (2025).
    - Development of thematic maps based on geosystem services indicators (e.g., erosion regulation, temperature regulation, groundwater provisioning).
    - To further assess the accessibility of different and suitability of geosystem services, further aspects were included, such as depth, contamination, conflicts of interest, nature protection, etc.

- For Malmö and Askersund, seven resp. five thematic maps for geosystem services were developed.

- Stakeholder/municipality feedback:
  - Webinar and Workshop 1: Introduce the concept of geosystem services and their potential applications in spatial or climate resilience planning. In the Askersund case, a focused discussion was held to identify and prioritize the most relevant geosystem services..
  - Workshop 2: Two different workshops to test maps with urban planners and civil servants at the Askersund and Malmö municipalities, respectively, assess usefulness, and gather improvement suggestions.

Section	Geosystem service	Indicator [unit]
Regulating services	Regulation of erosion	Soil eroded kg, ml-2t-1]
		Landscape index [-]
		Soil erodibility [-] *
	Regulation of water quantity	Reduced flood risk area [m2, m2person-1]
		Storage and permeability capacity [-] *
		Quantity of water filtered [l3/t]
		Water Retention Index (WRI) composed of sub-indicators [-]
		Permeability index [-] *
	Regulation of water quality	Quantity of water filtered [l3/t]
		Biochemical degradation capacity [-]
Provisioning services	Construction materials	Thermal conductivity (λ) [W/(K m)]
	Groundwater for drinking	Groundwater level [m]
		Current groundwater extraction [l3/h]
		Number of springs [-]
		Potential extraction capacity [l3/h]
		Hydraulic conductivity in rocks [log10(K)]
		Number of wells [-];

Table 1: Examples of indicators for geosystem services based on Lundin-Frisk et al. (2025), the services were systematically divided into provisioning, supporting, cultural, and regulating services.

6 RESULTS AND DISCUSSION

The participants in the stakeholder/municipality exchange in the workshops with the city of Malmö and the municipality of Askersund both gave a positive response to the geosystem services concept. The positive response primarily underscored the geosystem services concept for its communicative value in planning dialogues and for fulfilling its purpose to highlight resources and conflicts of interest. They also pointed out that some of the services in the developed maps are already presented under different nomenclature in the current planning process.

6.1 Development of geosystem services potential maps

For the city of Malmö, seven thematic geosystem services maps were developed and included accessibility and suitability. Highlighting the role of the subsurface in providing beneficial services for climate resilience, the following thematic geosystem service potential maps were created, based on previously elaborated indicators for geosystem services (Lundin-Frisk et al., 2025): regulation of erosion, temperature by the subsurface, groundwater quantity and provisioning, underground space (deep and shallow), and construction material. Additionally, the maps were developed further to indicate accessibility of the services (how easily accessible it is due to, e.g. above-ground constructions or depth) and suitability (how suitable it is to make use of certain geosystem services due to, e.g. contamination), thus also providing information about potential conflicts of interest or areas where there is currently untapped potential (Lundin-Frisk, 2025).

For the municipality of Askersund, the selection of five prioritised geosystem services themes was influenced by municipal preferences, risk perspectives, data availability, and assessment by researchers. Despite limited prior experience with the geosystem services concept among participants, the webinar and workshop 2 confirmed the importance of four thematic areas: Bearing capacity, infiltration and retention of storm water, resistance to erosion, and provision of rock aggregate. Drinking water supply (provision of groundwater) was assessed as less important for the comprehensive plan by the municipality planners, but

Gustafsson (2026) emphasised the societal importance and potential risks from climate change. The outcomes reflect a balance between practical planning needs and broader research considerations. The resulting geosystem services potential map for provisioning of groundwater on a municipal scale is shown in Figure 2, and additional maps were delveloped for each selected theme (Gustafsson, 2026).

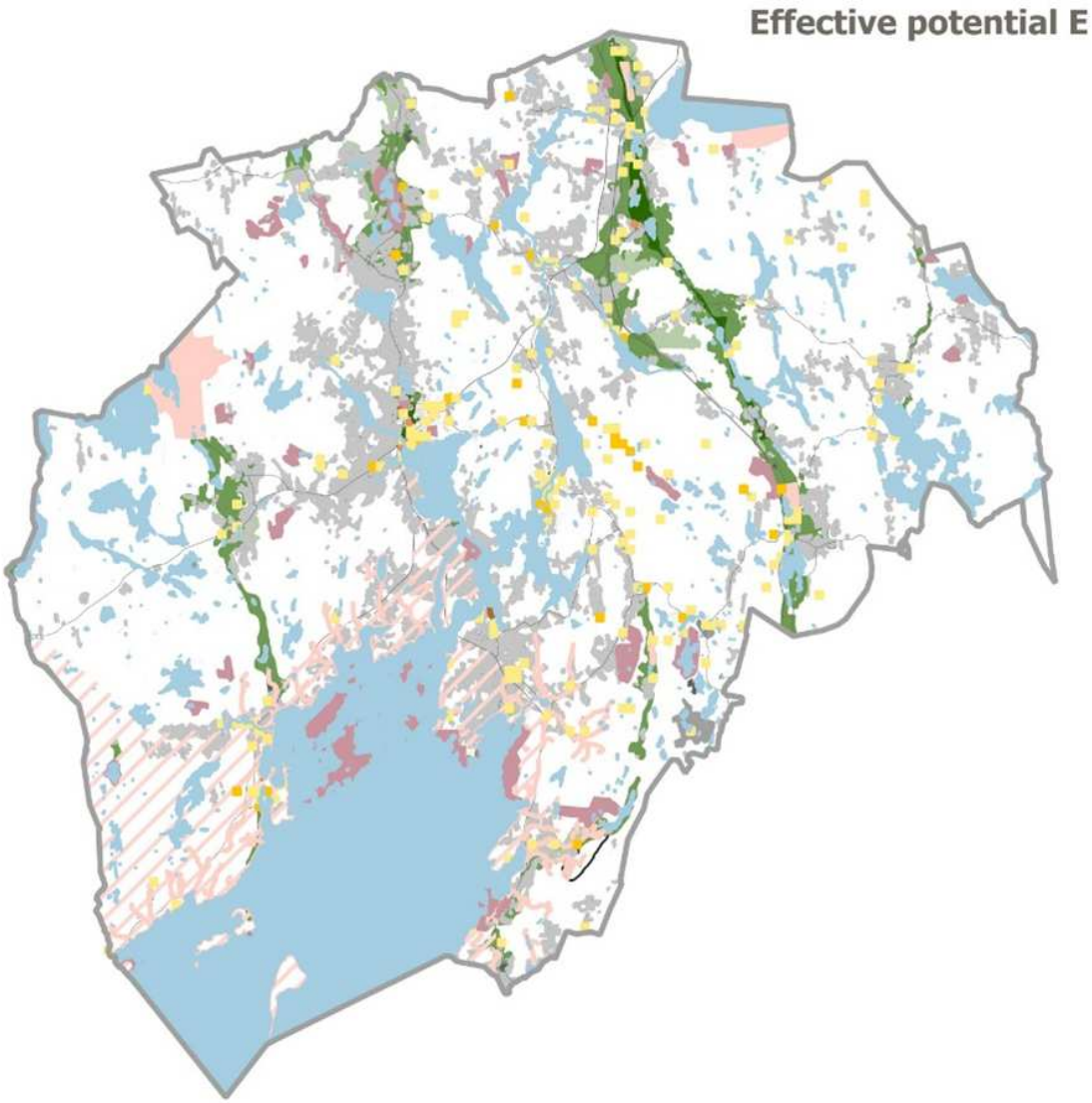


Fig. 2: Example map presenting a geosystem services potential map for groundwater provisioning on a municipal scale for Askersund (from Gustafsson, 2026).

6.2 Feedback from the municipalities and stakeholders

Preliminary results indicate that the city of Malmö is already considering the subsurface in its plans to some extent, for example, through stormwater parks that can delay and store incoming stormwater. Although the concept of geosystem services was new to workshop participants, it was positively received. It was recognised to potentially have a high communicative value for facilitating dialogue and improving the understanding of the contributions of the subsurface to enhance the city's climate resilience. The feedback from participants during the second workshop suggests that such maps may serve as a valuable basis for discussion in the early stages of planning, e.g. in the comprehensive planning process. The information provided by the maps can foster better collaboration among stakeholders from diverse backgrounds by offering a shared point of reference (Lunding-Frisk et al., 2026).

The webinar and the workshop gathered representatives from the municipality of Askersund, including a comprehensive planner, a GIS/map engineer, a land and development engineer, spatial planning architects, an environment inspector, and two relevant supervisors. As a first step, the group explored the relevance and practical application of nine pre-selected geosystem services for comprehensive planning. The discussion revealed that participants did not identify any missing aspects, though some, particularly those new to the

geosystem services concept, acknowledged the need for more time to fully assess its scope. Some of the services, such as groundwater provisioning, geological construction materials, and mineral resources, were deemed less relevant to current municipal planning. For mineral resources and construction material, this was related to the limited influence that the municipality exercises regarding these services and the permitting process. Participants also highlighted challenges in integrating complex map materials, preferring simplified, user-friendly formats. The most useful geosystem servicesand maps were those related to regulating erosion, infiltrating stormwater, and preventing harmful emissions, as these directly addressed pressing issues like buildability, stormwater management, and contamination (Gustafsson, 2026).

6.3 Discussion

The discussions in workshop 2 in both case studies highlighted the advantage of geosystem services maps to facilitate optimised subsurface use (e.g., geothermal energy, stormwater management) and resolving conflicts of interest. In the Malmö case, the workshop also facilitated stakeholder collaboration and innovative planning strategies. The scalability and applicability of geosystem services' potential maps to other urban contexts were also discussed and considered important in exchanges with both Askersund and Malmö.

During the workshop with the municipality of Askersund, data transparency, resolution, and scale stood out as key themes, especially regarding the stormwater infiltration and retention map, revealing that no single map can serve all users effectively. Too low a resolution of the maps developed within the project could miss critical details, while excessive detail may lead to overconfidence in uncertain data. Balancing these challenges requires aligning technical limitations (like data quality and availability) with user preferences. It was concluded that the purpose of each map must be defined and consistently communicated, from selecting geosystem services and through the development process.

The discussions at the Workshop 2 with the municipality of Askersund provided detailed comments on the five geosystem services potential maps, whereas the discussions at the Workshop 2 with Malmö held a more general character. The participants at the two Workshops (with Malmö and Askersund, respectively) had different backgrounds, and their overview may differ, with participants from Askersund likely working with a municipal-wide perspective. The workshops focusing on geosystem services maps were conducted earlier in Malmö than in Askersund, allowing insights and experiences from Malmö to be integrated into the Askersund case. Therefore, the maps for Askersund had been further developed at the time of the workshops and issues that were discussed in Malmö had been addressed.

The similarities between geosystem services and the established concept of ecosystem services facilitated communication with workshop participants. It is crucial to operationalize both ecosystem and geosystem services in spatial planning. While some geosystem services already align with Nature-based Solutions (NBS), more could be integrated – such as those vital for climate resilience. Expanding the scope of the NBS concept should also be considered as a potential path forward alongside the implementation of geosystem services in spatial planning.

7 CONCLUSIONS

The integration of geosystem services in spatial planning offers a promising concept for enhancing urban climate resilience as well as comprehensive planning. The use of maps in stakeholder engagement was deemed a critical instrument for effective planning. The exchange with the Askersund and Malmö municipalities indicates that the geosystem services potential maps should be further developed, as well as the indicators. Furthermore, there is a need for adaptivity for each mapping case regarding the indicators for geosystem services.

The study underscores that integrating the concept of geosystem services into spatial planning could enhance spatial planning, examplified by Malmö's climate change resilience plan and the comprehensive plan in Askersund. This can be achieved by

- enabling more effective planning and subsequently new or optimised uses of the subsurface, such as harnessing deep and shallow geo-energy for heating and cooling buildings, and improved utilisation of the subsurface for storing and delaying stormwater flow.

- improving the management of conflicts of interest, which is a key advantage of a more holistic perspective, as that provided by geosystem services.
- fostering better collaboration among various stakeholders in spatial planning processes, thus facilitating the implementation of innovative strategies that integrate the subsurface more effectively into climate resilience initiatives.
- A stronger connection between the concept of Nature-based solutions and the subsurface, and thereby geosystem services, should be considered for enhanced utilization of geosystem services.

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reviewed paper

Governing Green and Heritage-Led Revitalisation: Multi-Scalar Insights from the Nona Project in the Danube Region

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1 ABSTRACT

European policy initiatives such as the Green Deal, the New European Bauhaus, and the "No Net Land Take" objective call for sustainable, inclusive, and climate-resilient urban development. Yet many cities, especially small and mid-sized ones, struggle to operationalise these ambitions due to fragmented governance, unclear investment pathways, and limited institutional capacity. Heritage-led regeneration projects face particularly governance challenges: layered approval processes involving multiple heritage authorities, ownership fragmentation across public and private actors, technical uncertainty regarding structural interventions and conservation standards, and persistent institutional silos between heritage protection, urban planning, and economic development mandates.

This paper presents findings from the NONA project (New gOvernance for NewspAces), funded under the Danube Region Programme, which developed and tested a governance framework for green and inclusive regeneration of degraded urban areas. At the centre of this approach is a six-phase investment lifecycle that supports cities in structuring regeneration processes, from initial diagnosis through to implementation and long-term monitoring. The lifecycle model addresses recurrent implementation failures in heritage-led regeneration by making dependencies and prerequisites visible at early stages, introducing staged feasibility checks, and clarifying institutional responsibilities before design lock-in occurs.

Applied across ten pilot cities in the Danube Region, including Stuttgart, Cluj-Napoca, Odessa, Chișinău, Gabrovo, Veszprém, Šabac, Cazin, Ravne naKoroškem, and Virovitica, the model enabled local actors to align diverse objectives (heritage reuse, climate adaptation, and public space inclusion) with actionable steps tailored to their specific governance and resource environments. The lifecycle approach functions as a coordination and risk-reduction mechanism, helping cities to translate strategic goals into feasible project pipelines through feasibility checks, stakeholder engagement routines, and explicit sequencing of regulatory, technical, and financial prerequisites.

The findings demonstrate how a structured, adaptable governance process can bridge the gap between EU policy aspirations and local implementation realities. The paper argues that embedding lifecycle thinking into urban regeneration practice offers a replicable pathway for aligning institutional responsibilities, reducing fragmentation, and mobilising investment across varied urban contexts.

Keywords: governance models, degraded areas, heritage led regeneration, inclusive public space, urban planning

2 INTRODUCTION

2.1 European policy drivers and the call for holistic local transformation

Across Europe, cities face rising pressure to revitalise degraded and underused areas while addressing climate risk, social needs, and heritage preservation. Policy priorities promote compact development, adaptive reuse, circular approaches, and the reduction of land take and soil sealing, complemented by place-based and people-centred agendas (European Commission, 2019; United Nations, 2016; Decoville and Feltgen, 2023; Marquard et al., 2020). Regeneration is increasingly framed as a cross-sector transformation that requires coordination across planning, heritage, environment, mobility, public services, and social inclusion, and often across multiple jurisdictions.

Degraded and underused areas are commonly addressed through brownfield and adaptive reuse agendas, yet implementation remains shaped by uncertainty, missing or fragmented evidence (e.g., ownership, constraints), and weak coordination between planning and investment preparation (CABERNET, 2006; Barborič et al., 2022; Černič et al., 2022). Heritage-led regeneration intensifies these challenges through layered approvals, more fragmented ownership and stewardship arrangements, and higher technical

uncertainty when reconciling conservation standards with contemporary performance requirements (Tweed and Sutherland, 2007; Pendlebury et al., 2009; Bullen and Love, 2011; Veldpaus and Pereira Roders, 2014).

Against this backdrop, this paper investigates how a structured lifecycle governance model can bridge the gap between strategic regeneration ambitions and operational delivery, particularly in heritage-led and resource-constrained contexts. The central research question is: How and under what conditions does lifecycle governance improve feasibility, coordination, and investment readiness in urban regeneration? Drawing on empirical insights from ten pilot cities in the Danube Region, this study critically assesses the applicability, limitations, and contextual dependencies of the NONA lifecycle approach. In doing so, it contributes to ongoing debates in urban studies and planning around implementation logics, governance innovation, and institutional capacity for place-based transformation.

2.2 The implementation gap

While policy frameworks provide direction, many local administrations face recurring obstacles when moving from ambition to delivery. Across the pilots, these obstacles clustered around (i) sequencing failure, where feasibility constraints (ownership, approvals, technical studies) emerge after design or political commitments; (ii) coordination failure, where fragmented mandates and weak interfaces prevent alignment; and (iii) investment-readiness failure, where risk profiles, governance arrangements, and delivery assumptions remain too unclear to mobilise funding or partners (Roberts and Sykes, 2000; Couch et al., 2011; Tallon, 2013).

2.3 From ambition to delivery

This paper argues that lifecycle governance offers a pragmatic response to implementation failures by introducing a process logic that aligns strategic ambition with staged feasibility validation. Within the NONA framework, progression through the investment lifecycle is conditional on resolving key prerequisites – such as ownership clarification, regulatory approvals, and technical assessments – and on maintaining structured engagement among public authorities, civil society, and knowledge actors. This sequencing reduces premature design lock-in and improves the planning–finance interface through clearer roles, decision gates, and investor-facing project packaging (Healey, 2006; Ansell and Gash, 2008; Morris, 2013; Weber et al., 2014).

Although iterative governance requires calendar time, addressing regulatory, technical, and ownership uncertainties early increases the durability of outcomes and prevents late-stage project failure. In this sense, lifecycle governance deliberately counters pressures for accelerated planning that often lead to premature commitments and implementation risks (Flyvbjerg, 2009). For similar reasons, investors are engaged later in the lifecycle sequence. Early investor involvement in contexts of unclear land ownership or planning conditions may reinforce speculative land-holding behaviour and distort project objectives (Adams and Tiesdell, 2013). By contrast, sequencing investor engagement after governance conditions and feasibility parameters have been clarified helps ensure that financial actors participate in shaping credible, implementable projects rather than driving premature development pressures.Placing investor engagement later in the lifecycle therefore serves a governance function: it allows public authorities and local stakeholders to stabilise spatial objectives, regulatory conditions, and ownership arrangements before capital commitments shape project trajectories.

3 NONA APPROACH

3.1 Project overview and objectives

NONA (New Governance for New spAces) is a transnational project funded under the Danube Transnational Programme (2021–2027) that focuses on mainstreaming green investments into the revitalisation of degraded areas through governance innovation and practical tools. The project developed a common structure to support cities in structuring regeneration processes, clarifying responsibilities, improving investment readiness, and strengthening stakeholder coordination.The structure was tested through pilot actions across ten territories, enabling comparative learning across different territorial scales and planning contexts. The ten pilot cities represent diverse governance and regeneration contexts:

Regional scale: Stuttgart (Germany): Metropolitan context with heritage-led regeneration of industrial sites, involving complex multi-level governance and stakeholder coordination. Cluj-Napoca (Romania): Big city addressing heritage reuse in historic neighbourhoods with ownership fragmentation and capacity constraints. Chișinău (Moldova): Capital city testing lifecycle governance under resource-constrained conditions and Odessa (Ukraine).

Mid-sized cities: Gabrovo (Bulgaria): Mid-sized city revitalising industrial heritage sites with limited market appetite and unclear business models. Veszprém (Hungary): Mid-sized city integrating cultural heritage with climate adaptation and public space inclusion, requiring cross-sectoral coordination. Šabac (Serbia): Mid-sized city addressing brownfield reuse with fragmented ownership and regulatory uncertainty. Cazin (Bosnia and Herzegovina): Mid-sized city with limited administrative capacity.

Small sized cities: Ravne naKoroškem (Slovenia): Small municipality addressing industrial heritage reuse in a weak market context and Virovitica (Croatia).

These pilots deliberately cover different territorial scales (metropolitan, mid-sized, micro-municipal), governance conditions (strong/weak institutional capacity, single/multi-level mandates), and regeneration challenges (heritage-led reuse, climate adaptation, industrial brownfields, inclusive public spaces). This diversity enabled comparative assessment of how lifecycle governance performs across contexts and under what conditions it is transferable.

3.2 Six-phase investment life cycle

A core component of the NONA methodology is a six-phase investment lifecycle designed as a cyclical process rather than a linear sequence. The lifecycle is inspired by Project Cycle Management frameworks used by the European Commission, World Bank, and OECD (European Commission, 2004; World Bank, 2020), but adapted specifically for urban regeneration contexts characterised by high uncertainty, fragmented governance, and complex stakeholder environments. Unlike standard PCM approaches, which assume relatively stable objectives and clear institutional mandates, the NONA lifecycle emphasises iterative feasibility validation, continuous stakeholder engagement, and staged risk reduction suited to heritage-led and brownfield regeneration challenges.

From an analytical perspective, the six-phase investment lifecycle can be understood as a governance response to recurrent implementation failures observed in urban regeneration processes. Across many European contexts, regeneration initiatives tend to fail not due to a lack of strategic vision, but because of weak sequencing, late identification of feasibility constraints, fragmented institutional mandates, and poorly structured interfaces between planning and investment decision-making (Couch et al., 2011; Tallon, 2013). Lifecycle governance addresses these failures by introducing an explicit process logic that aligns strategic ambition with staged feasibility checks, clarified responsibilities, and iterative decision gates. Rather than assuming linear progression from vision to delivery, the lifecycle framing makes dependencies and prerequisites visible at early stages, thereby reducing the risk of premature design lock-in and late-stage project blockage. In this sense, lifecycle governance operates less as a normative planning model and more as a pragmatic coordination and risk-reduction mechanism that structures how actors, evidence, and investments are progressively aligned over time.

The lifecycle supports cities in moving from identification of needs to planning, land and environmental regulation, implementation, usage, and monitoring and evaluation. Participation is embedded across phases to ensure that the investment logic remains aligned with local needs and that decisions are supported by stakeholder cooperation. The lifecycle is operationalised through structured routines as stakeholder mapping (identifying actors, interests, and mandates at each phase), evidence collection for the degraded area (ownership, contamination, heritage status, infrastructure, market conditions), feasibility checks (staged validation of regulatory, technical, financial, and governance prerequisites), milestone logic (decision gates where progression is conditional on resolving specific constraints), preparation of investor-oriented materials (structured project information packages clarifying constraints, sequencing, and long-term operational assumptions).

For heritage-led regeneration specifically, the lifecycle marks checkpoints: Phase 1 (Identification): Early heritage status assessment, preliminary ownership mapping, and identification of approval layers. Phase 2 (Planning): Structured consultation with heritage authorities, technical conservation assessments, and

alignment of heritage protection with urban planning and economic development objectives. Phase 3 (Land and Environmental Regulation): Resolution of ownership fragmentation, completion of required heritage impact assessments, and clarification of regulatory prerequisites before design lock-in. Phase 4 (Implementation): Staged implementation logic that sequences conservation interventions with contemporary adaptations, allowing for technical adjustments as uncertainties are resolved. Phase 5 (Usage): Long-term stewardship arrangements that clarify maintenance responsibilities under heritage protection regimes. Phase 6 (Monitoring and Evaluation): Feedback loops that assess whether heritage values are maintained and whether governance arrangements remain effective.

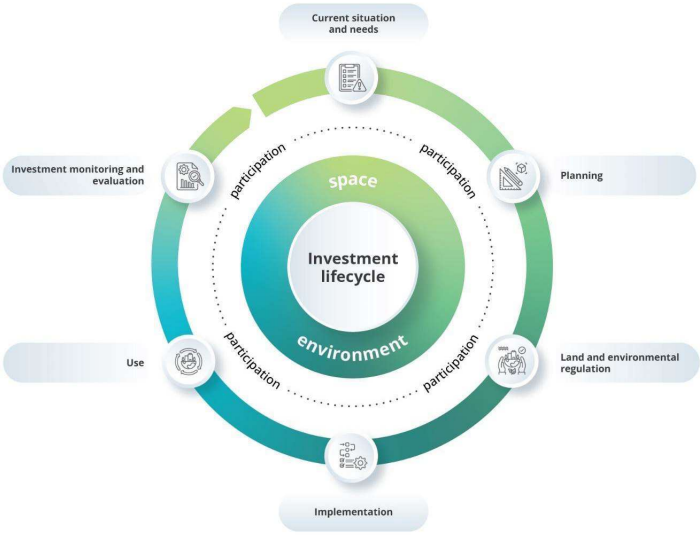


Fig. 1: Investment life cycle in the NONA methodology.

4 PILOT APPLICATION AND COMPARATIVE INSIGHTS

4.1 Methodology

This paper draws on qualitative, comparative analysis of ten pilot projects conducted under the NONA (New gOvernance for NewspAces) initiative between 2022 and 2025. The research is based on three primary data sources: (1) internal project documentation including feasibility reports, planning diagnostics, and stakeholder mappings; (2) records of participatory events and workshops held during each lifecycle phase; and (3) cross-pilot synthesis outputs produced collaboratively by local and transnational project teams.Analytical insights were generated through structured thematic coding of these materials, focusing on recurring governance challenges (e.g., sequencing failures, stakeholder fragmentation, unclear investment pathways) and lifecycle responses (e.g., feasibility checks, participation routines, decision gating). A matrix was used to compare how the lifecycle performed across different territorial scales (metropolitan, mid-sized, and micro municipalities) and regeneration types (heritage reuse, brownfield transformation, public space revitalisation). While the findings are grounded in real-world pilot implementation, they reflect early to mid-stage progress rather than completed projects. As such, the analysis emphasises process performance rather than long-term outcomes.

4.2 Pilot design and scope across territorial scales

The NONA methodology was tested across ten pilots deliberately selected to reflect different territorial scales, governance conditions, and regeneration challenges. This multi-scalar design enabled the project to assess whether a shared lifecycle governance approach can remain applicable across contexts ranging from complex metropolitan and functional urban rural settings to capacity-constrained mid-sized cities and border micro municipalities.

4.3 Pilot typologies and thematic alignment

This paper focuses on the pilot typologies that most directly inform the conference theme and the paper's argument, namely the implementation gap between European ambitions and local delivery, and the role of lifecycle governance in structuring green, inclusive, and heritage-sensitive revitalisation. Table 1 synthesises

the relevant pilot typologies by linking territorial scale to the implementation gap and to the specific governance functions supported by the NONA six-phase investment lifecycle. The typology groups are derived from cross-pilot synthesis (NONA, 2025) and reflect recurring patterns in governance challenges and lifecycle responses observed during pilot testing.

Methodological note: The pilots are grouped analytically by scale-related governance characteristics rather than by geographic location alone. Some pilots contribute to multiple typologies depending on the specific regeneration challenge addressed. For example, Stuttgart and Cluj-Napoca are classified under "functional urban and metropolitan contexts" due to multi-level governance complexity but also exhibit heritage-led regeneration characteristics. The grouping serves to highlight scale-sensitive governance patterns.

Pilot scale group	**Pilot typology (theme)**	**Pilots**	**Where the "implementation gap" shows up**	**What the NONA lifecycle supports**
Functional urban and metropolitan contexts	Multi-level regeneration and shared assets (water, land)	Stuttgart, Cluj-Napoca,	Fragmented mandates, cross-jurisdiction coordination, and uneven stakeholder urgency	Sequencing responsibilities, cooperation routines, and investor-facing clarity
Functional urban and metropolitan contexts	Heritage-led regeneration prerequisites	Cluj-Napoca, Chișinău	Approvals, technical studies, ownership, and financing uncertainty	Early-stage readiness pathway, staged risk reduction, clearer investment narrative
Mid-sized cities	Reuse of industrial assets and cultural-social infrastructure	Gabrovo, Šabac,Veszprém,	Weak project pipelines, and community acceptance issues	Structured pipeline building, participatory validation, prioritisation, and staging
Mid-sized cities	Inclusive public space revitalisation	Veszprém, Šabac, Cazin	Operational governance unclear, long-term stewardship risks	Roles for maintenance/use, co-creation across phases, monitoring, and iteration
Border micro municipalities	Industrial heritage or brownfield reuse in weak markets	Virovitica, Ravne naKoroškem	Business model uncertainty, limited investor visibility, and funding gaps	Decision-gating, phased implementation logic, investment packaging, and communication

Table 1: Scale-related constraints and added value of lifecycle governance.

4.4 Comparative findings from pilot testing

Across pilot typologies, several key insights emerged regarding how lifecycle governance functions in practice and how it addresses implementation failures. These findings are illustrated with short examples from pilot cities.

4.4.1. Integrated Governance and Cross-Sectoral Coordination

Pilot evidence confirms that sector-based planning is insufficient for complex green and heritage projects where responsibilities, externalities, and beneficiaries span administrative and sectoral boundaries. In Stuttgart, water was established as a binding spatial reference, enabling catchment-based planning that linked land use, hydrological interdependencies, and responsibilities across municipalities and institutions; this increased transparency over "impact chains" (retention–infiltration–runoff) and created early coordination points before project definition. In Cazin, a cross-sectoral coordination model between urban planning, municipal utilities, and development administration reframed a conventional public-space upgrade as a multifunctional green system (stormwater management, alternative materials, tree planting), improving feasibility through clearer sequencing and technical documentation aligned with permitting. In Virovitica, internal project teams improved inter-departmental coordination (planning–property management) and exposed the absence of city-wide integrated planning as a shared constraint, illustrating how lifecycle governance can function as a diagnostic device for fragmentation before it becomes a delivery risk.

4.4.1 From consultation to co-creation

Across pilots, the shift from one-off consultation to iterative co-creation emerged as a key mechanism for stabilising expectations and strengthening implementation capacity. In Šabac, the Local Action Group

(LAG) provided a shared governance interface that reduced fragmentation between city departments, public institutions, and external actors; co-creation outputs were progressively translated into implementation narratives through the Regional Investment Forum. In Gabrovo, the NONA Civil Society Bootcamp moved local actors from consultation to co-production and contributed to an integrated roadmap that positioned culture, ecology, and social inclusion as mutually reinforcing drivers of riverfront regeneration. In Veszprém, a stakeholder and population-survey methodology – supported by a redesigned communication strategy to counter rumors and increase willingness to engage – helped re-centre decision-making on residents' needs while keeping strategic flexibility for future investment choices.

4.4.2 Investment structuring and readiness

Pilots provide convergent evidence that investment readiness depends on timing: credible investor engagement generally requires early public de-risking, while premature 'capital seeking' without documentation can undermine credibility. In Cluj-Napoca, early involvement of financial actors (e.g., banks and EIB-linked expertise) as mentors – paired with ESG and EU Taxonomy alignments supported clearer bankability criteria and a shared "investment language", although fragmented ownership and lengthy permitting remain binding constraints. In Gabrovo, an operational phased concept (temporary–seasonal–permanent) strengthened municipal readiness by enabling testing and risk management before long-term capital commitments. In Chișinău, the lifecycle process clarified that structural assessments, heritage compliance pathways, and an operational model for phased activation are prerequisites for investor appetite in protected sites. In Veszprém, strong market interest in residential development was tempered by the pending comprehensive spatial plan, demonstrating how regulatory sequencing can delay investable packaging even where demand exists.

5 NONA ADDED VALUE AND TRANSFERABILITY

The comparative pilot testing indicates that the main contribution of NONA is not a single thematic intervention, but a repeatable governance routine that helps cities translate regeneration ambitions into implementable pathways. The six-phase investment life cycle provides a shared process logic that connects planning intent with feasibility, delivery, and long-term stewardship, reducing the risk that projects remain atthe concept level or become blocked when constraints emerge too late (NONA, 2025).

A first element of added value lies in clarifying sequencing and decision gates. By structuring regeneration as an investment life cycle, cities are supported in identifying prerequisites early, such as land and regulatory constraints, required studies, institutional roles, and realistic delivery assumptions. This improves the quality of project pipelines by making dependencies visible and by encouraging staged progression rather than one-step conceptual planning. The pilot examples (Stuttgart, Chișinău) demonstrate how this sequencing logic prevented premature design lock-in and late-stage regulatory blockage by making prerequisites explicit early.

A second element lies in strengthening cooperation through embedded co-creation. NONA treats participation as a continuous task across phases, supporting repeated moments of alignment among public actors, civil society, knowledge institutions, and private stakeholders. This helps reduce fragmentation not by institutional redesign alone, but by providing a shared process structure that clarifies when engagement is needed and what decisions it should inform. For projects involving heritage reuse, inclusive public space, and contested urban transformation, this sequencing of engagement is essential for legitimacy and long-term sustainability. The pilot examples (Veszprém, Gabrovo) demonstrate how structured stakeholder engagement across phases reduced late-stage opposition, improved long-term stewardship arrangements, and co-constructed feasible pathways that balanced community aspirations with technical and financial constraints.

A third element concerns investment readiness and risk reduction. Pilots showed that the ability to communicate a project credibly to potential funders, investors, and partners depends on clear information about constraints, governance readiness, sequencing, and long-term operation. The NONA approach supports this through structured investment packages and investor-facing communication, which helps cities present projects as staged, feasible propositions rather than isolated design ideas. Even in weaker markets or capacity-constrained administrations, this improves the basis for funding applications, blended financing, and partnership building.

Transferability, however, is conditional. The pilots also reveal persistent constraints linked to political continuity, administrative capacity, and market appetite. In metropolitan and functional urban contexts, the

main challenge is aligning multiple institutions and interests over time. In mid-sized and micro municipalities, the main challenge is maintaining continuous capacity for feasibility work, stakeholder engagement, and implementation preparation.

6 DISCUSSION: LIMITATIONS AND CONDITIONS FOR TRANSFERABILITY

6.1 Evidence-based and analytical approach

This paper is based on a qualitative comparative synthesis of NONA pilot applications. The analysis draws on pilot documentation and cross-pilot comparison materials produced during methodology testing, focusing on how governance bottlenecks and investment readiness barriers appear across different territorial scales and pilot typologies.

6.2 Interpreting the core contribution: lifecycle governance as a bridge between planning and investment readiness

A key insight emerging from the pilots is that the main barrier to implementation is often not a lack of ideas, but the absence of a shared process logic for moving from ambition to delivery.This is especially relevant in contexts where ownership issues, regulatory steps, required studies, or environmental burdens can halt a project once it is already politically and publicly announced. In such cases, the governance value lies in clarifying what must be resolved first, what evidence is required, and what institutional roles need to be formalised to reduce uncertainty.

For heritage-led regeneration specifically, the lifecycle logic addresses governance challenges that are particularly acute in these contexts layered approval processes (sequencing heritage authority consultations and technical assessments), ownership fragmentation (identifying ownership prerequisites early and staging negotiations), technical uncertainty (requiring conservation expertise and structural assessments at appropriate phases), institutional silos (creating formal coordination routines between heritage, planning, economic development, and environmental actors).

The pilots further suggest that regeneration becomes more credible when participation is embedded across phases. Stakeholder engagement that is sequenced and linked to concrete decisions can reduce fragmentation by stabilising expectations, building legitimacy, and improving coordination among public actors, civil society, knowledge institutions, and private stakeholders. This does not eliminate conflict, but it improves the capacity to negotiate trade-offs and to keep projects progressing through realistic decision gates rather than through ad hoc negotiation or late-stage opposition.

Table 2 provides the typology-oriented framing used to interpret patterns across contexts. Extracting generalisable insights from these patterns clarifies what aspects of the lifecycle approach remain stable across scales and which are more sensitive to administrative capacity or governance complexity.

These patterns suggest that lifecycle governance is transferable across scales, but requires adaptive implementation that respects local capacity, governance complexity, and market conditions. The core logic remains stable, but tools, engagement strategies, and support mechanisms must be tailored.

6.3 Critical Reflections and Transferability Conditions

While pilot applications suggest that lifecycle governance offers a promising response to implementation failures, effectiveness is conditional on enabling factors that vary by scale and institutional setting. Political continuity and administrative capacity are preconditions for sustaining feasibility work and decision-gating: in capacity-constrained contexts, early phases can stall when diagnostics, technical documentation, or mandate clarity cannot be produced at the required pace (Pritchett et al., 2013). NONA's contribution was therefore strongest where cities could institutionalise a minimum coordination nucleus (e.g., inter-departmental teams or a LAG) that persisted beyond individual events.

Market conditions and investor behaviour shaped the planning–finance interface across pilots. In stronger markets (e.g., Cluj-Napoca), early dialogue with finance actors supported bankability criteria and ESG-ready packaging, yet investors remained conditional on regulatory de-risking and predictable delivery assumptions. In weaker markets (e.g., Ravne naKoroškem; parts of Gabrovo), the lifecycle improved the credibility of grant applications and partnership building but could not substitute for systemic demand constraints; here,

"investment readiness" took the form of phased, low-regret interventions and capacity-building before larger capital commitments.

Category	Aspect	Metropolitan Contexts	Mid-sized Cities	Micro Municipalities	Cross-scale Notes
Stable across scales	Lifecycle logic	Applicable	Applicable	Applicable	Core sequencing, decision gates, feasibility checks, and engagement routines remain consistent.
Stable across scales	Prerequisites	High complexity	Moderate complexity	Lower complexity	Ownership, regulatory, technical, and financial prerequisites apply universally; complexity varies by scale and asset type.
Scale-sensitive	Coordination complexity	High (multi-level)	Medium	Lower actor number, capacity-intensive	Metropolitan settings need formal cooperation routines; smaller cities need lightweight but persistent coordination.
Scale-sensitive	Fragile phases	Phase 3 (land/regulation)	Phases 2–4 (planning→delivery)	Phases 1–2 (diagnosis/planning)	Vulnerability shifts with regulatory layers vs. internal capacity and evidence production.
Scale-sensitive	Market conditions	Stronger private appetite	Mixed	Weaker demand	Funding mixes differ: metropolitan areas can test blended finance; smaller cities rely more on public programmes and partnerships.
Scale-sensitive	Investment packaging value	High for institutional investors	High for mixed funding	High for grants/partners	Investor-facing clarity improves credibility across contexts, even where private capital is limited.

Table 2: Patterns of lifecycle governance across scales.

Finally, regulatory and procedural environments often conflicted with iterative regeneration logics. Heritage protection procedures (e.g., Chișinău) and slow plan revision cycles (e.g., Veszprém) illustrate how sequential approvals can delay even well-coordinated processes, shifting fragility to Phase 3 (land and regulation) or creating "dead time" between planning and investment packaging. Transferability therefore depends on adapting tools to local capacity (simplified checklists, external technical support) and on creating lawful pathways for temporary, reversible interventions that enable learning-by-doing without undermining conservation and accountability.

These findings align with broader urban governance literature emphasizing the importance of adaptive capacity, institutional learning, and phased implementation in managing complex urban transformations (Pritchett et al., 2013; Hodgson &Cicmil, 2006). Lifecycle governance is not a panacea, but a structured negotiation device whose success depends on its institutional embedding, technical support, and ability to adapt to local realities.

7 CONCLUSION

This paper has presented a comparative, multi-scalar analysis of the NONA project's lifecycle governance framework, designed to support the revitalisation of degraded urban areas through green and heritage-sensitive investments. Situated within the broader context of European policy ambitions – such as the Green Deal, the New European Bauhaus, and the "No Net Land Take" objective (European Commission, 2019; 2021) – the findings reinforce the persistent challenge of operationalising high-level policy objectives within fragmented, resource-constrained, and institutionally complex local governance systems (Couch et al., 2011; Pendlebury, 2013).

Drawing on pilot applications across ten Danube Region cities, the study demonstrates that a structured, iterative investment lifecycle – unlike traditional integrated planning models (Healey, 2006) or project management frameworks assuming linearity and institutional clarity (European Commission, 2004; World Bank, 2020), can serve as a pragmatic bridge between strategic ambition and implementation. Lifecycle governance addresses common failures identified in the literature, including sequencing gaps (Morris, 2013), coordination breakdowns (Ansell & Gash, 2008), and investment readiness constraints (Weber et al., 2014), by embedding decision gates, participatory routines, and feasibility logic into all stages of the process.

In heritage-led regeneration in particular, the NONA lifecycle adds distinct value by sequencing engagement with heritage authorities and technical assessments (Pendlebury et al., 2009), addressing ownership fragmentation (Tweed & Sutherland, 2007), and managing technical uncertainty (Bullen & Love, 2011). These are challenges that are generally under-served by conventional planning frameworks, which often lack mechanisms for continuous cross-sectoral coordination and early feasibility validation (Veldpaus& Pereira Roders, 2014; Hodgson &Cicmil, 2006).

Pilot findings confirm that the approach is applicable across scales, but that transferability depends on adaptive implementation aligned with local capacity and market context. As summarised in Table 2, while the core sequencing logic remains stable, capacity constraints and complexity levels shift vulnerability across phases (Pritchett et al., 2013). The pilots also echo insights from urban regeneration literature that successful delivery hinges less on having visionary plans and more on having structured processes to manage risk, negotiate trade-offs, and progressively align actors over time (Couch et al., 2011; Roberts & Sykes, 2000).

From a practical perspective, the main recommendation is to treat regeneration not as isolated planning exercises but as investment-ready, lifecycle-governed processes, where early outputs include clarified mandates, stakeholder roles, and feasibility evidence, not just design concepts. From a research perspective, further longitudinal studies are needed to track how later lifecycle phases, particularly implementation, usage, and monitoring, contribute to sustained outcomes in heritage conservation, social inclusion, and environmental performance.

Ultimately, the NONA lifecycle framework offers a replicable yet adaptable governance routine that helps cities move from fragmented ambition to feasible delivery, thereby advancing the EU's integrated, green, and inclusive urban agenda (European Commission, 2019; Decoville& Feltgen, 2023). As shown in diverse urban contexts, from Stuttgart to Ravne naKoroškem, the governance innovation lies not only in strategic alignment, but in operationalising complexity through structured decision-making and context-sensitive risk management.

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Governing the Green Energy Transition through Transformative and Collaborative Planning – the Case of Burgenland's Regional Concepts for Energy Development

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1 ABSTRACT

The transition to climate neutrality, which attempts to accelerate renewable energy generation, requires trade-offs due to the diverse demands on land use. As a consequence, early consideration of potential conflicts and transparency on the selection of type and location of energy generation, storage and distribution is key. Due to our poly-crises, we urgently need to reflect not only the necessity to orientate towards climate-neutrality but also the need to promote species and biodiversity conservation at the same time. Particularly, relevant aspects for biodiversity such as the connectivity can only be sufficiently treated at supra-local planning levels, while other indicators deserve a detailed consideration at local level (tiering).

The relevance to consider trade-offs and alternatives based on sufficient data and information by stakeholders becomes particularly evident at the regional level. The Austrian federal state Burgenland is often listed as a role model for energy transition at regional level and excellence in balancing trade-offs at earlier planning stages. Before starting with the first wind turbines in 1997, the regional self-supply share for electricity was at 1,5 %. Only 16 years later, in 2013 there was more electricity generated than used on an annual basis, evolving to up to 239 % in 2024. For 2030, the goal is to generate more clean energy (including energy for heat and mobility) than is used on an annual basis. This transition process is guided by a constantly evolving planning approach starting in 2002 which is strongly based on integrating diverse perspectives from multiple actors involved in planning.

This paper aims to describe the formal and informal involvement of stakeholders together with the planning approach as well implications for the consideration of biodiversity and landscape aspects. As a preliminary study, it examines the extent to which the planning approach affects the quality of the basis for decision-making and conflict minimisation with focus on biodiversity and landscape. In this context we investigated whether this iterative and collaborative planning approach with direct interlinking of SEA with zoning planning leads to a more comprehensive consideration of decision-relevant data bases and also to greater acceptance of local decision makers and citizens. Based on case study research and document analysis, the paper highlights achievements of this planning approach and outlines points for improvement. Our investigations serve as a pre-study for the Biodiversa+ project BIOGAIN, which deals with transformation towards biodiversity net-gain in strategic spatial planning for renewable energy development through a strongly transdisciplinary research approach and investigating the role of novel AI supported data collection and analysis in diverse planning contexts.

Keywords: Collaborative Planning, Green Energy Transition, Biodiversity Net Gain, Regional Governance, Urban Planning

2 INTRODUCTION

To tackle the challenges of decarbonisation and – as an important part of it – the transformation of the energy system is one of the most challenging tasks we face at present. Challenges refer to conflicting objectives regarding land uses leading to implications on e.g. biodiversity, human health, recreation or food security. The role of spatial planning is amongst others to provide land for energy generation facilities like wind park and PV installations and balancing trade-offs at the same time. The few experiences and fast technical development of wind turbines and PV-systems make this task challenging with the need to create a 'learning process' that can improve over time. Particulary, interrelationships between diverse types of renewable energy developments and consequences for biodiversity are still underresearched.

With experience in strategic planning for renewable energy systems since 2002, Burgenland is Austria's pioneer state in this field of spatial planning. It was the first federal state in Austria, where wind power

development took place at large scale and where spatial effects were addressed in a systematic way. Due to its rapid growth and expected land use related conflicts, the development of the energy sector became a spatial planning issue.

In Burgenland the energy transition claims a huge amount of space (3.000 ha zones for PV, 9.500 ha zones for wind parks), which is not directly comparable to any other spatial planning tasks with a comparable demand of land before. Impacts on biodiversity have become particularly relevant with regard to connectivity, particullarly when energy production meets linear infrastructure such as railway or highway infrastructure. Sandfort et al. (2025) demonstrated that renewable energy developments affect established animal corridors as they provide the reliable distance from settlements. This is particularly relevant as suitable spaces are challenging to find in case of extensive renewable energy expansion. Both the installation of power plants as well as the mitigation and compensation of negative impacts has required intensive amounts of land. In order to coordinate this, site selection processes and facilitate them with the appropriate data a large number of actors has been involved. Consequently, knowledge transfer and acceptance became crucial elements of the planning processes.

Considering the multiple pressures on land and the decline of biodiversity at the same time, a knowledge-based decision-making based on sound biodiversity data as well as learning from monitoring processes becomes key (Diaz et al., 2019). Net-gain policies, introduced by the EU legislation, will even more require a coordinated, strategic planning approach based on usable data and well-organized data sharing processes. Particuluarly then when we target biodiversity net-gain planning, the transparency between the rational ground for decision making and the value-tradeoffs becomes essential.

Based on the analysis of the strategic spatial planning process for renewable energy development in Burgenland so far, this paper reflects the formal and especially the informal involvement of diverse groups of actors in the integrated planning approach with SEA in light of their contribution to biodiversity data sharing as well as knowledge transfer. Against the background of planning theories – the collaborative planning approach (Healey, 1997) and the rational-collaborative planning model (Stoeglehner, 2010) – we discuss the implications of the integration of actors and their role and knowledge contribution.

Core research questions are i) which actors are involved throughout the strategic spatial planning process for renewable energy development in Burgenland so far and ii) how far their involvement influences the data sharing and knowledge transfer in the field of biodiversity and landscape. Finally, we want to discuss as a preliminary study, how far the experiences from Burgenland can provide a basis for learning in a transformative planning approach which focuses not only on compensation but also on the advancement of biodiversity in light of a net-gain planning approach.

Based on case study research including observations of one author and reflexive dialogue with the other authors, combined with document analysis, the paper highlights achievements of the planning approach taken in Burgenland and outlines relevant needs for improvement. Finally, we discuss entry points for additional data deriving from novel sources such as AI supported automated data collection. Our investigations serve as a pre-study for the EU-Biodiversa project BIOGAIN, which deals with transformation towards biodiversity net-gain in integrated spatial and energy planning through a strongly transdisciplinary research approach and investigating the role of novel AI supported data collection and analysis in diverse planning contexts.

3 BACKGROUND – THEORETICAL CONCEPTS OF PLANNING APPROACHES IN LIGHT OF GREEN ENERGY TRANSITION

Integrated spatial and energy planning has been a highly dynamic planning field with different approaches in all Austrian federal states. To discuss the contribution of formal and informal involvement of different groups of actors we introduce two theoretical planning concepts:

Dating back to the nineties of the previous century Healey (1997) explored planning as a collaborative governance process. According to her approach, planning should be organized as an inclusive, deliberative process that enables collective action across public agencies, private actors, and civil society. In this context, several authors discussed therewith how planning can be reframed away from top-down technocratic control towards communicative, dialogic practice grounded in public reasoning (Gunton and Day, 2003; Linnenluecke et al., 2017).

The concept after Healey (1997) includes the following key points:

- Communicative rationality: legitimacy and quality of decisions depend on open, inclusive discourse and reason-giving among stakeholders
- Institutional capacity: comprising knowledge resources, relational resources (trust, networks), and mobilization capacity
- Place and path dependency: effective planning engages local narratives and path dependencies to co-produce context-sensitive strategies.
- Strategy-making as iterative: Emphasis on iterative, reflexive 'strategy making' rather than fixed master plans, with experimentation, feedback, and learning.
- Power and inclusion: Process design must recognize power asymmetries and broaden inclusion so marginalized groups can influence outcomes.
- Governance focus: Planning is embedded in multi-actor governance networks; the task is to create arenas and interfaces for negotiation and coordination across sectors.

Several authors discussed the collaborative planning approach over the past three decades and developed it further in different thematic fields and planning contexts (e.g., Van Dijk, 2021 or Conzales and Connell, 2022). Already fifteen years ago, Stoeglehner (2010) introduced the rational-collaborative planning model, which combined the rational (facts, analysis) "level of facts" and collaborative (values, participation) strengths "level of value" as two essential components of planning. This approach outlines the importance of a sound information basis, and transparent aggregation rules to link values and facts (Stoeglehner, 2010).

More recent publications such as Jiricka-Pürrer and Stöglehner (2025) discuss the relevance and challenges of recognizing trade-offs with a focus on strategic planning contexts like integrated spatial and energy planning. In this context, the importance of a sound information basis as well as the risk of unperceived biases related to trade-offs becomes even more evident. Applying a rational–collaborative planning paradigm targets to increase transparency on values, and foster traceable aggregation rules for judging environmental significance.

In the field of impact assessment, a variety of scholars such as Cashmore and Richardson (2013) or Hansen et al. (2013) dealt with power relationships related to collaboration and actors' involvement. Partidario et al. (2023) elaborated further the discussion how decision-makers connect values and facts, influenced by power relation and actor constellations in an environmental assessment.

4 METHODOLOGICAL APPROACH

Our approach focuses on case study research (Yin, 2018), combining observations of one author with document analysis and reflective discurse with the co-authors against the background of planning theory. In the following we explain first our methodological approach for this preliminary study and then summarize the case study area's development in strategic spatial planning for renewable energy development.

4.1 Case study research

Due to his longterm experience in strategic spatial planning for renewable energy development, the first author had the ability to reflect from its personal experience and participation, the development of strategic spatial planning for renewable energy development over more than a decade. His involvement comprised the regional framework concepts as well as detailled examination for wind energy zones as expert reports from 2011 to 2021 as well as the following planning and assessment processes for the ordinance on wind energy zones with its amendments including the respective SEAs. For solar power development he contributed to both the generel guidelines for ground-mounted PV systems including the drafting of the criteria-set for planning and assessment of the zones. Furthermore he was involved in the planning and assessment processes for the ordinance on solar energy zones with its amendments including the respective SEAs.

With his background in spatial planning and a professional experience in environmental assessments, he contributed to the analysis of data sharing related to the procedural involvement of different groups of actors. Advances of strategic spatial planning for renewable energy development through careful site selection under the consideration of diverse needs and land use demands, is part of his PhD.

In this study his research focuses on the integration of biodiversity data. Due to his past responsibilities in developing environmental reports for the zoning planning in Burgenland for both wind and solar energy, he has the ability to not only reflect the documented outcome (see also 4.2) but also the procedural data collection processes as well as the involvement of different groups of actors.

The last author served as an independent counterpart for reflection with an extensive experience in environmental assessment both from research and practice in other fields of EA, providing structured feedback for the analysis of the planning process in order to question the related stakeholder involvement against the conceptional literature background of power dynamics and decision making in environmental assessments. Both developed this contribution – together with input from the third author – in an iterative, discursive process against the literature background on planning theory as well as literature on power dynamics related to stakeholder involvement.

4.2 Literature-supported analysis of planning documents

As a basis for discussion, the planning documents on strategic spatial planning for energy development in Burgenland have been taken into account.

For wind energy, zoning there are seven regional framework concept dating from 2002 to 2020 with 35 detailed examinations on municipal level, all conducted as expert report. Since the setting of a legal basis in 2022, there is an ordinance with currently 2 amendments and the corresponding environmental reports:

- Festlegung von Windkraft-Eignungszonen 2022. Integrierter Umweltbericht und Erläuterungsbericht. 2022
- Änderung der Verordnung, mit der Windkraft-Eignungszonen festgelegt werden. Integrierter Umweltbericht und Erläuterungsbericht. 2023
- Änderung der Verordnung, mit der Windkraft-Eignungszonen festgelegt werden. Integrierter Umweltbericht und Erläuterungsbericht. 2023
- For solar-PV zoning, there is an ordinance with currently four amendments in power and one in public consultation. The corresponding environmental reports were analyzed for this study:
- Verordnung mit der Eignungszonen für die Errichtung von Photovoltaik-Freiflächenanlagen im Burgenland festgelegt werden. Integrierter Umweltbericht und Erläuterungsbericht. 2021
- Verordnung mit der Eignungszonen für die Errichtung von Photovoltaik-Freiflächenanlagen im Burgenland festgelegt werden. Integrierter Umweltbericht und Erläuterungsbericht. 2022
- Änderung der Verordnung, mit der Eignungszonen für die Errichtung von Photovoltaik-Freiflächenanlagen im Burgenland festgelegt werden. Integrierter Umweltbericht und Erläuterungsbericht. 2023
- Änderung der Verordnung, mit der Eignungszonen für PV-Freiflächenanlagen festgelegt werden. Integrierter Umweltbericht und Erläuterungsbericht. 2023
- Änderung der Verordnung, mit der Eignungszonen für PV-Freiflächenanlagen festgelegt werden. Integrierter Umweltbericht und Erläuterungsbericht. 2024
- Änderung der Verordnung, mit der Eignungszonen für PV-Freiflächenanlagen festgelegt werden. Integrierter Umweltbericht und Erläuterungsbericht. 2026

Additionally, all the insights out of action research and scanning of the planning documents were double-checked with the corresponding entries in the Austrian Spatial Planning Reports (ÖROK, 2005; ÖROK, 2008; ÖROK, 2012; ÖROK, 2015; ÖROK, 2018; ÖROK, 2021; ÖROK 2024).

4.3 Description of the case study area – evolution of regional concepts for energy development in Burgenland

Historically, the federal state of Burgenland was the only region in Austria without any substantial generation of electricity. Until 1997 the share of regional self-supply was constantly below 2 % (STATISTIK AUSTRIA, 2025a), whereas even the Austrian capital Vienna, which is a federal state on his own, accounts 75 % in average from 1988-2024 (STATISTIK AUSTRIA, 2025b). It is therefore not

surprising that the provincial government seized the opportunity to take advantage of the technical and economic development of wind power together with the exceptionally good wind potential in the sparsley populated areas of Northern Burgenland and promoted the first-time-possible generation of electricity in a larger scale within state's borders. Soon after the construction of the first turbines, it became clear, that the dynamic development of wind power needs to be managed on a strategic level (ÖROK, 2005).

4.3.1 Wind power development

In 2002, the first regional framework concept for wind power development ('Regionales Rahmenkonzept für das Nördliche Burgenland') was elaborated. This concept presented general strategies and evaluation criteria as a basis for further approval processes of future wind parks. Furthermore, the area of 13 municipalities was investigated and six suitability zones as well as exclusion zones were designated. (ÖIR, 2002). Soon after the first concept, in 2004 a spatial extension to another nine municipalities was added (Regionales Rahmenkonzept für Windenergieanlagen Im Mittelburgenland und um Eisenstadt, 2004), resulting in then zones for 190 wind turbines (ÖROK, 2005). Both of them had the status of an expert report, without legally binding effect, but served as a technical decision basis in the approval processes (ÖROK, 2008). Since then, a number of revisions and extensions were elaborated.

A major revision and extension of the regional framework concepts for wind power development was elaborated in 2010 (ÖIR, 2010a; ÖROK, 2012). Not only, the evaluation criteria was adjusted to technical wind turbine development, but also a voluntary strategic environmental assessment was carried out, taking into account the cumulative effects of the planned development and serving as a basis of information for the neighbouring countries Hungary and Slovakia (ÖIR, 2010b). Reflecting one decade of strategic regional framework concepts for wind power development, two insights became clear: i) an assessment of individual turbines needs the broader regional context to be considered, and ii) for a comprehensive assessent of such a major intervention as wind parks, a sound regional basis involving all specialist departments and experts is necessary (ÖROK, 2012). In 2015, the first strategic concept for repowering of wind parks was elaborated, regulating the renewal of old wind turbines (ÖIR, 2015).

From 2002 until 2022, a total area of approximately 8.000 ha was designated as suitability zones for wind power, of which appr. 7.500 ha are to be counted as used. All of them based on the status of an expert report without legally binding effect. It took until 2022 until legal regulation of wind power development in the federal state of Burgenland was passed (Burgenländisches Erneuerbaren-Beschleunigungsgesetz - Bgld. EbBG, LGBl. Nr. 42/2022). Since then, suitability zones as well es exclusion zones for wind power development are continuously assessed in a legally binding process.

As of February 2026, 9 zones with a total amount of appr. 1.500 ha is designated by ordinance, all of which either already have wind turbines installed or are at least in the approval process. Additionally, appr. 8.000 ha of zones based on expert reports still host 415 wind turbines.

4.3.2 Large scale PV development

In the light of strong development pressure regarding ground-mounted PV-installations in the early 2010s, the federal state of Burgenland elaborated a general guideline for PV in 2013, called 'Photovoltaikanlagen auf Freiflächen. Rahmenrichtlinien für das Burgenland' (ÖIR, 2013). The aim of this guideline was to coordinate the spatial requirements of the PV expansion – especially with nature conservation – and thus raise the acceptance of installing ground-mounted PV-systems (ÖROK, 2015). Nevertheless, due to legal and economic development – subsidies for ground-mounted PV had been cancelled and feed-in tariffs had fallen sharply – the expected development did not take place.

In 2020, the guidelines have been evaluated and updated in line with current energy and climate targets and technical innovations. The 'Rahmenrichtlinie Photovoltaikanlagen auf Freiflächen für das Burgenland 2020' (ÖIR, 2020) provided a framework for the process and assessment criteria for zoning, planning, and construction of ground-mounted PV-systems and served as a basis for administrative proceedings in land-use planning and plant approval (ÖROK, 2021).

Based on the guidelines as a technical basis, an amendment of the provincial spatial planning act (Bgld. RPG 2019), announced as Burgenländisches Erneuerbaren-Beschleunigungsgesetz – Bgld. EbBG, LGBl. Nr. 42/2022, set a legally binding basis for further zoning for ground-mounted PV on provincial level. Since then, a number of changes and refinements were set in the spatial planning act. For instance, special rules

were elaborated for the direct supply of public infrastructure or industrial facilities, and for large.scale zones, there is no administrative procedure for changes in land-use plan needed on municipal level. Furthermore, since the amendment LGBl.Nr. 107/2024, the regulation also applies to thermal-solar facilities. As of February 2026, 80 zones with a total amount of appr. 3.000 ha is designated by ordinance, of which 2.600 ha are to be counted as used. Currently (February 2026), the fifth expansion of the ordinance is published as a draft bill for consultation and appraisal.

5 IN-DEPTH ANALYIS OF THE PLANNING APPROACH IN BURGENLAND

5.1 Status-quo of the planning and assessment process and analysis of actors involved

Strategic spatial planning for renewable energy development has a long history in Burgenland as sketched in section 4.1. From first informal concepts (ÖIR, 2002) to legally binding zones, the process has undergone a lot of changes, be it in its formal status, its spatial scope or the depth of planning. But still, some key principles remained the same from the beginning.

The process of defining criteria for assessment, examining only certain areas of interest instead of the whole federal state, setting mitigation measures and formulating recommendations for zoning always included relatively broad stakeholder involvement, an extensive discussion and negotiation process, the use of replicable assessment criteria and case-by-case determination of mitigation measures for each zone.

As the whole process started out of a recognized pressure and need, but without a solution already present, a lot of stakeholders from different sides were involved from the beginning.

Although the state's planning department has ever since been the owner of the process, the state environmental attorney turned out as a key player in the whole communication and negotiation process. The major challenge was to coordinate the different requirements and needs from different groups of stakeholders, thus a continuous and trustful communication with the state's nature conservation department as well as with NGOs in the field of nature conservation (like BirdLife or WWF) was crucial.

The political goal for the whole process always has been to foster renewable energy development while keeping acceptance of citizens very high. For rising local support, the municipalities in which the examination zones were located have been involved via their mayors and administrative bodies invited to planning workshops.

The developers of wind energy projects and their respective planners also have been involved in an early stage of the zoning process. What seems odd at first sight had the goal to bring in the technical perspective and also some understanding of the economic feasibility of this new kind of large-scale energy projects.

Another important principle has been, that not the whole federal state is the planning scope, but only certain parts of it, with specific interest of realizing projects. Thus, a more detailed planning procedure was possible and also the learnings could be implemented more easily in following processes.

Over the years, the process was evolving and became more and more standardized. After 20 years of strategic spatial planning for renewable energy development, finally in 2022 the legal basis was set for compulsory zoning as a prerequisite for further implementation of wind energy and ground-mounted PV-installations (Burgenländisches Erneuerbaren-Beschleunigungsgesetz – Bgld. EbBG, LGBl. Nr. 42/2022). This marked a big caesura in the development of the planning process, which which led to the current design, which is based on the following nine principles (own compilation based on ÖIR, 2025).

- The federal state's energy strategy is the basis for the whole process
- Planning is limited to specified examination zones with specific project interest
- Involvement of experts (nature conservation, legal processes, water management, cultural heritage, etc.) from administration as well as NGOs
- Early involvement of municipalities, consensus with municipalities
- Coordination of mitigation measures during zoning process with experts, municipalities and project developers
- Interconnection of zonal planning and Strategic Environmental Assessment: Consideration for protected goods already while determination of mitigation measures

- Workshops with municipalities (political and/or administrative representatives) to present and discuss zoning plans
- Zoning plans and environmental report available for public with opportunity to express their opinion before coming into force
- Determination of zoning via ordinance by the federal state (legal requirement for plant approval)

In the zoning process for the use of renewable energy, four phases can be identified: The starting phase to set the scope of the process and identify the examination zones. The planning phase for the detailed examination of all the zones including the coordination and negotiation with all relevant stakeholders. The legislative phase containing the finalisation of the environmental report, the public consultation as well as the required legal processes for the ordinance to come into force. The implementation phase, where the energy plant is approved and constructed with implementation of mitigation measures and monitoring of effects and impacts.

For a better understanding of which actors are involved to what extent in which phase, the following illustration (Fig. 1) gives an overview over the phases and stakeholder involved.

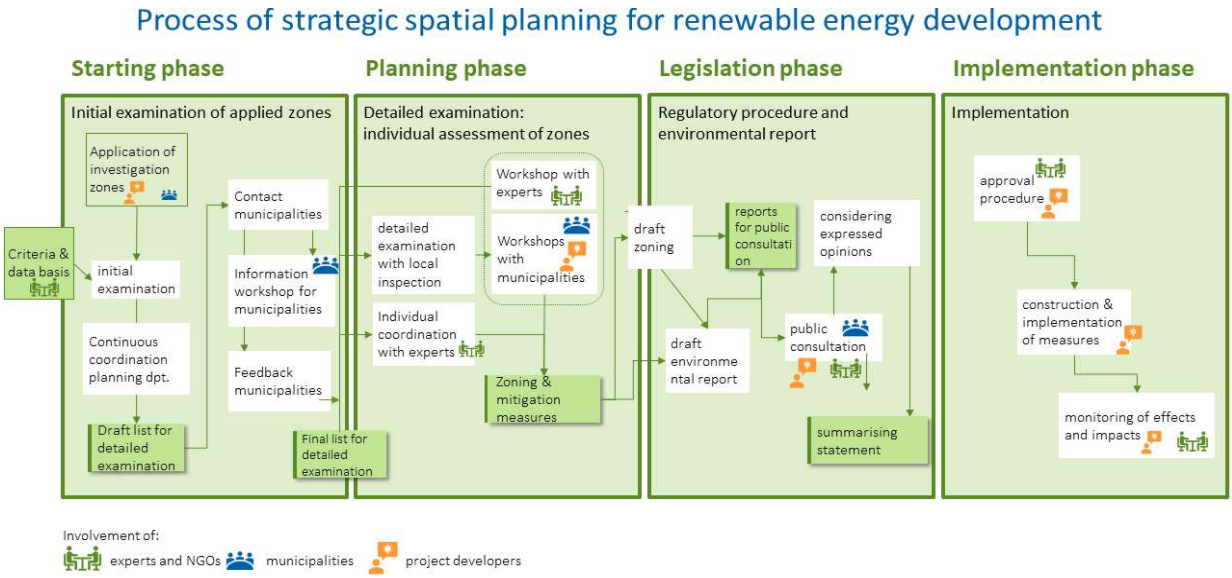


Fig. 1: Phases of the planning process and stakeholder involvement (own illustration based on ÖIR, 2025).

5.2 Reflection in light of the rational-collaborative planning model

According to the rational-collaborative planning model, there are three key aspects which have to be addressed: the 'level of facts', which stands for a well-established information base, the 'level of values' which represents a clear and agreed value system, and transparent rules about how to aggregate these two levels (Stoeglehner, 2010). In the following we reflect on the formal and particularly the informal integration of stakeholders of different groups of actors involved in the strategic spatial planning process for renewable energy development in Burgenland and implications for the consideration of biodivesity and landscape protection goals.

Against this background, two aspects will be reflected on in detail: data sharing and knowledge transfer as a contribution to the 'level of facts' as well as the systematic and transparent management of trade-offs related to conflicting interests in terms of laying the ground to the 'level of values'.

5.2.1 Analysis of data sharing and knowledge transfer in the processes with focus on biodiversity and species as well as their habitats (planning and accompanying SEA)

When coming to data, the zoning process faced two major challenges: First, and this was a special challenge in the early days, it was the fundamental question on what effects and impacts can occur when implementing large-scale renewable energy projects, and thus what data is needed for assessments of environmental impacts. Especially in the beginning, technology was new and developing very fast. Consequently, the list of relevant data and assessment criteria was elaborated step by step.

The second challenge referred to the existence and availability of data linked to these likely impacts. For the known possible effects and impacts, very little data existed ready-to-use, that could have been provided by provincial administration. For example, no state-wide biotope mapping existed. Thus, mutual learning together with institutional and stakeholder-related information, which stakeholders brought in during the process, was even more important in order to enable a corresponding factual and technical data basis. The process design with its broad involvement of stakeholders and different actors was very helpful for this. Thereby, it turned out, that not only the presence in the process is sufficient, but mutual trust is and belief in the process is crucial, otherwise there is a risk, that informal data is not provided. Transparent communication at the beginning of each zoning process and a mutual understanding of each actor's role and contribution possibilities created this confidence in the process.

Although the department of nature conservation in Burgenland had little comprehensive data on biodiversity-related topics, the individual experts have contributed a wealth of personal knowledge and experience on certain sites and special habitats that they contributed to the expert workshops. Sharing of such existing but rather general data often resulted in first assumptions which proved to be useful for further detailed non-site investigation by the planning team and cumulated to the 'zoning data base'. Examples are historical breeding sites or rarely used wildlife corridors.

BirdLife Austria, an NGO working in the field of bird protection, has been involved from the very beginning of the first development concepts, and the planning process can draw on an existing and continuously maintained database of bird observations. In addition, specific studies are being carried out as part of the zoning investigation, in which the existing data is being reviewed and supplemented. In northern Burgenland, where there is a very good existing database, high-quality results regarding birds and their habitats can thus be achieved very quickly. In central Burgenland, this broad database is lacking, meaning that the investigation process is much more complex and the results are nevertheless not as comprehensive as in the north, with many years of records. The results of the specific studies are fed back into the BirdLife-database. While different levels of citizens science and NGO data became evident across the planning scope, birds are overall still very well researched and monitored in contrast to other avian animals where less data derives from public sources and citizen science. While bird protection proved to be very important in the responsible designation of suitable areas for wind farms right from the start, it took 15 years for bat protection to be considered equally important. Bats are now the second most important species group to be included in the detailed studies.

Another important source of information were the workshops with the mayors of the respective municipalities. They knew their area best and had the opportunity to contribute their perceptions and experiences. Although most of them have not been experts in the field of biodiversity or nature conservation, they knew the history of the places and often provided important clues on specific habitats, which fostered transdisciplinary knowledge transfer that helped to put the right focus on the detailed investigations.

By involving project developers at an early stage of zoning planning and establishing good relations with them, helped to view and consider their research data e.g., deriving from monitoring of earlier energy projects or which they collect during preliminary studies for detailed plant planning and submission for approval. Although often being very detailed. nevertheless, it was crucial to check the developers' data for reliability and validity.

To sum up, the situation and handling of data in the zoning planning process in Burgenland has been highly heterogenous: General comprehensive mapping of habitats and biotopes was initially missing and planners profited strongly from informal expert knowledge queried during the workshops. Yet. a systematic structure to collect and process this information was missing. Data on bird protection was – at least for some parts of the federal state – existing in a comprehensive database maintained by the NGO BirdLife. This information was used as a baseline. As the planning and environmental assessments investigated further data during the planning process, a loop existed when this data was fed back into the database. For bats, no comparable database or continuous monitoring has existed. In this case the planning process benefited even more from, informal networks during the collaborative and iterative planning process. Data on connectivity like wildlife corridors was initially spread across different provincial and federal agencies and therefore sometimes difficult to access. Thus, data management and sharing became as relevant as the data collection itself. Based

on previous experience in the zoning process, first attempts have been made to continuously build up a database containing this information.

5.2.2 Systematic and transparent management of trade-offs

Strategic spatial planning for renewable energy development has from its beginning faced two, partly controversal objectives. On the one hand the generation of renewable energy as a contribution to achieving climate change migitation goals has been in the public interest. At the same time, Burgenland needed to safeguard nature conservation interests, which are particularly relevant due to highly valuable bird habitats like in the national park Neusiedlersee and European legal requirements linked to the habitat and bird directives across the country. Thus keeping a balance beteween all the differing, often competing claims on the use of space has been an intrinsic challenge throughout the planning process.

In order to minimize conflicts and trade-offs in zoning planning, the impact asssessment experts and planners therefore needed to select carefully the criteria needed based on the known impact chains at the planning time/stage and the available data. While the rational basis was set according to the data and its rational interpretation, the weihging of thecriteria was part of the collaborative negotiation process.

While there existed legally binding standards in some thematic fields, such as the prohibition of killing in species protection or the prohibition of deterioration in Natura 2000 habitats, stakeholders could discuss acceptable trade-offs for other topics such as the landscape appearance or the impairment of the landscape's recreational function only during the planning process. In these context the importance of the rational basis became even more evident.

Because the perception of changes to the landscape is an important factor in the acceptance of wind farms and utility-scale PV-installations (Schauppenlehner et al., 2024), particular attention has been paid to their assessment from the outset. It has proven important to make the necessary information available to the stakeholders involved in a transparent and comprehensible manner, and to design and communicate the assessment schemes in a comprehensible way. In the early stages of wind zoning, the visual impact of wind turbines was determined using dominance analyses (ÖIR, 2010). This is a method in which the proportion of the vertical field of vision occupied by the structures is used as a measure of their dominance. Only, by comparing the ratios of different wind park scenarios, the evaluation could be made understandable for all involved stakeholders.

With the onset of a certain habituation effect on wind power and the technical advancement of wind turbines, this method with its rigid measurements took a back seat and was replaced by qualitative evaluation of 3D visualizations (ÖIR, 2025). This also takes into account the significant development of rotor diameters, as it is now possible to consider not only the absolute height but also the appearance of the entire rotor. By presenting different scenarios and an expert assessment by the planning team, workshop participants (both experts and municipality representatives) could experience and discuss the different appearances. This has proven to be particularly valuable in repowering processes.

For particularly sensitive cases, such as the potential impact on the World Heritage Site Fertö – Neusiedler See, additional independent expertise was sought from BOKU university, which created a 4D-model of the study area in a landscape lab and enabled workshop participants to immerse themselves even more deeply in the modeled scenarios using VR glasses (Bittner et al., 2024). This gave even non-experts a good approximation of a changed landscape and, based on this, enabled them to weigh up the pros and cons.

By far the most frequently mentioned trade-off with PV systems is the large-scale restriction of agricultural usability of the land taken. This issue has been addressed via the conflict criterion 'use of high-quality agricultural land' and corresponding mitigation measures as the restriction to Agri-PV-systems. To gain municipalities' acceptance, it proved crucial to show the possibilities of combined land-use in the planning workshops with the municipality and convince stakeholders about its effectiveness. As agriculture and food sovereignity are important topics, there have been several cases, where municipalities first opposed against a PV-zone but where convicted as they got to know about the possibility of mandatory Agri-PV.

Zones for ground-mounted PV systems occupy large areas and therefore have the potential to cut off important migration corridors for wild animals. This kind of potential conflicts was especially difficult to assess, as the reactions, especially avoidance behaviour, were hard to predict without prior experiences with installations at this large scale. As a first mitigation measure to reduce fragmentation, most of the zones for

solar energy use only allow construction without fences. But still, discussions in workshops and with additional experts did not lead to a clear consent on how large the necessary distances should be. As a consequence, discussed examination zones nearby the internationally significant Alps-Carpathians Corridor have been deferred, and for corridors with minor significance, assumed distances have been set with the requirement of monitoring in order to gain important insights for future zones.

These examples show that knowledge about the impacts and also about the effectiveness of mitigation measures is not only essential in order to anticipate trade-offs or negative impacts, but also for a transparent, collaborative process that can be conducted on an equal footing in order to lead to a consensual value judgement of all involved stakeholders. This is where the data bases outlined in section 5.1.1 in combination with transparent assessment criteria and a proven set of mitigation measures proofed to be essential. For this reason, information workshops were held with municipalities. However, the focus of these workshops was on the process and opportunities for municipal participation, rather than on impacts in general. Often questions came up in the forefront about financial benefits for municipalities for hosting suitability zones or about opportunities for renewable energy communities.

6 DISCUSSION

The process for strategic spatial planning for renewable energy development in Burgenland has undergone many changes since its start almost 25 years ago. Starting with an idea but no specific experience and a high level of uncertainty in the field of biodiversity and landscape a broad stakeholder involvement was one of the first steps, mainly to gather information about the different needs and concerns. This was necessary, as there was no approved criteria set and comprehensive data base for assessment, which would be the precondition for a rational planning process based on objective facts (Stoeglehner, 2010).

Although, the composition of the involved stakeholders has changed over time, and knowledge on impacts and data related to renewable energy development went from individual contributors to the common process, it is still a strong element in the whole process, which not only safeguarded the consideration of different perspectives, but also has served as a strong source for information and data. The process in Burgenland shows that institutional capacity building has been able to develop shared knowledge like pointed out by Healey (1997) and foster confidence in collaboration and relationships. Our research confirmes studies such as Hansen et al. (2013) on the value of informal communication between actors at the micro-power dynamics level in the decision-making process related to the environmental assesssment. Moreover it showcases the organizational arrangements which have allowed mutual learning as in the case of the animal data reintegrated into public data bases.

One of the main characteristics of the zoning process in Burgenland was the timing of an early involvement of different kinds of stakeholders, in order to address general concerns and either resolve them or cancel planning in this area. Similar as pointed out by Partidario and Sheate (2013) multidirectional knowledge transfers among stakeholders at an early time increased the effectiveness of planning and integrated SEA. An important puzzle piece was the transparent communication at the beginning of each zoning process, so that all invited actors knew their possibilites to contribute to the process.

Planning and environmental assessments were set up as a set of incremental and iteraritve processes, concentrated on certain scopes (assessment areas) with specific project interests rather than the whole federal state. This approach triggered activity by stakeholders as the chance of implementation in the near future has been much higher than in case of a general planning concept for the whole federal state and sparked their interest in participation Furthermore, this approach provided the opportunity to deepen the planning into a more detailed level and implement learnings in the following zoning reviews.

The possbility for the municpalities to be involved, to opt out at the beginning of the process and to contribute in developing mitigation measures, together with a recognizable added value for the municipalities, led to highly accepted proecess with hardly any objections or citizens' inititives against individual projects and with wind power as part of the identity of northern Burgenland.

Nevertheless, some of the key concepts of the collaborative planning approach were missing or seem to be only partly implemented, compared to the theoretical framework. Although there is a broad stakeholder involvement, citizens were directly involved only in the legislation phase by having the possibility to express their opinion during the public consultation. Any earlier involvement of the public has been subject to

decision of the municpalities representatives Furthermore, the rather informally agreed process of participation involved the risk, that not all relevant stakeholders were involved or some got marginalized.

Overall, a rational-collaborative planning paradigm has been applied with institutionalized formats to exchange information and produce new data as a basis for planning and assessment. With regard to the rational-collaborative planning model (Stoeglehner, 2010) we see the following interesting aspects in the case of Burgenland's integrated spatial and energy planning processes become evident: The SEA was considered a meaningful and integrated part of the whole process due to its integrated nature which led to streangthening the 'level of facts' in combination with the involvment of stakeholders. No discussions which questioned the necessity of an SEA arised. The environmental objectives and respective mitigation measures could be developed and discussed throughout the planning process to meet examination criteria and to optimize the zones.

In terms of planning alternatives, via the integration of assessment in planning, the iterative process of planning and SEA targeted the development of most environmentally friendly alternatives. The planning process, however, did not allow room to consider system alternatives, as the focused zoning model did not question the clear planning task it pursued.

The incremental and iterative approach of assessing only certain zones with specific project interest thus bears the possibility, that the overarching goal of the zoning process could fade into the background. Moreover, in addition to all the advantages, the close integration of planning and assessment carries the risk of diluting the objectives of the SEA, namely minimzing impacts on biodiversity and landscape considering the whole territory. In this context, again the stakeholder involvement provided a 'corrective' in several circumstances. In the case of Burgenland the power dynamics (Partzsch, 2016) allowed actors, such as the nature conservation department of the federal government, to reiterate the importance of protected species and their habitats.

Finally, for the SEA applied at this scope, the question remained how far species that are currently less endangered will be considered with regard to interelationships between different types of energy generation (in the future). Approaching these questions, however, would prerequisite a diverse governance structure with new planning instruments.

7 CONCLUSIONS

Rational–collaborative approaches that integrate environmental objectives early and require environmentally friendly benchmark alternatives can raise environmental standards in planning. In our study we surveyed the informal integration of stakeholders in light of a rational-collaborative planning approach. Strategic spatial planning for renewable energy development in Burgenland was particularly interesting as it involves strategic long-term development with extensive demand of land with a high potential for conflicts. At the same time energy planning in Burgenland started more than two decades ago with a level of high uncertainty and little existing data particularly in the field of biodiversity and landscape.

Our contribution discussed the strategic spatial planning approach for renewable energy development in Burgenland with regard to the 'level of facts' and the 'level of values' as specified by the rational-collaborative planning model. The examples provided in the field of biodiversity and landscape illustrate the relevance of multi-face stakeholder involvement, which has contributed to both levels and allowed partly even learning of time. It points out advantages of the focus on clearly defined planning scopes but outlines at the same time its limitations.

Taking into account the implementation rate and the perceived acceptance in public, the process for strategic spatial planning for renewable energy development in Burgenland can be accounted successful so far. The informal involvement of different groups of actors lead to improvements in the field of biodiversity and landscape as illustrated in this article. Future research within the Biodiversa+ project BIOGAIN will continue to analyse the perception of these contributions to the planning process by the diverse actors themselves as well as limitations and expectations for improvement including the new abilities to foster data collection and analysis by support of artificial intelligence.

Above all, the reflection on the 'Burgenland model' can provide inspiration but cannot be applied 1:1 to other regions in Austria or internationally. Too different are the prerequisites, on the hand in terms of spatial conditions and energy potential, but even more in terms of institutional capacities and planning traditions.

This connects to challenges of case study research observed in other contexts, when testing of the first outcomes is recommended in other contexts (Yin, 2018). The transferability analysis in combination with additional empirical data collection will be part of the ongoing research in the Biodiversa+ project to identify levers for transformation towards biodiversity net-gain. Thorough analysis of data flows and prerequesits for biodiversity-net gain in combination with governance in strategic spatial planning of renewable energy development will continue this preliminary study presented herewith.

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reviewed paper

Heating with a Novel Type of Retrofitted Thermal Facade Activation and Heat Pump in a Residential Block in Vienna

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1 ABSTRACT

Decarbonisation of the building sector is a vital task to cut greenhouse gas emissions and reach Europe's climate targets. This paper presents a novel refurbishment concept which allows the substitution of a fossil-fuelled heating system with a heat pump solution via the addition of a retrofitted thermal activation of the façade for buildings dating from the 1950s and 1960s that can be implemented in full operation of the building. Furthermore, monitoring data from the heating season 2024/25 is used to establish the temporal behaviour of the heat generation system (air-to-water heat pumps), to describe the energy fluxes between various components of the heating system (heat generation, distribution and release), and to evaluate the efficiency of the heating system. The monitoring data used consists of temperature measurement data of the indoor and outdoor environment as well as the heating water flow and return temperatures and façade core temperatures. Additionally, heat meter data for various points in the heating system is used as well as electricity meter data of the heat pumps. Calculated values for amounts of heat generated are cross-validated using heat meter data where available. Results show that in comparison to the available heat meter data, the modelling approach for the thermal power quantification of the heat pumps results in overestimation which would need to be fixed by obtaining more data on the heat pumps' actual efficiency behaviour (COP) for various operating parameters. Finally, the SPF of the heat pumps was established for an observation period of approximately three weeks in January/February 2025 and was found to amount to 3.9.

Keywords: air-to-water heat pump, refurbishment, radiant systems, TABS, efficiency

2 INTRODUCTION

Heating systems using fossil fuels are responsible for approximately 17 % of Austria's greenhouse gas (GHG) emissions [BMK, 2023]. Especially older buildings in their original condition display high heating demands resulting in a higher energy consumption for heating purposes. Thermal refurbishment along with a switch to low-carbon heat generation systems and, if necessary, an adaptation of the heat dissipation systems are therefore key measures to increase the energy efficiency of a building. Especially the extension of existing heat dissipation systems poses a challenge in apartment blocks as access to the flats must be given to conduct the necessary plumbing and building work.

This paper presents a refurbishment concept for apartment blocks with a centralised heating system (one heat generation system for the entire building) that can be executed in full operation of the building and without requiring access to the residents' flats. This refurbishment concept is currently being tested in the course of a dedicated research project (*Sani60ies*, FFG project number 889521) in various test case properties, of which the pilot building located in Große Neugasse (Vienna,IV.) has been in operation and under observation via the monitoring system installed for sufficient time to provide the required data for analysis and evaluation of the heating system's behaviour and efficiency.The refurbishment concept comprises the installation of a hydronic heat dissipation system integrated into the façade from the outside, the thermal refurbishment of the building (thermal insulation applied to the cellar ceiling as well as the attic and the exterior walls) and the substitution of the existing fossil heating system with heat pumps. Details concerning the structure of the façade heating are given in the material and methods section. The measurement data used for the evaluations in this paper was collected during the winter of 2024/2025, during which time the heat generation system consisted of two air-to-water heat pumps at the stated test case building.

In this paper, the behaviour of the heat generation system is analysed by quantifying the amounts of heat produced by the heat pumps as well as the efficiency of the heat pumps in terms of their modelled *COP* and their *SPF* based on measurement data. Additionally, the monitored electrical power data of the heat pumps, the heat meter data as well as the indoor and outdoor air temperatures and the façade core temperature is

used to draw up a heat flow diagram (Sankey diagram) visualising the heat fluxes between the various components in the heating system for a selected time period.

This paper builds on preliminary work prepared for a conference paper for the 2026 IEA Heat Pump Conference (abstract no. 27) which is currently in the submission phase.

3 MATERIAL AND METHODS

The refurbishment concept and, in particular, the design of the façade heating is based on preliminary workespecially by SCHMIDT et al. [2017] and HINTERSEER et al. [2019] who suggest the retrofit of building façades either with capillary mats or multifunctional façade modules containing heating pipes. Further relevant research into radiant systems on a simulation or lab testing basis was conducted by GROß and SCHMIDT [2020], JUNASOVÁ et al. [2022], KRAJČÍK and ŠIKULA [2020], LECIEJ-PIRCZEWSKA and SZAFLIK [2024] and ZOU et al. [2025].

In this section, the case study building and the monitoring system are described and the calculations for the system analysis and evaluation are elucidated.

3.1 Case study building

The case study building is a multi-apartment block dating from 1968 and owned by the social housing association *Sozialbau AG*. It is located in Große Neugasse in Vienna's 4th district and features 2 shops and 20 flats on a conditioned floor area of 1,002 m^2. The building fabric of the external walls consists of *Durisol* bricks which are a mineralised wood wool casing filled with concrete [LEIER, 2024]. The external walls were thermally refurbished and furnished with heating pipes to form an additional heat dissipation system of the building in order to compensate for lowered heating water flow temperatures. These become necessary to ensure an efficient operation of the newly installed heat pumps substituting the old gas boiler. Fig. 1, left shows the structure of the external walls: the heating pipes (raised-temperature-resistant polyethylene pipes) are laid into channels cut into the 2 cm thick exterior render, on top of which the thermal insulation (expanded polystyrene (EPS)) is applied using dowels for fixing. The pipe gap is 30 cm (not to scale in figure). The process of the heating pipes installation is shown in Fig. 1 on the right. In total, the U-value of the exterior walls could be reduced to 0.2 W/m^{2}K instead of 0.93 W/m^{2}K before refurbishment.

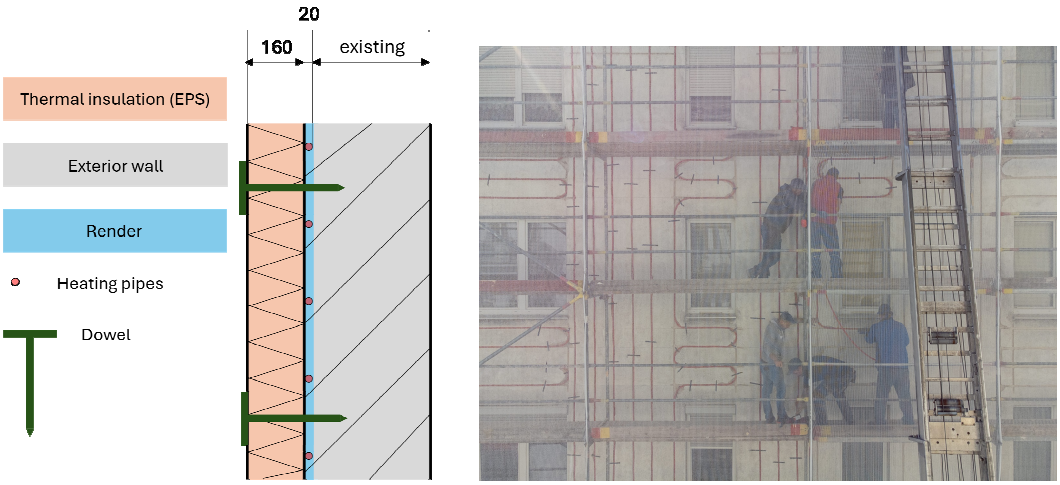


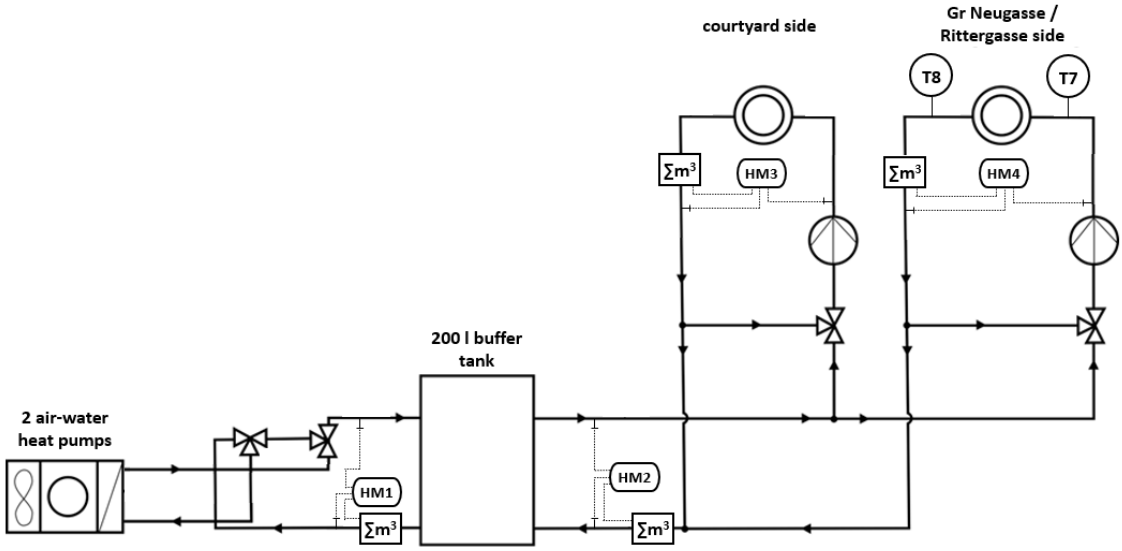
Fig.1: Structure of the external walls after refurbishment (left) and process of installing the heating pipes in the render of the façade before applying the thermal insulation (right).

The heat generation system consists of two *Stiebel Eltron* WPL-A 05 HK 230 Premium air-to-water heat pumps with an EN 14511 rated power of 5 kW at A-7/W35. These supply a buffer tank with 200 l capacity which, in turn, supplies the manifold splitting the heating water to the street and courtyard side heating loops. As indicated above, the façade heating supplements the existing radiator dissipation system. These radiators were still supplied using the gas boiler in the winter 2024/2025 and in operation throughout the heating season.

3.2 Monitoring system

To allow the detailed observation and evaluation of the installed heating system, an elaborate monitoring system was installed measuring the following parameters (all are relevant for the evaluations of this paper with the exception of the heating water flow or return temperature of each heating loop):

- Electrical power of the heat pumps
- Amount of heat transported from the heat pumps to the buffer tank, from the buffer tank to the manifold splitting the heating water into the street and courtyard side supply pipes, amount of heat transported to the street side heating loops and amount of heat transported to the courtyard side heating loops
- Heating water flow and return temperatures between the various system components in the plant room
- Heating water flow or return temperature of each heating loop to supervise presence of a water flow
- Façade core temperature at 5 locations
- Outdoor air temperature
- Indoor air temperature and humidity in one test flat



- Fig.2: Position of the heat meters HM1-4 and the PT100 temperature sensors T7 and T8 for the heating water flow and return temperature.

In particular, the electrical power $P_{el,i,j}$of the heat pumps was measured as 5 s mean values using two *Fluke* 1734 three-phase electrical power measurement loggers, the amount of heat transported between heat pumps, buffer tank and manifolds was metered using four *ista* heat meters with ultrasonic transducers and external temperature sensors and the heating water temperatures in the plant room as well as the outdoor air temperature were measured as 15 min mean values using PT100 temperature sensors.The heat meters were read locally at intervals of usually roughly one month. The electrical power loggers provide data for the period from 28th November until 6th December 2024, after which a logging gap due to technical issues with the loggers occurred which lasted until 18th December 2024. From 18th December, the issue was resolved and measurement data was again available until 17th March 2025 which is when the maximum local data storage capacity was reached.At this point, the heating season was, however, practically over due to rising outdoor temperatures. Moreover, as the datalogger collecting the 15 min mean values from the PT100 sensors had some technical issues until 22nd January 2025 resulting in logging gaps, outdoor air temperature data available as 10-minute mean values from *Geosphere Austria* [GEOSPHERE AUSTRIA, 2026] for the weather station "Wien Innere Stadt", ID: 5925 (ca. 600 m linear distance to the test case building) was used for the observation period before the indicated date. Furthermore, the only relevant measurements in the plant room for this paper are the flow and return temperature of the heating water supplied to the façade heating loops. These were only available for the street side heating loops for the winter 2024/2025 as the

sensors used for the courtyard side heating loops were relocated to measure the supply and return temperature of the radiator heating water. For the calculations described below, the heating water flow and return temperature was assumed to be the same for the entire system as both sides are operated to run on the same temperature levels (pumping and mixing units operated accordingly). The position of the heat meters and the temperature sensors measuring the flow and return temperature of the heating water of the street side is shown in Fig. 2.

The façade core temperature is measured using five PT100 temperature sensors which also log 15 minute mean values. Their location in the building façade is shown in Fig. 3.



Fig.3: Position of the façade core temperature sensors (T2-T6, green dots) on the façade in Rittergasse (left) and GroßeNeugasse (right). T1 had to be disconnected to allow the installation of the heating water flow supervision system. The red lines show the heating circuit piping.

The indoor air temperature was measured in one test flat using an *Efento* IoT data logger with a PT1000 temperature sensor. The flat is located on the top floor and looks out on to *Rittergasse* (two top left windows in Fig. 3).

3.3 Calculations

This section details the calculation methods used to establish the *COP* and heat generation of the heat pumps and visualise the heat flow in the heating system for a selected time period using the collected measurement data. Finally, the calculation method for the *SPF* quantification is presented.

3.3.1 Heat generation of the air-to-water heat pumps and COP

The momentary thermal power $\dot{Q}_{th,i,j}$per heat pump*i*per time step *j*was calculated based on their measured electrical power $P_{el,i,j}$and a calculated *COP* depending on the measured heat source (outdoor air) and heat sink (heating water) temperature $T_{source} = T_{out}$and T_{sink}:

$$\dot{Q}_{th,i,j} = P_{el,i,j} \cdot COP \quad [W] \tag{1}$$

Specifically, the*COP*for various heat source and sink conditions was calculated from the information given in the heat pumps' data sheet [STIEBEL ELTRON, s. a.] for the EN 14511 testing points. This was done by establishing the Carnot efficiency $COP_{Carnot}$for each of the three testing points A7/W35, A2/W35 and A-7/W35and then calculating the efficiency factor ζ from the COP_{Carnot} and the stated *COP* in the datasheet per test point by rearranging the following equation to give ζ:

$$COP = COP_{Carnot} \cdot \zeta = \frac{T_{sink}}{T_{sink} - T_{source}} \cdot \zeta \quad [-] \tag{2}$$

where T_{source} is the measured outdoor air temperature (+7, +2 and -7 °C for the test points) and T_{sink} is the setpoint flow temperature of the heating water (35 °C for the test points). The resulting ζ amounted to between 0.47 and 0.49 for the three given test points. Based on this, the *COP* of the heat pumps for other occurring heat sink temperatures was establishedaccording to eq. (2) by calculating the COP_{Carnot} for the three T_{source} of +7, +2 and -7 °C and assumingζ to be constant at 0.47 for all heat sink and source conditions as a worst case scenario. The other occurring setpoint flow temperatureswere determined from the heat pumps' online operation protocol (logbook) logging every change in the heat pumps' setpoints. This was used rather than temperature measurement data from the plant room due to the abovementioned logging gaps of the datalogger used. Fig. 4 shows T_{source} (*Geosphere Austria* data until 23rdJanuary 2025 00:00h and own data since then) and T_{sink} for the period of 1st December 2024 until 31st March 2026.

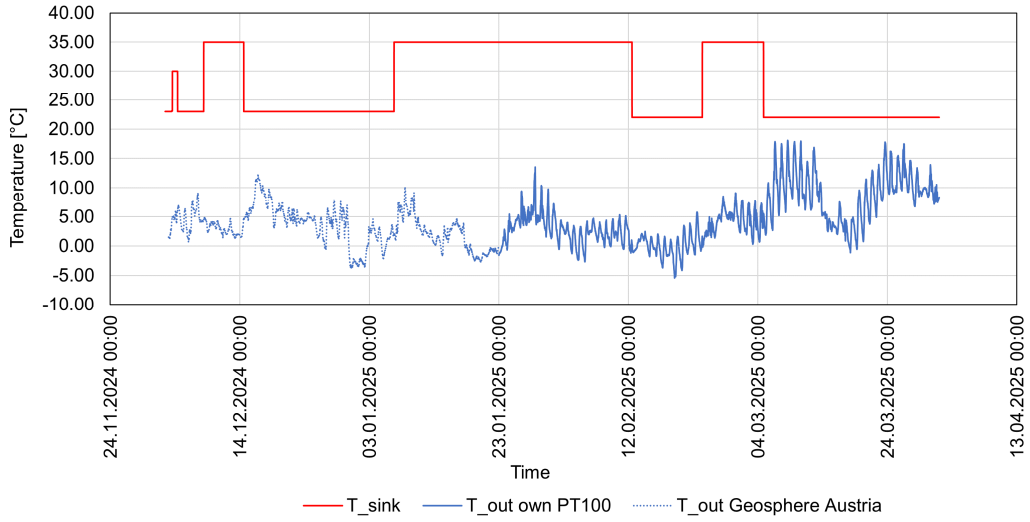


Fig.4: T_{source} (T_{out}) and T_{sink} (heating water setpoint temperature) for the time period from 1st December 2024 until 31st March 2025.

According to the heat pumps' operation protocol and as can largely be seen in Fig. 4, the occurring setpoint flow temperaturesT_{sink} amount to either 35, 30, 23.1, 23 or 22 °C. For every T_{sink}, a polynomial trend function was calculated to describe the *COP* depending on T_{source}= T_{out} (cf. alsoFig. 5 for a visualisation of the trend functions):

$$COP_{35} = 0.0026 \cdot T_{out}^{\ 2} + 0.1407 \cdot T_{out} + 4.3082 \ [-] \quad (3)$$

$$COP_{30} = 0.006 \cdot T_{out}^{\ 2} + 0.1675 \cdot T_{out} + 4.7321 \ [-] \quad (4)$$

$$COP_{23.1} = 0.0136 \cdot T_{out}^{\ 2} + 0.2875 \cdot T_{out} + 5.9727 \ [-] \quad (5)$$

$$COP_{23} = 0.0138 \cdot T_{out}^{\ 2} + 0.2901 \cdot T_{out} + 5.9958 \ [-] \quad (6)$$

$$COP_{22} = 0.016 \cdot T_{out}^{\ 2} + 0.3191 \cdot T_{out} + 6.2374 \ [-] \quad (7)$$

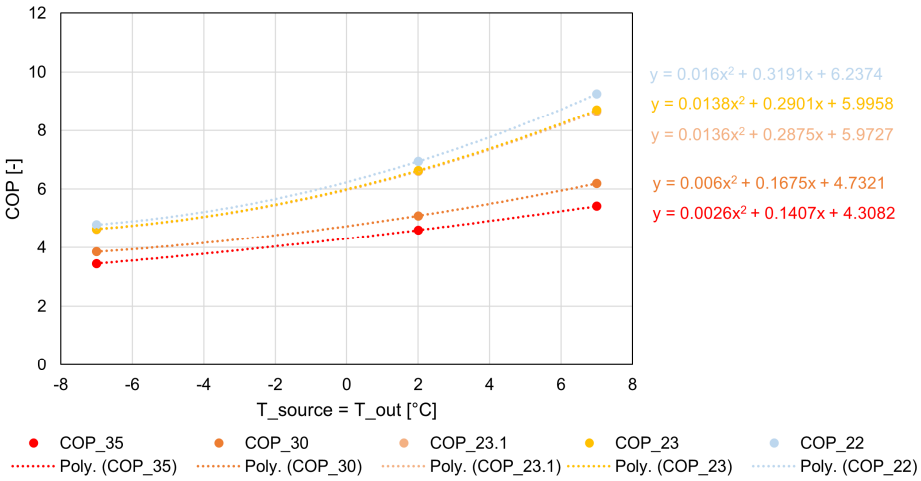


Fig.5: Trend functions of the *COP* for the various heating water flow temperatures T_{sink}.

Thus, for every time step in the evaluated period, the thermal power per heat pump $\dot{Q}_{th,i,j}$ is calculated via eq. (1) using the measured electrical power $P_{el,i,j}$ and the corresponding *COP* function taking in T_{out} according to eqs. (3-7). The amount of heat generated $Q_{th,i,j}$ per heat pump *i* and time step *j*is consequently calculated as:

$$Q_{th,i,j} = \frac{\dot{Q}_{th,i,j} \cdot \Delta t}{3{,}600{,}000} \quad [kWh] \tag{8}$$

where Δt refers to the measuring interval of 5 s. The total amount of heat generated per heat pump *i* is:

$$Q_{th,i,total} = \sum_{j=1}^{n} Q_{th,i,j} \quad [kWh] \tag{9}$$

Thus, the total amount of heat generated by heat pumps 1 and 2 is:

$$Q_{th,total} = Q_{th,1,total} + Q_{th,2,total} \quad [kWh] \tag{10}$$

The calculation of the heat pumps' thermal power and heat generation was conducted for the time period from 6th December 2024 until 17th March 2025. The start date corresponds to the date of the start of the heating mode of the heat pumps and the end date corresponds to the day where the maximum local data storage capacity of the electrical power meters was reached. Due to rising outdoor air temperatures, the heating season was, however, de facto over and the façade heating was operated at very low temperatures (22 °C) until 24th June 2025 which was the day on which the cooling mode for the summer was started. For the calculations of this section, the measurement data not given in 5 s intervals (temperature measurement data) was restructured to match the 5 s intervals of the electrical power measurement data.

3.3.2 Amount of heat transported between the various heating system components

For this, an observation period from 22nd January until 4th February 2025 was chosen as this is a period where all necessary data was available. For the amount of heat generated by the heat pumps, see section 3.3.1. The amount of heat transported to the buffer tank was read from heat meter HM1, see Fig. 2. The difference between the heat generated by the heat pumps and the heat meter data was put down as losses as well as imprecision of the model used to calculate the thermal power of the heat pumps. Furthermore, the heat losses of the buffer tank were calculated as the difference between the amounts of heat measured by the two heat meters on the generation (HM1) and dissipation side (HM2) of the buffer tank. The amount of heat transported to the manifold was calculated as the sum of the amount of heat read from the heat meter metering the courtyard side (HM3) and the amount of heat read from the meter metering the street side (HM4) of the heating circuits. The losses between the buffer tank and the manifold were calculated as the difference in amounts of heat between the buffer tank dissipation side heat meter (HM2) and the manifold (HM3 + HM4). For the last stage in the flow chart, the amount of heat transported to the indoor and outdoor environment ($Q_{facade,in}$and $Q_{facade,out}$) was calculated based on the method employed by SCHNEIDER [2025] for the cooling mode which was adapted here for the heating mode. This method establishes the heat fluxes from the façade heating into the indoor and outdoor environment ($\dot{Q}_{facade,in}$and $\dot{Q}_{facade,out}$) as follows:

$$\dot{Q}_{facade,in} = U_{in} \cdot A_{facade} \cdot \left(\bar{T}_{sys} - T_{in}\right) \quad [W] \tag{11}$$

$$\dot{Q}_{facade,out} = U_{out} \cdot A_{facade} \cdot \left(\bar{T}_{sys} - T_{out}\right) \quad [W] \tag{12}$$

where U_{in} and U_{out} refer to the U-value of the wall layers between façade heating pipes and indoor or outdoor environment of 0.97 W/m^{2}K and 0.25 W/m^{2}K, respectively.A_{facade} refers to the activated façade area of 569.6 m^2, T_{in} and T_{out} to the indoor and outdoor air temperature and $\bar{T}_{sys}$ to the mean system temperature of the façade heating which was calculated as:

$$\bar{T}_{sys} = \frac{T_{flow,GrNeu} + T_{return,GrNeu} + \bar{T}_{facade}}{3} \quad [°C] \tag{13}$$

where $T_{flow,GrNeu}$and $T_{return,GrNeu}$ refer to the flow and return temperature of the façade heating measured by T7 and T8 in Fig. 2 and $\bar{T}_{facade}$ to the mean façade core temperature calculated as the arithmetic mean of the temperature measured by the five PT100 sensors shown in Fig. 3:

$$\bar{T}_{facade} = \frac{\sum_{i=1}^{n} T_{facade,i}}{n} \quad [°C] \tag{14}$$

Where $T_{facade,i}$ is the temperature measured by the sensor i and n is the total number of sensors = 5. The amount of heat transported was calculated from the heat fluxes $\dot{Q}_{facade,in}$and $\dot{Q}_{facade,out}$ similarly to eq. (8):

$$Q_{facade,in} = \frac{\dot{Q}_{facade,in} \cdot \Delta t}{3{,}600{,}000} \quad [kWh] \tag{15}$$

$$Q_{facade,out} = \frac{\dot{Q}_{facade,out} \cdot \Delta t}{3{,}600{,}000} \quad [kWh] \tag{16}$$

with Δt as the time step of 15 minutes, i.e. 900 s. Finally, the difference between the heat metered by HM3 + HM4 in comparison to $Q_{facade,in}$ + $Q_{facade,out}$ was put down as losses as well as inaccuracies of the heat dissipation modelling.

3.3.3 SPF calculation

The *SPF* was established for the time period of 10th January until 4th February 2025. This is the longest heat meter reading interval with full availability of electrical power measurement data. The best available measured heat data for the heat pumps' thermal production is that logged by HM1 between the heat pump and the buffer tank inlet. The *SPF* was thus calculated as follows:

$$SPF = \frac{heat\ \text{transported}\ measured\ by\ heat\ meter\ \text{HM1}}{E_{el,total}} \quad [-] \tag{17}$$

where $E_{el,total}$ refers to the total electricity consumption of heat pumps 1 and 2:

$$E_{el,total} = E_{el,1,total} + E_{el,2,total} \quad [kWh] \tag{18}$$

which, in turn, are calculated as:

$$E_{el,i,total} = \sum_{j=1}^{n} E_{el,i,j} \quad [kWh] \tag{19}$$

Finally, the electrical power consumption per heat pump i and time step j is calculated as:

$$E_{el,i,j} = \frac{P_{el,i,j} \cdot \Delta t}{3{,}600{,}000} \quad [kWh] \tag{20}$$

With $P_{el,i,j}$as the mean power consumption of heat pump i in the time step j and Δt as the logging interval of 5 s.

4 RESULTS AND DISCUSSION

First, the results for the heat pumps' thermal power as well as heat production are presented along with the trajectory of their momentary *COP*. Then, the results of the heat flow analysis for the time period from 22nd January until 4th February are elucidated. Finally, the *SPF* resulting for the time period of 10th January until 4th February 2025 is presented.

4.1 Heat generation of the air-to-water heat pumps andCOP

The momentary thermal power$\dot{Q}_{th,i,j}$ as well as the cumulative heat produced $Q_{th,i,total}$per heat pump are shown in Fig. 6.

As can be observed, the thermal power of the heat pumps is reduced during periods of lower heating water setpoint temperatures, such as from 14th December 2024 until 6th January 2025 or from 12th until 23rd February 2025 where the setpoint temperature amounted to 23 and 22 °C, respectively. Furthermore, the prioritisation of heat pump 2 can be observed from the data in that heat pump 1 remains inactive during periods with lower demand. The prominent spikes in the momentary thermal power especially evident from 4th March 2025 are due to the reduction of the setpoint flow temperature to 22 °C at that date together with outdoor air temperatures rising to levels permanently above 5 °C and reaching upto 18 °C, resulting in a very high *COP*; see Fig. 7. The total calculated amount of heat generated during the entire observed timespan $Q_{th,total}$amounts to 15,028 kWh. Comparing this roughly to the amount of heat metered by the heat meter located between heat pumps and buffer tank (HM1) during the period of 6th December 2024 until 25th March

2025 of 13,543 kWh, a not inconsiderable discrepancy emerges, especially taking into account the logging gaps of the electrical power meters which, if filled, would result in even higher calculated amounts of heat.

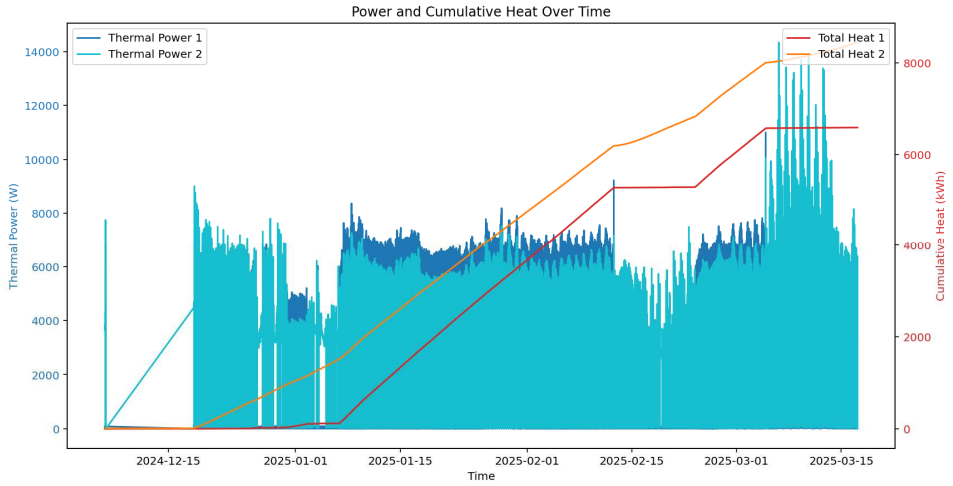


Fig.6: The thermal power provided $Q_{th,i,j}$ and cumulative heat generated $Q_{th,i,total}$ per heat pump for the timespan from 6th December 2024 until 17th March 2025.

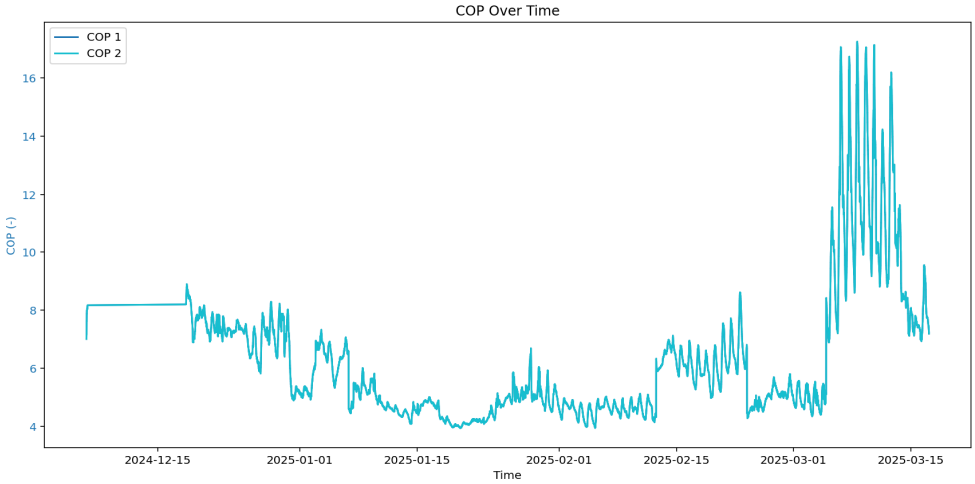


Fig. 7: The *COP* of the heat pumps for the time period from 6th December 2024 until 17th March 2025.

To give a clearer picture, a shorter time period according to a heat reading interval with full availability of electrical power data was selected and the amount of heat generated calculated. This is the period from 22nd January until 4th February 2025. The results are shown in Fig. 8.

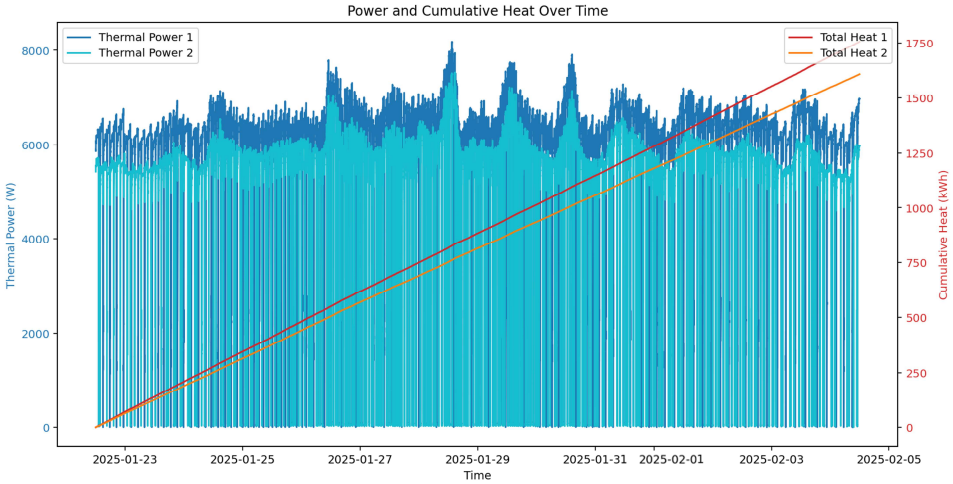


Fig.8: The thermal power provided $Q_{th,i,j}$ and cumulative heat generated $Q_{th,i,total}$ per heat pump for the timespan from 22nd January until 4th February 2025.

During this period, the heating water setpoint temperature amounted to 35 °C and the outdoor air temperature fluctuated between -2 °C and +13 °C.The *COP* fluctuated between 4 and 6.7, see Fig. 9.

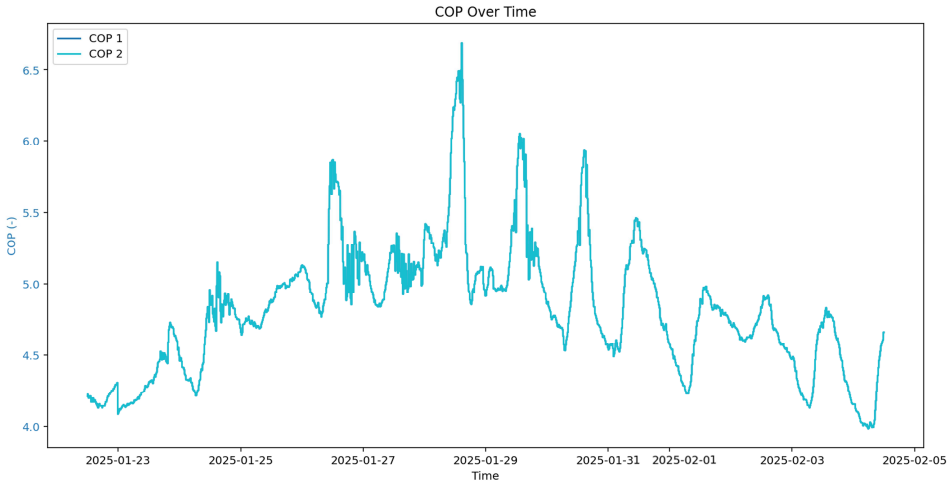


Fig. 9: The *COP* of the heat pumps for the time period from 22nd January until 4th February 2025.

During this period, the total amount of calculated heat amounts to 3,365 kWh and the amount of heat metered between heat pumps and buffer tank by HM1 to 3,142 kWh. Naturally, a certain amount of heat will be lost during transport from the heat pumps to HM1; however, as will be shown in the following section, heat losses in the buffer tank and piping are quite low for other components. A certain inaccuracy of the model must therefore be inferred.

4.2 Amount of heat transported between the various heating system components

To give a clearer picture of the amount of heat transported in the heating system, the timespan from 22nd January until 4th February 2025 with full monitoring data availability (temperature logging, heat metering and electrical power logging) was selected to visualise the observed and calculated energy fluxes. The results are shown in Fig. 10.

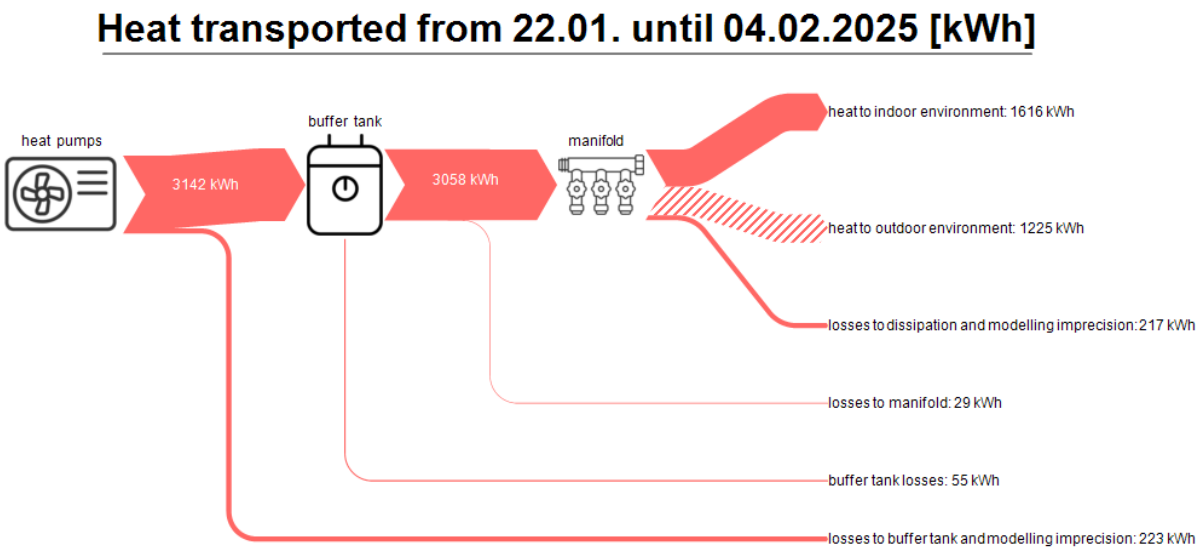


Fig. 10: Flow chart showing the measured and calculated amounts of heat transported between the various heating system components for the timespan from 22nd January until 4th February 2025.

This shows that of the 3,365 kWh produced by the heat pumps, 1,616 kWh (48 %) are supplied directly to the indoor environment and 1,225 kWh (36 %) are lost to the outdoor environment. However, the total amount of heat released via the façade activation of 2,841 kWh (84 %) contributes to the formation of a thermal barrier between indoor and outdoor environment and thus inhibits a potential heat flux from the indoor environment to the outdoor environment as long as the façade core temperature is higher than or close to the indoor air temperature. Thus, the heat flux from the façade to the outdoor environment is the price we pay for the formation of the thermal barrier. The heat losses of the buffer tank as well as of the piping

between buffer tank and manifold are relatively low which implies that the losses observed between the heat pumps and buffer tank as well as the manifold and the heat dissipation system (façade activation) are not entirely due to real losses in the piping, but also to inaccuracies of the models used to calculate the heat pumps' heat production as well as the heat release by the façade. The larger portion of the discrepancy at the heat generation end is very likely due to model inaccuracies as the pipe length between heat pumps and heat meter is rather short; however, the discrepancy at the dissipation end could indeed be mainly due to losses in the piping as the heating water travels some distance from the manifold in the plant room to the supply string at the bottom of the façade from which the individual heating circuits branch off. Various factors are likely to contribute to inaccuracies in the models used: apart from measurement errors, the assumptions made for the calculations are a source of inaccuracy. For the heat pumps' thermal power modelling, the estimation of the *COP* via the Carnot efficiency and an assumed constant ζ is, of course, a less accurate method than measured *COP* data for a larger number of testing points. Pertaining to this, also the assumption of a polynomial relationship between *COP* and heat source temperature could be questioned. For the façade heating's heat release calculation, the assumption of a uniform indoor air temperature in the entire building based on the measurement data for the only available indoor air temperature measurement device may not be representative for the entire building. Similarly, the assumption of the applicability of the heating water flow and return temperatures of the street side heating circuits to the courtyard side heating circuits must be borne in mind when interpreting the results. Overall, the largest source of inaccuracy seems to be the calculated *COP* which results in an overestimation of the thermal production of the heat pumps. This could best be rectified by establishing the behaviour of the heat pumps' efficiency via dedicated measurements.

4.3 SPF calculation

For the period of 10th January until 4th February 2025, a total amount of electricity consumed of 1,437 kWh in comparison to a measured amount of heat of 5,657 kWh was observed, resulting in a *SPF* of 3.9. This seems an acceptable *SPF* for the given heat source and heat sink conditions [ŠIMKO et al., 2024]. A slight inaccuracy in this calculation is caused by the positioning of the heat meter measuring the amount of generated heat (HM1). This is situated on the supply side of the buffer tank. Heat losses occurring in the piping between the heat pumps and the heat meter are therefore expected to result in slightly smaller amounts of measured heat than that produced by the heat pumps. However, these losses are expected to be small and bear a small significance to the *SPF* calculated.

5 CONCLUSION

In conclusion, the calculated *COP* fluctuates largely between 4 and 9 between 6th December 2024 and 17th March 2025 (with the exception of the outliers towards the end of the observation period with values of up to 17). The calculated total amount of heat generated amounts to 15,028 kWh, however, a comparison of this value to the heat meter data implies that the model overestimates the thermal power and heat production of the heat pumps. A more limited time period from 22nd January until 4th February 2025 with full availability of measurement data is chosen to evaluate the modelling approaches more closely and visualise the heat fluxes occurring between the various heating system components. It is found that the chosen modelling approach indeed overestimates the heat production of the heat pumps. The approach employed for the quantification of the heat fluxes directed from the façade heating to the indoor and outdoor environment appears to be more accurate. To counteract the thermal power overestimation, more information concerning the actual *COP* behaviour of the heat pumps would be necessary. In terms of the useful energy transported in the heating system, 48 % of the heat generated is released to the indoor environment and 36 % of the heat is lost to the outdoor environment. In terms of the total efficiency of the heat generation system, the *SPF* of the heat pumps amounts to 3.9for the period from 10th January until 4th February 2025.

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Hijacked Buildings and Emerging Forms of Informality in South Africa: Insights from Recent Urban Case Studies

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1 ABSTRACT

This paper examines the emergence of hijacked residential buildings in affluent suburbs as a new form of urban informality, using a qualitative case study of Bryanston in Johannesburg. Drawing on secondary data and informed by theories of informality as a mode of urbanisation, grey space and the Right to the City, the study shows that suburban hijackings are not isolated criminal incidents but structural outcomes of housing exclusion, weak governance of vacant property and housing financialisation. The findings reveal how informal rentalisation of high-value suburban properties provides precarious access to well-located urban space while reproducing vulnerability and exploitation. The paper argues that the suburbanisation of informality challenges spatially bounded planning imaginaries and enforcement-led responses and calls for metropolitan-wide, justice-oriented planning approaches that address vacancy, regulate informal rental markets and expand access to affordable housing in well-located areas.

Keywords: Hijacked buildings, Urban informality, Spatial justice, Housing inequality, Urban governance

2 INTRODUCTION AND BACKGROUND

Urban informality is a defining feature of contemporary cities and is increasingly understood not as a peripheral or temporary condition, but as a structural outcome of how cities are planned and governed. Critical urban scholarship argues that informality is produced through selective regulation, uneven governance, and exclusion from formal urban systems rather than through the absence of planning (Roy, 2005; Roy & AlSayyad, 2004). While informality has historically taken forms such as informal settlements and backyard dwellings, growing attention is being paid to the informal occupation of buildings. Vacant or underutilised properties, often linked to speculation, absentee ownership, or legal disputes, are increasingly repurposed as informal housing, creating concealed and hybrid spaces that blur the boundaries between formality and illegality and are sustained by fragmented governance and weak oversight (Lees et al., 2018; Yiftachel, 2009). In South Africa, urban informality is rooted in apartheid spatial planning, which excluded the majority of the population from well-located urban land and continues to shape contemporary inequality. Despite post-apartheid commitments to spatial justice, cities face persistent housing backlogs, rising costs, and limited access to affordable, well-located accommodation (Harrison & Todes, 2015; Turok & Visagie, 2018). Informality has therefore remained a structural feature of urban life, historically concentrated in informal settlements and backyard dwellings within townships (Lemanski, 2009). More recently, however, informality has begun to emerge within affluent suburban areas. In Johannesburg, hijacked buildings, once associated with inner-city decline, are increasingly appearing in well-located suburbs such as Bryanston, involving the illegal modification of high-value homes and unlawful service connections. These concealed practices challenge planning assumptions that equate informality with peripheral or deteriorated areas. This study uses a qualitative case study of hijacked residential properties in Bryanston to examine the dynamics of suburban informality and their implications for housing exclusion, governance failure, and spatial justice in South African cities.

2.1 Literature review and theoretical framework

Urban informality has been extensively examined within urban studies, particularly in relation to housing exclusion, governance failure, and spatial inequality. Early conceptualisations framed informality as a residual or transitional condition associated with poverty, rapid urbanisation, and weak state capacity. More recent scholarship has challenged this understanding, arguing that informality is not external to planning systems but is actively produced through them. Roy's (2005) conceptualisation of informality as a mode of urbanisation has been particularly influential in reframing informality as the outcome of selective regulation, uneven enforcement, and state inaction. From this perspective, informality emerges not where planning is absent, but where legality is unevenly applied across urban space. This reconceptualisation has been critical

in shifting attention away from informal settlements alone toward a broader range of informal practices embedded within formally planned environments. Informality is increasingly understood as a continuum rather than a binary, blurring distinctions between legality and illegality, and between formality and informality (Yiftachel, 2009). The concept of grey space further illuminates how certain urban practices remain tolerated, ignored, or intermittently enforced, producing spaces that are neither fully legal nor fully illegal. This theoretical framing is particularly relevant for understanding informal housing practices that occur within existing building stock, often concealed within formal neighbourhoods. A growing body of international literature examines the informal occupation of buildings as a response to housing shortages, rising costs, and speculative property markets. In cities across the Global North, including London, Berlin, Barcelona, and Athens, high levels of residential and commercial vacancy coexist with acute housing unaffordability. Scholars document how vacant or underutilised buildings, frequently held as speculative assets or entangled in legal disputes, have been informally occupied by low-income households, migrants, and homeless populations seeking access to well-located urban space (Aalbers, 2016; Lees et al., 2018). These cases demonstrate how informality can emerge even within strong regulatory contexts when housing is treated primarily as an investment rather than a social good. While some building occupations in these contexts are politically organised and linked to housing movements, others operate as informal rental arrangements mediated by unregulated landlords or intermediaries, blurring the line between resistance and exploitation (Pruijt, 2013). This distinction is important, as it complicates normative readings of informal occupation as inherently rights-based. Drawing on the Right to the City framework (Lefebvre, 1968; Harvey, 2008), scholars argue that informal occupation often reflects claims to urban space based on use and need rather than ownership. However, such claims are frequently distorted by unequal power relations and market pressures, resulting in precarious and exploitative living arrangements rather than substantive urban rights (Marcuse et al., 2009).

In the Global South, informal building occupation has long been observed alongside informal settlements, yet scholarship increasingly highlights its expansion beyond inner-city or visibly marginal areas. In São Paulo, centrally located office and residential buildings have been occupied by low-income households seeking proximity to employment and services, often governed through informal systems that regulate access, rent, and internal order (Caldeira, 2017). Similarly, in Mexico City, abandoned or partially completed apartment blocks have been informally occupied in contexts of weak enforcement, fragmented ownership, and post-disaster abandonment (Duhau & Giglia, 2008). In Indian cities such as Mumbai, informal subdivision of older buildings has intensified as formal housing becomes increasingly inaccessible, producing dense and unsafe living conditions within formally zoned urban areas (Bhan, 2016). Across both Global North and Global South contexts, several common themes emerge. Informal building occupation is closely linked to vacancy and underutilisation, particularly where housing is financialised and disconnected from social need. These forms of informality are often spatially concealed, embedded within formal neighbourhoods, and sustained through fragmented governance. Moreover, informal building occupations frequently operate as informal rental markets, where access to shelter is mediated by intermediaries who extract rent, reinforcing vulnerability rather than alleviating it. These patterns underscore Roy's argument that informality is a governance outcome rather than a spatial deviation.

Within South Africa, scholarship on informal housing has historically focused on informal settlements and backyard dwellings, particularly within townships. Backyard shacks have been widely documented as a coping strategy that enables households to generate income while accommodating those excluded from state-subsidised housing and formal rental markets (Lemanski, 2009). Planning and policy responses have largely treated such informality as spatially bounded, reinforcing the assumption that informality belongs in marginalised spaces. This framing aligns with critiques from spatial justice scholars, who argue that planning systems often reproduce inequality by normalising informality in some areas while criminalising it in others (Soja, 2010). Research on hijacked buildings in South Africa has primarily concentrated on inner-city Johannesburg, linking their emergence to deindustrialisation, white flight, property disinvestment, and the collapse of formal property management during the late apartheid and early post-apartheid periods (Beall et al., 2002; Huchzermeyer, 2011). These studies document how unlawfully occupied buildings are governed through informal and often criminal systems that regulate access and extract rent in the absence of effective state intervention. More recent evidence suggests that hijacked buildings are no longer confined to inner-city areas but are increasingly appearing in well-located suburban contexts, reflecting broader housing

affordability pressures and governance gaps. Despite these insights, there remains limited empirical work examining suburban hijacked buildings in South Africa through a theoretical lens that connects informality, governance, and spatial justice. Existing literature has yet to fully engage with how informality is shifting spatially into suburbs and what this reveals about the limits of current planning frameworks. By drawing on theories of informality as a mode of urbanisation, the Right to the City, and grey space, and situating suburban hijacked buildings alongside international experiences of informal building occupation, this study seeks to contribute to a more nuanced understanding of urban informality as a metropolitan-wide phenomenon shaped by structural inequality, vacancy, and governance failure.

3 RESEARCH METHODOLOGY

This study uses a qualitative case study approach to examine hijacked residential buildings in affluent suburban contexts, focusing on Bryanston in the City of Johannesburg as a critical and illustrative case. The study is exploratory and aims to unpack how hijacked buildings operate in suburban environments and what they reveal about housing exclusion, governance dynamics, and planning failure. Bryanston was selected due to the emergence of multiple high-profile hijacked luxury properties, which challenge assumptions that building hijackings are confined to inner-city or marginalised areas, and because sufficient public information exists to support robust analysis. The study draws on secondary qualitative data from investigative journalism, municipal documents, policy frameworks, and academic literature, which were analysed using thematic qualitative analysis combining deductive and inductive coding (Braun & Clarke, 2006). Theoretical lenses informed the initial coding, while cross-source triangulation was used to enhance analytical credibility.

4 FINDINGS AND DICUSSION

4.1 Suburban informality and the limits of planning imaginaries

A key finding of the study is the emergence of informality within affluent suburban contexts, which unsettles entrenched planning imaginaries that equate suburbs with formality, legality, and effective governance. Planning scholarship has long shown that the "suburb" is not merely a residential form but a normative project, built around assumptions of order, controlled density, private property protection and regulated access to urban services (Fishman, 1987; Knox, 2008). In many contexts, suburbs are governed through a combination of municipal regulation and privatised systems of control (e.g., security regimes, homeowners' associations, managed infrastructure), producing what some scholars describe as splintered or uneven urbanism, where services, rights, and protections are distributed unequally across space (Graham & Marvin, 2001). Within this frame, the appearance of hijacked luxury homes in Bryanston is not simply "informality in the wrong place"; it exposes the fragility and selective nature of suburban governance arrangements and the extent to which suburban order relies on assumptions of predictable ownership and continuous management. The Bryanston case also challenges the spatially bounded way in which informality is typically anticipated in planning practice. Much of the planning and housing literature, especially in South Africa, has treated informality as a phenomenon expected in townships, informal settlements, and inner-city areas shaped by disinvestment and marginality (Huchzermeyer, 2011). This has produced what Watson (2009) critiques as a persistent "informality–formality" binary in planning, where informality is handled through containment, upgrading, or enforcement in already marginalised zones, while suburban spaces are protected as sites of "proper" urbanism. The suburbanisation of informality destabilises this logic by showing that informality can be produced within formal planning regimes, not merely outside them.

Roy's (2005) theorisation is particularly useful here because it reframes informality as a mode of urbanisation and a product of governance rather than a location or sector. Seen through this lens, suburban hijackings are not anomalous but symptomatic of how urban legality is unevenly produced. Roy argues that states do not simply regulate informality; they actively construct it through selective enforcement and the normalisation of exceptions. This resonates with Yiftachel's (2009) "grey space" thesis, which emphasises that urban spaces often exist between legality and illegality, sustained by delayed enforcement, institutional ambiguity, and political calculation. The Bryanston case illustrates how suburban spaces can also become grey: properties can remain effectively "unseen" by governance systems when vacancy, absentee ownership, or weak monitoring create regulatory blind spots, until a crisis triggers sudden and forceful intervention. At the same time, the suburbanisation of informality must be read within the political economy of housing and

land. International debates on housing financialisation show how property is increasingly treated as an asset class rather than shelter, generating vacancy, absentee ownership, and disconnection between housing supply and housing need (Aalbers, 2016). When affordability crises intensify, the literature shows that informal and precarious habitation can appear in unexpected places, including within high-value neighbourhoods because access to well-located space is increasingly restricted through market mechanisms (Lees et al., 2018). In this sense, the Bryanston case is part of a broader urban contradiction: high-value suburbs may simultaneously embody wealth and become sites of concealed housing precarity when vacant properties are repurposed through informal occupation.

Critically, the visibility and politicisation of suburban informality also reveals the classed and racialised moral geographies of "acceptable" informality. Scholarship on "advanced marginality" and territorial stigma demonstrates how certain spaces become socially coded as legitimate sites for poverty and informality, while others are protected from it through intensified surveillance and boundary-making (Wacquant, 2008). In South African cities, this is amplified by apartheid's spatial legacy, where townships and informal settlements are often treated as the expected reservoirs of urban crisis, while suburbs are framed as spaces of entitlement and security. When informality appears in suburbs, it is more likely to be narrated as invasion, disorder, or criminality, rather than as a housing system failure, thereby legitimising enforcement-heavy responses and reinforcing spatial exclusion (Huchzermeyer, 2011; Watson, 2009). The suburbanisation of informality therefore exposes not only housing failure but also the limits of planning's dominant spatial imagination. It suggests that planning has often operated through a dual logic: normalising informality as a manageable condition in historically marginalised areas while treating its emergence in affluent areas as an exceptional threat. This dualism is increasingly untenable as metropolitan housing pressures intensify and as informal housing markets adapt to new spatial opportunities. The Bryanston case thus foregrounds a critical planning challenge: to move beyond spatial containment and moralised framings of informality, and to recognise suburban informality as a metropolitan-scale governance and housing question shaped by market exclusion, vacancy, and uneven regulation.

4.2 Vacancy, informal rentalisation and the production of grey urban space

The Bryanston case reveals how vacancy and informal rentalisation intersect to produce suburban grey space, transforming high-value private properties into sites of concealed informality. Vacant and underutilised homes often linked to absentee ownership, unresolved legal status, speculative holding, or long-term service disconnections, emerge as critical entry points through which informal occupation takes root. Importantly, this process is rarely abrupt. Instead, it unfolds incrementally as weak monitoring and the absence of proactive municipal intervention allow properties to be quietly subdivided, informally retrofitted, and reconnected to services over time. What initially appears as temporary or marginal illegality gradually solidifies into a stable, though informal, housing arrangement. This dynamic aligns closely with Yiftachel's (2009) concept of grey space, where urban practices exist between legality and illegality and are sustained through institutional ambiguity and selective enforcement. In suburban contexts such as Bryanston, properties are neither immediately sanctioned nor regularised; rather, they persist through tacit tolerance, delayed intervention, and fragmented governance. Suburbs are often assumed to be self-regulating through private ownership, security regimes, and zoning controls, resulting in limited proactive oversight by planning authorities. Responsibility for intervention is dispersed across departments concerned with housing, utilities, by-law enforcement, and public safety, allowing illegality to normalise until it becomes visible through infrastructural strain, safety risks, or financial loss. At that point, enforcement is intensified, often abruptly and punitively. However, the production of grey space in Bryanston is not solely a function of regulatory failure; it is also deeply tied to the informal rentalisation of vacant property. The findings indicate that hijacked suburban buildings operate primarily as informal rental housing rather than spontaneous squatting. Occupants reportedly paid rent to intermediaries who controlled access, subdivided internal space, and managed utilities, revealing a commodified form of informality embedded within private property regimes. This reflects broader debates on housing financialisation, where housing is treated as an asset rather than shelter, generating vacancy alongside acute housing need (Aalbers, 2016). In this context, informality becomes a market response to exclusion, filling the gap between unaffordable formal housing and unmet demand for well-located accommodation.

From a Right to the City perspective, these informal rental arrangements represent distorted claims to urban space. Residents seek proximity to employment, services, and infrastructure that affluent suburbs offer, yet access is mediated through precarious, marketised arrangements rather than rights-based inclusion (Lefebvre, 1968; Harvey, 2008). The right to inhabit the city is effectively reduced to the ability to pay informal rent to unregulated intermediaries, stripping it of its collective and political dimensions. Rather than democratizing access to urban opportunity, suburban informality reproduces exclusion through new spatial forms, where vulnerability is intensified by unsafe living conditions, lack of tenure security, and exposure to sudden displacement. Critically, this merged dynamic exposes a profound contradiction in planning governance. While planning frameworks emphasise spatial justice, efficiency, and sustainable land use, they offer limited mechanisms for regulating vacancy and informal rental markets within private property systems. Planning silence around speculation, absentee ownership, and the social obligations of property ownership enables the very conditions under which suburban informality emerges. Hijacked suburban buildings are therefore not simply governance failures or criminal deviations; they are products of a planning regime that tightly regulates land use while largely ignoring how property is held, left vacant, or informally commodified.

An instructive analogy is to view suburban hijacked buildings as the "backyard shacks of the affluent city"not in form, but in function. Just as backyard dwellings in townships absorb housing pressure through informal rentalisation on private plots, hijacked suburban properties absorb metropolitan housing demand through concealed subdivision and informal rent extraction within high-value homes. In both cases, informality is tolerated as long as it remains spatially and socially contained. When it breaches the moral and spatial boundaries of privilege, it is reframed as crisis, prompting enforcement rather than structural reform. This analogy underscores that suburban informality does not represent a breakdown of the urban system, but rather its adaptation, revealing how housing exclusion, vacancy, and uneven governance are redistributed across space rather than resolved. By foregrounding vacancy and informal rentalisation as central mechanisms, the Bryanston case demonstrates that suburban hijacked buildings are a critical lens through which to interrogate the limits of planning frameworks that separate land-use control from housing justice. Addressing such phenomena therefore requires moving beyond reactive enforcement toward metropolitan-scale interventions that confront vacancy, regulate informal rental markets, and expand access to affordable, well-located housing, before grey spaces harden into entrenched urban conditions.

4.3 Implications for planning, spatial justice and urban futures

Taken together, the findings reveal that suburban hijacked buildings are not anomalies but warning signals of deeper structural contradictions in South African cities. They expose the failure of planning systems to reconcile property regimes with housing justice, and the inadequacy of spatially bounded approaches to informality. For urban planning, this demands a shift from reactive enforcement toward metropolitan-wide strategies that address vacancy, affordability and access to well-located housing. This includes proactive monitoring of underutilised properties, stronger regulation of vacancy, and the expansion of transitional and affordable housing options in suburban and central locations. Without such interventions, informality will continue to adapt and reappear in new forms, further blurring the boundaries between formal and informal urban space. As a result, the suburbanisation of informality forces planners to confront uncomfortable questions about who the city is planned for, whose informality is tolerated, and whose is criminalised. Addressing hijacked buildings therefore requires not only technical solutions, but a reorientation of planning practice toward spatial justice and substantive urban inclusion.

5 CONCLUSION AND RECCOMENDATIONS

This paper has examined the emergence of hijacked residential buildings in affluent suburban contexts through a case study of Bryanston in the City of Johannesburg. Drawing on theories of informality as a mode of urbanisation, grey space, and the Right to the City, the study demonstrates that suburban hijackings are not isolated criminal anomalies but structural outcomes of housing exclusion, uneven planning regulation, weak governance of vacant property, and the financialisation of housing in deeply unequal cities. The findings reveal a significant spatial shift in informality, challenging entrenched planning imaginaries that confine informality to townships or inner-city areas. Vacant and underutilised suburban properties become grey spaces where illegality is normalised through institutional ambiguity and delayed intervention, while informal rentalisation offers precarious and exploitative access to well-located urban space. The Bryanston case exposes a central contradiction in South African urban planning: although policy frameworks emphasise

spatial justice and integration, planning practice continues to rely on spatial containment and enforcement-led responses to informality. Such approaches restore formal order temporarily but fail to address the structural drivers of suburban informality, leading to cyclical displacement and the reproduction of vulnerability across the metropolitan region. As housing pressures intensify, informality is likely to continue adapting and reappearing in new spatial forms unless these underlying conditions are addressed. In response, this paper argues for a shift toward proactive and justice-oriented urban governance. Municipalities should strengthen the monitoring and regulation of vacant and underutilised properties, including mechanisms that discourage prolonged vacancy and speculative holding. Planning and housing strategies must expand transitional, social, and affordable rental housing options in well-located suburban and central areas, including the adaptive reuse of suitable properties. Responses to hijacked buildings should be integrated across planning, housing, social development, and enforcement functions, moving beyond fragmented and punitive interventions. Finally, planners must rethink spatially bounded assumptions about informality and recognise it as a metropolitan-wide phenomenon shaped by structural inequality rather than a localised deviation. Addressing suburban hijackings effectively therefore requires not only improved regulation, but a reorientation of planning practice toward spatial justice and substantive urban inclusion.

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reviewed paper

How can the Transformative Research Methodology be Applied to Regional Governance?

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1 ABSTRACT

The transformative research methodology has become a widely recognised approach to increasing the impact of research on sustainability transitions. Methods such as real-world laboratories, experiments and interventions enable scientists, stakeholders and citizens to collaborate. However, this methodology has mostly been applied at a local level or to specific spatial issues in neighbourhoods or selected sites. This raises the question of how far the transformative research methodology could also be useful at more abstract scales, such as regions or metropolitan areas, and what adaptations or modifications would be required to contribute to regional or metropolitan governance.

In the case of the Metropolitan Region of Nuremberg, this question was addressed in the 'Climate Pact 2030 Plus' research project on the energy transition (BMFTR, 2023–2027). The Climate Pact provides an ambitious vision for regional climate policy and has set up Real World Labs in the fields of energy provision and building renovation to explore different approaches to stakeholder collaboration. Experiments and pilot projects were chosen for implementation, aiming at typological solutions that can be transferred to the metropolitan region. In addition, a monitoring and reporting tool enables reflection and evaluation.

Against the backdrop of its theoretical framework, the paper outlines the methodological approach adopted for the case study and details the experiences of its implementation during the initial phase of the project. Building on this, it considers to what extent sustainable transitions in metropolitan regions can benefit from transformative research, and which restrictions and methodological adaptations need to be taken into account to integrate it into transformative regional governance.

Keywords: metropolitan governance, regional governance, transformative research, real-world laboratory, energy transition

2 STUDY AREA: EUROPEAN METROPOLITAN REGION OF NUREMBERG

With its Climate Pact, the European Metropolitan Region of Nuremberg/Germany (EMN) has set itself the goal of promoting the energy transition and pursuing ambitious climate protection targets. The Klimapakt2030plus research project aims to develop a strategic transformation path and suitable governance and cooperation structures for energy transition and climate protection in the EMN.

The EMN was founded in 2005. In the EMN charter, the founding members laid down the rules and objectives of cooperation. The Council of the Metropolitan Region comprises eight cities and twelve districts (Standecker 2007). The development of the EMN is based on the already close interconnection of central urban axes, in particular the Nuremberg-Fürth-Erlangen chain of cities. These functional relationships, complemented by joint transport and infrastructure networks such as the Greater Nuremberg Transport Association, were important driving forces behind the growth of a polycentric metropolitan region in which Nuremberg is also the dominant centre. Since its foundation, the EMN has gradually expanded as other cities and districts have joined on a voluntary basis.

The governance structure of the EMN consists of several key elements:

- Metropolitan Region Council: This is the political decision-making body of the founding members and sets the strategic goals.
- Charter and Rules of Procedure: These define the institutional rules for cooperation, decision-making and financing.
- Specialist forums: Thematic working committees on the economy and infrastructure, science, transport and planning, culture, sport, heritage and leisure, marketing, climate protection and sustainable development. The forums are supported by initiative groups.
- Funding: The work of the EMN is made possible by contributions from local authorities, corporate donations and project funding.

The EMN is not a hierarchical governing body, but primarily functions as a network and cooperation platform. The governance of the EMN is based on voluntary participation, the principle of subsidiarity and cooperative network structures. This means that decisions are made at the local level wherever possible, while the metropolitan region itself primarily acts in an enabling and supportive capacity. It sees itself as a catalyst, moderator and supporter of regional self-organisation processes, without having any sovereign powers. Its role is to connect stakeholders, exchange experiences and facilitate joint strategies, such as in the 'Climate Pact 2030 Plus' project (Standecker 2007; European Metropolitan Region of Nuremberg 2023).

3 REQUIREMENTS FOR TRANSFORMATIVE RESEARCH AT CLIMATE PACT 2030PLUS

The research project 'Climate Pact 2030plus – Energy Transition in the Nuremberg Metropolitan Region' uses transformative research methods to support the energy transition. The project will run for five years (2023–2027) and is being carried out by a transdisciplinary research network comprising practitioners and scientists. The practitioners involved include the Nuremberg Metropolitan Region and the Nuremberg Energy Region, while the scientists include universities from the region and HafenCity University Hamburg as a partner for accompanying socio-ecological research and governance analysis. The project is funded by the Federal Ministry of Education and Research as part of its research for sustainability programme. From the ministry's perspective, Climate Pact 2030plus is a pilot project for the metropolitan region's level of action.

In view of the special spatial constellation of a metropolitan region, a number of specific conditions and requirements arise for transformative research:

- Multi-level governance: The energy transition in a metropolitan region is embedded in multi-level structures, from the municipal and district level to the metropolitan region level to state and federal policy, European guidelines and global contexts. Transformative research must therefore be designed to capture interactions and contexts at the various levels of governance. A multi-level-oriented understanding helps to uncover coordination problems between the levels and identify potential for improvement in the management of the energy transition.
- Urban-rural interdependencies: The Nuremberg metropolitan region encompasses urban centres and rural areas. Solutions in densely populated areas may differ from those in rural areas. For example, rural areas play an important role in the generation of renewable energy (wind farms, solar fields) due to their large open spaces, while urban areas are centres of consumption and innovation. Transformative research should therefore aim to highlight interactions (e.g. with regard to energy, resources, knowledge transfer) between cities and their surrounding areas.
- Implementation barriers and obstacles to transformation: Climate Pact 2030plus examines the governance of the energy transition at regional level. Barriers to implementation can be institutional (lack of responsibilities, silo thinking between sectors), socio-cultural (acceptance problems, conflicting values), economic (financing issues, distribution disputes) or technical/infrastructural. In addition, the research maps the roles of important key players (local administrations, political decision-makers, networks, industry/energy suppliers, etc.) and their power resources and interests.
- Transformative methods: As part of Climate Pact 2030plus, tests are being conducted to determine how transformative research methodology can be applied at the metropolitan regional level. This involves the use of transformation arenas, real-world laboratories and real-world experiments, among other things. The climate pact process culminates in a collective narrative for a shared future of regional development aimed at climate neutrality.

4 THEORETICAL FRAMEWORK: TRANSFORMATIVE GOVERNANCE

4.1 Fundamentals of transformation research

Transformation research deals with social change processes and the conditions under which they arise, stabilise or accelerate. In the Climate Pact 2030plus project, it serves to scientifically analyse the energy transition in the EMN and to make governance structures visible. The aim is to support decision-makers and actors in advancing the energy transition by examining ongoing processes and testing transformative control elements (WBGU 2016; Schneidewind and Singer-Brodowski 2014; Radtke and Canzler 2019). A

distinction is made between two complementary approaches. While transformation research aims to derive general system knowledge from the observation of real transformation processes, transformative research actively accompanies these processes in order to provide targeted support and gain a better understanding of them. In this understanding, transformations are enabled by social, economic and technical innovations. (WBGU 2016, pp. 20–33, also Hofmeister et al. 2021)

4.2 Role of transformation research in the Climate Pact 2030plus project

In the Climate Pact 2030plus project, overarching transformation research analyses the governance structures of the EMN in order to understand how political, economic and civil society actors interact with each other and which institutional paths promote or hinder the energy transition. At the same time, it pursues an explicitly transformative approach in the real-world laboratories: it plays a formative, cooperative and process-supporting role, without directly intervening in the governance structure of the EMN (Parodi et al. 2016). This results in a dual approach: analysis of the existing system on the one hand and experimental testing of new forms of control and transformation on the other.

The energy transition can be understood as a socio-technical transformation process that encompasses both technological and societal changes. Socio-technical systems consist of closely interwoven social and technical components that can only be changed together (Geels and Schot 2011). The transformation of a socio-technical system requires technical innovations as well as their embedding in social structures, market mechanisms and institutional frameworks.

4.3 Fundamentals of governance research

Governance research has its roots in various social science disciplines (van Kersbergen and van Waarden 2004), which makes it difficult to arrive at a uniform definition (Benz and Dose 2010). While ‘government’ refers to the system of government of a political entity, governance encompasses all processes that take place between state, private sector and civil society actors and aim to organise collective affairs (Benz and Dose 2010; WBGU 2016). Governance is thus understood as an umbrella term for the forms and mechanisms used to coordinate the interdependent actions of various actors. This includes both formal institutions, such as legal regulations and state administrative structures, and informal arrangements, such as cooperative networks (Benz and Kilper 2018, WBGU 2016, 544, 102). Governance is not understood as opposed to state action, but as an analytical framework that systematically encompasses different modes of governance, including state hierarchy, market mechanisms and civil society self-organisation. The focus is particularly on coordination and cooperation, as political control in complex fields such as the energy transition is hardly possible through hierarchical control alone (Benz and Kilper 2018).

4.4 Role of governance research in the Climate Pact 2030plus project

The accompanying research in the Climate Pact 2030plus project is based on an understanding of governance that encompasses both hierarchical governance and the participation of social and economic actors in decision-making processes. The analysis focuses on the applicable regulatory systems, institutional configurations and forms of interaction that shape the field of climate protection in the European Metropolitan Region of Nuremberg (Benz and Kilper 2018). The project distinguishes between five types of governance instruments: (1) regulatory instruments, (2) financial assistance, (3) market participation, (4) organisational instruments and (5) informal instruments.

4.5 Metropolitan regions as governance areas

Metropolitan regions develop from socio-economic interdependencies that increasingly overlap existing municipal and administrative boundaries. Due to urbanisation, changing commuter flows and economic networks, the political and administrative boundaries of many cities and counties no longer correspond to the actual functional areas. Metropolitan regions are responding to this change by forming broader territorial boundaries that better represent and organise current social, economic and infrastructural interdependencies (Yan and Growe 2022). This presents the challenge that governance cannot be focused exclusively on urban centres, but must actively integrate the surrounding peripheral areas in order to avoid regional imbalances. Concepts such as ‘communities of responsibility’ are intended to promote a new ‘spatial awareness’ that strengthens cooperation and solidarity within the region (Miosga 2007).

The governance of metropolitan regions is generally voluntary and characterised by the principle of subsidiarity. Decisions should be made as locally as possible, while the metropolitan region itself primarily assumes a coordinating role: it acts as a catalyst and moderator for regional self-organisation processes. By networking actors and exchanging experiences, it strengthens regional capacity for action, but generally without having any sovereign powers of its own (Standecker 2007; European Metropolitan Region of Nuremberg 2023). Overall, metropolitan regions are emerging as governance spaces that are characterised less by formal hierarchies than by cooperative networks. Their special quality lies in their ability to connect regional actors, enable collective problem-solving and coordinate long-term transformation processes (such as the energy transition) across institutional boundaries.

4.6 Metropolitan regional transformative climate governance

Metropolitan regional transformative climate governance can be understood as a form of governance that aims to achieve the sustainable transformation of socio-technical systems (in the Climate Pact, this refers in particular to the energy system and building stock) within polycentrically organised metropolitan areas or regions. It combines knowledge of profound social transformation processes (WBGU 2011; Schneidewind and Singer-Brodowski 2014; Radtke and Canzler 2019) with an understanding of governance that encompasses intentional forms of coordination between governmental, economic and civil society actors (Benz and Dose 2010; WBGU 2016; Benz and Kilper 2018). This form of climate governance is transformative because it aims to integrate technical, economic, social and political-administrative knowledge in order to shape knowledge-intensive processes such as the energy transition (Dewald et al. 2019). At the same time, it offers an analytical approach that takes into account institutional frameworks, stakeholder landscapes, forms of cooperation and path dependencies typical of long-term transformation processes (Czada and Radtke 2018). It is metropolitan-regional because it takes place in a space characterised by close socio-economic interdependencies, functional urban-rural relationships and the overlapping of municipal boundaries (Yan and Growe 2022; Miosga 2007).

In the Climate Pact 2030plus project, metropolitan regional transformative climate governance forms the theoretical framework for analysing and shaping the energy and climate transformation.

5 TRANSFORMATIVE METHODS

The methods of transformative research focus on various levels of action within the complex multi-level structure of the EMN.

- Steering committee. A select group of decision-makers from the metropolitan region ensures that the work of Climate Pact 2030plus is linked to real-world processes. The steering committee also acts as an interface between the Metropolitan Region Council and the expert forums, enabling the transfer of results and the adoption of the necessary resolutions.
- Transformation arenas. At the metropolitan region level, annual transformation and climate pact conferences have established transformation arenas that facilitate exchange, networking and information sharing among the stakeholders involved. They create spaces for knowledge exchange and enable discussion of implementation approaches. Participatory and co-creative working methods aim to promote interaction and activate participants.
- Transformation agenda. At the start of the project, the EMN already had a target document, the Climate Pact. This was revised in the first few years of cooperation in a collaborative working process. The Climate Pact is a joint strategy paper in which the members of the metropolitan region voluntarily commit themselves to actively promoting climate protection and the energy transition. The Climate Pact creates a common framework, formulates strategic goals and bundles the political commitments of the participating municipalities and districts. However, these are kept open enough to allow sufficient room for creativity and adaptation to changing conditions during the implementation process.
- Real-world laboratories. Two real-world laboratories, ‘Energy Supply Transformation’ and ‘Building Stock Transformation,’ were also set up at the metropolitan region level. They deal with the topics of energy and heat supply as well as building renovation. Real-world laboratories are research infrastructures in which experiments are carried out under real-world conditions (Beecroft

et al. 2018; Parodi et al. 2016). As cooperation platforms, they bring together a wide variety of actors from the respective subject areas, who jointly develop and test strategies and measures for implementing the Climate Pact. The collaboration aims to generate various forms of knowledge that contribute to transformation processes (Beecroft et al. 2018, Benz and Dose 2010): system knowledge, target knowledge and transformation knowledge. The design of the real-world laboratories provides for a variety of working methods, such as workshops, excursions and individual consultations, in order to achieve the highest possible level of transformation activity in the region.

- Experiments and experimental spaces. The implementation processes of the real-world laboratories are organised in a variety of ways and are geared towards the needs of the respective measure. This has led to the creation of sub-regional energy supply companies organised as inter-municipal cooperatives. In the field of building renovation, region-wide training events, for example for homeowners or property managers, offer solutions and attempts are being made to identify and overcome obstacles in the renovation sector. This can then be done on a small scale as a pilot project.
- Monitoring and reporting: As part of Climate Pact 2030plus, a monitoring system has been developed to track progress in climate protection and the energy transition. In addition to presenting numerical values, the monitoring system also includes reporting that showcases successful projects and measures. This is intended to encourage others to follow suit and recognise the respective project sponsors. The monitoring system differentiates between districts and independent cities, thereby helping to highlight pioneers and encouraging laggards to become more involved in climate protection and the energy transition. (Ulrich et al. 2026)

6 CONCLUSION

The Climate Pact serve as central platforms for supporting and disseminating the regional transformation processes initiated by Climate Pact 2030plus. They are key building blocks for bringing project results to the region while at the same time incorporating new ideas from practice and involving regional actors in the transformation process.

For sustainable spatial development, transformative research offers a repertoire of methods that supports co-creative processes and provides a space to move from the idea to experimental testing. Until now, these approaches have been used predominantly in small-scale contexts, such as at the neighbourhood level (e.g. Oltmann et al. 2022). The Climate Pact 2030plus research project attempts to scale these experiences to the metropolitan regional level.

The metropolitan region offers both advantages and challenges for transformative research approaches. On the one hand, the abundance of diverse actors available simply due to the size of the area is an advantage. They make it possible to identify sufficient transformation pioneers and forge innovation alliances. On the other hand, the large size of the area makes it difficult to establish the proximity and trust that are prerequisites for successful cooperation. Consequently, it is necessary to respond to the complex multi-level structure of the metropolitan region with a multi-level methodology of transformative research. Large-scale real-world laboratories play with the different levels of action, applying formats for the entire region as well as smaller-scale experiments, with the selection depending on the respective topics.

Furthermore, there are special requirements for the integration of transformation processes into metropolitan regional governance. The EMN's steering committees are also the key decision-making structures for the implementation of transformative experiments and other results of the cooperation process. This requires system knowledge in order to make use of the necessary access points and negotiation forums.

These requirements also give rise to further research questions, such as how transformative research processes can be integrated into existing multi-level structures, how urban-rural specifics affect transformation, both in terms of potential and possible restrictions, or whether the specific spatial structure of a metropolitan region – for example, centralised or polycentric – gives rise to special requirements for transformative research. And, of course, the question arises for a metropolitan region as to what extent the instruments of transformative research can permanently supplement the repertoire of regional development,

i.e. can experimental forms of governance in the context of real-world laboratories increase stakeholder cooperation and innovation dynamics selectively or even permanently?

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reviewed paper

Identifying Vulnerable Population under Heat Stress: A Data-Driven Urban Risk Assessment Using Remote Sensing, Citizen Science and Census Data

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1 ABSTRACT

Cities are increasingly confronted with rising temperatures and more frequent heatwaves, posing significant challenges for urban resilience and spatial planning. In this study, we investigate heat exposure and its interaction with social vulnerability in the cities of Augsburg, Zwickau and Hamm, Germany, based on remotely sensed, geo- andcensus data as well as citizen science air temperature data. A comprehensive 2.5D urban model was developed, integrating 30 different parameters such as vegetation shares, impervious surfaces, and building parameters like density or floor area ratio, as well as spectral characteristics like Normalised Difference Vegetation Index (NDVI) or satellite-based Land Surface Temperature (LST). In combination with citizen science (‘gathered by the public’) air temperature data measurements, it enabled 100m resolution modelling of heatwave peaks. Machine-learning techniques (Random Forest, RF) and multivariate techniques, particularly Partial Least Squares (PLS) regression, performed convincingly in handling the uncertainties inherent in citizen-science air temperature loggers and ensured robust, area-wide heat wave exposure predictions.

In parallel to modelling heatwave exposure, social vulnerability was assessed using the 2022 census data in Germany. Age structure serves as the core vulnerability indicator, with residents above 65 identified as particularly sensitive, and younger cohorts considered moderately vulnerable compared to the remainder of the population. Merging the information on social vulnerability with the modelled heat exposure, an exposure weigheted Heat Vulnerability Index (HVI) was created at the grid level, revealing spatial patterns of heat risk across the three cities.TheHVI highlights the most heat-endangered urban areas where residents are most likely to suffer from heat.

The findings provide a robust evidence base for municipal adaptation strategies and risk-sensitive planning. The study underscores that meaningful heat-risk assessment is only possible throughintegration of social vulnerability, and that its spatial granularity is crucial for designing effective, locally adapted measures to enhance urban resilience.

Keywords: Heatrisk, Social Vulnerability, Heat Exposure, Population, Heat Vulnerability Index

2 INTRODUCTION

Worldwide, many cities experience extreme heat and rising exposures are projected for the future (Friesen & Taubenböck, 2025, IPCC, 2022). It has become one of the most critical climate-related hazards in urban areas, with increasing morbidity and mortality. The combined influence of global climate change and therefore an increase in the number and severity of heatwaves on the one hand and urban heat island (UHI) effects on the other hand disproportionately affect temperature conditions in cities (Ramachandra et al., 2025, Dodman et al., 2022, Gilabert et al., 2021). The UHI is the product of dense built-up structures, impervious surfaces, limited vegetation,anthropogenic emissions from air conditioning, industries and vehicles, as well as limited airflow. In this process, urban areas experience significantly higher temperatures than their rural surroundings (Ramachandra et al., 2025, Liu et al., 2024). At the same time, ongoing climate

change is leading to an increase inboththe frequency and intensity of heatwaves. In combination with rapid urbanization (Taubenböck et al., 2024) this leads to thermal stress in urban agglomerations and and inceased risk for human health, infrastructure, and urban livability (Dodman et al., 2022, Gilabert et al., 2021).

Remote sensing has become a cornerstone of urban heat analysis and modelling. Its ability to provide information for spatially continuous and temporally consistent observations of land surface temperature (LST) as well as related surface characteristics over large areas stands out (Li et al., 2013, Weng, 2009, Voogt & Oke, 2003). Multiple sensors like Landsat, MODIS, or Sentinel are widely used to identify urban heat hotspots, to quantify the surface UHI (SUHI), and examine the influence of land cover on surface temperatures (e.g. Zargari et al., 2024, Aslan & Koc-San, 2016). However, satellite-derived LST only approximates near-surface air temperature. In complex urban environments, such as street canyons and residential neighbourhoods, LST often fails to capture spatial variability in air temperatures (Li et al., 2013, Voogt & Oke, 2003). Moreover, the heat that people actually experience is defined by air temperature, together with humidity, radiation, and wind (Oke et al., 2017).

To overcome limitations, citizen science (CS) air temperature measurements are increasingly used as input data for urban heat modelling (e.g. Leichtle et al., 2023 a & b). The data are collected via personal, CS weather stations, and stored in publicly accessible servers, providing alternative and low-cost input air temperature data(Meier et al., 2017).Combined with remote sensing data, CS observations improve the spatial resolution of temperature estimates compared to LST data and enable more realistic representations of thermal conditions experienced by urban populations (Fenner et al., 2021, Zumwald et al., 2021).

However, heat-related impacts are not determined by temperature alone. Risk emerges from the combination of thermal exposure and social vulnerability of exposed inhabitants. The latter varies across urban neighbourhoods due to differences in age structure, health status, socioeconomic conditions, housing quality, or access to cooling resources (Weigand et al., 2023, Dodman et al., 2022, Dong et al., 2020).Elderly individuals, young children, people with chronic illnesses, and socioeconomically disadvantaged groups are particularly susceptible to heat stress, often experiencing disproportionate health burdens during extreme heat events (Dodman et al., 2022, Harlan et al., 2013). Integrating vulnerability indicators with remote sensing-based heat metrics is therefore essential to move from heat exposure mapping towards a risk-oriented perspective that better reflects real-world impacts (Dodman et al., 2022; Chen et al., 2018).

Therefore, this study aims to identify urban heat hotspots by jointly considering heat exposure during heatwave conditions and spatially explicit age-related vulnerability. By combining heatwave models based on remotely-sensed landcover and spectral information like Land Surface Temperature, as well as CS air temperature, with socio-demographic vulnerability factors, this paper establishes a Heat Vulnerability Index (HVI) locating the areas within cities posing the greatest risk to human populations. Such an integrated approach aims at a more comprehensive understanding of urban heat risk and aims to support targeted adaptation strategies, informing urban planning, public health interventions, and climate adaptation efforts in cities.

3 MATERIAL AND METHODS

This section introduces the study area, describes the datasets used and their pre-processing steps, and outlines the methodology applied for the heatwave models as well as the HVI.

3.1 Study area

The study was conducted in three mid-sized German cities: Augsburg, Hamm, and Zwickau, each representing distinct urban contexts in terms of geography, demographic structure, and local climate. Their location within Germany is shown in Fig.2, top left.

Augsburg, located in the state of Bavaria in southern Germany, has a population of approximately 308,000 inhabtitants within an area of about 147km² (Stadt Augsburg a, 2026, Amt für Statistik und Stadtforschung der Stadt Augsburg, 2026). The city experiences a warm temperate climate with relatively high precipitation throughout the year (Köppen-Geiger classification Cfb). The summers are warm and the winters cool (Climate-Data.org a, 2026, Beck et al., 2018).

Hamm is situated in the federal state of North Rhine-Westphalia in western Germany and has an estimated population of around 180,500 inhabitants across approximately 226km² (Stadt Hamm a, 2026, Statistisches

Bundesamtd, 2026). The city's climate is also classified as warm temperate with mean annual temperatures of 10,3°C and relatively even precipitation throughout the year, accompanied by warm summers and cool winters often near or slightly below freezing (Köppen-Geiger classification Cfb; Climate-Data.org b, 2026, Beck et al., 2018).

Zwickau, located in the state of Saxony in eastern Germany, is the fourth largest city in Saxony with about 87,000 inhabitants and covers roughly 102km² (Stadt Zwickau a & b, 2026). The local climate is similarly temperate with warm summers and cold winters typical of Central Europe, reflecting the Cfb climate regime by Köppen-Geiger with average temperatures of 9,1°C and high precipitation numbers throughout the year (Climate-Data.org c, 2026, Beck et al., 2018). Zwickau's location in the Mulde river valley and its surrounding topography influence local microclimatic conditions. The position in the valley causes a traffic jam of warm air within the heavily overheated districts, especially during summery, windless weather conditions (Stadt Zwickau c, 2026).

Collectively, these three cities represent a range of urban settings in Germany with temperate climates, all of which are increasingly affected by heat stress during summer as a consequence of climate change and the rising frequencyand intensity of heatwaves (Stadt Augsburg b, 2026, Stadt Zwickau c, 2026, Stadt Hamm b, 2026).

3.2 Data

This section presents the datasets used for heatwave modelling (see Section 3.3.1 for a detailed methodological description) and for the identification of age-related population vulnerability. Both datasets serve as input variables for the construction of the HVI, which is described in detail in Section 3.3.2 and is used to spatially assess heat risk across the three test cities.

3.2.1 Input Data for HeatwaveModelling

Citizen Science air temperature data

CStemperature data form one part of the heatwave modelling input for the three test cities. Observations were sourced from two CS sensor networks: Netatmo Citizen Weather Stations and Sensor.Community (formerly Luftdaten.info). Previous studies show that crowdsourced air temperature data are statistically comparable to official meteorological observations, supporting their use in urban climate and heatwave analyses (Leichtle et al., 2023b).

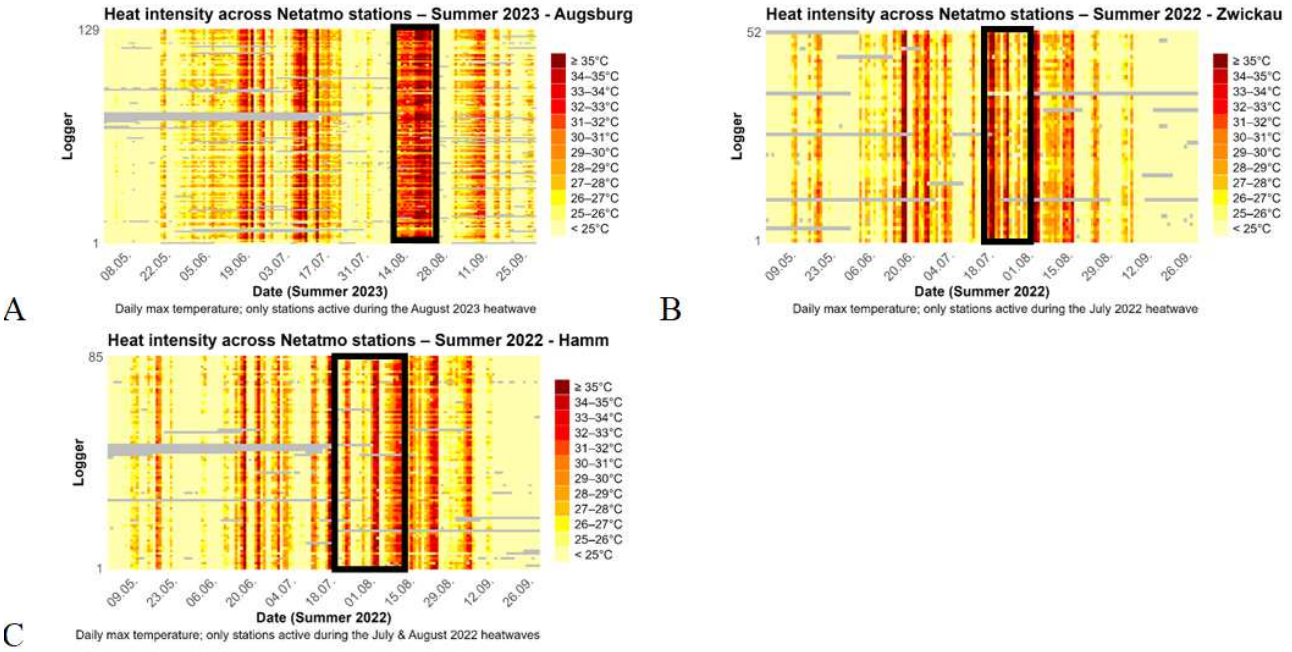


Figure 1: Heat intensity across Netamto stations during summer 2023 for Augsburg (A) and summer 2022 for Zwickau (B), and Hamm (C). In each case, the black box highlights the time period from which the data used in this study were derived.

Netatmo Citizen Weather Stations are commercial devices produced by the French company Netatmo. The outdoor module measures air temperature and relative humidity at a temporal resolution of five minutes.

Data are transmitted automatically and wirelessly to Netatmo serversand, if users consent, are made publicly available and can be collected from the Netatmo network (https://weathermap.netatmo.com/) via the Netatmo Application Programming Interface (API, https://dev.netatmo.com/). For this study, Netatmo data were retrieved for the period August 2023 for Augsburg (13.08.-26.08.2023, 129 loggers, Fig.1A), July 2022 for Zwickau (18.07.-31.07.2022, 52 loggers, Fig.1B) and July and August of 2022 for Hamm (18.07.-12.08.2022, 85 loggers, Fig.1C), representing real time heatwaves visible in the data (Fenner et al., 2021).

The second data source, Sensor.Community, provides environmental data from an open-source sensor network. Data were accessed via the Open Sensor Web platform (now operating under the name Sensoto), which aggregates measurements from multiple open environmental sensor networks (PIKOBYTES GmbH, 2026). Sensor.Community data were also downloaded via an API for the same periods as Netatmo (Hamm: twologgers; Augsburg: eightloggers; Zwickau: twologgers). The sensors are assembled by users themselves and were originally designed for fine dust measurements rather than meteorological observations. The recording resolution is two and a half minutes. The spatial distribution of the loggers from both CS networks is shown in Fig.2.



Figure 2: Spatial distribution of the Netatmo (orange) and Sensor.Community (pink) loggers throughout the test cities Augsburg (A), Zwickau (B), and Hamm (C). In Augsburg 129 Netatmo and eight Sensor.Community loggers, in Zwickau 52 Netatmo and two Sensor.Community loggers, and in Hamm 85 Netatmo and two Sensor.Community loggers were applied. In the background, impervious surfaces can be seen.

In contrast to official meteorological stations, data from both CS networks are not subject to formal verification procedures and may exhibit various sources of error. These include issues related to sensor installation, station design (e.g. insufficient ventilation), sensor calibration, and data transmission problems (Fenner et al., 2021). To address these uncertainties, in a first quality-control step, the CS temperature data were adjusted using the CrowdQC+ R package (Fenner et al., 2023), which applies statistical methods to detect and correct measurement biases (Bechtel et al., 2024).

To prepare the data for modelling, daily maximum air temperature values were derived for each CS logger and used as model input. After aggregation, all stations were manually re-evaluated regarding the plausibility of their maximum temperatures. This screening showed that some loggers recorded unusually high temperatures in predominantly vegetated areas, while others showed unexpectedly low values in densely built-up structures, contradicting expected land - temperature relationships (Leichtle et al., 2023a). These inconsistencies were particularly evident in Hamm and Zwickau, where the number of sensors was limited and not all Local Climate Zones (LCZs; Stewart and Oke, 2012) were sufficiently represented (e.g. only one sensor representing industrial areas). As these anomalies were likely related to station design (e.g., insufficient radiation shielding) and only became apparent in relation to surrounding land cover, they were not detected by the standard CrowdQC+ quality control.

As a consequence, for Zwickau and Hamm, a limited number of daily maximum air temperature values were slightly manually adjusted to improve the physical plausibility and representativeness of the temperature input data used for model development.In Hamm, four stations were adjusted: three near vegetated areas

were slightly lowered to align with comparable sensors within the test city, while one inner-city station was slightly increased.In Zwickau, one station was slightly lowered, as it recorded one of the highest temperatures citywide despite being located in a green area next to a large water body, where lower readings would typically be expected.

Landcover data

In addition to meteorological data, landuse landcover (LULC) information was used to model heat exposure during heatwave events. For this purpose, LULC classifications derived from very high-resolution (VHR) satellite imagery were employed. The datasets include WorldView-3 imagery for Augsburg acquired on 19th of July 2018 (30 cm spatial resolution), WorldView-2 imagery for Zwickau acquired on 25th of July 2022 (50 cm), and GeoEye imagery for Hamm acquired in 2020, consisting of two images from 27th of April and 8th of May 2020 (40 cm). All three images were obtained from European Space Imaging, EUSI (https://www.euspaceimaging.com/).

Image classification was conducted using the software eCognition. For the VHR WorldView datasets, knowledge-based approaches relying on spectral image characteristics were applied, while the GeoEye dataset was classified using a Convolutional Neural Network (CNN; Montensinos López et al., 2022, Geiß et al., 2022)followed by a knowledge-based post-classification refinement. The final LULC products provide detailed information on vegetation (including height attributes), water bodies, and impervious surfaces, including buildings. Overall accuracies rank from 87% in Zwickau to 94% in Hamm.

The classified land cover data were aggregated to a regular 100 m × 100 m INSPIRE-compliant grid (European Comission, 2013) covering the entire extent of each test city for model application. In addition, a separate 100 m × 100 m grid was generated for the surroundings of the temperature sensor locations to establish relationships between air temperature and land cover characteristics.

Based on the LULC classifications and supplementary geospatial datasets, including normalised digital surface models (nDSMs) and Open Street Map data, a range of additional parameters were derived at the grid-cell level. These include shadow cast at noon and dawn, green volume, climate effective vegetation (cooling effect extending beyond the local site, green spaces ≥ 0.5 hectar, Aram et al., 2019), sky view factor, distance to the city centre, and building-related metrics such as building density, building volume, and floor area ratio.

Furthermore, spectral information from the VHR imagery and additional Landsat-8 data (30 m spatial resolution, retrieved through the Google Earth Engine) were integrated into the grid framework. For each city, Landsat-8 acquisition periods were selected to closely match the acquisition dates of the respective VHR images. Accordingly, Landsat-8 data from April to August 2022 were used for Zwickau, from April to August 2020 for Hamm, and from April to August 2018 for Augsburg. The spectral variables include the Normalized Difference Vegetation Index (NDVI) and surface albedo. Furthermore, Land Surface Temperature (LST) was incorporated as a climatological metric, computed as the mean summer LST over the period 2013-2024 based on all available Landsat-8 data for the summer periods for each respective city.

The final output consists of a spatially comprehensive 100 m × 100 m grid for each test city and an additional grid centered at the locations of the CS temperature measurements, also with a 100m x 100m resolution. Each grid cell contains the full set of derived land cover, structural, and spectral parameters used for heat exposure modeling. An overview over included parameters is shown in Table 1.

Building parameters	Landcover parameters	Describing parameters	Spectral parameters
• Volume • Density • Floor area ratio	• Imperviousness • Water • Vegetation *(all, green volume, climate effective, ≤2m, 2m - ≤10m, 10m - ≤20m, > 20m)*	• Distance to centre • Shadow • Sky View Factor	• NDVI • Albedo • LST

Table 1: Overview of the parameters included in the areawide grid cells covering the test cities and in the grid cells surrounding the logger locations.

3.2.2 Social Vulnerability

Data from the German Census 2022, provided on a nationwide 100 m × 100 m grid and accessible via the Zensus database (Statistisches Bundesamt a & b, 2022), served as the primary source. Two census datasets

were employed:population counts disaggregated into 10-year age groups (<10 years to >80 years; Alter in 10er-Jahresgruppen in Gitterzellen (A), Statistisches Bundesamt a, 2022), andpopulation counts disaggregated into five age classes (<18 years, 18–29 years, 30–49 years, 50–64 years, and ≥65 years; Alter in 5 Altersklassen in Gitterzellen (B), Statistisches Bundesamt b, 2022).Each grid cell stores the number of residents belonging to the respective age group. Grid cells corresponding to the study areas were extracted from these nationwide datasets. As land cover information is available on an INSPIRE-compliant 100 m grid (see Section 3.2.1), the census grids align precisely with the land cover grids within the test cities.

Previous studies have shown that residents aged 65 years and older areparticularly vulnerable to heat stress, while young children and infants also face elevated heat-related risks (e.g. Azan et al., 2015, Arsad et al., 2022, United Nations Children's Fund, 2023, Hajat et al., 2007). Accordingly, these age groups constituted the primary focus of the present analysis. To do so, three data preprocessing steps were carried out. Initially, datasets (A) & (B) were combined into one grid layer. The new grid contains all columns from both data sets. Secondly, to enable a fine-scale assessment of age-specific heat exposure below four years of age, the population below 10 years of age was even further refined using the GENESIS database (Bevölkerung: Kreise, Stichtag, Geschlecht, Altersgruppen, Statistisches Bundesamt c, 2026), which provides city-level relative age-group shares. For the cities of Hamm and Augsburg, the relative shares of children aged <3 years, 3–5 years, and 6–10 years are available. Proportions of these sub-age groups within the total population under 10 years of age were calculated and applied to the 100m census grid cells, resulting in a refined spatial representation of children's age groups. For Zwickau, no city-specific sub-age-group information for children under 10 years was available. In this case, the mean proportions derived from Hamm and Augsburg were used to disaggregate the population under 10 years of age into the same three sub-age groups, ensuring methodological consistency across all study areas. In a third preprocessing step, both census information age intervals were combined. Up until age group 50-59 years, the present paper uses the information from dataset (A), including the newly defined sub-age groups below 10 years of age. Above 60 years of age, based on previous publications, the threshold 65 years and older should be used (e.g. Kohon et al., 2024, Reid et al., 2012). Therefore, this age group from dataset (B) had to be combined with the age classes 60-69 years, 70-79 years and above 80 years from datset (A)to derive the age group 60-64 yearsin order to generate consistent age coverage while using the age group 65 years + from dataset (B) for the analysis. This was achieved by summing the age classes 60–69, 70–79, and ≥ 80 years from (A) and subtracting the 65+ population from (B). As both datasets are stored within the same grid structure, this operation was performed directly at the grid-cell level.

The final age categories used in the analysis are: < 3 years, 3–5 years, 6–9 years, 10-19 years, 20-29 years, 30-39 years, 40-49 years, 50-59 years, 60–64 years, and ≥ 65 years.

3.3 Methodology

3.3.1 Heatwave Modelling with Partial Least Squares Regression or Random Forest and Validation

Partial Least Squares Regression (PLS) and Random Forest (RF) were applied to model maximum air temperature patterns under heatwave conditions in the three test cities Augsburg, Zwickau, and Hamm, using in-situ observations from the CS networks Netatmo and Sensor.Community. PLS was selected as the primary approach because it performs well with limited observations and strong multicollinearity among predictors (Pirouz, 2006), both of which characterise the dataset (e.g., correlations between impervious surfaces, bare soil, and vegetation-related variables). Given the restricted number of CS temperature measurements, this robustness was particularly relevant. For comparison, RF was additionally implemented. As a non-parametric, non-linear method (Breiman, 2001), RF can capture complex relationships between land cover patterns and air temperature and is generally robust to multicollinearity, often outperforming conventional regression approaches, although predictions remain limited to the value range represented in the training data (He et al., 2025; Oukawa et al., 2022; Breiman, 2001).

The model input consisted of daily maximum CS temperature measurements per logger and a set of land cover and spectral variables extracted from grid cells surrounding the sensor locations. Based on these data, both models established statistical relationships between air temperature and land cover as well as spectral parameters (see section 3.2.1).For each city, both modelling techniques were developed, and the better-

performing modelwas subsequently applied to the complete spatial grids covering the test cities to generate spatially continuous temperature estimates for heatwave conditions to analyse heat exposure.

The results were validated using the statistical error measuresMean Absolute Error (MAE) and Root Mean Squared Error (RMSE), based on a 10-fold cross-validation procedure in which the dataset was repeatedly split into training and test subsets and the performance metrics were averaged across all sections.Both metrics are widely used to measure model performance (Chai & Draxler, 2014), and provide information about the average model-prediction error, in this study expressed in degree Celsius. Compared to MAE, RMSE gives more weight to outliers (Willmott & Matsuura, 2005). Moreover, two heat-specific validation metrics were applied to assess the model's performance under extreme heat conditions. Heat-days are defined as days with maximum air temperatures of at least 30°C (EEA, 2021). This is particularly important because a model may show low overall MAE or RMSE while still misrepresenting extreme temperatures during heatwave situations. The first metric is theProbability of Detection (POD) adjusted to heat-days, defined as the fraction of observed heat-daysthat were correctly classified by the model. POD ranges from 0 to 1, with values close to 1 indicating a high ability to detect heat events (NOAA a, 2026, Mohapatra et al., 2025, Developmental Testbed Center, 2009). In the context of this study (modelling heatwave extreme scenarios), POD therefore evaluates the spatial consistency between observed and modelled heat-day locations. High values indicate that the model correctly identified those locations that experienced extreme heat during the observed heatwave.In addition, the Mean Error onhot days (also referred to as hot-day Bias) is used as a fourth evaluation metric. It quantifies the difference between the mean of predicted heat-day temperaturesand the mean of observedheat-day temperatures (maximum temperature ≥ 30°C), giving information about over- or underestimation of extreme heat.Values close to zero indicate a minimal bias(Stanski et al., 1989, NOAA a, 2026, NOAA b, 2026).Together, these two heat-specific metrics allow the assessment of model performance under extreme heat conditions. POD assesses the spatial agreement in the identification of heat-affected areas, while the hot-day bias evaluates the accuracy of the modelled heat intensity within these areas.

3.3.2 Development of theHeat Vulnerability Index

Building on existing studies that link population vulnerability to thermal exposure, a HVI was developed to integrate both heat exposure and population susceptibility at the grid-cell level (e.g.Rupp et al., 2026, Zhang et al., 2019, Johnson et al, 2012). Heat exposure is represented by spatially modelled daily maximum air temperatures during heatwave conditions, while population vulnerability is approximated using age-specific population groups, following established findings in the literature.Based on evidence indicating increased heat-related health risks, population groups aged 65+ years were classified as highly vulnerable, whilechildren below 3 years of age as vulnerable (e.g. United Nations Children's Fund, 2023, Arsad et al., 2022,Azan et al., 2015,Hajat et al., 2007). Children under three years were considered slightly less vulnerable (weighting factor 0.3) than the 65+ age group (weighting factor 0.4), as epidemiological studies show that heat-related mortalityis higher among older adults (e.g. An der Heiden et al., 2020, Linares & Díaz, 2008).All remaining age groups were considered to exhibit comparatively low heat-related vulnerability (weighting factor 0.1).

Prior to index construction, all input variables were z-standardised, resulting in a mean of zero and a standard deviation of one for each indicator. This standardisation ensures comparability among variables measured on different scales and enables their weighted combination(e.g. Ko et al., 2021, Guo et al., 2019).

The social component of the index was calculated as a weighted linear combination of the standardised age-group indicators, representing social heat vulnerability (0.4 for age groups above 65 and 0.3 for age groups below three). To account for heat exposure, this social vulnerability component was subsequently multiplied by the standardisedmodelled maximum air temperature per grid cell. The resulting exposure-weighted HVI thus highlights locations where high population vulnerability coincides with elevated heat exposure.Finally, the continuous HVI values were classified into three relative vulnerability classes (Low, Medium, High) using the 33rd and 66th percentiles as class thresholds. This quantile-based classification facilitates a relative comparison of heat vulnerability patterns within each test city.

4 RESULTS

This section explains the results of the heatwave modellingapproaches and the results of the calculation of the HVI for all three test cities.

4.1 Heatwave Models

The results of the heatwave models, portraying the spatial distribution of maximum air temperatures observed during a real heatwave period, are shownin Fig. 3, with the corresponding statistical metrics summarisedin Table 2. For Augsburg, PLS performed best with an RMSE of 2.73°C, a MAE of 2.23°C, a hot-day Bias of -2.59°C, and a POD of 1. The relatively high RMSE indicates that the model occasionally produces larger errors, particularly on the hottest days, as this metric gives more weight to outliers (here, maximum temperatures). The MAE is slightly lower, as it is less sensitive to extreme values, reflecting that the model performs well on average. Nevertheless, the mean error remains around 2°C. The hot-day Bias reveals a systematic underestimation of heat intensity at the loggers' locations. Despite this, all heat-day locations (POD = 1) were correctly captured, demonstrating strong spatial agreement during the heatwave scenario. In Hamm, PLS was also used to model the areawide heatwave situation. With an RMSE of 2.89°C, Hamm exhibits the highest overall deviations among the three test cities, indicating the presence of potentialtemperature outliers. The MAE of 2.32°C indicates generally accurate predictions despite these deviations. Thehot-day Bias is the smallest among the three test cities at -0.24°C, reflecting only a minor underestimation of extreme heat intensities. Similar to Augsburg, all heat-day locationswerecaptured correctly (POD = 1), indicating excellent spatial detection at the sensor locations. In Zwickau, RF outperformed PLS, particularly in visual comparison (not shown). The heatwave model achieves the best statistical validation metrics, with anRMSE of 1.57°C and a MAE of 0.96°C, indicating very low deviations and high accuracy. The hot-day Bias shows a small underestimation (-0.59°C), while POD = 1 confirms that all heat-day locations were correctly identified at the logger sites.

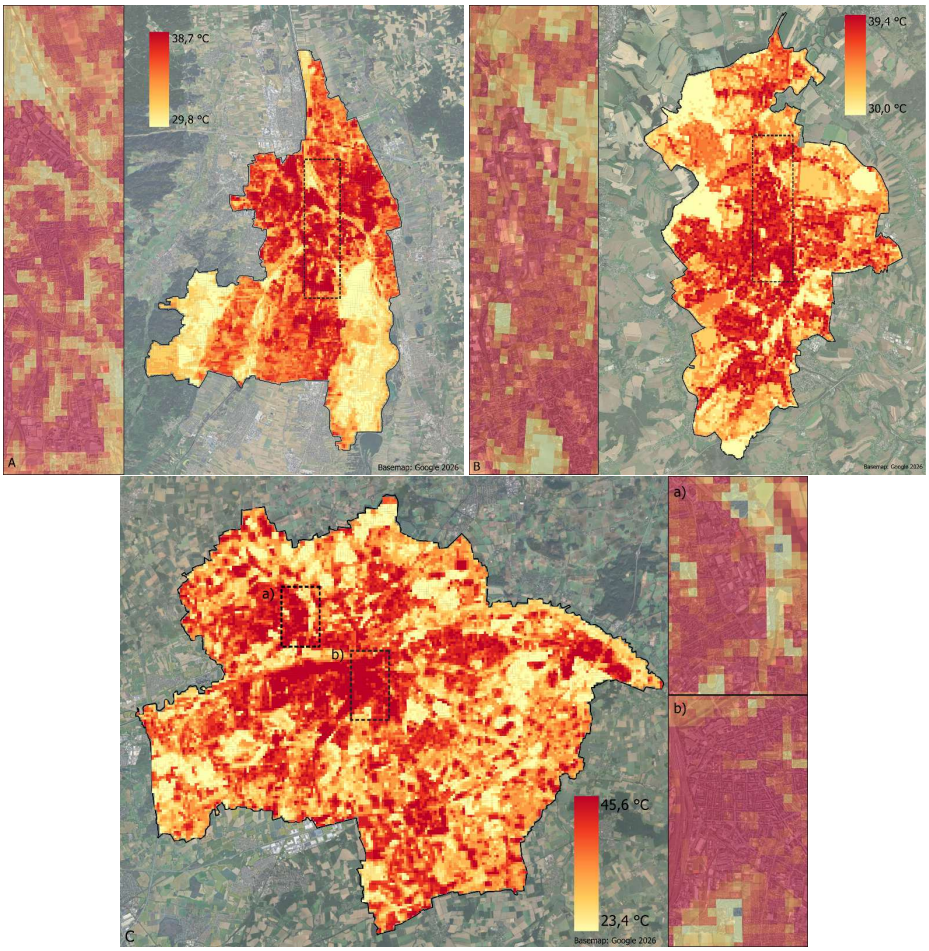


Figure 3: Heatwave model results for Augsburg (A), Zwickau (B), and Hamm (C).

In the cartographic representation (Fig.3), the hottest locations are generally located in the inner-city districts and industrial areas (dark red), whereas forested zones remain comparatively cool (light yellow). In Augsburg (A) the zoomed-in area shows the inner city of Augsburg, along with the surrounding northern and southern districts. Maximum temperatures reach nearly 39 °C in the city centre and industrial zones, while areas along the rivers and water structures as well as more forested areas, remain the coolest. In Zwickau (B), the close-up view shows the inner city in the south extending northward into industrial areas, with temperatures reaching nearly 40 °C. Cooler areas are observed around the inner-city water body and a park. For Hamm (C), two zoomed-in areas are presented: Zoom a) highlights an industrial area with high temperatures, surrounded by cooler forested zones, while Zoom b) shows the city centre with maximum temperatures reaching up to 45°C.

	Model	RMSE[°C]	MAE[°C]	Hot-day Bias [°C]	POD
Augsburg	PLS	2.73	2.23	-2.59	1
Zwickau	RF	1.57	0.96	-0.59	1
Hamm	PLS	2.89	2.32	-0.24	1

Table 2: Validation metrics results for the three test cities Augsburg, Zwickau, and Hamm.

4.1.1 Heat Vulnerability Index

The results ofthe exposure weighted HVI are presented in in Fig.4, with the heatwave models shown beneath with transparency. The HVI is only displayed for areas where the census data provide population information. Therefore, non-built-up areas and industrial zonesare excluded (dark red areas in the background, where heat intensity is also high during heatwaves).

For all three cities, locations within the inner-city districts (zoomed excerpts) exhibit predominantly high HVI values, indicating that these areas experience both elevated heat exposure and a comparatively large population of residents above 65 years of age or below 3 years of age. However, cells with a high HVI are not confined to the inner-city districts. As Fig. 4 illustrates, high HVI values are distributed across the urban areas, highlighting locations where extreme heat exposure coincides with a high age-related social vulnerability regarding heat related health risks. Medium and low HVI zones are predominantly scattered throughout suburban and less densely built-up areas, even though also present in the inner-city areas.

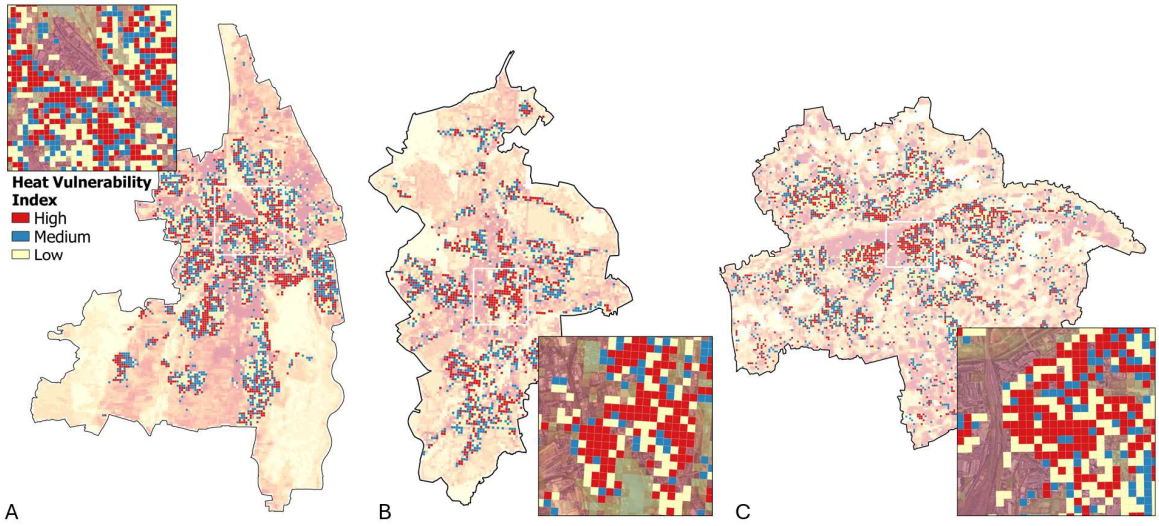


Figure 4: Heat Vulnerability Index for Augsburg (A), Zwickau (B), and Hamm (C).

5 DISCUSSION

In general, this study demonstrates that the proposed approach –combining multisensor remote sensing data, machine learning techniques, CS air temperature measurements, and census data–enables the robust identification of urban heat hotspots. Importantly, the analysis goes beyond the assessment of heat exposure alone by explicitly incorporating social vulnerability, thereby capturing not only where the hottest locations are, but also where vulnerable populations are most affected.

This integrated perspective is particularly valuable for the development of targeted heat adaptation strategies, as it highlights neighbourhoods where elevated heat exposure coincides with a high proportion of vulnerable age groups. The identification of these hotspots provides a critical basis for urban planning, public health

interventions, and resource allocation, supporting more effective mitigation ofheat-related health impacts during heatwave events.

Despite the overall validity and usefulness of the results, several methodological limitations, uncertainties within the CS data (e.g. bias due to logger design or missing validation with an official networkas part of this study) and potential improvementsshould be acknowledged. Concerning the heatwave temperature models, the results indicate that a systematically transferable temperature model across cities is not yet achievable. Instead, city-specific adaptation of temperature data is required, particularly when the available data volume is limited.As demonstrated in the case of Hamm and Zwickau, in comparison with Augsburg, where there are many more data loggers available, insufficient data coverage may not adequately compensate for local biases. Furthermore, if the data pool does not sufficiently represent all LCZ, e.g. only one sensor representing industrial areas in Hamm or only one sensor representing open green space and near water areas in Zwickau, model performance can be reduced, and therefore, the input CS temperature data had to be adapted manually beforehand. In addition, the statistical metrics did not always indicate optimal model performance. However, this limitation is of secondary importance for the primary objective of this study, which focuses on identifying the relative spatial distribution of the most heat-exposed areas, rather than exact temperature values. Systematic over- or underestimation of absolute temperature does not substantially affect the identification of relative heat hotspots within the urban context. Moreover, model experiments during the modelling process revealed that very good statistical performance can sometimes coincide with visually unrealistic spatial patterns, e.g. predicting industrial or densely built-up areas as cooler than adjacent largervegetated areas, highlighting the importance of combining quantitative validation with qualitative, visual evaluation within the framework of using CS data.

It is also important to acknowledge that air temperature measurements obtained through CS approaches represent a valuable data source; however, they capture only near-surface air temperature and not the heat stress actually experienced by people, which results from a combination of air temperature, humidity, radiation, and wind (Oke et al., 2017).

Beyond these methodological aspects, the assessment of social vulnerability could be further refined in future research. In the present study, vulnerability related to age structure was considered based on existing studies and the thresholds used; however, evidence from studies suggests that heat-related health risks increase substantially with advancing age (e.g. Arsad et al., 2022, Benmarhnia et al., 2015). Differentiating weighting factors within the elderly population, for example,higher vulnerability for age groups above 75 years, could therefore potentially improve the representation of heat susceptibility. In addition, further vulnerability indicators such as income level or housing conditions could be incorporated to better reflect adaptive capacity, which was not explicitly accounted for in this analysis (e.g. Rupp et al., 2026,Kohon et al., 2024). Including such socioeconomic variables would allow for a more comprehensive characterisation of population vulnerability and resilience to extreme heat events. Wilson et al. (2024) recently demonstrated that heat related health risks seem to be strongly dependent on external circumstances.

Moreover, the current vulnerability assessment is temporally static and does not account for variations in population exposure over the course of the day or between weekdays and weekends. However, people's spatial distribution and activity patterns differ between daytime and nighttime, as well as between working days and weekends. A time-dependent analysis could therefore provide more realistic insights into heat exposure and associated risks, particularly by capturing commuting patterns and daily mobility. Related to this, industrial and commercial areas were excluded from the vulnerability analysis due to the absence of census data. Nevertheless, these areas can host large numbers of workers during daytime hours on weekdays and may thus represent significant, yet currently unaccounted-for, zones of heat exposure. Incorporating daytime population data or workplace-related exposure estimates would further enhance the realism and applicability of the vulnerability assessment, especially for occupational heat risk management.

6 CONCLUSION

Overall, this study provides a robust and transferable methodological framework for the identification of urban heat risk by integrating temperature exposure during heatwave conditions with social vulnerability indicators. Despite existing limitations, the results offer valuable insights for heat risk management and demonstrate the added value of combining environmental exposure with demographic vulnerability. The

proposed approach therefore represents a meaningful contribution to urban climate research and offers a solid foundation for future refinements and practical applications in heat adaptation planning.

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reviewed paper

If Planning is Complex and Political, maybe Planning is the Solution: Improving Infrastructure Quality in Global South Cities

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1 ABSTRACT

The Global South is undergoing unparalleled urbanisation rates, alongside profound consequences for infrastructure demand and supply. This paper examines the relationship between the political economy and infrastructure planning in the global south cities. A particularly disturbing trend in Global South development is the explosion of large-scale, internationally-financed infrastructure developments that serve exclusive interests while abandoning the everyday necessities of majority populations. Drawing on literature from diverse geographic contexts, we explore the political economy of urban planning in understanding complexity as essential. The paper identifies key mechanisms linking the intersection of climate vulnerability with factors such as sociopolitical issues, poor governance, and limited technological capability, further declining infrastructure resilience. Infrastructure discrepancies in informal settlements echo deliberate poor policy choices and planning failures, isolating these areas. Additionally, we examine evidence on KwaZulu-Natal, South Africa, a particularly valuable empirical context for understanding planning's role in infrastructure improvement, disaster response, and resilience. Evidence shows that climate-induced disasters associated with risk and vulnerability are aggravated by socioeconomic issues, including housing deficiencies, compelling people to construct settlements in flood-prone zones. Finally, we propose several key pathways that emerge from this analysis for advancing more effective, equitable planning in Global South cities. The paper concludes that addressing institutionalized participatory planning as standard practice, integrating planning across sectors and governance levels, adopting explicit equity frameworks in planning, investing in municipal capacity building, decolonizing planning knowledge and practice and address the political economy of infrastructure would shape local institutional capability and encourage adaptive learning as opposed to continued dependence on external finance expertise.

Keywords: Global south, cities, urban planning, infrastructure, political economy

2 INTRODUCTION

The Global South encompasses previously marginalized countries across Latin America, Africa, Asia, Oceania and the Caribbean (Al hothaufi et al.,2025). Studies on global south cities indicate that planning's complexity and political nature can operate as both a hurdle and a passageway to infrastructure quality. Political instrumentalization (Sajjad and Javed, 2022), governance fragmentation (Schoulund et al., 2021), economic constraints (Sajjad and Javed, 2022) and social inequalities (Tiznado-Aitken, 2022) create multilayered problems to infrastructure development. However, effective interventions influence these complexities, for example, integrated planning developments transformed institutional fragmentation into viable interdisciplinary cooperation in Argentina, obtaining increased spatial quality at minimal extra costs (Schoulund et al., 2021). This literature review answers the following research question: How can planning and political nature influence quality infrastructure in the Global South cities ? To answer this question, we outline below the literature review, methodology, survey these phenomena, and discuss how these influences affect the quality of infrastructure in the Global South cities.

3 METHODOLOGY

The literature review was conducted using PRISMA protocols (Moher et al., 2016) Scopus is the main used database for research in bibliometric analysis. The search of the literature was specifically on publications between 2021 and 2026. The database search in Scopus was done and categorised using the following keywords.

- "Urban planning" AND "Global South"

- "Quality infrastructure" AND "Politics" AND "Complex"
- "Infrastructure quality" AND "Approach" AND "Developing countries"

The inclusion criteria were all articles published between 2021--2026 in the field of urban planning to improve quality infrastructure in Global South cities (Table 1).

Inclusion Criteria	Exclusion Criteria
Articles with topics relating to planning in Global South cities	Outside urban planning scope
Articles with topics relating to infrastructure development	Unpublished disserations and thesis
Articles with topics related to the complexity of politics and planning	Non-English Language

Table 1: Inclusion and Exlusion criteria for the data extracted

The search in the literature was directed by screening titles and abstracts for each article to confirm eligibility. The in-depth information on the selection process is presented in Fig. 1 as guided by the PRISMA protocols. The review identified 527 studies in Scopus, of which 9 were duplicates and consequently removed. 30 were used for this paper.

A key outcome from KwaZulu-Natal study is that though policy outlines exist, severe governance gaps hinder effective implementation. Cities have distaster management policies and land-use plans, yet management failures and feeble institutional capacity weaken effectiveness (Alam and Bhat, 2025). Moreover, government has not been able to satisfactorily involve vulnerable societies in policy formulation and implementation. The fiasco to reinforce and promote public participation abandons vulnerable societies powerless against disasters (Oreta, 2025). Recommendations evolving from KwaZulu-Natal study emphasise to institutionalise noteworthy community engagements and participation in all spheres of planning and implementation, establish robust intergovernmental coordination, and increase resource allotment to address disaster risk mitigation (Oreta, 2025).

4 FINDINGS

4.1 The Global South Urban Crisis: Context and Challenges

In urban settings, the Global South is challenged with fragmented governance, institutional constraints and informal development requiring green infrastructure approaches aligned to the context to improve equitable city regeneration and climate resilience (Al hothaufi et al.,2025).). In Menoni (2025) it was found out that the relationship between climate vulnerability and factors such as limited technological ability sociopolitical issues, and governance further deteriorates infrastructure resilience. Flooding in urban areas has become progressively severe in several Global South metropolises, with severe occurrences documented across Africa, China, Latin America, Southeast and South Asia. The impacts are disturbing, with numerous metropolises experiencing repetitive flooding incidences that reveal human vulnerability and infrastructure weaknesses.

A particularly disturbing characteristic in urbanization in Global South cities is the explosion of large-scale, internationally financed infrastructure developments that serve exclusive interests while abandoning the everyday necessities of majority populations. Countries in the Global South constantly invest in comprehensive, vanity infrastructure developments, which do not benefit the majority citizens (Shatkin, 2022). An example is Walter et al (2025) on the effect of spatial planning on the development of export-oriented green-hydrogen projects. The researchers analysed how spatial planning impacted the development of export-oriented green-hydrogen projects in South Africa, Namibia and Chile. The study revealed that, South Africa, Namibia and Chile have developed dissimilar planning approaches for export-oriented green-hydrogen projects. South Africa pursued a facilitative approach, Namibia a restrictive approach, whilst Chile is transitioning from a market-centred towards a restrictive approach. The different approaches indicate different stakeholder interests and political priorities and suggest diverse outcomes on the expansion of export-oriented green-hydrogen projects in terms of their size, number, shared infrastructure, acceptance and socio-environmental effect. The study underscored the need for properly designed high-quality spatial planning outlines.

Al hothaufi et al. (2025) emphasized the urgency to repurpose underutilized spaces into multifunctional green infrastructure. The study explored case studies in Latin America, Asia, and Africa, mainly focused on underutilized public spaces, brownfields and vacant lots. Analysis revealed four thematic groups: spatial analysis (site identification), (2) community-led and participatory planning, (3) policy and governance

mechanisms, and (4) multifunctionality in green infrastructure strategies. Key gaps incorporate limited integration of spatial, procedural, and social justice into green infrastructure planning. Reliance on outdated datasets that disregard altering vacancy patterns and informal land use. Cities in India exemplify this problem, for instance, a scrutiny in the transportation infrastructure development in Mumbai Municipal Region has failed to meet the demand for infrastructure, as a result, excessive delays, traffic jams, and an absence of inclusive and integrated transportation systems (Shaban and Sattar, 2023). The infrastructure shortage is not merely a financial or technical problem but depicts political choices on which needs are prioritised and resource allocation. Increased urbanisation throughout the Global South remains to be embedded by poorly managed and unplanned expansion, aggravating services deficiencies and ecological stress (Zhou et al., 2022). SV

In Adom et al. (2025) the South African context is surveyed and echoes the country has formulated an in-depth climate change adaptation framework reinforced by substantial legislative milestones, comprising the National Climate Adaptation Strategy, the landmark Climate Change Act, and the ground-breaking Coastal Adaptation Response Plan. Even so, evidence shows existing leadership gaps, including industry influence, lack of political will, complexity, short-term focus, international collaboration challenges, inadequate skills and understanding significantly delay the implementation of an in-depth climate change adaptation framework in the country.

4.2 The Political Economy of Urban Planning: Understaning Complexity as Essential

Urban planning is characteristically political and contains decisions about resource distribution, land allocation, and which voices have substance in shaping cities. It is imperative to understand planning as political and not perceive planning as a weakness to defeat. The structural ferocity of spatial conversion in Global South metropolises reflects socio-spatial reform in hybrid neoliberal governments, resulting in momentous harm to marginalised and poor groups (Burte and Kamath, 2023). Studies similar to Prasad et al., (2023) explored informality glitches to smart urban planning in Indian metropolises and proved how informality – an essential distinguishing factor of Global South metropolises – remains largely unseen in smart urban planning frameworks. These frameworks show significant disregard of informality at the cost of socio-spatial division, creating a fundamental challenge for smart city development claiming to serve all residents. The implication is clear planning that ignores the political dimensions of infrastructure -whose needs are served, what values guide planning, how power shapes decisions – inevitably reproduces existing inequalities. This is not an accidental outcome but rather a structural feature of planning systems that have not been fundamentally reformed to address equity concerns.

George-Williams et al (2026) further explored Sierra Leone's water sector, an investigation on stakeholder relationships and governance dynamics. The study identified key actors and their interests, roles, interdependencies and influence, while also investigating systemic barriers in political, economic, social, technical, and environmental dimensions. The findings revealed an extremely fragmented governance ecosystem, categorised by donor dependency, weak enforcement, overlapping mandates, and the side-lining of community voices. Though current reforms comprising donor-financed infrastructure projects, new regulatory institutes, and community-based projects illustrate improvement, they remain mostly insufficient, reactive, and piecemeal to address rooted structural deficiencies.

Das (2025) confirmed the difficulty of planning in cities in the Global South spreads beyond political contention to deep institutional disintegration. Amplified urbanization has moulded situations where particular agencies manage separate infrastructure systems energy, transport, water, waste without proper coordination, as a result, creates duplicated investments, inefficient resource allotment, and inconsistent interventions. Studies on infrastructure planning problems in developing cities illustrate how insufficient governance structures, poor shareholder coordination, and resource constraints destabilise integrated planning and execution. Critical limitations in city infrastructure development encompass resource constraints, poor shareholder coordination, inadequate urban drainage, insufficient governance, fractured solid waste management, insufficient sewerage, and improper transportation systems (Caldern-Ramrez et al., 2025).An essential intricacy in urban planning in the Global South is the occurrence of informal economies and informal settlements. Research has shown informal settlements are rapidly expanding but continue to be excluded from formal urban planning frameworks and official data platforms. In South Africa,

approximately one in four urban people reside in informal dwellings, however their realities are often ignored in urban development planning (Mangara and Dorasamy, 2025).

4.3 Evidence in KwaZulu Natal: Planning Contexts and Imperatives

Understanding socioeconomic vulnerability and risk to disasters induced by climate change requires the assimilation of geographic information systems, spatial techniques, socioeconomic vulnerability and risk mapping, and hazard exposure mapping (Menoni, 2025). Studies directly related to the South African setting reveals that disaster risk and vulnerability focuses on informal dwellings where environmental hazards, infrastructure deficits, and housing inadequacy converge, aggravated by socioeconomic influences such as housing shortages convincing individuals to build settlements in flood-prone zones (Alam and Bhat, 2025).

The KwaZulu Natal (KZN) province is renowned for occasionally suffering natural disasters (Aiseng and Gamede, 2023). In KZN, the city of eThekwini is one district that is well-known to have been gravely affected by devastating floods, with distressing effects on its extensive informal settlements (Dlamini et al, 2024). The city of eThekwini is an example of a colonial city in South Africa, designed to be unable to accommodate a population over the city limits. As a result, several township settlements were developed using the apartheid settlement approach contained by a fifty kilometre radius of the metropolis (Thinane et al. 2023). The legacy of the apartheid regime and its spatial planning, old and dilapidated infrastructure, governance challenges, rapid sprawling of informal settlements and lack of visible early warning communication to the destitute living on high-risk areas contribute to the distressing flood effects (Ngcamu,2023). A report by the Moses Kotane Institute documented that the harm inflicted by the disastrous floods in eThekwini were intensified by inadequate infrastructure, poor urban planning, and houses constructed on hilly areas (Ngcamu,2022). The absence of housing is a major challenge confronting government, and it forces the marginalized people to build informal houses on land unauthorized for human settlements, precisely floodplains and slopy land (Dlamini et al. 2024).

Nonetheless, findings illustrated that response interventions in flood disaster in KZN were rapid and efficient; however, several gaps existed in pre-disaster and post-disaster management (Olanrewaju and Reddy, 2025). Accordingly, the increase in knowledge in the connection of climate hazards and inadequate infrastructure exposes planning as a key factor in disaster risk mitigation, making it important to conduct a comprehensive literature review to identify approaches to reconceptualise planning for cities in the Global South. This paper aims to use Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to document the knowledge of quality infrastructure in Global South cities, identify emergin themes and new approcahes in the literature. Following this introduction, we discuss the methodological PRISMA method concentrating on how the data was gathered and analysed for this paper. The subsequent section presents findings obtained from the systematic analysis. Following, a discussion on findings and and a conclusion.

5 CONCLUSION

The failures of planning visible across Global South cities are not inherent failures of planning itself but rather failures of planning systems that have not been fundamentally reformed to address equity, democracy, and sustainability concerns. These systems continue to reflect colonial legacies, top-down imposition, elite capture, and exclusion of marginalised communities. They persist in treating infrastructure as a technical problem amenable to engineering solutions while ignoring the social, political, and economic dimensions of infrastructure access and quality. They continue to prioritise vanity projects serving elite populations while infrastructure essential to the majority's survival deteriorates.

The idea of transformative planning would fundamentally look different. The concept begins with clear commitments to equity, democracy, and social justice. It would encourage participatory procedures, to ensure authentic public voice in decisions impacting the futures and lives of the public (Terdoo, 2024). Transformative planning would connect multiple aims – disaster resilience, housing, environmental protection, service delivery, and employment – within clear frameworks instead of continuing sectoral, fragmented approaches (Hakiman and Sheely, 2023). It would acknowledge and work with infrastructure heterogeneity rather than imposing standardised, externally-designed solutions. It would build local institutional capacity and support adaptive learning rather than perpetuating dependence on external expertise and financing (Wieszczeczynska et al., 2024).

In conclusion, planning is not a failed endeavour or an impediment to development in Global South cities. Rather, planning, when fundamentally reconceptualised to prioritise equity, democracy, and social justice, represents an essential tool for addressing the interconnected crises of urbanisation, infrastructure inadequacy, climate vulnerability, and spatial inequality. The evidence presented throughout this paper, drawn from diverse contexts across the Global South, demonstrates that effective, inclusive, participatory planning can mitigate disasters, promote sustainable development, and advance social justice (Menoni, 2025; Terdoo, 2024). The task ahead is not to abandon planning but to transform it – to create planning systems that genuinely serve the needs of majority populations, that integrate multiple objectives through coherent frameworks, that build local capacity and knowledge systems, and that confront power inequalities perpetuating urban inequality and injustice.

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reviewed paper

Implementation of a City Information Model on a Micro-Urban Scale: Qualitative Streetscape Analysis using the SSSEIC Method

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1 ABSTRACT

Semantically rich 3D models at the building scale have long been established through Building Information Modelling (BIM), which has become a standard in interdisciplinary planning practice. By contrast, City Information Modelling (CIM) at the urban scale has yet to reach comparable consolidation or widespread use. Existing frameworks vary in focus and integrate a multitude of different datasets, yet they typically operate at similar scales: large urban areas or even entire cities. Consequently, these models often support only low levels of detail, with buildings represented as simple volumes and public space reduced to terrain surfaces.

Between the building and urban scales lies a critical but underrepresented level: the street or neighbourhood scale. The spatial characteristics of streets are central to urban quality of life, shaping potential uses, social interaction, mobility, and environmental performance. It is therefore crucial to understand and capture the built environment at this level. Detailed modelling of streetscapes offers a unique opportunity to represent fine-grained physical and perceptual characteristics, enabling digital environments that more authentically reflect human experience. Such models facilitate comprehensive analyses and the identification of potentials within street spaces – factors that are increasingly vital in the context of climate change, where street-level morphology and materiality directly affect heat exposure, shading, ventilation, and overall resilience.

This paper provides a review of the existing CIM frameworks and presents the implementation of a City Information Model on a micro-urban scale using the SSSEIC method as a framework for qualitative (and quantitative) streetscape analysis. The method provides a systematic approach to describing and evaluating the spatial configuration and perceptual attributes of streets, bridging the gap between CIM and BIM to form a consistent modelling logic at the street scale. It includes street uses and surfaces, underground installations (pipes and cables), facades of the adjacent buildings and organisation of the ground floor area including uses, all objects in public space (street furniture), and ecological aspects which inlcude all plants and green spaces. Through this comprehensive structure, the SSSEIC method supports the creation of a semantically rich micro-urban CIM that serves both as an analytical tool and as a foundation for future design processes.

Keywords: CIM, 3D Model, Streetscape, Public Space, qualitative analysis

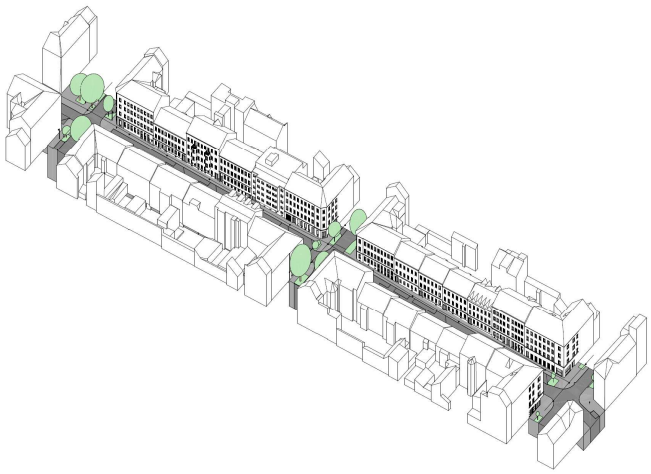


Fig. 1: Street space model created following the SSSEIC method © Tobisch, Löschenbrand, Psenner

2 INTRODUCTION

Over the past few decades, new planning methods and tools have emerged in the conceptualisation, planning and construction of the built environment. Individual 2D drawings were replaced by 3D models and the

resulting plan views. The digital models were gradually provided with more and more data that went far beyond purely geometric information.

At the building scale Building Information Modelling (BIM) has established itself as the semantically enriched successor to 2D and 3D CAD drawings and has long since become the standard, particularly in interdisciplinary planning processes. In contrast, urban planning continues to rely predominantly on GIS-based tools. Semantically enriched 3D models on the city scale, so called City Information Models (CIM) also are available and used, but they are far from having the same standardisation or prevalence as those at the building scale. Although existing frameworks differ in their focus and integrate various data sets, they generally operate at the level of large urban areas or even entire cities. Consequently, these models frequently support only a rudimentary level of detail, with edifices commonly depicted as elementary volumes and public spaces simplified to terrain surfaces.

Meanwhile, an all-important level remains largely unexplored by widespread new modelling approaches: the streetscape. Whilst the relevance of street space features (adjacent buildings, the ground floor zone and its use, street furniture, the presence and arrangement of vegetation and the like) for the perception of public space, social participation and, in general, the quality of urban life has long been established (Jacobs 1961, Rudofsky 1969, Gehl 1971, Anderson 1978, Jacobs, Whyte 1980, Appleyard/Gerson/Lintell 1981, Jacobs 1993) and urban designers increasingly advocate for design on a human scale, placemaking and highlight the importance of livable cities (Stojanovski et al. 2020) outdated technologies are still used for its analysis, planning and potential assessment.

2.1 A Model for Streets

Detailed modelling of streetscapes can represent a powerful approach for capturing the physical, spatial and perceptual nuances of urban environments in one place. It can enable the creation of digital representations that more accurately reflect how streets are experienced by people. By incorporating elements like geometries of the street and surrounding buildings, materials, functions and vegetation these models can offer a richer, more nuanced understanding of street spaces than traditional representations using 2D plans. Consequently, they can facilitate an in-depth analysis of a variety of aspect like environmental or traffic performance, spatial comfort, and social functionality, while also supporting the identification of existing and potential street uses within the urban fabric.

Beyond the involvement of planners and municipal actors, there is a wide range of other stakeholders like entrepreneurs, residents, and passers-by within the streetspace. Given this number of actors, the organization of participation and influence within public street space becomes a critical question. In current practice, opportunities for multidisciplinary collaboration and co-creative processes remain limited, as responsibilities are typically divided into discrete segments of the street and addressed in a largely sequential manner. (Tobisch/Löschenbrand/Psenner 2025A) Various aspects of interdisciplinary collaboration can be addressed with the help of street space modelling. Firstly, connections and interrelationships between different disciplines and their areas of influence can be visualised. Furthermore, the use of a model that provides all participants with real-time access enables direct collaboration without the need to exchange plans from different programmes in various data formats.

The importance of such detailed representation and interdisciplinary methods is ever growing in the face of rapid climate change. Street-level morphology, material characteristics as well as the presence and placement of vegetation play a critical role in shaping microclimatic conditions, directly influencing heat accumulation, solar exposure, shading patterns, airflow and as a result thermal comfort of street users and residents. Accurate streetscape models therefore provide an essential foundation for evaluating climate resilience and informing design strategies aimed at mitigating heat stress, improving ventilation, and enhancing overall environmental performance. In this context, detailed streetscape modelling becomes not only an analytical tool for assessing current circumstances and potentials, but also a key instrument for supporting more adaptive, resilient, and human-centred urban design. This is particularly relevant because municipalities have limited time and financial resources, yet time is of the essence when it comes to maintaining quality of life in cities amid changing conditions. The number of streets that can be adressed at any given time is limited, so in addition to quickly implementable and inexpensive interventions using tactical urbanism, the targeted use of resources for permanent redesign is crucial. Priority should be given to those street spaces that, on the one hand, have a high need for intervention, but on the other hand also have the most potential and promise the

greatest impact. Through the accurate presentation and processing of systemic information, both the suitable street spaces and the most sensible interventions can be selected in a targeted fashion.

2.2 Relevant Aspects

In order to enable analysis and comparison of different streets, including those with very different basic conditions, it is crucial to enable both qualitative and quantitative assessments. But before the issue of a suitable framework of consideration and modelling approach can be addressed, the relevant aspects within the streetspace have to be identified. The focus here is on all those aspects that constitute the real-life qualities street spaces as perceived by its users. For the identification of these qualities, interviews with experts from different disciplines were conducted and a workshop was held.[1] The resulting findings were complemented and refined by additional literature analysis and together form the basis for the qualities to be considered in the modelling. This quite extensive is by no means considered exhaustive and will be expanded further in the future. Nevertheless, it provides a useful overview of the range of topics and will therefore be used as a starting point for an initial examination of the subject. In this process, over 250 qualities or parameters of the street space have been identified (Tobisch/Löschenbrand/Psenner 2025A). Since most qualities can be viewed from different perspectives, it is not possible to separate them into distinct categories. Nevertheless, for the purpose of illustrating the range of aspects, the following broad thematic groups could be identified: relevant geographical information (i.e. street orientation and topography), the public space itself and its uses (i.e. surfaces, furniture, distribution of space and traffic volume), the adjacent buildings (i.e. facades, ground floor zone and uses), the urban infrastructure (i.e. underground installations, lighting), ecological topics (i.e. vegetation, microclimate, wind, sun exposure and shadows), matters related to perception (i.e. visual relationships, noise, temperature) and sociological factors (user groups, frequencies as well as quality of stay).

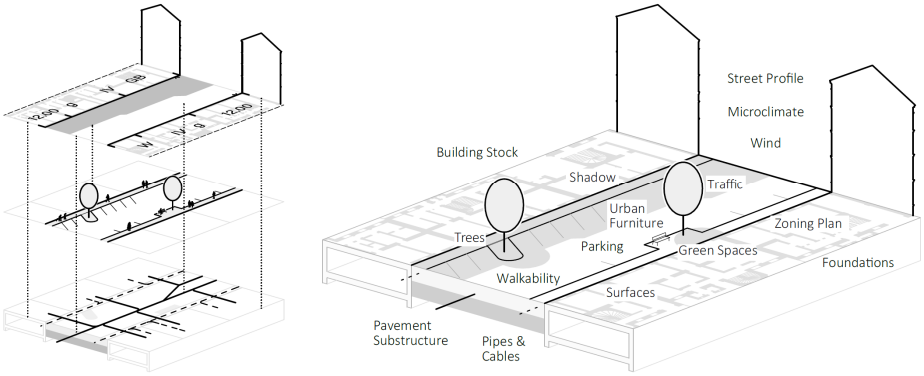


Fig. 2: A wide range of different aspects are represented in the street space, which a framework for a qualitative street space model is required to reflect. © Löschenbrand, Tobisch, Psenner

It is important to highlight that a combination of physical and non-physical aspect was identified. For the first category, the depiction within a 3D model and an underlying object-oriented database is straightforward, while the latter requires an alternative approach of consideration. Thus, a framework suitable for qualitative and quantitative street space analysis needs to be able provide a structure for both cases.

2.3 Research Questions and Methods

This paper aims to explore street space modelling by addressing questions that appear straightforward but, when examined in depth, reveal the underlying complexity of the topic:

What modelling frameworks and tools are currently available (BIM, CIM, etc.), what are their capabilities and limitations in relation representing street spaces on a micro-urban scale? What are the challenges with regard to methods, technical feasibility, data availability and workflow when modeling street spaces? How can a suitable framework for semantic street space modelling be conceptualised, and which components are required to support qualitative and quantitative analysis?

[1] A comprehensive discussion of the interviews conducted (the fields of expertise covered, the questionnaire and the survey results) and a description of the setting and results of the workshop was already published. (Tobisch/Löschenbrand/Psenner 2025A)

The methodological approach of this paper is exploratory and iterative in nature, combining a review of existing modelling concepts with the development and testing of a conceptual framework for street space modelling. The first step, existing concepts and tools for modelling the built environment are analysed with regard aspects relevant to street space considerations, including examination scale, representational accuracy, and the ability to capture semantic information. Based on the limitations identified, the methodological, technical, and organisational challenges associated with detailed street space modelling are subsequently examined. In a second step, questions of data availability, data quality, and data handling are explored using the case study of Vienna. The case study serves as test field for assessing the feasibility, limitations, and practical implications of implementing a detailed, semantically enriched street space model under real-world conditions. The findings from the review of existing frameworks and from the case study are then brought together to develop a proposed method for street space modelling. The resulting framework is subsequently applied in the construction of micro-urban CIM models for selected streets, allowing its internal logic, representational capacity, and analytical capabilities to be tested and reflected upon. In this way, the modelling process itself becomes an integral part of the methodological inquiry, informing both the refinement of the framework and the discussion of its potentials and limitations.

3 RESULTS

3.1 Review of Existing Frameworks

3.1.1 Building Models

Building Information Modeling (BIM) is a digital methodology for the integrated representation, management, and exchange of information related to the physical and functional characteristics buildings. (Xue et al. 2021) Unlike traditional CAD programmes, where elements are represented by blocks (composed of geometric elements), BIM programmes are based on architectural elements that can be placed freely from a prefabricated library. This object-oriented approach also reveals the roots of this approach, which can be traced back to the manufactoring industry (Eastman et al., 2011). For each of these elements, a range of information is stored in a database, which provides the model with its semantic properties. Today, BIM software for 3D modelling, such as Graphisofts ArchiCAD and Autodesks Revit, is more widely used than traditional CAD software, with the BIM standard having long been established in practice. IFC (industry foundation classes) define the corresponding standards for the both the structural framework and the file exchange format. They are structured hierarchically according to the requirements of building modelling (project, site, building, storey, element) and depict the relationships between elements and contain their underlying information. This allows data to be exchanged between different actors or even joint models to be operated. BIM thus functions not only as a three-dimensional modelling approach, but as an information management framework that supports process integration and data interoperability within the built environment. While BIM enables highly detailed representations, its structure is geared towards building production and management, and therefore does not offer modelling logic that goes far beyond the property scale, making it difficult to depict spaces that extend beyond that.

3.1.2 Urban Models

City Information Modeling (CIM) was introduced by Lachmi Khemlani in 2007 as an urban-scale counterpart to Building Information Modeling (BIM). Since its emergence, the concept has become increasingly prominent in academic urban research and has also gradually been adopted in urban design and planning practice (Souza/Bueno 2022, Xue et al. 2021). The initial approaches to CIM were strongly influenced by existing frameworks and combined Building Information Modelling (BIM) and Geographic Information Systems (GIS) data environment concepts (Xu et al., 2014). While often framed as a purely technical modelling approach, CIM can also been understood more broadly as a conceptual lens through which theories, methods, and tools from multiple disciplines can be integrated and examined on an urban scale analogues to BIM on the building scale (Stojanovski, 2013). It is described as three-dimensional model on an urban scale, that is based on city information data and has a multidisciplinary framework for collaboration (Xu et al. 2001).

Recent studies have a broader technical scope and emphasize advances in data acquisition and processing, including laser scanning, point clouds, artificial intelligence, and visual programming languages (La Russa et

al. 2023), as well as the role of CIM in smart city initiatives and urban digital twins (Cureton/Hartley 2023). By now, CIM is also understood as a means of covering and illustrating a wide range of other topics. Omrany et al. (2023) made an effort to identify all topics within this increasingly broad field and have compiled the most important areas of application for CIM: natural disaster management, urban building energy modelling, urban facility and infrastructure management, land administration systems, urban microclimate improvement, smart cities and digital twins, improvement of social engagement, and urban landscaping design. However, the main applications remain often supporting urban planners in designing sustainable cities and enabling the technically informed governace of cities (Souza/Bueno 2022).

Despite this growing body of work, a clear and universally accepted definition of CIM has remained elusive. CIM can therefore be understood less as a single, well-defined methodology and more as an umbrella term encompassing a range of intelligent city modelling approaches. What all of them seem to have in common is a three-dimensional representation and the inclusion of other, not necessarily spatial data in a semantic database of some kind. Nevertheless, some standards are also gaining ground here, arguably the most commonly used standard for CIM is CityGML (Ohori et al. 2018) developed by the Open Geospatial Consortium (OGC). Similar to IFC it is an application independent framework and exchange format. A particular interesting feature in CityGML is its Level of Detail (LoD) concept, which describes the level of detail for different objects (such as buildings, vegetation and terrain). Starting with LoD0 (footprint and roof edge), through LoD1 (block representations), LoD2 (roof models), LoD3 (detailed models), levels of representation accuracy are classified using the example of a built structure (OGP 2021). With all LoD being able to represent indoor information as well.[2] While very different degrees of accuracy can be classified here, the high levels of detail in particular are rarely found in large scale applications. Therefore, an example for one of the various limitations in CityGML with regard for the modelling of street spaces is the missing representation of elements above the street surfaces i.e. objects in public space (Beil 2025).

Other terms for urban models, which are becoming increasingly popular, usually refer to similar concepts that cover partially the same subject areas, but differ in their scope or focus. One example is the term (urban) digital twin (UDT), which also describes a semantic 3D model of urban dimensions. However, digital twins generally represent the current state of a city, while CIM has no restrictions of this kind and therefore enables also representations of the past and simulations of the future. At the same time, UDTs usually represent a structure for the dynamic monitoring, management or development of urban space and are therefore anove all to be understood as a governance tool. However, as Cureton & Hartley (2023) emphasise, good CIM is a prerequisite for making the transition from static (GeoBIM) models to dynamic UDTs.

3.1.3 Street Models

In addition to BIM and CIM, which are both semantic 3D models, there are already several different approaches to representing street spaces using various methods, levels of detail and amount of information, which are examind in the following.

Street View Imagery (SVI) is the most commonly used representation od streets and readily available on a multitude of platforms.[3] It is deployed for a number of different uses, most prominently for the creation and mainteinance of spatial data infrastructure, but also for the extraction of greenery, urban morphology analyses, transportation and mobility analyses, urban perception and more (Biljecki/Ito 2021). As it contains detailed visual information, it is also suitable for for reviewing the built environment (Kelly et al. 2013). However, due to the manner in which SVI is recorded (georeferenced photos are stitched together to form panoramas) they do not inherently contain explicit geometrical data and can therefore not be classified as street models.

One step beyond this are representations that are constructed with (textured) 3D meshes – often created combining surveying methods like photogrammetry or LiDar scans – which makes them visually detailed and geometrically accurate. While these models feature a relatively high level of detail (that still seems to be

[2] The original LoD4 class, which referred to interior models, was dropped in CityGML 3.0, as was the linking of semantic information with the level of detail in the modelling.

[3] The most widely used platforms are undoubtedly Google Street View and Apple Look Around, but Mapillary, which is based solely on images captured by users, also offers extensive coverage. Additionally, many municipalities conduct their own data collection, like the Kappazunder program by the City of Vienna (which simultaneously captures other data sets, such as 3D point clouds)

lacking in the case of objects in public space accoring to Golombek/Marshall 2021) that makes them appealing for examining individual street spaces, they are missing a sense of depth that can be perceived in the street space (i.e. through the windows of adjacent buildings) and are usually lacking all semantic information. While a lot of information is discernable from these meshes (the human eye can differentiate between a tree and a house and is able to identify the permeable parts of facades from closed walls) this information cannot be automatically processed and analysed without performing additional processing steps (Babahajiani et al. 2017). In this regard, there are also efforts to develop a method for a pipeline from point clouds to the semi-automated creation of object-based 3D models using AI. (La Roussa et al. 2023) However, the focus here is on buildings and building blocks; modelling of public spaces is not (yet) included.

In comparison, the semantic road model as described by Beil (2025:81) and based on CityGML in fact contains solid three-dimensional elements instead of surface meshes. In addition to the street surface, various objects in public space, like street signs and traffic lights are represented, as well as the adjacent buildings as simple volumes. In this case, the term semantic refers mainly to information concerning transport infrastructure, such as the hierarchies of functions when two streets meet. This approach does not include the detailed modelling of adjacent buildings, ground floor zones or the space underneath the surface. Vegetation, however, is included, but only visual factors are taken into account here; the underlying ecological data is not recorded.

The procedural modelling of street spaces is another approach, that enables the creation of detailed 3D models using 2D map data and a set of rules to generate a model for example using 3D-GIS aplications like Esri CityEngine (Badwi/Elliaty/Youssef 2022) or using OpenStreetMap data and Houdini (Gao/Gao/Yu 2022). These necessary parameters and variables can relate to the design of the street space itself (lanes, sidewalks) as well as the design of the adjacent buildings (building age, style, façade elements) and elements in public space (street lighting and furniture). This approach is generally also able to produce solid 3D elements equipped with semantic information. Although these models can sometimes be highly detailed they remain a generated approximation of reality and do not represent the actual qualities of the real location (Kelly 2021).

There are a number of other modelling approaches on a similar scale, worth mentioning here is the Neighbourhood Information Model (NIM) by Cookes (2025) and the Settlement Information Model (SIM) concept described by Sattler (2024). The aim in both approaches is to model entire neighbourhoods of settlements (in the latter case post-war housing estates), including their buildings, the associated open spaces and street spaces using a BIM-based method. In addition, Sattler aims to incorporate social aspects and parameters relevant to quality of life. While both these approaches still appears to be very much in the conceptual phase (with the authors mainly reflecting on existing tools and frameworks themselves), they also reflects the desire to create a semantic model on a similar scale that achieves a high level of detail and combines several domains (buildings, open spaces, streets) that are traditionally treated separately as well as non-physical aspects.

Outside of the field of modelling the built environment for research and design purposes, there is other use cases for highly sophisticated visual models of street spaces, most notably the gaming sector.[4] Procedural modelling using a set of rules or predesigned module libraries is in this case employed to generate realistic representations (in terms of geometries and surfaces) of spaces without any reference to real-life locations (whereby not only the street itself, but the entire city's street network is created). While in this context, the richness of detail serves as a backdrop for the gameplay only, but it does, in fact, reveal how these spaces need to be modelled in order to be representative to how public spaces are actually perceived – in great detail.

Due to the absence of a clear definition for CIM, there is also a lack of distinction from street space models. At the same time, approaches for street models often often use the same modelling logic as either building-related or city-wide models, and the limiting factor in applying detailed road space models to entire cities seems to be mainly computing power. At the same time, modelling concepts for settlements (Sattler 2024) or building blocks (La Roussa et al. 2023) are also being considered in a similar scale and level of detail (in

[4] Impressive examples of this can be found particulary on media platforms: e.g. https://80.lv/articles/001agt-006sdf-procedural-brooklyn-in-houdini

CityGML terms this corresponds to LoD3). Therefore, street space models are described here as CIM on a micro-urban scale in order to also incorporate similar concepts within this superordinate terminology.

While the existing frameworks analysed cover various aspects that are relevant to a qualitative street space model, there does not appear to be a comprehensive compilation of these in a single framework to date. The various authors identify numerous difficulties and limitations of their respective methods. While none of these frameworks were developed with the intention of creating a qualitative street space model, some of the limitations mentioned above also apply in this context. Further challenges anticipated the creation of a detailed, semantically rich 3D street model are highlighted in the following section.

3.2 Challenges

The challenges involved in creating a new framework are manifold. This section will address those that have already emerged from the analysis of existing frameworks. Others that only arose during the course of the process can be found in the subsequent chapters.

3.2.1 Depicting non-physical aspects

Arguably the greatest challenge for a framework for the analysis of street spaces from a qualitative perspective is that of integrating non-object-related or non-physical aspects. The aim of any semantic model is to attach all relevant aspects to modelling objects. These modelling objects do not necessarily have to be real-life physical objects – examples include the road centre lines frequently used in GIS analyses or the representation of uses as spatial volumes in BIM applications – but spatially precise delimitation is still a prerequisite for the representation as a modelling object.

Therefore all the identified relevant aspects were examined with regard to their representability. Different groups were identified: those aspects that can be represented in 3D objects, groups of 3D objects or can be calculated from them, those for which non-physical modelling objects can be created, and those that cannot be represented at all on a street segment basis. As will be outlined below in 3.3.2 all these aspects are covered in the theoretical framework, but the latter group had to be left out of the modelling logic for the time being. The information relating to these aspects cannot therefore be processed and evaluated directly in the model and must still be covered in another form.

3.2.2 Data availability and handling

One challenge concerning street space modelling is the data, since an accurate model on that scale requires a rather large amount of highly detailed data. Many of the methods examined use only specially created data sets (i.e. LiDar scans). These are often technically demanding, expensive or time-consuming to produce. Therefore, the present study strives to acquire as much data as possible from existing and publicly available data sets, only when no data is available, additional data is collected. Since data availability can vary greatly from municipality to municipality, making it difficult to draw general conclusions, this study focuses on the case of Vienna. A total of three research streets was investigated, and all data-related challenges that arose in the process are outlined here, including availability, compilation, handling, processing and collection.

The data review was carried out in the following steps. First, the digital data sets that are publicly available as open government data (OGD) on the platform data.gv.at were examined, starting with the 3D data sets and continuing with the 2D datasets. Then, analogue data sets from archives were consulted. Finally, any missing data was supplemented by manual collection on site.

The identified relevant 3D datasets are the terrain model (Geländemodell Dreiecksvermaschung) and, because the building model only has a low level of detail, the roof model (Generalisiertes Dachmodell LOD2.1).[5] However, neither of these two data sets can be imported directly into the street space model, as they are surface meshes (instead of solids) and do not provide the desired level of detail. For example, the terrain model is only a rough approximation that does not show any height differences within the street space (such as kerb edges). Similarly, although the roof model shows the volume and approximate shape of the buildings (sometimes even including bay window), it does not provide any further information (balconies,

[5] Geländemodell Dreiecksvermaschung Wien (https://www.data.gv.at/katalog/en/dataset/bb86970f-3cef-4f9a-a79b-ff277ea925c8), Generalisiertes Dachmodell (LOD2.1) Wien (https://www.data.gv.at/katalog/dataset/86d88cae-ad97-4476-bae5-73488a12776d)

façade design, entrances etc are missing). Therefore, both data sets can only be used as crude basis for modelling. Some of this missing information can directly be supplemented from 2D data sets. For example, the 2D city map (Mehrzweckkarte)[6] contains additional elevation points that enable more accurate modelling of the road surface, but even here the exact difference in height at the kerb is not specified. However, this map does indicate the division of the street space itself, i.e. the location of the kerb, the existing green areas, the arrangement of some elements in the street space (such as meter boxes or lampposts), and the building plots, footprints and position of the entrances and is therefore one of the key sources of data. Aerial photographs[7] were also used to obtain additional information about the street space, such as the number and type of parking spaces, the location of garage entries and additional objects in public space that are not already covered by the 2D city map (such as traffic signs, rubbish bins or benches). The records of cables and pipes (Zentrales Leitungskataster&Digitales Kanalinformationssystem)[8] provide information about underground infrastructure in the street space. These data sets are also only provided in 2D, and the availability of information for modelling (dimensions, height information) varies greatly. Since this data cannot be corrected manually, some assumptions have to be made in order to approximate the real situation. For more detailed information about the existing trees, beyond that provided by the 2D city map, such as tree species, tree height and age, the tree cadastre[9] was consulted. The City of Vienna maintains its own non-public application for image and Lidar data (Kappazunder[10]), where the surveys from 2020 are also available as OGD, but since the data is outdated and requires intensive pre-processing due to the large data volume, it was not used in this case. The spatial OGD datasets are generally available as dxf and, in some cases, as shp, allowing them to be opened and edited using standard CAD or GIS programmes, the aerial photos are available as jpeg. Some data can also be read directly via a web application (i.e. kanis) although this has to be done manually, it is the simplest method for manageable research areas.

In addition to digital data sets, analogue sources were consulted. Plans of all buildings adjacent to the streets, which can be accessed in the archives of the Building Department (Baupolizei – MA37), enable the three-dimensional construction of the façades and, on the ground floor, the spatial structures behind them. Since these building plans are sometimes very old, there are often discrepancies to other datasets that become apparent when combining them. A common example is the representation of floor plans on a perfectly rectangular plot of land, even though in reality the lengths of the plot sides and angles of the corners vary. In these cases, abstraction and approximation of the information is necessary.

All data necessary for a qualitative analysis that has not been mentioned above was collected on site. This includes photographic documentation of the façades, which allows for the precise reconstruction of detailed structures such as placement and appearance of doors, windows, balconies and mouldings. In addition, all furniture in the public space was recorded and the use of the ground floor zone as perceived from the street was documented. For more accurate modelling of the street surface, kerbs and other height differences were also measured. The remaining data was checked against reality and corrected where necessary.

3.3 Towards a Street Space Model

Based on the information obtained from the review and with the results of the investigation of the challenges in mind, a framework for a semantically rich street space model was developed.

3.3.1 Spatial and Conceptual scope

Since street spaces are in some cases highly specialised for specific purposes and the relationships between different streets in the network lead to diverse dependencies, restrictions have been set for the area under consideration. Given that the analysis is aiming to focus on the individual street itself, all streets whose use and design is primarily guided by higher-level systemic considerations, such as transport axes or shopping streets, are therefore excluded for the time being. Thus, the framework was limited to the consideration of secondary streets that mainly reflect local needs and conditions.

[6] Mehrzweckkarte Vektordaten (https://www.data.gv.at/katalog/dataset/stadt-wien_mehrzweckkartevektordatenwien)
[7] Orthofotos 2024 (https://www.data.gv.at/katalog/datasets/81868c1e-ce21-4c57-b53b-09fd5ffa0d0d)
[8] Zentrales Leitungskataster (https://www.wien.gv.at/verkehr/strassen/leitungskataster/), Digitales Kanal Informationssystem (https://kanis.at/)
[9] Baumkataster bzw. Bäume Standorte Wien (https://www.data.gv.at/katalog/en/dataset/c91a4635-8b7d-43fe-9b27-d95dec8392a7) or in the web viewer (https://www.wien.gv.at/umweltgut/public/grafik.aspx?ThemePage=11)
[10] Description of the Kappazunder application (https://digitales.wien.gv.at/projekt/kappazunder/)

The smallest possible area of consideration that allows for the desired qualitative analysis and is therefore sufficient for the creation of the framework was determined in the next step. In order to perform the analysis, at least one street segment (i.e. from intersection to intersection) is needed to be able to identify the qualities present and their interrelationships. As corner situations hold a distinctive position within the urban fabric – historically significant functions were often situated on the ground floors of corner buildings. (Psenner 2023) Information regarding the hierarchies between different user groups can also be found at this intersection of different streets. It is essential that these intersections are also included in a 3D street model. The street segments to be examined therefore need to have intersections at both ends that creates a corner situation on both sides of the street (meaning T-intersections are not suitable end points). Since, in addition to the façades, the connections and relationships with the ground floor zone and its uses are particularly relevant to the quality, functionality and design of the street space (Tobisch/Psenner 2021, Psenner 2023), they are modelled in their entirety and their uses are also documented.

To ensure that the framework and modelling logic are able to represent a wide range of conditions, research streets from different eras of construction were selected (Gründerzeit, interwar period and present day).

3.3.2 Introducing the SSSEIC Method

The SSSEIC method framework structure makes use of various components from other concepts (such as BIM and CIM) and introduces new logic wherever no suitable elements exist. All of the aspects collected were divided into three categories: those that can be modelled within the area under consideration, those that apply to the entire street segment, and those that extend far beyond the spatial scope and must therefore be considered in a higher-level analysis. For clear identification, those groups were named modelling parameters, meta parameters and evaluation parameters.

The group of modelling parameters is further subdivided and structured hierarchically. While in building-related projects the IFC nested structure goes from project to site to building to storey to element, a different spatial organisation must be considered for the street space. For this purpose, the street space is divided into five different spheres: The street level itself (the surfaces of the street space and all its uses), the street furnishing (all objects that are located in the public space above the surface: lighting, traffic lights, signs, benches, etc.), the underground (everything below the streetlevel i.e. the pipes and cables), the building level (the facades and the ground floor zones including the uses), and ecology (all vegetation). These five groups were chosen on the one hand based purely on spatial considerations (e.g. separation of public space and its enclosing elements), and on the other hand because they represent the typical (main) areas of consideration for different experts, thus providing a logical basis for interdisciplinary collaboration. Also for this reason, ecology has been highlighted separately – it sometimes extends into several spatial spheres, but is addressed by one field and therefore forms its own unit.

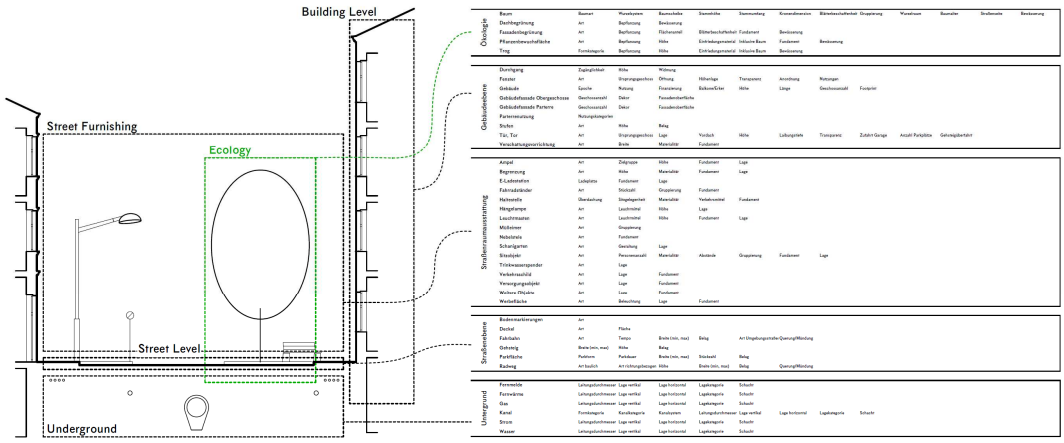


Fig. 3: The street is divided into different spheres within the framework. © Löschenbrand, Tobisch, Psenner

Within these spheres, there are sometimes further distinctions (individual buildings within the building level) followed by the individual modelling objects. These objects are equipped with a range of properties relating to the object type, dimensions, surface and context (there can always be several properties per category). Within the context category in particular, relevant information for qualitative analysis can be recorded that

relates not just to individual objects but rather to the relationships between them (e.g. a bench is situated under a tree)

With this SSSEIC framework, streets could already be accurately and comprehensively described. In the next step, this framework was therefore be put to the test to determine its applicability for the construction of a CIM on a micro-urban scale.

3.3.3 Modelling Programme

Currently, since there is no framework specifically tailored to semantic 3D modelling of streets, there is also no suitable programme available on the market. Therefore, in some of the cases already described (see 3.1.3), as well as in the present study, programmes that were originally intended for a different use were adapted for this purpose. This of course introduces its own set of problems and challenges, one of the most complex of which is circumventing the modelling logic built into the programmes.

After an initial test of CAD and GIS programmes to identify their respective limitations, CAD programmes were given preference over GIS programmes due to their capability to produce detailed representations. Since the lack of detailed and semantically rich street space models was the initial motivation for this study, the focus was ultimately placed on this aspect of modelling over others. A detailed representation usually leads to a restriction of the manageable research area, but this was not a concern for the initial three research streets and was therefore tolerated as a limitation for the time being. Therefore, all programmes that enable fine-scale representation were selected for closer consideration.

The input of GIS data was of minimal benefit due to the high proportion of manual work required and was therefore not a decisive criterion, which is why Vectorworks (a CAD programme with GIS data embedding) did not have an advantage over other CAD programmes. Ultimately, ArchiCAD was selected because its semantic database structure, based on freely selectable ‘properties’, allowed for a relatively high degree of customisation to create a proprietary framework. Nevertheless, there were certain limitations, which will be described in more detail below.

3.3.4 From Framework to Model

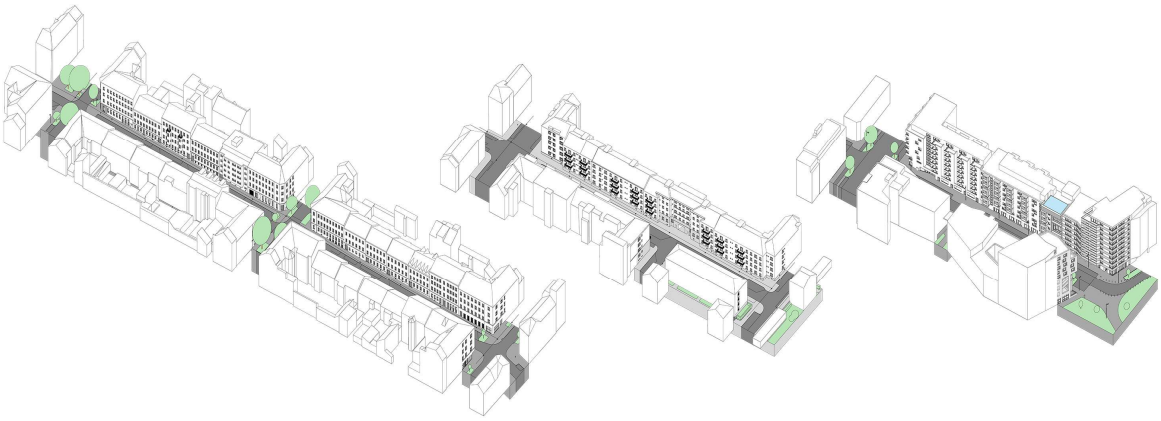


Fig. 4: Models of the three Viennese research streets © Tobisch, Löschenbrand, Psenner

For modelling purposes, ArchiCADs built-in logic, which is based on ifc standards was omitted as far as possible, therefore the parameters of the framework were established as properties. All modelled objects were assigned the properties, wherever the were known. For quantitative evaluation, apart from numerical values resulting from the geometry, only these properties were consulted. In addition, layers were used to display and hide elements during the modelling process, these were also based on the framework and are partially overlapping with the properties. In addition, layers were also used, which were also based on the framework and are partially congruent with the properties. They were mainly used to be able to show and hide elements, thus achieving a good view on the one hand, but also faster editability on the other. However, this revealed the first insurmountable issues with the logic inherent in the programme, as the layers cannot be freely selected for all elements. For example, doors and windows are designed as part of the wall and are therefore always located on the same layer. Similar challenges also arose with individual geometries, one example of which is the floor-by-floor structure of the model in the programme, which prevents openings that span several floors from properly displayed. To counter this problem, the façades above the ground floor

were no longer modelled floor by floor, but in their entirety with wall elements spanning multiple floors. Since the same applies to the placement of windows and doors in wall bends, workarounds that are also common for BIM models were used for the ground floor zone itself, for example, placing a second, empty opening in the adjacent wall. Another difficulty was the mesh tool, which is intended for modelling terrain. Here, the triangulation of the surfaces seems completely arbitrary, and the surface can only be clicked on at elevation points but not elsewhere on the surface. As already mentioned, the entire model had to be built manually. Since ArchiCAD is a building oriented software, the workflow was, as expected, easiest for architectural elements that are mainly horizontal or vertical, while other elements that are angled or curved, such as underground pipes and cables that are aligned with the eleveation of the street were tedious to create. Ultimately, the morph tool was frequently used, as it allows for free modelling with only minimal restrictions.. This was particularly useful for decorative elements on the façade and for furniture in public spaces. Initially, the amount of work involved is considerable because objects first have to be modelled, but the elements can be stored in the object library and used repeatedly, even across different files.

As already mentioned, no elements could be directly incorporated (ultimately, there was one exception: the roof model was used to represent the envelope for the roof and the backside of the buildings adjacent to the street and also the surrounding buildings). Therefore, a large amount of modelling work was necessary for the model creation. Similar to BIM models, populating the database remains in part a manual task. For aspects that are non-physical but can be represented in the model and within one street segment, a series of modelling objects (mostly zones) were created for evaluation. While consistent objects are preinformed with semantic content from the get-go, aspects with changing information (such as zones that can have different uses) or the relationships between elements have to be added by hand. Nevertheless, the CIM models on a micro-urban scale could generally be created based on the framework, and corresponding quantitative and qualitative evaluation was also possible.



Fig. 5: View of a street space model superimposed with semantic information from the database © Tobisch, Löschenbrand, Psenner

4 DISCUSSION

So far, the framework has proven useful for the qualitative description of street spaces, but there are still a number of challenges that are the subject of ongoing conceptual efforts.

Methodological Limitations

The method itself has not yet been finalised in terms of workflows and thereofre still exhibits some limitations. For example, although the evaluation parameters are included in the framework, their integration or relationship to the model has not yet been further elaborated. An analysis workflow that reincorporates these parameters that cannot be depicted within the model itself is presently under active development.

Technical Limitations

The technical limitations mainly include programme-related challenges. The use of a BIM programme was feasible for modelling individual road segments, albeit not ideal, but would lead to performance issues in larger sections. In past modelling approaches, streets were at times modelled in sections and divided into several files to avoid this problem. (Psenner 2023) Even though a considerable effort is currently being made

by various parties, at the time of writing this text, no adequate programme is yet in sight. Although there are some concepts that have been announced as being in development, including a CIM by Stojanovski et al. (2025) that covers the relevance of detailed morphological elements, at least in theoretical considerations, and could therefore potentially be a step in the right direction.

Organisational Limitations

Creating the models and the underlying databases is an extremely labour-intensive process. The data imported from the data sets merely serves as a basis for the manual creation of the model. In addition, all elements of the 3D model (modelling objects) are manually assigned their corresponding properties, with up to ten different variables available per object. It is evident that modelling a single street requires a considerable amount of time. Consequently, extending the analysis to several interconnected roads or entire urban areas is only feasible if data sets are automatically integrated into the 3D model, such automation (possibly involving the use of AI) represents a promising area for future academic research.

In addition to the aforementioned limitations, further noteworthy insights can be derived from the present study. The different construction ages of the street spaces did not result in a significant difference when creating the models; it was simply a matter of using different objects (i.e. lampposts instead of suspended lights). However, the building structures differed significantly in terms of the modelling effort required – the smaller and older the structures were, the greater the effort required. However, this was mainly attributable to the quality of the planning documents. As anticipated, the qualitative analyses did reveal significant differences in the qualities of the street space from different eras and, consequently, differing potentials for redesign. (Tobisch/Löschenbrand/Psenner 2025B)

5 CONCLUSION

This paper set out to investigate the potential of detailed, semantically enriched 3D modelling approaches for the analysis and evaluation of street spaces, a scale that remains insufficiently addressed by existing BIM- and CIM-based frameworks. While building-scale BIM and city-scale CIM have become well established for their respective purposes, the streetscape – despite its central importance for urban life, perception, and climate resilience – continues to be analysed using fragmented, largely outdated methods. The findings of this research confirm that this gap is not merely technical, but conceptual, rooted in the lack of a modelling logic that adequately reflects the spatial, functional, perceptual, and social complexity of street spaces.

Through the review of existing frameworks, it became evident that none currently offers a comprehensive solution for qualitative street space modelling. BIM provides high geometric and semantic detail but is limited by its building-oriented logic, while CIM approaches typically operate at a scale and level of abstraction that precludes meaningful representation of street-level qualities. Existing street modelling approaches, although diverse, either lack semantic depth, sufficent level of detail or were created for a different purpose entirely. Against this backdrop, the SSSEIC method was developed as an attempt to systematise and integrate relevant aspects of street spaces within a coherent framework that is compatible with semantic 3D modelling.

The application of this framework in a micro-urban CIM, using ArchiCAD as a test environment, demonstrated that detailed and qualitatively rich street space models can indeed be created and evaluated, albeit with considerable effort and technical limitations. In particular, the integration of non-physical aspects, data availability, and the lack of dedicated modelling software remain significant challenges. Nevertheless, the results show that the proposed framework enables a holistic description of street spaces and supports interdisciplinary analysis, prioritisation, and decision-making – an increasingly urgent need in the context of climate adaptation and constrained municipal resources.

Ultimately, this research should be understood as a foundational step rather than a finished solution. Further work is required to refine evaluation workflows, incorporate automation, and, last but not least develop tools specifically tailored to a CIM on a micro-urban scale. Even so, the study demonstrates that treating streets as a distinct and central scale of urban modelling holds substantial promise for more resilient, human-centred, and informed urban design practice.

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Implementation of a Forecast-Based Predictive Controller in a Residential Building

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1 ABSTRACT

To support the European Union's decarbonization pathway for buildings – phasing out fossil heating and cooling by 2040 and achieving zero-emission standards by 2050, this work presents a forecast-based model predictive control (MPC) for thermally activated building components (TAB). TAB provides large-area, low-temperature heat transfer and substantial thermal storage, enabling the controller to use environmental inputs such as solar irradiation to maintain comfort. The proposed MPC reduces complexity by embedding a lightweight, physics-based building model directly in the controller source code and avoiding heavy machine learning pipelines. A 48-hour forecast horizon with hourly updates leverages weather data (temperature, wind, cloudiness) and on-sitebuilding measurements to compute additional heating/cooling actions. Optimization is formulated first via least-squares error minimization for temperature tracking, then extended to a cost-based objective that includes dynamic tariffs, local renewables, CO2 price signals, and a season-dependent comfort band to enable short-term load shifting. Demonstrations in residential buildings in Vienna and Lower Austria show feasibility, high thermal comfort, and improved operability for non-expert users. The results indicate that a complexity-reduced MPC can deliver cost-aware, climate-aligned control with practical implementation effort, supporting broader adoption in the residential sector.

Keywords: Forecast-based controller, model predictive control, load shifting, urban resilience, urban planning

2 INTRODUCTION

In order to slow climate change, the European Union has set a guideline to decarbonize the building stock. The guideline has two distinct milestones on how to achieve that. Until 2040, fossil fuels for heating and cooling have to be phased out and replaced by renewable energies. In the year 2050, the building stock has to reach the standard of a zero-emission building(Europäische Union, 2024).

Thermal component activation is an important basis for sustainable and climate-friendly new buildings. It enables heating energy to be transferred over a large area to the respective residential units at a low flow temperature. This system turns the activated building mass into a large heat storage unit that can absorb and release a large amount of heat energy without causing significant fluctuations in the temperature of the concrete core(Heidenthaler et al., 2021). Based on this system, a controller has been developed that is capable of recording environmental influences such as solar radiation for a period in the future and, based on this forecast, controlling the heat input into the component activation in such a way that the desired target temperature is not significantly exceeded or undershot. For example, solar radiation is actively used to maintain the temperature. Additional functions, such as the inclusion of peak wind power,can be integrated into the forecast-based predictive control (MPC) through extensions and boundary conditions.

3 FORECAST-BASED PREDICTIVE CONTROLLER

Model predictive control (MPC) is a constrained optimal control approach that uses a predictive model to compute control actions over a finite horizon, updating the plan as new data arrive in a receding-horizon manner. It relies on a building model together with current measurements, state estimates, and forecasts of disturbances such as weather to predict and optimize future behavior. A state estimator provides the controller with the best available estimate of the building's internal state for decision making. The controller then manipulates actuators such as heat flows, valve openings, and pump powers to reduce energy use while maintaining occupant comfort within specified bounds. MPC can be formulated as linear, nonlinear, or hybrid, with the choice driven by modeling fidelity and computational considerations. MPCs enable short-term load shifting by using forecast data toshift required heat and cold production into favorable times(Drgoňa et al., 2020).

Yu et. al. estimate, that an MPC can save up to 26,9% in monthly electricity costs, when compared to a basic rule based controller with the same constraints (Yu et al., 2025). This depends of course on more than one factor. Electricity prices, climate and the properties of the residential building are some of the decisive properties when it comes to measuring the cost savings of an MPC.

3.1 Complexity of MPCs

Model predictive controllers for multi-party residential buildings in the literature can be found in a variety of types. Some models use complex machine learning algorithms to filter noise or adapt to new system behaviour. Machine learning can also be applied to certain sub-tasks for example to rework weather forecast data. Different models have varying complexity when it comes to training, implementation and maintenance. Zong et al. give an overview of the advantages and disadvantages of complex MPC models driven by machine learning and sophisticated algorithms:

Pro	Cons
Factors in stochastic properties of disturbance variables (e.g. weather forecast, occupancy profiles)	Highly complex for regular users, as the required background knowledge for active interaction can be high.
Can react to variable energy prices and other influential variables	Time-consuming data analysis and modelling
Can realize short-term load shifting	MPC strategies require higher investments which may not be compensated by additional savings in a short time
Can be formulated in a distributed manner. Computational load can be split among several solvers.	

Table 1: Advantages and disadvantages of MPCs in the residential building sector (Krz et al., 2019)

Zong et al. explain, that an MPC can improve on the concept of a regular outdoor temperature-based controller by factoring in stochastic properties of disturbance variables like weather pattern, occupant related disturbances like airing or cooking and dynamic electricity prices. An MPC is able to include a number of variables and decide the best time for energy distribution in it´s set boundries and time limits, making short time load shifting possible. On the contrast, MPCs elevate the complexity of control. This leads to challenges and boundaries that can hinder the implementation and operation of MPCs. When designing MPCs, machine learning often is at the center of the approach. Reliable models need a lot of training time and data to work sufficiently enough. A building model is also needed, as well as a processing unit where all the data is connected and applied to the building model. A complex MPC needs more attention in the implementation phase when compared to regular controllers and are mostly handled by the developers due to higher complexity. This also applies to data analysis and adjustments in operation. Higher complexity and solutions outside the norm, like an MPC lead to higher investment costs and therefore longer payback periods, when compared to widespread controllers. Another boundry is set by the users. Many MPC concepts fail, because regular users are not able to operate the controller in the right way. While the complexity for the MPC can be high, the interface for the user is required to be straight foreward and easy to use and understand(Krz et al., 2019),(Georges, 2019),(Kamthe and Deisenroth, 2018),(Yang et al., 2020).

3.2 Reduction of Complexity

Reducing the complexity of an MPC addresses the disadvantages of these controllers and can lead to a better outcome when it comes to implemented projects and user acceptance. An MPC in its core is an optimizer. To reduce the complex machine learning models, a different approach is suggested by Wolf et al., 2020. By using easier models that do not rely on sophisticated artificial neural networks, several advantages can be shown. Most MPCs for residential buildings use a highly sophisticated building model in a specialized simulation program like TRNSYS, MATLAB or EnergyPlus. The core idea is to map the energy balance of the set boundaries with given input variables. The output of this can be used in the further optimization. While highly accurate, the computational effort and possible interface issues can restrict the choice of the MPC´s hardware platforms. Building a basic building model that is capable of portraying the energy balances, masses and window areas has a sufficient quality for control operations and can be implemented in

the source code of the MPC, making it lightweight. Depending on the aim of the MPC, the optimization can be streamlined as well. If the goal is to meet a certain setpoint, a simple minimization of the sum of squares error between room temperature and setpoint temperature can achieve these results and can be embedded into the source code (Wolf et al., 2020).

4 STRUCTURE OF AN MPC WITH REDUCED COMPLEXITY

As presented before, building an MPC controller with reduced complexity is possible. To better understand its workings the following diagram describes the structure of the proposed MPC:

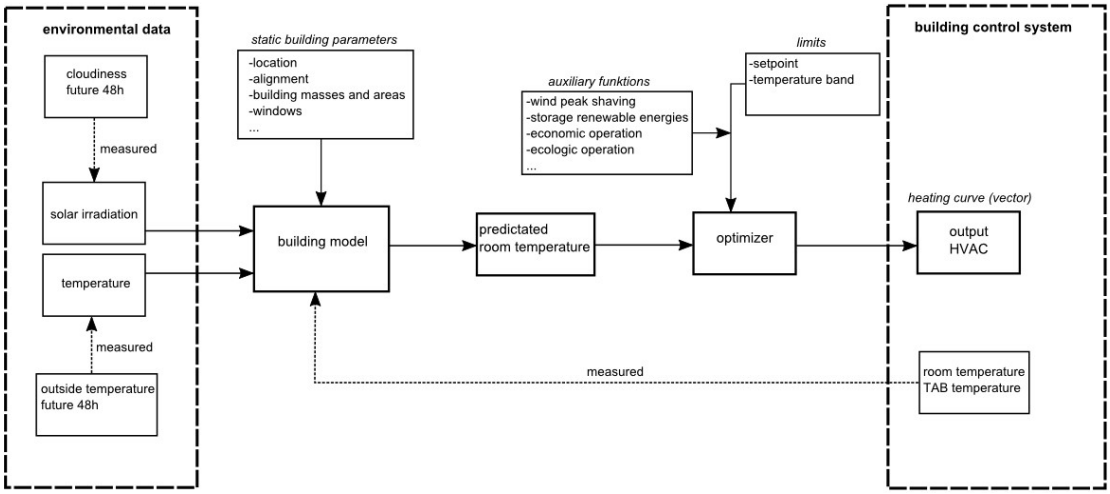


Figure 1: Structure of an MPC with reduced complexity

The outlined structure is based on MPC controllers that are already in active use in residential buildings in Vienna and Lower Austria, Austria. In the following part, the individual components will be described.

4.1 Sensor and Forecast data

The proposed MPC has a forecast horizon of 48 hours. For this purpose, local weather forecast data for the next 48 hours is retrieved. The data consists of outside temperature, wind speeds and cloudiness. The cloudiness in percent of blocked sunlight in combination with the solar irradiation and the course of the sun's position for the given location make it possible to approximate the solar irradiation.

For the calculations, live data from the building is needed. The room air temperature, temperature of thermally activated building components (TAB), outside temperature and energy meters have to be integrated into the MPC to deliver data of the state of the system for each new calculation (Wolf et al., 2020).

4.2 Building model

The building model is the central component of the MPC. For new buildings, the structure of the walls and the building materials used are known. This makes it possible to calculate the thermal storage mass Cp,R of the building. The thermal storage capacity of the thermally activated building components Cp,TAB must be taken into particular consideration. The solar inputs QSolardepend on the orientation and size of the windows, as well as the solar irradiation, which is influenced by cloud cover, time of day and season. Convection and ventilation losses QConv represent the heat losses of the building during the heating period. These heat quantities can be easily calculated for ventilation systems. The model ignores disturbance variables that are difficult to calculate QDist. For example, variables such as internal gains from electrical appliances or heat losses through ventilation via windows or doors are not considered in the model.

To understand how much energy have been put into the considered zone, an energy meter is used. In the schematic the energy meter is implemented using a temperature sensor to measure the temperatures on supply flow and return flow and a flow meter on the returnflow instead of the proposed single unit device. To control the heat flow into the zone in the heating period, a three-way valve is used, mixing the returnflow with the supply flow to establish the desired resulting flow temperature that is specified by the MPC(Wolf et al., 2020).

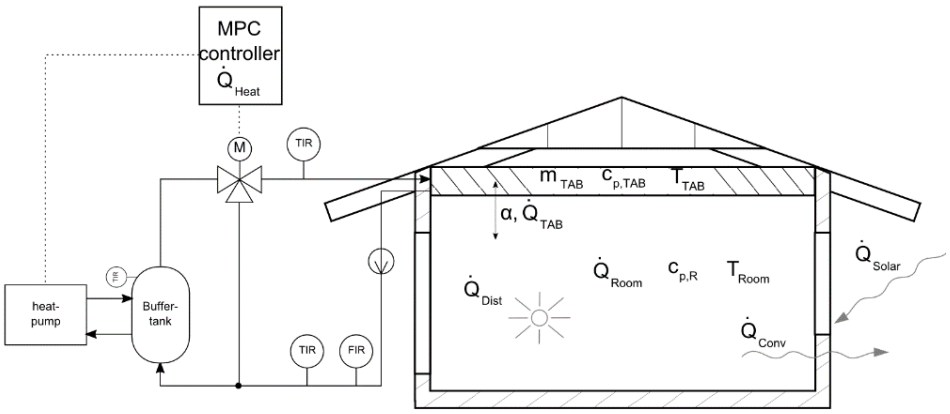


Figure 2: Schematic structure of the building model(Wolf et al., 2020)

This building model is implemented into the complexity reduced MPC via the coding language C, directly in the source code. The properties of the building like mass, alignment, window area and room dimensions are transferred into a static building model. Dynamic variables like outside temperature, room temperature and solar irradiation are projected onto this model.

4.3 Optimization

To optimize the temperature comfort, the setpoint temperature of the user has to be met with high precision. For this, the MPC can use the forecast data to mitigate the effects of environmental impacts on the room temperature.

For this, the dynamic forecast data (outside temperature, solar irradiation) is projected onto the static building model. The actual room temperature (T_{real}) gives the system a starting point for calculations. A predictive room temperature vector for the next 48 hours is calculated from this building model via the energy balance. The first task of the optimizer, which represents the next step, is to compare this predictive room temperature with the target room temperature set by the user and to specify a heating or cooling load for the heating system. In the basic version of the MPC, the deviation from the optimum comfort level (setpoint temperature of the user) is determined by minimizing the error sum of squares (LSE) (Klepicet al., 2023).

$$f(\vec{x}) = \sum_{i=0}^{47} \left(T_{SP,i}(\vec{x}) - T_{real,i}\right)^2 \rightarrow min \tag{1}$$

As described in (1), the aim of the basic optimization function is to minimize the offset of the room temperature (T_{real}) from the setpoint temperature (T_{SP}). The result of the optimization is a heating/cooling vector for the next 48 hours. The first element of this vector is transferred to the heating and cooling generator system and represents the energy demand for the following hour. This calculation is repeated every hour. (Klepic et al., 2024)

To take this approach a step further, the target function is converted into a cost optimization. This consists mainly of three parts as described in equation (2)

$$f(\vec{x}) = \sum_{i=0}^{47} \left(C_{Comfort,i}(\vec{x}) + C_{Cost,i}(\vec{x}) - B_{preheat,i}(\vec{x})\right) \rightarrow min \tag{2}$$

The optimization consists of three parts.

$C_{Comfort,\ i}(\vec{x})$represent costs for not reaching the desired temperature levels. To increase the flexibility, a temperature band around the setpoint is introduced. It gives the MPC the ability to shift load into favorable time spans. For summer and winter this temperature band looks different, as shown in Table 2.

The temperature band is different for heating and cooling seasons. The reason is that in the heating season, overheating requires energy and therefore gives the system the flexibility to store more heating energy into the TAB when the conditions are favorable. This stored heating energy can be used to keep the room

temperature levels into set limits during unfavorable production times. For cooling this principle is the exact opposite.

	Upper band	Lower band
Cooling season	T_{SP} + 1K	T_{SP} -3K
Heating season	T_{SP} + 4K	T_{SP} – 0,5K

Table 2: Amplitude of the temperature band for heating and cooling

$C_{Cost,\ i}(\overline{x})$ are the actual costs for the energy required to produce the heating or cooling energy required to reach the targeted room temperature levels. For these costs, locally produced renewable energy systems, like photovoltaic or wind can be implemented. Flexible energy tariffs and costs for CO_2 can also be included to give a more holistic approach to costs of energy use (Wolf *et al.*, 2020; Klepic *et al.*, 2024).

$B_{preheat,\ i}(\overline{x})$ describe a bonus for preheating or precooling. Energy use is to be moved into hours with favorable costs, which reduces the costs for heat production in the observed forecast horizon.

5 CONCLUSION AND OUTLOOK

The presented work aligns with the European Union's pathway toward decarbonizing the building stock by 2040 and achieving zero-emission performance by 2050. By leveraging thermal component activation (TAB) as a distributed storage and low-temperature heat transfer system, and combining it with a forecast-based model predictive control (MPC), the approach enables efficient, comfort-oriented operation that actively uses environmental inputs such as solar irradiation and variable energy costs.

A central contribution is the reduction of MPC complexity. By embedding a lightweight, physics-based building model directly into the controller source code, avoiding heavy machine learning pipelines, and adopting streamlined optimization objectives, the proposed MPC maintains the core benefits of predictive control – load shifting, cost-aware operation, and comfort assurance – while reducing implementation effort, computational burden, and user-side complexity. The integration of a temperature band around the setpoint provides the flexibility required for shifting energy use to favorable time windows, with asymmetric bounds tailored to heating and cooling seasons to exploit TAB storage effectively. The cost-oriented formulation allows inclusion of local renewable generation, dynamic tariffs, and CO2 price signals, thereby supporting both operational savings and climate targets.

The proposed MPC is currently in the demonstration phase in 3 projects. One project is already operational in Purkersdorf, Austria. It consists of 2 residential units in a two-family home and is controlled by an MPC with comfort optimization. The second demonstration project is called "ZQ3Demo" and consists of 15 residential units in a housing estate in Donaustadt, Vienna. Here a mixture of MPCs with comfort optimization and cost function optimization is tested. Four residential units with rule-based controllers are monitored as well to compare the results of the MPCs to conventional controllers. Another project with 3 residential units controlled by an MPC is currently providing data in Wolkersdorf, Austria. This project called "Zukunftshaus Wolkersdorf" consists of 3 comfort optimization MPCs.

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🏆 reviewed paper

Implicit Sufficiency in Regional Planning? Insights from a Town Center Revitalisation Programme in Styria, Austria

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1 ABSTRACT

Village and town centers are increasingly recognized as key locations for creating compact, high-quality living environments with short distances, social interaction, and local economic activity. Regional programs of urban development emphasize their importance as multifunctional hubs that can reduce daily transportation needs, support local services, and counteract urban sprawl. However, it remains largely unclear to what extent these centers can contribute to reducing space and material consumption.

This paper examines the role of sufficiency within the framework of the "Starke Zentren" (Strong Centers) initiative, a regional support program in Styria (Austria). This program aims to assist municipal decision-makers through advisory services and strategic guidance for strengthening village and town centers. Sufficiency refers to the reduction of absolute resource consumption through demand-oriented spatial development and complements strategies of consistency and efficiency. We use sufficiency as an analytical lens to identify resource-reducing aspects of that program.

We investigate which forms of sufficiency, understood as resource-saving strategies, are reflected in the measures of the "Starke Zentren" initiative through a qualitative content analysis. We systematically categorize existing measures by type (strategy, tactic, pilot) and assign them to spatial fields of action. This approach reveals the aspects of sufficiency implicitly addressed and where substantial gaps remain. The findings indicate that many measures exhibit only moderate transformation potential (as derived from program descriptions), while strongly sufficiency-oriented interventions remain rare. Tensions between economic revitalization and resource conservation constrain their impact. The analysis also highlights the adjustments and complementary measures that are necessary to strengthen the sufficiency orientation of existing center-development strategies.

Keywords: Sufficiency, Regional Planning, Town Center Revitalization, Resource reduction, Regional programmes

2 INTRODUCTION

Rural village and town centers in European context gained increasing attention as key spaces for everyday life. Recent academic and policy-oriented contributions highlight not only the need to maintain local services and social meeting places, but also the importance of territorial cohesion in the face of structural change and demographic shifts (Ciampa et al., 2025; OECD, 2021). Village and town centers play a crucial role in the quality of life of their residents. In contrast to functionally separate settlement structures, the focus is now on compact and multifunctional centers that can meet daily needs within short distances, promote shared use, and offer accessible public spaces. Therefore, strengthening village and town centers has become a central objective of spatial planning strategies at the European and national levels, particularly with regard to sustainability, accessibility, and the efficient use of existing settlement structures (OECD, 2021; ÖROK, 2019).

Despite the focus on village and town centers, it is unclear to what extent their revitalization is linked to low resource consumption or sustainable everyday practices. Many village and town center revitalization strategies follow a growth-oriented planning paradigm and are primarily aimed at economic activation and competitiveness, even though many of the regions are experiencing demographic decline (Leick/Lang, 2018; Sancho Reinoso/Dax, 2024). Often, village and town center revitalization efforts still involve expansion into peripheral areas and car-centric mobility, which can lead to urban sprawl and resource-intensive everyday practices (OECD, 2021; ÖROK, 2019).

The prevailing growth-oriented development logic is increasingly being questioned in academic discourse also within the discipline of urbanism. Recent publications emphasize the need to acknowledge material limits and develop a system that gradually transforms existing spatial structures into resource-efficient and

regenerative systems (Degros et al., 2023). From this perspective, prosperity is no longer solely associated with growth, but rather with the ability to reconcile well-being and ecological limits (Jackson, 2009).

While programs for the revitalization of villages and town centers are typically formulated with consideration for sustainability, quality of life, and spatial efficiency, they lack a systematic analysis of whether and how these measures can contribute to an absolute reduction in resource consumption in residents' everyday lives. Questions of limiting, prioritizing, and determining the appropriate level of spatial development are of central importance and often remain unanswered in center-oriented planning strategies (OECD, 2021; Sancho Reinoso/Dax, 2024). In this paper, we use the concept of sufficiency as an analytical approach. Sufficiency focuses on reducing overall resource demand through the design of everyday practices, spatial structures, and usage patterns. In contrast to efficiency- and consistency-oriented approaches, which primarily address the nature of resource use, sufficiency raises the question of what level of spatial development, infrastructure, land take (including soil sealing and urban sprawl), and material consumption is appropriate (Böcker et al., 2020). The sufficiency perspective allows us to conduct a differentiated analysis of existing planning measures in relation to villages and town centers by highlighting the implicit resource potential as well as the structural limitations of an existing policy program. Instead of making normative assessments, the goal is to examine the extent to which existing programs already enable resource-efficient everyday practices.

We examine the concept of spatial sufficiency using the regional initiative "Starke Zentren" in the Austrian state of Styria as a case study. Launched in 2022 by Department 17 (Landes und Regionalentwicklung) of the Styrian government, this interdepartmental program aims to strengthen Styrian village and town centers as multifunctional focal points of everyday life by concentrating local services, social infrastructure, public spaces, and mobility within existing settlement structures. It is conceptualized as a support program for municipalities, providing strategic consulting, process support, and knowledge exchange. The program targets municipalities that are interested in strengthening their town center, reorganizing daily life, local services, and social interaction (Steirische Landesregierung, 2023). Although the initiative explicitly refers to sustainability, quality of life, and inner-city development, it does not define sufficiency as a guiding principle or sets targets for the absolute reduction of land use, material consumption, or mobility needs. This makes the program a particularly suitable case study for analyzing how sufficiency potentials are implicitly embedded in existing planning practices without being formulated as an explicit political objective.

Against this background, this paper addresses the following research question: To what extent and in what ways are principles of spatial sufficiency implicitly reflected in the measures and practices of the "Starke Zentren" initiative? To this end, we employ the method of a qualitative content analysis of a catalog of measures provided to us for internal use by the "Ortskernkoordination" (town center coordination team) of the "Starke Zentren" initiative. With considering sufficiency as an analytical tool, we contribute to the discussion of resource-efficient spatial development in rural municipalities. We demonstrate how sufficiency can be integrated into regional planning and how it can be enhanced by additional measures as an implicit byproduct. Furthermore, we propose differentiating between strategic, tactical, and pilot projects as a framework for the catalog of measures, as this, in our opinion, enables comprehensive and long-term planning. The paper demonstrates the opportunities for spatial sufficiency that the initiative offers, but also highlights its limitations.

3 THEORETICAL FRAMEWORK

3.1 Sufficiency as a Sustainabilty Strategy

Sufficiency is one of three sustainability strategies next to efficiency and consistency (Rudolf/Schmidt, 2025; Huber,1995; Huber, 2000). All three strategies are commonly discussed as approaches aiming to reduce environmental pressures and resource consumption. They differ fundamentally in how this overarching sustainability goal is pursued. While efficiency is based on technological innovations and aims to achieve the same output with less input, consistency aims to organize product processes in such a way that closed material cycles are created. Sufficiency, by contrast, addresses the question of limitation by reducing overall demand and defining an appropriate level of resource use.

When it comes to spatial development, efficiency and consistency play an important role especially when it is about energy-efficient buildings, renewable energy systems, and circular construction methods. However,

these strategies primarily address how resources are used rather than questioning how much resource use is necessary. As a result, efficiency and consistency strategies are often discussed in combination with rebound effects, where relative improvements offset increased demand or expanded use (Sorrell et al., 2020).

Against this background it is important to understand that sufficiency is not an alternative to efficiency or consistency, but rather complements them. Sufficiency can be understood as a framework that defines demand-related limits, while efficiency and consistency address how the remaining resource use can be organized with less impact (Böcker et al., 2020). Aside from that, sufficiency should not be confused with self-sufficiency or autarky.

3.2 From Sufficiency to Space

In academic discourse, sufficiency is described as a normative and theoretically contested concept. It has recently been discussed at various analytical levels, including consumption patterns (Sandberg, 2021), business systems (Niessen/Bocken, 2021), processes of social change (Lage, 2022), and multi-level governance perspectives (Jungell-Michelsson/Heikkurinen, 2022).

Building on these debates, Iten et al. (2024) emphasize that sufficiency requires a political and institutional framework to be effective, particularly at the local level. Local authorities could thus act as catalysts for systemic change toward sufficiency. Although the local level is identified as a key sphere of action for sufficiency policies, it remains unclear how such policies manifest in concrete spatial and everyday usage patterns.

In parallel, the architectural and urban planning discourse also argues that prevailing planning routines are driven by accumulation logics and equate spatial growth with prosperity and progress. This has led to an immense consumption of land, materials, and energy, while simultaneously obscuring the ecological limits of spatial development (Degros et al., 2024).

From this perspective, sufficiency cannot be achieved solely through consumption-oriented approaches or political leadership, but must also incorporate urban design and spatial planning. Hertweck (2022) also advocates for a planning- and design-oriented understanding of sufficiency that considers existing spatial structures, the building stock, and infrastructure systems. Sufficiency thus becomes a question of repair, transformation, and reduction within the built environment, rather than the goal of individual restraint. Taken together, these perspectives highlight the need to analyze how sufficiency-oriented political ambitions are spatially implemented and anchored in planning practices.

In this paper, spatial sufficiency is therefore understood as an outcome of the interaction between political frameworks, planning instruments, and spatial practices, rather than as an explicitly formulated planning objective. This is especially important because space not only structures everyday life but also stabilizes practices and enables long-term effects. From an urbanism perspective, sufficiency addresses the intensity of resource consumption – i.e., the question of what constitutes an appropriate level of consumption.

In this study, we define the relevant resources as (1) land take and soil sealing, (2) material use embodied in the built environment, particularly the balance between new construction and reuse, and (3) mobility-related demand, especially car dependency shaped by settlement structure and the distribution of everyday functions. These dimensions are key interfaces through which spatial development can reduce (or increase) absolute resource demand.This is particularly relevant with regard to questions of how much land use is appropriate and involves addressing issues of appropriateness, prioritization and limitation.

To address sufficiency from a spatial perspective, this paper builds on the work of Böcker et al. (2020), who outline how sufficiency can be understood in relation to space and infrastructure. Their approach shifts attention away from individual behavior and towards the conditions under which everyday needs can be met with low resource consumption.

Instead of focusing on individual behavior or voluntary restraint, sufficiency is examined here through the ways in which spatial structures and planning decisions shape social practices. We use the term socio-spatial to emphasize that resource-demanding practices are shaped by spatial arrangements as well as institutional and social conditions. In this sense, sufficiency is understood as a socio-spatial orientation: its effect consists out of an interaction of spatial arrangements, institutional settings, and patterns of use. This approach should neither consist of individual measures nor be conceived in isolation at the local level. Sufficiency can be applied in particular to land use, the organization of daily life, and the availability of shared infrastructure.

Strategies such as compact settlement structures, functional diversity, and the accessibility of shared spaces could be closely linked to sufficiency measures. Although they do not automatically lead to sufficiency, they create important prerequisites for reducing resource consumption and therefore deserve closer analytical consideration.

3.3 Town Center Development between Economy and Everyday Life

The transformation of a village or town center is not a neutral process; it is influenced by the political and economic dependence on local supply, jobs, and central services. Many communities find themselves in a difficult position due to their reliance on specific economic sectors. The loss of supply utilities and restaurants represents a significant setback for the community. These dependencies shape the design, use, and evaluation of central spaces.

Since sufficiency manifests itself through spatial structures, everyday practices, and shared infrastructure, it can represent a suitable strategy for this challenge within existing village and town centers. However, it is important to examine the logics that dominate the planning and development of these spaces. Many regional policy programs adhere to a growth-oriented approach (Rauhut/Humer, 2020). This growth-oriented perspective is reflected in international policy frameworks, such as those of the OECD, which predominantly conceptualize cities and urban centers through lenses of economic performance, productivity, and competitiveness (OECD, 2020). Consequently, the success of town center revitalization is often assessed through economic indicators such as the diversity of commercial services or visitor numbers. The role of town centers as spaces of everyday life, social interaction, and non-commercial use is frequently treated as a secondary benefit rather than a core quality of village and town centers.

However, the process of revitalizing village and town centers should take a holistic approach, combining all vital aspects. Quality in town centers cannot be reduced to economic performance alone. A strong center should radiate openness and accessibility to all residents. Public spaces should accommodate both long-term and short-term uses and enable staying, not only movement. Neither completely empty centers nor purely transit-oriented spaces foster urban life. Public spaces should rather enable a range of everyday activities, informal encounters, and forms of appropriation that contribute to social life and a sense of belonging are indicative of a good urban life (Gehl, 2021).

Such qualities are difficult to capture through economic indicators, but are essential for long term vital, lively, inclusive village and town centers.

3.4 Resource Consumption and Spatial Structures

From a sufficiency perspective this economic tension is directly linked to patterns of resource consumption. Spatial decisions based on logics for economic activation often lead to monofunctional structures, low functional diversity, and the displacement of everyday uses to other locations. Typical examples include retail parks or service clusters developed at the urban fringe, which concentrate single uses and are primarily accessible by car.

Such monofunctional development patterns limit opportunities for shared and multifunctional infrastructure, especially in traffic-oriented spaces (Bendiks/Degros, 2021), and are associated with increased per capita consumption of land, energy, and energy-intensive infrastructures (EEA, 2016).

Given the scarcity of resources and the need to develop a system that simplifies resource conservation for residents, economic stabilization alone is insufficient. Furthermore, a transformation of everyday practices, which are closely linked to spatial structures, is necessary. For example, high dependence on private car use, as well as monofunctional residential areas with detached single-family homes, contribute significantly to land, material, and energy consumption (Anderson et al., 1996; EEA, 2016). These practices are not merely expressions of individual preferences, but are structurally embedded in spatial planning decisions, infrastructure provision, and housing supply (Ehrlich et al., 2017). Sufficiency-oriented strategies within policy programs can gradually transform these patterns, promoting compact city centers, short distances, shared infrastructure, and alternatives to resource-intensive forms of housing and mobility.

4 RESEARCH DESIGN

Sufficiency is rarely explicitly formulated as a goal in spatial development programs, even though such programs have long-term effects on spatial structures and everyday practices. This study therefore analyzes an existing program to identify implicit effects related to sufficiency, prevailing implementation logics, and structural gaps. Rather than proposing new normative concepts, the analysis aims to identify concrete levers in current planning practice that can be used to gradually strengthen sufficiency-oriented principles. The standardized spatial delineation method for city and village centers, developed within the framework of the "Starke Zentren" initiative, forms the basis for defining a village or town center. This method is a GIS (Geographic Information System) technique based on a spatial multi-criteria analysis. Each cell of this grid is assessed and weighted based on its historical buildings, building density, land use diversity, population density, public transport connections, and the designation of building land according to the applicable zoning plan. A catchment area of 300 meters is defined around the town center, determined by pedestrian paths, and is considered the extended town center. This definition forms the spatial frame of reference for the analysis carried out in this study.

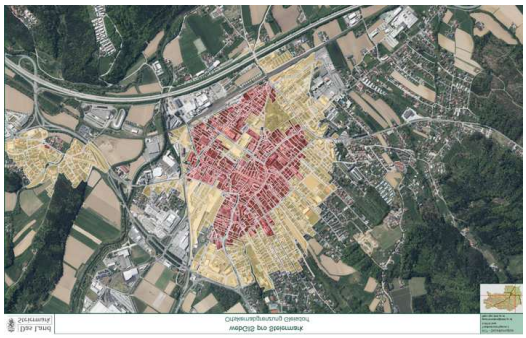


Fig. 1: Definition of the town centre. Example of a definition of a town centre using the GIS model, based on several spatial criteria.

Based on this spatial definition, the analysis examines a set of 51 measures implemented in thirteen municipal town and village centers. The analysis draws on measure descriptions provided by the "Ortskernkoordination" (local center coordination) unit of the Styrian State Administration, for internal use. All measures have already been implemented and are part of a real development process. Sufficiency is not an explicit goal of the initiative, but is applied here as an analytical lens.

Analysis step	Description	Output
Program documents	Catalog with 51 measures from the Strong Centers initiative, including brief descriptions, images, and location details	Standardized qualitative dataset
Qualitative coding	Deductive and inductive coding of each measure according to: measure type (strategy / tactics / pilots), field of action, potential resource-saving side effects	Structured coding matrix
Interpretative analysis	Identification of patterns, dominant implementation logics, tensions, and gaps	Analytical patterns and typologies
Results	Synthesis of findings across levels of action and fields of intervention	Identification of implicit sufficiency potentials and structural limitations

Table. 1: Analytical procedure. Applied in the qualitative content of the "Starke Zentren" initiative, from program documents to interpretive synthesis.

4.1 Methodology

Each measure in the Catalogue includes information on the municipality, a corresponding image, and a brief description. Additional clarifications were obtained through discussions with the "Ortskernkoordination" (local center coordination). The document offers a standardized overview of the measures, thereby providing a consistent and comparable basis for the analysis.

The analysis employs a qualitative content analysis, primarily based on deductive logic, but also incorporating inductive elements. The analytical categories were derived from the theoretical framework, while dominant implementation logics were identified inductively from the material, following a flexible approach to qualitative content analysis as commonly applied in urban planning research

(Sheydayi/Dadashpoor, 2023). The analytical categories were selected to capture the implicit sufficiency-related effects of the measures implemented within the "Starke Zentren" initiative.

4.2 Coding and Analytical Categories

4.2.1 Measure Type

Since the document does not differentiate between various types of measures, a classification into strategy, tactic, and pilots was initially established. This classification serves as an analytical framework to illustrate the impact level of the measures and their potential interrelationships.

We define those measures as strategies that illustrate a long-term spatial orientation, that formulate and consolidate overarching goals. Tactics, on the other hand, refer to principles and procedures that can be applied situationally without yet being fully operationalized. In this work, pilots are defined as spatially and temporally specific, sometimes experimental implementations in which tactical approaches are specifically tested and further developed. As spatially defined individual projects, pilots enable the linking of different areas of impact, such as social, functional, and structural aspects.

This classification builds on Michel de Certeau's distinction between strategies and tactics, originally developed in "The Practice of Everyday Life" (de Certeau, 1984). While strategies refer to institutionalized, long-term frameworks, tactics operate within existing structures through situational, improvisational actions. We extend de Certeau's dichotomy by adding pilots as a third, implementation-oriented category.

This triadic framework aligns with our understanding of contemporary urban practice, where the combination of tactical engagement with strategic design can transform everyday environments through experimental pilots (Bendiks/Degros, 2021). This triad structures both the analysis and the interpretation.

4.2.2 Field of action:

In this step, the measures were assigned to their respective fields of action. This reveals which thematic areas of town center development the measures focus on and which areas are underrepresented. This categorization encompassed building, mobility, landscape, social meeting points and process. The classification into these categories emerged from the short descriptions of the measures. Measures concerning the transport system, improving routes, or parking space management were assigned to the mobility category. The building category included those measures relating to the conversion or structural development of (existing) buildings. Measures focusing on everyday uses, functional mix, or the activation of vacant properties for social, economic, or cultural purposes were grouped under social meeting points. Landscape encompassed those measures addressing public space and quality of stay, and spatial openness, including squares, open spaces, and landscape-related features. Finally, the process category included measures that serve as steering instruments, coordination processes, or institutional framework conditions.

4.2.3 Resource saving side effect

To obtain a clear answer to the question of which sufficiency relevant side effects arise from the initiative's measures, it was defined for each measure whether and in what form it can save resources. This is relevant to show in what way the measures of "Starke Zentren" initiative already make a contribution to the reduction of land, material and mobility use, even without an explicit sufficiency strategy. A resource-reducing side effect was identified if a resource reduction could be derived from the description of the measures. Only potential and indirect effects were considered, not actual or measurable savings.

4.2.4 Complementary measures for sufficiency impact

Since sufficiency is rarely achieved through isolated measures, but rather depends on the strategic combination of several instruments and framework conditions, additional measures were identified that would be necessary to stabilize the sufficiency-related potential of individual interventions.

Additional instruments, regulations, or potential combinations with other measures were identified to define further gaps in the overall strategy and to demonstrate pathways to a holistic spatial strategy. These additions were derived analytically and are not considered existing program objectives.

Measure	Municipality	Measure type	Field of action	Sufficiency-relevant side effect
Senior Living	Fehring	Pilot	Building	Centralisation of care functions; reduced mobility demand; reuse of inner-city location
Ongoing Functional Overview	Weiz	Tactic	Process	Enables reuse and functional mix; supports inner development – no direct resource saving side effect
Town Center Development Strategy	Feldbach	Strategy	Process	Potential framing of land-use limitation and inner development priorities– no direct resource saving side effect
Local Supply store in town centre	Fehring	Pilot	Social meeting	Reduced car dependency; consolidation of everyday services
Parking relocation to second row	Ilz	Pilot	Mobility	Reclaiming public space; reduced traffic dominance
Public space redesign	Trofaiach	Pilot	Landscape	Increased shared use; social activation (material-intensive intervention)

Table 2: Examples. Provides illustrative examples of measures and their coding. The selection serves to demonstrate how the analytical categories were applied.

5 LIMITATIONS

The analysis is based on standardized and intentionally concise descriptions of measures, which provide a comparable program-level overview rather than detailed project documentation. The study focuses on the conceptual and structural characteristics of the measures, rather than on individual planning processes.

The analysis does not include site visits, analyses of spatial quality or observations of the actual use or appropriation of the implemented projects. Instead, it examines the measures at a programmatic level, addressing their potential implications for spatial structures and resource-related practices. Actual resource savings are not measured; the focus lies on identifying implicit sufficiency-related potentials and dominant implementation logics embedded in the measures. A differentiated assessment of these contextual conditions was beyond the scope of this study. Consequently, the results do not evaluate intentional sufficiency strategies, but reveal implicit sufficiency potentials and structural limitations within an existing planning program.

6 RESULTS

6.1 Character of Measures

The measures address revitalizing town centers, activating public spaces, promoting social meeting places, and location-based policy guidelines, such as attracting growing businesses to the town center to support further development. However, these approaches are not translated into concrete implementation strategies. At the same time, the measures remain tied to a specific municipality and are frequently illustrated with images from local settings, thus formally maintaining their local context. This characteristic is analytically relevant because the measures cannot be understood as classic reference projects or as fully developed and reproducible tools.

6.2 Distribution of Measures by Type

Building on these characteristics of the measures described in section 4.2.1, certain trends can nevertheless be identified and categorized into the triad of strategies, tactics, and pilots. This categorization serves to determine the level at which the measures operate and their interrelationships. A concrete example for a strategy is the measure to develop a “town center development strategy” in the municipality of Feldbach. According to the description in the catalog of measures, a town center strategy provides an overview, organizes areas of action, and shows which tools can be effectively used to strengthen the town center. It

creates a clear framework for targeted action, is clearly designed for long-term changes and defines overarching goals.

A typical example for tactics is the measure “Ongoing Functional Overview” from the municipality of Weiz, in which ground floor uses are mapped and regularly updated. This measure creates an important basis for decisions regarding future developments, but it does not yet formulate a concrete implementation; rather, it remains a permanent, principled instrument.

As a concrete example of a pilot project, we describe here the new construction of “Senior Living” project in Fehring, where assisted living and nursing care are deliberately located in the town center at Sonnenhof. The central location enables short daily commutes, strengthens local services, and promotes social participation. Care thus becomes a visible part of daily life in the center and contributes to the revitalization of the town center.

Overall, the categorization in measure types shows that the measures are predominantly situated at a tactical level, while strategic objectives are present only sporadically, and pilot projects are primarily formulated implicitly. The focus is therefore on principled approaches that mediate between long-term orientation and concrete spatial implementation.

Measure Type	Number	Percentage
Strategy	8	~16 %
Tactic	23	~45 %
Pilot	20	~39 %

Table 3: Division of Measure Type.

6.3 Fields of Action

In accordance with the coding framework described above, the measures were assigned to five fields of action in order to identify thematic gaps and prioritize them. The categorization was based on the five thematic areas of buildings, mobility, landscape, social meeting places, and process. While the measures cover all five key areas, they demonstrate a clear direction and thematic focus of the initiative.

Building-related measures largely consist of initiatives aimed at repurposing, densifying, and activating existing buildings, but also those that focus on inner-city development in the form of housing in the town center for all age groups. This is exemplified by the Sonnenhof in Fehring, mentioned in the previous chapter. A fundamental focus on existing buildings and multiple uses indicates a potential relevance depending on the specific form of implementation.

Mobility-related measures, on the other hand, play a more subordinate role and are limited to improving pedestrian connections in the town center and parking management. The example of the municipality of Ilz shows how a newly constructed parking lot in a second row can revitalize parts of the main square. Relocating parking spaces allows for the reduction of traffic-dominated areas in the town center.

Landscape measures for designing public spaces and increasing their quality of life are also somewhat less common in the collection of measures. A concrete example of this would be the redesign of public space in Trofaiach, where the demolition of a building deemed unsaleable according to the measure’s description created a new public space in the town center. Even though the demolition of buildings is highly resource intensive. From a sufficiency perspective, Landscape interventions could take an important role in strengthening village and town centers. They can not only promote encounters and increase the visibility of everyday uses, but also encourage communal use and reduce the need for private retreats. Furthermore, they can contribute to climate change adaptation, create infiltration areas, and promote biodiversity in the town center.

Measures to strengthen social meeting points are those that promote everyday functions, mixed-use development, and social interaction. Through proactive zoning policies and cooperation with the operator, the local grocery store in the town center of Fehring was secured. Instead of relocating existing businesses, a new local supplier was built on the main square with a parking lot at the second row, connected by a passageway to increase foot traffic in the town center. This consolidates everyday services in the center and thus indirectly contributes to reducing mobility and land use.

Process-oriented measures would be those that promote management, coordination, and the long-term development of the town center. A concrete example would be the role of the "caretaker", a responsible person on-site who oversees processes and ensures transparency, reliability, and smooth operations. Such a person was appointed, for example, in the municipality of St. Gallen. Without coordinating processes, effects relevant to sufficiency remain sporadic and difficult to scale. Overall, it can be said that the largest proportion of measures concerns the process-oriented approach to strengthening the town center.

A total of 27% of the measures were categorized as processes. The topics of social meeting places (25%) and buildings (24%) are also increasingly being addressed, while the categories of landscape (16%) and mobility (8%) receive less attention. Each measure was assigned to one dominant field of action. While this classification highlights a thematic focus of the initiative, it leaves open the question of whether and to what extent these measures will actually lead to resource savings in the various dimensions of security of supply.

6.4 Resource saving Side Effect

No measurements or quantifiable impact analyses were conducted; instead, implicit effects were inductively derived from the catalog of measures. For this purpose, all measures were assigned to a dominant resource-saving side effect. Of the 51 measures, potential resource savings could be identified for 32. Six types of resource savings emerged; the most frequent resource-saving side effects relate to spatial sufficiency and the avoidance of further land consumption through densification (10 measures). Material-related side effects occur primarily when existing buildings are repurposed or renovated instead of being newly constructed (5 measures).

Furthermore, resource-saving side effects result from shared use and multiple uses (10 measures), which simultaneously avoid infrastructure expansion. Four measures show a potential reduction in car journeys through spatial proximity, pedestrian and bicycle connections, or centralized services. Furthermore, some of the measures offer indirect resource savings through the use of existing spaces when businesses are relocated to the town center (two measures). One measure relates to resource savings due to short supply chains, namely the farmers' market in Fehring. This example illustrates how short value chains embedded in the local context can contribute to sufficiency-related effects beyond the immediate spatial intervention.

Nevertheless, it should be noted that many measures have multiple resource-saving side effects, depending on the context and implementation.

The example of the local supplier in the center of the municipality of Fehring demonstrates that while the primary benefit is a reduction in car use, it also saves space by avoiding peripheral retail locations. By promoting everyday encounters and ensuring a reliable supply of goods, this measure also addresses a social sufficiency dimension and can be interpreted as counteracting conventional market-driven retail development.

The resource-saving side effects are not evenly distributed but are primarily concentrated on measures for inner-city development, repurposing, and functional consolidation. This particularly applies to measures for the revitalization, conversion, and multiple use of vacant properties. Since none of the measures explicitly aim at resource conservation, the material and space savings can be attributed to the desired spatial proximity and the existing use of the existing buildings.

6.5 Complementary measures:

This section examines which complementary measures are necessary to fully exploit the potential for resource savings. As already mentioned, resource conservation rarely results from isolated individual measures, but rather from a combination of spatial, institutional, and regulatory frameworks. Various complementary measures can be identified in this regard.

One of the most frequently identified missing links is a regulatory framework to halt outward development. Most measures can only achieve their resource-saving effect if expansion on the outskirts of towns and villages is stopped. Restrictive zoning designations and limitations on new land zoning can therefore be considered key complementary measures.

Furthermore, complementary measures often relate to land use and ownership instruments, such as land acquisition, pre-emption rights, leasehold rights, and long-term usage agreements. These instruments indicate that sufficiency-related effects depend less on individual projects than on long-term control over key sites

and their uses. Practice-based insights from informal expert discussions suggest that the initiative already considers such instruments, but their implementation is often constrained by limited municipal financial capacity.

While the analysis shows that car-oriented infrastructure is being relocated and potentially reduced, these interventions are rarely embedded in a comprehensive mobility strategy that prioritizes walking, cycling, or public transport. A complementary measure would therefore be an integrated, sufficiency-oriented mobility strategy that explicitly prioritizes active mobility and public transport and links these modes to spatial planning, zoning, and parking policies.

The implementation of renovation and modernization projects further depends on funding schemes and regulatory frameworks that favor reuse over new construction. Transparent financing structures and shared financial risk can support refurbishment and adaptive reuse, thereby reducing material and land consumption associated with replacement building.

Even measures classified as process-oriented – such as "caretakers", town center partnerships, or monitoring tools ¬ require linkage to formal decision-making mechanisms to unfold their potential. Without clear mandates, resources, and competences, such measures remain enabling frameworks without direct influence on implementation. For example, a "caretaker" requires authority to intervene, and a vision for the town center needs to be translated into concrete spatial and functional priorities.

Finally, sufficiency also concerns private space. The activation of town centers cannot fully compensate for the underuse of existing residential space in peripheral or low-density housing areas. Complementary measures could therefore include regulatory, advisory, and incentive-based instruments that enable shared living arrangements, subdivision, or adaptive reuse of existing housing stock.

7 DISCUSSION

The analysis of the "Starke Zentren" initiative's package of measures revealed no explicit sufficiency goals. The initiative's objectives focus on revitalization, provision, and activation, rather than resource reduction, limitation, or finding the right balance. Nevertheless, sufficiency is implicitly visible as a byproduct, albeit indirectly and in a highly fragmented manner. This includes, for example, measures for inner-city development or those aimed at reusing existing buildings. However, the sufficiency- related aspects are not systematically framed as part of an explicit program logic and therefore remain contingent on local context and implementation.

7.1 Sufficiency across levels of action: strategy, tactic, and pilots

This becomes particularly clear by distinguishing between strategic, tactical, and pilot level of action. Here, the analytical framework, applied in this study helps to identify leverage points for strengthening sufficiency-oriented spatial development without introducing new policy instruments. The analysis shows that sufficiency is reflected unevenly across different levels. While it is not reflected at the strategic level, there are sufficiency-oriented measures implicitly anchored at the tactical level. At the same time, ambivalent logics emerge at the pilot level: although reuse is frequently articulated as a goal, demolition and new construction continue to occur. Overall, sufficiency appears implicitly and inconsistently across different levels of action.

7.2 Blind spots: landscape, non-development, and ecological functions

Nevertheless, some dimensions of sufficiency, that are crucial for long term resource conservation, are only addressed peripherally. Measures related to landscape primarily aim to upgrade public space into social gathering places, while aspects such as soil functions, unsealing, water retention, microclimate regulation, or biodiversity promotion are largely absent from the measure descriptions. Yet, the integration of ecological functions is central not only to climate change adaptation but also to sufficiency, as sufficiency concerns not only the use of space but also the deliberate absence of development. From this perspective, landscape could be strategically employed to reduce land consumption over the long term.

7.3 Spatial quality, design, and everyday usability

Furthermore, most measures in the catalog are hardly analyzed in terms of their spatial and design qualities, as the descriptions primarily focus on function, use, or activation, but hardly on spatial quality, intensity of

use, or the everyday usability of spaces without consumption. Only attractive and well-designed spaces can lead to a reduction in private retreats and a shift towards shared use. Good design should be understood as a path to sufficiency in its own right. Many measures that enable sufficiency are primarily regulatory – zoning, land policy, parking regulations – but while regulations can be restrictive, design can be empowering. Sufficiency therefore requires both regulatory and design-based approaches.

7.4 Growth paradigms and structural limits to sufficiency

Another structural aspect that constrains the implementation of sufficiency is the persistence of growth-oriented planning paradigms. Despite demographic projections indicating that almost two-thirds of Styrian municipalities are expected to shrink in the coming years (Atlas zur Landesentwicklung Steiermark), the initiative continues to focus strongly on revitalization, attracting new businesses, and activating existing ones.

The aim is not to limit growth, but rather to redirect it. Explicit strategies addressing limitation, non-development, or stabilization are largely absent.

This is particularly relevant for sufficiency, which requires not only efficiency and optimization but also acceptance of stabilization and, in some cases, downsizing. Peripheral municipalities, in particular, could benefit from withdrawal strategies or prioritization measures aimed at securing existing communities rather than pursuing growth.

This reveals a structural tension between growth-oriented planning paradigms and sufficiency-oriented spatial development.

7.5 Sufficiency as a complementary strategy

Overall, applying sufficiency as an analytical framework enables a new interpretation of the "Starke Zentren" initiative. Even if sufficiency is not explicitly mentioned in the program, it becomes visible through the analysis. However, resource conservation will remain limited in the implementation measures as long as outward development, parking logic, and growth-oriented assumptions largely remain untouched. Beyond regulatory instruments, sufficiency-oriented spatial development also depends on whether everyday services, construction activities, and maintenance can be organized within a limited territorial context. Strengthening local value creation can therefore support sufficiency by reducing dependency on extensive supply chains, without implying self-sufficiency or autarky. A more deliberate engagement to zoning logics, land ownership, land policy, parking regulations, and governance structures could strengthen the contribution of municipalities to a more resource-conscious use of space.

Sufficiency should not be understood as stagnation or deprivation, but rather serve as a strategic decision-making framework, that complements efficiency and consistency approaches. When applied as part of a broader review process, alongside consistency and efficiency, it can support socially effective and resource-conserving spatial interventions that contribute to a high quality of life in village and town centers.

8 CONCLUSION

The research question formulated at the beginning of the study, to what extent and in what way principles of spatial sufficiency are implicitly reflected in the measures of the program for the revitalization of village and town centers, can be answered as follows: While sufficiency is present in the program, it appears predominantly as a fragmented byproduct of activation-oriented planning logics.

Applying sufficiency as an analytical lens reveals where the program's measures already go beyond growth-oriented logics, but also where they systematically reach their limits due to structural constraints. Because sufficiency is not strategically framed within the program, resource conservation and questions of appropriate consumption levels remain highly context-dependent and unevenly anchored.

The analysis further demonstrates that the transformative potential of sufficiency-related measures depends on the interplay between institutional negotiation processes and their spatial translation. From this perspective, sufficiency requires a clear strategic orientation to become effective beyond isolated effects, supported by action-guiding tactical principles and spatially anchored pilot projects. Understanding and strengthening the interrelations between these levels – strategy, tactic, and pilots – represents a key contribution of this study and a promising starting point for further research.

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Beyond the scope of this analysis, sufficiency-oriented town center strategies could be complemented by measures addressing private space consumption, for instance through advisory services or incentive programs supporting shared use of living space.

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reviewed paper

Integrating Spatial Data and Indigenous Knowledge Systems for Resilient Urban Planning: Lessons from South Africa

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1 ABSTRACT

Johannesburg's marginalised settlements are among the most dynamic urban environments globally. These locations have limited infrastructure resources, which have negatively impacted household livelihoods. There is a critical need for developing planning support systems to improve the quality of life in these communities. As part of the city's transformation strategy, urban agriculture has emerged as a critical approach to enhancing food security and economic empowerment, particularly in marginalized areas. However, effective planning for urban agriculture necessitates spatial intelligence and community engagement. This study employs a mixed-method approach, combining indigenous knowledge systems with spatial data to assess land suitability. The findings present a land suitability index to inform spatial planning, demonstrating how integrating GIS and citizen science strengthens urban resilience through adaptive land use, improved local food systems, and climate change mitigation.

Keywords: Geographic Information Systems, food security, citizen science, urban resilience, spatial planning

2 INTRODUCTION

In urban areas, there are often multiple competing activities for limited land. The combined effects of climate change and anthropogenic forces are altering urban ecosystems. These adjustments lead to ecosystem tipping points and, subsequently, shifting ecosystems, and are believed to negatively affect communities with ecosystem-dependent livelihoods. Ostensibly, in developing countries, little to no attention has been given to marginalised communities, particularly amid the growing pressure from climate change and human activities.

This, therefore, makes the study of marginalised populations very urgent in these parts of the world because these populations still rely on food obtained directly from these sources. Moreover, studies have shown that the attainment of many sustainable development goals (SDGs) is directly and indirectly linked to the quality, quantity, or availability of agricultural land, which influences the direct or indirect benefits that humans derive from land. In particular, ecosystem services can help achieve SDGs related to the environment.

The literature there is growing scientific evidence indicating that Geographic Information Systems (GIS) can provide essential tools for mapping land suitability, analyzing spatial patterns, and integrating urban agriculture into broader urban planning frameworks. Recently, citizen science has complemented GIS by actively involving local communities in data collection, monitoring, and decision-making, ensuring that urban agriculture initiatives align with local needs and priorities. In respect of SDGs 1 and 2, which stand for no poverty and zero hunger, respectively, ecosystem services provide resources and livelihoods for millions of people, especially for rural and marginalized communities.

In developing countries such as South Africa, little research has been conducted on combining indigenous knowledge (IK) systems with spatial data to assess land suitability, particularly for marginalised communities. The structure and functioning of marginalised communities in urban settings are characterised by precarious livelihoods. For this reason, it is expected that deploying GIS and citizen science could alleviate the negative developmental changes and support these communities.

3 LITERATURE REVIEW

Over the years, scholars have developed computer-based support systems that are either focused on user-friendliness or on planning qualities. Much of the research on planning support systems (PSS) implementation focuses on understanding and improving the user-friendliness of the instruments (Te Brömmelstroet 2013; Long et al. 2011). Pelzer (2016) defines PSS as digital tools that aim to facilitate planning strategies. Whilst Jiang et al. (2003, p. 1) describe PSS as "spatial decision making systems with particular application for planning, which involves a wide range of professionals with diverse backgrounds and the general public concerned." PSS can accordingly be described as planning tools that facilitate collaborative planning by focusing on specific steps of the planning process and by improving the strategic capacity of these plans (Pelzer 2016; TeBrömmelstroet 2016a, b).

Tools to enable the spatial targeting of urban agriculture must therefore be developed to provide scientific methods that enable urban planners to implement spatial transformation in South Africa and other cities in the Global South. The complexities of modern urban planning have led to the introduction of PSS, which seeks to assist planners in shaping their city's development and in making land-use decisions. Spatial planning for urban agriculture in cities of the developing world, such as Johannesburg, is made difficult by the lack of appropriate data. In most cases, informal land-use activities are discussed descriptively and statistically, leaving out their spatial characteristics. This makes the orderly planning very difficult if not impossible, especially given that the informal activities dominate the marginalised areas of most developing countries. In the absence of other spatial datasets, this unique PSS provides a handy way to reveal spatial locational trends among informal land-use activities and the preferred locational behaviour of informal urban agricultural activities in the city. In the South African context, developing a PSS to guide and inform urban agriculture requires a model that is user-friendly, interactive, and allows the end-user to easily modify and interpret the results. The introduction of geospatial analysis platforms in conjunction with planning policies (namely the Spatial Planning and Land Use Management Act 16 of 2013, SPLUMA) and the housing Atlas (Council for Scientific and Industrial Research 2008) has enhanced how PSS are formulated. Nonetheless, though the potential merits of implementing PSS are vast, most African cities have not yet integrated them into their daily practice, as they lack the required mechanisms to do so.

Within this theoretical tradition, resilience is not reducible to infrastructural robustness or technological optimisation. Rather, it is produced through diversity, redundancy, modularity, feedback sensitivity, and adaptive governance. Knowledge diversity is therefore not peripheral but central to resilience. Systems that rely on singular epistemologies risk brittleness, whereas epistemic pluralism enhances adaptive capacity by broadening interpretive and response repertoires. Despite this, urban planning institutions have historically privileged technocratic and positivist knowledge systems, often marginalising experiential and indigenous epistemologies (Nkosi et al, 2022). This epistemic hierarchy raises a critical tension: while resilience theory emphasises diversity and learning, planning practice frequently narrows legitimate knowledge to scientifically codified forms. It is within this contradiction that debates about the integration of IK and scientific knowledge must be situated.

Indigenous Knowledge can be conceptualised as a cumulative, place-based system of ecological understanding, embedded within social norms, cultural values, and livelihood practices. From a resilience perspective, IK contributes to what is often described as ecological memory the repository of practices and experiences that enable communities to respond to recurring environmental variability. In agrarian and peri-urban contexts, such knowledge includes seed selection, soil management, seasonal forecasting, and risk-spreading strategies that have evolved through iterative adaptation. Empirical studies consistently demonstrate that development initiatives that ignore IK often face resistance, limited uptake, or unsustainable outcomes (Chanza & Musakwa, 2022; Moyo-Nyoni, 2022; Kom et al., 2023). Within a resilience framework, this may be interpreted as a disruption of local feedback systems and social learning processes. When external technical interventions override embedded practices without participatory negotiation, they may erode social capital and undermine adaptive governance.

However, resilience theory also demands a critical interrogation of IK. While IK enhances diversity, it is not inherently adaptive under all conditions. Rapid urbanisation, climate change, and socio-economic transformation can render certain practices maladaptive. Scholars caution against romanticising IK as uniformly sustainable or universally applicable (Gómez-Baggethun, 2022; McGregor, 2023; Zurba & Papadopoulos, 2023). From a systems perspective, resilience includes the capacity for transformation,

therefore, IK must be understood as dynamic and evolving rather than static and sacrosanct. The erosion of IK in urbanising contexts particularly in urban agriculture represents a loss of ecological memory that may reduce system redundancy and increase vulnerability (Swiderska et al., 2022; Ricart et al., 2023). Yet preservation alone is insufficient; resilience requires adaptive recombination of knowledge rather than mere conservation. Calls for integrating indigenous and scientific knowledge systems are widespread (Chirisa et al., 2021). International policy discourses similarly advocate aligning scientific innovation with local priorities to achieve sustainable natural resource management (Chanza & Musakwa, 2022). However, the concept of integration is frequently under-theorised and politically neutralised. Scientific knowledge is typically institutionalised, standardised, and validated through formal methodologies privileging abstraction, quantification, and replicability. IK, by contrast, is often tacit, relational, and embedded within cultural and moral frameworks. Efforts to process IK through scientific epistemic criteria risk epistemic reductionism, translating complex relational knowledge into decontextualised data points. Such practices may reproduce epistemic injustice, where indigenous systems are recognised only insofar as they conform to scientific standards.

Resilience scholarship has increasingly recognised that governance systems are shaped by power relations. Whose knowledge is legitimised within urban planning institutions is not merely a technical question but a political one. Adaptive co-management and knowledge co-production are frequently proposed as solutions; however, without explicit attention to power asymmetries, these frameworks risk becoming procedural formalities rather than transformative practices. Thus, the integration of IK and scientific knowledge must be reframed as epistemic negotiation rather than technical assimilation. This requires institutional reflexivity, participatory governance structures, and recognition of plural ontologies. In urban agriculture, for instance, combining indigenous soil fertility practices with agronomic research and climate modelling may enhance productivity and resilience but only if local actors participate meaningfully in defining problems, priorities, and success metrics. From a resilience perspective, the goal is not simply integration but transformative capacity, the ability of urban systems to reconfigure governance, institutions, and practices in response to structural pressures. The persistence of epistemic hierarchies within urban planning institutions may constrain such transformation. If IK is incorporated only instrumentally valued for its utility but excluded from decision-making authority, then resilience efforts may reinforce existing inequalities rather than address systemic vulnerability.

4 METHODOLOGY

Region G is situated approximately 36 km south of the Johannesburg, Central Business District. According to the Spatial Development Framework (SDF), communities in this region are among the most geographically isolated within the city. This peripheral location has resulted in limited access to economic opportunities, social amenities, and critical infrastructure (Fig. 1). Despite several public sector interventions, including housing developments and the provision of basic services, the area continues to face significant challenges. These include high concentrations of dense informal settlements, inadequate public infrastructure, and persistent spatial disconnection from social and economic opportunities, which together contribute to entrenched poverty and high unemployment levels. The quality of life of residents in Region G is further undermined by crime and safety concerns, with vulnerable groups disproportionately affected.

Spatial data were collected through systematic geographic mapping of both formal and informal land-use activities in Region G. Data collection focused on areas surrounding suburban shopping centres, industrial zones, transportation and communication nodes, residential areas, as well as open spaces and road networks. Land-use activities were recorded in situ using a Global Positioning System (GPS), resulting in the capture of 452 spatial points. Base maps were previously scanned and geo-referenced to establish a spatial framework, after which land-use features were identified and digitised. Density analysis was then applied to assess spatial patterns and quantify temporal changes, with results expressed in both absolute and percentage terms.

5 FINDING AND DISCUSSION

Understanding the community of Region G’s relationship with nature is crucial to the area's well-being and sustainable development in the face of climate change. The City of Johannesburg Climate Change Action Plan (2021) has identified Region G as highly vulnerable to the effects of Climate change. As such, Region

G is susceptible to and unable to cope with the adverse effects of climate change, including climate variability and extremes. The communities in Region G depend on the area for survival, and the environment and surrounding areas determine whether sustainable development is to be achieved. Assessing the linkages among the environment, livelihoods, and climate change is essential for sustainable development. The key issues in the area are air pollution from uncontrolled burning, clearing the ridge for informal settlements, and littering around economic activity areas. There is a need for education campaigns to raise awareness of the adverse impacts and to also build capacity at key locations, such as community facilities.

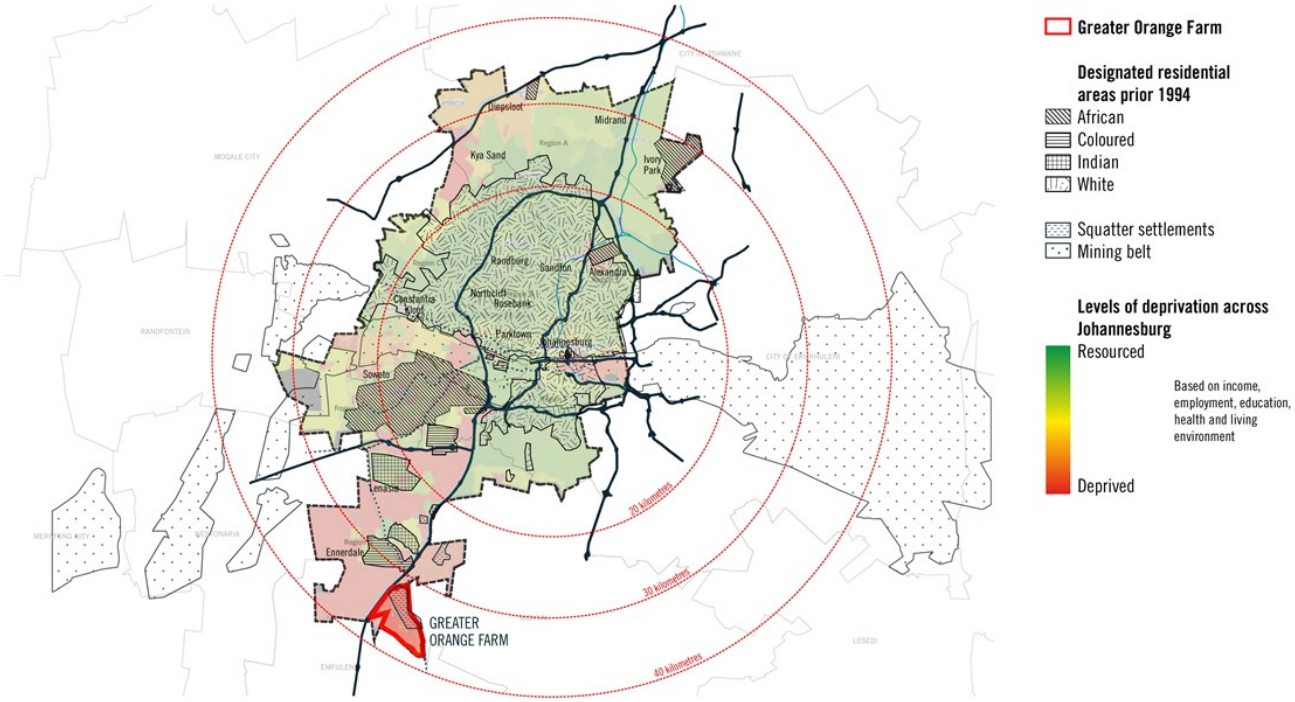


Fig. 1: Study area

Continued growth of informal urban agricultural activities in Region G will most likely lead to further densification and congestion, eventually hindering the promotion of sustainability and smart cities. The question, therefore, becomes, can more growth in these areas be sustained or should growth be channelled elsewhere? (Musakwa et al. 2017). Perhaps a serious paradigm shift is required that promotes integrated settlements, given the limited available land. Areas currently used for urban agricultural activities but unsuitable or poorly located for formalisation are located in the upper northern, southern, and eastern areas. These poorly located areas are mostly in wetlands, consistent with the weighted criterion, since dolomite had a greater influence. These areas are traditionally townships, mostly populated by low-income groups and far from economic opportunities. It is very difficult to develop on these unsuitable sites as the presence of dolomite increases construction costs and the risk of subsidence and damage to infrastructure. Interestingly, large populations inhabit these areas, and it is not necessarily smart given the risks, in the future, it is advisable for the city not to promote housing development for low-income families in dolomite areas due to the associated cost implications. However, if unavoidable, the rational design approach can be implemented.

From Fig. 2, it is clear that the moderately well-located land is mostly located adjacent to the well-located land. This shows that suitability gradually declines as one moves away from the well-located sites that almost form a concentric pattern. Likewise, the less well-located areas are farther from the very well-located areas. This is consistent in South African cities as a result of the apartheid segregation policies. What is more worrying is that, 25 years after independence, the same spatial pattern still broadly exists. This casts doubts on the smartness and the seriousness of the current planning system in reversing the apartheid planning.

Findings from interviews with stakeholders revealed the following formalised farming activities (see Fig 3), through communal gardens. While all the sites are within the highly suitable and moderately suitable ranks, they require maintenance and upkeep. The suitability ranking correctly designated the Urban Resilience hub as a strategically located site, and the debate remains whether the programs and services offered there are accessible to all residents. There is a need to roll out satellite offices of the Urban Resilience hub to other community facilities. The findings demonstrate that IK plays a critical role in shaping urban agricultural

practices in the City of Johannesburg. Farmers rely on locally embedded, experience-based knowledge to respond to resource constraints, particularly water scarcity, limited land, and poor soil quality. These practices highlight the adaptive nature of IK within an urban socio-ecological context.

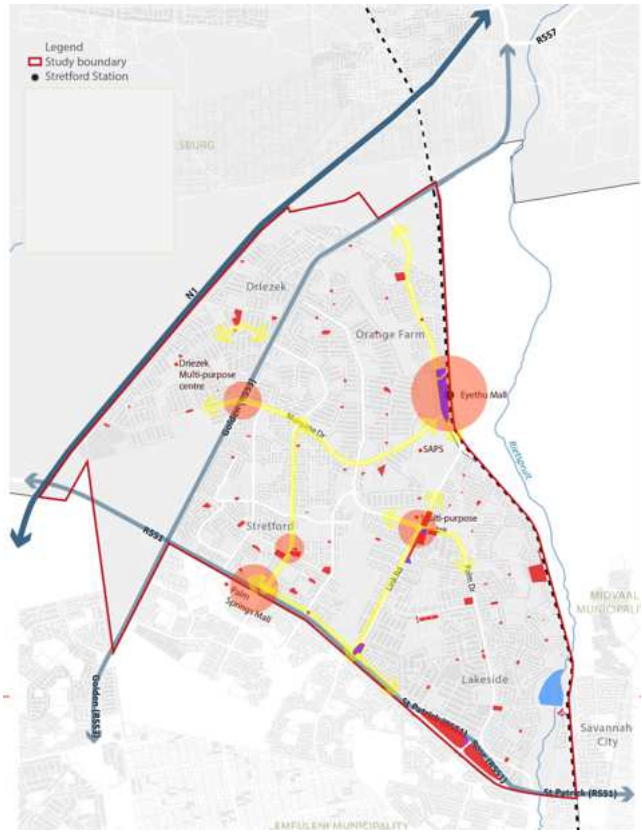


Fig. 2: Concentration of agricultural activities

Water conservation strategies, including rainwater harvesting, greywater reuse, and mulching, reflect practical responses to irregular water supply and seasonal variability. Similarly, composting and the use of plant-based bio-fertilisers are widely employed to restore soil fertility while reducing reliance on commercial inputs. Crop diversification and rotation enhance resilience by minimising pest risks and maintaining soil health, while natural pest control methods such as garlic, chilli, and neem-based solutions demonstrate an ecological understanding of pest dynamics. Knowledge exchange through community networks further strengthens adaptive capacity, enabling farmers to share seeds, techniques, and locally tested solutions. Overall, IK strategies contribute significantly to sustainable, low-input urban food production and represent an important knowledge system that can inform more inclusive urban agricultural policy and planning frameworks.

Participation in formal urban agriculture is low due to various factors. These are mainly due to a lack of adequate access to land for farming, poor access to the market because of limited and inconsistent supply of the produce, and lack of access to services such as water in areas where land is available. The farming activity noted in Region G is through communal and backyard gardens. The food resilience hub shares a space with the City of Johannesburg's skills centre and the Discovery Business Hub. There is a lack of integration among the three spaces, resulting in the loss of opportunities to train local farmers. There is also no programme to research innovative ways to improve urban agriculture and overcome some of the identified challenges. sSome farmers use the open spaces available near their houses. When speaking to a local farmer, who is currently working at the food Resilience Unit, he indicated that the local farmers are faced with the following challenges;

- Lack of farming tools to distribute to urban farmers
- Urban farmers require fencing material
- Lack of land to practise urban farming
- Lack of water supply

- Farmers are not equipped with enough skills to understand the difference between organic or chemical farming techniques, which then affects the final produce.
- Limited communal farming projects
- Lack of skills training to support farmers to be able to manipulate land to obtain maximum output (which crops/plants to grow together; crop rotation; and which crops grow better together etc).



Fig 3. Samples of formalised agricultural activities

6 CONCLUSION

Within the Southern African context, there remains a limited body of modelling-based research to inform policy on strategic land identification. In marginalised areas such as Region G, balancing the need to stimulate emerging local economies with the imperative to protect natural ecosystems is critical. This study demonstrated the application of a Planning Support System (PSS) tool to identify strategically located land suitable for urban agriculture. The growing emphasis on sustainable development in marginalised urban areas positions urban agriculture as a viable emerging economic activity with the potential to enhance livelihoods and overall quality of life. However, identifying appropriate land and empowering residents from informal settlements remains a persistent challenge in South African cities. The findings of this study contribute evidence to support more informed, spatially grounded policy interventions aimed at advancing inclusive and sustainable urban development.

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reviewed paper

Integrating Traditional Authority Participation into Land Use Planning: Implications for Sustainable Rural Housing Delivery

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1 ABSTRACT

Efforts to advance sustainable rural development in South Africa depend significantly on municipalities' ability to coordinate land use planning within contexts where customary land governance remains dominant. Traditional authorities continue to influence land allocation, settlement formation, and community decision-making; however, their participation within statutory planning frameworks remains inconsistently institutionalised and procedurally ambiguous. This study examines how traditional authority participation can be more effectively integrated into municipal land use planning to enhance sustainable rural housing delivery. A systematic review guided by PRISMA 2020 was conducted across Scopus and Web of Science and complemented by policy document analysis of Integrated Development Plans, Spatial Development Frameworks, Land Use Management Schemes, and relevant legislation. Findings reveal persistent governance misalignments characterised by parallel land allocation systems, institutional ambiguity, limited technical capacity, and weakly structured participatory mechanisms. The paper proposes an operational integration framework grounded in institutionalised participation platforms, co-produced land use guidelines, reciprocal capacity-building, and integrated monitoring mechanisms. The study contributes actionable guidance for municipalities seeking to reconcile dual land administration systems and strengthen inclusive rural housing delivery.

Keywords: Customary land governance, land use planning, participatory governance, sustainable rural housing, rural development

2 INTRODUCTION

Securing sustainable rural development remains a persistent challenge in South Africa, particularly in regions where rapid demographic shifts, uneven service provision, and entrenched spatial inequalities continue to shape settlement outcomes. While municipalities are constitutionally mandated to lead spatial planning and housing delivery, much of rural South Africa remains governed by customary land tenure systems, in which traditional authorities play a central role in land allocation, settlement formation, and community governance. This dual system of land administration presents both opportunities and tensions for land use planning, especially in efforts to deliver sustainable and inclusive rural housing.

Land use planning frameworks, formalised through instruments such as Integrated Development Plans (IDPs), Spatial Development Frameworks (SDFs), and Land Use Management Systems (LUMS), are intended to guide coordinated development and equitable access to land, services, and housing. However, existing scholarship highlights a persistent misalignment between statutory planning systems and customary land governance practices, resulting in fragmented decision-making, contested authority, and implementation gaps in rural development (Ntsebeza, 2005; Oomen, 2005; Claassens, 2015). Traditional authorities often function as intermediaries between rural communities and the state, yet their participation in formal planning processes remains inconsistently defined, weakly institutionalised, and largely consultative rather than collaborative.

Recent debates within planning and governance literature call for more inclusive, participatory, and context-sensitive planning approaches, particularly in underserved rural areas where formal institutions alone struggle to respond to local needs (Sihlongonyane, 2015; Todes & Turok, 2018). At the same time, rural housing delivery continues to be constrained by insecure tenure, unclear land rights, and limited coordination between municipal planners and customary institutions, undermining long-term sustainability and local resilience (Ainslie & Kepe, 2016; Koelble & Lipuma, 2011).

Despite growing recognition of the importance of traditional authorities in rural governance, there remains a critical gap in empirical and conceptual work that systematically examines how their participation can be meaningfully integrated into land use planning frameworks, rather than treated as an external or parallel process. Much of the existing literature focuses either on customary land tenure or on statutory planning systems in isolation, offering limited guidance on practical participation pathways that could bridge these governance regimes in support of sustainable rural housing outcomes.

This paper examines the integration of traditional authority participation into land use planning to enhance sustainable rural housing delivery in South Africa. It aims to assess existing approaches to incorporating traditional authority involvement within municipal land use planning instruments, such as Integrated Development Plans (IDPs), Spatial Development Frameworks (SDFs), and Land Use Management Schemes (LUMS). Additionally, it seeks to identify key governance and institutional barriers that lead to misalignment between customary land governance and statutory planning frameworks. The study proposes an integrated participatory intervention designed to strengthen collaboration between traditional authorities and municipalities in the delivery of sustainable rural housing. By conducting a systematic review of peer-reviewed literature, analyzing municipal planning instruments, and examining comparative case studies from South Africa, the research aspires to contribute to ongoing discussions about rural planning reform, participatory governance, and spatial justice. Addressing contemporary calls for innovative, inclusive, and resilient rural development strategies that harmonize state-led planning with locally grounded governance systems.

This paper, therefore, positions traditional authority participation not as an external consultative requirement, but as a core governance dimension of sustainable rural housing delivery within South Africa's statutory planning framework.

3 CONCEPTUAL AND POLICY GROUNDING OF CUSTOMARY GOVERNANCE AND PARTICIPATION IN RURAL HOUSING

Customary land governance continues to shape land access, settlement formation, and housing development across large parts of rural South Africa. Under customary tenure systems, traditional authorities play a central role in land allocation, dispute resolution, and community decision-making, operating through socially embedded norms and practices that differ from statutory land administration (Ntsebeza, 2005; Oomen, 2005). While these systems retain local legitimacy, they coexist uneasily with municipal land use planning frameworks, creating parallel governance systems that complicate rural housing delivery and tenure security.

Post-apartheid reforms have struggled to reconcile customary authority with democratic and developmental local government. Although the Constitution recognises traditional leadership and the Spatial Planning and Land Use Management Act (SPLUMA) promotes inclusive and participatory planning, the role of traditional authorities in spatial planning remains ambiguously defined (Claassens, 2015; Koelble & Lipuma, 2011). Consequently, land allocation in customary areas frequently occurs outside Spatial Development Frameworks (SDFs) and Land Use Management Systems (LUMS), undermining spatial coordination and long-term sustainability.

From a planning theory perspective, communicative and collaborative planning frameworks emphasise inclusive decision-making, recognition of local knowledge, and negotiated governance between state and non-state actors (Healey, 1997). In practice, however, participatory planning in rural South Africa remains uneven. Empirical studies demonstrate that traditional authorities are often positioned as consultees rather than institutional partners in municipal planning processes, limiting their influence over spatial and housing outcomes (Sihlongonyane, 2015; Todes & Turok, 2018).

The coexistence of statutory and customary systems produces persistent governance barriers, including overlapping mandates, unclear authority, and institutional power imbalances (Claassens, 2015; Ainslie & Kepe, 2016). These misalignments contribute to delayed housing delivery, insecure tenure, and spatially fragmented settlements. Treating customary governance as external to formal planning systems reinforces institutional fragmentation rather than enabling integrated rural development.

Despite these challenges, emerging scholarship identifies integrative approaches such as negotiated planning agreements, joint planning forums, and co-governance mechanisms that formally recognise traditional

authorities within planning processes (Ainslie & Kepe, 2016; Sihlongonyane, 2015). However, such approaches remain case-specific and under-theorised, highlighting the need for systematic synthesis and practical guidance aligned with SPLUMA mandates.

4 METHODOLOGY: SYSTEMATIC REVIEW AND POLICY DOCUMENT ANALYSIS

This study employed a systematic literature review approach to examine how traditional authority participation can be integrated into land use planning to improve sustainable rural housing delivery in South Africa. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al., 2021), ensuring transparency and reproducibility in study selection and data extraction.

A search was conducted across multiple academic and policy databases, including Scopus, Web of Science, JSTOR, and Google Scholar. Additional sources included municipal planning documents, Integrated Development Plans (IDPs), Spatial Development Frameworks (SDFs), Land Use Management Schemes (LUMS), and relevant legislation (e.g., SPLUMA, 2013). Search terms included combinations of "customary land "governance", "traditional authorities", "land use planning, participation", "SPLUMA", and "rural housing". Peer-reviewed journal articles, policy-oriented studies, and relevant grey literature published between 2005 and 2025 were considered to capture post-apartheid governance dynamics. Full-text screening assessed inclusion criteria: (1) relevance to municipal planning or customary governance; (2) focus on rural housing delivery or settlement planning; (3) empirical evidence or policy frameworks. After full-text review, 62 studies and 18 municipal or government documents were included in the final analysis. Thematic synthesis was used to identify recurring governance challenges, participation models, and integrative practices. Comparative South African case studies were analysed to contextualise institutional dynamics and identify transferable lessons for municipal planning practice.

5 REVIEW FINDINGS: GOVERNANCE GAPS AND EMERGING THEMES

5.1 Misalignment Between Customary Governance and Statutory Planning

The review reveals consistent misalignment between customary land allocation practices and municipal planning instruments.

Traditional authorities often allocate land independently of SDFs and land use schemes, resulting in spatial fragmentation, irregular planning of infrastructure, and service inefficiencies (Ntsebeza, 2005; Koelble & Lipuma, 2011). On the other hand, participation becomes a mere procedural formality rather than a genuine collaborative effort: While SPLUMA promotes active participation, interactions with traditional authorities, this often tends to be more of a ticking the box exercise than a substantive one. Meetings typically lack the willingness and preparedness to engage in meaningful dialogue; for instance, government authorities arrive with a formal agenda, focusing on centralising legislation, municipal laws, and regulations rather than fostering open, genuine engagement. As a result, the scope of participation often remains limited to initial consultation phases. In these instances, discussions lead to a consultative phase where no consensus is achieved, conflicts arise, and stakeholders are ultimately left feeling marginalised, with minimal influence over final planning decisions. Highlighting a significant disconnect between the mandate for participation and the reality of its implementation (Sihlongonyane, 2015; Todes and Turok, 2018). In terms of capacity and institutional gaps, it is evident that limited planning abilities within municipalities pose a significant barrier. This is further compounded by insufficient technical support provided to traditional authorities, resulting in ineffective collaboration between the two entities. The disconnect between these systems often leads to a lack of mutual understanding regarding governance processes, which only exacerbates feelings of mistrust and perpetuates institutional silos. Such dynamics can stifle progress and hinder effective governance, according to Claassens (2015).

Figure 1 below presents a synthesis of key governance challenges affecting the integration of traditional authorities into municipal land use planning and links these challenges to proposed integrative planning responses. Drawing on SPLUMA principles and analysis of IDPs, SDFs, and LUMS, the table highlights persistent issues such as institutional ambiguity, fragmented decision-making, capacity limitations, and weak participatory mechanisms. It further outlines targeted interventions, including institutionalised participation platforms, co-produced land use guidelines, capacity-building initiatives, and integrated monitoring and

conflict resolution mechanisms aimed at strengthening cooperative governance and supporting sustainable rural housing delivery within customary land tenure contexts.

Planning Implications

Theme	Planning Implication	
Parallel governance	Separate land allocation systems	1. Fragmented settlements 2. Weak participation
Consultative engagement only	Low local legitimacy	1. Fragmented settlements 2. Weak participation
Capacity gaps	Limited planning literacy	Delayed housing delivery

Figure 1: Planning Implications

6 PROPOSED PLANNING INTERVENTIONS FOR INTEGRATING TRADITIONAL AUTHORITIES

Drawing on the systematic review and analysis of policy and planning literature, this study proposes four interrelated interventions to strengthen the integration of traditional authority participation into land use planning for sustainable rural housing delivery.

6.1 Institutionalised Participation Platforms within Municipal Planning

Municipalities should formalise the participation of traditional authorities through structured, legally recognised platforms embedded within existing planning instruments such as Integrated Development Plans (IDPs) and Spatial Development Frameworks (SDFs). Rather than ad hoc consultation, traditional authorities should be positioned as institutional partners in planning forums, particularly during the formulation, review, and implementation phases of spatial and housing plans. This approach aligns with SPLUMA's emphasis on cooperative governance and inclusive decision-making, while enhancing the legitimacy and local relevance of rural housing interventions. Lessons can be learnt from Joint Planning Forums in KwaZulu-Natal (Sihlongonyane, 2015): Municipalities established structured forums where chiefs and councillors jointly reviewed SDF proposals. This reduced conflict between statutory planning and customary land allocation, demonstrating practical institutionalisation. For the Umlalazi Municipality (Mngomezulu, 2020), Municipal leadership created ward-level committees, including traditional leaders, leading to more transparent land allocation and improved housing project implementation.

6.2 Co-produced Land Use Guidelines for Customary Areas

To address misalignment between land allocation practices and statutory planning frameworks, municipalities and traditional authorities should jointly develop context-sensitive land use guidelines tailored to customary tenure systems. These guidelines can translate SDF principles into locally applicable spatial rules that respect customary practices while promoting sustainable settlement patterns, infrastructure coordination, and environmental protection. Co-produced guidelines offer a practical mechanism for bridging formal planning requirements with lived governance practices in rural areas. Co-designed settlement layouts allowed traditional leaders to allocate land while maintaining alignment with municipal zoning and infrastructure plans. For example, the Gauteng Rural SDF Pilot (Gauteng Department of Human Settlements, 2021): Drafted land use guides for peri-urban villages, blending customary allocation protocols with municipal building standards.

6.3 Capacity Building and Technical Support for Hybrid Governance

Effective participation requires both institutional recognition and technical capacity. Municipalities, supported by provincial governments, should invest in targeted capacity-building programmes for traditional authorities on land use planning, housing policy, and development control processes. Simultaneously, planners and municipal officials require training on customary tenure systems and culturally embedded governance practices. Strengthening mutual capacity can reduce institutional mistrust and improve coordination across dual land administration systems.

Workshops can be organised to train chiefs and municipal officials on planning processes, clarifying their roles and procedures. This can lead to improved tenure security and expedited housing project approvals. Capacity-building initiatives can empower communities by enhancing their understanding of Integrated Development Plan (IDP) processes, thereby increasing their participation in rural housing planning. According to Matlala and Uwizeyimana (2020), technical support has enabled under-resourced municipalities to effectively implement improved outcomes in participatory governance.

6.4 Integrated Monitoring and Conflict Resolution Mechanisms

The integration of traditional authorities into planning processes should be supported by transparent monitoring and conflict resolution mechanisms. Joint monitoring committees can track housing delivery outcomes, land allocation decisions, and compliance with agreed planning frameworks. Clear procedures for resolving disputes between municipalities, traditional authorities, and communities can prevent delays and enhance tenure security. Such mechanisms promote accountability while recognising the plural governance realities of rural South Africa.

This can be accomplished through community monitoring committees that facilitate the resolution of disputes related to land allocation and housing construction, thereby fostering trust and enhancing project sustainability. Formal mediation between municipalities and traditional authorities potentially reduces overlapping land claims and mitigates service delivery protests.

7 CONCLUSION

This paper demonstrates that sustainable rural housing delivery in South Africa is fundamentally shaped by how effectively municipalities integrate customary governance systems into statutory planning processes. Persistent misalignments between traditional authorities and municipal planning frameworks continue to undermine tenure security, spatial coherence, and development outcomes. While traditional authorities remain central to land allocation and community governance, their participation in planning processes is often weakly institutionalised.

By synthesising scholarly literature, policy frameworks, and municipal planning instruments, this study advances a structured approach for integrating traditional authority participation through institutionalised platforms, co-produced planning guidelines, capacity-building, and integrated monitoring mechanisms. Grounded in SPLUMA and participatory planning principles, the proposed framework offers practical guidance for municipalities navigating dual land administration systems. In doing so, the paper contributes to debates on rural planning reform, spatial justice, and inclusive development, while providing actionable insights for strengthening sustainable rural housing delivery in customary land contexts.

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reviewed paper

It's A Kind of Magic! Addressing The Arnstein Gap in Planning with the QICE Public Participation Performance Framework

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1 ABSTRACT

The gap between citizens' aspirational desires for public involvement quality in planning and the perceived current level, a.k.a. the Arnstein Gap, is well-documented (Bailey and Grossardt 2006, 2010). Authors Bailey and Grossardt have demonstrated in recent work how this Arnstein Gap is consistent across different geographical contexts and that it has remained more or less consistent across twenty-five years of these measurements (Bailey 2019, Bailey and Grossardt 2025). To the degree that Arnstein Gap presents a societal problem, for instance, a large Gap reflects lack of public confidence in professional activities and plans, and thereby signals a lack of legitimacy in the planning system overall, it is a problem that merits attention, analysis, and efforts directed at solution – even if these can only ever be partial (Weymouth and Hartz-Karp 2019).

Building on previous work including CORP here I explore strategies that planners can use for delivering strong public involvement performance and thereby nudging the Arnstein Gap smaller. Strategically avoiding engineering process aims around slippery, opaque, loaded and contradictory terms including "trust" and "consensus" (Shakeri 2025), this paper applies the QICE (Quality, Inclusion, Clarity, and Efficiency) framework for public involvement design and measurement and explores how QICE allows planners to address the competing desires of multiple stakeholder groups including citizens, planners, and project managers and sponsors (Bailey et al. 2015). Performance measurements are presented and the impacts are discussed using extensive real-world data from more than twenty years of project work. With acknowledgment to Freddie Mercury and his bandmates, this is not really "A Kind of Magic"; instead, these results suggest that public involvement process design using a multistakeholder framework in conjunction with careful operationalization that includes logical method selection and sequencing can deliver high performance across multiple criteria.

Keywords: Arnstein Gap, public participation, citizens, spatial planning, public involvement

2 INTRODUCTION

We begin with a fundamental question: what does it mean, to deliver "good" public involvement? And, according to whom? Accommodating, incorporating, making effective use of, and to some extent reconciling, input from large numbers of participants with wildly varying levels of confidence in private- and public-sector project managers and sponsors, resource endowments and investment propensities, experience, education and knowledge is a persistent challenge. In research articles this is framed as a solution-resistant "wicked problem" (Carcasson 2020) that confounds theorists. For decades it appears to have overwhelmed practitioners and professionals in terms of amelioration, even if not solution.

While acknowledging the dimensions of the problem and addressing it, research and professional literatures ran a gamut from participant exclusion or denial, for instance the TRB's infamous "guidance" in their 1999 White Paper on Public Involvement to "identify naysayers". In his book on wicked problems, Head (2015, 137) argues that "Rather than a reliance on expert-driven science and data analysis, a central focus is on how to convince a majority of citizens that political leaders are providing policy leadership." Setting up dichotomies of citizens vs. experts reinscribes and augments the polarization that is an increasingly universal concern.

These approaches treat participation as an input-output system and either do not acknowledge the role of method, or focus on methods – perhaps "approaches" – that prove totally impractical in the real world, such as seeking "consensus" and "building trust". None of these approaches work, because they seek to enforce the expert episteme on the citizens throgh process control, involving participant and data selection or denial, and even manipulation while turning participation into a politcal theater. Mantysalo et al. (2023:11) summarize thus: "In our view, the underlying problem is that the theoretical work on communicative

planning, and related ideas on deliberative democracy in planning, mainly focus on illegitimate forms of exercising power over others."

Apart from the voluminous literature that acknowledges the apparent intractability of this "wicked problem" in various ways, we know these approaches do not work because large and temporally-consistent and geographically-extensive data sets show that the citizen-perceived Arnstein Ladder levels (Arnstein 1969) are between 2 and 4 and that an Arnstein Gap is apparently a universal phenomenon (Bailey and Grossardt 2025). If so, then what could be more "legitimate"?

To state our foundational assumptions we define "good public involvement" using measurable multi-stakeholder sourced criteria, delivered with the intent of reducing the documented and universal Arnstein Gap.

All planning and urban development decions are to some degree public goods decisions because they involve the expenditure of public monies and the allocation of benefits, costs and risks across the public who fund the projects. This means that resource and legal constraints play a major role in determining what may be termed the feasible planning and urban design envelope. However even within constrained development projects, such as block-scale Transit-Oriented Development, or urban zoning, almost always a range of options exists. This article examines how best to design and deliver public involvement in defined and constrained real-world cases. Blue-sky visioning is considered as a separate domain.

From this contested starting point, we summarize the methodology termed Structured Public Involvement, or SPI (Bailey et al 2003, 2010, 2011). We designed SPI according to the principles of John Rawls's (1971) Theory of Justice, around three pillars of (i) procedural justice, (ii) access to justice, and (iii) distributional justice with the assumption that the first two are primary and that the third is conditioned by these first two (for more, see Bailey and Grossardt 2010, Grossardt and Bailey 2018). This is not an absolute; of course, because justice may be construed differently by individuals or groups but a clear starting definition is critical for design and measurement purposes.

We identify the sociopolitical domain within which planners operate and present a four-group stakeholder model. Epistemic challenges that capture dimensions of the "wicked probkem" are defined in relation to these stakeholder groups. Building on this model, we explain the development of a four-axis framework for evaluating the performance of public participation (QICE) that addresses the needs and desires of each stakeholder group. Drawing on more than twenty-five years of real-world data, we show how high performance public participation in planning is fostered by logical model development and application in partnership with stakeholders.

3 EPISTEMIC CHALLENGES

Numerous epistemic challenges exist to effective large-group participation; e.g. Citizen "ignorance" (Krek 2005, Poplin 2022); Stakeholder Strategery; competing desires and needs (Fung 2015); process scalability (Campbell and Marshall 2000); planning domain constraints, the role of technology; and institutional factors such as the overall levels of confidence in the project sponsor (Johansen and Upham 2026). Studies examining challenges to public participation in planning reiterate well-published key points; e.g. "In addition, the arrangement of forums, workshops or public meetings requires adequate funds, long preparation time, and enough staff." (Abas et al 2023) and "low interest to participate" and "low efficiency". This is not surprising considering the lack of measurement criteria for public involvement. According to former CEO Gordon Bethune (1998), "What you measure is what you're going to get." No measurement = no delivery.

We begin by partitioning the decision domain into four stakeholder groupings; citizens, public participation professionals (PPP), technical experts and project sponsors. The diagram represents typical – not idealized – interactions between groups; PPP cannot work without public participation, project managers are often responsible to, or are themselves, elected officials and may attend or direct meetings, while technical experts may interact with public data but are not always required to intereact personally with citizens.

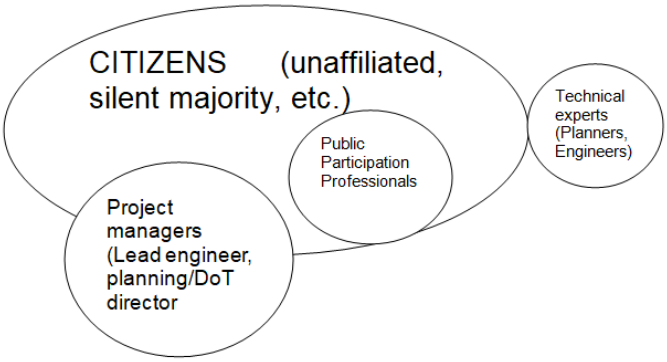


Figure 1: SPI Stakeholder group framework (Bailey et al 2003, 2012, 2015)

Given the epstimic challenges, and the stakeholder domains as outlined, how may we – the professionals – design and deliver higher-performance public involvement? Recognizing that what professionals want is not likely to match perfectly, if at all, with what either project sponsors or citizens want, the first step is to identify performance measurements that are meaningful to each stakeholder group. This requires defining a multicriteria performance framework. It is also critical to ensure that the criteria are measurable using indicators that are consistently applicable, transparent and meaingful to each respective group.

Measurement	Stakeholder Group	Indicator	Method of evaluation
Q – Quality	Citizens	Likert-scale satisfaction	Real-time anoymouus polling, written or electronic
I – Inclusion	Professionals, project managers	Count of attendees, count of self-identified stakeholder groups, demographic matching using participant data	Facilitator counts, keypad inventory,
C – Clarity	Professionals	Utility for professionals e.g. planners, engineers	Scorecard, post-meeting narrative surveys with thematic analysis
E – Efficiency	Project managers, sponsors and investors including responsible public bodies	ROI performance for project sponsors and managers	Net cost divided by Q, I and C metrics e.g. cost per attendee or data point,

Table 1: Inventory of QICE performance framework (Bailey et al 2012, 2015)

This separation of criteria allows for process measurement to be performed for each group in partial isolation; we say partial because there are interdependencies and feedbacks between each group and their valuations, but there are compelling reasons why such an effort should be made.

Citizens, for example, are often not familiar with professional design vocabularies (Grossardt et al 2002, Bailey et al. 2007). Highway engineers speak in terms of “Level of service” which is a compound network performance measure that is not simple to explain to non-engineers (Roess and Prassas 2014). Planners have recognized for more than a century that zoning classifications are also not always clearly understood by citizens (Williams 1922, Reynolds 1969). Therefore it may not be useful to adjudicate process performance from the citizen viewpoint using any of these professional design vocabulary criteria.

Lane (2005:283) argues that “Specifically, it makes little sense to evaluate public participation in terms that are not shared by the planning model itself.” While planners have requisite expertise, that is desired by citizens as shown by aspirational Arnstein Ladder level six, and the process must generate data that is directly useful to planners, the authors disagree with this perspective if it is interpreted to exclude some evaluation criteria that are not subject to planners‘ definitions. By collapsing criteria into professional terms, and designing and conducting the process in hock to this professional discourse, this resituates public involvement at a lower Arnstein Ladder level than necessary (Bailey and Grossardt 2006, 2025).

Another consistent refrain consists of “low education levels among the public” (Marzuki 2015). While citizens may desire education in technical and legislative procedures that govern how and when they are asked to appear and contribute, it is critical not to condition participation on normative “levels” of education or understanding. All values should be accorded equal weight during elicitation. Any other choice is fascism. This does not mean that all values willl emerge in the eventual configuraitons and solutions, but that they were included equally as inputs without prejudice.

This matrix was developed independently of, and slightly prior to, the seven-axis framework presented by Kubicek et al. (2010) and used by Bertelsmann Stiftung to evaluate participation projects for their 2011

Mohn Prize in Vitalizing Democracy (Bertelsmann 2011). It is interesting that despite the diverse origins of the research syntheses of authors Bailey and Grossardt on the one hand (urban planning and transportation projects in the US, primarily Anglo referencing and sources) and Kubicek et al. on the other (primarily German experience and German-language literature), the four criteria in Table 1 map well to four of the Kubicek et al. criteria.

For method application transition, the next consideration is which technique(s) to use? And when? There are a plethora of participation techniques and considerable debate about their qualities. By performing a literature review (bailey et al 2012, 2015), the authors identified a range of techniques and than evaluated their peformance across the four dimensions of QICE. Figure 2 shows a graphical representation of selected techniques.

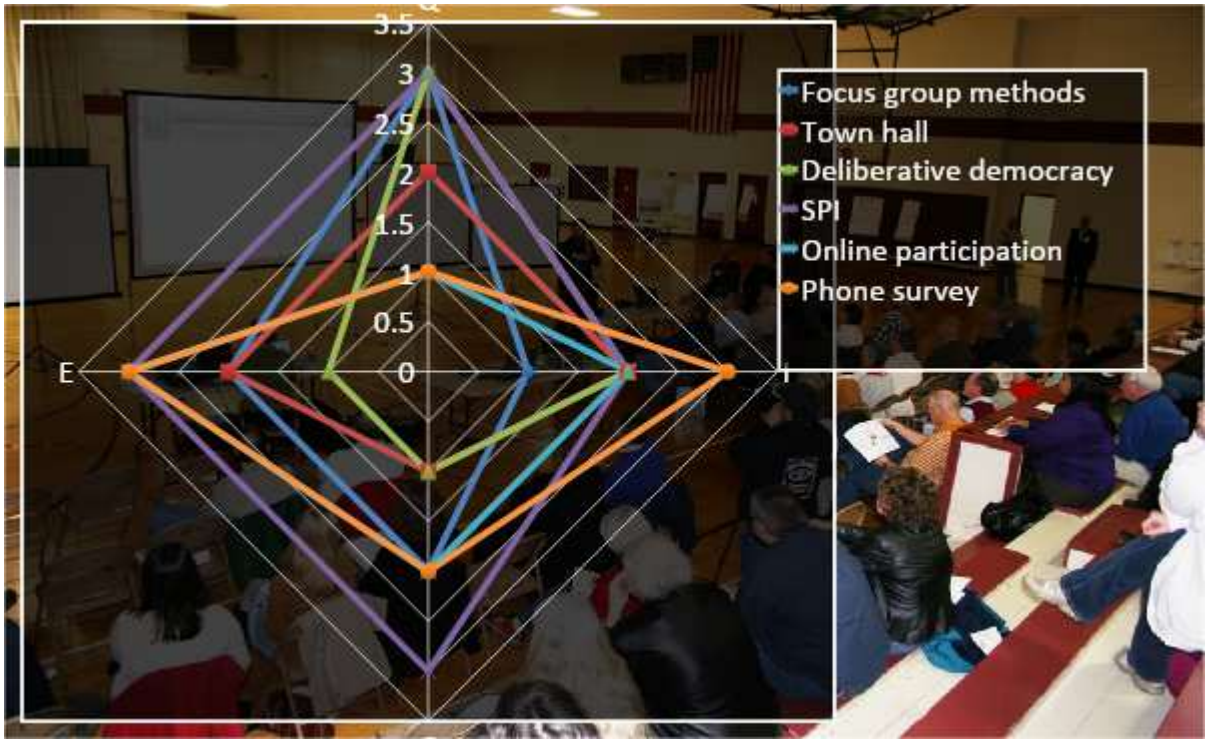


Figure 2: QICE evaluation of participation techniques (Bailey and Grossardt 2010)

Over the years since, more scholars have observed these lacunae and have joined the calls for more comprehensive and objective approach to design of participation e.g. Stelzle and Noenning (2019) who note "Another expected upcoming development is a more systematic approach to the combination of methods. At the moment the combination of methods depends on the experience of the moderator (e.g. the commercial TRIPLEX participation model) and without a proper scientific background."

We (Bailey et al. 2015, Grossardt and Bailey 2018) unpack the term "combining" methods into two distinct domains; selection and sequencing. Selection of methods can be supported by reference to their peformance with respect to each axis of QICE (Fig 2); internet and telephone surveys are efficient, yielding high data per unit cost, but do not generate high Q. Citizens advisory panels that are heavily invested in process and who are well known to planning authorities can yield high Q, but low I because they do not include large numbers and in some cases cannot be argued to be representative of larger valuations.

Additionally the temporal order of methods matters, for instance, high I can be supported by employing the online participation which can increase interest and therefore, number of participants, and High Q obtained from inperson meetings (above) can increase online participation numbers with sufficient awareness. Presentation of unfeasible or widely-reviled planning options in time-and resource-intensive inperson meetings and charettes, resulting in frustration, low-Q and low-I, can be avoided by conducting the broader phone/online surveying prior. We encourage readers to extend these performance mappings and identify trade-offs across other techniques.

Following Rydin and Pennington's (2000) definition of "the collective action problem" and the role of social capital, there are many facets of process performance that are desirable and often regarded as challenging to

achieve. For now, we focus on two key process performance dimensions that reflect how the application of QICE across numerous projects delivers useful and important results; i) the process/outcome dichotomy and ii) the transferability/universality of the method.

4 DECOUPLING OF PROCESS SATISFACTION FROM OUTCOME SATISFACTION

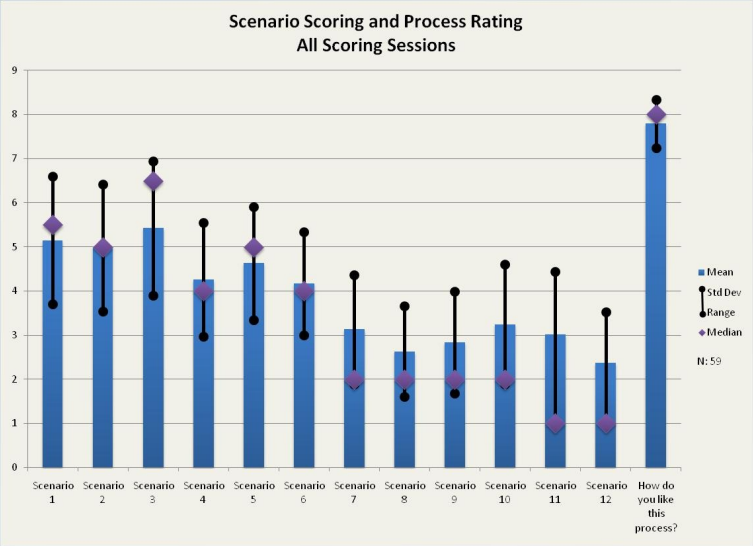


Figure 2 shows citizen evaluations of twelve geovisualized future use scenarios for a large nuclear plant (Bailey 2011, Ormsbee 2011), conducted on a scale of 1 to 9 points where 1 is “least suitable” and 9 is “most suitable.” The mean scenario scores ranged from 2.3 to 5.4. The process mean was 7.8. This is one meeting with fifty-nine participants. However, the authors have published identical data from more than three hundred public meetings that show results fully consistent with this slide. In no case has the mean for any outcome option exceeded the suitabilty evaluation for the SPI process.

Another issue that emerged from the database was the coupling between personal preferences and process outcomes. These processes have no champions. They diffuse power. Their outcomes can be hard to predict for those invested in the elite design system, even those with considerable experience and deep community ties. On one occasion, to illustrate the concern, we proposed to a context-sensitive bridge design team that we all participate in a sweepstake prior to the public involvement process (Bailey et al 2007). Everyone contributed a dollar and winner take all. There were eighteen team members and thirty-two visualizations representing potential designs for public evaluation. The team members included bridge designers, architects and planners with decades of experience. Nobody won the sweep.

5 CONSISTENCY OF PERFORMANCE

The large group process challenge is not in the first instance conditioned by the specific planning or urban design project. The overall problem of elicting useful data from large numbers of participants with widely varying levels of knowledge, investment, and confidence in the sponsoring entities and then converting these data into useful design and planning guidance that may be actioned by professionals in their domains is shared by all such public processes; for example. Environmental management, energy futures, transportation system investment and development, park policy and more. Achieving this while delivering high satisfaction levels to each of the involved stakeholder groups, who often have non-aligned or even competing objectives, is another hallmark.

Therefore, processes that demonstrate consistent performance with respect to all stakeholder groups across multiple applications in different contexts, locations and scales, may stake their claim to be high performance public involvement. These SPI data sets are representative of numerous others that the authors have aggregated over more than twenty-five years of real-world SPI work.

This is much more than simply asserting that planning does not have a lock on charettes, or that immersive VR computer visualization is best suited for urban design.

We have focused here on the systemic design aspects of the SPI protocol, which are necessary but not sufficient conditions. There are a set of further operational considerations that must be met in delivering this

performance that we lack space to address fully here. However, these may be summarized in terms of meeting facilitation practices (Schuman 2005, Hunter 2009, Herd 2019) e.g. always start and end meetings on time; ensure technology is backed up, maintain a high proportion of participant-driven data thriughout the meeting to prompt discussion; respond to all questions, ensure all participants can evaluate if they choose to do so, resist process hijacking by individuals, and much more. One primary addition to these established principles is the central role of citizen-generated SPI data in structuring group process discussion, conducting issue probing and ensuring high Q-metric delivery (c.f. Bailey and Grossardt 2003, 2018).

We encourage readers to review an under-appreciated CORP classic, Alenka Krek's 2005 article on "Rational Ignorance of the Citizens in Participatory Planning", explicating how and why civic disengagement is not the cause of, but is driven by, poor public involvement in planning, and in conjunction with the QICE frameworks, then analyze how impressions that motivate rational disengagement may be mitigated via high-performance methods.

6 DESIGN "ROBUST" (I.E. GAMING-RESISTANT) PROCESSES

We define "robust" in this context as the capacity to resist gaming, meaning disproportionate influence development by any party or group; for example, it is not desirable that a Citizens Advisory Board (CAB) convened by municipal authorities takes it upon itself – or is encouraged to – function as a proxy for larger groups without any verfirication of valuations vis-a-vis any larger, apparently less-involved groups. We say "apparently" because in a number of cases, poorly-designed processes that rely heavily on CAB input for planning decisions, can result in the sudden triggering of large-scale participation by previously dormant groups that can deliver project crisis.

Process "gaming" is characteristically epsitemically-centered (by the academe and professional experts) as a citizen or stakeholder problem. Certainly there are participants and groups who seek to realize a specific outcome and will work to that end regardless of how many different or opposing views they encounter. Numerous professional guides have premised suggestions on this principle; for example the 1999 TRB Public Involvement White Paper contained exhortations such as "identify naysayers".

However there is also the possibility of internal gaming by experts, such as planners or engineers, who for whatever reasons are invested in a specific design or outcome and seek to reverse-manage public involvement processes to ensure that their preferred outcome is realized (Grossardt and Bailey 2018, p.x). Becasue these experts are integral and essential to the project, and their views are often privileged compared with the lay majority, this possibility requires careful consideration. On the one hand, the point of public involvement is to elicit and incorporate views and values from citizens at large, while on the other, the knowledge of planning and design experts is essential in identifying and delivering functional built-environment outcomes.

How do we know if a process is gaming-resistant? The overall Q-scores for the project are indicative, because processes that are not conducted according to principles of justice that are aligned with citizen beliefs and expectations are not adjudicated with high suitability scores.

So now, we can evidence-supported prediction that, with 95 percent confidence, we can achieve a Q-metric (citizen process satisfaction score) of 8 points or higher on a 1 through 10 point scale on any public goods project using this protocol. We can also conclude that regardless of the perceived satisfaction levels of specific outcomes, the process can be evaluated with high scores. These deliveries conform to John Rawls' theoretical formulation of procedural justice (Rawls 1971), around which the SPI process was designed (Bailey and Grossardt 2010).

7 THE VALUE OF PERFORMANCE MEASUREMENT

In 2008, during a research presentation at a large community visualiztion facility in the US attended by numerous professionals and researchers, we showed an early set of SPI performance data and we were asked "So, why aren't you millionaires?" This was an unexpected question and at that time, we found ourselves confounded. Perhaps fortunately for our sanity as researchers, our goal was not to accrue large personal wealth but, as we reflected later, we considered how the question could be depersonalized and inverted to ponder systematically, if not monetarily, then what objective value is there in such performance measurement?

This prompted us to research official bodies. We wrote the Office of Management and Budgeting to inquire if there were requirements for data gathering by Federal agencies . There are twenty-three of these agencies, which spend billions of dollars each year on mandated public meetings and involvement via compulsory EIS and NEPA and other legislative requirements. There was – and still is – no requiement to document anything except the procedural timeline and registration conformance to e.g. checkboxing the 28-day advance notice of a public event or project proposal. This means, for instance, that there is no count of attendees – something that we as classroom instructors are habituated to performing in our daily and yearly lives and recording in our systems. In the years since, transportation has implemented requirements for public involvement practice guides and reporting via e.g. STIPs, however, these are not mandatory and are not subject to Federal aggregation and reporting.

From the funding and agency viewpoint, then, the realistic, systemwide answer was – and still is – none. This is not just about SPI, but applies equally to any method developed around a performance framework. Without performance metrics, any process can be labeled "inclusive" "efficient", "useful" and so on.

The role of technology in planning

According to Deep (2023, 664) "The integration of technology into urban planning enhances resource allocation, promotes sustainability, and improves overall quality of life." Technology & Architecture (2025) asserts that "Urban planning is now more inclusive, sustainable, and efficient thanks to these developments." Yet these claims lack hard data and are moreover contradicted by an extensive research literature as well as numerous media productions that are skeptical, describing only specific and limited utility if any at all.

Technology does not magically solve the group process problems in planning, or indeed any domain. Christman and Schinagl (2023:141) argue that the technological facilitation of "translocal planning" and "digital datafication of spatial realities" constitute both risks and potentials for planning.

It is the job of professionals and process designers to ensure that all participants' valuations may be elicited without such tacit screening. For example, forms of computer visualization are well-proven to be useful in this way, for instance by presenting specific spatial and structure configurations and use patterns in a way that matches participants' sensory understandings, so that they may more effectively evaluate different options. Immersive environments are one example. GIS has a mixed reputation for effective transmission of land use options, with some studies finding while others find promotion of exclusion and disenfranchisement. As Aitken (2014) finds in her survey, ICT overall "requires critical reflection to ensure that it does not aggravate, rather than alleviate, these problems. For example, reliance on ICTs may risk leading to new inequalities in access to planning systems. Furthermore, questions relating to who participates, and who controls participation in planning processes remain relevant and pressing."

8 AI! "IT'S A KIND OF MAGIC!"

Four decades on, Freddie Mercury's words are most apposite. Constant exhortations regarding the ultility – the inevitability – of AI and the "need – to adopt now permeate – even saturate – popular culture (RTF 2025), trade blogs, professional publications and research articles. For example, Deep's review article (2023, 664) asserts that "The integration of technology into urban planning enhances resource allocation, promotes sustainability, and improves overall quality of life." However there is no data presented in support and no definitions of these terms are offered. In this way the purported benefits of AI mirror the "benefits" of previous tech-waves in planning; and have we not all heard this before with respect to GIS (Nedovic-Budic 1999), visualization (Scroth 2010), internet participation and deliberation portals (Aguirre and Nyerges 2011) etc.?

Sanchez et al. (2026:294) perform a review of published papers and argue that AI in planning presents ethical challenges including "bias, transparency, accountability, privacy, and misinformation" which are to be countered by "human oversight and continuous monitoring" – thereby essentually negating the very economic and ostensible "efficiency" reasons for AI adoption and implementation.

The specter of AI watching AI and failing to deliver useful output is already visible in the education field, where anti-plagiarism tools use AI to combat student and researcher use of AI and not only fail but foster mistrust (Giray 2024). In a blunt MIT Sloan School blog post titled "AI Detectors Don't Work: Here's What to Do Instead", "OpenAI, the company behind ChatGPT, even shut down their own AI detection software

because of its poor accuracy." At this stage, inclusion of AI in analysis of public invovement data in any capacity beyond data summary would be premature and may be counterproductive.

In sum, although these technolgies have had some impact, primarily improving visualization capacity and fidelity in the professional fields of planning, engineering and urban design, and they have been shown to deliver useful, if limited, increments in specifc metrics such as youth participation, (a component of the I - metric), they patently have not delivered a revolution in the reach and quality of public participation and they have not "democratized" (Stockholm 2026).

Planning projects involving the valuable resource commitments of numerous participants with the goal of long-term infrastructure arrangement and build are not a good time for experimentation involving technology premised on fact-free and often tacitly incentivized elite adoption. System failure, lack of transparency, and overall frustration with the disconnect between real life and planning are risks.

In discussions of equity in planning, the emphasis on the "digital divide" presupposes that those who do not or cannot access the technology are estranged from the nonarticulated but authentic or meaningful participation of those who can and do. This framing masks a core issue of data reliability and stakeholder confidence in technologies particularly those of remote participation. Even without employing the "T-word" or trust – a word that the authors find hightly problematic in planning for reasons advanced previouisly at CORP and elsewhere (Grossardt and Bailey 2018, Bailey and Grossardt 2025, Bailey 2025a, Bailey 2025b) – it is clear that many citizens are dubious of the motives and effect of such deployment.

Therefore, implementation of technology to support participation in planning systems can rely on techniques that are tried, tested, evaluated and whose properties are known from all angles. The SPI results shown here illustrate that evidence-driven selection of technologies and integration into methods based on fit with a performance evaluation framework such as QICE can deliver useful results for all stakeholders.

9 THE TWO T-WORDS: TECHNOLOGY AND TRUST

Tech systems are even positioned to compete with each other on the principle of "trust" in pursuit of adoption e.g. Kudu (2019) "Given the current topology of technology innovations, there is no solution better than blockchain that embodies trust." The apogee is reached in IT and tech promotional discourse for urban system design and management, for example according to XRSI "Smart cities built on RDG™ do more than deploy new tools. They build citizen trust as the cornerstone of a sustainable and inclusive digital society." AI-driven license plate reader vendor Flock (2025) claims "Building Public Trust Through Transparency: How Flock Helps Communities – and Why You'll Want to Be Part of It." Yet, none of these define "trust" nor how exactly they "help communities" and there are many people who want no part of it (Deflock Tucson 2025, Colorado Newsline 2025, The Oaklandside 2025 etc.)

An emerging research literature suggests that the higher the stakes, the lower the "trust" in IT; for example, according to Shoabjareh et al. (2024, p.8) "....when individuals make more crucial decisions, particularly regarding work trips, a higher level of distrust in technology (in this case TIAs) has a considerably stronger adverse effect on the usage of the technology."

There is much more that could – maybe should – be said, but the larger point here is that "Trust" is not evident in historic or current Arnstein Gap data, regardless of the adoption and social permeation of IT and communication technologies. In some cases, technology is not even a solution in search of a problem, but more closely resembles a problem in search of another problem. Instead, positioning technology by testing it and evaluating logically how each instance promotes Q, I or C and therefore E, is a more promising and sustainable way to integrate technology into planning than shotgun promotion or data-free forced application.

10 CONCLUSION

This is a vast, open territory whose contours are unclear, and the stakes for planners – and all of us – are high. Planners must mediate between the ever-increasing and polarized demands of vested parties, which now appear to include well-funded IT and AI-driven interests, as well as traditionally-recognized elite factions. With social exclusion, disenfranchisement and polarization all increasing, a patently-intensifying loss of confidence in civic institutions, particularly planning (RITP 2025), and the consequent temptation to retreat from larger engagement with citizens strengthening, it is more important than ever to consider the

importance of method in shaping not only the QICE-measurable quality of public involvement but also planners' and citizens' experience.

In the meantime, we continue to analyze the core concepts including the how the T- and C- words are used (Bailey and Grossardt 2025) and how these concepts are mobilized in academic, institutional and professional planning discourses to frame the goals of public involvement and comparing these with broader citizen understandings. Our aim with this ongoing program is investigate how the expansive, indeterminate, and problematic concept of "trust" may be reformulated as a justice-based process goal (Rawls 1971), in part, to more accurately capture what both planners intend and citizens want, i.e. increased confidence in process and outcomes. A relatively limited literature is emerging that directly connects process design and planning delivery; for instance, research in international contexts demonstrates that, via attention to process design, a reduction in the Arstein Gap can be achieved (Weymouth and Harz-Karp 2019).

This "wicked problem" needs logical, systematic, iterative, and evidence-driven reasoning. As Bryson et. al. (2013, p.30) state: "Effective and operable measures of participation can help policy makers learn from implementation so that they can enhance the effectiveness of the remainder of the participation effort they are currently working on and build long-term institutional capacity for future participation." Enhancing the effectiveness of the participation effort can be advanced by means of granular focus on process design and performance criteria including QICE outcomes. In pursuit of this broad-scope and long-term goal, the QICE project database, exemplified here, demonstrates consistent performance across temporal, geographical and project domains.

"The waiting seems eternity

The day will dawn of sanity"

Queen 1986

We hope so. Meantime, we conclude, with respect to Freddie Mercury and his bandmates: It's Not A Kind of Magic! It's The Application of Logic!

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reviewed paper

Land-Use Conflict and Traffic Congestion on the N12: Evaluating Planning Responses at the Moroka Bypass, South Africa

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1 ABSTRACT

Rapid urbanisation and an increasing demand for housing in land-constrained areas often intensify land-use conflicts and place significant strain on existing transport infrastructure. In South Africa, national road corridors are critical connectors between towns, cities, and provinces. The integration of well-designed on- and off-ramps is essential to sustain efficient mobility. However, stop-controlled intersections on these corridors, as opposed to grade-separated interchanges, cause significant disruptions to traffic flow, accessibility, and safety, uncovering weaknesses in integrated and sustainable planning. This study examines the R558 stop-controlled intersection along the N12 at the Moroka bypass and compares its performance with four on-and-off ramps serving Soweto and surrounding neighbourhoods along the same corridor. Using quantitative methods, it is possible to confirm or disprove a hypothesis, as the formulae can be tested repeatedly. Spatial data was also consequently used to visualise these trends. Findings indicate that the four ramped interchanges effectively support traffic flow, access, and movement along the N12, demonstrating resilience against increased development pressures. In contrast, the R558 stop-sign intersection performs poorly, characterised by congestion, increased travel times, and heightened safety risks. The study also reveals that inadequate integration of transport planning into rezoning and residential development decisions exacerbates these problems, undermining mobility and regional sustainability. It concludes that sustainable and resilient infrastructure planning, particularly the timely provision of grade-separated interchanges, is essential to mitigate traffic conflicts arising from new developments in land-constrained areas.

Keywords: Sustainable planning, National road corridors, Mobility and accessibility, Land scarcity, Moroka bypass

2 INTRODUCTION

Urban growth often affects environmental and socio-economic dynamics, leading to improper land use in rezoned areas due to exponential population growth and housing demand. Zare et al. (2025) noted that according to World Bank data, currently about 56% of the world population is urban dwellers, and by 2050, it would have risen to nearly 70%. The expansion process of urban growth dominates in existing core areas as well as within other periphery core areas, as emergence (Perveen et al., 2017). In South Africa, emerging urban areas are common within the road corridors that normally connect towns, cities, and provinces. Breški and Maljković (2025) asserted that urban land use and quality of life are affected by the efficiency of road infrastructure and sustainable mobility. Hence, Xu et al. (2023) pointed out that planners and policymakers need to take advantage of advanced information and communication technologies to improve urban mobility paradigms and transportation system networks.

Transportation systems are vital for urban economic activities and social development through road infrastructure networks for the movement of people and goods between different locations (Marian et al., 2024; Bayata et al., 2025). Reliability and safety of transportation systems have been over-researched through exploring the well-being and safety of both passengers and drivers on the roadways (Ulak et al., 2019; Siebke et al., 2023). However, these dynamics in transportation are essential and received attention. According to the World Health Organisation (WHO), approximately 50 million non-fatal injuries and more than a million road traffic deaths occur worldwide each year (Brunner et al., 2019; Riedmaier et al., 2020; Karbasi & O'Hern, 2022). Khashayarfard and Nassiri (2021) argued that accidents resulting in road traffic deaths and injuries are mostly caused by driver errors, such as speeding, poor visibility, fatigue, and

distractions. Less has been researched on the impact of infrastructure on road traffic accidents compared to road traffic congestion caused by infrastructure (Islam, 2025; Syla et al., 2025).

Commuters' well-being, economic activities, and environmental sustainability are significantly affected by the critical challenge of urban traffic congestion caused by transportation infrastructure (Islam, 2025). In South Africa, national road corridors are vital transportation infrastructure that feature separate interchanges with properly designed on- and off-ramps and stop-controlled intersections. Osman (2023) stated that frequent sites of traffic congestion are within the intersections but worse within the four-leg intersections. This study intended to explore the significant disruption to traffic flow, accessibility, and safety at the four-leg intersection of R558 and N12. Breški and Maljković (2025) claimed that smartly planned road infrastructure improves traffic flow, which minimizes traffic delay and reduces fuel consumption and emissions, which significantly contribute to a sustainable environment and urban mobility.

According to the World Health Organisation (WHO), road traffic accidents cause over a million deaths and 50 million non-fatal injuries worldwide each year (Brunner et al., 2019; Riedmaier et al., 2020; Karbasi & O'Hern, 2022). Most accidents result from human error, including speeding, poor visibility, fatigue, and distractions (Khashayarfard & Nassiri, 2021). However, the role of infrastructure in influencing these incidents, especially congestion caused by infrastructural shortcomings, has received comparatively less attention (Islam, 2025; Syla et al., 2025).

In South Africa, national road corridors feature various intersection types, including grade-separated interchanges and stop-controlled intersections. The latter, particularly four-leg intersections such as the R558 and N12 junction, often experience significant traffic congestion and safety issues (Osman, 2023). Smartly planned road infrastructure can improve traffic flow, reduce delays, fuel consumption, and emissions, contributing to sustainable urban mobility (Breški and Maljković, 2025). Intersections are critical nodes in transport networks where traffic conflicts arise due to opposing and converging vehicle flows (Bayata et al., 2025). Traffic congestion at intersections contributes significantly to environmental pollution and escalates transport costs (Li et al., 2024).

3 LITERATURE REVIEW

The Transport Impact Assessments (TIA) in the road network provides essential insight into traffic flow through the assessment outcome on the evaluation of the impact of controlled intersections and uncontrolled/free-flow highway segments (Marian et al., 2024). This includes roadway design, accessibility, and traffic congestion that reflects the traffic demand, network performance, safety, and environmental sustainability. In the capital city of Albania, Tirana, TIA was conducted using the fixed-time traffic systems that impact the traffic flow and compromise safety and environmental sustainability, as well as stress drivers with time delays (Syla et al., 2025). On the other hand, TIA mostly integrates human intervention into the traffic flow or congestion. For instance, Ulak et al.'s (2019) TIA in the city of Tallahassee, Florida, United States of America, was based on human behaviour in relation to the T-intersections, focusing on the experience and age of the driver.

There is intensive literature on TIA using traffic and network performance, which evaluates how land use development and infrastructure changes affect traffic flow. Cakici and Murat (2019) argued that conflict in traffic flow persists due to a lack of optimisation-based traffic management approach consideration in the traffic volume and network. These are determinant factors in the TIA when utilising the traffic demand and road network performance for new development settlement with the periphery core areas that have attracted high working households within the road corridors. Osman (2023) emphasises that there is an exceeding capacity on the road network due to rapid urbanisation and population growth in Sweden, which increases traffic demand because of more trips taken within limited spaces. Ultimately, the expansion of urbanisation results in traffic congestion due to the increasing number of vehicles that transport the growing number of passengers and drivers on unchanged road networks, such as the Moroka bypass N12.

Safety and pollution as main factors in the TIA are common in the evaluation of traffic congestion within various intersections. According to Xu et al. (2025), crash frequency and severity are usual measurements in the TIA when considering traffic safety, which is critical in urban planning. Particularly for intersections that experience rapid increases of vehicles affected by the continuation of residential development. Many scholars have concentrated on the introduction of autonomous vehicles since human error was identified as

the main factor that compromises road safety (Riedmaier et al., 2020; Khashayarfard & Nassiri, 2021; Ploeg et al., 2021; Karbasi & O'Herns, 2022) rather than the effect of land use change influenced by population growth. Instead, Siebke et al. (2023) considered the impact of autonomous emergency braking systems in different modes of transport on road safety at intersections. Additionally, traffic congestion within the intersection causes vehicles to emit a lot of carbon monoxide (Bayata et al., 2025; Syla et al., 2025). Zare et al. (2025) advocate for the integration of efficiency and resilience into urban transportation system assessment to limit air pollution at road intersections.

3.1 Intersection Performance Evaluation

The intersections on urban road networks are very vulnerable points of traffic congestion, particularly on controlled intersections where there are opposite direction traffic patterns (Marian et al., 2024). Intersection performance plays a huge role in the quality of road services for users by evaluating using metrics as an indicator for the efficiency of the volume-to-capacity ratio as well as control time (Zare et al., 2025). Islam (2025), under urban road traffic management, adopted the Travel Time Index (TTI) and Planning Time Index (PTI) as performance indicators to quantify the time penalty incurred by travellers during free-flow conditions and congestion periods. According to Islam (2025), higher values indicate severe delay in the ratio of peak-period travel time, meaning when the value of TTI is greater than 1.0, it indicates high congestion, and when it is much lower than 1.0, it resembles the free-flow travel time. For the observed intersection, Shirazi et al. (2023) stated that a comprehensive performance evaluation done at a downtown Las Vegas intersection was through traffic measurement that directly estimates any of the trajectories, such as turning movement count or speed, to mimic a realistic traffic flow.

3.2 Scenario-Based Traffic Simulation

Scenario-based traffic simulation utilises various computational models to examine infrastructure upgrades, policy interventions, future traffic growth, or the scenario of 'do-nothing' in urban road management (Perveen et al., 2017; Bayata et al., 2025). Various models such as AIMSUN, TOPSIS, VISSIM, YOLO, etc., are utilised to determine broader traffic pattern analysis over a larger area or provision of detailed traffic behaviour. Xu et al. (2025) claimed that many studies commonly use AIMSUN and VISSIM that efficiently handle scenarios because of their friendly interfaces and versatility abilities to switch between simulations. The three simulations are predictive and exploratory tools explored based on the researcher's comparison scenarios, especially for robust planning that considers the calibration and validation of traffic challenges (Ulak et al., 2019; Li et al., 2024; Breški & Maljković, 2025). Varga et al. (2023) believe that at a network level, a macroscopic approach is preferred for traffic demand and assignment, such as space mean speed, traffic density, and traffic flow volume in regions. Bayata et al. (2025) noted that mesoscopic is good to describe traffic flow as a homogeneous continuum employing equations for both vehicle clusters and networks. While microscopic, concentrate on vehicle routes when describing traffic flow (Xu et al., 2025).

3.2.1 Traffic Volume Analysis

In transportation planning applications, traffic volume analysis is one of the paramount parameters (Apronti et al., 2016). Khan et al. (2018) stated that analysis is critical for efficient management and control of congestion levels that are magnified in urban intersections where there is a high number of conflicts when there is extreme traffic volume. Transportation analysis and management systems mostly utilise traffic volume forecasts to adequately characterise traffic patterns and reaction towards variability (Wagner-Muns et al., 2017). For instance, Khan et al. (2018) advocate for the use of Unmanned Aerial Vehicles (UAVs) in dense, inaccessible, or hazardous areas to generate matrices for analysing traffic volume. Additionally, area scale affects the traffic volume measurement and analysis in both network base and nodes, which are covered over different periods (Macioszek & Kurek, 2021). However, Macioszek and Kurek (2021) argue that most Global South countries, which are not equipped with tolling systems, automated traffic counters, or other technologies, make use of systematic observation for analysing traffic volume. The volume of traffic flow in the past decades since the 1980s has been analysed by applying various non-parametric (supervised machine learning) and parametric methods (Janković et al., 2021).

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3.3 Queueing Theory on Transport Impact Assessment

Regarding TIA, there is a wide spectrum of research on understanding queueing theory to determine the traffic flow through applying various traffic-queue modelling (Gunes et al., 2020; Wang et al., 2020; Zhao & Gilbert, 2025). The theoretic approach is about collecting data using any form of system and technology to assess traffic flow and waiting time of vehicles in an intersection (Bui, 2018). According to Wang et al. (2020), using actuated traffic information, the mathematical traffic queue model usually analysis delays and queues by estimating the intersection traffic volume. Gunes et al. (2020) asserted that queuing theory provides performance calculations by mathematically examining traffic scenarios to derive results based on issues around waiting time or delay due to the structure of the infrastructure. Mostly the use of queuing theory is to have a broader range of applications as a canonical way to address complex traffic systems and elaborate on the dynamics that lead to traffic delay and congestion (Timmerman, 2022). Zhao and Gilbert (2025) claimed that the analytical study in queuing theory is about characteristics that delay the flow.

4 METHODOLOGY

A quantitative research approach was adopted, integrating numerical traffic data with spatial analysis to ensure objective measurement and replicability of results. The quantitative component enabled the testing of assumptions related to traffic growth, intersection performance, and the effectiveness of Transport Impact Assessments (TIAs). Traffic data were obtained from secondary sources, including municipal traffic count records, South African National Roads Agency Limited (SANRAL) datasets, and previously submitted TIA reports associated with residential developments in the study area. These datasets comprised Average Daily Traffic (ADT), peak-hour volumes, turning movement counts, and heavy vehicle percentages. Where necessary, historical counts were compared with more recent data to assess traffic growth trends.

The study area is located south of Johannesburg, focusing specifically on the R558 stop-controlled intersection along the N12 at the Moroka Bypass (see Figure 1). This intersection experiences recurring congestion and varying degrees of delay, particularly during peak periods, making it a suitable case study for evaluating the implementation and effectiveness of TIAs. The R558 intersection was selected due to its strategic function as a feeder route connecting residential developments to the regional road network and its documented traffic delays. For comparative purposes, four nearby ramped interchanges along the N12 corridor were included in the analysis to benchmark operational performance and assess whether alternative intersection configurations could better accommodate increasing traffic volumes.

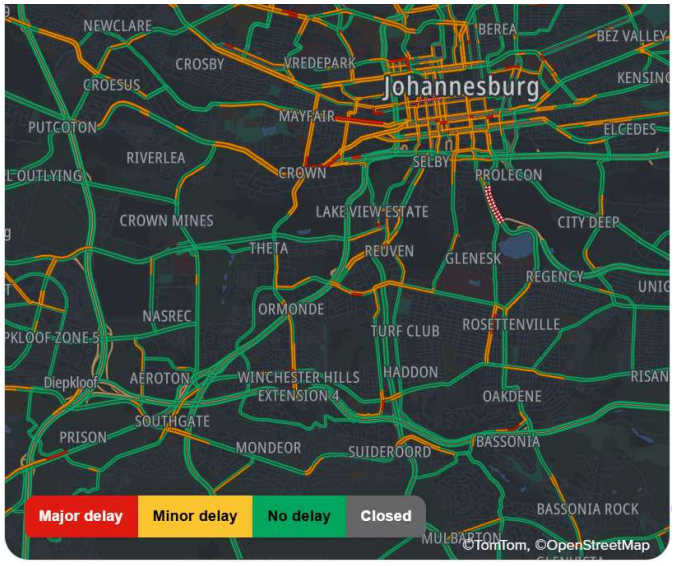


Fig. 1: Study Area

Spatial data were used to visualise traffic patterns, congestion levels, and network connectivity within the study area. Geographic Information System (GIS) software was employed to map traffic volumes, intersection layouts, surrounding land uses, and residential development patterns. Spatial layers included road network shapefiles, intersection control types, zoning data, and aerial imagery. These visualisations assisted in identifying spatial correlations between residential growth and traffic demand, as well as illustrating capacity constraints at critical nodes.

The methodology section further elaborates on the procedures for the traffic volume analysis. Peak-hour traffic volumes were extracted and analysed using standard traffic engineering formulae to calculate volume-to-capacity (v/c) ratios, Level of Service (LOS), and average control delay. Queuing theory principles were applied to estimate queue lengths and waiting times at the stop-controlled intersection under existing and projected traffic conditions. Scenario-based microsimulation tools such as AIMSUN and VISSIM were considered from Xu et al. (2025); however, due to limitations in detailed input data (such as signal phasing, driver behaviour parameters, and calibrated network models), the study prioritised traffic volume analysis supported by deterministic queuing models. This approach ensured methodological consistency and reliability given the available datasets, while still enabling a rigorous assessment of how TIAs accounted for projected traffic impacts associated with residential development in the corridor.

5 FINDINGS AND DISCUSSION

The findings illustrate clear temporal variations in congestion across both annual and weekly scales along the N12 corridor. Although the monthly congestion profiles for 2024 and 2025 follow comparable seasonal trends, suggesting that broader structural travel patterns remain relatively stable, important inter-annual differences are evident in cumulative delay and peak-period intensity (see figure 2).

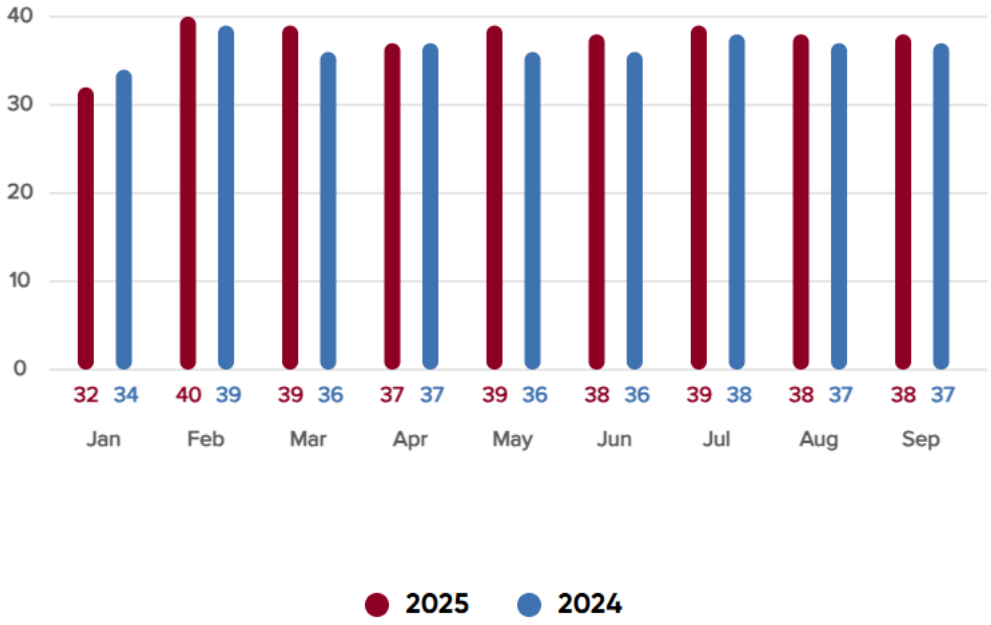


Fig. 2: 2024 vs 2025 congestion trend

At the annual scale, commuters in 2025 experienced approximately 65 hours of peak-period congestion, representing an increase of 3 hours and 50 minutes compared to 2024 during comparable peak observations. However, when cumulative annual delay is considered, total time lost decreased from 153 hours in 2024 (6 days and 9 hours) to 98 hours in 2025 (4 days and 2 hours), reflecting a net reduction of 55 hours. This apparent discrepancy suggests that while certain peak segments intensified in duration or intensity, overall congestion exposure across the year declined. Such a shift may reflect improved traffic distribution, adaptive commuter behaviour (e.g., peak spreading), minor operational adjustments, or localized network improvements.

5.1 Temporal Variations in Congestion

Weekly and diurnal analyses reveal more pronounced temporal dynamics (see figure 3). Mondays consistently recorded the highest congestion levels, particularly during the morning peak period (07:00–08:00). This pattern aligns with typical post-weekend demand surges, where work-related commuting is at its highest. The finding that travelling before 07:00 on Mondays could save up to four hours annually for a commuter undertaking a 30-minute trip highlights the sensitivity of congestion to relatively small temporal shifts in departure time. This reflects a network operating near capacity, where marginal increases in flow result in disproportionate increases in delay.

06:00am	17 min 50 s	17 min 50 s	17 min 40 s	17 min 30 s	17 min	15 min 10 s	15 min 30 s
	23 min	23 min	22 min 40 s	22 min	20 min 50 s	16 min	16 min 10 s
08:00am	22 min 20 s	22 min 30 s	22 min 10 s	21 min 10 s	19 min 50 s	17 min 10 s	17 min
	19 min 40 s	20 min	20 min	19 min 30 s	19 min 10 s	18 min 10 s	17 min 40 s
10:00am	19 min 10 s	19 min 30 s	19 min 30 s	19 min 20 s	19 min 30 s	19 min	18 min 10 s
	19 min 20 s	19 min 50 s	19 min 40 s	19 min 40 s	20 min	19 min 30 s	18 min 30 s
12:00pm	19 min 30 s	20 min	19 min 50 s	20 min	20 min 30 s	19 min 50 s	18 min 20 s
	19 min 30 s	20 min	20 min	20 min 10 s	20 min 30 s	19 min 50 s	18 min 20 s
02:00pm	19 min 40 s	20 min 10 s	20 min 10 s	20 min 20 s	20 min 50 s	19 min 20 s	18 min 10 s
	20 min 40 s	21 min 30 s	21 min 30 s	21 min 30 s	21 min 50 s	18 min 50 s	18 min
04:00pm	23 min 20 s	24 min 10 s	23 min 50 s	23 min 40 s	22 min 50 s	18 min 30 s	17 min 50 s
	23 min	24 min 10 s	23 min 40 s	23 min 30 s	21 min 50 s	18 min 10 s	17 min 40 s
06:00pm	20 min 20 s	20 min 50 s	20 min 40 s	20 min 50 s	20 min 10 s	18 min 30 s	18 min 10 s
	18 min 50 s	19 min	19 min	19 min 20 s	19 min 10 s	18 min 40 s	18 min 10 s
08:00pm	18 min 10 s	18 min 20 s	18 min 20 s	18 min 20 s	18 min 30 s	18 min 20 s	17 min 50 s

Fig. 3: Weekly congestion

Peak-period comparisons further indicate that, in 2024, commuters experienced more than 20 minutes of congestion delay per 30-minute trip during both morning and evening peaks. While for 2025, congestion intensity declined to over 13 minutes (morning peak) and 12 minutes (evening peak) per 30-minute trip. Despite this improvement, the morning peak consistently exhibited higher congestion levels than the evening peak in both years. This asymmetry reflects directional commuter flows toward employment nodes during the morning, resulting in concentrated demand over shorter time intervals. Evening travel tends to be more dispersed in departure times and destinations, reducing peak intensity. The spatiotemporal assessment confirms that congestion is not uniformly distributed but concentrated at specific nodes and corridors. Delays were particularly pronounced near off-ramps, intersections, and high-access-density zones, where friction between through-movements and local access traffic reduces effective capacity.

5.2 Impact of Land-Use Types on Traffic Flow

The spatial analysis demonstrates a strong association between congestion intensity and surrounding land-use patterns. High-density residential developments, mixed-use corridors, and commercial activity zones were consistently linked to elevated traffic volumes and longer delays. These land-use types generate high trip production and attraction rates, particularly during peak commuter periods.

Key observations include:

- High-density residential areas contribute significantly to morning outbound flows and evening inbound flows, amplifying directional congestion.
- Nearby commercial and retail corridors increase midday and evening traffic, extending congestion beyond traditional peak periods.
- Activity nodes along major arterial corridors intensify turning movements and reduce intersection efficiency, particularly at stop-controlled and ramp-adjacent intersections.

Where land-use intensification occurred without proportional upgrades to road capacity or intersection control, congestion levels were notably higher. This finding suggests that, in some instances, TIAs may have underestimated cumulative impacts or that mitigation measures were insufficient relative to actual development uptake and traffic growth.

6 IMPLICATIONS FOR TRANSPORT PLANNING

The temporal and spatial patterns observed have several implications for transport planning along the corridor. Firstly, the clear relationship between high-density land uses and congestion intensity underscores the necessity of aligning development approvals with network capacity assessments. TIAs should incorporate cumulative impact modelling rather than evaluating developments in isolation. Seondly, given the concentration of congestion during the Monday morning peak, demand management measures such as flexible work hours, staggered school start times, and remote work incentives could significantly reduce peak intensity.

Since congestion clusters around off-ramps and intersections, targeted geometric improvements (e.g., additional turning lanes, improved channelisation, or signalisation where appropriate) may yield greater benefits than corridor-wide widening. Additionally, sustained land-use intensification without parallel investment in public transport will likely reverse the 2025 congestion improvements. Enhancing public transport accessibility along high-density corridors could mitigate further traffic growth. The year-to-year variation demonstrates that congestion is dynamic and responsive to both behavioural and infrastructural factors. Continuous traffic monitoring and periodic reassessment of TIAs are therefore essential to ensure that mitigation measures remain effective under evolving demand conditions. Overall, the findings indicate that while congestion levels in 2025 were lower than in 2024 on a cumulative basis, traffic pressure along the corridor remains structurally high and closely linked to land-use intensity. Without coordinated spatial and transport planning interventions, future development is likely to erode the observed improvements and reintroduce escalating congestion trends.

7 CONCLUSION

This study provides an empirical assessment of transport infrastructure performance within the context of accelerating residential development, making a key contribution by quantitatively linking land-use change, traffic growth, and intersection performance within a constrained corridor environment. By integrating traffic volume analysis, queuing theory, and spatiotemporal congestion assessment, the research moves beyond descriptive evaluation and demonstrates measurable operational disparities between grade-separated interchanges and at-grade control.

The findings confirm that the R558 stop-controlled intersection along the N12 corridor operates inefficiently as traffic demand increases. Persistent congestion, extended peak-period delays, and elevated conflict exposure underscore the structural limitations of stop-control in a high-growth, high-volume environment. In contrast, ramped interchanges along the same corridor exhibit comparatively stable performance, highlighting the operational resilience afforded by grade separation under similar demand conditions. This comparative analysis constitutes a central contribution of the study, providing evidence-based justification for selecting an infrastructure typology in rapidly developing peri-urban contexts.

Furthermore, the study demonstrates that inadequate integration of transport planning into rezoning approvals and residential development processes significantly amplifies congestion pressures. Where land-use intensification proceeded without proportional infrastructure upgrades, volume-to-capacity ratios increased, queue lengths extended, and system reliability declined. By quantifying cumulative delay and identifying spatiotemporal congestion patterns, the research illustrates how incremental development decisions can collectively compromise corridor-level functionality. A further contribution lies in the methodological approach. In the absence of detailed simulation inputs for microsimulation platforms, the study demonstrates the robustness of traffic volume analysis supported by deterministic queuing theory as a practical, replicable evaluation tool in data-constrained environments. This provides a transferable framework for similar corridors where comprehensive simulation modelling is not feasible.

The study therefore concludes that sustainable and resilient transport systems require proactive alignment between land-use planning and infrastructure provision. Timely implementation of grade-separated interchanges, rigorous cumulative impact assessment within Transport Impact Assessments (TIAs), and continuous traffic performance monitoring are essential to safeguarding mobility, safety, and long-term regional efficiency. Without such alignment, infrastructure lag will continue to undermine network performance and erode the functional sustainability of rapidly urbanising corridors.

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Landschaftserleben für alle – Entwicklung eines Leitfadens zur Gestaltung von barrierearmem und erlebnisorientiertem Wandertourismus für Blinde und Sehbeeinträchtigte

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1 ABSTRACT

Die Orientierung im Raum wird bei sehenden Personen primär über visuelle Informationen gesteuert, was Wandern als Freizeit- und Erholungsaktivität besonders populär macht. Touristische Angebote – wie Panoramawanderwege, Lehrpfade mit Schautafeln oder Burgenbesuche – sind ebenfalls überwiegend auf den visuellen Sinn ausgerichtet. Personen mit Blindheit oder signifikanter Sehbehinderung, deren Anteil in einer demografisch alternden Gesellschaft steigt, haben daher oft keinen adäquaten barrierefreien Zugang zu diesen Angeboten und erleben in diesem Freizeitbereich häufig keinen ausreichenden Erholungswert.

Das Projekt „Landschaftserleben für Alle“ adressiert diese Lücke, indem es funktionale Barrierefreiheit mit erlebnisorientierter Inklusion verknüpft und damit die UN-Behindertenrechtskonvention operationalisiert. Ziel des Projektes ist die Identifikation von Erfolgs- und Hemmungsfaktoren für die touristische Aufwertung von Naturräumen und Attraktionen aus der Perspektive blinder Nutzerinnen und Nutzer. Im Rahmen von Gruppeninterviews, Mapping-Wanderungen und Co-Design-Workshops werden Gestaltungsprinzipien für die Besucherlenkung sowie ein Erleben durch andere Sinne entwickelt.

In einer ausgewählten Pilotregion wird in einem ersten Schritt ein bestehender Wanderweg sowie dort befindlichen „Sehenswürdigkeiten“ hinsichtlich ihrer Eignung für prototypische Barrierelösungen und ihres Erlebnispotential analysiert. Durch die Durchführung iterativer Usability-Tests mit blinden Wanderern wird der exemplarisch optimierte Weg verfeinert. Zudem werden Leitlinien für eine Gestaltung erarbeitet, die über die reine Zugänglichkeit von Informationen hinausgeht. Abschließend erfolgt der Transfer des erworbenen Wissens in einem praxisorientierten Leitfaden sowie einer begleitenden Workshop-Reihe an Planerinnen, Planer, Touristikerinnen, Touristiker, Entscheidungsträgerinnen und Entscheidungsträger.

Damit möchte das Projekt ein inklusives Modell etablieren, das nicht nur die physische Zugänglichkeit, sondern auch das subjektive Erholungs- und Gemeinschaftserlebnis von Menschen mit Sehbehinderung nachhaltig verbessert.

In diesem Beitrag liegt der Fokus auf der Darstellung der Auftaktphase September 2025 bis März 2026. Es werden Teilprojektziele, methodische Herangehensweisen und erste Ergebnisse vorgestellt.

Keywords: Inklusion, Barrierefreiheit, Sehbeeinträchtigte, Tourismus, Besucherlenkung

2 PROBLEMSTELLUNG & HINTERGRUND

Weltweit leiden mindestens 2,2 Milliarden Menschen an einer Sehbehinderung (World Health Organization, 2019, p. 26). Zudem steigt die Prävalenz von Blindheit und Sehbeeinträchtigung mit zunehmendem Alter (Burton et al., 2021, p. 503). So führt die Statistik zu Schwerbehinderten in Deutschland (Stand 2023) 104.670 Personen mit Blindheit oder hochgradiger Sehbehinderung auf. Davon waren rund 88 % 45 Jahre und älter (GENESIS-Online, 2025, 22711-02).

Freizeitgestaltung, insbesondere die Teilnahme an Outdoor-Aktivitäten, stärkt das körperliche, emotionale und soziale Wohlbefinden der Menschen. Durch Bewegung im natürlichen Umfeld werden Fitness und Gesundheit gefördert, während gleichzeitig positive Gefühle und soziale Kontakte entstehen. Blinde und sehbeeinträchtigte Personen erleben erhebliche Barrieren bei Mobilität und Freizeit im Freien, die oft dazu führen, auf solche Aktivitäten zu verzichten. In einer Umfrage unter 345 Erwachsenen, die von Blindheit oder Sehbeeinträchtigung betroffen waren, wurden sowohl individuelle Faktoren wie „Entspannung” (36,4 %), „Spaß haben“ (35,6 %), „Gewichtskontrolle“ (33,1 %) als auch soziale Bedürfnisse wie „Zeit mit Familie und Freunden verbringen“ (27,5 %) bzw. „neue Freunde gewinnen“ (28,2 %) als wichtige Motivatoren für körperliche Aktivität im Outdoor-Umfeld angegeben. Als Hemmnisse für die Ausübung körperlicher Aktivitäten außer Haus wurden „Transport“ (54,8 %), „fehlendes Angebot an individuell passenden Aktivitäten“ (47,0 %) sowie „Mangel an barrierefreien Angeboten“ (32,5 %) genannt (Flynn et

al., 2024, p. 5). Auch Stanimirov et al. (2020, p. 94) identifizierten bauliche Barrieren und mangelnde Zugänglichkeit von Transportmitteln als massive Hindernisse für körperliche Aktivitäten bei jungen Erwachsenen mit Sehbehinderungen. Hamed & Masoud (2023, p. 17) untersuchten den Grad der Zufriedenheit von Menschen mit Sehbehinderungen (n = 74, Alter 18-85 Jahre) in Bezug auf Infrastruktur und Outdoor-Aktivitäten. Sie schlussfolgerten, dass die Zufriedenheit mit Aktivitätsmöglichkeiten im Freien von Menschen mit Sehbehinderungen sehr heterogen ist und von der Art ihrer Augenerkrankung (z. B. Makuladegeneration: zentrale Gesichtsfeldausfälle versus Retinitis pigmentosa: periphere Gesichtsfeldausfälle), dem Zugang zu assistiven Technologien (z. B. Langstock versus technologische Hilfsmittel) und sozioökonomischen Merkmalen abhängt (z. B. Alter, Bildungsgrad, Einkommen). Blinde und sehbehinderte Personen weisen somit ein hohes Maß an Heterogenität hinsichtlich ihrer individuellen Bedürfnisse auf, um bei körperlichen Aktivitäten im Freien Sicherheit zu empfinden und Erholung zu erleben. Diese Differenziertheit bereits in der Planungsphase von touristischen Konzepten und Gestaltung von Wanderwegen zu berücksichtigen, stellt alle Beteiligten vor beträchtliche Herausforderungen. Barrierefreies Wandern, verstanden als die Möglichkeit für Menschen mit Behinderungen, Naturpfade selbstständig oder mit Unterstützung zu genießen, ist eine Aufgabe, die noch nicht vollumfänglich gelöst wurde (Mantuano & Bruno, 2025, p. 5701).

2.1 Barrierefreiheit und Inklusion – zumindest im deutschen Recht eine (ungewollte) Abgrenzung?

In Deutschland ist die Barrierefreiheit rechtlich auf mehreren Ebenen verankert, wobei das Grundgesetz in Art. 3 (3) Satz 2 das Fundament bildet, indem es festlegt, dass niemand wegen seiner Behinderung benachteiligt werden darf (GG, 1949, zuletzt geändert 22.03.2025). Auch das Kernanliegen der UN-Behindertenrechtskonvention (UN-BRK) sieht vor, dass Menschen mit Behinderungen keine zusätzlichen oder „besonderen“ Rechte erhalten. Stattdessen werden universelle Menschenrechte so konkretisiert, dass sie auch unter den spezifischen Lebensbedingungen von Menschen mit Behinderungen wirksam werden. Teilhabe ist kein Akt der Wohltätigkeit, sondern einklagbares Recht (Beauftragter der Bundesregierung für die Belange von Menschen mit Behinderungen, o. J.). Die Konvention macht unmissverständlich klar, dass Menschen mit Behinderungen Anspruch auf volle, wirksame und gleichberechtigte Teilhabe in allen Lebensbereichen haben.

Zur nationalen Umsetzung der UN-BRK wurden Strukturen geschaffen, um die Aufgabe einerseits staatlich umzusetzen, andererseits aber auch als gesamtgesellschaftlichen Prozess verstanden zu wissen. So obliegt dem Bundesministerium für Arbeit und Soziales (BMAS) die politische Steuerung im Rahmen der Entwicklung eines Nationalen Aktionsplans, einem umfassenden Maßnahmenkatalog mit über 400 Projekten, die das Ziel verfolgen, Lücken zwischen Gesetzeslage und tatsächlicher Lebensrealität zu schließen. Als Schnittstelle zwischen Staat und Gesellschaft fungiert die staatliche Koordinierungsstelle der/s Beauftragten der Bundesregierung für die Belange von Menschen mit Behinderungen, die Öffentlichkeitsarbeit und Maßnahmen zur Bewusstseinsbildung in den Blick nimmt (Beauftragter der Bundesregierung für die Belange von Menschen mit Behinderungen, o. J.). Diese institutionellen Strukturen bilden den Rahmen für die rechtliche Konkretisierung, die auf Bundesebene durch das Behindertengleichstellungsgesetz (BGG) erfolgt. Dieses regelt die Barrierefreiheit der öffentlichen Einrichtungen des Bundes und definiert in § 4 den Begriff wie folgt: „Barrierefrei sind bauliche und sonstige Anlagen, Verkehrsmittel, technische Gebrauchsgegenstände, Systeme der Informationsverarbeitung, akustische und visuelle Informationsquellen und Kommunikationseinrichtungen sowie andere gestaltete Lebensbereiche, wenn sie für Menschen mit Behinderungen in der allgemein üblichen Weise, ohne besondere Erschwernis und grundsätzlich ohne fremde Hilfe auffindbar, zugänglich und nutzbar sind. Hierbei ist die Nutzung behinderungsbedingt notwendiger Hilfsmittel zulässig.“ (Behindertengleichstellungsgesetz - BGG, 2002, Zuletzt geändert durch Art. 7 G v. 2022 I 760).

Hinsichtlich der technischen Vorgaben, die die Zugänglichkeit von Gebäuden und Mobilitätsräumen regeln, ist insbesondere DIN 18040 hervorzuheben. Diese zentrale Normenreihe regelt das barrierefreie Bauen, wobei Teil 1 sich auf öffentlich zugängliche Gebäude und Teil 3 auf den öffentlichen Verkehrs- und Freiraum bezieht. Zu den öffentlich zugänglichen Gebäuden gehören nach § 50 Abs. 2 Musterbauordnung (MBO) insbesondere auch Einrichtungen der Kultur und des Bildungswesens sowie Sport- und Freizeitstätten (Bundesfachstelle Barrierefreiheit). Mit dem Ziel, auch nicht-physische Barrieren in den Bereichen Information und Kommunikation für Menschen mit Behinderungen systematisch abzubauen und

ihre gesellschaftliche Teilhabe zu stärken, konkretisiert das Barrierefreiheitsstärkungsgesetz (BFSG) diese Rechte auf Produkte wie Selbstbedienungsterminals und digitale Dienstleistungen beispielsweise im Bereich Personenbeförderung. (Barrierefreiheitsstärkungsgesetz - BFSG, 2021 (BGBl. I S. 2970)/6. Mai 2024 (BGBl. 2024 I Nr. 149), § 1).

Die deutsche Gesetzgebung konzentriert sich obigen Ausführungen folgend vorrangig auf den formalen Zugang zu Räumen und Informationen unter eher technisch-funktionalen Aspekten. Der englische Begriff "accessibility" scheint sprachlich präziser. Maaß & Rink (2020, pp. 39–40) sehen hier eine Diskrepanz zwischen der UN-Behindertenrechtskonvention und der deutschen Rechtspraxis: während die UN-BRK gesellschaftliche Adaptation fordert, also inklusive Aspekte mitdenkt, fokussiert das BGG auf formalen Zugang zu gesellschaftlichen Teilbereichen durch Bereitstellung erforderlicher Ressourcen und Hilfsmittel. Auch das Bundesteilhabegesetz (BTHG) von 2016, welches das Sozialgesetzbuch IX (SGB IX) umfassend reformiert hat, um die Selbstbestimmung und Teilhabe am gesellschaftlichen Leben zu stärken, lieferte keinen Beitrag zu einem substantiellen Paradigmenwechsel (Kulke, 2020, p. 169).

Das inklusive Denken erfordert jedoch weniger gesetzliche Regelungen, sondern eher Aufklärung und Bildung, denn der Umgang mit Menschen mit Behinderungen wird allzu oft eher aus Unsicherheit und Unkenntnis vermieden.

In Bezug auf die praktische Umsetzung merken Maaß & Rink (2020, pp. 39–40) an, dass die Umsetzung von Inklusion und Barrierefreiheit oft grundlegende Zielkonflikte aufwirft, da sich die Anforderungen verschiedener Behinderungsarten und Nutzergruppen widersprechen: abgesenkte Bordsteine ermöglichen Rollstuhlfahrern und Personen mit Rollator urbane Mobilität, während Menschen mit Sehbehinderung auf taktil wahrnehmbare Kanten zwischen Gehweg und Fahrbahn angewiesen sind, die jedoch für mobilitätseingeschränkte Personen Barrieren darstellen. Und auch innerhalb einzelner Behinderungsarten besteht eine Heterogenität der Anforderungen: bestimmte Formen von Sehschädigung erfordern eine kontrastreiche Gestaltung, während dies für andere Sehbehinderungen Blendeffekte und damit eine Beeinträchtigung darstellt. Diese widersprüchlichen Bedürfnisse verhindern die Realisierung universeller Barrierefreiheit.

Das Bekenntnis zu Gleichheit und Inklusion sowie der Respekt vor den unterschiedlichen Lebensweisen und Wahrnehmungen der Menschen sollte auch auf die inklusive Gestaltung unserer natürlichen Lebensräume ausgeweitet werden. Dies umfasst nicht nur urbanes Grün und städtische Parks. Auch Wälder und Wanderwege müssen in den Blick genommen werden (Bell, 2018, p. 4). Neben der Zugänglichkeit und sicheren Mobilität sollte auch die Erlebnisqualität für Sehbeeinträchtigte mitgedacht werden. Oftmals konzentriert sich die Gestaltung und Inszenierung von „Sehenswürdigkeiten“ ausschließlich auf visuelle Aspekte. Durch einen Zugang mit Berücksichtigung von Sehbehinderungen können intensivere, multisensorische Erfahrungen erschlossen werden – eine Bereicherung für Sehende und für Sehbeeinträchtigte gleichermaßen.

2.2 Orientierung im Raum: Gemeinsamkeiten und Unterschiede zwischen Blinden und Sehenden

Die koordinierte und zielgerichtete Bewegung der eigenen Person durch die Umgebung wird als Navigation bezeichnet. Dafür werden unterschiedliche kognitive Fähigkeiten benötigt: die Fähigkeit den Raum wahrzunehmen, um sich im Umfeld zu lokalisieren, sowie die Fähigkeiten, sich zu erinnern und logische Schlüsse zu ziehen. Die Orientierung der eigenen Person im Raum beruht auf einer Kombination aus sensorischen Informationen, inneren Gedächtnisrepräsentationen und externen Hinweisreizen. Beim Navigieren werden permanent Antworten auf drei Fragen gesucht: Wo bin ich?, Wo ist mein Ziel? und Wie komme ich dorthin? Montello hat den Navigationsprozess in drei Teilprozesse differenziert (vgl. Abbildung 1), die diese Fragen beantworten (Montello, 2005, p. 260).

Die Bewegungsfähigkeit im Raum ist ein komplexes Zusammenspiel verschiedener kognitiver und sensorischer Prozesse. Sensorische Signale liefern Informationen darüber, wie unsere Bewegung absolut im Raum (z. B. vestibulär und propriozeptiv) oder in Bezug auf unsere Umgebung (z. B. visuell, auditiv) ausgeführt wird (Cuturi et al., 2016, p. 241). Das Vestibularsystem im Ohr liefert Informationen zu Lage und Bewegung des Kopfes, während Propriozeptoren im Muskel- und Skelettsystem Körperstellungen und Bewegungen kontrollieren, die die Wahrnehmung der räumlichen Lage unterstützen. Das visuelle System dient zur Abschätzung von Entfernungen und Objekterkennung.

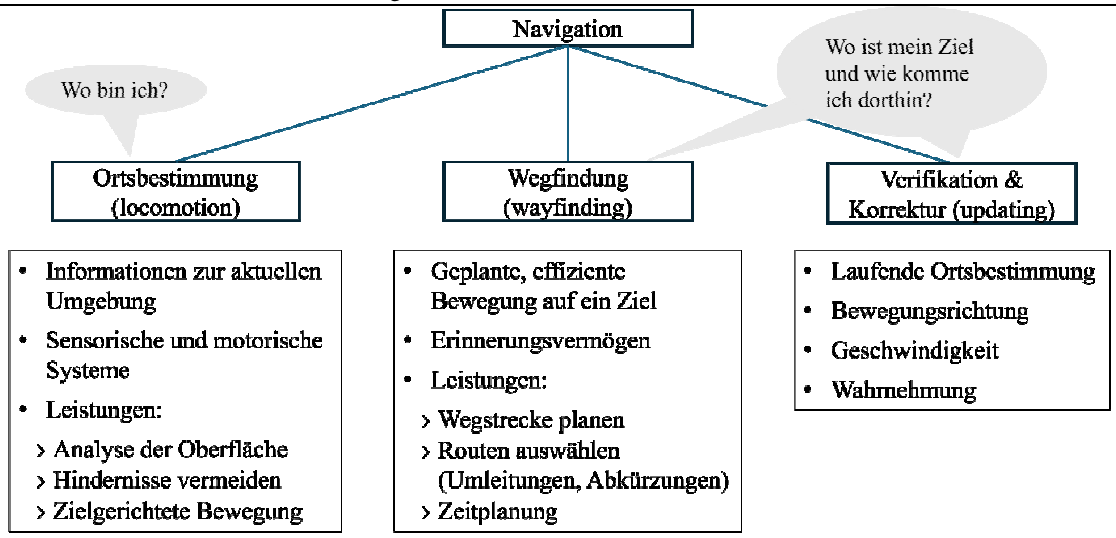


Abbildung 1: Gliederung des Navigationsprozesses in drei Teilprozesse (eigene Darstellung nach Montello, 2005).

Bei Blinden entfällt lediglich letztere Systemkomponente, die durch die stärkere Einbindung der anderen Sensoren weitgehend kompensiert werden kann. So nutzen einige blinde Personen ihren Langstock nicht nur zum Tasten, sondern erzeugen damit auch Geräusche oder produzieren selbst Klickgeräusche. Diese Echoeffekte nutzen sie, um die eigene Position innerhalb von Straßenräumen, Passagen oder Landschaften zu bestimmen (Bell, 2017; Cuturi et al., 2016, p. 242; Montello, 2005, p. 262; vom Lehn, 2008, p. 5). Die Wahrnehmung von reflektiertem Schall hilft auch dabei, Hindernisse bei Annäherung zu antizipieren. Wenn diese Echosignale durch äußere Einflüsse wie starken Wind, Regen oder Schnee maskiert werden, kann dies zu erheblicher Desorientierung führen, da die akustischen „Sichtverhältnisse“ getrübt werden (Bell & Petty, 2018, p. 5).

Neben sensorischen und motorischen Systemen benötigt das Gehirn auch mentale Repräsentationsmodelle. Diese können im Allgemeinen egozentrische oder allozentrische Informationen sein, die entweder in „Routen”- oder „Vermessungs”-Darstellungen resultieren. Erstere Strategie beruht auf der Feldperspektive des Beobachters, während letztere eher einer kartenähnlichen Projektion aus Vogelperspektive als Überblickswissen ähneln (Cuturi et al., 2016, p. 241). Beim Erwerb von Routenwissen spielt die sequenzielle Abfolge von Vektoren und Knotenpunkten in Form von Landmarken und Abbiegevorschriften eine Rolle. Landmarken sind für Sehende sichtbare, eindeutig erkennbare Objekte oder Merkmale in der Umgebung, die als Referenzpunkte für die Orientierung dienen. Sie helfen, die eigene Position zu bestimmen („ich bin an der Kirche“) sowie die Richtung auf das Ziel abzuleiten („der Park liegt aus meiner Richtung rechts vom Rathaus“). Vektorbezogene Verhaltensvorschriften wie „an der Kreuzung nach rechts abbiegen“ strukturieren den Weg. Während Sehende visuelle Landmarken nutzen, ist die Auswahl solcher ortsfesten Anker für Nicht-Sehende schwieriger. Die Routennavigation wird von blinden Personen meist gut bewältigt, da sie sich auf kinematische Strategien stützen können, indem sie Informationen über ihre eigenen Bewegungen und die der Umgebung verarbeiten. Diese Informationen werden in einem idiothetischen Referenzsystem, einem körperselbstbezogenen Koordinatensystem, das ausschließlich auf propriozeptiven, vestibulären und kinästhetischen Signalen beruht, gespeichert. Durch wiederholte Bewegungen wird dieses interne Referenzsystem stabilisiert und dient blinden Menschen als verlässliche Basis für die Navigation (Cuturi et al., 2016, p. 241).

Zusammenfassend lässt sich feststellen, dass die Kombination aus hochsensiblen vestibulären und propriozeptiven Signalen sowie einem gut entwickelten idiothetischen Referenzsystem blinden Personen ermöglicht, ihre Position und Richtung zuverlässig zu bestimmen, selbst wenn visuelle Informationen fehlen. Saerberg (2010, p. 369) beschreibt dies pointiert: „Not a single sense is missing when one sense is ‘missing’. It’s just that the whole is composed of a different mixture of the senses”.

Im Kontext von Sehbehinderungen werden die Begriffe Orientierung und Mobilität insofern abgegrenzt, als Orientierung sich auf den Prozess der Positions- und Kursverfolgung in der Umgebung bezieht (vgl. Abbildung 1: Locomotion und Updating) und auch als Makronavigation bezeichnet wird. Dagegen umfasst Mobilität, auch Mikronavigation genannt, das Erkennen und Umgehen von Hindernissen auf dem Weg (vgl.

Abbildung 1: Wayfinding) und meint eher die Fähigkeit, sich effizient und sicher im unmittelbaren physischen Umfeld zu bewegen (Giudice & Legge, 2008, p. 482). Zahlreiche Assistenzsysteme, von einfachen Hilfsmitteln bis zu KI-integrierten Technologien, deren Handhabung u. a. in speziellen Mobilitätstrainings vermittelt werden, fördern sowohl Makro- als auch Mikromobilität. Systeme mit sonarbasierten (Schallsensoren), bildbasierten (Kameras oder Laser) oder infrarotbasierten Sensoren (IR) sowie GPS-Geräte liefern dem Nutzenden akustische und/oder vibrotaktile Signale (Giudice & Legge, 2008, p. 485). Unter die Gruppe Electronic Orientation Aids (EOAs) fallen GPS-gestützte Navigationssysteme. Sie assistieren im Rahmen der Makronavigation, helfen also, Position und Kurs im Raum beizubehalten, während man sich von Punkt A nach Punkt B bewegt (Fernandes et al., 2019, p. 166). Die Technologien der Navigationshilfen lassen sich unterteilen in visuelle Bildsysteme, nicht-visuelle Datensysteme, kartenbasierte Lösungen und 3D-Soundsysteme (Abidi et al., 2024, p. 1). Mit dem Langstock als traditionelles Hilfsmittel können nur Hindernisse auf Bodenniveau wahrgenommen werden. Mit einer Reichweite von rund 1,5 m hilft er auch nur im unmittelbaren Umfeld (Fernandes et al., 2019, p. 160). Ein kritischer Aspekt der Mikronavigation ist der Schutz vor Hindernissen in Kopf- oder Brusthöhe, die ein herkömmlicher Langstock oder auch ein Assistenzhund nicht erfassen. Herunterhängende Äste, Schranken, Schilder, halboffene Garagentore, in den Weg ragende Fensterläden oder Blumenkübel auf Fensterbänken führen als Luftbarrieren bei Kollision oft zu Verletzungen (Sáez et al., 2015, p. 74). Moderne Electronic Travel Aids (ETAs) unterstützen die Mikronavigation durch Hinderniserkennung und erweitern den perzeptuellen Radius erheblich (Fernandes et al., 2019, p. 162). Geräte wie der UltraCane nutzen beispielsweise Ultraschall, um Hindernisse in einer Entfernung von bis zu 4 bzw. 5 m sowie Luftbarrieren und Tiefenänderungen (Drop-offs), z. B. Stufen oder Bordsteinkanten zu detektieren (Giudice & Legge, 2008, p. 485). Diese technologische Entwicklung transformiert die Mikronavigation von einer rein taktilen „Abtast-Erfahrung“ zu einer multisensorischen Raumwahrnehmung, die dem Nutzenden mehr Zeit für Reaktionen gibt und die Gefahr von Unfällen durch Barrieren reduziert. Die Integration verschiedener Sensoren wie Ultraschallsensoren und LiDAR zur Hinderniserkennung und Echtzeit-Rückmeldung aus der ETA-Gruppe in Navigationssystemen macht diese elektronischen Hilfsmittel zunehmend effektiv bei der Unterstützung der Hinderniserkennung und der sicheren Navigation in einer Anwendung (Abidi et al., 2024, p. 1).

2.3 Naturerleben und Wandern mit Sehbeinträchtigung

Wie alle Menschen haben auch Menschen mit Behinderungen ein intensives Bedürfnis danach, Naturgebiete zu besuchen (Chikuta et al., 2017, p. 12). Die Interaktion mit der Natur ist ein grundlegendes Element für das Wohlbefinden jeder einzelnen Person und die wachsende Forschungsevidenz belegt, dass der Besuch von Grünflächen wie Parks und Wanderwegen erhebliche Vorteile für die geistige und körperliche Gesundheit mit sich bringt (Mantuano & Bruno, 2025, p. 2). Dies bestätigte u. a. eine Studie aus dem Jahr 2019, die basierend auf den Erfahrungen von 31 Personen mit unterschiedlichen Formen und Schweregraden von Sehbehinderungen hinsichtlich deren Naturerlebnisse skizzierte. Sie zeigte, dass die Teilnehmerinnen und Teilnehmer das Naturerleben als Momente des Friedens, als Befreiung vom stressigen städtischen Umfeld empfanden und bereits darin ein enormer Erholungswert liegt (Bell, 2019, p. 307). Allgemein sind die Erfahrungen blinder Wanderer jedoch geprägt von einem Spannungsfeld zwischen dem Wunsch nach Autonomie – es trägt zur Steigerung des Selbstwertgefühls durch das Meistern von Herausforderungen bei (Nigg et al., 2025, p. 3037) – und der Realität physischer Hindernisse. Im Sinne des „Rechts auf Risiko“ darf man blinden Menschen durchaus auch anspruchsvollere Naturerfahrungen jenseits flacher Asphaltwege zutrauen und anbieten, sofern die Risiken durch angemessene Unterstützung handhabbar bleiben (Bell, 2017, p. 49).

2.4 Barrierefreier Tourismus = inklusiver Tourismus?

Der barrierefreie Tourismus stellt einen aufstrebenden und relevanten Nachfragebereich dar. Darunter werden Angebote verstanden, die öffentliche Räume ohne architektonische, kulturelle, sensorische, einstellungsbezogene, kommunikative oder informative Barrieren zugänglich machen – eine Anforderung, die für die Branche nach wie vor eine erhebliche Herausforderung bedeutet. Barrierefreiheit darf nicht am Parkplatz enden; sie muss die Information vor der Reise, den Transport zum Startpunkt und die Orientierung vor Ort umfassen (International Standard, 2021; Nigg et al., 2025, pp. 3031–3032). Buhalis & Darcy (2011, p. 10) definieren „accessible tourism“ als „eine Form des Tourismus, die auf der Zusammenarbeit zwischen verschiedenen Interessengruppen basiert und es Menschen mit besonderen Bedürfnissen, einschließlich

Mobilität, Seh-, Hör- und kognitiven Einschränkungen, ermöglicht, durch die Bereitstellung von universell gestalteten Tourismusprodukten, Dienstleistungen und Umgebungen unabhängig, gleichberechtigt und würdevoll zu agieren“. Auch hier spiegelt sich lediglich der Grundgedanke der reinen Zugänglichkeit wider. Die Erlebnis- und Bedürfnisorientierung sollte bei der Planung und Entwicklung touristischer Produkte als Selbstverständnis gelten; im barrierefreien Tourismus dominiert jedoch häufig ein problemorientierter Ansatz (Bundesministerium für Wirtschaft und Technologie [BMWi], 2008, p. 119). Vor diesem Hintergrund bietet die Grundidee des Universal Design einen geeigneten Rahmen, um Barrierefreiheit systematisch mit Erlebnis- und Bedürfnisorientierung zu verknüpfen. Das Konzept bezeichnet die Gestaltung von Umgebungen, Produkten und Kommunikationsmedien, sodass sie von allen Menschen unabhängig von Alter, Körpergröße, Fähigkeiten oder Behinderungen genutzt, verstanden und wahrgenommen werden können. Universal Design wurde bereits im Jahr 1985 von dem US-amerikanischen Architekten Ronald L. Mace konzipiert und eingeführt (Mantuano & Bruno, 2025, p. 24). Es ist eher technisch-funktional orientiert und zielt darauf ab, dass Barrierefreiheit „unsichtbar“ in das Design integriert wird. Seine sieben Prinzipien, u. a. gerechte Nutzung, einfache und intuitive Benutzbarkeit, eine gewisse Fehlertoleranz und geringer körperlicher Aufwand bilden ein theoretisches Rahmenwerk, welches das Risiko von Barrieren reduziert und die Nutzerzufriedenheit erhöht (World Tourism Organization, 2025, p. 16). In der Informationsvermittlung sollte zudem das „Zwei-Sinne-Prinzip“ berücksichtigt werden, wonach Informationen und Signale im öffentlichen Raum so gestaltet sein müssen, dass sie für Menschen mit Beeinträchtigungen über mindestens zwei der drei Sinne – Hören, Sehen oder Tasten – wahrnehmbar sind (World Tourism Organization, 2016, p. 18). Innerhalb eines Zeitraums von etwa zwanzig Jahren hat sich die Gestaltungsphilosophie von Universal Design über Inclusive Design und Human-Centred Design weiterentwickelt und mündete schließlich in das Konzept „Design for All“. Dieses Gestaltungsparadigma verankert die menschliche Vielfalt, soziale Inklusion und Gleichberechtigung als zentrale Leitprinzipien. Beide Konzepte, sowohl Universal Design als auch Design for All, lehnen eine Gestaltung ab, die Menschen mit Behinderungen durch Sonderlösungen stigmatisiert (Mantuano & Bruno, 2025, p. 24).

3 PROJEKT „LANDSCHAFTSERLEBEN FÜR ALLE“

3.1 Projektidee und Zielsetzung

Das Projekt „Landschaftserleben für Alle“ zielt auf die Entwicklung eines Leitfadens zur Gestaltung eines funktional zugänglichen und erlebnisorientierten Wandertourismus für blinde und sehbeeinträchtigte Personen ab. Dabei wird Barrierefreiheit mit erlebnisorientierter Inklusion verknüpft. Essenziell ist die konsequente Einbindung der Zielgruppe in allen Entwicklungsphasen, um ein Design zu vermeiden, das auf potenziell fehlgeleiteten Antizipationen sehender Personen beruht. In einem ersten Schritt werden Gelingensbedingungen und Hemmnisse für ein barrierefreies Erleben bereits vorhandener, touristisch aufgewerteter Pfade (z. B. Themenwege, Lehrpfade) zusammen mit Blinden und Sehbeeinträchtigten eruiert und Handlungsoptionen aufgezeigt. Diese Erkenntnisse und ergänzende Analysen sollen in einem weiteren Teilprojekt anschließend auf das Ziel einer sicheren Besucherlenkung auf Wanderwegen mit und ohne Begleitperson übertragen werden. Dabei werden Lösungsansätze sowohl mit der Zielgruppe als auch mit touristischen Akteuren entwickelt.

3.2 Entwicklungsdesign und Methoden

Als erfolgversprechend wird die entwicklungsorientierte Methode des Backcastings angesehen. Der Ansatz ist charakterisiert durch die Entwicklung eines wünschenswerten Zukunftsbildes und die anschließende rückwärtige Betrachtung der Gegenwart zur Ableitung von Strategien und Plänen zur Erreichung dieser Zukunft (Vergragt & Quist, 2011, p. 747). Die Methode des Backcasting lässt sich aus dem Bereich ökologische Planung (Jessel & Tobias, 2002, p. 244) auch auf ein solches Inklusionsprojekt übertragen, indem zunächst eine wünschenswerte Zukunftsvision eines vollkommen barrierefreien und multisensorisch erlebbaren Wanderangebots für blinde Menschen definiert wird. Ausgehend von diesem angestrebten Zielzustand werden rückschreitend die notwendigen Handlungsstränge und Maßnahmen – wie der Abbau physischer Barrieren, die Schulung von Personal oder die Bereitstellung digitaler Orientierungshilfen und Informationen – identifiziert, um die Gegenwart gezielt in Richtung dieses Idealzustands zu beeinflussen. So sollen Planungslösungen jenseits aktueller Hemmnisse entwickelt und die soziale Inklusion als festgesetztes Ziel normativ verankert werden. Da Backcasting normative, zielorientierte sowie problemlösende

Eigenschaften aufweist, wird dieser Ansatz als besonders geeignet für die Analyse der Zugänglichkeit von Natur angesehen (Groulx et al., 2021, p. 813). Ein solcher zukunftsorientierter Rahmen erfordert zugleich partizipative Verfahren, damit die rückwärts gerichtete Strategieentwicklung von den tatsächlichen Erfahrungen und Bedürfnissen der betroffenen Nutzergruppen geleitet wird. Diese ganzheitliche Strategie stellt auch sicher, dass die Zielgruppe letztendlich auch die Vorteile nutzen kann, die aus einem Aufenthalt in der Natur resultieren (Dickson et al., 2025, p. 1377; Greyling et al., 2025, p. 1768). Auch die sozio-kulturellen und kommunikativen Dimensionen sollen Berücksichtigung finden, indem die Herangehensweise bei Planenden im Bereich des Tourismus untersucht wird.

Neben dieser rückwärtsgerichteten Zielentwicklung liegt dem Entwicklungsdesign der aus dem Bildungsbereich stammende methodologische Forschungsrahmen des Design-Based-Research Ansatzes (DBR) zugrunde. Dieser verknüpft wissenschaftlichen Erkenntnisgewinn mit der Entwicklung innovativer Lösungen für praktische Probleme. Forschung und Entwicklung gestalten sich dabei als zirkuläre, iterative Prozesse, die jeweils klar getrennte Ziele verfolgen, um generalisierbare Befunde zu Gestaltungsprinzipien zu gewinnen (Euler & Sloane, 2014, p. 7). Durch Partizipation in allen Entwicklungsphasen, Backcasting vom Idealzustand und iterative Verbesserung im DBR-Zyklus wird sichergestellt, dass blinde Menschen die Natur vollumfänglich und würdevoll erleben können.

Die Projektphasen verfolgen unterschiedliche Teilziele und nutzen eine breite Methodenpalette (vgl. Abbildung 2).

Meilensteine	Methoden	Ziel
Partizipative Bedarfsanalyse mit den Betroffenen: a) Auf Kundenseite: Blinde und Sehbeeinträchtigte b) Auf Anbieterseite: Akteure im Tourismus auf Verwaltungsebene	• Gruppendiskussionen • Semi-strukturierte Interviews • Vor-Ort-Begehungen • teilnehmende Beobachtungen • Dokumentenanalysen	Entwicklung einer Zielvorstellung: a) Verstehen der subjektiven Erfahrungen, Bedürfnisse und Erwartungen hinsichtlich Barrieren und Erlebniswert b) Ermitteln von Fehlvorstellungen und Wahrnehmungsbarrieren
Raumauswahl und Analyse	• Barriereanalyse • Landschaftscharakterisierung • GIS-Analyse	Auswahl eines repräsentativen, touristisch relevanten Raumes
Gestaltungskonzept & Prototypenentwicklung	• Co-Design-Workshops mit blinden Teilnehmer:innen und Blindenwanderführern	• Ableitung von Kriterien für den Leitfaden • Erstellung von konkreten Gestaltungsvorschlägen
Evaluation & Feedback	• Usability-Tests • Expert:innen-Feedback mit Planer:innen	• Validierung der Lösungen • Anpassung der Konzepte
Dokumentation & Sensibilisierung	Leitfaden für Planer:innen, Workshopreihe für Entscheidungsträger	• Wissenstransfer • Nachhaltigkeit & gesellschaftliche Wirkung

Abbildung 2: Projektübersicht

Als Methoden in der Analysephase zur Erhebung der Bedürfnissen und Erwartungen der Zielgruppe werden Befragungen, Beobachtungen und Videographien, Gruppendiskussionen und sensorische Kartierungen empfohlen (vgl. Bell, 2018; Misharina, A., Betts, E., 2023, pp. 238–243). Auch Walking Interviews (vgl. Abbildung 3) können Informationen zu subjektiven Erfahrungen, positiven bewerteten Erlebnisfaktoren und Motivatoren zum Wandern liefern.

Die sozio-kulturelle Dimension auf Seiten lokaler Akteursgruppen wird mittels Dokumentenanalysen, Befragungen und teilnehmenden Beobachtungen untersucht, um Einstellungs- und Wahrnehmungsbarrieren sowie Fehlvorstellungen zu identifizieren.

Mithilfe der Analyseergebnisse können technische, räumliche und kommunikative Maßnahmen für eine multisensorische, erlebnisorientierte Besucherlenkung konzipiert und Innovationen um Landschaften erlebbar zu machen entwickelt werden. In dieser Entwicklungsphase sollen in partizipativen Co-Design-Workshops die Gestaltungskonzepte verfeinert, implementiert und Prototypen iterativ getestet werden. Nach Evaluation und Anpassung der Konzepte soll der Wissenstransfer schließlich in einem Leitfaden für Akteursgruppen dokumentiert und in einer Workshopreihe umgesetzt werden.



Walking Interviews

Die Walking-Interview-Methode dient primär der Erfassung von Personen-Ort-Beziehungen, indem Forschende die Teilnehmenden auf deren - üblicherweise vertrauten - Strecken begleiten. Durch das gemeinsame Gehen erhalten sie unmittelbaren Einblick u. a. in das Handlungsfeld, die emotionalen Bewertungen des Raums sowie die Interaktionsmuster, die sich dabei entfalten. Gleichzeitig ermöglicht das Verfahren die gezielte Sensibilisierung für sensorische Eindrücke (visuell, auditiv, olfaktorisch), die im Alltag häufig unbeobachtet bleiben, und erlaubt es, diese durch situativ eingebettete Fragen zu explorieren.

Die Methode zeichnet sich durch interaktive, spontane Dialoge aus, die sowohl die subjektive Wahrnehmung des Raums als auch die soziale Dynamik der Teilnehmenden in situ beleuchten. Dieser Spontanität folgend, können die Leitfragen vorab festgelegt oder im Verlauf des Spaziergangs emergent entwickelt werden. Vor Beginn wird den Teilnehmenden der Zweck und das Vorgehen transparent erläutert, wodurch ein hohes Maß an Autonomie und Kontrolle über den Gesprächsverlauf gewährleistet wird.

Abbildung 3: Methode der Walking Interviews nach Evans & Jones, 2011, pp. 849–850

In diesem Beitrag wird das Vorgehen während der initialen Phase der Bedarfsanalyse skizziert. Da die Datenauswertung derzeit noch nicht abgeschlossen ist, beleuchten die folgenden Ausführungen den aktuellen Stand des Projekts als work-in-progress.

3.3 Partizipative, praxisorientierte Bedarfsanalyse

Dem übergeordneten Ziel folgend, sollen in einem ersten Schritt Erfolgs- und Hemmungsfaktoren für die touristische Aufwertung von (Natur-)räumen aus der Perspektive blinder Nutzerinnen und Nutzer identifiziert werden. Zum Auftakt wurde im Wintersemester 2025/2026 ein Studienprojekt mit fünf Studierenden der Masterstudiengänge „Räumliche Umweltplanung“, „Stadtplanung“ sowie „Stadt- und Regionalentwicklung“ durchgeführt. Das Projekt ist im Lehrgebiet Physische Geographie und Fachdidaktik der Rheinland-Pfälzischen Technischen Universität Kaiserslautern-Landau verortet. Zum Zeitpunkt der Erstellung des Beitrag ist die Projektarbeit noch nicht beendet. Daher werden im Folgenden nur die dem Lehrformat „Projekt“ immanente offene Herangehensweise, die angewandte Methodik und erste Ergebnisse dargestellt.

Der partizipative Ansatz wird in der ersten Analysephase insofern verfolgt, dass im Rahmen von Gruppendiskussionen und einer begleitenden Wanderung sowohl die Bedürfnisse der Zielgruppe als auch die aktuelle Praxis beteiligter Akteursgruppen sondierend untersucht werden.

3.3.1 Gruppendiskussionen mit Vertreterinnen und Vertretern der Blindenwandercommunity

Als Auftaktveranstaltung in der ersten Projektphase luden die Studierenden im Masterprojekt zunächst Betroffene aus der Blindenwander-Community zu einer Gruppendiskussion ein. Neben blinden Wandernden auf der Konsumentenseite waren auch zertifizierte Wanderführer zu Gast, die Blindenwanderungen organisieren und leiten. Insbesondere der Inklusionswart des Deutschen Blindenvereines, der selbst erblindet ist, sowie der Referent für inklusives Wandern im Deutschen Wanderverband, konnten aus ihrem enormen Erfahrungsschatz als Wanderer, Organisatoren von Blindenwanderungen und Ausbildern von Blindenwanderführern berichten. Die Studierenden erhielten einen ersten Einblick in die Stärken hinsichtlich Navigationsfähigkeiten und Nutzung von Assistenzsystemen sowie erste Hinweise auf Schwachstellen in Bezug auf eigenständiges oder begleitetes Wandern. Im Kontext des Landschaftserlebens wurden unterschiedliche Motivationen – von Entspannung bis sportliche Herausforderung – genannt. Dem Backcasting-Ansatz folgend wurden erste wünschenswerte Komponenten eines barrierefreien Wanderns für Blinde identifiziert.

3.3.2 Gruppendiskussionen mit regionalen Akteurinnen und Akteuren im Bereich barrierefreier Tourismus

In einem weiteren Workshop stellte u. a. der Projektleiter für barrierefreien Tourismus Südliche Weinstraße e. V. Kernelemente seiner Arbeit vor. Ein Überblick über Initiativen und Leitfäden, u. a. das Zertifikat „Reisen für Alle“, sowie die Kurzvorstellung von Best-Practice-Beispielen zeigten die vielfältigen

Herausforderungen in der Praxis auf. Im Austausch wurde deutlich, dass auch bei den Fachreferentinnen und Fachreferenten ein Bildungsbedarf zu den spezifischen Bedürfnissen blinder Menschen besteht. Bisher richten sich die Angebotsentwicklungen überwiegend an mobilitätseingeschränkte Personen und fokussieren primär auf Barrierefreiheit, während erlebnisorientierte Ansätze nur nachrangig berücksichtigt werden.

3.3.3 Walking Interviews im Rahmen einer Blindenwanderwoche

Um Berührungsängste abzubauen und zu erleben, welchen Unterstützungsbedarf Blinde und Sehbeeinträchtigte beim Wandern benötigen, assistierten die Studierenden der Projektgruppe als „Buddy" jeweils einer blinden Person bei der Blindenwanderwoche am Reckweilerhof (Wolfstein, Pfalz). Hier bewältigten die insgesamt 19 Teilnehmenden mit Sehbeeinträchtigung aus Deutschland und Österreich täglich eine Wanderung zwischen 10 und 15 km, die auch speziell angepasste Führungen in „Sehenswürdigkeiten" wie Museen oder Burgen umfassten (Schwarzwaldverein Pfalz-Weitsicht e. V.). Die Betreuung einer blinden Person während einer Wanderung verdeutlichte, dass blinde Menschen weniger eingeschränkt sind, als es oft von Sehenden angenommen wird. Obwohl sie visuelle Informationen nur eingeschränkt wahrnehmen können, sind sie keineswegs hilflos. Vielmehr nutzen sie moderne Technologien, um ihre Unabhängigkeit zu fördern. Selbstbestimmung und Würde wurden als zentrales Bedürfnis wahrgenommen. Das zeigte sich darin, dass es geschätzt wurde, Unterstützung zu leisten, ohne in eine übermäßige Fürsorglichkeit oder das „Bemuttern" zu verfallen. Ein weiterer Erfahrungsmehrwert bezog sich auf die Kommunikation. Diese konnte zwar knapper ausfallen als erwartet, dafür war der Anspruch an präzise Angaben bei der begleiteten Navigation sehr viel höher, sodass die Studierenden eine Schärfung ihrer Kommunikationsfähigkeit reflektierten.

Neben den Erfahrungen als Begleitperson konnten die Studierenden auch die Walking-Interview-Methode (vgl. Abbildung 3) pilotieren, um Beweggründe für das Wandern zu ergründen. Die Motivation zum Wandern wurde in der Gruppe als sehr heterogen in Bezug auf den Anspruch an Geländeschwierigkeit wiedergegeben: während einige breite, eher ebene Forstwege bevorzugten, gaben andere an, die Herausforderung eines schmalen Single Trails zu suchen. Auch erste Anhaltspunkte zum Erleben konnten gesammelt werden: Neben Geselligkeit und Austausch wurden auch Stille bzw. eine angenehme Naturgeräuschkulisse (Vögel-, Wind-, Wasser- und Laubgeräusche) als Motivatoren erwähnt.

Diese Praxiserfahrungen gaben erste Aufschlüsse über die erforderliche Detailtiefe von Unterstützungsangeboten sowie zu den Kriterien, die ein Landschaftserleben für Blinde und Sehbeeinträchtigte fördern können.

3.4 Raumanalyse

Für die schrittweise Entwicklung barrierefreier touristischer Services wird empfohlen, an bestehende Attraktionen und Angebote anzuknüpfen und diese sukzessive im Hinblick auf Zugänglichkeit und Erlebbarkeit für Alle weiterzuentwickeln (BMWi, 2008, p. 116). Im Rahmen der Raumanalyse wurde daher eine pragmatische Vorgehensweise zur Identifikation eines repräsentativen, touristisch relevanten Untersuchungsgebietes gewählt. Ausgehend von den auf den regionalen Webseiten vermarkteten Wanderrouten in der Region Südliche Weinstraße/ Pfälzerwald erfolgte zunächst eine Vorauswahl anhand definierter Kriterien: Schwierigkeitsgrad „leicht", maximal 300 Höhenmeter, maximale Streckenlänge von 15 km sowie verfügbare Informationen zur Bodenbeschaffenheit. Dieses Screening ergab 70 potenziell geeignete Routen. Anschließend wurden diese Routen anhand allgemeiner Eignungskriterien weiter gefiltert, darunter ÖPNV-Anbindung, Mobilfunkabdeckung (für den Einsatz von Assistenzsystemen), sichere Querungsmöglichkeiten, Mindestwegebreiten sowie Überschneidungsfreiheit mit anderen Nutzungen (z. B. Radverkehr). Die verbleibende Auswahl wurde im Sinne einer erlebnis- und bedürfnisorientierten Ausrichtung auf zwei Zielprofile hin bewertet: einerseits sportlich orientierte Nutzende (höhere Toleranz für Steigungen und Distanzen, Akzeptanz schmaler Trails), andererseits genussorientierte Nutzende (Einkehrmöglichkeiten, geringe Steigungen, gut ausgebaute Wege). Aus dieser Sichtung wurden drei Routen identifiziert und hinsichtlich ihrer Barriereeigenschaften sowie dem Erlebnispotential kartiert.

Für die exemplarische Optimierung wurde schließlich eine Route ausgewählt, die sowohl urbane als auch naturnahe Abschnitte umfasst und in Teilbereichen als Themenweg angelegt ist. Diese Route wurde anhand der in der Bedarfsanalyse gewonnen Erkenntnisse hinsichtlich Schwachstellen und Gestaltungspotential zur besseren Erlebbarkeit untersucht. Als häufige Schwierigkeit wurde auch hier die Lenkung vom Bahnhof zum

Startpunkt identifiziert. Gerade in der Vorbereitungsphase eines Ausflugs oder einer Reise sind verlässliche Informationen für Menschen mit Beeinträchtigungen essentiell (Nigg et al., 2025, p. 3037). Informationen zu Wanderwegen beschränken sich in der Regel auf Aussagen zur Weglänge, Steigung und Sehenswürdigkeiten. Für Sehbeeinträchtigte sind jedoch auch Informationen zur Wegbeschaffenheit, Orientierungshilfen wie akustische Profile, genaue Abbiegehinweise und insbesondere ein sicheres Auffinden des Startpunktes einer Route wichtig. Während oft Serviceangaben zu ÖPNV-Anbindung oder Parkmöglichkeiten für Sehende verfügbar sind, brauchen Sehbeeinträchtigte klare Instruktionen zur Wegführung vom ÖPNV-Ausstieg bis zum Start der Wanderung. Daher wurde dieser Abschnitt explizit mitgedacht.

3.5 Partizipative Entwicklung eines Gestaltungskonzeptes

Die Entwicklung des Gestaltungskonzeptes ist zum Zeitpunkt der Erstellung dieses Beitrags noch in Arbeit, daher können derzeit nur grundlegende Prinzipien und Ideen dargelegt werden. Die Planung geht davon aus, dass Blinde ihre technischen Assistenzsysteme für Makro- und Mikronavigation (vgl. EOAs und ETAs) aus dem Alltag nutzen, um zumindest im Siedlungsbereich zu navigieren. Barrieren und Herausforderungen wurden zunächst aus Sicht der sensibilisierten Studierenden erfasst. Als Lösungsansatz wurde eine projekteigene, browserbasierte Applikation entwickelt, die als Ergänzung zu EOAs und ETAs zu verstehen ist und detailliertere Informationen für einen barrierefreien Zugang bereitstellt. Dazu wurden für Blinde geeignete Landmarken identifiziert und passende Verhaltensvorschriften zur Navigation formuliert. Als Grundlage dienten u. a. existierende Kriterien für Trail-Schwierigkeiten für mobilitätseingeschränkte Personen, die objektive Bewertungskriterien physischer Barrieren wie Steigung, Oberflächenbeschaffenheit, Länge von Gefälleabschnitten berücksichtigen (Mantuano & Bruno, 2025, p. 5701). Zusätzlich sollen Kriterien für z. B. akustische Korridore oder taktile Landmarken wie Boden- und Geländetextur erarbeitet und ergänzt werden.

Um auch das Erleben zu fördern, wurden die Points of Interest entlang des Weges hinsichtlich erforderlicher Ergänzungen oder anderer Zugänge jenseits der reinen Bereitstellung der gleichen Inhalte über den auditiven Sinn untersucht. Beides, sowohl zusätzliche Navigationshilfen als auch die inhaltliche Aufbereitung, wurden in die Applikation eingepflegt, die per Sprachsteuerung bedient werden kann (vgl. Abbildung 4). Die App wurde basierend auf OpenStreetMap-Daten entwickelt und soll so gestaltet werden, dass sie sowohl für Nutzende den intendierten Mehrwert generiert, als auch von Touristikern niedrigschwellig mit Inhalten gefüllt und gepflegt werden kann. Ebenfalls wesentlich für die Nutzung von Themenwegen ist eine adäquate Information im Vorfeld sowie eine transparente Beschilderung. Hierzu werden ebenfalls erste Lösungsansätze erarbeitet.

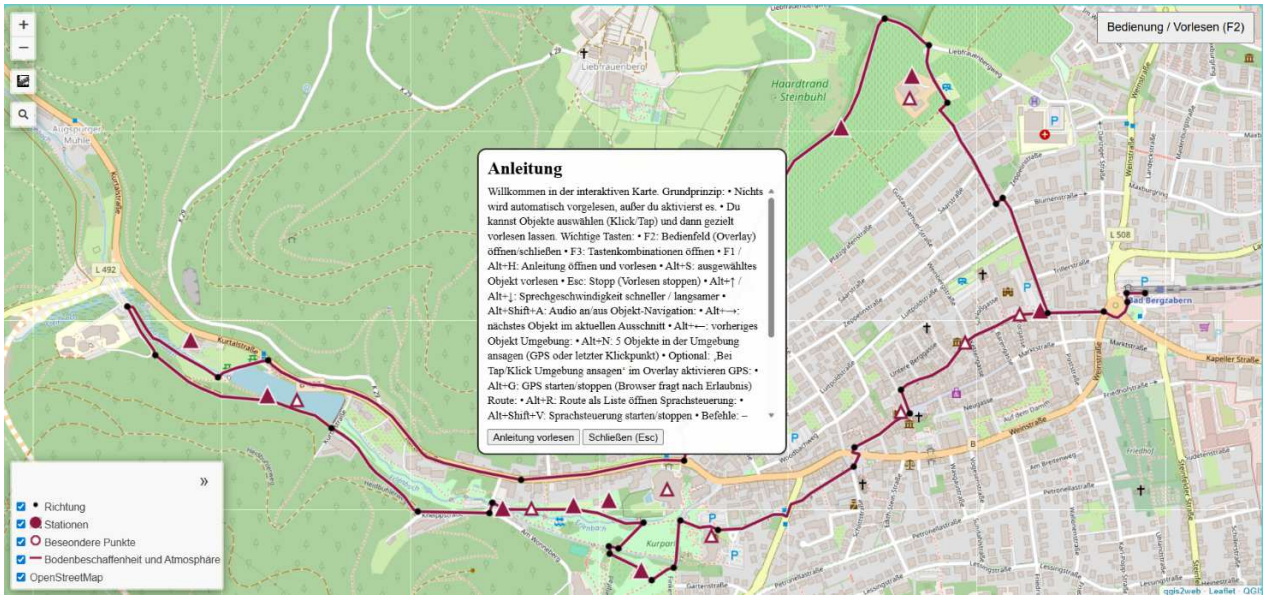


Abbildung 4: Screenshot aus der Web-App: Untersuchungsgebiet aus OpenStreetMap und Overlay zur Anleitung der App-Steuerung (eigene Darstellung)

Eine erste Vor-Ort-Begehung mit Blinden half, weitere Barrieren und Erfordernisse für Navigationshilfen zu identifizieren. Der Erhebungszeitpunkt im Winter ermöglichte eine Begehung bei geringem Publikumsverkehr, was sowohl die Videographie als auch die Konzentration auf den Weg und die systematische Erfassung relevanter Barrieren erleichterte.



Abbildung 5: Eindrücke aus der ersten Vor-Ort-Begehung mit Blinden zur Identifikation von Barrieren und Zugänglichkeiten

Hier wurden Detailfragen wie “Sind die Wechsel der Bodenbeschaffenheit mit dem Langstock erkennbar?”, “Ist die Abzweigung mit den Navigationshilfen der App auffindbar?” oder “Reicht die vorhandene Infrastruktur, um Attraktionen wie z. B. das Kneippbecken sicher zu nutzen?” geklärt (vgl. Abbildung 5) und Instruktionen und Informationen modifiziert. Die anstehende tiefergehende Auswertung dieses ersten Usability-Tests, der videographisch begleitet wurde, kann weiteres Entwicklungspotenzial aufzeigen.

Weiterhin sollen Motivations- und Hemmfaktoren für das Wandern erhoben und analysiert werden. Dazu nahmen die Studierenden an einem Blindenstammtisch teil. Hier wurde das Projekt kurz vorgestellt und zur Teilnahme an einem Leitfadeninterview eingeladen. Dieses richtet sich sowohl an Personen, die bereits wander, als auch an solche, die dies bisher nicht tun. Als erste kurze Rückmeldung seitens der Studierenden wurde erwähnt, dass es gerade Personen, die im höheren Alter erblindeten, noch große Sicherheitsbedenken gibt, die sie von solchen Freizeitaktivitäten abhalten. Detaillierte Ergebnisse dieses Stammtischbesuchs stand bei Fertigstellung dieses Beitrags noch aus.

3.6 Weiterentwicklung und Ausblick

Der im Studienprojekt exemplarisch optimierte Weg sowie der Lösungsansatz der Web-App sollen sowohl mit den Blinden als Nutzenden als auch mit Touristikern als Anbietenden weiterentwickelt werden. Um auch das Erleben stärker zu fördern, ist eine multisensorische Kartierung mit der Zielgruppe vorgesehen, die u. a. „Hörenswürdigkeiten“ verorten soll.

Parallel zur Weiterentwicklung des Weges und der Web-App werden mittels der Leitfadeninterviews weitere Motivatoren oder Hemmnisfaktoren in Bezug auf Wandern ermittelt, um auch die Teilziele zum Erlebbarmachen von nicht aufbereiteten Wanderwegen außerhalb von Siedlungen mit und ohne Begleitung anzugehen. Die Ergebnisse daraus fließen in die Konstruktion eines Fragebogens ein, der über die Blindenverbände gestreut wird, um sowohl die Zielgruppe der Wandernden als auch der (noch)-nicht-Wandernden zu erreichen.

Auch die Ebene der regionalen Akteurinnen und Akteure im Tourismus wird Gegenstand weiterer Forschung sein. Projektbeteiligte Tourismusverantwortliche in der Kommunalverwaltung und übergeordneten Ebenen signalisieren ein starkes Interesse an den zu entwickelnden Leitlinien und erweisen sich als sehr kooperationsbereit. So ist beispielsweise eine Gruppe aus Mediengestaltern und Touristikern bereit, ihre Vorgehensweise bei einem Workshop zur digitalen Ausgestaltung eines Themenweges mittels teilnehmender Beobachtung begleiten zu lassen. Damit schaffen die geplanten Untersuchungen eine solide Grundlage, um praxisnahe Leitlinien im co-kreativen Prozess mit den relevanten Akteursgruppen zu entwickeln und ihre Implementierbarkeit unter realen Bedingungen zu prüfen.

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"Intensify Industry by Double": How Environmental Policy can Foster Economic Densification

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1 ABSTRACT

The EU's goal to achieve "No Net Land Take" requires substantial reductions in land conversion by 2030. It also means that, from 2050 onwards, the total area covered by "buildings and infrastructure" cannot increase unless it is compensated for elsewhere. This, among other implications, forces a reconsideration of how a growing economy can be accommodated within finite spatial limits.

In this paper, we explore two projects that aim to revive and intensify existing industrial areas taking into account the fact that the redevelopment should be economically viable.

In 2017 the Sheffield School of Architecture was invited by Atelier Brussels to examine how industrial land in the metropolitan South-West could be used more efficiently. The project responded to a wider policy ambition: reconciling urban growth with the preservation of space for manufacturing, making economic activity visible in the public space, and supporting emerging circular-economy dynamics. Through an in-depth design investigation of five contrasting industrial sites – Bollinckx, Bempt, Paul Gilsonlaan, the Audi expansion zone, and Allnex – the team developed a systematic and transferable approach to unlocking latent capacity within existing economic estates. Their method demonstrates how build-up, build-out, and infill strategies, combined with shared-space configurations, multi-storey industrial typologies, and the reuse of irregular or underutilised spaces, can collectively double usable economic floor area without increasing land take. Applied across the cases, this method yielded more than a 200% rise in usable floor area, demonstrating the broader potential of spatial intensification within highly constrained urban-industrial environments.

Recently we applied a similar approach to an old industrial area to the east of Brussels. The site is partially situated in a flood prone area and is waiting for redevelopment. The method developed by SSoA was used to construct a real estate calculation model to estimate the potential return on investment. The case study consists currently of a small scale logistics sheds, between a small river and the Brussels' orbital ring road. Due to the potential flooding problems the river needs more space for water management, leaving less space for the logistics activities. The model starts from the shrinking footprint of the buildings, and aims to optimize the redevelopment by adding multiple storeys. In this case the logistic activities were organized on the ground floor, with other economic activities, parking and long term private storage on the upper floor. To get to a viable project, the floor surface was tripled.

Keywords: economic redevelopment, intensification, multi-storey industrial building, No Net Land Take, urban planning

2 A PERFECT STORM: A GROWING ECONOMY WITHIN SPATIAL CONSTRAINTS

Several ongoing transitions are simultaneously pushing up the spatial demand of the European economy at a time when the possibilities for outward expansion are becoming increasingly constrained. This coincidence of upward demand and tightening land conditions constitutes a kind of perfect storm for spatial planning: the economy requires more space at the moment when land conversion becomes increasingly difficult to justify.

First, open strategic autonomy has gained importance in European industrial and trade policy since the 2020pandemic and Russia's invasion of Ukraine exposed vulnerabilities in global value chains and the EU's dependence on external production capacity. In its New Industrial Strategy, the European Commission stresses that Europe must become less dependent on others for critical technologies, raw materials, food, infrastructure and security (European Commission, 2020). This ambition has since been operationalised through the Green Deal Industrial Plan (2023) and the Net Zero Industry Act (2023) which accelerate the deployment of battery manufacturing, heat pumps, electrolysers, network technology, renewable energy equipment and CCS technologies – all of which require significant land (ESPON, 2023).

Second, the transition towards a circular economy introduces new spatial functions into metropolitan production systems. Circular consumption and production models rely on repair, reverse logistics, urban mining, recycling, storage and sorting activities, most of which require additional logistics floor area and proximity to consumption centres in order to reduce transport distances (ESPON, 2019). These processes are

therefore not easily externalised to distant industrial regions, but compete for space within the existing urban and industrial fabric. The Critical Raw Materials Act adds to this demand by requiring that by 2030 at least 10% of annual consumption be extracted within the EU and 40% be processed in the EU, further expanding the need for physical sites for extraction, processing, storage and logistics.

A third driver concerns the spatial footprint of the post-carbon energy system. Electrification of industry and mobility, combined with the roll-out of renewable energy production and storage, requires substantially more space than the former fossil-based system in which critical parts of extraction and processing occurred outside the EU (Perpiña Castillo et al., 2024). Solar farms, wind parks, hydrogen storage, CCS terminals and mining and recycling facilities exert spatial claims – often in rural areas with low artificialisation (Geronnez et al., 2024).

However, this upward pressure on economic land demand coincides with a structural tightening on the supply side of land. Environmental and climate legislation increasingly restricts the conversion of open land, but also generates new spatial claims for soil protection, ecosystem restoration, water retention and climate adaptation. The European target of achieving No Net Land Take by 2050aims to halt the net conversion of open land into built surfaces, implying that new developments must be compensated elsewhere or avoided altogether (European Commission, 2016). The Soil Monitoring Law introduces binding rules for soil health, while the Nature Restoration Law sets explicit targets for ecological restoration.Moreover, climate adaptation policies restrict the amount of developable land available for economic activities – even within areas legally designated for economic use. Water safety and drought management require additional space for riverbeds, wetlands and infiltration zones; climate adaptation encourages de-sealing and the expansion of green–blue networks.

Finally, another mechanism further tightens the supply side: the social acceptability of production facilities is declining (ESPON, 2023). As Peleman (2018) argues, due to automation and sectoral restructuring, the spatial footprint of economic activities is increasingly decoupling from visible positive externalities such as employment, status or territorial identity. Industrial areas therefore contribute less to the symbolic and spatial capital of territories, while their environmental and landscape burdens remain tangible. As a result, local willingness to host new production sites or accept additional soil sealing is diminishing, even when such facilities are desirable from a regional or national perspective.

In highly urbanised regions, these combined dynamics lead to what Geronnez et al.(2025) describe as territorial saturation: the land system loses its capacity to accommodate additional activities through expansion alone, as both ecological imperatives and competing societal needs occupy the remaining spatial slack. Under such conditions, the classical planning response of outward extension becomes increasingly infeasible.

Taken together, these trends create a situation in which demand is structurally pushed upward while supply is structurally tightened.

3 "MADE IN BRUSSELS": DOUBLING INDUSTRIAL SURFACE AREA

Several strategies have been advanced in recent years to sustain productive capacity within finite territorial envelopes.These include the functional reconversion of obsolete industrial fabrics (Furlan, 2022); the vertical intensification of productive floor area; the sharing of logistics and service infrastructure across firms; the co-location of compatible economic functions; and the deployment of circular-economy models that retain added value within metropolitan space (Geronnez et. al., 2025). Other approaches involve the redesign or reallocation of access infrastructure to reduce circulation footprints, and the development of multi-storey industrial typologies that combine production, storage and ancillary services on constrained sites. Together, such strategies shift the emphasis from land procurement to land productivity: the objective becomes not to expand industrial land, but to extract more economic, social and circular value from the land already designated for productive use.

3.1 The 2017 Made in Brussels Live project

The Made in Brussels project provides a concrete illustration of such a strategic shift. Commissioned as part of the 2017 Atelier Brussels initiative, students of the Sheffield School of Architecture (SSoA) were asked to

explore how five existing yet outdated industrial estates[1] in Brussels' southwestern metropolitan belt could be revived and intensified to accommodate new economic activity without displacing industry out of the city. The brief explicitly framed the retention of productive activities within the city as desirable for reasons of employment – particularly to preserve activities relying on low- and medium-skilled labour – and city servicing. At the same time, the challenge was to secure the highest possible return in terms of added value, urban servicing and employment outcomes, among other improvements.

Rather than producing a conventional masterplan or zoning proposal, the project operated as a live urban experiment that tested how architectural and spatial design methods could reveal latent productive capacity within the existing industrial fabric. Five contrasting sites were selected to represent different typologies of metropolitan industry – from densely built metal workshops to pavilion-style business parks and logistics sheds – allowing the project to probe a broad range of spatial, infrastructural and regulatory conditions.

3.2 Four strategies for industrial intensification

Before engaging in spatial design, the students conducted a spatial analysis of the existing industrial fabric across the five sites. This spatial reading revealed that a substantial share of land within functioning industrial estates was occupied by low-intensity uses such as oversized manoeuvring yards, perimeter safety buffers, fenced circulation corridors and lightly used paved yards. These configurations resulted in high land consumption per unit of productive floor area and limited opportunities for firms to expand within their plots.

More importantly, the analysis revealed a mismatch between the spatial organisation of these old industrial estates (with dispersed pavilion buildings, fragmented parcels, and over-dimensioned setbacks) and the operational needs of contemporary production, which depends on the co-location of firms to reduce transport and handling, shared infrastructure, shorter material flows, flexible floor area for changing production cycles etc. Such configurations are difficult to realise within estates designed for single tenants, segregated parcels and extensive surface parking.

These spatial conditions also meant that a series of residual spaces – perimeter buffers, manoeuvring yards and internal voids – could be reactivated as spatial reservoirs for intensification. This provided the basis for three types of design strategies:

(1) Build-up, by adding additional floors above existing footprints

(2) Build-out, by extending volumes into underused perimeter zones or internal yards; and

(3) Infill, by inserting new volumes into the internal voids typical of pavilion-style layouts.

In addition to these physical strategies, the project explored shared servicing strategies, in which circulation and logistics infrastructure (ramps, yards, loading bays, waste handling or storage) could be shared among firms to reduce duplication and free up surface area for productive activity. These strategies underscored that industrial land is not merely an assemblage of occupied and vacant parcels, but a spatial system organised through rules of access, servicing and logistics that can be redesigned to unlock additional productive capacity.

3.3 The intensification flow diagram

Beyond generating site-specific design proposals, however, the project was able to synthetisize the above findings into a flow diagram that articulates a transferable sequence for intensifying industrial land. The diagram links the spatial reading of an industrial estate to a series of decision points that establish how additional productive floor area can be accommodated within a given site without increasing land take.

Rather than prescribing a single design solution, the diagram tests different intensification options in a structured order. It first assesses whether additional floor area can be achieved by adding storeys (build-up), then whether ground-level expansion is feasible within residual or perimeter spaces (build-out), and finally whether voids within the estate can support new volumes (infill). If these strategies alone do not produce sufficient floor area, the diagram activates a fourth lever: shared servicing, where logistics, yards, ramps, parking or storage are reorganised collectively across firms to free up additional productive space.

[1] The five sites included: (1)Bollinckx in Anderlecht; (2) Bempt in Forest, (3) Paul Gilsonlaan in Drogenbos; (4) the Audi expansion zone in Drogenbos; and (5) Allnex in Drogenbos

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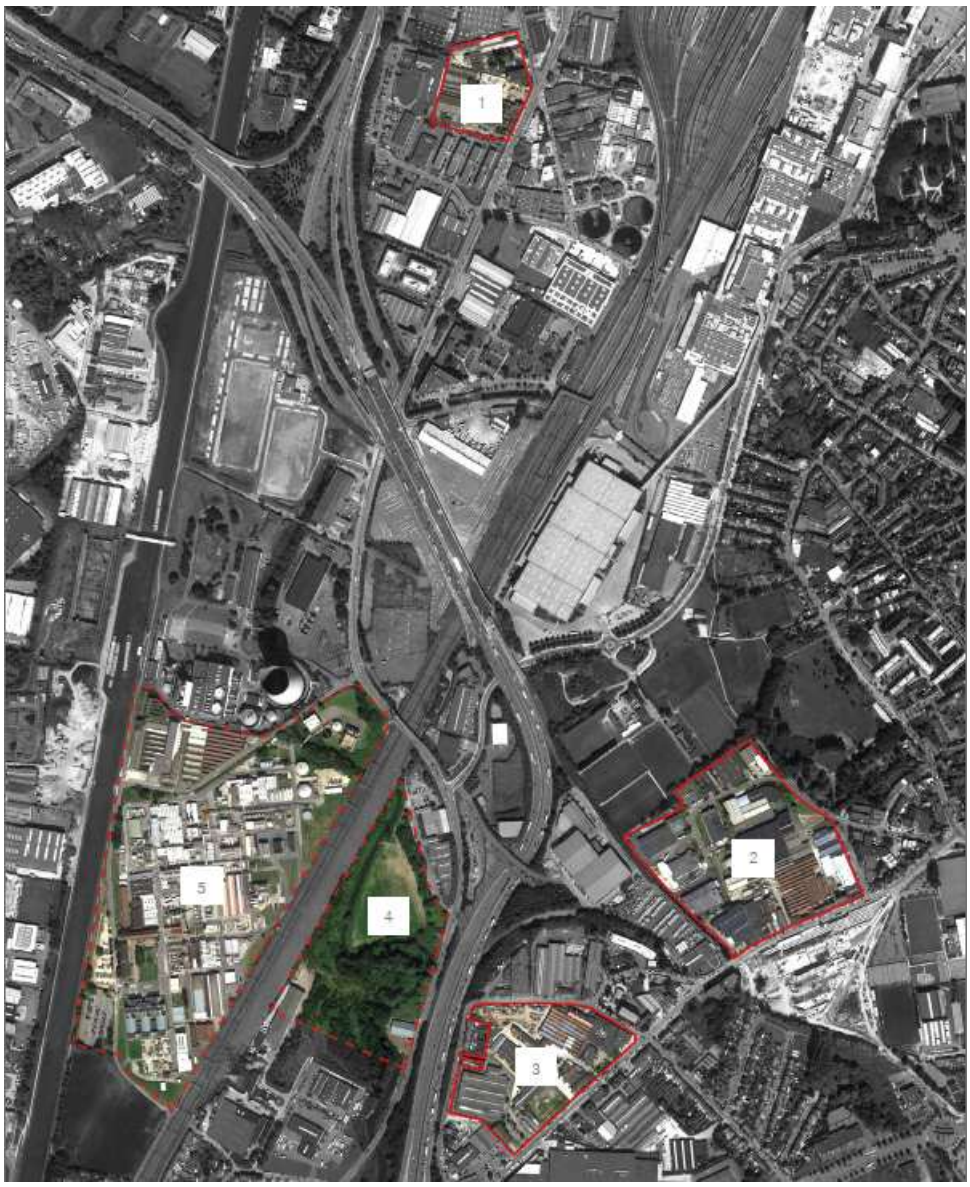


Figure 1: The five sites selected for the 2017 Brussels Live Project. Source: Made in Brussels (2017)

While developed within a design-studio environment, the value of the flow diagram lies in its generalisability. It provides metropolitan planners, public land agencies and private developers with a systematic method for assessing the intensification potential of industrial estates, including those that differ in sectoral composition, ownership structure or regulatory context. In doing so, it shows that doubling industrial surface area is not only a spatially plausible outcome for exemplary cases, but a methodologically reproducible approach for dealing with scarce industrial land under conditions of territorial constraint.

3.4 Policy relevance

Applying the intensification sequence across the five sites consistently yielded increases of more than 200% in usable economic floor area, without expanding the land take footprint. These figures are indicative rather than predictive – the proposals were not cost-engineered nor tested against permitting– , but they demonstrate that substantial additions of productive floor area are spatially feasible within existing industrial estates under realistic urban constraints.

More generally, the project illustrated that design methods can uncover forms of latent productive capacity that remain invisible within conventional planning frameworks, which tend to categorise industrial land primarily by zoning, parcelisation and functional designation rather than by spatial performance. In this sense, the project reframed metropolitan industrial estates as spatial assets rather than planning liabilities, and positioned intensification as an alternative to both relocation and net land take.

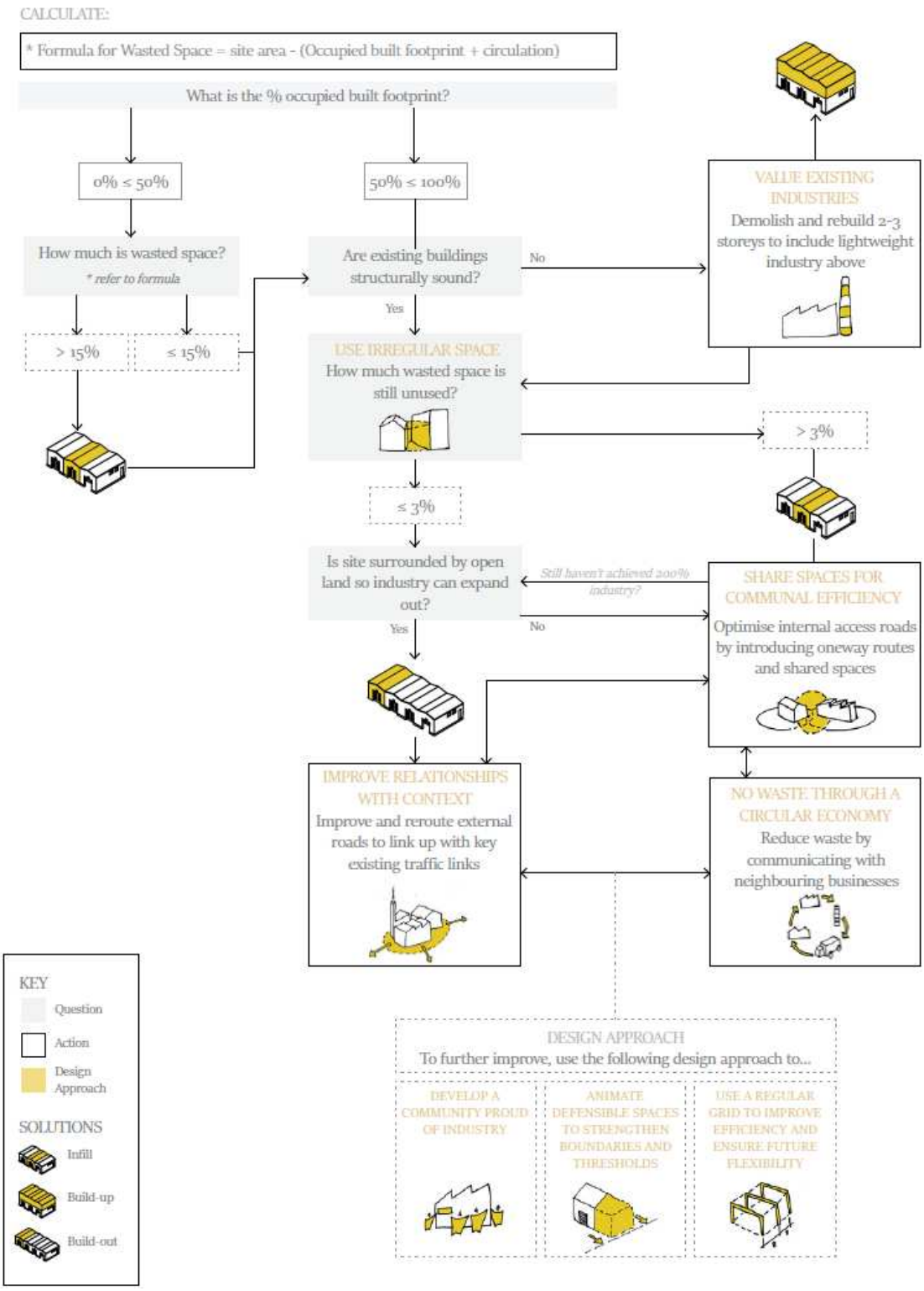


Figure 2: The intensification flow diagram. Source: Made in Brussels (2017)

4 TESTING THE THEORY: IS DOUBLING EVEN VIABLE?

The logical next question is whether such spatially plausible intensification can also prove viable under real development conditions. While the previous sections have demonstrated that doubling industrial floor area is conceptually and spatially feasible within existing estates, these insights emerged largely from design-driven investigations unconstrained by market dynamics, construction costs, regulatory sequencing or ecological requirements. In practice, however, metropolitan redevelopment occurs under a widening set of constraints. Sites must accommodate more surface area within a given space while supporting the co-location of economic, residential, recreational and service functions – all within spatial regimes that historically

separated such uses rather than mixed them. More importantly however, climate adaptation and soil policies require the he reduction of sealed surfaces and the reservation of space for water retention, floodplain restoration and blue–green networks.

Under such conditions, classical intensification strategies that build-out or fill-in often fall short. If the residual surfacethat previously enabled horizontal expansion – in between spaces, yards, setbacks and manoeuvring zones –, is increasingly reassigned to ecological, hydrological or public-space functions and is thus no longer available for development, vertical intensification therefore becomes the primary remaining lever: productive uses must be stacked rather than spread. Yet build-up strategies introducestructural and logistical complexities and thus higher construction costs, which in turn require higher revenues or new value models to close the business case. The viability question then becomes whether such vertical stacking can be made economically investable under metropolitan market conditions.

4.1 The case of Zaventem Fabriekstraat

We were able to test this question in the context of a recent consultancy on improving spatial performance in the Brussels Airport region, commissioned by the Flemish Department of Environment and Spatial Develompent. The assignment examined how municipalities in the airport noise corridor could accommodate economic and residential programmes without increasing exposure to aviation noise, while at the same time improving spatial cohesion and aligning redevelopment with climate and soil policies. This required exploring options for more productive land use, mixed-use intensification and selective relocation of sensitive functions.

Within this broader study, the Fabriekstraat industrial estate in Zaventem was selected as one of the strategic test cases. The site borders the residential centre of Zaventem and is located at the lowest point of the Woluwe valley, resulting in both pluvial and fluvial flood exposure. It consists almost entirely of sealed soil and interrupts the ecological continuity of the broader valley green structure, thereby creating a clear task to restore or re-establish green–blue connections across the site. In addition, the combination of airport, rail and road noise places it within multiple strategic noise contours where new housing is generally deemed undesirable without mitigation. At the same time, the site is well connected: it is serviced by an important public transport corridor, lies near Zaventem train station and the Brussels–Leuven cycle highway, and already hosts productive activities with significant surface demands.

These conditions made Fabriekstraat a representative stress test for metropolitan industrial intensification: any strategy to retain or expand productive capacity would have to contend simultaneously with water management, de-sealing, ecological continuity, logistics accessibility and also noise-sensitive programme allocation.

To explore spatial intensification on the site, three design scenarios were developed. All three tested a different spatial logic for combining economic, residential and ecological functions under severe noise and hydrological constraints. In the first scenario, a south–north gradient was introduced ranging from housing to mixed-use to vertically stacked economic functions. Housing was placed along the southern edge, outside the 50 dB Lden aircraft noise contour, while the central part of the site accommodated mixed-use buildings combining economic and residential programmes in roughly equal proportions. Toward the ring road, the programme shifted to predominantly economic uses with a higher intensity, resulting in a scenario where the economic and residential programmes were relatively balanced in gross floor area. A substantial green buffer was introduced along the R0 to act as a noise screen.

The second scenario maintained the ambition of mixing economic and residential programmes while strengthening the ecological and hydrological functioning of the Woluwe valley. The valley was widened into a continuous blue–green corridor, logistics access and manoeuvring space were consolidated, and large sealed surfaces were de-paved to create floodable open space. Here, productive functions were clustered along the ring road while the mixed-use band in the centre of the site carried both living and working programmes at comparable levels, and housing increased slightly compared to Scenario 1. The spatial organisation was clearer and the overall residential programme moderately larger, reflecting the improved environmental conditions created by the blue–green corridor.




Figure 3: Fabriekstraat project area, Figure 4: Pluvial flood risk.





Figure 5: Aircraft noise, Figure 6: Road traffic noise.




Figure 7: Protected heritage, Figure 8: Green structure.

The third scenario departed more drastically from the existing condition by avoiding development in the water-sensitive valley altogether and placing the economic programme as a buffer between the ring road and the residential core. In this scenario, housing moved closer to the town centre and the share of pure economic floor area increased relative to the mixed-use portion. This strategy enabled the creation of a wide green buffer along the R0 – potentially with sculpted topography – and tested whether productive volumes could

shield the town from road traffic noise. Municipal feedback considered this spatial logic the most promising due to its hydrological robustness and urban legibility, although noise-related limitations for new housing remained.

	Scenario 1	Scenario 2	Scenario 3
Economic programme	16.718 m²	15.976m²	~13.483 m²
Residential programme	14.704 m²	20.178 m²	~10.690 m²
Ratio residential-economic	1:1,14	1:0,79	1:1.26
Total costs	€232M	€247,2M	€282M
Total revenues	€94,7M	€107,2M	€79.9M
Result	-€137,3M	-€140M	-€202,3M

Table 1.

Spatially, the three scenarios showed that higher productive capacity within the existing perimeter is possible when logistics is reorganised and ecological continuity restored. Financial modelling, however, demonstrated that each scenario resulted in substantial deficits under current market conditions. This prompted a second analytical step in which the site was subdivided into functional sub-areas to introduce greater flexibility and tailoring in the financial models. By disentangling the economic programme from housing, water and public-space components, it became possible to test what economic development could achieve on its own terms – technically, operationally and financially. Within this decomposition, the western strip along the ring road – Zone West – displayed the highest carrying capacity for productive uses at higher intensities and is therefore examined in the following section.

4.2 Zone West: building up economic surface

Within Zone West, two stacking alternatives were subsequently developed that both tested whether productive capacity could be doubled within the existing perimeter while halving the footprint and reducing sealed surfaces. In both configurations, productive activities were distributed vertically up to 30m in height, with consolidated servicing and manoeuvring zones placed along the western façade facing the R0. This organisational strategy allowed the building to internalise logistics, parking and circulation functions that would otherwise consume surface area, while freeing up the eastern side toward the valley for water retention, de-sealing and ecological connectivity. Both alternatives therefore demonstrated that spatial intensification and climate adaptation need not be contradictory objectives, provided access and logistics are restructured in three dimensions rather than two.

The first alternative explored a metropolitan productive programme composed of logistics, small and medium-sized enterprise (SME) spaces, office-like functions and self-storage. These activities were selected not only for their compatibility with the site's multimodal accessibility but also for their capacity to support higher rental levels and diversified revenue streams. The configuration doubled total floor area from approximately 25,000 m² today to around 54,200 m² in this first alternative, while reducing the footprint from 27,930 m² to 14,656 m². The economic performance was strongly driven by self-storage, which was expected to achieve high unit revenues (~€8,200/m²) and served as a cross-subsidising component for the remaining productive uses. The alternativewas expected to produce a total surplus of more than €18 million, indicating that a vertically stacked productive building can be made investable when the programme incorporates higher-yield functions alongside industrial uses, thereby increasing average revenue levels and supporting the additional CAPEX of multi-storey structures. The resulting building type resembles emerging urban-industrial architectures in other European metropolitan regions, where productive uses are increasingly embedded within high-value, multi-tenant ecosystems rather than isolated in single-storey sheds.

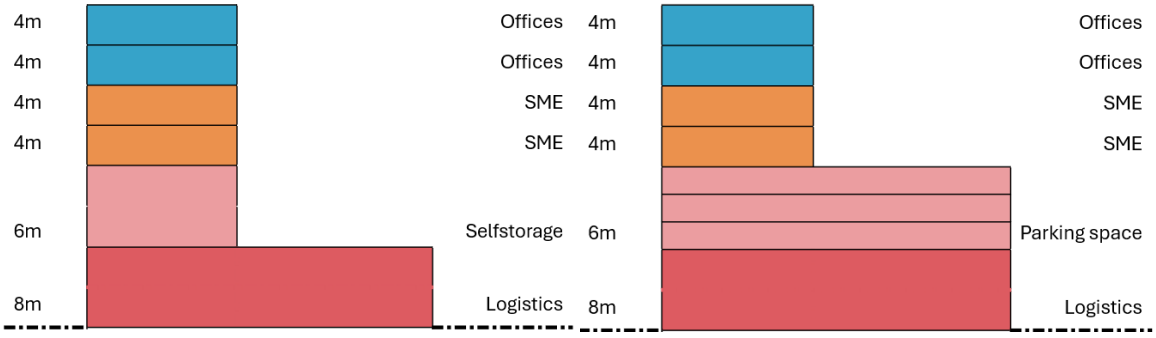


Figure 9: Zone West – Alternative 1, Figure 10: Zone West – Alternative 2.

The second alternative tested a more conservative programme by allocating large portions of the building to multi-lever car park in addition to productive uses. Although the footprint reduction was identical to the previous scenario, the vertical build-up was even more pronounced: total floor area increased from roughly 25,000 m² to approximately 85,000 m², thereby more than tripling productive capacity within the same perimeter. Economically, however, the scenario performed less strongly due to the lower unit revenues associated with parking (~€ 950/m²), resulting in a narrow surplus of approximately € 0.4 million. While effectively break-even, the second alternative nevertheless demonstrated several important insights: first, that mobility-related programme can be structurally internalised within the productive envelope rather than consuming surface area; second, that footprint reduction and intensification do not necessarily depend on high-yield functions; and third, that vertical stacking remains technically feasible even under lower market rents, albeit without generating significant surplus value.

Taken together, the two alternatives illustrate that vertical intensification of productive uses is spatially and structurally feasible under metropolitan conditions, but that financial viability is highly sensitive to programme composition, revenue logic and the ability to incorporate functions with higher value profiles. In other words, the question is no longer simply whether productive capacity can be doubled, but under what economic and institutional conditions such doubling becomes financeable.

5 CONCLUSION

The cases discussed in this paper demonstrate that the ambition to "double" industrial capacity within a fixed perimeter is not merely a speculative design exercise. The Sheffield School of Architecture framework of build-up, build-out, infill and shared servicing strategies proved transferable across contrasting metropolitan conditions and confirmed that latent productive capacity in existing estates can be mobilised to structurally increase usable floor area without additional land take.

Yet, the SSoA-framework presupposes a relative freedom from external constraints. The ability to reorganise access, servicing and circulation in three dimensions presumes that residual space remains available for manoeuvring, buffering or shared logistics. In more metropolitan contexts, this residual space is now increasingly claimed by non-economic objectives that are no longer peripheral but central to planning regimes. Climate adaptation, soil improvement, water retention and green–blue continuity introduce binding claims on footprint, permeability and morphology – as illustrated in Zaventem, where flood exposure and green-structure restoration absorbed much of the former expansion space. Doubling productive capacity thus requires not only vertical stacking ("build-up") but a simultaneous reduction of sealed surfaces and a shrinking of the operational footprint.

These non-economic objectives can, however, act as productive constraints rather than absolute limits. In the case of Zaventem, flood mitigation and ecological continuity functioned as design drivers for a new three-dimensional organisation of logistics and productive space. The result was not simply a more ecological project, but one in which productive capacity could be multiplied within a smaller sealed surface. In this sense, the ecological turn of planning can operate as a push factor for industrial innovation rather than a brake.

The question that remains is whether such climate-adaptedintensification can also be made economically viable. The answer is not universal but conditional: viability depends less on the spatial configuration than on the composition of the programme. The Brussels cases show that multi-storey productive buildings can become investable when higher-revenue functions are incorporated to cross-subsidise productive uses; they break even under conservative revenue profiles and perform strongly under diversified ones. Complex vertical industrial architectures therefore appear not only spatially compatible with climate-adapted planning regimes, but economically plausible within metropolitan property markets – provided that programme composition and value models evolve accordingly.

In sum, metropolitan reindustrialisation under "no net land take" conditions is not only conceivable, but actionable. It requires a combined shift in design, planning and development practice: from land consumption to land productivity and from orizontal to vertical planning logics. The empirical horizon now moves from proving feasibility to scaling and institutionalisation.

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reviewed paper

Leaving No One Behind: Planning for Inclusive Resilience in Marginalised Communities

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1 ABSTRACT

Marginalised communities experience a higher level of impacts from climate change and disasters and typically have limited access to resources and support to recover and rebuild. Globally, inclusive resilience planning has become crucial in mitigating these inequalities and ensuring that no one is left behind. Although various tools exist for implementing inclusive resilience in South Africa's planning, municipalities face challenges in integrating climate change adaptation into local planning. To address these challenges, this paper explores inclusive resilience planning strategies to alleviate residents' hardships and ensure that no one is left behind in the face of climate change and other shocks. Building on this, the study employed a qualitative research approach to analyse the lived experiences and viewpoints of the residents. The study results highlight that marginalised communities are diverse, emphasising that each community has specific needs and challenges that must be considered in resilience planning. Typically, spatial planning practices employ the top-down approach rather than incorporating marginalised communities. Current power imbalances and social exclusion can exacerbate inequities, and resilience planning frameworks often overlook them. The study recommends that to promote inclusive resilience in marginalised communities, policymakers must prioritise community-based methods, address power imbalances and social exclusion, incorporate marginalised communities into inclusive resilience planning strategies, and prioritise the voices and viewpoints of residents. The study seeks to contribute to both policy and academia by translating the global LNOB principle into a context-specific framework for flood resilience in rural South Africa, enhancing equitable participation and minimising vulnerability.

Keywords: Inclusive Resilience, Marginalised Communities, climate change, inclusive planning, urbanism

2 INTRODUCTION

The principle of Leaving No One Behind (LNOB) is vital to the Sustainable Development Goals (SDGs) of the 2030 Agenda, highlighting a worldwide devotion to equity in development results (United Nations, 2015; Gupta and Vegelin, 2023). Essentially, LNOB requires planned efforts to prioritise the needs of the improvised and most marginalised communities, ensuring that development processes and results benefit all members of society (Ubillus and van Ongevalle, 2024). This principle promotes the need to identify and solve structural inequities that exacerbate vulnerability in the context of climate change in order to implement resilience-building solutions. Marginalised communities experience a greater level of impacts from climate change and disasters and typically have limited access to resources and support to recover and rebuild (Mendis et al., 2023). As a result, LNOB necessitates not only inclusive development rhetoric but also the meaningful integration of marginalised communities into the resilience planning processes. This requirement is especially important in South Africa, where the legacy of apartheid spatial planning continues to produce deeply ingrained inequalities, with poor and vulnerable communities extremely exposed to climate-related disaster risks (Parnell and Pieterse, 2014; Maranga and Dorasamy, 2026). Due to their continued development in underserved and environmentally risky places, historically marginalised communities are particularly exposed to the problems posed by climate-related disasters (Smith et al., 2022). Climate change is intensifying extreme weather patterns, leading to heavy rainfall, contributing to catastrophic disasters, causing misery, and disrupting both urban and rural communities (Raphela, 2025). In support of this view, the United Nations reports that floods accounted for 43% of all natural disasters that occurred globally between 1995 and 2015. Among those who experienced any natural catastrophe, these occurrences affected over half (56%) and resulted in the deaths of over a quarter (26%) (Abdrabo et al., 2020). These trends highlight that flood risks and damages are increasing in frequency and severity, thereby

compounding existing inequalities and increasing community vulnerability. In South Africa, residents are increasingly settling in flood-prone areas, especially among the poor and marginalised residents facing growing exposure and risks due to both environmental and socio-political factors (Dube et al., 2021; Raphela, 2025). In conclusion, the increasing impacts of climate change are making floods more frequent and severe, increasing community vulnerability, and necessitating urgent, adaptable solutions to protect both urban and rural residents.

Rural settlements in developing countries are increasingly vulnerable to high flood risks due to heavy runoff or an increase in water levels in a specific location that exceeds the environment's capacity to absorb water (Ampofo et al., 2024; Munyai et al., 2021). Unfortunately, South Africa stands out as one of the developing countries that frequently suffer from the devastating effects of climate change-related calamities, notably heavy rainfall-induced flooding (Raphela, 2025). Provinces in South Africa, such as Limpopo, KwaZulu-Natal, North West, and the Eastern Cape, are disproportionately affected by more extensive flood risks due to a combination of geographic and government-related weaknesses (Munyai et al., 2021). This spatial marginalisation, combined with poor municipal capacity to enforce climate change adaptation strategies, increases the vulnerability of these communities and exposure to flood risks and undermines the practical application of LNOB in resilience planning (van der Berg, 2023). Globally, inclusive resilience planning has become crucial in mitigating these inequalities and ensuring that no one is left behind (Makamanzi, 2025). Although frameworks and tools exist for inclusive resilience planning, current strategies in South Africa are weakly tailored to address the intersecting challenges of environmental hazard, social vulnerability, and inequalities. Specifically, there is a lack of locally grounded, participatory tools that incorporate LNOB principles into flood resilience approaches for rural communities, and this highlights a significant research and practice gap. To address this gap, this paper aims to create a practical, grounded approach to flood resilience that actively involves marginalised communities and addresses social, spatial, and environmental inequalities. The study seeks to contribute to both policy and academia by translating the global LNOB principle into a context-specific framework for flood resilience in rural South Africa, enhancing equitable participation and minimising vulnerability.

3 LITERATURE REVIEW

3.1 Leaving No One Behind, inclusive development, and climate change

The principle of LNOB, embedded within the 2030 agenda for sustainable development, represents a normative commitment to equity that is particularly urgent in the context of climate change (United Nations, 2023). Although the 2030 Agenda focuses on sustainable development, it simultaneously advances inclusive development, allowing space for achieving social, ecological, and relational inclusiveness (Gupta and Vegelin, 2023). This commitment is reinforced by the pledge to leave no one behind and to reach the furthest behind first (United Nations, Gupta and Vegelin, 2023). Consequently, the conceptualisation of inclusive development of the Sustainable Development Goals (SDGs) builds on respecting human rights and achieving social justice, which are the groundwork for the 17 goals and 169 targets of the SDGs (Magdalena,2023). While LNOB emerged within border sustainable development discourse, its relevance has become increasingly pronounced as climate change intensifies social, economic, and environmental inequalities (Taratori and Comim, 2025). Marginalised communities frequently face higher exposure to hazards such as floods, droughts, and extreme heat; greater sensitivity due to limited financial resources and institutional support (Naess et al, 2021). The marginalised communities, particularly in rural and flood-prone areas, are often exposed to the highest level of climate risk while possessing the least adaptive capacity.

LNOB provides not only a moral framework but a governance imperative that requires climate policies to prioritise structurally vulnerable populations rather than pursue uniform adaptation strategies. It calls for a climate change policy that prioritises structurally vulnerable groups rather than uniform adaptation approaches that may overlook differentiated needs. Climate change intersects with inclusive development but does not define it; it acts as a stress multiplier that exposes and intensifies pre-existing inequalities (Ali, et al. 2025). Communities already excluded from infrastructure networks, financial systems, and political representation often face heightened exposure to climate hazards (Putsoane et al., 2024). For this reason, adaptation and disaster risk reduction strategies must therefore be embedded within broader equity frameworks to ensure that resilience investments do not disproportionately benefit already advantaged populations (Majlingova and Kadar, 2025). Inclusive development also emphasises participatory governance,

where decision-making processes must move beyond consultation towards meaningful inclusion (Ahmad and Islam, 2024). Such inclusion enables marginalised groups to influence policy design, implementation strategies, and budgeting priorities. Participatory planning strengthens accountability and ensures that development interventions reflect lived realities (Sebunya and Gichuki, 2024). This is particularly important in marginalised communities, where top-down planning approaches frequently overlook local knowledge and socio-cultural dynamics

3.2 Rural vulnerability in the context of leaving no one behind

In recent years, many parts of South Africa have been devastated by floods, severely affecting the most vulnerable communities (Govender et al., 2025). Despite measures to reduce flood risk and the implementation of adaptation measures, there is always a measure of harm to livelihoods, health and wellbeing, and the economy that persists far beyond flood events (Govender et al., 2025). Both rural and urban areas in south Africa face several challenges related to climate change and these challenges highlight a vulnerability (Zhou et al., 2022)understanding the vulnerability in this context can be approached from two perspectives: the starting point approach which considers that vulnerability is generated by multiple factors and processes, and the end-point approach which considers vulnerability as the residual of climate change impacts (O'Brien, 2004; Zhou et al., 2022). Rural vulnerability is a central concern within the framework of Leaving No One Behind (LNOB), particularly as climate change increasingly interacts with long-standing patterns of exclusion. Communities in rural areas often experience multidimensional deprivation shaped by spatial marginalisation, insecure land tenure, limited access to basic services, weak infrastructure, and constrained economic opportunities (Nyamwanza et al., 2025). Limited access to financial services, insurance mechanisms, early warning systems, and institutional support further constrains the ability of rural households to anticipate, absorb, and recover from climate-related shocks (Appavoo, 2024). Within the LNOB framework, these differentiated impacts underscore the need to recognise climate vulnerability as socially produced and unevenly distributed.

Planning for inclusive resilience in marginalised rural communities, therefore, requires integrating climate considerations into broader inclusive development strategies (Lunga, 2025). Land use planning plays a critical role in linking climate change adaptation with LNOB principles. In many rural areas, settlements are in environmentally sensitive or hazard-prone zones due to customary land allocation practices, historical displacement, or limited availability of safe land. Risk-sensitive and inclusive land use planning can reduce exposure by guiding settlement patterns, protecting ecosystems, and aligning development decisions with climate projections (Hada and Shaw, 2025). Crucially, integrating customary systems with formal planning frameworks, while ensuring meaningful community participation, is essential for operationalising inclusive resilience (Parsons et al., 2025). Participatory governance is a key mechanism through which LNOB can be translated into climate-resilient planning outcomes. Marginalised rural communities are frequently excluded from decision-making processes related to climate adaptation, disaster risk management, and development planning (Mendis et al., 2023).

4 METHODOLOGY

The study employed a qualitative research approach to analyse the lived experiences and viewpoints of the residents in the Thulamela Local Municipality with particular focus on rural vulnerability, land-use governance, and climate-related risks such as flooding. The qualitative research approach aligns with the principle of LNOB and inclusive development, as it enables the investigation of social, cultural, and institutional factors that shape the vulnerability in marginalised communities. The interviews were conducted with key informants, including tribal authorities, municipal officials, town planners, and policymakers. The semi-structured interview for key informants was anticipated to last for 15-20 minutes. An in-depth qualitative perspective on the customary land allocation process and tools, as well as flood risks in Thulamela Local Municipality, was obtained through interviews, which were crucial to this study. Key informants, including tribal authorities, municipal town planners, and community representatives, participated in semi-structured interviews to discuss governance frameworks, tools, processes, and challenges in implementing formal land-use planning and decision-making processes. Depending on the participants' choices and availability, the interviews were conducted in various ways, including both in person and online. To protect the participants' identities and ensure respectful engagement with the customary land governance system, ethical principles, including informed consent and confidentiality, were

strictly adhered to. Interview data, which were qualitative and collected from key informants such as tribal authorities, municipal officials, and the community, were examined using thematic data analysis (Atlas.ti). This involved transcribing the key informants' responses, identifying recurring ideas, coalescing this information into meaningful categories, and interpreting the themes, especially those related to customary land governance processes and tools, as well as the environmental considerations of the traditional authorities.

5 FINDINGS AND DISCUSSION

5.1 Land allocation and governance challenges

The perceptions of Thulamela Local Municipality residents who participated highlight a community that feels caught between the demands of tribal authorities and the expectations of modern land governance. The residents emphasise that land allocation in rural areas under the tribal authorities is characterised more by favouritism and inconsistency, with some residents being allocated larger or safer stands that are not in areas that are vulnerable to flooding. In contrast, others are placed in areas that are not feasible for residents to reside in, such as locations close to rivers. This imbalance has created a sense of inequality and dissatisfaction with how land is currently allocated in the village, where most residents think their voices are excluded from decisions that directly impact them. The absence of title deeds, PTO, or formal documentation further fuels the insecurity, and the landowner worries about their ability to protect or develop the land they have purchased in the future. Another recurring perception among residents is the concern and fear about the lack of spatial planning implemented by the tribal authorities. Houses built near the river face constant threats and risks from flooding influenced by climate change, and residents believe these risks are exacerbated by poor planning before land is allocated. An example is shown in Figure 1, a boundary fence that has been moved by floods.



Fig. 1: Fence that has moved due to heavy floods. Source: Author, 2025

5.2 Flood vulnerability

Participants have frequently expressed frustration at being placed in areas that are not feasible for residents to live in, simply because locations that are feasible for residents to live in have already been unfairly allocated in the past. These challenges are not just material losses; residents feel neglected and believe their safety is not prioritised by those who oversee land-use planning. These experiences shape the perception that the system in rural areas is unfair and does not prioritize residents' safety. As the area is prone to floods (see Figure 2). Lastly, the residents perceive that the tribal authorities work with no transparency and insufficient accountability. The residents have emphasised that the process of land allocation is informal, is more centred on verbal agreements with no formal documentation, and involves a small-scale site inspection without involving the technical experts who can assess whether the place is suitable for people to reside in. Most

suggestions are that the system must be reformed to ensure fairness, transparency, and inclusivity, especially by involving residents in decision-making and ensuring formal land tenure. Overall, the Thulamela Local Municipality's perception paints a picture of a community seeking community involvement, equity among the residents, and safety and legitimacy in the land allocation process.



Fig. 2: Floods in Thulamela Local Municipality villages. Source: Author, 2025

5.3 Policy and institutional gaps

Key informants emphasised the gaps in policy understanding and enforcement among tribal authorities, highlighting the necessity for capacity building, land policies, tools, and frameworks that accommodate rural areas, as well as greater involvement and engagement from key informants. The suggestions brought up by key informants cater to the demarcation of sites process, utilising GIS tools that will show areas under tribal authorities to resolve conflicts, educate tribal authorities about formal land allocation, and enhance transparency and residents' involvement in decision-making. For spatial planning, these findings highlight the need for multi-level land governance tools and frameworks that can put together the tribal authority and municipal structures, improve the risk-sensitive and sustainable land use in rural areas, and encourage inclusive decision-making to ensure that it is equitable, safe, and efficient land use management in both rural and urban areas. Favouritism, unequal land allocation, a lack of official documents, and poor enforcement of municipal frameworks are challenges that highlight larger land governance issues in rural areas' property management. Land allocation may exacerbate social injustices, marginalise rural area communities, and make it more challenging for residents to access government assistance or development plans. Stand allocation alone is inadequate for a thriving land-use management; institutional changes, promoting collaboration between key informants, and transparent PTO or title deed issuance procedures are also necessary. Customary land governance may become more effective, sustainable, and responsive to the requests of all stakeholders by integrating Indigenous knowledge and involvement with municipal statutory planning tools and frameworks such as SPLUMA. This will improve inclusive growth and lower long-term risk exposure.

6 IMPLICATIONS AND RECOMMENDATIONS

In rural South Africa, traditional land-use planning frequently increases vulnerability by ignoring the needs and viewpoints of marginalised people. Settlements are situated in environmentally dangerous places, making them more vulnerable to floods and other climate-related hazards, because of historical spatial inequality and top-down planning techniques. This emphasises how important it is to have inclusive and risk-sensitive land use planning, where decisions about infrastructure development, ecosystem preservation, and settlement distribution are informed by both community knowledge and scientific evidence. While participatory planning guarantees that local priorities and sociocultural dynamics affect land use decisions, the findings suggest that combining traditional land governance systems with official city planning might increase equity and decrease hazard exposure. Land use planning that embraces the Leaving No One Behind (LNOB) principle also highlights the need to deliberately target the most disadvantaged people in order to ensure that spatial growth builds resilience rather than exacerbates already-existing disparities. In the end,

land use planning needs to change from being a strictly technical endeavour to a socially conscious, inclusive, and flexible procedure that reduces vulnerability and boosts community resilience.

Promoting inclusive flood resilience in marginalised rural communities requires policymakers and planners to use a participatory, community-centered planning approach. Throughout all phases of planning, execution, and oversight, municipalities must establish systems that guarantee the meaningful participation of marginalised groups, such as women, youth, the elderly, and individuals with disabilities. To align customary land allocation methods with risk-sensitive land-use planning, traditional authorities and municipal planning institutions must work together more closely. Additionally, localised vulnerability assessments that combine community knowledge and scientific climate data to create context-specific adaptation methods should be incorporated into resilience planning. To improve community-level adaptive capability, capacity-building programs such as training on early warning systems, disaster preparedness, and climate adaptation should be given top priority. Lastly, to guarantee that interventions actually help the most vulnerable groups, resilience frameworks must incorporate monitoring and evaluation methods that specifically track equitable effects. Through the integration of LNOB principles into planning instruments, governance frameworks, and implementation procedures, municipalities can progress toward climate adaptation paths that are more socially just, sustainable, and equitable.

7 CONCLUSION

This study highlights that inclusive resilience planning is not a one size fits all approache because rural communities in South Africa experience distinct vulnerabilities shaped by historical, social, and environmental factors. The voices, experiences, and expertise of disadvantaged resilients must be incorporated into effective resilience policies, which must transcend top-down governance. Policymakers and practitioners can improve fair participation, lessen vulnerability, and increase adaptive capacity to climate-related threats like flooding by incorporating the LNOB principle into frameworks tailored to the situation. Ultimately, inclusive resilience planning offers a pathway to more equitable, sustainable, and socially just climate adaptation in rural South Africa. The study emphasises how crucial it is to integrate participatory mechanisms that involve women, youth, the elderly, and people with disabilities, as well as to ensure that scientific data on hazards is supplemented by local knowledge and to harmonise customary land governance with formal municipal planning processes. By fostering community trust, equity, and decision-making agency, such strategies can improve social resilience in addition to physical resistance to floods.

The paper also emphasises the need for resilience planning to take into account social, institutional, and governance aspects of vulnerability in addition to environmental and infrastructure issues. Effective operationalisation of inclusive methods can be achieved through risk-sensitive land use planning, capacity training for tribal authorities and municipal officials, and tools such as GIS-based site demarcation and formalised land documentation. By incorporating LNOB principles, interventions are guaranteed to be sustainable, egalitarian, and locally relevant, lowering long-term vulnerability and promoting social justice. In the end, inclusive resilience planning provides rural communities with a way to adapt to climate change in ways that are community-driven, socially conscious, and environmentally aware, resulting in more equitable, secure, and sustainable futures.

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reviewed paper

Mapping Park Maintenance Disparities Across Johannesburg's Socio-Economic Landscape: A Pilot Assessment Study

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1 ABSTRACT

Public parks provide essential recreational spaces in urban areas; however, their conditions and utility vary significantly across neighborhoods. This pilot study examined park maintenance disparities in Johannesburg by developing a classification system and documenting conditions of 28 parks across Johannesburg's seven regions using four criteria: infrastructure, amenities, maintenance, and safety. This assessment enabled the selection of three parks across socio-economically distinct areas in the city. In the analysis, field observations were combined with satellite imagery from Google Earth Pro. Three independent assessors achieved strong agreement in their evaluations, validating our assessment approach. The results revealed striking unevenness in the conditions and utility among the focused parks. While James & Ethel Gray Park is in an affluent suburb spanning 467,819m² with excellent facilities and active community involvement, End Street North Park in the Central Business District (CBD) covers only 14,366m² and maintains basic cleanliness but lacks comprehensive recreational amenities. Lastly, Doris Park, located in a mixed-income neighborhood, occupies just 12,636m², 37 times smaller than the James & Ethel Gray Park, with deteriorated and poorly maintained sporting facilities. These patterns reflect persistent spatial injustice rooted in apartheid-era planning. The findings demonstrate that neighborhood wealth strongly correlates with parks' conditions and utility, highlighting the urgent need for equity-focused urban planning in South African cities for enhance public parks functionality.

Keywords: Urban Inequality, Park Maintenance, Spatial Analysis, Johannesburg, Satellite Imagery.

2 INTRODUCTION

Recreational centres are a necessity in human settlements. Aside from serving as points for social recreation and integration, especially among youths, they are points for communal social services, exercise, and relaxation (Alison et al., 2016; Dayle, 2022; Jeeva & Gumbo, 2023; Khanyile & Fatti, 2022). Consequently, governments across contexts have strived to site, furnish, and maintain public parks in strategic locations across urban settings, as they provide spaces for recreation in dense urban landscapes (Jeeva & Oosthuizen, 2023). While significant investment has been demonstrated in the establishment and maintenance of public parks in developing contexts, such as South Africa, recent observations of the conditions and utility of public parks in the country, particularly in the City of Johannesburg, showed unevenness, indicating the possible impact of demographic and socio-economic factors on the conditions and utility of parks in the city (Hofer et al., 2022; Jeeva & Oosthuizen, 2023). To ascertain the possibility of these connections, this paper explores the conditions of parks across socio-economically distinct communities, documenting differences, mapping patterns, and developing a classification system for public parks in the City of Johannesburg.

To effectively document and classify the over 2000 public parks in the city (Khanyile & Fatti, 2022), an initial pilot study focusing on a few parks to develop and validate an assessment tool is required. This paper serves this purpose by:

(1) Developing and validating a classification system for assessing park maintenance conditions and utility in developing urban contexts.

(2) Documenting maintenance disparities across three parks representing distinct socio-economic communities in Johannesburg.

(3) Conduct a comparative spatial analysis of the parks from the satellite and photograph imagery.

Over the years, studies establishing a connection between the economic dimension and spatial features in South Africa have been scanty (Alison et al., 2016). Despite growing recognition of urban park inequality in South Africa (Venter et al., 2020; Khanyile & Fatti, 2022), systematic documentation of park maintenance disparities remains limited. Existing studies examine park access (Khanyile & Fatti, 2022) or usage patterns (Jeeva & Gumbo, 2023) but do not systematically assess maintenance conditions across socio-economic

gradients. Furthermore, no validated classification system exists for comparing park quality in South African contexts. This pilot study addresses these gaps by developing an assessment tool specifically suited to Johannesburg's conditions while documenting the extent and spatial patterns of maintenance disparities across the city's diverse neighborhoods.

3 LITERATURE REVIEW

3.1 Theoretical Framework: Environmental Justice and Spatial Justice

This paper leverages a combination of Environmental Justice (EJ) and Spatial Justice, two complementary theoretical traditions for developing an assessment framework. The framework serves a dual purpose of guiding the selection of assessment indicators and the interpretation of observed disparities in this paper.

As articulated by Schlosberg (2007), Environmental Justice, a theory commonly used for analysing urban green infrastructure (Venter et al., 2020; Hofer et al., 2022), asserts that equity in the distribution of environmental amenities, such as public parks, across social groups, despite racial, income, or related socio-demographic differences, is important. Consequently, the theory posited that three indicators comprising; (i) distributive justice, concerned with the equitable allocation of park space and resources (corresponding to the infrastructure and amenities indicators); (ii) procedural justice, relating to community participation in park governance (reflected in community engagement observations); and (iii) recognition justice, which demands acknowledgment of the needs of marginalized communities (relevant to the safety and maintenance indicators in lower-income areas) are relevant to measuring park quality and untitlity.

This tripartite EJ framework, synthesized with Buchholz's (2011) concept of Spatial Justice, which foregrounds the role of geographic space in reproducing social inequalities, provides a coherent theoretical rationale for the four assessment indicators adopted in this study.

3.2 Assessment Criteria: Theoretical and Empirical Justification

Post-apartheid South Africa has continued to struggle with balancing the entrenched socio-economic inequalities among its citizens (Shackleton & Gwedla, 2021). This inequality, prominent in spatial planning, is evident in the size and conditions of public parks around the country (Dayle, 2022; Jeeva & Oosthuizen, 2023). Particularly in Johannesburg, township redevelopment has been on the increase, an attempt to overhaul the status of townships (Alison et al., 2016), buttressed by Hofer et al. (2022) as one of the approaches to addressing past inequality while promoting environmental justice in the city.

To rate the condition of public parks, there is a need for measurement indicators. Premised on literature, such as Dayle (2022), ascertaining a park's condition is based on three criteria of maintenance, management, and safety. Clearly, these indicators are critical for parks to function effectively and attract park users. However, other important factors, such as the presence of sports facilities and support infrastructure, are not captured by Dayle, calling for the exploration of additional literature with more encompassing criteria. Jeeva and Gumbo (2023), in their study that examined the quality of parks and their utilization in three different suburbs of Potchefstroom, South Africa, adopted five criteria as recommended by the Urban Land Institute. These were: park's condition, access to users, park utility, context relevance, and park's flexibility. Primarily, these criteria focus more on users' evaluation of parks than on the physical components of the parks.

This paper streamlined the park assessment criteria to four: infrastructure, amenities, maintenance, and safety, representing a synthesis of Dayle (2022) and the Urban Land Institute criteria (Jeeva & Gumbo, 2023). Crucially, the selection of these four indicators is not merely pragmatic but theoretically justified: infrastructure and amenities correspond to the distributive dimension of EJ (what resources are materially present); maintenance operationalises the procedural dimension (the regularity and quality of state service delivery); and safety captures the recognition dimension (whether the park environment acknowledges the rights and needs of all potential users). This alignment between the EJ framework and the chosen assessment indicators provides the theoretical grounding that a purely empirical classification system would lack.

3.3 Indicator Weighting: Rationale and Limitations

A key methodological decision in any classification system is whether to apply equal or differential weights to assessment indicators. This study applies equal weighting across the four indicators, consistent with

approaches adopted in comparable multi-criteria park assessment tools in the Global South (Badiu et al., 2016; Zuniga-Teran et al., 2020). The rationale for equal weighting rests on three grounds: first, in the absence of a validated South African benchmark for indicator prioritisation, differential weighting would introduce unverifiable assumptions; second, EJ theory does not privilege any single dimension of justice over others (Schlosberg, 2007); and third, the pilot nature of this study prioritises diagnostic breadth over precision weighting. Nevertheless, it is acknowledged that future iterations of this classification system, informed by community-level priority surveys and expert elicitation, may benefit from applying differential weights. For instance, safety might warrant higher weighting in high-crime urban contexts, while maintenance frequency may be paramount in tropical climates with rapid vegetation degradation. These refinements are identified as a direction for subsequent research.

4 METHODOLOGY

This paper adopts a comparative case study approach that combines observational assessment with quantitative satellite imagery and photographs. The observation covers physical inspection of the selected parks for condition assessment using four indicators of infrastructure, amenities, maintenance, and safety, as curated from the literature (Dayle, 2022; Jeeva & Gumbo, 2023). Infrastructure assessment focuses on the structure of the parks, such as the fencing, restrooms, etc. Amenities cover all recreational facilities available for people, maintenance explores the extent to which maintenance staff frequent the facility for repair, cleaning, and upgrading, while safety is on the protection provided for both people and facilities in the park. Satellite imagery and photographs are used to analyze the vegetation density differences, the surrounding neighbourhood, and infrastructure visibility.

4.1 Park Selection

In the selection of the parks, the researcher, in collaboration with two research assistants, visited four parks in each of the seven regions (A-G) in the city of Johannesburg. The parks' conditions were assessed using the four criteria mentioned above to group the parks into well-maintained (depicted in green), fairly maintained (orange), and vandalized (red) categories. From the assessment, three parks were purposively selected out of the 28 parks surveyed across 7 regions, with each from the three categories, to enable adequate coverage of the varied demographic and socio-economic factors that characterized the city. The parks selected for this study are shown in Table 1 and Figure 1.

S/N	Parks	Location	Demographic Features
1	James & Ethel Gray Park	Birdhaven, south of Melrose Arch	Affluent suburb, occupied by elites.
2	Doris Park	Yeoville, inner-city neighbourhood	Mixed nationalities and economic classes.
3	End Street North Park	Central Business District (CBD)	Residential/business area; exposed to informal recyclers and homeless persons.

Table 1: Selected Parks and their Demographics. Source: Researcher's compilation.



Figure 1: A Map of Johannesburg showing the three Parks adopted in this paper. Source: Captured by the Researcher using Google Earth Pro.

4.2 Assessment Procedure and Inter-rater Reliability

In the assessment of these parks, the researcher and his two assistants assessed the parks independently but simultaneously. Each of the assessors scored the parks on the initial indicators using a 0–5 point scale.

Table 2 presents inter-rater reliability results for James & Ethel Gray Park as a representative example. Discrepancies within 1 point are considered as agreement, indicating a 100% agreement rate. Photographic documentation supported the resolution of discrepancies by providing objective evidence of park conditions. Similar agreement patterns were observed across all three parks. Using the criterion of 'within 1 point' as agreement on the 5-point scale, the three assessors achieved 100% agreement across all four indicators for all three parks, demonstrating strong consistency in the application of assessment criteria.

Indicator	Assessor 1	Assessor 2	Assessor 3	Agreement?
Infrastructure	5	5	4	Partial (2 of 3 agree)
Amenities	5	5	5	Complete (3 of 3 agree)
Maintenance	4	5	4	Partial (2 of 3 agree)
Safety	5	4	5	Partial (2 of 3 agree)

Table 2: Inter-rater Reliability Test Result. Source: Researcher's compilation.

To further assess the reliability of the classification system beyond observer agreement, the categories adopted in this study (well-maintained, fairly maintained, and vandalized) were compared against the Green Flag Award criteria, an internationally recognised benchmark for park quality standards (Keep Britain Tidy, 2023) and the Trust for Public Land's ParkScore framework (TPL, 2023). While these external benchmarks were developed in different national contexts, the overlap in their core dimensions (physical condition, amenity provision, safety, and maintenance regularity) with the four indicators used in this study provides a degree of external criterion validity. James & Ethel Gray Park's profile (extensive infrastructure, high amenity provision, regular maintenance, secure environment) aligns with Green Flag's 'excellent' category; End Street North Park corresponds to a 'satisfactory' rating; and Doris Park's profile reflects conditions associated with 'substandard' or failing assessments in both frameworks. This external alignment strengthens the construct validity of the classification system developed here, even as formal cross-national validation remains a limitation and a direction for future work.

4.3 Satellite Imagery Analysis

In addition, satellite images and photographs of the parks were also taken to further authenticate the assessments. To capture the aerial perspective of the parks, the study adopted Google Earth Pro, while the researchers used their mobile phones to take pictures of notable areas in the parks. High-resolution imagery of the parks was taken in November 2025 to assess the parks' boundary, vegetation, infrastructure visibility, neighborhood context, and encroachment and degradation indicators. The images were taken at an interval of a day to ensure consistency in vegetation and terrain appearance.

5 FINDINGS AND DISCUSSION

The findings of this paper comprise field observations, satellite images, and photographic assessments of the selected parks in the city of Johannesburg.

5.1 James & Ethel Gray Park

In this park, all assessors found that the park infrastructure was adequate, and the recreation amenities included facilities suitable for kids and adults. The park surroundings are also clean and well-fenced to safeguard both the property and the lives of the park users. Evidently, in Figure 2, the park is situated in a well-organized residential community with lush green vegetation. This finding shows that this park meets the four criteria (i.e., infrastructure, amenities, maintenance, and safety) adopted in the assessment. The researchers also noticed an indication of community partnership with municipal officials in the maintenance of the parks through the establishment of the James and Ethel Gray Park Foundation (https://jamesandethelgrayparkfoundation.org/), where people are encouraged to support the maintenance of the park with donations.



Figure 2: An Aerial view of James & Ethel Gray Park and its neighbourhood. Source: Captured by the Researcher using Google Earth Pro.



Figure 3: A Cross Section of the Scenery at the James & Ethel Gray Park.

The assessment of satellite imagery in Figure 2 showed that the park occupies an area of about 467,819m², making it one of the biggest parks in the city. This wide area enables the park to incorporate many recreational sports, such as golf, long tennis courts, etc. Furthermore, the image showed significant vegetation coverage, creating lushness not only in the parks, but also in the neighbourhood. Vegetation health assessment from satellite imagery showed vibrant green coloration across the park, indicating healthy, well-irrigated vegetation with tree canopy coverage exceeding 40% of the park area. In complementing these, images combined in Figure 3 showed available facilities for enhancing the comfort of the park users, such as car parking, clear boundaries, and without any indication of encroachment.

The combination of the researchers' assessment and satellite imagery evaluation positioned the James & Ethel Gray Park as a well-maintained park, serving park users effectively. Interpreted through the EJ framework, this park exemplifies the distributive justice dimension: it benefits from both municipal investment and private community capital (via the foundation), producing a compounding advantage for an already affluent area. This pattern aligns with Venter et al.'s (2020) 'Green Apartheid' thesis, whereby historical inequalities are reproduced through differential access to both public and private environmental resources. The park's profile thus illustrates how structural privilege is materially encoded in urban green space.

5.2 End Street North Park

This park is located at the centre of the city where residential and business buildings intersect, as shown in Figure 4. In the assessment of the park, it was found that the location of the park exposes it to encroachment from homeless people, who lodged around the perimeter of the park, despite it being well-fenced. Within the perimeter of the park, no significant infrastructure was noticed aside from the adjoining buildings that looked like municipal office buildings sharing space with the park; however, about four recreational facilities were seen, mainly for kids. Despite the encroachment, the park environment is well-maintained without any

visible graffiti or damage. This cleanliness is assumed to be due to the location of the park in the city centre, where its status can be easily noticed and thus poses a likely damage to the reputation of the city.

Given its location, adequate parking spaces are lacking, and the available spaces have been encroached by Taxis that have adopted the space (see Figure 6) as an informal park station. This limits the extent of the safety of cars belonging to park users. Going by the adopted indicators, the End Street North Park is limited in infrastructure, recreation amenities, and safety, even though it is well-maintained. It is because of these observations that the park is categorized as fairly maintained.



Figure 4: An Aerial view of End Street North Park, and its neighbourhood. Source: Captured by the Researcher using Google Earth Pro.



Figure 5: A close look at the End Street North Park.

The satellite image showed that the park occupies a relatively small land area of 14,366m², and within this space, two municipal buildings are positioned on either side of the park. From a spatial justice perspective, this park's condition demonstrates what Buchholz (2011) identifies as 'unjust geographies': the park is maintained for reputation rather than residents' welfare, representing a form of procedural injustice where maintenance decisions are driven by the municipality's image management rather than the recreational needs of the surrounding community. This performative maintenance, cleaning for visibility rather than function, illustrates a superficial compliance with EJ distributive norms that masks procedural and recognition failures.

5.3 Doris Park

Doris Park is in Barnato Street of Yeoville, an inner city in Region F, and is characterized by diversity, with residents from multiple nationalities. This disparity, coupled with the economic status of most residents, created a kind of urban slum around the park (see Figure 7). Informal recyclers and homeless people clustered around the dilapidated park facilities. As shown in Figure 8, the basketball court is in shambles, and the surrounding area is littered with makeshift bedding belonging to the homeless, recycled items, indications of fecal contamination, and evidence of waste burning. Furthermore, the park is used as a commercial hub where people display and sell wares, such as clothes, electrical appliances, and related accessories. The park lacks perimeter fencing or any form of infrastructure or protection. Available facilities were open spaces for people to play football and basketball, away from the damaged court.



Figure 6: A Cross Section of the End Street North Park Scenery.

This park failed to attain any of the assessment indicators. Clearly, there is nothing that warrants maintaining at the park; rather, it requires a complete reconstruction. Lastly, the park environment is unsafe, given the concentration of informal economic activities and visible environmental contamination.



Figure 7: An Aerial view of Doris Park in its neighbourhood.



Figure 8: A Cross Section of the Scenery at the Doris Park, Johannesburg.

An assessment of the satellite image indicated that the park occupies 12,636m² of land. It is in a low-income neighbourhood, populated mostly by foreigners. The community streets were littered with waste, dilapidated houses, and evidence of street dwellings. Satellite imagery shows vegetation present, but with irregular distribution and evidence of stress. This pattern resonates with Shackleton and Gwedla's (2021) observation that vegetation stress is disproportionately concentrated in historically disadvantaged neighbourhoods, a legacy of apartheid-era green infrastructure underprovision. The Doris Park case represents the most severe expression of recognition injustice: the community's needs are rendered invisible by municipal governance, and the park's informal appropriation by vulnerable populations is a symptom of deeper spatial exclusion rather than community agency. Addressing conditions at Doris Park therefore requires more than physical

reconstruction; it necessitates recognition of the social drivers of the park's current state within broader equity-oriented urban governance reform.

5.4 Comparative Spatial Analysis from Satellite Imagery

The analysis of the satellite and photograph imagery revealed four distinct spatial patterns among the observed cases. These patterns are interpreted below not merely as descriptive contrasts, but as evidence of structurally produced spatial injustice across the EJ dimensions identified in the theoretical framework.

5.4.1 Park Size and Green Space

Based on measurements, the James & Ethel Gray Park (467,819m²) has the largest land area, which is 32 times that of End Street North Park (14,366m²) and 37 times that of Doris Park (12,636m²). This imbalance in land allocation for parks shows the level of spatial injustice that characterized South Africa (Shackleton & Gwedla, 2021), as buttressed by Alison et al. (2016) and Hofer et al. (2022), a problem that has continued to raise classism among South Africans.

The magnitude of this size disparity itself is analytically significant. Park size directly determines the type and diversity of recreational amenities that can be provided (Badiu et al., 2016), meaning that smaller parks in lower-income areas are structurally constrained in their capacity to meet community recreational needs regardless of maintenance quality. This creates a compounding disadvantage: communities in greatest need of public recreational space, because they lack private alternatives (Venter et al., 2020), and are allocated the smallest public spaces, reproducing rather than compensating for private resource inequality.

5.4.2 Boundary Definition and Encroachment

Across the observed parks, satellite imagery indicated that James & Ethel Gray Park has a clear boundary demarcation, devoid of encroachment. One observed factor preventing encroachment is the layers of security, such as gates manned by security men and several security cameras, created around the community. In the submission of Alison et al. (2016), communities such as this are referred to as 'gated communities,' an eclosed living space with distinct spatial control. Similarly, evidence of a defined boundary is also reflected at the End Street North Park, although with indications of vehicle encroachment in the parking areas. As for the Doris Park, there are no discernible boundaries in aerial view, with informal structures and activities extending into park space.

Boundary clarity is not merely an aesthetic or administrative concern; it is a marker of institutional commitment to park protection. The absence of boundary definition at Doris Park signals municipal disinvestment and corresponds to the lowest score on the infrastructure indicator in this study. This aligns with Shackleton and Njwaxu's (2021) finding that the absence of institutional boundary-setting is a primary driver of park degradation in under-resourced communities.

5.4.3 Surrounding Context

An assessment of the aerial view of the satellite imagery reveals stark differences in neighborhood structure and organization. James & Ethel Gray Park integrates seamlessly into a low-density, planned suburban fabric with spacious properties and tree-lined streets. End Street North occupies a small pocket of the high-density commercial and residential development. Doris Park is situated in an informally developed, high-density neighborhood characterized by irregular building patterns and minimal green space beyond the park itself. This analysis indicated a strong connection between community status and public facility management, a submission in alignment with the conclusions of Alison et al. (2016) and Jeeva and Gumbo (2023).

Surrounding context is not independent of park condition but co-constitutive of it. Following Buchholz's (2011) framework, the spatial organisation of the neighbourhood, itself a product of apartheid planning, determines the resources, social capital, and governance attention that flow to the park. This co-constitutive relationship means that park improvement strategies that treat parks in isolation from their surrounding socio-spatial context are likely to have limited and unsustainable impact.

5.4.4 Infrastructure Visibility

The satellite imagery positioned James & Ethel Gray Park as the most furnished, with multiple visible recreational facilities, such as sports courts, pathways, and parking areas. At the End Street North Park,

infrastructure and sports facilities are limited, while Doris Park has no visible formal infrastructure, aside from the open space with collapsing facilities.

To adequately present a clear comparison among the selected parks, a summary table is prepared as follows:

Assessment Indicators	James & Ethel Gray Park	End Street North Park	Doris Park
Park Area (m²)	467,819	14,366	12,636
Location Context	Affluent suburb	Central Business District	Diverse, mixed-income area
Infrastructure Quality	Adequate infrastructure; well-fenced perimeter; secure boundaries.	Limited infrastructure; shares location with municipal buildings; well-fenced but compromised by encroachment.	No perimeter fencing; no protective infrastructure; completely overrun and exposed.
Recreational Amenities	Extensive facilities for children & adults	Limited amenities for children only	No functional facilities; damaged basketball court; only open spaces available
Maintenance Indicators	Clean surroundings, lush green vegetation; regular upkeep evident	Well-maintained environment; no visible graffiti or damage	No maintenance evident; complete reconstruction needed
Safety Features	Secure fencing, safe for users and property; organized residential setting	Limited parking safety; taxi encroachment; homeless presence around perimeter	Unsafe environment; homeless clustering; visible contamination; open drug/commercial activities.
Community Engagement	Active partnership: James and Ethel Gray Park Foundation; donation-supported maintenance	Not observed	No community organization engagement; park repurposed for informal commerce.
Environmental Condition	Pristine; well-organized; significant lush vegetation, integrated with affluent neighborhood landscape	Clean despite location challenges; maintained to protect the city center image	Littered with makeshift bedding, recycled items, waste-burning evidence, fecal matter
EJ Dimension (Primary)	Distributive + Procedural + Recognition (all dimensions met)	Partial Procedural (maintenance only; distributive & recognition deficits)	All EJ dimensions absent; complete spatial injustice
Overall Assessment Score	Meets all 4 criteria (infrastructure, amenities, maintenance, safety)	Meets 1 of 4 criteria (maintenance only)	Meets 0 of 4 criteria; requires complete reconstruction

Table 3: Comparative Assessment of Key Indicators Across Three Parks. Source: Researcher's compilation.

Evidently, from the comparative assessment, there exists a connection between demographic features of communities and the conditions of public parks therein, a conclusion like that of Dayle (2022) and Hofer et al. (2022). Interpreted through the EJ and Spatial Justice frameworks introduced above, these differences are not incidental but structurally produced: they reflect the cumulative advantage accruing to historically privileged communities and the cumulative disadvantage concentrated in historically marginalised ones. As Venter et al. (2020) argue, such patterns constitute 'Green Apartheid,' wherein the material landscape of urban green infrastructure continues to reproduce the spatial logics of the apartheid era long after its formal abolition.

Furthermore, the observed park size disparity reflects the legacy of apartheid in disproportionate land allocation that favours elite settlements (Khanyile & Fatti, 2022; Shackleton & Gwedla, 2021). These findings align with the submission of Venter et al. (2020), who posited that high-end communities enjoy both private and public facilities, leaving low-end communities with only public facilities, often overwhelmed by excessive use due to high population density.

6 CONCLUSION

The conditions of public parks in Johannesburg and similar contexts have continued to reflect the socio-economic realities of their neighbourhood. This trend, as found in the adopted case study, exposes the spatial injustice that has characterized resource and facility allocation right from apartheid South Africa. Even though apartheid has been formally abolished, its legacy still reflects in the size and condition of parks. Addressing this trend goes beyond park upgrading; it requires that economic inequity be addressed to enable communities to contribute to public infrastructure management.

The assessment framework developed in this study, grounded theoretically in Environmental Justice and Spatial Justice frameworks, and operationalised through four empirically derived indicators (infrastructure, amenities, maintenance, and safety), offers a replicable tool for systematic park condition assessment in South African cities. The application of equal indicator weighting in this pilot study is justified by the absence of validated local benchmarks and the breadth-first aims of a pilot assessment; future studies should explore differential weighting informed by community priority surveys and expert consultation. Furthermore, the partial external validity demonstrated through alignment with Green Flag Award and ParkScore criteria should be extended through formal cross-national comparative validation.

In addition, there is a connection between the parks' condition and usage. This is because people are attracted to parks that offer safety and multiple recreational facilities and avoid those considered unsafe and devoid of necessary facilities. Governments, in addition to addressing systemic inequality, need to encourage community stakeholders' participation in park management, especially in informal contexts. This could reduce park vandalism, as the community would serve as a watchdog for the government.

This study's three-park pilot, while limited in scale, provides a validated foundation for a systematic city-wide assessment of Johannesburg's 2000+ public parks. Future research should expand the sample to achieve statistical power sufficient for regression-based analysis of the relationship between neighbourhood socio-economic characteristics and park quality scores, moving from the observational contrasts documented here to inferential analysis. This would strengthen the evidence base for equity-targeted park investment policy in South African municipalities.

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reviewed paper

Media Narratives and the Case for Accelerated Digital Transformation in City of Johannesburg (2022-25)

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1 ABSTRACT

The City of Johannesburg (CoJ) continues to position digital transformation as a central pillar of its shift toward smart urban management, with platforms such as Joburg Connect, the e-Joburg Portal, and the My Smart City App intended to modernise service reporting, spatial data management, and administrative coordination. Yet media reporting from 2022–2025 paints a picture of severe governance instability, deteriorating infrastructure, and persistent service failures, raising critical questions about the role digital systems can realistically play in stabilising a fragmented metropolitan region. Drawing on Digital Media Content Analysis of major South African media outlets, this study examines how service delivery narratives construct public perceptions of municipal capacity and identifies the governance gaps that digital systems could potentially address.

Media accounts consistently portray Johannesburg as experiencing chronic infrastructure failures, leadership volatility, and weak institutional coherence. These narratives reveal that service failures are often exacerbated by slow information flows, poor interdepartmental coordination, fragmented reporting mechanisms, and an absence of real-time operational data, precisely the areas where digital service delivery tools have the greatest transformative potential. Rather than viewing digitalisation as a superficial "digital band-aid," the media evidence suggests that more comprehensive adoption of integrated digital systems could strengthen early detection of service failures, improve cross-regional coordination, and allow planners to make more evidence-driven decisions.

The study argues that Johannesburg's governance crisis demonstrates not the limits of digital transformation, but the urgency of accelerating it. Effective metropolitan management will require the expansion of interoperable digital platforms, citywide data governance standards, and unified reporting frameworks capable of producing equitable, real-time insights. Strengthening digital adoption is therefore essential for rebuilding institutional capacity, restoring citizen trust, and improving the responsiveness of regional planning systems.

Keywords: Digital governance, Smart urban management , Digital service delivery tools, Madia narratives, City of Johannesburg

2 INTRODUCTION

The increasing use of digital technology in cities across the globe is becoming an essential component of urban government, providing citizens with streamlined access to municipal services and increased opportunities to participate in their local government. The development of the 'smart city' concept has driven a major shift in how municipalities govern their cities and provide services to citizens, through the integration of digital technologies into solutions for complex urban problems (Fernandez-Anez et al., 2018; Lytras et al., 2018).

Johannesburg, the largest metropolitan municipality in South Africa, has established a "Smart City" vision, which reflects the current international trends toward automation, using data to inform decisions, and delivering services electronically (Netshirando, Munyoka, & Kadyamatimba, 2024; City of Johannesburg, 2021).

In the last ten years, Johannesburg has launched numerous digital platforms to increase the efficiency of its municipal operations and to engage citizens. Some of these digital platforms are the e-Joburg portal to pay bills online, the Joburg Connect application to interact with customers, the My Smart City mobile app to report faults, geographic information systems to create and manage maps based on geographic information, and cloud-based administrative systems (City of Johannesburg, 2022). These are part of a larger initiative by South Africa to transform digitally, supported at the national level by policies and frameworks like the

National e-Government Strategy (2017), the National Integrated ICT Policy (2016), t he SA Connect Broadband Policy (2013) and updated versions of the Protection of Personal Information Act (POPIA) legislation regarding the collection, storage and usage of personal information (Government of South Africa, 2025; DPSA, 2021).

Despite significant advances in technology and other forms of innovation, the performance of service delivery for residents of Johannesburg continues to deteriorate, as evidenced by repeated failures of city infrastructure, disruptions to the water supply system, continued power outages, a complete collapse of the city's waste management systems, and overall urban decay. Leadership instability is another issue hounding the city of Johannesburg, where there have been nine mayors in the last eight years, creating an environment that does not allow for effective and continuous governance (Masiya, 2022; The Star, 2024). Reporting on the crisis of public trust and frustration in the form of protests and failed governance at all levels of service delivery in 2022-2025 through the media demonstrates a broad level of public dissatisfaction.

3 PRELIMINARY LITERATURE REVIEW

3.1 Smart Governance and Urban Digitalisation

Digital governance is one of the most important aspects of urban transformations for all cities globally and for cities both in the developed and developing world. The smart city agenda has been gaining momentum globally as cities are looking to use digital technologies to improve the way they govern locally with improved efficiency, increased transparency, and greater inclusion in the participatory processes of local governance (Lytras et al., 2018; Meijer & Bolívar, 2016). At its heart, smart governance represents the idea that digital technologies will improve public administrations, citizen involvement, and provide evidence-based decision-making through data analysis (Connolly & Bannister, 2012). Examples of cities that have established themselves as model smart city environments include Barcelona, Singapore and Tallinn, and these cities represent highly advanced smart city environments where digitalization is incorporated into transport, energy, planning, citizen reporting, and administrative functions (Espinosa & Pino, 2024; Bakıcı, Almirall, & Wareham, 2013). These examples demonstrate that while technology is necessary for digital transformation, it is also dependent upon governance stability, institutional capacity and coherent strategic leadership.

3.2 Digital transformation in the Global South

Digital Transformation in the Global South is quite a different picture. While there is increasing enthusiasm for Information and Communications Technology (ICT) -based governance models globally, numerous municipalities in Africa are finding it challenging to acquire the fundamental resources required to be able to implement and sustain e-government systems, which include reliable electrical power, robust physical infrastructure, affordable Internet access, and adequate governmental administrative capacity (Shava & Vyas-Doorgapersad, 2025; United Nations, 2022). In South Africa, municipalities face countless structural issues that continue to impede the development of their technical capabilities, including outdated municipal infrastructure, significant operational deficits, severe shortage of skilled personnel, and unequal distribution of access to technology. These systemic deficiencies exacerbate the digital divide, resulting in poor access to data, digital tools, and digital knowledge among low-income communities who are frequently unable to afford the necessary technologies or obtain the necessary education to use them effectively. Therefore, unless the root causes of inequality are addressed through digitalization, it will inadvertently perpetuate exclusion rather than create a more inclusive civic environment

3.3 Johannesburg's Digitalisation Journey

While numerous studies have identified the many technical and infrastructural barriers to digital transformation in developing cities, other barriers are also significant, namely, political instability, poor governance and accountability, and the fragmented nature of governance itself. Scholars note that successful digital initiatives require long-term strategic coordination, stable political backing, and reliable implementation (Netshirando, Munyoka, & Kadyamatimba, 2024; Munyoka & Maharaj, 2019). In many instances, such efforts will be derailed due to changes in government, and therefore, leadership, or a shift in priorities by municipalities, resulting in systems being only partially implemented, abandoned digital projects, and a general waste of digital investment (Netshirando et al., 2024). For example, as a result of

coalition instability, there have been numerous changes in executive leadership in Johannesburg since 2007, which has caused an unstable environment in providing an improved strategic vision, and thus undermined institutional memory and coordination (Masiya, 2022). Smart governance theory notes that technology alone cannot overcome the deficiencies associated with poorly functioning institutions of governance; therefore, a strong institutional base of administration, a predictable political environment, and coordinated service delivery systems must exist before technology may be successfully integrated into governance (Meijer & Bolívar, 2016; OECD, 2020).

3.4 Governance structure of the City of Johannesburg

Johannesburg is South Africa's largest metropolitan municipality and is an intricate urban system that provides the majority of South Africa's economy, politics, and culture. It has over 4,8 million people residing within its borders (Stats SA, 2022) and is governed using a decentralized and multi-layered system intended to address the size and diversity of Johannesburg's urban service delivery. A clear understanding of this structure is critical to understand the city's digital transformation trajectory because the administrative capability, institutional configuration, and political arrangement will influence how digital and non-digital services are developed, delivered, and experienced by residents.

Johannesburg has adopted a decentralized regional model that includes seven administrative regions (A-G) that are designed to place the provision of municipal government closer to community members, while at the same time ensuring that the development of each region remains aligned with the overall city-wide development priorities outlined in the Local Integrated Development Plans (LIDPs) (City of Johannesburg, 2022). In this model, each of the seven administrative regions addresses the socio-economic conditions specific to each area (e.g., Sandton, Alexandra, Diepsloot, Soweto, and Orange Farm) that reflect the unique needs of each area, and ensure that service delivery addresses spatial inequality and varying levels of development.

The decentralized regional model is further supported by a network of Municipal-Owned-Entities (MOEs) that provide a number of key municipal services. Examples of these entities include; City Power, Johannesburg Water, Pikitup, Johannesburg Roads Agency (JRA), City Parks, Metrobus, and the Johannesburg Zoo. All of these MOEs are required to function on a business basis and achieve financial sustainability while providing their mandated public service. The creation of the MOE structure was intended to create efficiencies in service delivery and to create professionalism in the delivery of public services; however, the use of a network of separate, autonomous MOEs creates significant coordination challenges that can impact the deployment of digital technologies.

Administrative activities are centred at the Metro Centre in Braamfontein. It is home to the offices of the City Manager, and all other administrative departments; and is therefore where the City Manager, who heads up all the various departmental areas of responsibility, including emergency services, public safety, libraries, heritage management, spatial planning, land use regulations, and traffic control, is located (City of Johannesburg, 2022). Johannesburg has also developed a number of sophisticated administrative systems in recent times, one example being the Land Information System (LIS), a fully digital platform that brings together data on properties, land uses, payment history, and ownership details to provide a level of transparency and enable the development of data-driven planning processes. The appointment of a Chief Information Officer (CIO) further demonstrates the city's determination to formalise its digital governance structure and ensure that it complies with national data management and access to information laws.

In terms of political administration, Johannesburg is governed via the mayor-council model of government as established by the Municipal Structures Act (Act No 117 of 1998). The legislative component of the government comprises a 270-member city council consisting of 135 ward councillors elected from each of the wards of the municipality, and 135 proportional representation (PR) councillors. These members of the city council are responsible for making bylaws, approving the annual budget, and ensuring that the executive branch of government provides adequate oversight and accountability (City of Johannesburg, 2022). The executive component of the government is headed by an Executive Mayor, who is supported by the Mayoral Committee. The role of the Executive Mayor and the Mayoral Committee is to lead the direction of the municipality's policy agenda, provide oversight and direction of the service delivery process, and provide strategic leadership to achieve the municipality's long-term objectives. The administrative function of the government is provided by the City Manager, who is responsible for implementing the policies of the

municipality and providing coordination and oversight functions for the provision of services by the various departments and branches of the municipality. This layering of the three components of the local government model is theoretically designed to provide a balance between the legislative oversight of the executive, the policy direction of the executive and the implementation of those policies through the administrative function. However, the political environment within Johannesburg has historically been unstable and subject to changes in coalitions and leadership, resulting in no single political party winning sufficient support in any of the municipal elections held since 2000 to form a stable government.

The instability of the mayoral office due to coalition governance has caused the City of Johannesburg's political structure to be in a state of constant flux. As a result, the City of Johannesburg has implemented reform intended to create accountability within the institutions and streamline communication channels; for instance, it now allows regional directors to report directly to executive directors and not through several layers of bureaucracy. However, despite these attempts at centralization, fragmentation remains a persistent problem that can disrupt long term planning and continue to hinder the ability of departments to provide continuity for their digital transformation projects. The Citizen Relationship and Urban Management (CRUM) initiative, has been identified as an important administrative innovation which is aimed at improving how local government responds to citizens' needs at the front line, by sending multidisciplinary teams to deal with problems such as unauthorized electrical connections, litter and the destruction of public works (City of Johannesburg, 2022). Although, the CRUM represents a step towards decentralizing citizen responsiveness and toward enabling participatory urban management, ultimately its success will depend on a number of governing factors beyond the control of the initiative itself, for instance, lack of funding, high staff turnover rates and poor interdepartmental coordination.

The total governance of Johannesburg depicts an institutionally complex city that has political instability and a mixed governance model of corporate service delivery. This type of governance will affect how well the city is able to deliver effective digital solutions. The city's governance structure includes the appropriate institutional architecture to create the conditions for smart governance (decentralization, the presence of a dedicated MOE, developing data-based administrative tools), but the operational realities of governance include fragmented decision-making authority, variable institutional capacity, and unstable policies. Therefore, the city's digital development strategy is directly connected to its governance coordination, administrative efficiency, and political stability. An understanding of the governance system of Johannesburg creates important background for understanding the constraints, problems, and contested perspectives described in the media stories examined in this research study.

3.5 Media, Governance, and Public Perception

The media has an important role in this governance environment – it is not only a source of information but also helps set agendas and holds the government accountable. The way the media reports government performance affects the way citizens perceive their government's performance; magnifies citizen frustration with government; and ultimately determines the level of trust that citizens have in government (Abrahams & Everatt, 2019). Where citizens depend upon media to be informed regarding the operation of local government, the media's portrayal of issues like corruption, poor service delivery and political instability, significantly affect the legitimacy of government action. The media's reporting of digital tools, both positive and negative, significantly contributes to how citizens interpret municipal digitalization efforts. Therefore, the media provides a primary source of evidence through which to assess public sentiment toward smart city initiatives.

3.6 Identified Research Gap

The City of Johannesburg (CoJ) is working to transform digitally as well as to create a smart city, but there have been consistent and wide-ranging reports of serious and ongoing failure of basic services and crippling political instability in the public media. Most existing scholarly research has focused upon the technical and administrative efficiency of digital government, therefore, it has largely ignored the influence that non-technical governance failures can have on the success of digital government. This study addresses this gap by systematically examining how public media narratives report and exaggerate underlying governance crises, and how this reporting of governance crises fundamentally reduces public trust and participation in CoJ's digital initiatives.

4 METHODOLOGY

The study adopts an interpretive qualitative research methodology to evaluate how media stories represent municipal service provision and the ability of local governments to govern the city of Johannesburg. The researcher selected an interpretive qualitative research methodology because it examines how meaning, perception, and institutional capability are socially constructed and conveyed through discourse instead of being seen as objective measures (Denzin & Lincoln, 2018; Creswell & Poth, 2018).

A qualitative content analysis (QCA) method was applied to analyze systematically textual data collected from major South African media sources, which include South African national newspapers and online news sites. In media-governance research, QCA provides an effective means for identifying dominant narratives, patterns of framing, and latent meanings contained in public communication (Braun & Clarke, 2021; Schreier,2016).

Media content produced from 2022-2025 was analyzed during a time when increased service delivery disruption, political instability, and governance issues were evident in the city of Johannesburg. Media items that referred to municipal services and digital systems were sampled for use in this analysis. A combination of deductive and inductive thematic coding methods was used to identify common themes in these samples. The coding scheme was developed based on deductive coding from extant literature on Smart Urban Governance, Digital Transformation and Metropolitan Management (Anthopoulos, 2017; Meijer & Bolívar, 2016; Kitchin et al., 2019) and inductive coding to allow for new themes to be identified as they emerged from engaging iteratively with the sample.

A focus was placed on identifying recurring narrative frames of responsibility and attribution for service delivery failure and governance capacity issues. Additionally, a particular focus was placed on whether digital systems were referenced as tools to monitor and coordinate service delivery, to improve accountability or to undertake institutional reform. Media framing theory was also used as an analytical lens to examine how repeated representations have shaped public views of municipal performance and institutional legitimacy (Matthes, 2017).

As the study utilizes only publically available media sources and does not involve a direct interaction of the researcher with any participant(s), the study represents an extremely low level of ethical risk. The media and document based research has been identified as being exempt from the formal ethical approval requirements in accordance with accepted ethical guidelines to media and document based research (British Sociological Association, 2017) .

5 FINDINGS

The qualitative content analysis was synthesized to identify the most common service delivery narratives as a result of the media scan and group them into key thematic categories based on frequency, intensity and emphasis of the narratives. The themes outlined below represent the issues that have been consistently highlighted within Johannesburg's media coverage from 2022 through 2025; they provide insight into how service delivery challenges, and the use of digital municipal tools, are portrayed across various media outlets. The themes are summarized in the table below, along with an estimate of the number of media outlets reporting on these themes, and the overall focus of their reporting on this theme. The thematic map is intended to empirically support which service delivery failures are the most visible within the public discourse, and highlight the “fragmentation gap” between high level policy objectives and the day-to-day realities of operation in the City of Johannesburg.

Theme	Volume of Media Outputs*	Media Platforms	Representative Narrative Focus
Water & sanitation	High	Print, Online, Broadcast	Prolonged outages, tanker reliance, health risks
Electricity supply	High	Broadcast, Print	Power cuts, infrastructure overload, protests
Governance instability	Medium–High	Print, Online	Leadership turnover, coalition politics
Citizen protest & trust	Medium	Print, Broadcast	Road blockades, service-related protests
Informal settlements	Medium	Investigative, Online	Extreme exclusion, sanitation collapse

Table 1: Dominant Service Delivery Themes in Media Reporting on the City of Johannesburg (2022–2025)

5.1 Scope and Nature of Media Coverage

Following the media scan it has been confirmed that municipal service delivery in the city of Johannesburg, is an extremely high-profile, and continually reported issue throughout Gauteng's large print and broadcast media; both national and regional outlets have frequently covered service delivery issues, government instability, and citizen protests through The Sowetan, The Star, eNCA, SABC News, City Press, and Daily Sun. Given that Gauteng functions as the economic and media center of South Africa, the service delivery issues in Johannesburg receive much greater than proportional national coverage and thus are exposed to significantly higher levels of national scrutiny and shape opinions regarding metropolitan governance.

Reports of this nature are becoming increasingly common, and as such, the overall trend of the service delivery narrative is trending toward a "crisis". The tone of many reports has become critical; citizens feel frustrated, and institutions appear to be failing. The most obvious examples include "residents say they have been forced to fend for themselves due to the continuous collapse of basic services." (The Sowetan, 2024) and "Johannesburg remains a city that struggles to keep the electricity on and the water flowing." (eNCA, 2025) As such, service delivery failures are no longer seen as episodic; rather, they are now viewed as systemic and ongoing.

5.2 Dominant Service Delivery Themes in Media Reporting

5.2.1 Water and Sanitation Failures as a Chronic Urban Crisis

Water supply failures were the leading problem area for the entire duration of this research study. Prolonged water interruptions, water tankers, burst pipes, aging infrastructure, unauthorized connections, and Johannesburg Water's inability to provide a guaranteed supply during peak demand were identified by media reports as major problems. The media consistently depicted long stretches of time (days to weeks) without water, with few explanations from city officials. Residents interviewed by SABC News stated "We have not had water for weeks, and no one from the City tells us when it will be fixed" (SABC News, 2023).

Other media accounts included communities queuing for extended periods at water tankers, which arrived late or not at all (The Star, 2024). These experiences are especially prevalent in township/ informal settlement areas such as Meadowlands, Kanana Extension Four, and Diepkloof, where water shortages intersect with sewage failures, creating serious public health issues. The lack of timely communication and the slow response times from city officials reinforce citizen perceptions of government inefficiency and disengagement.

5.2.2 Electricity Supply Disruptions and Infrastructure Overload

Electricity outages are the second most common theme for the media. While the media's coverage of these issues is frequently framed through the residents' protests in areas like Northriding and Alexandra, the violence against city power employees who attempt to repair the power outages is documented.

An eNCA report cited a resident who stated that "electricity goes off almost every week, and when technicians arrive, they leave without fixing anything" (2024). In addition to this, The Sowetan reported that City Power personnel were “forced to withdraw from an area after coming under attack while responding to an outage” (2023). Former Mayor Kabelo Gwamanda's official comments about the electricity failures frame them as the result of the lack of planning, poor use of existing capacity due to overloading, and poorly coordinated departments, rather than just budgetary constraints. These comments further support the view that the problems caused by electricity failures represent governance failures at the level of planning and departmental coordination.

5.2.3 Governance Instability and Leadership Turnover

Media reports indicate that leadership instability is a common theme of explanation for service delivery failure. Frequent changes in political leadership are repeatedly linked to the poor performance of services by media outlets, which reported on the fact that in Johannesburg alone there have been nine different mayors during the last eight years. In articles it was explained that both short mayoral tenures and coalition-based government create conditions where it is difficult to achieve institutional memory, long-term planning and continuity.

The same political analyst who was interviewed by The Star stated that “every new mayor arrives with a new agenda, leaving incomplete projects and stalled reforms behind” (2024) similarly, IOL referred to Johannesburg as “a city trapped in permanent transition, unable to implement long-term solutions” (2023). Media commentaries regularly relate leadership instability to the lack of progress with respect to the repair of its damaged physical infrastructure, its inability to develop effective accountability mechanisms, and its slow pace of implementation of digital reforms. Therefore, the media portrays leadership instability as a systemic barrier to effective governance and not simply a political issue.

5.3 Citizen Protest, Trust Erosion, and Public Perception

The majority of citizens across all the years expressed their frustration through media reports about protests, which were viewed as reactions to the prolonged lack of services rather than one-off disruptions to services. Media documented protests in areas such as Bruma, Cyrildene, Malvern, Houghton, Diepkloof, and Soweto to be examples of the accumulated dissatisfaction of citizens regarding water, electricity, waste collection, corruption, and unauthorized development.

A protester was quoted by City Press (2024) stating, “we only get attention when we block roads or burn tyres”. This is an example of a common theme of citizens, indicating that formal complaint channels do not work effectively. Survey-based data from Gauteng City Region Observatory Quality of Life Survey has also been used by media to reinforce this view, with media reporting that “more than half of Johannesburg residents remain dissatisfied with municipal services” (Daily Sun, 2023). Media analysis of decreasing public trust is being associated with political uncertainty, erratic and uneven service delivery, and what appears to be corrupt practices.

Informal Settlements as Sites of Extreme Service Exclusion

Media representations depict informal settlements as sites of compound vulnerability, where, in relation to service delivery failures, the impacts are at their most severe. For example, the Kanana Extension Four community was documented by the Wits Vuvuzela in a report on an extreme case of sanitary failure, an absence of electricity supply, and unsafe housing conditions.

A recent report noted, “raw sewage runs openly between shacks, while residents have no access to electricity or refuse removal” (Wits Vuvuzela, 2022). Such media coverage highlights the intersection of service delivery failures with poverty, geographic marginalization, and low levels of institutional presence. Moreover, this media coverage illustrates how informal settlements are largely unaccounted for within formal data collection/monitoring/reporting systems, which serves to support notions of unequal data visibility and 'governance blindspots'.

5.4 Implications for Digital Governance and Planning Systems

Despite predominantly negative coverage of crises by the media, both media and residents commonly attribute the root cause of breakdowns in the delivery of services to gaps in information, failures in coordination, and slow responses from the government. A common complaint of residents is that “no one tells us what is happening or when services will be restored” (SABC News, 2024). The lack of communication and transparency is an area where digital governance and planning systems can provide significant added value, particularly in terms of real-time monitoring of services, reporting across all municipal-owned entities, enhancing interdepartmental coordination, and facilitating transparent communication with citizens.

Rather than dismissing the potential of digitalisation, the media provides evidence that the crisis in Johannesburg is the result of an uneven or incomplete implementation of digital technology, rather than the technologies themselves being inherently flawed. The indirect support of media narratives for the proposition that accelerated, complete, and inclusive digital systems will be necessary for stabilizing metropolitan governance and regaining the trust of citizens is thus supported.

6 DISCUSSIONS

The conclusions suggest that there are serious limits on how much a city can rely on its digital systems to solve long-standing urban governance problems. With respect to Johannesburg's media coverage in this study, it was shown that, although new digital systems have been put into place, they do so under the same

constraints as were present before their creation. Thus, this supports the critical smart governance literature (Kitchin et al., 2019) and (Meijer & Bolívar, 2016), that, regardless of what digital systems are developed or implemented, technology is unable to compensate for unstable governance, poor coordination among institutions, and poor accountability structures. Thus, the most significant obstacle to effective digital urban management is the level of governance instability and not the amount of technological capability available.

The results show that in addition to this, media coverage does not support the idea of dismissing digitalisation as only a surface-level or symbolic approach. Instead, it is implied by the media narratives that more complete digital systems can produce improvements for service delivery (e.g., via use of real-time data, facilitating cross-agency coordination, and providing early warnings), which would be most effective when digital tool usage are embedded in a consistent set of institutional norms and have the backing of strong, continuous, and relatively stable organizational capacity and leadership.

This research will contribute an innovative empirical view to the "smart governance" literature through media representation, examining how the way media represent digital government development is related to citizen perceptions of the institutions involved, their legitimacy, and the expectations that exist for future development in these areas. It also highlights the need to treat digital reform as a governance reform and not simply a technological reform when service delivery failures persist, and political stability is at issue. Additionally, if significant improvements in coordination, accountability, and responsiveness do not occur as a result of digital reform, then there is a real risk that it may be seen by citizens as simply a symbolic gesture.

7 CONCLUSION

This study investigated how media narratives create public perceptions of service delivery and governmental capacity in the city of Johannesburg, particularly examining the role of digital systems within these media representations. The results show that the service delivery crisis in Johannesburg is largely represented by the media as being due to governance instability, changes in leadership, and institutional fragmentation, rather than failures of technology.

These challenges do not suggest that digital transformation has failed; instead, they are indicative of the need to fast-track digitalisation and simultaneously stabilize institutions. Integrated digital platforms, standardized data governance structures, and harmonized reporting frameworks were identified as key to improving metropolitan responsiveness, increasing accountability, and regenerating citizen trust.

Within a larger research project concerning how citizens view digital local government services, this paper contributes to the debates on smart governance and digitalization of metropolitan areas of the Global South through an emphasis on the role of public debate to legitimate and form expectations of digital reform.

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🏆 reviewed paper

Methoden zur Bewertung erneuerbarer Energiewende-Potenziale im urbanen Gebäudebestand: Analyse-Ergebnisse aus dem Projekt EWV4EnergieWende

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1 ABSTRACT

Der Klimawandel und die aktuelle Energiekrise verstärken bestehende soziale, wirtschaftliche und infrastrukturelle Herausforderungen im urbanen Raum. Der Ausbau erneuerbarer Energien sowie die Etablierung von Erneuerbare-Energie-Gemeinschaften (EEG) gelten als zentrale Hebel zur Reduktion fossiler Energieträger, zur Erhöhung der Energieunabhängigkeit und zur langfristigen Stabilisierung von Energiekosten. Seit Inkrafttreten des Erneuerbaren-Ausbau-Gesetzes (EAG) im Jahr 2021 wurden in Österreich zahlreiche EEGs und Bürgerenergiegemeinschaften (BEG) gegründet. Diese Entwicklung konzentriert sich jedoch bislang überwiegend auf ländliche Räume, während der dicht verbaute urbane Raum weiterhin deutliche Umsetzungsdefizite aufweist. Das neue Elektrizitätswirtschaftsgesetz (ElWG), das im Dezember 2025 im Nationalrat beschlossen wurde und das per Oktober 2026 in Kraft treten wird, verspricht hier relevante Änderungen.

Insbesondere in Mehrparteienhäusern und innerstädtischen Baublöcken erschweren regulatorische Rahmenbedingungen, technische Restriktionen, wirtschaftliche Unsicherheiten sowie soziale und organisationale Faktoren die Umsetzung gemeinschaftlicher Energieprojekte. Interessenskonflikte zwischen Eigentümerinnen, Eigentümern, Nutzerinnen und Nutzern, fehlende kurzfristige wirtschaftliche Anreize, komplexe rechtliche Anforderungen (z. B. Wohnungseigentumsrecht, Denkmalschutz) sowie eine als hoch wahrgenommene technische und organisatorische Komplexität führen zu Zurückhaltung und geringer Akzeptanz. Diese Barrieren treffen insbesondere einkommensschwächere Haushalte und verstärken bestehende Ungleichheiten im Kontext von Energiearmut.

Das hier vorgestellte Projekt „EWV4EnergieWende. Konkrete Beiträge zur urbanen Energiewende am Beispiel der Immobilien des Evangelischen Waisenversorgungsvereins Wien“ (FFG-Projekt Nr. 923352) setzt genau an dieser Schnittstelle an und verfolgt das Ziel, Hemmnisse und Erfolgsfaktoren für den Ausbau erneuerbarer Energien und die Gründung von EEGs im dicht verbauten urbanen Raum systematisch zu identifizieren und darauf aufbauend praxisnahe Lösungsansätze zu entwickeln. Ein besonderer Fokus liegt auf klaren, inklusiven und gendersensiblen Kommunikationsstrategien, die technologische und organisatorische Komplexität reduzieren und den Zugang zu gemeinschaftlichen Energieprojekten erleichtern.

Als empirische Grundlage dienen sieben innerstädtische Bestandsgebäude im Eigentum des Evangelischen Waisenversorgungsvereins Wien (EWV). Für diese Liegenschaften werden Status-quo-Erhebungen, technische und energetische Analysen sowie sozialräumliche Potenzialanalysen durchgeführt. Ergänzend finden strukturierte Stakeholderinnen- und Stakeholdergespräche mit Gebäudenutzerinnen, Gebäudenutzern, Eigentümerinnen, Eigentümern und weiteren relevanten Akteurinnen und Akteuren statt. Auf Basis der erhobenen Daten werden das technische Potenzial für erneuerbare Erzeugungsanlagen, Möglichkeiten zur Bildung von Energiegemeinschaften sowie wirtschaftliche und organisatorische Umsetzungsvarianten untersucht.

Die Ergebnisse münden in einem Maßnahmenkatalog sowie in einem Stufen- und Umsetzungsplan, der konkrete Empfehlungen für einzelne Gebäude und Baublöcke formuliert und sowohl Chancen als auch Risiken transparent darstellt. Das Projekt leistet damit einen Beitrag zur Schließung der Lücke zwischen politischen Zielsetzungen, technologischen Möglichkeiten und tatsächlicher Umsetzung im urbanen Raum. Die gewonnenen Erkenntnisse bieten eine übertragbare Wissensbasis für weitere Projekte und können als

Orientierung für Eigentümerinnen, Eigentümer, Kommunen, Wohnbauträgerinnen und Wohnbauträger dienen, um die Energiewende sozial gerecht, partizipativ und stadtverträglich voranzutreiben.

Keywords: Energiewende, Bestand, Just Transition, Planung, Wandel

2 ENGLISH ABSTRACT

Climate change and the current energy crisis are intensifying existing social, economic and infrastructural challenges in urban areas. The expansion of renewable energy sources as well as the establishment of renewable energy communities (RECs) are considered key levers for reducing the use of fossil energy carriers, increasing energy independence and stabilising energy costs in the long term. Since the Renewable Energy Expansion Act (EAG) came into force in Austria in 2021, numerous RECs and citizen energy communities have been established. However, this development has so far been largely concentrated in rural areas, while densely built urban areas continue to show significant implementation deficits.

In particular, regulatory frameworks, technical restrictions, economic uncertainties as well as social and organisational factors hinder the implementation of collective energy projects in multi party residential buildings and inner city building blocks. Conflicts of interest between property owners and users, a lack of short term economic incentives, complex legal requirements such as condominium law or heritage protection, and a high perceived level of technical and organisational complexity lead to reluctance and low acceptance. These barriers particularly affect low income households and exacerbate existing inequalities in the context of energy poverty. The new Electricity Industry Act (ElWG), which was passed by the National Council in December 2025 and will enter into force in October 2026, promises relevant changes in this area.

The project presented here, “EWV4EnergieWende. Concrete contributions to the urban energy transition using the example of properties owned by the Evangelischer Waisenversorgungsverein Wien” (English translation from the German project title; FFG project no. 923352), addresses this interface directly. Its objective is to systematically identify barriers and success factors for the expansion of renewable energy and the establishment of RECs in densely built urban areas and, on this basis, to develop practical and implementation oriented solutions. A particular focus is placed on clear, inclusive and gender sensitive communication strategies that reduce technological and organisational complexity and facilitate access to collective energy projects.

The empirical basis of the project consists of seven inner city existing buildings owned by the Evangelischer Waisenversorgungsverein Wien (EWV). For these properties, status quo assessments, technical and energy analyses as well as socio spatial potential analyses are conducted. In addition, structured stakeholder interviews with building users, property owners and other relevant actors are carried out. Based on the collected data, the technical potential for renewable energy generation systems, options for forming energy communities, as well as economic and organisational implementation models are analysed.

The results are consolidated into a catalogue of measures and a phased implementation plan that formulates concrete recommendations for individual buildings and building blocks and transparently presents both opportunities and risks. The project thus contributes to closing the gap between political objectives, technological possibilities and actual implementation in urban contexts. The findings provide a transferable knowledge base for further projects and can serve as guidance for property owners, municipalities and housing providers to advance the energy transition in a socially just, participatory and urban compatible manner.

3 HERAUSFORDERUNGEN VON ERNEUERBARE-ENERGIE-GEMEINSCHAFTEN (EEGS) IM URBANEN RAUM

Die Energie- und Klimakrise stellt Städte vor tiefgreifende Transformationsprozesse. Urbane Räume sind einerseits Hauptverursacher energiebedingter Treibhausgasemissionen, andererseits besonders stark von steigenden Energiepreisen, Versorgungsunsicherheiten und sozialen Auswirkungen wie Energiearmut betroffen (Revi et al., 2014). Die europäische und nationale Energie- und Klimapolitik – etwa im Rahmen des European Green Deal – setzt daher verstärkt auf den Ausbau erneuerbarer Energien sowie auf neue Organisationsformen der Energieerzeugung und -nutzung (Europäische Kommission, 2019; Rechtsinformationssystem des Bundes, 2026a). Erneuerbare-Energie-Gemeinschaften (EEG) gelten als vielversprechendes Instrument, um Bürgerinnen und Bürger aktiv in die Energiewende einzubinden,

regionale Wertschöpfung zu stärken und soziale Teilhabe zu fördern (Klima- und Energiefonds, 2023). Das neue Elektrizitätswirtschaftsgesetz (ElWG), das im Dezember 2025 im Nationalrat beschlossen wurde und das per Oktober 2026 in Kraft treten wird, verspricht hier relevante Änderungen. (Rechtsinformationssystem des Bundes, 2026b)

Trotz günstiger rechtlicher Rahmenbedingungen bleibt die Umsetzung im dicht verbauten urbanen Raum bislang deutlich hinter den Erwartungen zurück (Fischer et al., 2024; Klima- und Energiefonds, 2026). Die Gründung und der Betrieb von EEGs in Städten sind durch ein komplexes Zusammenspiel unterschiedlicher Faktoren geprägt (Klima- und Energiefonds, 2023; Taromboli et al., 2025):

- Regulatorische Herausforderungen: Uneinheitliche gesetzliche Vorgaben, rechtliche Unsicherheiten sowie Anforderungen aus Wohn- und Baurecht erschweren die Planung.
- Technische Barrieren: Bestandsgebäude verfügen häufig über veraltete elektrische Infrastruktur, begrenzte Dachflächen oder Einschränkungen durch Denkmalschutz.
- Wirtschaftliche Aspekte: Hohe Investitionskosten, lange Amortisationszeiten und aktuell vergleichsweise günstige Energiepreise reduzieren die Motivation zur Umsetzung.
- Soziale und organisationale Faktoren: Fehlendes Wissen, wahrgenommene Komplexität sowie Interessenskonflikte in Mehrparteienhäusern behindern Entscheidungsprozesse.

Diese Faktoren führen dazu, dass urbane Potenziale für erneuerbare Energien bislang nur unzureichend genutzt werden. Vor diesem Hintergrund stellt das Paper einen methodischen Ansatz zur Bewertung technischer Potenziale sowie zur systematischen Erfassung organisationaler, sozialer und rechtlicher Hemmnisse für EEGs im dicht bebauten urbanen Bestand vor und gibt anhand erster Projektergebnisse einen Einblick in dessen Anwendung.

4 METHODIK UND FALLSTUDIENANSATZ

Als empirische Grundlage der Untersuchung dienen sieben Bestandsgebäude in Wien, die sich im Besitz des Evangelischen Waisenversorgungsvereins (EWV), einer seit über 160 Jahren bestehenden gemeinnützigen, mildtätigen und kirchlichen Vereinigung, befinden. Mit dem EWV steht ein institutioneller Eigentümer zur Verfügung, der die Umsetzung sozial verträglicher Maßnahmen zur Energiewende in seinem Gebäudebestand aktiv verfolgt und dabei auch baublockbezogene Lösungsansätze in Betracht zieht. Bei den untersuchten Objekten handelt es sich überwiegend um gründerzeitliche Bestandsgebäude, deren Baualter spezifische technische und rechtliche Rahmenbedingungen mit sich bringen. Die Gebäude verteilen sich auf mehrere Wiener Gemeindebezirke: Drei Objekte befinden sich im 4. Bezirk (Wohllebengasse 11 und 15 sowie Prinz-Eugen-Straße 42), zwei im 14. Bezirk (Hütteldorfer Straße 123 und Mauerbachstraße 34), eines im 15. Bezirk (Holochergasse 11) und eines im 16. Bezirk (Neulerchenfelder Straße 43). Die Mauerbachstraße 34 im 14. Bezirk stellt einen Sonderfall dar, da sich diese als einzige Liegenschaft im semi-urbanen Raum befindet und freistehend ist. Alle übrigen untersuchten Gebäude sind Teil geschlossener Baublöcke im innerstädtischen, dicht bebauten urbanen Raum. Als Baublock wird hierbei der räumlich zusammenhängende Gebäudekomplex verstanden, der sich aus mehreren, durch Straßenzüge begrenzten Liegenschaften zusammensetzt. Daraus ergeben sich die EWV-Baublöcke Wohllebengasse, Prinz-Eugen-Straße, Hütteldorfer Straße, Holochergasse und Neulerchenfelder Straße.

Methodisch kombiniert werden:

- Technische Bestands- und Potenzialanalysen,
- Erhebung von Energieverbrauchskennzahlen,
- Wirtschaftliche Vergleichsrechnungen,
- Grundbuchsanalysen,
- Qualitative Stakeholderinnen- und Stakeholderinterviews mit Nutzerinnen, Nutzern, Eigentümerinnen, Eigentümern, Expertinnen und Experten.

Dieser Mixed-Methods-Ansatz ermöglicht eine integrierte Betrachtung regulatorischer, technischer, wirtschaftlicher und sozialer Dimensionen, wobei das Projektkonsortium so zusammengestellt ist, dass die hierfür relevanten Fragestellungen integriert bearbeitet und die jeweiligen Expertisen gezielt eingebracht

werden können. So ist die B-NK GmbH mit ihrer ausgewiesenen Erfahrung in sozialnachhaltigen Fragestellungen maßgeblich für die Identifizierung sozialer und organisationaler Hemmnisse verantwortlich und führt sowohl die Grundbuchsanalysen als auch die qualitativen Stakeholderinnen- und Stakeholderinterviews durch. Durch ihre langjährige Tätigkeit in gendersensibler Forschung, Prozessbegleitung sowie in der Entwicklung inklusiver und diversitätssensibler Kommunikationsstrategien trägt die B-NK GmbH wesentlich dazu bei, die im Projekt identifizierten technischen und organisatorischen Anforderungen in verständliche, zielgruppengerechte Ansprache- und Beteiligungskonzepte zu übersetzen.

Die MACH GmbH ist ein Ingenieur- und Beratungsbüro mit Fokus auf erneuerbare Energien und nachhaltige Energiesysteme. Im Projekt bringt die MACH umfassende technische sowie praxisnahe Erfahrung in der Planung und Umsetzung von „Raus aus Öl und Gas“-Konzepten ein – von Photovoltaik, Wärmepumpen und Biomasse bis hin zu integrierten Quartierslösungen. Zu den zentralen Aufgaben zählen die Ausarbeitung technischer Konzepte, Kostenschätzungen, die Entwicklung und Gründung von Energiegemeinschaften sowie Umsetzungs- und Wärmeversorgungskonzepte. Ergänzt wird dies durch fundierte Energieberatung, Berichtserstellung, Präsentationsausarbeitungen sowie die Begleitung von Eigentümerinnen-, Eigentümer-, Stakeholderinnen und Stakeholderprozessen.

Darüber hinaus ist die Gebäudeverwaltung Stieglmayer e.U. als zentrale Schnittstelle zur Praxis in das Projekt eingebunden. Als Verwalterin der EWV-Gebäude stellt sie den direkten Kontakt zu Eigentümerinnen, Eigentümern, Mieterinnen und Mietern her und unterstützt die Erhebung praxisrelevanter Daten. Die Weber Harrer Rechtsanwälte GmbH & Co KG unterstützen das Projekt juristisch und bringen ihre Expertise in rechtlichen Fragestellungen zur Gründung und Umsetzung von EEGs ein.

5 VALUE SCORE ZUR ERFASSUNG DER TECHNISCHEN RAHMENBEDINGUNGEN

Der Ansatz Value Score dient der systematischen Erfassung und Bewertung der technischen Rahmenbedingungen auf Ebene einzelner Gebäude unter Berücksichtigung des räumlichen Kontexts des jeweiligen EWV-Baublocks. Bestandteile des Ansatzes sind die Begehung, die Bestandserfassung sowie die Durchführung der Value-Score-Bewertung. Ziel ist es, unterschiedliche Versorgungsvarianten vergleichbar zu machen und eine fundierte Entscheidungsgrundlage zu schaffen.

5.1 Begehung

Beim Umstieg von fossilen Energien auf erneuerbare Energien in Mehrparteienhäusern bildet eine umfassende Bestandsanalyse die Grundlage. Dabei werden der bauliche Zustand, die bestehende Heiz- und Warmwasserversorgung sowie der Energiebedarf der Wohneinheiten untersucht. Die Begehung bildet den ersten Schritt der technischen Analyse und erfolgt primär auf Ebene des einzelnen Gebäudes. Ergänzend werden erste Einschätzungen zu den räumlichen Voraussetzungen im jeweiligen Baublock, dem sich die EWV-Immobilien befinden, vorgenommen, da gemeinschaftliche Energienutzungen und EEGs einen effizienteren und wirtschaftlicheren Betrieb ermöglichen können. Auf dieser Basis entsteht ein technisch und wirtschaftlich tragfähiges Gesamtkonzept, das Lösungen wie Wärmepumpen, Fernwärme oder hybride Systeme mit Effizienzmaßnahmen kombiniert. Entscheidend für den Projekterfolg ist zudem die frühzeitige Einbindung von Eigentümerinnen, Eigentümern, Verwaltung, Bewohnerinnen und Bewohnern, um Förderungen, Umsetzungsschritte und den langfristigen Betrieb transparent und sozial verträglich zu gestalten.

Nachfolgende Schritte sind bei einer Begehung maßgebend:

- Begutachtung vor Ort
- Erhebung der Versorgungsmöglichkeiten
    - Anlagenbeschreibung
    - Anlagenaufnahmen
- Konzeptionierung der Versorgungsvarianten:
    - Alternativenergien
    - Photovoltaik
- Nähere Betrachtung der möglichen Alternativversorgungsmöglichkeiten

- Möglichkeiten zur Installation von Photovoltaik

5.2 Bestandserfassung

Zu Beginn der Bestandserfassung werden die vorhandenen Unterlagen gesichtet und im Rahmen eines Ortsaugenscheins überprüft sowie mit den tatsächlichen Gegebenheiten abgeglichen. Darauf aufbauend erfolgt die Erhebung möglicher Versorgungsvarianten unter Berücksichtigung der „Raus aus Gas"-Klimaziele. Die in Frage kommenden Systeme werden technisch und wirtschaftlich gegenübergestellt, einschließlich einer Bewertung des Photovoltaikpotenzials sowie der verfügbaren Ressourcen für Wärmepumpensysteme wie Brunnen, Erdwärmesonden oder Eisspeicher. Ergänzend dazu wird eine wirtschaftliche Vergleichsrechnung durchgeführt, in der Fördermöglichkeiten und Variantenvergleiche berücksichtigt werden. Abschließend werden die Ergebnisse zusammengefasst und eine Empfehlung ausgesprochen, sowohl auf wirtschaftlicher Basis als auch mithilfe der eigens entwickelten Mach-Systemmatrix, dem sogenannten Value Score Bewertungssystem. Dieses bewertet die Varianten anhand technischer, ökologischer, sozialer und nutzungsbezogener Kriterien und berücksichtigt zusätzlich Zukunftsfähigkeit sowie regulatorische Rahmenbedingungen.

5.3 Value Score

Die Beurteilung der untersuchten Heizsystemvarianten erfolgt im Rahmen einer 30-jährigen Betrachtung und basiert auf einer Kombination aus wirtschaftlicher Analyse sowie einer qualitativen Mehrkriterienbewertung mittels der MACH-Systemmatrix Value Score. Ziel ist es, sowohl monetäre als auch nicht-monetäre Entscheidungsfaktoren transparent gegenüberzustellen.

Die wirtschaftliche Bewertung erfolgt anhand der Barwertkosten, berechnet nach der dynamischen Wirtschaftlichkeitsrechnung gemäß ÖNORM M 7140. Dabei werden sämtliche investitions-, betriebs- und verbrauchsabhängigen Kosten über den gesamten Betrachtungszeitraum berücksichtigt. Ergänzend werden die Betriebskosten separat ausgewiesen, wobei sowohl verbrauchsgebundene als auch betriebsgebundene Kosten über einen Zeitraum von 30 Jahren einfließen. Diese Darstellung ermöglicht eine differenzierte Analyse zwischen einmaligen Investitionen und laufenden Kostenstrukturen der jeweiligen Systeme.

Parallel zur Kostenbetrachtung erfolgt die qualitative Bewertung der Varianten mittels der Systemmatrix MACH Value Score. Diese Bewertung basiert auf einer systematischen Gegenüberstellung technischer Kriterien, ökologischer Auswirkungen, sozialer und nutzungsbezogener Aspekte sowie der Zukunftsfähigkeit unter Berücksichtigung regulatorischer Rahmenbedingungen. Jede Kategorie ist mit klar definierten Einzelkriterien hinterlegt und wird anhand eines einheitlichen Punktesystems bewertet.

Pro Bewertungskategorie können maximal 100 Punkte erreicht werden. Die Value Score ergibt sich aus der Summe aller Einzelbewertungen und stellt einen aggregierten Kennwert zur gesamtheitlichen Beurteilung der Systeme dar. Je höher die Value Score, desto besser schneidet die jeweilige Variante in der integrierten Betrachtung aus Wirtschaftlichkeit, Nachhaltigkeit und Zukunftstauglichkeit ab.

Exemplarische Ergebnisse der Kostenanalyse und der Value-Score-Bewertung werden in Abbildung 1 gemeinsam dargestellt und ermöglichen einen transparenten Vergleich der untersuchten Heizsysteme sowie eine fundierte Entscheidungsgrundlage.

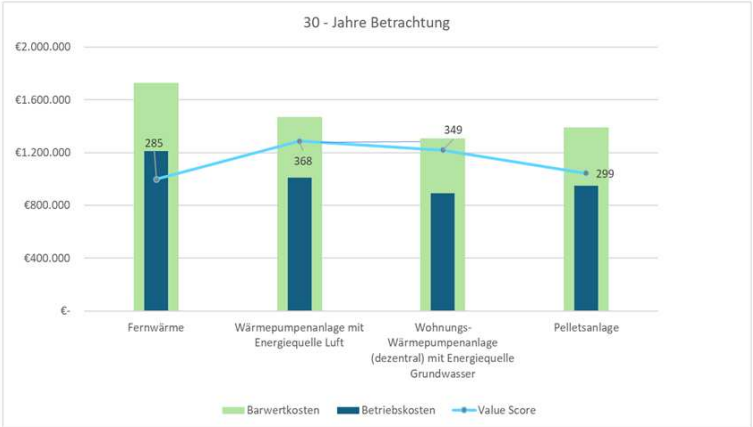


Abbildung 1: MACH – Value Score exemplarisch (MACH Energiegesellschaft GmbH 2025)

Abbildung 2 zeigt exemplarisch die 30-jährige Betrachtung der untersuchten Versorgungsvarianten auf Basis der Value Score für Fernwärme, Wärmepumpen (WP) mit den Energiequellen Luft und Wasser sowie Pelletsanlagen und stellt die jeweiligen Bewertungen der einzelnen Dimensionen der Value Score dar.

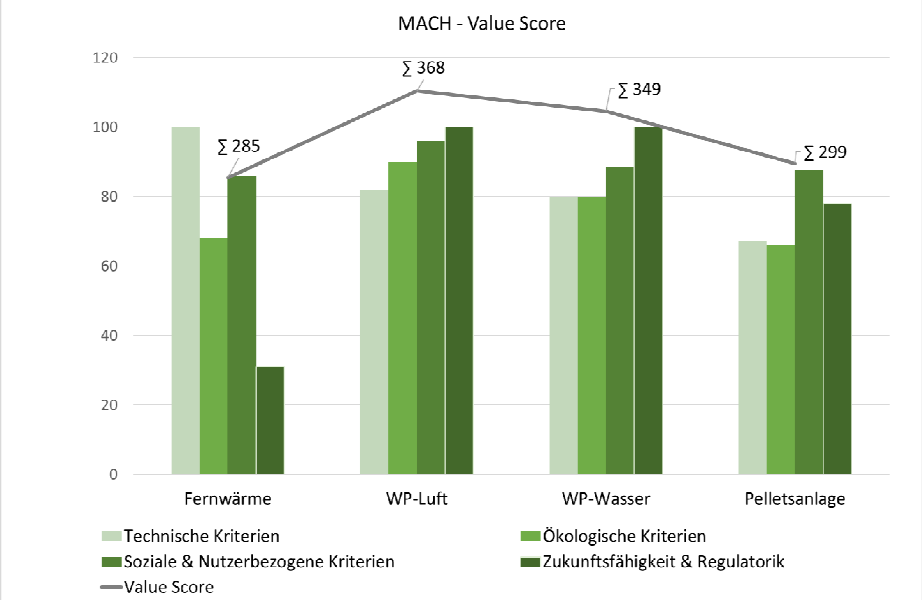


Abbildung 2: 30 – Jahre Betrachtung innerhalb der MACH – Value Score exemplarisch (MACH Energiegesellschaft GmbH 2025)

6 ANSATZ ZUR ERFASSUNG ORGANISATIONALER UND SOZIALER RAHMENBEDINGUNGEN

Neben der Analyse der technischen Rahmenbedingungen werden auch die organisationalen und sozialen Rahmenbedingungen untersucht. Diese Erhebung erfolgt auf Baublockebene, um eine fundierte Entscheidungsgrundlage für baublockbezogene Lösungen zu schaffen und jene Voraussetzungen zu erfassen, die für gemeinschaftliche Energielösungen und Energiegemeinschaften relevant sind.

6.1 Organisationale Status-Quo-Erhebung und Eigentumsstrukturen

Die organisationale Status-quo-Erhebung zielt auf die Analyse der Eigentums- und Organisationsstrukturen auf Baublockebene ab. Dafür wurde eine Grundbuchanalyse der sieben untersuchten EWV-Bestandsgebäude sowie der jeweils zugehörigen Baublöcke durchgeführt. Grundlage bildeten Grundbuchsauszüge aller Liegenschaften innerhalb der definierten Baublockgrenzen. Die Eigentumsverhältnisse wurden systematisch in Excel erfasst und strukturiert ausgewertet, um die Zusammensetzung und Verteilung der Eigentümerinnen und Eigentümer innerhalb der Baublöcke vergleichbar darzustellen. Aus den Grundbuchsauszügen wurden Informationen zur jeweiligen Eigentumsform (Alleineigentum, Miteigentum oder Wohnungseigentum), die Anzahl der tatsächlichen Eigentümerinnen und Eigentümer pro Liegenschaft, der Typ der Eigentümerinnen unterschieden nach natürlichen und juristischen Personen sowie Name und Adresse der Eigentümerinnen und Eigentümer entnommen. Bei juristischen Eigentümerinnen und Eigentümern wurden ergänzend Angaben zur Organisationsform berücksichtigt.

Auf Basis der aufbereiteten Daten wurden deskriptive Häufigkeitsauswertungen durchgeführt. Ausgewertet wurden unter anderem die Verteilung der Eigentumsformen innerhalb der Baublöcke, die Anzahl der Eigentümerinnen und Eigentümer pro Liegenschaft, die Zusammensetzung der Eigentümerinnen und Eigentümer nach natürlichen und juristischen Personen sowie deren weitere Differenzierung nach Organisationsformen sowie Firmensitz- und Wohnsitzländern. Zusätzlich wurde die Eigentumsform in Beziehung zum Typ der Eigentümerinnen und Eigentümer ausgewertet. Die Ergebnisse wurden in Diagrammen und kartographischen Darstellungen aufbereitet und ermöglichen eine vergleichende Analyse der Eigentumsstrukturen sowohl innerhalb einzelner Baublöcke als auch zwischen den untersuchten Standorten. Dieses methodische Vorgehen ist essenziell, um die spezifischen organisatorischen und strukturellen Voraussetzungen der untersuchten Objekte zu verstehen und die komplexen sozialen sowie rechtlichen Rahmenbedingungen für die Implementierung von EEGs im urbanen Raum zu analysieren.

Außerdem sind Kenntnisse über Eigentumsstrukturen notwendig für die Entwicklung zielgruppengerechter Kommunikationsstrategien.

6.2 Stakeholderinnen- und Stakeholderinterviews

Ergänzend zur organisationalen Status-quo-Analyse werden qualitative Stakeholderinnen- und Stakeholderinterviews eingesetzt, um die untersuchten Fallstudien aus einer sozialen Perspektive zu kontextualisieren. Die Interviews richten sich an zentrale Akteursgruppen im Umfeld der untersuchten Gebäude, darunter Nutzerinnen, Nutzer, Eigentümerinnen, Eigentümer, Expertinnen und Experten. Grundlage bilden semistrukturierte Interviewleitfäden, die Raum für unterschiedliche Rollen der Interviewpartnerinnen und Interviewpartner lassen und dennoch Vergleiche ermöglichen. Inhaltlich werden unter anderem der Wissensstand und Einstellung zu erneuerbaren Energien sowie wahrgenommene Hemmnisse und Chancen, Aufgabenverständnisse, relevante Zielgruppen und Beteiligungsmöglichkeiten im Kontext der Energiewende beleuchtet. Die Interviews dienen der ergänzenden Einordnung der organisationalen Analyse und der Erfassung sozialer Dynamiken, organisationaler Abläufe und kommunikativer Anforderungen im Zusammenhang mit gemeinschaftlichen Energieprojekten.

7 ERGEBNISSE DER TECHNISCHEN SOWIE ORGANISATIONALEN UND SOZIALEN ANALYSEN

Die Analysen zeigen, dass grundsätzlich relevante Potenziale für die Nutzung erneuerbarer Energien in den EWV-Gebäuden und EWV-Baublöcken vorhanden sind. Deren tatsächliche Ausschöpfung hängt jedoch stark von standortspezifischen Rahmenbedingungen ab. Technische Lösungen müssen objektspezifisch angepasst werden, wobei Bewertungsmethoden, wie der MACH Value Score, die Abschätzung und Auswahl geeigneter Lösungsoptionen unterstützen. Gleichzeitig wird deutlich, dass aufgrund unterschiedlicher sozialer und organisationaler Voraussetzungen zielgruppengerechte Kommunikations- und Beteiligungsformate essenziell sind, um erneuerbare Energien und Energiegemeinschaften im urbanen Raum nachhaltig zu etablieren. Im Folgenden wird ein Einblick in die Ergebnisse gegeben.

7.1 Technische Rahmenbedingungen

Die Analyse der technischen Rahmenbedingungen auf Gebäudeebene zeigt, welche Versorgungsoptionen für die einzelnen EWV-Gebäude grundsätzlich in Betracht kommen und welche davon jeweils als beste Lösung bewertet werden. Zwischen den einzelnen Gebäuden lassen sich deutliche Unterschiede hinsichtlich der technisch geeigneten Versorgungslösungen erkennen. In mehreren Fällen der Projektfallstudie stellte sich eine Wärmepumpenanlage als bevorzugte Option heraus, wobei je nach Gebäude sowohl Luft als auch Grundwasser als Energiequelle identifiziert wurden. Als zweithäufigste geeignete Lösung erwies sich der Einsatz von Pelletsanlagen. Andere untersuchte Optionen, insbesondere Fernwärme sowie Wärmepumpensysteme mit Geothermie oder Eisspeicher, konnten in keinem der analysierten Gebäude als optimale Lösung ausgewiesen werden.

Abbildung 3 zeigt im Rahmen der Analyse der technischen Rahmenbedingungen exemplarisch die MACH-Systemmatrix Value Score für das EWV-Gebäude Holochergasse 11. An diesem Standort wurden die Varianten Fernwärme, Wärmepumpenanlage mit Energiequelle Luft sowie Pelletsanlage geprüft. Andere Optionen wie Geothermie oder Eisspeicher wurden nach der Begehung und Bestandserfassung aufgrund der räumlichen Gegebenheiten und der fehlenden Verfügbarkeit nutzbarer Geothermie von Beginn an ausgeschlossen. Die Abbildung 3 stellt die Barwertkosten (hellgrüne Balken), die Betriebskosten (dunkelgrüne Balken) sowie den Value Score (hellgraue Linie) dar.

Auf Grundlage der wirtschaftlichen Vergleichsrechnung und der Value-Score-Bewertung wird die Variante einer Wärmepumpenanlage mit Energiequelle Luft für die weitere Umsetzungsplanung empfohlen. Ausschlaggebend dafür ist die höchste Gesamtbewertung im Value Score, die sich aus einer Kombination aus hoher Energieeffizienz durch Nutzung von Umweltenergie, geringen lokalen Emissionen, vergleichsweise niedrigen und stabilen Betriebskosten sowie einer hohen Zukunftsfähigkeit im Hinblick auf Klimaziele, regulatorische Anforderungen und Förderprogramme ergibt. Zusätzlich weist diese Variante praktische Vorteile im Gebäudekontext auf, darunter ein geringerer Platzbedarf im Vergleich zu Pelletanlagen, ein einfacher, weitgehend wartungsfreier Betrieb sowie die gute Kombinierbarkeit mit Photovoltaikanlagen zur Eigenstromnutzung. Zwar weist die Variante der Pelletsanlage mit rund sechs

Prozent geringeren Kosten einen leichten wirtschaftlichen Vorteil auf, erzielt jedoch im Value Score eine niedrigere Gesamtbewertung, insbesondere aufgrund höherer Emissionen vor Ort, eines erhöhten Platzbedarfs für Lager- und Fördertechnik sowie eines höheren betrieblichen Aufwands. Erste Einschätzungen der räumlichen Voraussetzungen im Baublock deuten zudem darauf hin, dass die Umsetzung einer gemeinschaftlichen Energielösung grundsätzlich möglich ist. Diese Potenziale werden im weiteren Projektverlauf vertieft analysiert und mit den Ergebnissen der organisationalen und sozialen Untersuchungen abgeglichen.

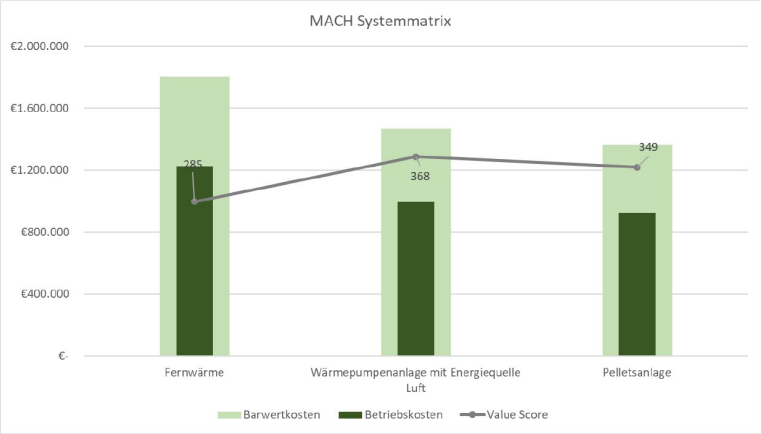


Abbildung 3: MACH Systemmatrix Value Score für die Holochergasse 11 (MACH Energiegesellschaft GmbH 2025)

7.2 Organisationale und soziale Rahmenbedingungen

Die Ergebnisse der organisationalen Status-quo-Analyse auf Baublockebene zeigen deutliche Unterschiede zwischen den untersuchten Baublöcken hinsichtlich ihrer Eigentumsstrukturen. Diese Unterschiede prägen die organisatorischen Rahmenbedingungen, unter denen Maßnahmen zur Nutzung erneuerbarer Energien und zur Umsetzung von EEGs entwickelt werden können.

Abbildungen 4 und 5 zeigen exemplarische Diagramme aus den deskriptiven Häufigkeitsauswertungen für den EWV-Baublock Holochergasse, der sich im 15. Wiener Gemeindebezirk befindet und insgesamt zwölf Liegenschaften umfasst. Abbildung 4 stellt die Verteilung der Eigentumsformen innerhalb des Baublocks dar und macht die grundlegende Eigentumsstruktur sichtbar. Der Großteil der Liegenschaften befindet sich mit sieben Objekten im Alleineigentum, während zwei Liegenschaften in Miteigentum und drei im Wohnungseigentum stehen. Abbildung 5 fokussiert auf die im Wohnungseigentum befindlichen Liegenschaften und zeigt die jeweilige Anzahl der Eigentümerinnen und Eigentümer pro Objekt. Dabei weist eine Liegenschaft drei Eigentümerinnen und Eigentümer auf, eine elf und eine dreizehn Eigentümerinnen und Eigentümer. Die Analyse und Darstellung dieser Strukturen ermöglichen eine differenzierte Erfassung der Eigentumsverhältnisse im Baublock und schaffen die Grundlage für einen vergleichenden Abgleich mit den Strukturen anderer Baublöcke.

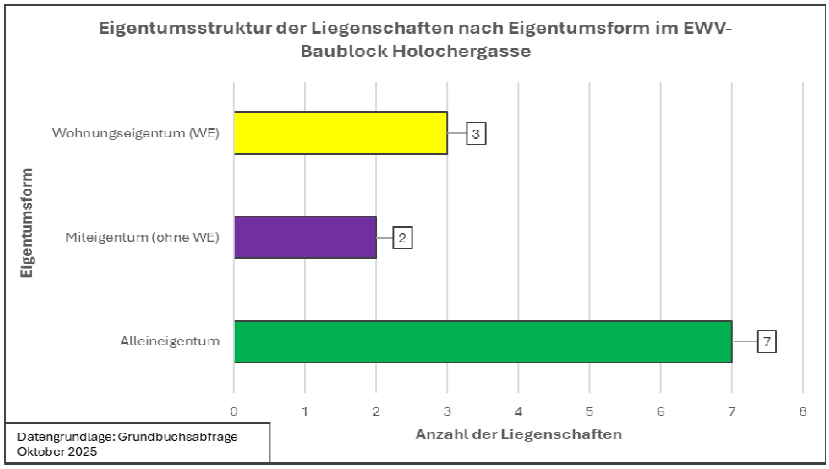


Abbildung 4: Anzahl der Liegenschaften mit Eigentumsform Wohnungseigentum (WE), Miteigentum und Alleineigentum im EWV-Baublock Holochergasse (B-NK GmbH 2025)

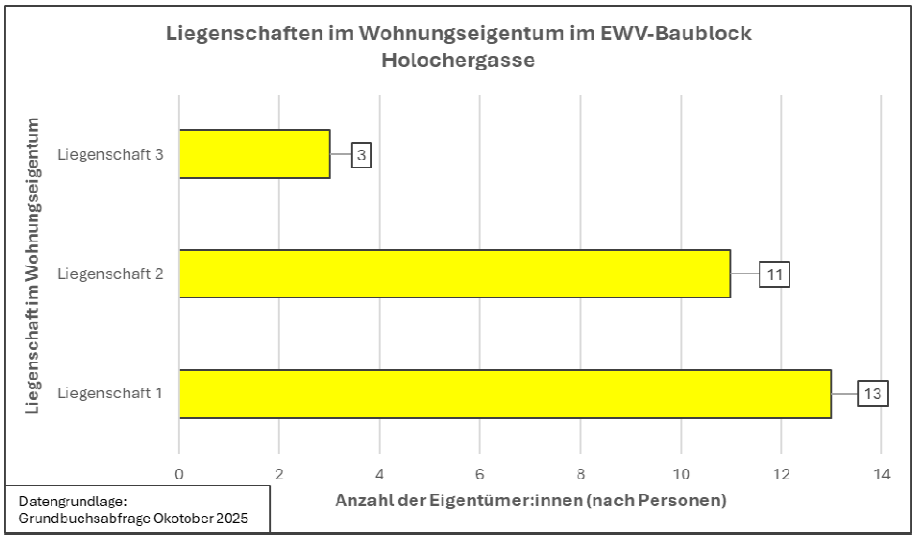


Abbildung 5: Anzahl der Eigentümerinnen und Eigentümer bei Liegenschaften im Wohnungseigentum (WE) im EWV-Baublock Holochergasse (B-NK GmbH 2025)

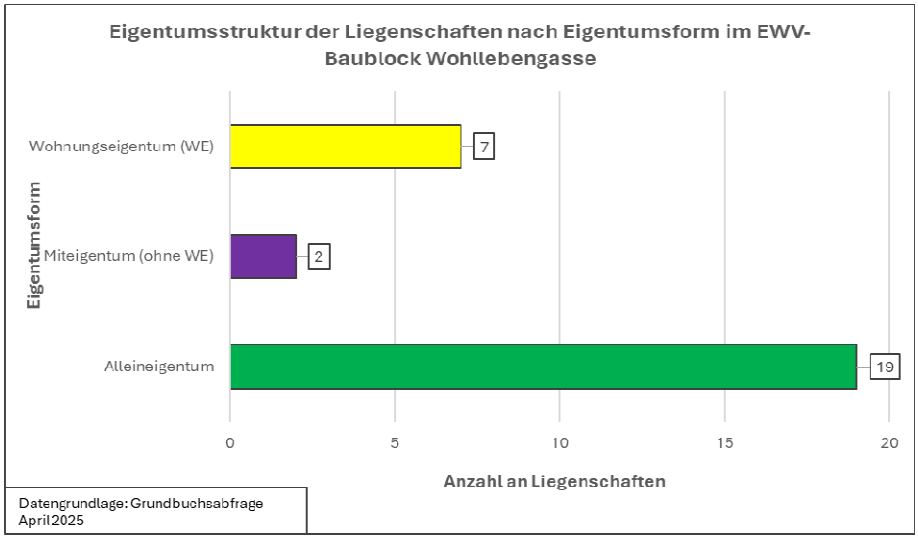


Abbildung 6: Anzahl der Liegenschaften mit Eigentumsform Wohnungseigentum (WE), Miteigentum und Alleineigentum im EWV-Baublock Wohllebengasse (B-NK GmbH 2025)

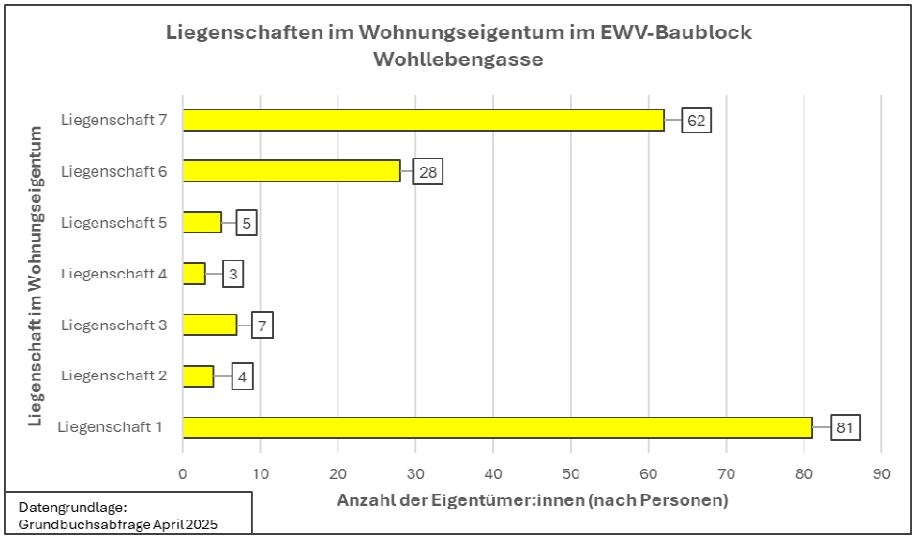


Abbildung 7: Anzahl der Eigentümerinnen und Eigentümer bei Liegenschaften im Wohnungseigentum (WE) im EWV-Baublock Wohllebengasse (B-NK GmbH 2025)

Abbildungen 6 und 7 zeigen die gleichen Diagrammtypen wie Abbildungen 4 und 5, jedoch für den EWV-Baublock Wohllebengasse. Dieser befindet sich im 4. Wiener Gemeindebezirk und liegt damit näher am

innerstädtischen Bereich als der EWV-Baublock Holochergasse. Mit insgesamt 28 Liegenschaften ist er zudem mehr als doppelt so groß. Wie Abbildung 6 zeigt, wird auch in diesem Baublock der Großteil der Liegenschaften mit 19 Objekten im Alleineigentum geführt. Zwei Liegenschaften befinden sich in Miteigentum und sieben im Wohnungseigentum. Abbildung 7 verdeutlicht darüber hinaus eine hohe Heterogenität hinsichtlich der Anzahl der Eigentümerinnen und Eigentümer pro Wohnungseigentumsobjekt, die von drei bis zu 81 Eigentümerinnen und Eigentümern reicht. Insgesamt wird deutlich, dass sich der EWV-Baublock Wohllebengasse sowohl in seiner Größe als auch in der Komplexität der Eigentumsverhältnisse deutlich vom EWV-Baublock Holochergasse unterscheidet. Auch weitere untersuchte Merkmale, etwa der Anteil natürlicher und juristischer Eigentümerinnen und Eigentümer sowie die Differenzierung nach Organisationsformen und Wohnsitzländern natürlicher Eigentümerinnen und Eigentümer, weisen auf eine stärkere strukturelle Vielfalt hin. Der EWV-Baublock Wohllebengasse ist damit insgesamt heterogener und organisational komplexer aufgebaut als der EWV-Baublock Holochergasse.

Auf Basis der exemplarisch dargestellten Baublöcke lassen sich übergeordnete Zusammenhänge zwischen Eigentumsstruktur und organisatorischen Rahmenbedingungen ableiten. In Baublöcken mit überwiegendem Alleineigentum und einer geringen Anzahl an Eigentümerinnen und Eigentümern sind die Eigentumsstrukturen insgesamt überschaubar. Solche Konstellationen finden sich insbesondere dort, wo natürliche Personen dominieren und nur wenige unterschiedliche Organisationsformen vertreten sind. Die Kombination aus klaren Eigentumsverhältnissen und geringer Eigentümerinnen- und Eigentümervielfalt schafft vergleichsweise günstige Voraussetzungen für Entscheidungsprozesse und weitere projektbezogene Vertiefungen. Demgegenüber stehen Baublöcke mit einer ausgeprägten Heterogenität der Eigentumsverhältnisse. Diese sind durch einen hohen Anteil an Wohnungseigentum, stark variierende Anzahlen von Eigentümerinnen und Eigentümern pro Liegenschaft sowie eine große Bandbreite an natürlichen und juristischen Eigentümerinnen und Eigentümern gekennzeichnet. Insbesondere im Wohnungseigentum zeigt sich eine erhebliche Spannweite der Eigentümerinnen und Eigentümerzahlen. Ergänzend weisen diese Konstellationen eine hohe Vielfalt an Organisationsformen juristischer Personen sowie eine breite Streuung der Wohnsitz- und Firmensitzländer auf. Aufgrund der damit verbundenen erhöhten Anforderungen an Kommunikations-, Entscheidungs- und Beteiligungsprozesse sind solche Baublöcke als besonders herausfordernd in Bezug auf die Gründung einer EEG einzuschätzen.

Ergänzend zur Analyse der Eigentumsstrukturen liefern die qualitativen Stakeholderinnen- und Stakeholderinterviews vertiefende Einblicke in die sozialen und kommunikativen Rahmenbedingungen, unter denen Entscheidungen im Gebäudebestand getroffen werden. Die ersten Auswertungen zeigen, dass insbesondere finanzielle Aspekte, der wahrgenommene organisatorische und bauliche Aufwand sowie eine geringe Sichtbarkeit von Notwendigkeit und Nutzen zentrale Hemmnisse darstellen. Darüber hinaus bestätigen die Interviews, dass die jeweilige Eigentumsstruktur für Entscheidungsprozesse von Bedeutung ist, da sich Interessenlagen und langfristige Zielsetzungen je nach Eigentumsform unterscheiden. Auch soziodemographische Merkmale der Eigentümerinnen, Eigentümer, Nutzerinnen und Nutzer, etwa Alter oder Einkommenssituation, beeinflussen die Wahrnehmung von Maßnahmen und die Bereitschaft zur Beteiligung.

Zusammenfassend zeigt sich, dass in einzelnen Baublöcken vergleichsweise homogene Eigentumsverhältnisse vorliegen, während andere durch eine hohe Vielfalt an Eigentümerinnen und Eigentümern, Eigentumsformen und institutionellen Strukturen gekennzeichnet sind. Diese Erkenntnisse bilden eine zentrale Grundlage für die weitere Projektarbeit und die Entwicklung geeigneter Lösungsansätze, wobei die Ergebnisse der Stakeholderinnen- und Stakeholderinterviews insbesondere für die Ausgestaltung zielgruppengerechter Kommunikationsansätze von Bedeutung sind.

8 SCHLUSSFOLGERUNGEN UND AUSBLICK

Das Projekt verdeutlicht, dass für die Umrüstung auf erneuerbare Erzeugungsanlagen und die Gründung von EEGs im dichtverbauten urbanen Raum technische Lösungen und Potenziale gebäude- und baublockspezifisch abgeschätzt werden müssen. Der Ansatz Value Score bietet hierfür eine detaillierte und strukturierte Möglichkeit zur Potenzialanalyse und Erhebung der technischen Rahmenbedingungen. Auf Baublockebene können sich technische Potenziale und Umsetzungshemmnisse deutlich von Einzellösungen unterscheiden, wodurch die Bedeutung des Baublocks als relevante Maßstabsebene im Kontext der urbanen Energiewende hervorgehoben wird. Darüber hinaus liefert das Projekt auf Grundlage der organisationalen

Status-Quo-Analyse auf Ebene des Baublocks und qualitativen Interviews zentrale Erkenntnisse zu sozialen, organisationalen und rechtlichen Hemmnissen, die den Ausbau von erneuerbaren Energien und die Umsetzung von EEGs maßgeblich beeinflussen und im Planungs- und Umsetzungsprozess berücksichtigt werden müssen. Dies erfordert neue Ansätze in Planung, Kommunikation und Governance, da Energiewendeprojekte nicht ausschließlich als technische Vorhaben, sondern auch als sozial-organisationale Aushandlungsprozesse zu verstehen sind. Um unterschiedliche Eigentümerinnen-, Eigentümer-, Nutzerinnen- und Nutzergruppen einzubinden, sind eine gezielte Ansprache sowie die Entwicklung zielgruppengerechter, gendersensibler und inklusiver Kommunikations- und Beteiligungsformate erforderlich. Auf Basis der im Projekt gewonnenen Erkenntnisse wird im weiteren Verlauf ein Stufen- und Umsetzungsplan entwickelt, der kurzfristige und langfristige Maßnahmen zur Umsetzung enthält und eine Entscheidungshilfe für Eigentümerinnen, Eigentümer, Nutzerinnen und Nutzer bieten soll. Dabei werden auch wirtschaftliche, soziale und organisatorische Risiken berücksichtigt. Der Stufen- und Umsetzungsplan soll das zentrale Bindeglied zwischen der energetischen Analyse des Bestands und der konkreten Umsetzung von Sanierungs- und Transformationsmaßnahmen bilden. Ziel ist es, einen strukturierten, praxisnahen und zugleich zukunftsorientierten Pfad aufzuzeigen, der eine schrittweise Reduktion des End- und Primärenergiebedarfs ermöglicht und die Grundlage für eine weitgehende Dekarbonisierung der Wärmeversorgung schafft.

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Methodische Lücken und digitale Potenziale: Kommunale Entscheidungsprozesse im Wandel der Planungskultur

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1 ABSTRACT

Die raumbezogene Entscheidungsfindung in kommunalen Planungsprozessen ist stark von implizitem Wissen, individuellen Routinen und situativen Aushandlungen geprägt, während methodische Ansätze nur begrenzt oder indirekt Anwendung finden. Dieser Beitrag untersucht empirisch Möglichkeiten zur methodischen Optimierung der Entscheidungsfindung des Planungsprozesses und leitet auf Basis eines Mixed-Methods-Designs (Experimente, Fallstudien, Fokusgruppe und Umfrage) zentrale Ansätze zur Weiterentwicklung raumbezogener Entscheidungsfindung ab. Darauf aufbauend wird ein konzeptioneller Rahmen entwickelt, der die identifizierten Ansätze auf konkrete Digitalisierungsstrategien für die Weiterentwicklung kommunaler Entscheidungsprozesse überträgt. Damit adressiert die Arbeit die Frage: „Wie kann Planungskultur ihr Erbe bewahren und zugleich die methodische Zukunft raumbezogener Entscheidungsfindung in kommunalen Planungsprozessen gestalten?“. Die empirischen Ergebnisse führen zu Weiterentwicklungsansätzen in zwei Bereichen: Prozessverbesserung und Verfahrensverbesserung. Insgesamt zeigt sich, dass die Zukunft raumbezogener Entscheidungsfindung weniger in isolierten Tools liegt, sondern in der gezielten Verbindung verschiedener Bereiche: Einerseits durch Strukturierung, Datenverarbeitung, Kommunikation und Transparenz, andererseits durch einfache, flexible und standardisierbare Methoden, die die alltägliche Planungspraxis unterstützen.

Keywords: Entscheidungsfindung, Planungsmethoden, Planungskultur, Digitalisierung, Planungsprozess

2 EINLEITUNG

Kommunale Planungsprozesse sind strukturierte Verfahren, mit denen Städte und Gemeinden ihre räumliche und gesellschaftliche Entwicklung planen, steuern und umsetzen. Die Entscheidungsfindung stellt sich dabei als ein multiskalaren, interdisziplinären und dynamischen Prozess dar, in dem menschliche und technische Komponenten eng miteinander verflochten sind (Batty 2018). Ziel ist es, öffentliche Interessen, rechtliche Vorgaben und private Bedürfnisse in Einklang zu bringen. Zunehmend geraten diese Prozesse jedoch in ein Spannungsfeld aus wachsender Komplexität, begrenzten personellen und finanziellen Ressourcen sowie steigenden Anforderungen an Transparenz, Nachvollziehbarkeit und partizipative Beteiligung (Streich 1998; ARL 2024a; ARL 2024b). Während neue digitale und datenbasierte Werkzeuge Einzug in viele Bereiche der Stadt- und Regionalentwicklung gehalten haben, bleibt jedoch der Kern des kommunalen Planens, die Entscheidungsfindung in der informellen Vorphase mit der Bewertung- und Abwägung, methodisch fragmentiert und zu wenig untersucht (Fürst 2004; Lobeck & Wiegandt 2019, Müller 2025). Entscheidungen entstehen in diesem Teilprozess häufig implizit, auf Basis individueller Erfahrung, situativer Abwägung und institutioneller Routinen und vor allem Aushandlungsprozessen (Danielzyk & Sondermann 2018; Müller 2025). Methodische Ansätze, die diesen Prozess systematisch strukturieren und empirisch fundieren könnten, sind bislang nur punktuell etabliert (Bachmann 2012).

Gleichzeitig steigen die Erwartungen an kommunale Planungen, nachvollziehbare, datenbasierte und transparente Entscheidungsprozesse zu ermöglichen (Scholles 2005; Schachtner 2024). Politische, rechtliche und gesellschaftliche Anforderungen führen dazu, dass planerische Entscheidungen nicht nur fachlich begründet, sondern auch kommunizierbar, partizipativ und überprüfbar sein müssen (Scholles 2005; Bachmann 2012; Laux et al. 2018). Gerade digitale Ansätze bieten hier verschiedene Einsatzmöglichkeiten (Hersperger et al. 2022; Sabri & Witte 2023; Müller et al. 2024). Damit rückt die Frage in den Vordergrund, wie die raumbezogene Entscheidungsfindung in Planungsprozessen weiterentwickelt werden kann, um diesen Anforderungen gerecht zu werden und gleichzeitig die planerische Gestaltungsfreiheit mit dem Handlungsspielraum, den Planungsträger bei der Ausgestaltung von Plänen und Konzepten haben, um Ziele zu erreichen zu erhalten.

Die bisherige Forschung zur Entscheidungsfindung in der Raumplanung ist überwiegend von theoretischen sowie normativ-prozeduralen Perspektiven geprägt. Empirisch fundierte Analysen, die an den tatsächlichen Entscheidungspraktiken ansetzen und diese systematisch weiterentwickeln, sind hingegen vergleichsweise

selten. Entsprechend mangelt es bislang an ganzheitlichen Weiterentwicklungsansätzen (Li et al. 2022). Die vorliegende Untersuchung setzt hier an: Auf Basis eines Mixed-Methods-Ansatzes (bestehend aus Experimenten, Fallstudien, einer Fokusgruppe und einer bundesweiten Befragung) wurde die Entscheidungsfindung in kommunalen Planungsverfahren systematisch untersucht, um Weiterentwicklungsansätze zu generieren.

Ziel ist es, auf planerischen Entscheidungsstrukturen aufzubauen und daraus Ansätze für eine methodische, organisatorische und technologische Weiterentwicklung zu formulieren. Die Bewahrung des Erbes professioneller Planungskultur steht dabei im Vordergrund sowie die gleichzeitige Integration neuer methodischer und digitaler Ansätze, um die Zukunft raumbezogener Entscheidungsfindung aktiv zu gestalten. Dabei werden empirische Ansätze als Ausgangslage für die weitere Forschung entwickelt, die einen hohen Praxisbezug aufweisen und einer weiteren empirischen Erprobung unterzogen werden sollten. Die Forschungsfrage hierzu lautet: „Wie kann Planungskultur ihr Erbe bewahren und zugleich die methodische Zukunft raumbezogener Entscheidungsfindung in kommunalen Planungsprozessen gestalten?“. Im Kontext der REAL CORP 2026 „Cherish Heritage, Plan Now, Create Future!“ wird somit einen Beitrag zur Diskussion über die Zukunft raumbezogener Entscheidungsprozesse im Spannungsfeld zwischen Tradition und Innovation geliefert. Es werden Wege aufgezeigt, wie durch den bewussten Einsatz methodischer Ansätze ein lernender, nachvollziehbarer und resilienter Planungsprozess entstehen kann, der den Anforderungen der Praxis entspricht.

3 THEORETISCHER RAHMEN

Innerhalb des theoretischen Rahmens erfolgt zunächst eine Einordnung entscheidungs- und planungstheoretischer Perspektiven. Darauf aufbauend werden Planungsmethoden im Planungsprozess dargestellt sowie Methoden und Instrumente der raumbezogenen Entscheidungsfindung im Kontext der digitalen Transformation eingeordnet. Diese strukturierte Vorgehensweise dient dazu, die theoretischen Grundlagen systematisch aufzubereiten und ein konsistentes analytisches Fundament für die anschließende empirische Untersuchung zu schaffen.

3.1 Entscheidungstheorie und Planungstheoretische Perspektiven

Unter raumbezogener Entscheidungsfindung wird im Folgenden ein Prozess innerhalb der kommunalen Planung verstanden, in dem lokale Regierungen und Planungsbehörden planerische Entscheidungen vorbereiten und treffen (Meise & Volwahsen 1980). Dieser Prozess fokusiert sich in diesem Beitrag auf den informellen Vorentwurf und umfasst somit vielfältige und komplexe Planungsaufgaben, wie etwa die Umnutzung einer Brachfläche, bei der unterschiedliche Nachnutzungsalternativen bewertet und gegeneinander abgewogen werden (Frej & Almeida 2022).

Die raumbezogene Entscheidungsfindung beinhaltet somit die Analyse relevanter Daten, die Bewertung möglicher Handlungsoptionen sowie deren Abwägung und Ausahl im Hinblick auf verschiedene Kriterien (Laux et al. 2018). Durch diesen Prozess werden Alternativen sichtbar gemacht, miteinander verglichen und in Beziehung gesetzt, um letztlich eine begründete planerische Entscheidung zu treffen (Müller et al. 2024).

Die klassische Entscheidungstheorie betrachtet Entscheidungsprozesse als rationales Abwägen von Alternativen auf Grundlage vollständiger Information (Laux et al. 2018). Diese Annahme wird in der kommunalen Planungspraxis jedoch nur selten erfüllt. Entscheidungen entstehen meist unter Unsicherheit, Zeitdruck, politischem Einfluss und begrenzten Ressourcen. Herbert A. Simon (1972) beschreibt dieses Phänomen als „bounded rationality“ (begrenzte Rationalität), die davon ausgeht, dass Akteure nicht optimal, sondern zufriedenstellend „satisficing“ entscheiden (Hernández & Pérez-Ortega 2019). In kommunalen Planungsprozessen bedeutet das: Planerinnen, Planer, Entscheidungsträgerinnen und Entscheidungsträger verfügen zwar über Fachwissen, müssen ihre Entscheidungen aber in einem komplexen institutionellen, rechtlichen und sozialen Umfeld treffen. Entscheidungen werden dadurch zu einem iterativen Prozess, der von Unsicherheiten, individuellen Wertvorstellungen, Erfahrung, Intuition und politischer Aushandlung geprägt ist (Scholich 2008; Schimank 2022).

Die Planungstheorie ergänzt die Entscheidungstheorie um soziale, kommunikative und normative Dimensionen. Während frühere Ansätze, etwa der rational-comprehensive approach (Faludi 1973), Planen als linearen, analytischen Prozess verstanden, betonen neuere Theorien die kommunikative, kollaborative und adaptive Natur von Planung Forester (1989). Im kommunalen Kontext ist Planung selten ein

technokratischer Prozess, sondern vielmehr ein interaktiver Aushandlungsprozess zwischen Fachplanung, Politik, Verwaltung und Öffentlichkeit. Ansätze wie die Kommunikative Planungstheorie Healey (1997) und Innes (1995) sowie die kollaborative Rationalität (Innes & Booher 2010) verstehen Entscheidungen als Ergebnis von Dialog, Argumentation und Verständigung. Planung ist damit weniger die Anwendung einer Methode, sondern ein reflexiver Lernprozess, der durch Partizipation, Verhandlung und den Umgang mit Zielkonflikten geprägt ist (Roggendorf et al. 2011; Wiechmann 2018). Als Anhaltspunkt des Vorgehens in der raumbezogenen Entscheidungsfindung stellt Müller (2025) dar, dass sich im raumbezogenen Entscheidungsfindungsprozess innerhalb von kommunalen Planungsprozessen ein hybrides Muster aus drei Typen: freier, strukturierter und diplomatischer Entscheidungsfindungsprozess ergibt. Die sich in ihrer Logik, Vorgehensweise und Bewertungsgrundlage unterscheiden, in der Praxis jedoch häufig überlappen, jedoch bei Weiterentwicklungen berücksichtigt werden müssen.

3.2 Planungsmethoden im Planungsprozess

Planungsmethoden spielen in der Theorie eine zentrale Rolle im Entscheidungsfindungsprozess, da sie Struktur, Nachvollziehbarkeit und Transparenz in planerische Abläufe bewirken (Fürst & Scholles 2008; Streich 2011; Scholles 2018). Sie ermöglichen es, normative und faktische Aussagen zu trennen und Konsensprozesse zu unterstützen. Planungsmethoden tragen somit wesentlich zur Rationalität und Legitimation von Entscheidungen in kommunalen Planungsprozessen bei (Scholles 2005) und bilden damit eine Schlüsselkomponente für die Weiterentwicklung raumbezogener Entscheidungsfindung. Ein methodisches Vorgehen zielt darauf ab, Sachverhalte im Lichte definierter Planungsziele sowie zugrunde liegender normativer und wertebezogener Rahmenbedingungen zu beurteilen. Es stellt damit ein zentrales Instrument zur systematischen Analyse gesellschaftlicher Problemstellungen dar und unterstützt deren Übersetzung in handlungsleitende Konzepte (Wolf 1998).

Zugleich darf methodisches Vorgehen nicht den Eindruck einer technokratischen Determination erwecken, sondern muss Handlungsspielräume offenhalten (Jacoby & Kistenmacher 1998). Während in den 1960er- und 1970er-Jahren formalisierte, quantitative Verfahren wie KNA oder NWA dominierten, verlagerte sich der Fokus seit dem Communicative Turn hin zu kommunikativen und partizipativen Ansätzen (Diller & Oberding 2018). Heute gilt in der Praxis ein pluralistisches, kontextabhängiges Methodenverständnis als zentral, das quantitative und qualitative Elemente verbindet (Diller & Müller 2025). Diese Sichtweise erklärt, warum in der Praxis häufig methodische Offenheit und Flexibilität bevorzugt werden. Planerinnen und Planer bewegen sich zwischen normativen Vorgaben z. B. BauGB, politischen Erwartungen und der Notwendigkeit, tragfähige Kompromisse auszuhandeln. Bei diesen Aushandlungen funktionieren hoch systematisierte oder mathematische Berechnungen zur Entscheidungsfindung nur begrenzt (Forester 2020). Gleichzeitig werden digitale Technologien als Lösungen für alle städtischen Probleme dargestellt (Kitchin et al. 2019). In diesem Transformationsprozess nehmen Planerinnen und Planer bislang überwiegend eine reaktive Rolle ein. Anstatt den Wandel aktiv zu gestalten, beobachten sie die fortschreitenden Veränderungen zunächst und passen bestehende Werkzeuge und Instrumente schrittweise an die neuen Rahmenbedingungen an (Douay & Lamker 2023).

3.3 Methoden und Instrumente der raumbezogenen Entscheidungsfindung im Rahmen der digitalen Transformation

In einer von multiplen Krisen geprägten Welt sind Weiterentwicklungen von Methoden und Instrumenten der raumbezogenen Entscheidungsfindung in der Planung unerlässlich.

Der Einsatz von Methoden ermöglicht es, Inhalte sowohl innerhalb informeller als auch formeller Instrumente systematisch zu erarbeiten und dadurch definierte Zielsetzungen zu unterstützen (Diller 2009). In der theoretischen Auseinandersetzung wird dabei häufig kein scharfer Trennstrich zwischen Methoden und Instrumenten gezogen. Einerseits können Methoden als Instrumente des Erkenntnisgewinns verstanden werden, andererseits entfalten Instrumente ihre Wirksamkeit maßgeblich durch ihre methodische Ausgestaltung (Hübler 2005).

Für die Weiterentwicklung von Entscheidungsfindungsprozessen kommt insbesondere den Instrumenten eine zentrale Bedeutung zu. Bereits Bechmann (1981) weist darauf hin, dass Instrumente als Mittel dienen, „ein Subjekt [...] [einzusetzen], um ein anvisiertes Ziel zu erreichen. Sie enthalten Handlungsanweisungen im Hinblick auf die Erreichung von Zielen. Bei diesen Handlungsanweisungen kann es sich um Rezepte,

Heuristiken, Regeln, Techniken und Methoden handeln, mit deren Hilfe eine Situation manipuliert und verändert werden kann.

Dabei zeigt sich auch der Megatrend „Digitalisierung“, welcher sich auf räumliche Strukturen und Entwicklungen auswirkt (ARL 2022). Der Fokus auf digitale Ansätze als Weiterentwicklung ergibt sich daraus, dass die häufig diskutierten Defizite von raumbezogener Entscheidungsfindung als Element von Planungsprozessen primär im Bereich der Informationsverarbeitung, Kommunikation, Transparenz und Prozessorganisation liegen (Hersperger et al. 2022, Mualam 2024). Dabei verändert die fortschreitende Digitalisierung die Art und Weise, wie Informationen erzeugt, verarbeitet und durch Instrumente in Planungsentscheidungen integriert werden (Potts 2020; Sabri & Witte 2023, Hersperger et al. 2022). Big Data, Geoinformationssysteme (GIS), BIM, digitale Zwillinge und Künstliche Intelligenz (KI)-basierte Analysen eröffnen neue Möglichkeiten, komplexe räumliche Zusammenhänge zu modellieren und Entscheidungsprozesse datenbasiert zu unterstützen (Dembski et al. 2020; Müller & Karic 2024). Der technologische Fortschritt in Hard- und Software ermöglicht es, räumliche Wirkungszusammenhänge in bislang unerreichter Komplexität abzubilden, zu visualisieren und analytisch auszuwerten. Planerische Entscheidungen können dadurch zunehmend auf quantitativen Modellierungen aufbauen, während entsprechende Zusammenhänge zuvor häufig nur qualitativ beschrieben oder abgeschätzt wurden. Dies eröffnet neue Möglichkeiten, Planungsgrundlagen und methodische Vorgehensweisen transparenter und nachvollziehbarer darzustellen (ARL 2022). Gleichzeitig hält KI zunehmend Einzug in die Diskussion um die Optimierung von Planungsprozessen (Lartey & Law 2025).

Jedoch besteht unter den Planenden selbst unterschiedliche Erwartungen an Planungsprozesse, die durch die im Zuge der Digitalisierung eröffneten Möglichkeiten eher verstärkt als nivelliert werden. Ihre Überbrückung erfordert einen gezielten und reflektierten Einsatz innovativer Formate und ist ohne zusätzliche personelle und zeitliche Ressourcen im laufenden Tagesgeschäft kaum zu leisten (ARL 2022).

4 EMPIRISCHE UNTERSUCHUNG

Die empirische Untersuchung wird im Folgenden anhand des Forschungsdesigns und der Darstellung der angewendeten Methoden vorgestellt. Darauf aufbauend werden die zentralen Ergebnisse erläutert und die Ableitung von Befunden zu den Weiterentwicklungsansätzen dargestellt.

4.1 Forschungsdesign und Methodik

Die Untersuchung kommunaler Entscheidungsprozesse in der Raumplanung erfordert ein Forschungsdesign, das sowohl die impliziten, oft nicht formalisierten Entscheidungspraktiken als auch die institutionellen, organisatorischen und kulturellen Rahmenbedingungen planerischen Handelns erfassen kann. Als Forschungsdesign wurde ein Mixed-Methods-Ansatz angewendet, welcher qualitative und quantitative Ansätze kombiniert, mit einem Convergent Parallel Design (Guest & Fleming 2014).



Abb. 1: Überblick über das multimethodische Forschungsdesign mit vier komplementären Erhebungsansätzen (eigne Abbildung)

Die Untersuchung umfasste innerhalb dessen vier methodische Bausteine (vgl. Abb.1), um einen umfassenden und sich ergänzenden Blick auf die Thematik zu gewährleisten:

Im Detail wurden die methodischen Erhebungen wie folgt konzipiert, durchgeführt und ausgewertet:

Durch Experimente mit Studierenden der Geographie und Raumplanung sollten kognitive und prozessuale Muster bei der Entscheidungsfindung planerischer Alternativen aufgedeckt werden. Die Experimente wurden im Rahmen eines Planspiels mit 205 Studierenden durchgeführt und durch zwei standardisierte Fragebögen (einen vor und einen nach dem Experiment) begleitet. Das Planspiel als experimenteller Rahmen erlaubte es, Entscheidungsprozesse kontrolliert zu variieren, Alternativen systematisch gegenüberzustellen und individuelle Bewertungslogiken explizit zu erfassen. Die begleitenden standardisierten Fragebögen vor und nach dem Experiment dienen dazu, Veränderungen im Methodenverständnis, in der Wahrnehmung von Komplexität sowie in der Reflexion von Entscheidungsstrategien nachvollziehbar zu machen. Die Experimente liefern damit eine analytische Grundlage für das Verständnis jener Entscheidungsmechanismen, die später in realen Planungskontexten wirksam werden.

Fallstudien in Kommunen wurden durchgeführt, um reale Entscheidungsprozesse in ihrer institutionellen, politischen und organisatorischen Einbettung zu erfassen. Die Erhebung erfolgte durch insgesamt 19 leitfadengestützte Expertinnen- und Experteninterviews in neun ausgewählten Kommunen deutschlandweit. Die Planungsfälle waren dabei informeller und formeller Natur, die Kommunen zeichneten sich durch unterschiedliche Größenmaßstäbe aus. Leitfadengestützte Expertinnen- und Experteninterviews ermöglichen es, die komplexen Zusammenhänge aus der Perspektive der handelnden Akteurinnen und Akteure zu rekonstruieren. Die Fallstudien bilden somit das empirische Rückgrat für die Ableitung praxisnaher Weiterentwicklungsansätze.

Eine Fokusgruppe mit 10 Fachplanerinnen, Fachplanern, Entscheidungsträgerinnen und Entscheidungsträgern zur Diskussion von Perspektiven zur Bewertung in Planungsprozessen und Planungsmethoden, Routinen sowie Zielkonflikten innerhalb der Entscheidungsfindung. Die Gruppendiskussion ermöglicht es, geteilte Deutungsmuster, Konfliktlinien und implizite Normen sichtbar zu machen, die in Einzelinterviews nur begrenzt zugänglich sind. Gleichzeitig dient die Fokusgruppe als reflexives Element, um die in Experimenten und Fallstudien identifizierten Befunde kritisch zu spiegeln und einzuordnen.

Eine bundesweite Umfrage konzipiert als Vollerhebung unter Planerinnen und Planern innerhalb von Kommunen ab 10.000 Einwohnern in Deutschland zur Erfassung von Strukturen, Rahmenbedingungen, Methodenverständnis und Entscheidungsverhalten wurde ergänzend durchgeführt. Insbesondere im Hinblick auf Digitalisierungsstrategien ermöglichte sie eine realistische Einschätzung von Umsetzungsbedingungen und Akzeptanzpotenzialen, durch 145 vollständig ausgefüllte Fragebögen.

Die Datenanalyse erfolgte durch qualitative Inhaltsanalysen (Fokusgruppe und Fallstudien) nach Kuckartz (2018) und wurden mit deskriptiver Statistik und Inferenzstatistik (Experimente und Umfrage) kombiniert, um die erhobenen Daten zusammenzufassen, zu beschreiben und um Muster zu identifizieren sowie diese zu validieren. Die methodische Triangulation ermöglichte ein tiefes Verständnis sowohl der individuellen als auch der institutionellen Logiken von Entscheidungsfindung.

4.2 Zentrale Ergebnisse

Die Ergebnisse der empirischen Untersuchung zeigen, dass Planungsmethoden in der Praxis zunehmend an ihre Grenzen stoßen. Trotz der Vielzahl vorhandener Planungsmethoden findet in der kommunalen Praxis kaum eine systematische methodische Unterstützung der Entscheidungsfindung statt, wie sich vor allem in den Fallstudien gezeigt hat. Viele Akteure verfügen über unscharfe oder divergierende Vorstellungen, was unter einer „Planungsmethode“ zu verstehen ist. Der Einsatz erfolgt situativ, selten standardisiert und häufig ohne Dokumentation. Expertinnen und Experten betonen die wachsende Komplexität planerischer Prozesse, bedingt durch technologische, gesellschaftliche und institutionelle Dynamiken. Eine befragte Person fasst dies prägnant zusammen: „Der Prozess dahin, also der Ablauf, die Methodik dazu, die ist nicht weit genug entwickelt [...] da ist ein Riesendefizit und da müsste man dran.“ (Fokusgruppe Teilnehmerin oder Teilnehmer 5 – akademische Institution). Strukturierte Verfahren wie SWOT-Analysen oder Nutzwertanalysen werden zwar punktuell genutzt, verlieren aber an Relevanz zugunsten kommunikativer oder pragmatischer Aushandlungsprozesse.

Aus den Interviews und Fokusgruppen lassen sich insgesamt zentrale Anforderungen an zukünftige Planungsmethoden ableiten: Effizienz und Ressourcenschonung, die Vereinfachung und Straffung von Prozessen, Flexibilität im Umgang mit unterschiedlichen Kontexten sowie Transparenz und Nachvollziehbarkeit der Entscheidungslogik. Methoden sollen z.B. nach Aussage einer Expertin bzw. eines Experten „vom gesunden Menschenverstand her zugänglich“ bleiben (Interview Hessen, Mittelstadt – Leitung Stadtplanungsamt) und gleichzeitig wissenschaftlich fundiert sein: „Es ist wichtig, dass wir uns auf Ergebnisse von anerkannten Institutionen stützen und nicht versuchen, das Rad neu zu erfinden.“ (Interview Hessen, Mittelstadt – Leitung Stadtplanungsamt). Dabei bestehen Vorbehalte wie aus der Umfrage hervor geht gegenüber digitalen und KI-gestützten Verfahren, die zwar potenziell Effizienz und Transparenz erhöhen könnten, in der Praxis aber noch wenig Vertrauen genießen. Die empirischen Befunde verdeutlichen, dass digitale Verfahren bislang nur in geringem Umfang Anwendung finden. Ausschlaggebend hierfür sind laut den Interviews und der Fokusgruppe insbesondere fehlende Erfahrungswerte, begrenzte personelle und finanzielle Ressourcen sowie eine ausgeprägte Skepsis gegenüber der Transparenz algorithmischer Entscheidungsunterstützung.

Quantitative Befunde bestätigen diesen Bedarf: In den Experimenten bewerteten 88 % der Teilnehmenden vorgegebene Methoden positiv, während Zeitdruck, als belastend und digitale Werkzeuge nur verhalten positiv eingeschätzt wurden (48 % positiv, 45 % neutral). Die bundesweite Umfrage unter Planungsakteuren ergab ähnliche Prioritäten: Als wichtigste Anforderungen wurden Einfachheit, Benutzerfreundlichkeit, Transparenz, Flexibilität, Effizienz und rechtliche Umsetzbarkeit genannt. Hemmende Faktoren sind dagegen der Zeit- und Ressourcenaufwand, methodische Unsicherheiten und die mangelnde Passung bestehender Verfahren.

Besonders kritisch wird die Quantifizierung nicht messbarer Werte gesehen. Ein Interviewpartner bezeichnete etwa die Nutzwertanalyse als „Scheinmethodik“, da sie versuche, „Themen zu quantifizieren, die nicht quantifizierbar sind“ (Interview Hessen, Mittelstadt – Leitung Planungsbüro). Stattdessen wird der kommunikative und kreative Charakter von Planung hervorgehoben: „Planung ist ein kreativer Prozess, der sehr viel Spielraum hat“ (Interview Hessen, Mittelstadt – Leitung Planungsbüro).

Die empirischen Ergebnisse verdeutlichen damit ein erhebliches Innovationspotenzial: weniger in der Entwicklung neuer Einzelmethoden, sondern in der prozessualen und organisatorischen Integration bestehender und digitaler Ansätze.

Weiter konnten durch Triangulation der empirischen Analysen Kernelemente in Form von Ansätzen zur Weiterentwicklung der Entscheidungsfindung generiert werden. Auf Grundlage der Analysen lassen sich neun übergreifende Innovationsansätze identifizieren, die keine singulären Methoden, sondern konzeptionelle Weiterentwicklungsrichtungen darstellen:

Erstens wird der Bedarf nach Methoden für den alltäglichen Gebrauch betont: praktikable, leicht anwendbare Instrumente wie Checklisten oder Ampelsysteme, die Entscheidungsprozesse strukturieren und visualisieren werden gewünscht.

Zweitens fordern die Befragten eine Vereinfachung und Effizienzsteigerung der Verfahren. Trotz des häufig formulierten Ziels der „Beschleunigung und Vereinfachung“ (Interview, Stadtstaat – Leitung Stadtplanung) bleibe deren Umsetzung bislang unzureichend.

Drittens spielt die Datenverarbeitung eine Schlüsselrolle. Fehlende Standards und heterogene Datenformate erschweren die Arbeit der Planenden erheblich: „Da gibt es kein einheitliches Datensystem […] 700 Formate“ (Fokusgruppe Teilnehmerin oder Teilnehmer – nicht zuortbar). Der Einsatz von KI wird zwar als potenziell hilfreich, derzeit jedoch als „noch zu früh“ (Fokusgruppe, Teilnehmerin odere Teilnehmer 6 – Stadtplanungsämter) und methodisch unsicher eingeschätzt.

Viertens wird die Strukturierung des Entscheidungsprozesses als zentrales Entwicklungsfeld gesehen. Baukastensysteme und Leitbilder können dazu beitragen, Informationen zu ordnen und Diskussionen zu fokussieren.

Fünftens kommt den Diskussions- und Aushandlungsprozessen besondere Bedeutung zu: Planung wird zunehmend als Moderation von Kommunikation verstanden. „Ich mache gar nicht mehr wirklich Planung, sondern steuere Prozesse und Kommunikation“ (Fokusgruppe, Teilnehmerin oder Teilnehmer 3 – Planungsbüro).

Sechstens wird die Steigerung der Transparenz als notwendige Bedingung für Akzeptanz hervorgehoben. Digitale Plattformen und frühzeitige Bürgerbeteiligung sollen Entscheidungsprozesse nachvollziehbarer machen, ohne sie zu überfrachten.

Siebtens wird die Konservierung von Erfahrung als zukünftige Herausforderung benannt, um Wissen trotz Fachkräftemangel über digitale Werkzeuge oder „digitale Zwillinge“ Fokusgruppe Teilnehmerin oder Teilnehmer 5 – Hochschulvertreter) verfügbar zu halten.

Achtens wird das Wettbewerbsverfahren als kreativer und flexibler Ansatz bewertet, der Variantenvielfalt und Innovation fördert: „Man muss einfach probieren“ (Fokusgruppe Teilnehmerin oder Teilnehmer – nicht zuortbar). Denn hier bietet sich laut der Fokusgruppe zur Förderung der ein Wettbewerbsverfahren an, bei welchem Alternativen und Varianten frei entwickelt werden.

Neuntens wird eine Standardisierung z.B. durch ein Tool als Ansatz vorgestellt. Denn die Umfrage verdeutlichte, dass etwa ein Drittel der Befragten offen und 40% neutral für ein standardisiertes Tool ist, welches den Entscheidungsprozess durch z.B. strukturierte Informationsaufbereitung u.a. digital unterstützen könnte.

4.3 Ableitung: Von Befunden zur Weiterentwicklung

Die Übertragung von der empirischen Analyse zur Weiterentwicklung des Planungsprozesses mit dem Element der Entscheidungsoptimierung erfolgt dabei in zwei Schritten der Prozessverbesserung mit sechs Ansätzen und der Verfahrensverbesserung mit drei Ansätzen (vgl. Abb.2). Die Unterscheidung ist erforderlich, da empirische Analysen sowohl Probleme der Ablaufstruktur (Prozess) als auch der Entscheidungsmethodik (Verfahren) sichtbar machen. Alle Ansätze der Weiterentwicklung resultieren dabei ebenso aus den empirischen Erhebungen. Diese unterschiedlichen Ansätze erfordern differenzierte Formen der Ausgestaltung der Weiterentwicklung:



Abb. 2: Ansätze der Weiterentwicklung (verändert nach Müller 2025)

Die darauf aufbauenden konzeptionellen Ansätze zur digitalen Weiterentwicklung folgen in Abb.3. Die digitale Konzeptionalisierung der Ansätze zur Weiterentwicklung stellen keine unmittelbaren empirischen Befunde dar, sondern sind als konzeptionelle Weiterentwicklungen zu verstehen, die auf den empirisch rekonstruierten Entscheidungspraktiken aufbauen. Ziel ist es nicht, konkrete digitale Lösungen zu evaluieren, sondern strukturelle Potenziale der Digitalisierung aufzuzeigen, die an den in der Empirie identifizierten Defiziten und Handlungsspielräumen ansetzen. Die vorgeschlagenen Ansätze sind somit empirisch informiert, theoriegeleitet und als Diskussions- und Entwicklungsrahmen für zukünftige Forschung und Praxis konzipiert.



Abb. 3: Digitale Konzeptionalisierung der Ansätze der Weiterentwicklung (eigne Abbildung)

5 DISKUSSION

Im Folgenden wird diskutiert, welche Herausforderungen mit der methodischen Anwendung im Planungsprozess allgemein einhergehen und inwiefern Digitalisierung als Hebel der Weiterentwicklung dienen kann, um die Planungskultur in ihrem Erbe zu bewahren und zugleich die methodische Zukunft raumbezogener Entscheidungsfindung in kommunalen Planungsprozessen aktiv zu gestalten.

5.1 Herausforderungen in der methodischen Anwendung im kommunalen Planungsprozess

Ein zentrales Ergebnis der Untersuchung ist der mangelnde systematische Methodeneinsatz in der kommunalen Planung. Zwar existiert eine Vielzahl an Planungsmethoden und Bewertungsverfahren, ihre Anwendung bleibt jedoch uneinheitlich, kontextabhängig und selten dokumentiert. Viele Planerinnen und Planer verfügen nur über begrenzte Kenntnisse, welche methodischen Ansätze zur Bewertung und Abwägung tatsächlich geeignet sind, oder sie empfinden vorhandene Verfahren als zu starr für die dynamische Realität kommunaler Planung, vor allem in Hinblick auf die Aushandlungsprozessen. Diese Beobachtung deckt sich mit der Planungstheorie, nach der methodische Verfahren zwar Rationalität und Transparenz schaffen sollen, in der Praxis jedoch nur begrenzt durchsetzbar sind, weil Planung kein rein linear-analytischer Prozess ist (Fürst & Scholles 2008). Vielmehr bewegen sich Planerinnen und Planer im Spannungsfeld zwischen normativen Vorgaben, politischer Einflussnahme und sozialen Aushandlungsprozessen, wodurch formalisierte Methoden oft als unzureichend oder zu rigide empfunden werden (Scholich 2008; Forester 2020).

Hier offenbart sich ein grundlegendes Dilemma: Die Praxis verlangt nach Flexibilität und Handlungsspielraum, während methodische Verfahren auf Standardisierung und Nachvollziehbarkeit zielen. Diese Spannung erklärt, warum strukturierte Ansätze häufig nur selektiv genutzt werden. Gleichzeitig entstehen dadurch Defizite in der Transparenz und Nachvollziehbarkeit, was insbesondere bei strittigen oder politisch sensiblen Projekten problematisch ist.

Die Ergebnisse legen nahe, dass die Zukunft nicht in einer strikten Formalisierung durch einzelne klassische Planungsmethoden liegt, sondern in einer methodischen Hybridisierung: einer Kombination aus klaren Bewertungsrahmen, anpassungsfähigen Tools und kommunikativen Aushandlungsmechanismen. Welche vor allem die Ebene der Prozessverbesserung und der Verfahrensverbesserung umfassen und somit zur Entscheidungsoptimierung beitragen.

5.2 Digitalisierung als Hebel der Weiterentwicklung

Vor dem Hintergrund rasanter technologischer Entwicklungen bietet die Integration digitaler und auch KI-basierter Werkzeuge erhebliche Potenziale für die kommunale Entscheidungsfindung. Dies knüpft direkt an die theoretisch beschriebenen Grenzen rationaler Entscheidungsfindung „bounded rationality“ an (Simon 1972). KI-gestützte Instrumente können diese Grenzen nicht aufheben, aber sie erweitern die Möglichkeiten, Informationen zu strukturieren und Alternativen sichtbar zu machen (Hernández & Pérez-Ortega 2019).

In allen vorgestellten Ansätzen zur Weiterentwicklung wäre eine Weiterentwicklung des Aspektes durch KI denkbar. Denn digitale Instrumente können helfen, Daten zu strukturieren, Szenarien zu simulieren und Alternativen vergleichbar zu machen. Damit adressieren digitale Werkzeuge zentrale Elemente der klassischen Entscheidungstheorie, insbesondere die Notwendigkeit der systematischen Analyse und Bewertung von Handlungsoptionen (Laux et al. 2018). Zugleich wird deutlich, dass digitale Verfahren als methodische Bausteine im Sinne eines pluralistischen Methodenverständnisses funktionieren, wie es in der Planungspraxis etabliert ist (Fürst & Scholles 2008; Diller & Oberding 2018). Gleichzeitig erfordern sie ein neues Verständnis von Planung: Der Planer wird neben den Aushandlungen in Planungsprozessen auch zunehmend zum Moderator zwischen Menschen, Daten und Algorithmus. Die empirischen Befunde zeigen jedoch, dass digitale Verfahren bislang kaum genutzt werden. Vor allem aufgrund fehlender Erfahrung, begrenzter Ressourcen und Skepsis gegenüber algorithmischer Transparenz. Diese Zurückhaltung ist nachvollziehbar, betont aber die Notwendigkeit einer methodischen und institutionellen Brückenbildung zwischen analoger Planungspraxis und digitaler Innovationskultur.

Digitale Ansätze und KI kann hierbei nicht als Ersatz für menschliche Entscheidung verstanden werden, sondern als Unterstützungsinstrument, das Wissen strukturiert, Entscheidungsprozesse dokumentiert und Erfahrungswissen für künftige Projekte konserviert. Damit trägt die Digitalisierung und KI zu einem lernenden Planungssystem bei, das sowohl auf vergangene Erfahrungen als auch auf neue Daten reagieren kann.

6 FAZIT UND AUSBLICK

Aus der Verbindung von Entscheidungs- und Planungstheorie sowie den Überlegungen zur Digitalisierung ergibt sich eine theoretische Rahmung raumbezogener Entscheidungsfindung, die zugleich die Grundlage für die empirische Analyse zur Weiterentwicklung raumbezogener Entscheidungsprozesse bildet. Die theoretische Rahmung verdeutlicht das planerische Erbe und zeigt auf, wo und warum methodische Ansatzpunkte in der Praxis bestehen. Die Diskussion macht deutlich, dass die kommunale Entscheidungsfindung methodisch an einem Wendepunkt steht. Die Frage: „Wie kann Planungskultur ihr Erbe bewahren und zugleich die methodische Zukunft raumbezogener Entscheidungsfindung in kommunalen Planungsprozessen gestalten?“ kann dadurch beantwortet werden, dass durch die Heterogenität der Planungsprozesse und die vielfältigen Rahmenbedingungen, die auf den Planungsprozess wirken nicht die Suche nach einer universellen Methode im Mittelpunktsteht, sondern die Entwicklung eines modularen, adaptiven Frameworks, das an unterschiedliche Planungskontexte anschlussfähig ist. Somit nicht die Einführung neuer Einzelmethoden, sondern die Kombination aus Prozessverbesserung und Verfahrensverbesserung entscheidend ist.

Zwar existieren zahlreiche Planungs- und Bewertungsverfahren, ihre Anwendung bleibt jedoch punktuell, unstrukturiert und selten institutionell verankert. Hier setzt die Weiterentwicklung an. Weder rein erfahrungsbasierte noch vollständig methodische z.B. algorithmische Verfahren sind zukunftsfähig. Vielmehr bedarf es einer Integration von Prozess- und Verfahrensverbesserungen, die organisatorische, methodische und technologische Innovationen miteinander verbindet. Die neu entwickelten Ansätze der Weiterentwicklung (vgl. Abb. 2) zeigen, dass Prozessverbesserungen die organisatorische Grundlage schaffen. Verfahrensverbesserungen bieten konkrete Instrumente für die Praxis. Sie ermöglichen es, bestehende Defizite, wie etwa fehlende Struktur, mangelnde Transparenz und Datenverarbeitung systematisch zu adressieren. Durch die Verbindung von Ansätzen auf der Prozessebene sowie Verfahrensebene entsteht ein handlungsfähiger Rahmen für die Weiterentwicklung raumbezogener Entscheidungsfindung, welcher neben den konzeptionellen Überlegungen (vgl. Abb. 3) weitergedacht und empirisch übertragen und getestet werden sollten.

Darüber hinaus verdeutlichen die Ergebnisse das große Potenzial der Digitalisierung, welche an diesen Bereichen im Rahmen des digitalen Wandels erkennbar wird. KI kann Planende unterstützen, komplexe Informationen zu strukturieren, Alternativen und Varianten zu generieren und Entscheidungsprozesse nachvollziehbar zu machen. Dabei ersetzt sie keine planerische Kompetenz, sondern erweitert sie um datenbasierte Perspektiven und algorithmische Lernfähigkeit. Der kommunale Entscheidungsprozess sollte so zu einem lernenden System werden, das Erfahrungen konserviert, Wissen übertragbar macht und Transparenz fördert.

Für die Wissenschaft eröffnet der Beitrag neue Perspektiven auf die Interdisziplinarität der Entscheidungsforschung: Psychologie, Informatik, Soziologie und Planungswissenschaft. Die Einbeziehung dieser Disziplinen in weitere Forschung kann gemeinsam dazu beitragen, die Ansätze der Weiterentwicklung zu verfeinern und empirisch weiter zu prüfen.

Insgesamt leistet die Untersuchung damit einen Beitrag zu einer methodisch reflektierten, digital anschlussfähigen und adaptiven Planungskultur, die auf Lernen und Nachvollziehbarkeit basiert. Sie macht deutlich, dass die Zukunft kommunaler Planung nicht in der Automatisierung, sondern in der intelligenten Verbindung von menschlicher Expertise und technologischer Unterstützung liegt. Es kann eine neue Generation raumbezogener Entscheidungfindung in kommunalen Planungsprozessen entstehen, die sowohl das Erbe der Planung bewahrt, als auch deren Zukunft aktiv gestaltet.

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reviewed paper

Multi-Level Governance and Contested Authority in Thaba Phatswa: An Institutional Mechanisms Approach under TRANCRAA

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1 ABSTRACT

The Transformation of Certain Rural Areas Act (TRANCRAA) represents a pivotal legislative intervention in South Africa's post-apartheid land reform trajectory, designed to devolve land administration powers from national to municipalities and communities. Unlike restitution or redistribution, TRANCRAA focuses on governance transformation rather than ownership transfer, aiming to embed participatory decision making and tenure security. Its national ambition, however, has produced uneven local outcomes. This paper examines TRANCRAA's implementation in Thaba Phatswa, a rural settlement in the Free State where the absence of traditional leadership placed community leaders/members at the centre of negotiations with municipal authorities. The case highlights how national legislation interacts with local institutional dynamics, producing contested authority and hybrid governance arrangements. By narrowing the focus to institutional theory, the study analyses how four mechanisms of ambiguity, layering, silence, and bricolage shaped the trajectory of transformation. Ambiguity reflected unclear mandates, layering added new procedures without retiring old ones, silence manifested in non decisions, and bricolage captured adaptive blending of formal rules with local practices. Methodologically, the paper employs a qualitative case study with mechanism tracing, drawing on archival records, interviews, and procedural timelines. Findings show that contested authority is not simply a failure of policy design but an emergent property of institutional processes. Outcomes included partial tenure recognition, governance vacuums, and uneven empowerment of community leaders. The contribution is twofold: empirically, it provides a grounded account of TRANCRAA's local implementation; theoretically, it advances institutional scholarship by demonstrating how transformation can be studied through mechanisms rather than broad policy outcomes. Policy implications include the need for mandate clarity and procedural retirement to reduce ambiguity and layering, while recognising bricolage as a constructive adaptive practice.

Keywords: TRANCRAA, Land reform, Spatial Justice, Regional transformation, Participatory governance

2 INTRODUCTION

South Africa's post-apartheid land reform trajectory has been characterised by ambitious legislative interventions aimed at redressing historical dispossession and restructuring rural governance (Hall, 2004; Cousins, 2007). Among these, the Transformation of Certain Rural Areas Act (TRANCRAA) of 1998 represents a pivotal attempt to devolve land administration powers from national to local structures (South African Government, 1998). TRANCRAA sought to empower rural communities by transferring authority over land tenure and resource management to municipal and community-based institutions, thereby promoting participatory governance and spatial justice (Walker, 2008).

However, the implementation of TRANCRAA has been uneven, exposing tensions between national policy ambitions and local institutional capacities (Lahiff, 2007). Rural settlements such as Thaba Phatswa in the Free State provide critical insights into how transformation is negotiated through multi-level governance arrangements. Here, municipal authorities, community leaders and members interact in complex ways, producing outcomes marked by contested authority, procedural silences, and adaptive governance practices.

This paper critically examines the institutional theory of transformation, foregrounding four mechanisms: ambiguity, layering, silence, and bricolage as the analytical lens (Cousins & Hall, 2011; Scott, 1985). By situating Thaba Phatswa within a multi level governance framework (Marks & Hooghe, 2004; Bache & Flinders, 2004), the study asks how these institutional mechanisms produce and sustain contested authority in the implementation of TRANCRAA. In doing so, it contributes to institutional scholarship on land reform by showing that contested authority is not simply a failure of national policy, but an emergent property of institutional processes negotiated across multiple levels of governance.

3 LEGISLATIVE AND HISTORICAL CONTEXT: FROM SEGREGATION TO TRANSFORMATION

To understand the institutional friction in Thaba Phatswa, one must recognise that TRANCRAA was not written onto a blank slate. Instead, it was an attempt to overwrite a deeply entrenched, colonial-era administrative logic that prioritized state control over communal autonomy.

3.1 The Legacy of the 1963 Coloured Rural Areas Act

Before the 1998 enactment, Thaba Phatswa along with 22 other rural settlements was governed under the Coloured Rural Areas Act (Act 24 of 1963) (South African Government, 1998). This legislation was a tool of the apartheid state designed to manage "Coloured" reserves through a paternalistic, top-down structure. Under this system, land was held in trust by the Minister, and local "Management Boards" acted as administrative extensions of the central government rather than representative bodies of the people. This created a path-dependent legacy of land being viewed as a state-managed asset rather than a community right.

3.2 TRANCRAA: A Mandate for Devolution

The Transformation of Certain Rural Areas Act (Act 94 of 1998) was introduced to dismantle this legacy which comprises three pillars: restitution, redistribution, and tenure reform (Hall, 2004; Cousins, 2007). Its primary objective was to facilitate a "handover" of land from the national trust to either a local municipality or a Communal Property Association (CPA). The Act mandated a strict, two-year transitional period during which:

(1) Community Consultations were to determine the preferred entity for land ownership.

(2) Rights Inquiries were to be conducted to identify legitimate residents and land users.

(3) Governance Structures were to be established to ensure democratic land administration.

3.3 The Thaba Phatswa Deviation

While the national legislation assumed a smooth transition, the reality in Thaba Phatswa diverged sharply. In many other rural areas, Traditional Authorities played a significant role in mediating these transitions. However, Thaba Phatswa's history as a "Coloured" rural area meant it functioned without a recognised traditional leader, leaving a power vacuum.

When the local implementation finally gained momentum in 2007, nearly a decade after the Act was passed, the Mantsopa Local Municipality and community leaders found themselves in a state of Institutional Layering. The old Management Board mentalities had not been "retired," and the new TRANCRAA procedures were being superimposed onto a community that was already skeptical of municipal capacity. This historical baggage transformed an administrative handover into a decade-long struggle for spatial justice and tenure security.

This historical backdrop illustrates that the "silence" and "ambiguity" observed in the 2000s were not accidental. They were the result of a modern, democratic Act (TRANCRAA) attempting to function within a spatial and administrative framework built for segregation and control. The timeline below illustrates the significant delay between national policy creation and local execution in Thaba Phatswa, highlighting the breakdown of statutory timelines.



Fig. 1: TRANCRAA Legislative & Implementation Timeline

4 THEORETICAL FRAMEWORK: AN INSTITUTIONAL MECHANISM APPROACH

This paper is anchored in institutional theory, which emphasises that institutions are not static structures but evolving systems of rules, norms, and practices that shape governance outcomes (Cousins & Hall, 2011). Institutional theory provides a lens for understanding how transformation under TRANCRAA is mediated by processes internal to institutions rather than being determined solely by policy design. It highlights how authority is contested, negotiated, and adapted through mechanisms that produce both continuity and change.

Transformation occurs when these interact, often producing unintended outcomes. In the case of TRANCRAA, a national Act designed to devolve authority, institutional theory helps explain why local implementation in Thaba Phatswa generated contested authority rather than seamless governance. It shows that institutional change is rarely linear; instead, it is mediated by mechanisms that actors use to interpret, adapt, or resist rules (Mahoney & Thelen, 2010).

4.1 Justice-Oriented Models

This paper draws on four normative frameworks to evaluate whether TRANCRAA advanced justice in Thaba Phatswa:

- Fraser's Tripartite Model of Justice (2008) argues that transformation must be assessed across three dimensions, redistribution, recognition, and representation as dimensions of justice. In Thaba Phatswa, redistribution relates to tenure security, recognition to the inclusion of community voices, and representation to participation in governance forums.
- Sen's Capabilities Approach (1999) frames transformation as the expansion of substantive freedoms and opportunities. TRANCRAA's success can thus be evaluated by its ability to enhance the capabilities of rural residents to access land, resources, and socio-economic opportunities.
- Young's Five Faces of Oppression (1990) identifies marginalisation, powerlessness, cultural imperialism, exploitation, and violence as structural barriers to justice. These categories help interrogate how contested authority and procedural silences perpetuate exclusion in Thaba Phatswa.
- Scott's Everyday Resistance (1998) highlights subtle forms of resistance silence, negotiation, and informal practices that communities employ to navigate imposed structures. This lens is particularly relevant for understanding how Thaba Phatswa residents respond to institutional ambiguity and uneven support.

These models provide the normative benchmarks against which transformation is assessed.

4.2 Institutionalism Theories

To explain why TRANCRAA's implementation diverged from legislative intent, this paper integrates four strands of institutional theory:

- Rational Choice Institutionalism views institutions as rule systems that structure strategic behaviour. TRANCRAA altered incentives by clarifying authority and embedding accountability (North, 1990; Ostrom, 1990).
- Historical Institutionalism highlights how past arrangements and critical junctures shape present governance trajectories (Hall & Taylor, 1996). In Thaba Phatswa, apartheid-era tenure systems and early TRANCRAA decisions created path dependencies that continue to constrain authority distribution. TRANCRAA's delayed rollout (1998–2007) reflects institutional inertia and layering (Pierson, 2000; Thelen, 2004).
- Sociological Institutionalism focuses on legitimacy and cultural scripts it emphasises adaptive, hybrid arrangements where actors recombine formal procedures with local norms to craft workable governance solutions. In Thaba Phatswa, bricolage is evident in community negotiations, procedural silences, and pragmatic compromises which reflects normative adaptation (Meyer and Rowan, 1977; DiMaggio and Powell, 1983).
- Discursive Institutionalism highlights how ideas and narratives shape institutional acceptance. Competing discourses of transformation and cultural autonomy mediated compliance and resistance (Schmidt, 2008; Schmidt, 2010).

These theories explain how institutional mechanisms ambiguity, layering, silence, and bricolage mediated outcomes.

4.3 Institutional Mechanism

Four mechanisms are central to this analysis:

- Ambiguity: Lack of clarity in rules and mandates, allowing multiple interpretations of authority. In Thaba Phatswa, municipal and community leader responsibilities overlapped, creating contested spaces of governance (Hall, 2004).
- Layering: The accumulation of new rules without retiring old ones, producing institutional complexity. TRANCRAA's transitional procedures layered onto municipal practices, generating confusion about applicable rules (Mahoney & Thelen, 2010).
- Silence: Strategic non decision and deferral, which create governance vacuums. Municipal officials often avoided tenure decisions, leaving community leaders without clear guidance (Scott, 1985).
- Bricolage: Adaptive blending of formal rules with local practices. Community leaders reworked institutional arrangements to fit local realities, producing hybrid governance structures (Cleaver, 2012).

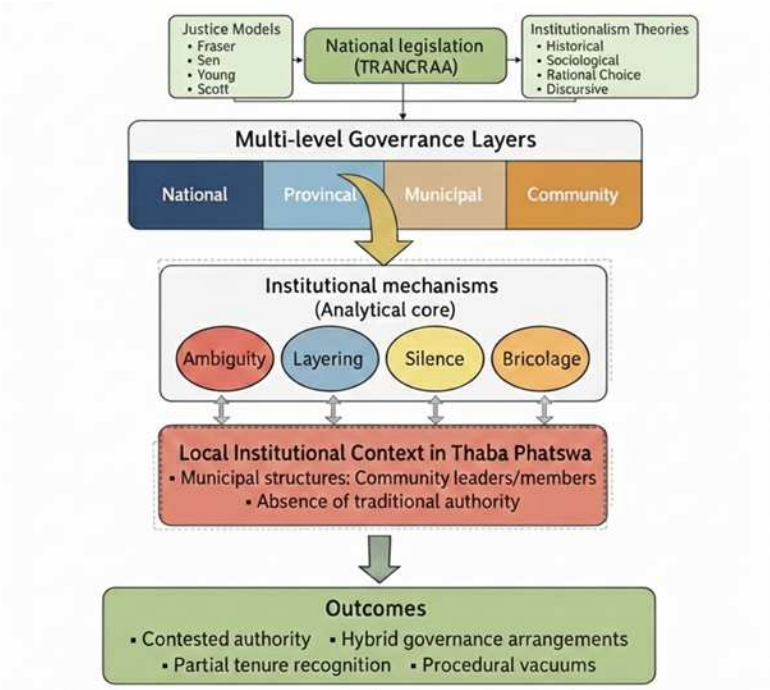


Fig. 2: Dynamic Conceptual Framework for Transformation under Thaba Phatswa

4.4 Multi-Level Governance Context

These mechanisms operate within a multi-level governance (MLG) framework, which highlights the distribution of authority across national, provincial, municipal, and community levels (Marks & Hooghe, 2004; Bache & Flinders, 2004). TRANCRAA sets the national legislative framework, but its outcomes depend on how provincial oversight, municipal capacity, and community agency interact. Institutional theory, combined with MLG, provides a robust framework for analysing how contested authority emerges in Thaba Phatswa.

Together, these frameworks provide a multi-dimensional approach: MLG situates the case within governance structures, while Fraser, Sen, Young, and Scott illuminate the substantive and procedural aspects of transformation. This layered theoretical foundation enables a nuanced analysis of how TRANCRAA's implementation both empowers and constrains communities in practice. By integrating institutional theory with mechanism-based analysis, this study demonstrates that contested authority is not simply a failure of national policy but an emergent property of institutional processes. Ambiguity, layering, silence, and

bricolage are therefore not peripheral dynamics but central to understanding how transformation is negotiated under TRANCRAA.

4.5 Conceptual Framework

Figure 1. below visually integrates these justice models and institutionalism theories. It shows how both lenses converge on the Thaba Phatswa case study and explain the observed outcomes.

Justice models provide the evaluative lens for assessing whether TRANCRAA advanced equity and empowerment. Institutionalism theories explain why transformation was uneven, highlighting the role of strategic behaviour, historical legacies, normative adaptation, and discursive framing. Together, they illuminate how institutional mechanisms shaped outcomes in Thaba Phatswa: contested authority, hybrid governance, procedural silences, and partial tenure recognition.

5 METHODOLOGY

This study employs a qualitative case study design centred on Thaba Phatswa in the Mantsopa Local Municipality. To move from descriptive narrative to causal explanation, the research utilises mechanism tracing. This method allows for the identification of the intervening steps (the "cogs and wheels") between the legislative input (TRANCRAA) and the governance outcomes (Contested Authority).

5.1 Case Study: Thaba Phatswa as an Institutional Battleground

5.1.1 Socio-Spatial Context and the Mantsopa Local Municipality

Thaba Phatswa (GPS coordinates: 29.3139 S, 27.1181 E) is a rural settlement near the Leeu River and Amenia Dam (downstream), situated in the eastern Free State, falling under the jurisdiction of the Mantsopa Local Municipality as depicted in Fig. 3 (locality plan) and Fig.4 (Mantsopa town typology), respectively. Its history is distinct from the surrounding commercial farming areas; it was established as a "Coloured" rural area, which placed it under a specific legislative trajectory the 1963 Coloured Rural Areas Act.

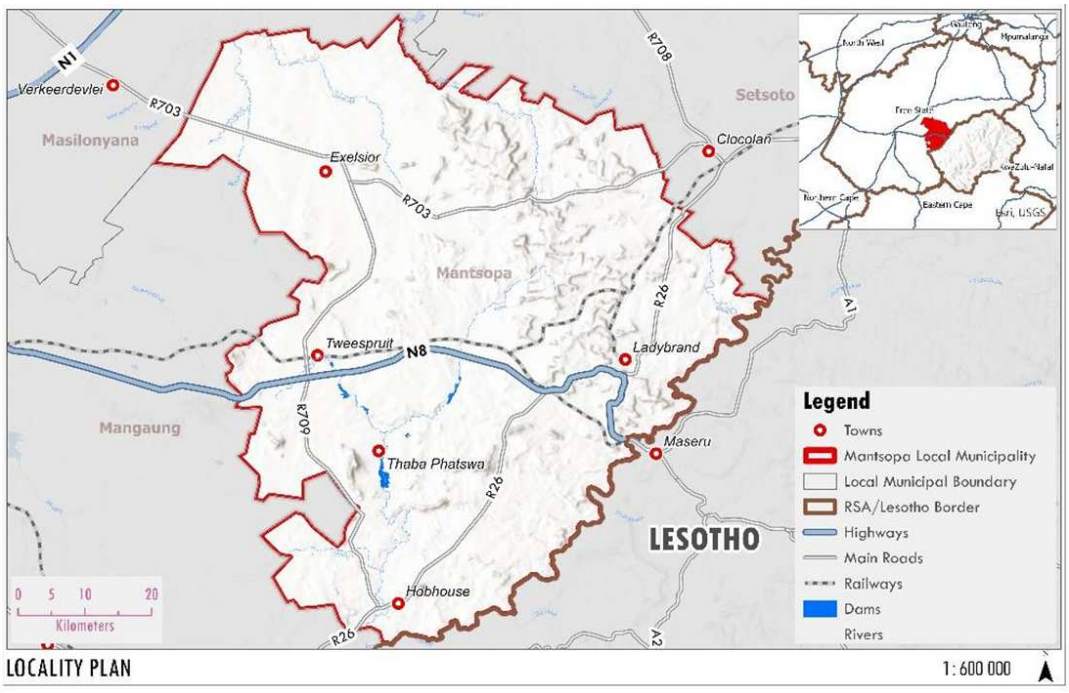


Fig. 3: Thaba Phatswa within Mantsopa Local Municipality; Source: (Mantsopa SDF, 2025)

This historical classification is critical. Unlike many South African rural areas governed by a Kgosi or traditional council, Thaba Phatswa lacks a recognised traditional leadership structure. This absence of a "traditional buffer" meant that when TRANCRAA was enacted, the community of 228 households was forced into a direct, unmediated confrontation with municipal bureaucracy. The settlement's classification under TRANCRAA has paradoxically impeded its development, perpetuating spatial inequality and socio-economic exclusion. Currently, Thaba Phatswa functions as a dormitory settlement with a low population density and no industrial land uses. The local economy is stagnant, with only three business sites located

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peripherally on the main access road. Consequently, the community remains highly dependent on the urban nodes of Thaba Nchu, Tweespruit, and Ladybrand for basic social amenities and economic support.

5.1.2 The "Negotiated" Implementation (2007–Present)

While TRANCRAA was passed in 1998, formal implementation in Thaba Phatswa only gained momentum in 2007. This nine-year delay created a "procedural vacuum" where residents lived in a state of legal limbo. For a community plagued by high unemployment and a heavy reliance on social pensions and grants, this stagnation has been devastating. When the Mantsopa Local Municipality eventually initiated rights inquiries, they did not encounter a passive community. Instead, they met a group of active "bricoleurs" – residents who had already begun to develop informal land-use practices to survive the state's strategic silence. This agency is a survivalist response to the municipality's failure to provide social support or protect local assets, such as livestock, which is continually threatened by cross-border theft from Lesotho.

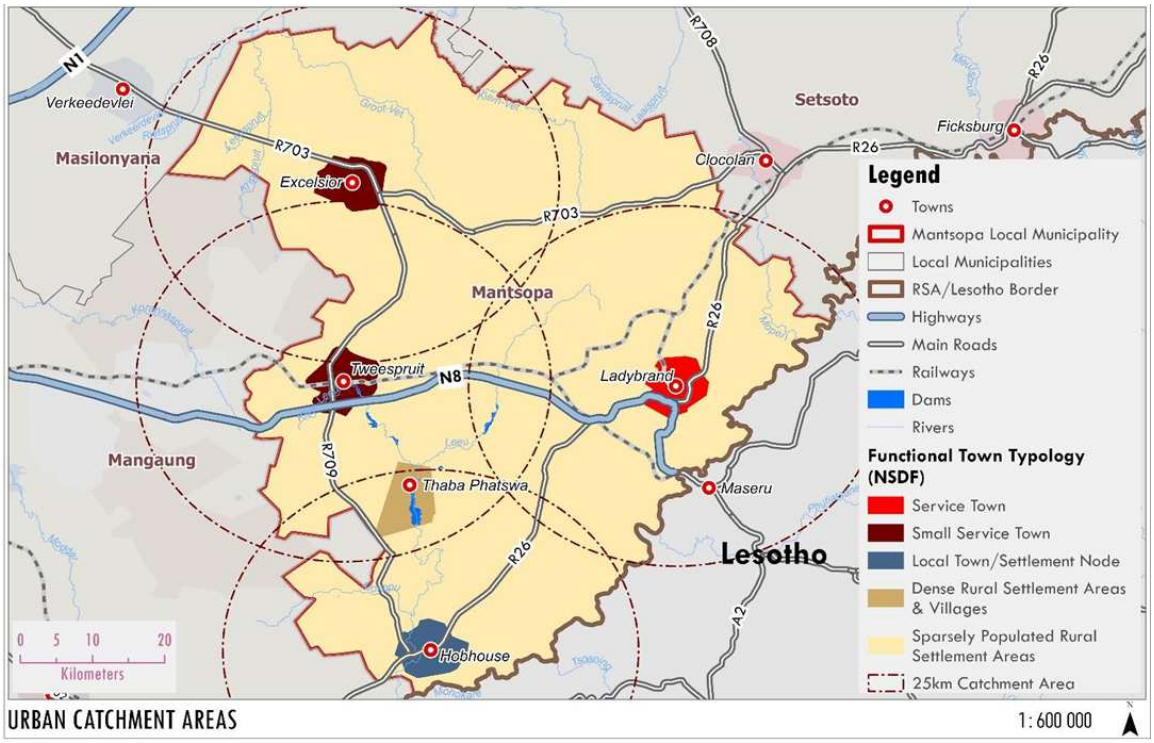


Fig. 4: Mantsopa Town Typology Source: (Mantsopa SDF, 2025)

5.1.3 The Convergence of Mechanisms

- The “battleground” in Thaba Phatswa is defined by three primary institutional frictions that sustain this socio-economic marginalisation:
- Jurisdictional Friction (Ambiguity): The municipality often treats Thaba Phatswa as municipal-owned land for administrative convenience. This prevents the community from leveraging their land for development, as authority remains unclear.
- Administrative Residue (Layering): Municipal officials often resort to paternalistic, top-down governance styles inherited from the apartheid-era Management Boards, stifling participatory decision-making.
- Adaptive Agency (Bricolage): In response to the lack of clear directives from the DALRRD, community members have “cobbled together” local committees to manage grazing rights and residential allocations. This is an attempt to create order in an area served by only a single primary school and minimal state presence.

5.1.4 Outcomes: Partial Recognition and Stalled Justice

The result of this case study is a state of contested authority. The community has successfully resisted total municipal overreach through bricolage, but they have yet to achieve full tenure security. They exist in a state of partial tenure recognition, where their rights are acknowledged in practice but remain unresolved in the

formal deed registry. This lack of finality ensures that Thaba Phatswa remains a peripheral dormitory settlement, where spatial justice is deferred, and the residents' economic vulnerability is institutionalised.

The methodological approach ensures that the findings are grounded in evidence, and not a random occurrence but a traceable outcome of how ambiguity and layering were navigated by local actors. Whilst by utilising the rigorous coding strategy, the paper confirms that the concept of "Hybrid Governance" is not used as a vague descriptor but is presented as the logical and traceable result of specific institutional behaviours.

5.2 Mechanism Tracing as an Analytical Tool

Mechanism tracing was operationalised by searching for specific "diagnostic signals" within the case study data that correspond to the four mechanisms:

- Tracing Ambiguity: Identifying contradictions in official municipal correspondence and interview transcripts where jurisdictional boundaries between the state and community leaders regarding land allocation and grazing rights were left undefined.
- Tracing Layering: Mapping instances where administrative "residue" from the 1963 Coloured Rural Areas Act (such as Management Board logic) influenced the modern implementation of 1998 mandates.
- Tracing Silence: Analysing chronological gaps in the procedural timeline and identifying "non-decisions" in municipal records that effectively stalled development for the 228 households.
- Tracing Bricolage: Documenting the adaptive behaviours of community members who substituted missing formal procedures such as local registries to manage livestock safety with local informal practices.

5.3 Data Collection and Sources

The study draws on a triangulated dataset to ensure validity:

(1) Archival and Document Analysis: A review of national legislation (TRANCRAA), municipal reports, and community meeting minutes dating back to the 2007 implementation start.

(2) Procedural Timelining: The construction of a decade-long timeline to visualise the temporal disconnects and "strategic silences" of the state.

(3) Semi-Structured Interviews: Engaging with key stakeholders to capture the "lived experience" of institutional friction. This included:

- Community leaders and long-term residents.
- The Ward Councillor and municipal officials.
- Representatives from the Provincial Department of Land Reform and Rural Development (DALRRD).

5.4 Ethical Considerations and Site Selection

Thaba Phatswa was purposively selected as an extreme case due to the absence of traditional authority. This provides a "clearer view" of community-municipal power dynamics without the mediating influence of a chief. This site is particularly significant given the socio-economic vulnerability of the residents and the sensitive nature of land tenure in the region. Ethical clearance was obtained to ensure the total anonymity of participants.

5.5 Data Analysis: Coding via Institutional Mechanisms

The analysis followed a deductive thematic approach, utilising the Dynamic Conceptual Framework as a coding template to identify patterns of institutional behaviour:

- Coding for Ambiguity: Applied to data reflecting jurisdictional friction, such as conflicting accounts between the Mantsopa Municipality and residents regarding the veto power over land use.
- Coding for Layering: Focused on language where stakeholders referred to pre-1998 administrative procedures (Act 24 of 1963) still being applied to current TRANCRAA applications.

- Coding for Silence: Identified “procedural deferrals” where residents expressed a sense of being “ignored” or “stalled”. These were mapped against the timeline to prove that municipal silence was a strategic choice.
- Coding for Bricolage: Captured “adaptive agency” where community leaders improvised governance structures such as informal land-use registries to fill vacuums created by state absence.

5.6 Constructing the Mechanism-Outcome Chain

The final stage involved pattern matching to reconstruct the causal chain: from the initial Legislative Mandate (input), through the intervening Mechanisms (process), to the final Governance Outcomes of contested authority and partial tenure recognition. This methodological approach ensures that the findings are not anecdotal, but are grounded in evidence. It confirms that the current state of Hybrid Governance and the socio-economic exclusion of Thaba Phatswa are traceable results of how institutional ambiguity and layering were navigated by local actors.

6 FINDINGS AND DISCUSSION: THE CAUSAL PATH TO CONTESTED AUTHORITY

The study identifies that the state of governance in Thaba Phatswa is not a random failure of policy, but a traceable result of four institutional mechanisms interacting over two decades. By combining the empirical data with theoretical interpretation, this section demonstrates how the "negotiated gridlock" structures the socio-economic reality of the settlement.

6.1 The Production of Contest: Ambiguity and Layering

The initial state of contested authority was produced by the collision of two contradictory administrative “rulebooks”.

- The Evidence: Interviews with municipal officials and the Ward Councillor revealed a persistent “Management Board” mindset, where top-down directives from the 1963 Act era still dictate local land-use logic. Simultaneously, archival correspondence between the Mantsopa Local Municipality and the DALRRD showed no clear consensus on who holds the final “veto” over grazing land allocation.
- The Discussion: This represents a classic case of Institutional Layering (Thelen, 2004). Because the 1963 rules were never formally retired, they became "sedimented" beneath the 1998 TRANCRAA mandates. This layering creates Institutional Ambiguity (North, 1990), where the “rules of the game” are ill-defined. Consequently, both the municipality and community leaders claim legitimate authority, sparking a jurisdictional battle that prevents any formal development of business sites.

6.2 The Sustenance of Contest: Strategic Silence

Once the contest began, the findings show that the state utilised “silence” to maintain the status quo without resolving the underlying conflict.

- The Evidence: The constructed Procedural Timeline confirms a near-total cessation of formal activity between 1998 and 2007. More recently, residents reported that requests for formal title or security interventions regarding cross-border stock theft from Lesotho were met with "procedural deferrals" and non-decisions.
- The Discussion: This Strategic Silence (Schmidt, 2008) functions as an administrative tool. By remaining silent, the municipality avoids the political cost of choosing between community autonomy and municipal control. However, this silence has a high human cost: it justifies the institutional deferral of capital expenditure, explaining why a community of 228 households still relies on a single primary school and must travel to Ladybrand or Thaba Nchu for basic amenities.

6.3 The Institutionalisation of Contest: Bricolage and Hybridity

The findings highlight how the community “settled” into this contest through adaptive agency, creating a permanent, albeit precarious, governance structure.

- The Evidence: In the absence of a traditional leader or municipal support, community members acted as “bricoleurs”. They established local grazing committees and informal land-use registries to fill the procedural vacuum.
- The Discussion: This is Institutional Bricolage (Cleaver, 2012) in its purest form. While this bricolage allows for survival, it institutionalises a Hybrid Governance Arrangement. These informal systems now exist in a permanent friction with formal state authority. This "ordered disorder" represents a stalled form of spatial justice, the community is empowered enough to resist municipal overreach, but too marginalised to achieve the formal tenure security required to break the cycle of high unemployment and grant dependency.

The interaction of these mechanisms produces a state of Partial Tenure Recognition. As summarised in the framework below, the socio-economic fragility of Thaba Phatswa is the direct physical manifestation of this institutional gridlock.

Mechanism	Institutional Manifestation	Socio-Economic Impact
Layering/Ambiguity	"Clash of rules" between 1963 and 1998 Acts.	No investment in business sites; dormitory status.
Strategic Silence	Procedural deferrals and non-decisions.	Lack of social infrastructure and state support.
Bricolage	Informal community committees.	Survival without protection from stock theft.

7 CONCLUSION AND POLICY RECOMMENDATIONS

The implementation of TRANCRAA in Thaba Phatswa serves as a poignant reminder that land reform in post-apartheid South Africa is not merely a legislative event, but a continuous and contentious institutional process. By applying an institutional mechanisms approach, this study has moved beyond a binary "success-failure" narrative to reveal the "cogs and wheels" of stalled transformation.

7.1 Synthesising the Findings

The central enquiry of this research sought to understand how specific mechanisms produce and sustain contested authority. The study concludes that the institutional landscape of Thaba Phatswa is defined by three critical phases:

- Production: Ambiguity and Layering produced the initial contest by forcing modern democratic mandates to compete with "sticky" apartheid-era administrative residues.
- Sustenance: Strategic Silence served to sustain this contest, as procedural deferrals by the Mantsopa Local Municipality prevented the finality of land handover and kept the 228 households in a developmental “grey zone”.
- Institutionalisation: Bricolage, while a testament to community agency in the absence of traditional authority, ultimately institutionalised the contest by creating parallel, hybrid governance systems that manage local livestock and grazing in the face of threats like cross-border theft.

7.2 Contribution to Scholarship and Practice

Theoretically, this paper advances Multi-Level Governance discourse by demonstrating that contested authority is an emergent property of institutional friction. It highlights that in "Coloured" rural areas where traditional buffers are absent, the confrontation between the state and the citizen is direct and often leads to a "dormitory settlement" stasis.

7.3 Policy Recommendations

To achieve genuine spatial justice and resolve the socio-economic exclusion of Thaba Phatswa, the following interventions are proposed:

- Decommissioning Legacy Systems: The DALRRD and the Mantsopa Municipality must prioritise the „administrative retirement“ of legacy 1963 regulations. This would reduce Institutional Layering and provide a clear legal field for TRANCRAA procedures.

- Formalising Bricolage: Rather than viewing local adaptations as “deviations”, policy should recognise hybrid governance arrangements as constructive responses to local context. Formalising community-led committees could bridge the gap where traditional authority is absent.
- Ending Strategic Silence: Municipal performance must be tied to the resolution of long-standing tenure arrangements. Resolving the "procedural vacuum" is the only way to attract investment into local business sites and reduce the community's total dependency on Ladybrand and Thaba Nchu.
- Integrated Security and Tenure: Addressing cross-border livestock theft requires a governance structure that grants community “bricoleurs” the formal authority to collaborate with state security organs.

7.4 Final Reflection

The journey of Thaba Phatswa reflects the broader South African struggle to align national aspirations with local realities. While authority over land remains contested, the resilience of the community’s residents suggests that the path to spatial justice lies in a more flexible, adaptive governance framework, one that acknowledges that transformation is not just about changing title deeds, but about resolving the historical and institutional power dynamics that define rural life.

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Paid or Unpaid Social Housing? Rethinking South Africa's Social Housing Dilemma

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1 ABSTRACT

Social housing in South Africa is intended to promote affordability and post-apartheid spatial reconfiguration; however, its implementation is hindered by an ongoing policy dilemma: should it be entirely paid for, nearly free, or cross-subsidised? This paper analyses the conundrum as an issue of governance and spatial fairness rather than merely a pricing discussion. This analysis utilises policy evaluation and qualitative insights from municipal and sector experts in Johannesburg to assess three funding frameworks: rent-based cost-recovery social housing, near-free public rental and subsidy-based provision, and hybrid cross-subsidy models, including inclusionary housing. The paper examines the distribution of financial, operational, and spatial risk among the State, providers, and low-income households for each model. The results indicate that the distinction between "paid and unpaid" obscures the more critical issue of cost incidence over time: who bears the burden of land, infrastructure, maintenance, and affordability, and what are the implications for long-term urban inclusion? Although the near-free social housing model offers increased accessibility, it often externalises costs through peripheralisation and service difficulties. Cost-recovery approaches provide institutional rigour but are increasingly challenged by escalating land and construction expenses. Hybrid models offer the most robust locational potential, contingent upon enough governance capacity to manage land, infrastructure, and compliance. The study asserts that the viability of social housing is best understood as a nexus of land, money, and governance, advocating policies that emphasise strategically positioned land, infrastructure coherence, and enforceable affordability, rather than the dichotomy of free versus paid housing.

Keywords: Social housing, Spatial justice, South Africa, Affordable housing, Subsidised housing

2 INTRODUCTION

Post-apartheid South Africa has utilised housing policy as a primary mechanism for social restitution, supported by the constitutional right to appropriate housing (RSA, 1996). The nation's initial housing initiative prioritised the swift provision of subsidised ownership housing, most notably through the Reconstruction and Development Plan (RDP) and Breaking New Ground (BNG) programmes, resulting in the construction of millions of units since 1994 (Africa Check, 2023). The expansion of mass distribution improved access to formal shelters but resulted in notable spatial trade-offs; to minimise unit costs, numerous projects were established on less expensive peripheral land, frequently distant from economic hubs and service centres (DoH, 2004; Beier, 2023). This peripheralisation might replicate the spatial mismatch of the apartheid era by converting free housing into liabilities of commute expenses, time scarcity, and limited access to metropolitan possibilities (Soja, 2010; Beier, 2023).

The State enhanced its policy toolset to incorporate social rental housing and institutional models to foster medium-density growth in strategically situated restructuring regions (DoH, 2003; RSA, 2008). Social housing, in this context, aims to be both geographically transformational and financially sustainable, underpinned by a capital subsidy and administered by recognised social housing institutions (SHRA, 2017; Scheba et al., 2021). Nonetheless, execution has been hindered by rising building expenses, limited site availability in urban areas, and inconsistent intergovernmental collaboration on land and essential services (Scheba et al., 2021; Steyn and Hirsch, 2025).

This study examines how several funding models – paid, near-free, and hybrid cross-subsidy – allocate financial risk, governance accountability, and geographic results among the State, providers, and people. The paper reframes the discussion from a binary perspective of free versus paid housing to one of cost incidence, temporal burden, and institutional capacity, viewed through the lens of spatial justice. Johannesburg presents a compelling example due to its integration of urban social housing, municipal rental properties, intentional

densification policies, and a developing inclusionary housing framework. The primary concern in this context is not merely whether low-income individuals can make payments, but rather if the broader land, infrastructure, and governance framework can maintain affordability in strategically situated metropolitan areas over time.

3 LITERATURE REVIEW AND POLICY CONTEXT

3.1 Spatial Equity and Housing Placement

Spatial justice links distributive justice to the geography of accessibility: who resides where, and under what circumstances? And with what nearness to employment, transportation and services (Soja, 2010). In South Africa, spatial justice is intrinsically linked to the urban structure established by apartheid, which entrenched marginalised black townships and restricted access to economic and civic resources (DoH, 2004). Housing delivery that perpetuates distance to opportunity may result in units being delivered, yet it can exacerbate inequality by imposing spatial burdens on impoverished households (Soja, 2010; Beier, 2023). This renders location a fundamental aspect of affordability rather than a secondary planning factor. Affordable housing should not be evaluated solely on the financial cost of units or rentals; rather, it must also be considered in terms of its impact on the wider social and spatial costs borne by low-income households. From this viewpoint, the task extends beyond conventional housing provision to encompass the creation of affordable housing that is also conducive to urban development.

3.2 From mass freehold subsidy to diversified affordable housing instruments

The State's first subsidy strategy emphasised the transfer of ownership to low-income households, achieving extensive implementation across succeeding administrations (Africa Check, 2023). Policy evaluations and academic studies have identified dangers of marginalisation, inconsistent construction quality, and subsequent municipal service challenges when impoverished households are unable to afford continuous services (DoH, 2004; GroundUp, 2018; Somdyala, 2018). The Breaking New Ground policy shift was expressly aimed at enhancing settlement integration and establishing sustainable human settlements rather than merely providing housing units (DoH, 2004).

3.3 Social housing: viability, subsidies and delivery drift

Social housing in South Africa was formalised through enabling policy and subsequent legislation(s), highlighting the focus of social housing on zoning restructuring and institutional delivery (DoH, 2003; RSA, 2008). It depends on capital grants and controlled rental affordability to serve low to middle-income populations (SHRA, 2017). Empirical research indicates a shift in delivery – when land markets and subsidy limits render central sites unviable, projects relocate to more affordable peripheral areas, undermining the desired spatial transformation (Scheba et al., 2021). Sector criticism emphasises the affordability limitations of subsidy-only models and the increasing interest in alternate mechanisms, particularly public land release and cross-subsidy strategies (Steyn and Hirsch, 2025). Recent comparative studies further emphasise the importance of land access and governance in influencing delivery success. Makalima and Sokhetye (2025) analyse the contexts of Johannesburg, Cape Town, and Durban, revealing that speculative landholding, arduous rezoning procedures, inadequate intergovernmental coordination, and prolonged approval processes compromise the viability of social housing. They assert that the sustainability of social housing relies not solely on the sufficiency of subsidies but also on the institutional capacity to acquire and manage urban land.

3.4 Hybridisation: Inclusionary housing and public land enabled affordability

Hybrid instruments integrate public land, regulatory frameworks, and private capital to generate mixed-income results. Inclusionary housing is a significant strategy in which private development is contingent upon the provision of affordable housing or similar (CoJ, 2019). Public land has facilitated mixed developments, in which land value is utilised to cross-subsidise affordable components, gaining significance in South African metropolitan areas as fiscal constraints escalate (Somdyala, 2018; Steyn and Hirsch, 2025). These models can enhance location outcomes but also create complexities in governance and delivery, necessitating robust regulatory design, contracting, and oversight (Steyn and Hirsch, 2025). In global comparisons, Arbab and Shabani (2023) demonstrate, through a case study of urban regeneration in Isfahan, Iran, that affordable housing should not be regarded just as a technological outcome of redevelopment. Long-

term affordability relies on trust-building, involvement, land redistribution, clarity in registration, and the ability to prevent the displacement of current residents post-implementation. This substantiates the assertion that hybrid and regeneration-focused affordability methods require enforceable procedures to sustain affordability beyond initial project completion.

3.5 Conceptual framework: Social housing viability as a land-finance-governance nexus

This study conceptualises the viability of social housing as the result of a three-way interplay of land regime, funding logic, and governance capability. The land regime pertains to the ownership, control, or release of urban land, including the conditions and duration associated with these actions. This includes public land release, private acquisition, leasing agreements, affordability covenants, and the sustainability of land control beyond the initial project execution. The financial rationale pertains to the allocation of capital and operational expenses among the State, social housing institutions, private entities, and tenants. This study presents that rationale through three models: (i) rent-based cost recovery, (ii) near-free/publicly subsidised provision, and (iii) hybrid cross-subsidy. Third, governance capacity denotes the institutional capability to orchestrate land assembly, approvals, subsidies, infrastructure, contracting, monitoring, and long-term asset management.

Collectively, these three dimensions influence the distribution of risk across agents and thus generate varied spatial outcomes. When land is inadequately situated, distributed tardily, or conveyed without enduring affordability regulations, even extensively subsidised housing can perpetuate peripheralisation. When revenue models are inconsistent with maintenance responsibilities, even strategically positioned projects may become financially vulnerable. In contexts of weak governance, hybrid approaches may offer inclusion yet ultimately compromise long-term affordability. The approach thus redirects the research from the limited dichotomy of “paid” versus “unpaid” housing to a more profound inquiry: how do land control, cost incidence, and institutional coordination influence long-term affordability, spatial justice, and asset sustainability?

In this context, long-term land ownership is not a peripheral legal matter but a fundamental determinant. It assesses whether land value is appropriated for public advantage or surrendered to speculative forces; whether affordability can be maintained through long-term leaseholds, covenants, or public ownership; and whether housing retains its social utility after the initial subsidy phases. Comparing the three models is particularly crucial: cost-recovery systems rely on consistent access to strategically located land at non-speculative prices; near-free systems frequently externalise costs when inexpensive peripheral land replaces well-located land; and hybrid systems are most efficient when public land or enforceable land-use obligations ensure long-term affordability in development.

4 METHODOLOGY

The study employs a qualitative case-study methodology focused on the Johannesburg Metropolitan Municipality, South Africa’s most populous urban area, as a critical site for examining social housing delivery under conditions of land scarcity, institutional fragmentation and growing housing affordability pressures. It integrates policy and documentary analysis of national housing instruments and municipal frameworks, as well as semi-structured interviews with municipal housing officials, Social Housing Initiatives executives, and practitioners engaged in rental and mixed-income delivery. Policy documents encompassed instruments for the social housing programme and restructuring objectives (DoH, 2003; RSA, 2008), municipal rental stock instruments (DHS, 2009), and Johannesburg’s inclusionary policy (CoJ, 2019). Twelve interviewees were selected through purposive criterion sampling, supplemented, where necessary, by snowball sampling to ensure the inclusion of respondents with first-hand institutional knowledge of the three funding logics examined in the paper. Interviews were conducted between June and July 2025 upon the receipt of ethical approval from the Ethics and Plagiarism Committee (FEPC) of the Faculty of Engineering and the Built Environment at the University of Johannesburg. The selection of research respondents was guided by role relevance rather than statistical representativeness to secure analytically rich perspectives on land access, funding arrangements, operational viability, and locational outcomes. Analytical coding focused on three themes: financial sustainability, risk allocation, and geographical consequences (Soja, 2010; Scheba et al., 2021). The aim was not statistical but analytic generalisation – extracting applicable lessons regarding governance and financial processes within an urban South African context.

5 FINDINGS: COMPARATIVE ANALYSIS OF THREE FUNDING MODELS

5.1 Model 1: Rent-based cost-recovery social housing (the paid model)

The cost-recovery model is the most systematically organised of the three identified models, as it integrates capital subsidies, institutional financing, and rental income to facilitate operations, maintenance, and debt servicing. It fundamentally embodies the stated rationale of South African social housing: regulated rentals in strategically situated restructuring zones. In practice, its feasibility is progressively limited by escalating land values, construction inflation, utility costs, and maintenance demands. Providers must maintain affordability while managing substantial operational risks, including arrears, lifecycle maintenance, and cash-flow pressures associated with delayed subsidy processes. The current evidence indicates that, under land-use restrictions and subsidy constraints, the model tends to expand outward or exert upward pressure on rental rates, thereby undermining its restructuring objectives.

Expert views from private developers interviewed substantiate this trend by demonstrating that project execution is significantly reliant on the timing of grant assistance and the institutional capacity of social housing organisations to oversee both development and long-term asset management. This indicates that the approach is not merely "compensated" due to renters' rental contributions. It is, instead, a delicate equilibrium in which suppliers assume a significant share of financial and management risk to ensure affordability remains stable.

5.2 Model 2: Near-free public rental stock and freehold subsidy (the 'unpaid/near free')

The near-free model, encompassing heavily subsidised public rental and entirely subsidised ownership, is crucial because it serves those unable to afford regulated rentals or traditional financing. Consequently, its redistributive value is considerable. However, the findings indicate that this methodology frequently reallocates rather than eliminates costs. The State and municipalities incur capital, service, and maintenance costs, while households often bear hidden spatial costs through extended commutes, transportation expenses, and limited access to opportunities. Your table demonstrates that "free" offering can externalise costs via distance and municipal service obligations.

Interview findings indicate that even heavily subsidised delivery relies on prepared infrastructure and municipal investment goals. Practitioners observed that social housing and associated affordable provisions can only advance if the city can sustain water and other municipal services, and that the current focus on the inner city is closely linked to restructuring and building repurposing methods. In essence, near-free housing is never devoid of operational costs; it relies on significant upstream public funding and ongoing managerial capabilities.

5.3 Model 3: Hybrid cross-subsidy (mixed-income, inclusionary and public-land enabled approaches)

The hybrid model integrates public regulation, public land, and private finance to produce affordable housing units via cross-subsidy. In Johannesburg, this encompasses inclusionary housing and other mixed-income strategies facilitated by public land. Its primary advantage is geography, as it increases the likelihood of affordability in high-opportunity areas where subsidy-only models frequently falter. Interview findings robustly corroborate this interpretation. A council official elucidates that Johannesburg's inclusionary housing strategy was designed as a planning tool and a land-value-capture mechanism, rather than a traditional municipal housing initiative. When the City allocates supplementary development rights, a portion of the resulting land-value increase is dedicated to affordable housing through on-site delivery requirements (Respondent X1, 2025).

In another vein, Respondent X3 indicates that the City is diligently overseeing approved inclusionary units; yet it also reveals that official approvals far exceed the number of units actually constructed. This signifies a continual disparity between regulatory commitment and actual implementation.

The identical evidence further underscores the model's vulnerability. Bulk contributions and infrastructure-related fees were recognised as significant impediments, despite developers obtaining additional units via the scheme. Hybrid models possess the greatest locational potential; yet they require extensive governance, including legal clarity, infrastructure capability, monitoring, and persistent political commitment.

6 DISCUSSION

A significant inference arising from the study is that land ownership and the duration of land management are critical across all three scenarios. The feasibility of social housing is influenced not only by the financing of units but also by the retention of well-located property in public control, its transfer with enforceable affordability stipulations, or its integration into speculative land markets. When the State relinquishes strategic control of prime land, affordability costs escalate significantly, shifting the burden to tenants (through higher rents), municipalities (through financial liabilities), or families (due to peripheral locations and transportation costs). Conversely, when land is publicly aggregated, banked, leased, or governed by long-term affordability clauses, even hybrid models exhibit greater capacity to sustain affordability. This renders land governance a longitudinal concern: the inquiry extends beyond the current location of housing to whether land arrangements maintain societal value throughout the asset's lifespan.

The 'paid vs unpaid' framing is analytically deficient across the three models. From the perspectives of spatial justice and governance, the critical factors are the temporal cost incidence and the congruence of incentives with locational results (Soja, 2010; Scheba et al., 2021). The near-free model facilitates inclusion for the impoverished but often perpetuates spatial disadvantage in peripheral areas, thereby shifting costs from housing budgets to transportation and municipal services (DoH, 2004; Beier, 2023). In contrast, cost-recovery models incorporate a sustainability framework. Still, they may falter under inflation and land scarcity, leading to either a decline in affordability (via rent increases) or a weakening of restructuring (through peripheral drift) (SHRA, 2017; Scheba et al., 2021). Hybrids can enhance spatial outcomes but necessitate advanced governance capabilities to oversee contracting, monitoring, and the preservation of affordability throughout time (CoJ, 2019; Steyn and Hirsch, 2025).

A persistent governance issue is the brevity of political time horizons, which may favour immediate unit delivery narratives, especially 'free housing' pledges, over long-term asset management and mixed-income viability (Somdyala, 2018; Steyn and Hirsch, 2025). Additionally, there is disjointed intergovernmental cooperation regarding land release, infrastructure financing, and the implementation of restricted zones (DoH, 2003; Scheba et al., 2021). From a spatial justice standpoint, chages must see location as an essential performance requirement rather than a discretionary goal dependent on remaining finances (Soja, 2010; DoH, 2004).

This typology, while rooted in South Africa, holds broader significance for cities outside the Global South, including those in the Global North facing land inflation, displacement due to regeneration, and a renewed focus on inclusionary housing. The fundamental issue across these contexts remains consistent: the interplay of land control, subsidy design, and governance capacity in maintaining long-term affordability. Table 1 summarises Johannesburg's key social housing policies, supporting legislation, and delivery systems, all applicable across South Africa.

Model	Core funding logic	Primary risk bearer(s)	Typical spatial tendency	Spatial justice implications
Cost recovery social housing	Capital grants + debts + rents	Social Housing Institutions (cashflow/maintenance); tenants (affordability)	Mixed; drift outward under land/subsidy constraints	Justice depends on securing well-located sites (Scheba et al., 2021)
Near-free subsidy (Reconstruction Development Programme/Community Residential Units)	State funds capital; low/no payments	State/municipalities (fiscal + services); households (location)	Often peripheral (Reconstruction Development Programme); variable for Community Residential Units	'Free' can externalise costs via distance and municipal (Beier, 2023)
Hybrid cross-subsidy	Public land/incentives + market surplus	Shared (state land value; private market; manager operations)	Better chance of central/well-located delivery	High potential if governance and enforcement are strong (Styn and Hirsch, 2025)

Table 1: Key social housing policies, legislation, institutions, and delivery systems in South Africa. Source: Authors, 2025.

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7 CONCLUSION

This study contends that South Africa's social housing issue is not most effectively analysed through a dichotomy of paid vs unpaid supply. In the context of policy and execution in Johannesburg, it demonstrates that rent-based cost recovery, nearly free public provision, and hybrid cross-subsidy each redistribute costs differentially among the State, providers, and people. The crucial contrast is not in whether housing is ostensibly free or compensated, but in identifying who ultimately bears the financial, managerial, and spatial responsibilities, and the implications for long-term affordability and urban inclusivity.

The results demonstrate that cost-recovery social housing provides enhanced institutional discipline; however, it is progressively burdened by escalating land, infrastructure, and maintenance expenses. The near-free distribution is essential for the most impoverished households; yet, it often obscures budgetary and spatial challenges, particularly when delivery relies on remote land or inadequate maintenance systems. Hybrid solutions, particularly inclusionary and public-land-enabled strategies, offer the most promising potential for improved locational outcomes, contingent upon sufficient governance capacity to manage land release, prepared infrastructure, compliance, and long-term costs.

The article contends that the feasibility of social housing should be regarded as a land-finance-governance issue. In Johannesburg and comparable South African cities, the primary focus should not be on the rhetorical debate between free and paid housing, but rather on acquiring strategically located land, synchronising housing provision with infrastructure development, enhancing the responsiveness of subsidy mechanisms, and reinforcing the transition from approvals to completed and managed housing units. The discourse on paid versus unpaid is less significant than the institutional framework governing cost allocation across time.

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Partizipative Energiesystemanalyse auf der Basis eines urbanen digitalen Zwillings und einer Smart-Meter-Datenanalyse zur Förderung von Plusenergiequartieren

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1 ABSTRACT

Eine nachhaltige urbane Transformation erfordert Wege für eine städtische Energiewende, einschließlich der Einrichtung von Plusenergiequartieren (PEQs).[1] Für die Planung und Umsetzung von PEQs sind technische Lösungen und Simulationswerkzeuge für städtische Energiesysteme erforderlich. Die EU hat in ihrem „Implementation plan on positive energy districts“ das Ziel formuliert, 100 „Positive Energy Districs“ (PEDs) zu errichten und um dieses ehrgeizige Ziel zu erreichen ist die Einbeziehung aller gesellschaftlichen Akteure erforderlich. Zu diesem Zweck müssen innovative Forschungs-, Informations- und Kommunikationsstrategien entwickelt werden. Das transnational finanzierte Forschungsprojekt DigiTwins4PEDs konzentriert sich auf die Entwicklung eines urbanen digitalen Zwillings (UDT)[2] als dynamische digitale Darstellung städtischer Energiesysteme unter Verwendung von realen Daten und fortschrittlichen Simulationswerkzeugen. Der digitale Zwilling erleichtert die integrierte Analyse des Energiebedarfs und -angebots auf Stadtteil und -ebene. Er ermöglicht die Erstellung und Analyse zukünftiger Entwicklungsszenarien zur Simulation der Performance von PEQs. Er unterstützt fundierte Entscheidungen der Stadtverwaltung für eine nachhaltige städtische Energiewende. In diesem Projekt werden innovative Methoden und Umsetzungsstrategien entwickelt, die durch einen partizipativen Prozess unterstützt werden, an dem wichtige Interessengruppen und Bürger in den Phasen des gemeinsamen Entwurfs, der gemeinsamen Gestaltung und des gemeinsamen Lernens beteiligt sind. In verschiedenen Fallstudien werden die Bürger während des gesamten Projekts einbezogen, sodass bürgergetriebene Maßnahmen zur Schaffung von PEQs effizienter berücksichtigt und umgesetzt werden können. Neue Tools und Methoden werden mithilfe des UDT auf Basis des CityGML-Datenformats entwickelt und angepasst, um die Beteiligung der Öffentlichkeit an der Umsetzung der Energiewende zu erhöhen. Diese Tools ermöglichen es den Bürgern, aktiv an der Gestaltung der zukünftigen Energiewende ihrer Gemeinden mitzuwirken und so fundierte und abgestimmte Entscheidungen zu unterstützen.

Die entwickelte Urban-Digital-Twins-Plattform wird in verschiedenen städtischen Fallstudiengebieten (Wien, Stuttgart, Rotterdam, Breslau) im Rahmen eines öffentlichen Beteiligungsprozesses getestet, um gemeinsam mit den Bürgern die vielfältigen Aspekte zu adressieren, die für die Einrichtung von PEQs entscheidend sind.

Der hier präsentierte Beitrag diskutiert das Konzept der Bürgerbeteiligung, den Prototypen der UDT-Plattform sowie dessen Implementierung bzw. Parametrisierung in der Wiener Fallstudie. Weiters wird ein Tool vorgestellt, das Bürgern die Analyse der eigenen Smart-Meter-Daten ermöglicht, um damit den eigenen Energieverbrauch besser zu verstehen, und das dadurch die Parametrisierung des UDTs unterstützt.

Keywords: Digitaler Zwilling, Partizipative Stadtplanung , Positive Energy Districs, Simulationstools, Energiesystemanalyse

2 EINLEITUNG UND MOTIVATION

Städte stehen unter hohem Handlungsdruck, Energieverbrauch und Treibhausgasemissionen zu reduzieren und zugleich Versorgungssicherheit sowie sozialen Ausgleich zu gewährleisten. Plusenergiequartiere (PEQs) – urbane Teilräume, die im Jahresmittel mehr erneuerbare Energie erzeugen als verbrauchen – gelten als vielversprechender Baustein für die kommunale Klimaneutralität. Digitale Methoden, insbesondere urbane digitale Zwillinge (UDTs), haben sich als Schlüsseltechnologie etabliert, um komplexe Wechselwirkungen sichtbar zu machen und Optionen transparent zu vergleichen (Taylor et al., 2021; Zhang, 2013). Gleichzeitig

[1] PEQs = PEDs
[2] Urban Digital Twin

liefern Smart-Meter-Infrastrukturen hochfrequente Zeitreihen, wodurch sich präzise Diagnosen und Maßnahmen ableiten lassen – von temporalen Benchmarks bis zur netzdienlichen Lastverschiebung . Partizipative Planungsansätze verbessern die Qualität und Akzeptanz von Maßnahmen, insbesondere wenn Ergebnisse durch UDT verständlich visualisiert und diskutiert werden. Das im DigiTwins4PEDs Projekt entwickelte Framework zeigt, wie Living Labs, Co Design und Co Learning die Co Creation flexibler PEQ Szenarien unterstützen . Damit Partizipation wirksam ist, müssen Rollen, Entscheidungslogiken und Rückkopplungsschleifen transparent gestaltet werden (Azadi et al., 2025).

3 METHODIK

Die nachfolgend beschriebene Methodik wurde im Rahmen des DigiTwins4PEDs Forschungsprojekts entwickelt. Nach einer kurzen Einführung zum entwickelten Modellierungsschema konzentrieren wir uns auf die Implementierung der Wiener Fallstudie, deren Datenmodell und die spezifischen Lastverschiebungen. Weiters wird auf die partizipative Analyse der Smart-Meter-Daten mittels eines selbst entwickelten Online Tools eingegangen. Details zur Methodik der UDT-Plattform finden sich auch in .

3.1 Daten- und Systemarchitektur der UDT-Plattform

Abbildung 1 zeigt das allgemeine Modellierungsschema. In DigiTwins4PEDs dient die auf PostgreSQL basierende CityGML 3D City Database (kurz: 3DCityDB) als zentrale Speicher- und Austauschplattform für Energy ADE angereicherte CityGML-Gebäudemodelle. Hierdurch wird eine strukturierte Speicherung, Abfrage und Verarbeitung energiebezogener Attribute gewährleistet. Die Energy ADE spielt eine entscheidende Rolle bei der Verwaltung komplexer energiebezogener städtischer Datensätze, ermöglicht einen effizienten Datenaustausch zwischen Simulationswerkzeugen wie SimStadt und MAPED (siehe unten) und gewährleistet Skalierbarkeit, Datenkonsistenz und Interoperabilität innerhalb des Projekt-Workflows.

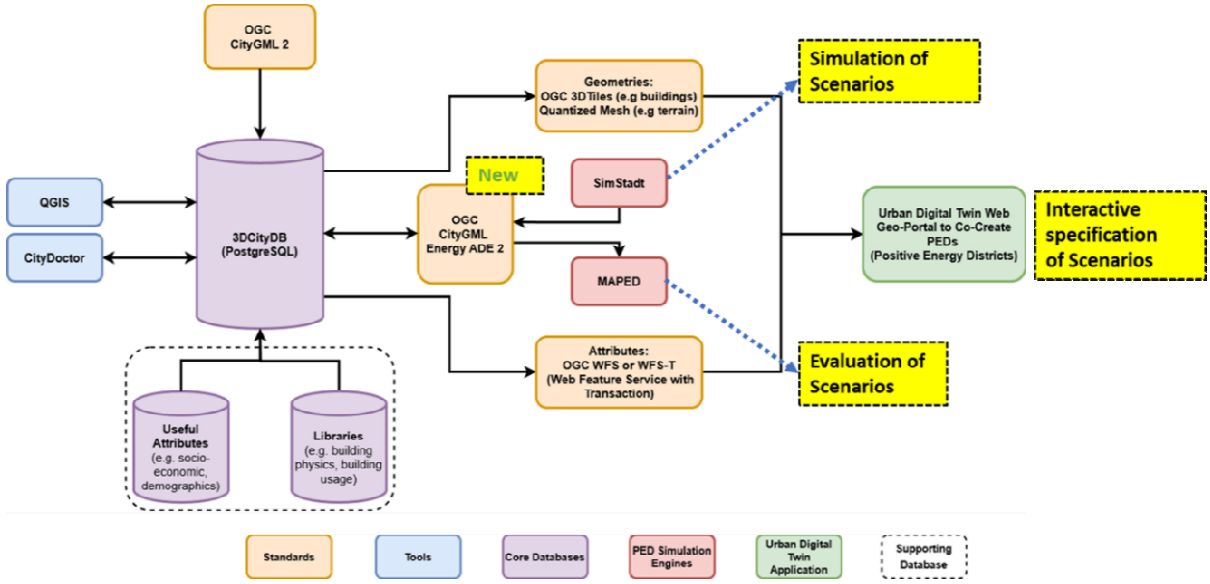


Abbildung 1: UDT-Systemarchitektur ©DigiTwins4PEDs

3.2 SimStadt

SimStadt ist eine an der HFT Stuttgart entwickelte städtische Simulationsumgebung, die reale Stadtplanungsdaten für Energieanalysen von Gebäuden, Quartieren, Städten und Regionen nutzt. Sie ermöglicht hochauflösende Simulationen des Heiz- und Kühlbedarfs, Potenzialanalysen für Photovoltaik auf Dächern, Fassaden und Bodenflächen sowie Untersuchungen zu Gebäudesanierungen, erneuerbaren Energiesystemen, Strombedarf, Lastprofilen, Fernwärme, Wasserbedarf und Lebensmittelpotenzialen (Padsala et al., 2021). Damit unterstützt SimStadt Architekten, Planer, Energieexperten und Behörden bei integrierten Energieplanungsprozessen und der Entwicklung nachhaltiger städtischer Maßnahmen.

Als zentrale Eingabe dient das standardisierte CityGML-Datenmodell, das städtische Objekte und Attribute als 3D-Stadtmodell bereitstellt. SimStadt ergänzt diese Modelle um erforderliche Eigenschaften und integriert die erzeugten Energiesimulationsergebnisse wieder in den CityGML-Datensatz. Für die Energieberechnung benötigt SimStadt zusätzlich Wetterdaten und Gebäudeeigenschaften. Das Wettermodul

generiert aus standortbezogenen Monatswerten synthetische Stundenwerte. Gebäudeeigenschaften werden in bauphysikalische und nutzungsbezogene Parameter unterteilt, die als Bibliotheken und Workflow-Schritte vorliegen. Die bauphysikalische Bibliothek enthält Daten zu Konstruktionen, Materialien und U-Werten. Über die Gebäudenutzung werden Solltemperaturen, interne Lasten und Belegungen verschiedener Gebäudetypen definiert.

Im Projekt DigiTwins4PEDs übernimmt SimStadt die Energiesimulation auf Gebäudeebene, insbesondere für Heiz-/Kühlbedarf, PV-Potenzial und elektrische Lastprofile. Die Ergebnisse werden über die Energy ADE in 3DCityDB gespeichert und ermöglichen einen strukturierten Datenaustausch mit MAPED.

3.3 MAPED

MAPED ist ein Bottom-up Rapid-Assessment Tool zur Energieanalyse, mit dem der Energiebedarf und das Energieangebot von Stadtteilen analysiert und deren Eignung für eine positive Jahresenergiebilanz bewertet werden können, indem lokale erneuerbare Energiequellen zur Deckung des Strom- und Wärmebedarfs des Stadtteils genutzt werden. MAPED wurde vom AIT auf der Grundlage des bewährten Endverbrauchs-Konzepts des IAEA-Modells MAED entwickelt . MAPED konzentriert sich auf die Bewertung des Nutz- und Endenergiebedarfs auf Stadtteilebene und umfasst den Energiebedarf von Haushalten (Wohngebäuden) und Dienstleistungsgebäuden (Nichtwohngebäuden), städtischer Landwirtschaft, Industrie, Gewerbe und Mobilität. Darüber hinaus bietet es einen vereinfachten Ansatz zur Bewertung und Abschätzung der lokalen Erzeugung erneuerbarer Energien zur Deckung des Wärme- und Strombedarfs unter Verwendung von Photovoltaik, Solarthermie und Wärmepumpen. Weitere lokale Versorgungsoptionen wie Biomasse, Abwärme und Windkraft können ebenfalls berücksichtigt werden. Die Nutzung der lokalen erneuerbaren Energiepotenziale hängt von den jeweiligen Rahmenbedingungen, der Topologie, der sozialen Akzeptanz sowie den geltenden regulatorischen Vorgaben ab. Der MAPED-Ansatz bewertet den Endenergiebedarf auf der Grundlage demografischer, sozialer und technologischer Daten des betrachteten Stadtteils. MAPED setzt den spezifischen Energiebedarf für die Bereitstellung von Gütern und Dienstleistungen systematisch in Beziehung zu den sozialen, wirtschaftlichen und technologischen Faktoren, die den Bedarf an einem bestimmten Energieträger beeinflussen. Dazu gehören die Bevölkerungszahl und das -wachstum, die Anzahl der Einwohner pro Wohneinheit, die Anzahl der in Haushalten und Dienstleistungen verwendeten Elektrogeräte, das Mobilitätsverhalten und die Präferenzen hinsichtlich der Verkehrsmittel, die Entwicklung der Effizienz bestimmter Gerätetypen und die Marktdurchdringung neuer Technologien oder Energieformen. Die erwarteten zukünftigen Trends für diese bestimmenden Faktoren (Drivers), die „Szenarien" darstellen, werden exogen eingeführt. Dies ermöglicht die Bewertung der erforderlichen Maßnahmen, um das betrachtete Gebiet innerhalb der vorgegebenen demografischen, sozialen, technischen und baulichen Spezifikationen in einen PED zu überführen.

Abbildung 2 veranschaulicht den methodischen Ansatz zum Mapping urbaner Quartiere sowie zur integrierten Analyse von Energiebedarf und -versorgung. Der Energiebedarf wird sektoral nach dem Endnutzungsansatz modelliert und anhand sozioökonomischer und technischer Treiber auf Nutz- und Endenergieebene bewertet.

Die Analyse umfasst fünf Wohngebäudetypen, charakterisiert durch Wohnungsgröße, Belegungsdichte und Energieeffizienz beim Heizen und Kühlen, sowie fünf Kategorien des Dienstleistungssektors (u. a. Büros, Bildung, Handel, Gesundheitswesen sowie Hotellerie/Gastronomie). Nutzenergieformen (Raumheizung/-kühlung, Warmwasser, Haushaltsstrom, Mobilität und ggf. industrielle Prozesse) werden über Effizienz- und Durchdringungsparameter mit den jeweiligen Endenergieträgern verknüpft und für ein Basisjahr anhand realer Daten kalibriert.

Die Energieversorgungsanalyse bewertet lokale erneuerbare Potenziale, einschließlich Photovoltaik (Dächer, Fassaden, Frei- und Verkehrsflächen) sowie Solarthermie, Geothermie, Biomasse und Mikrowind. Auf dieser Basis wird das Potenzial zur Erreichung einer positiven jährlichen Energiebilanz des Quartiers abgeschätzt. Zentrale Hebel zur Umsetzung eines Plusenergiequartiers (PEQ) sind Effizienzsteigerungen, die maximale Nutzung lokaler erneuerbarer Energien sowie Energieflexibilitäten durch Speicher und die Interaktion mit regionalen Strom- und Wärmenetzen.

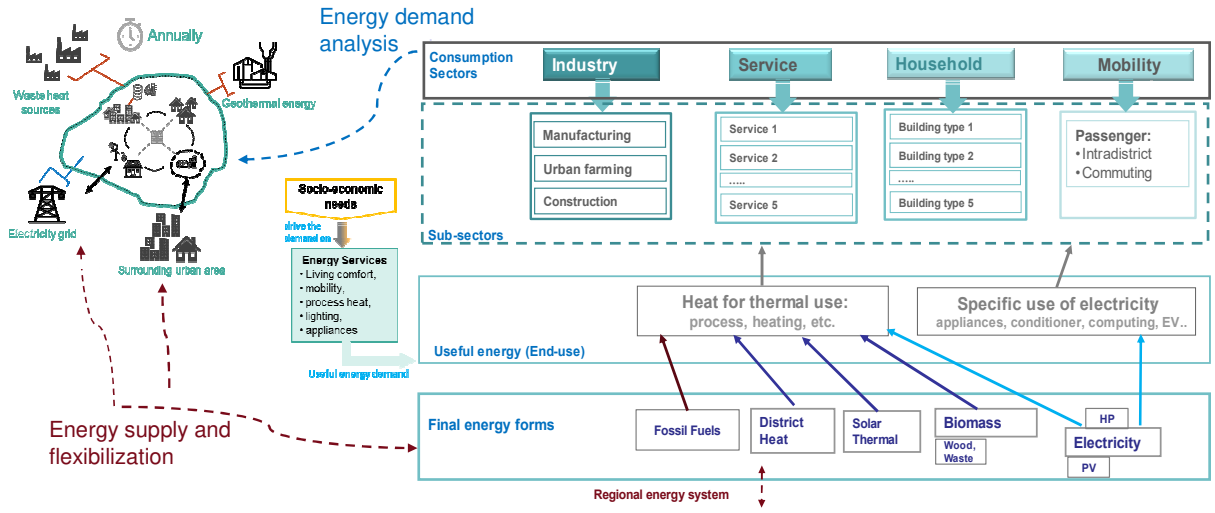


Abbildung 2: MAPED-Konzept zur Aufschlüsselung des Energiebedarfs des Stadtteils nach Brennstoffen und Verbrauchssektoren sowie zur geplanten Energieversorgung und zum Energieaustausch mit dem Nachbarschaftsenergiesystem ©AIT

Da SimStadt und MAPED in den DigiTwins4PEDs-Workflow integriert sind, werden die von SimStadt generierten Energiedaten auf Gebäudeebene über die Energy ADE auf Bezirksebene aggregiert und dann in MAPED verwendet. Diese Integration stellt sicher, dass detaillierte Energiebewertungen auf Gebäudeebene, wie z. B. Energiebedarf und Photovoltaikpotenzial, zu Strategien für die Energieflexibilität auf Bezirksebene beitragen, darunter Energieausgleich, Integration erneuerbarer Energien und Maßnahmen zur Nachfragesteuerung.

3.4 Datenmodell der Fallstudie Wien

Die Fallstudie in Wien konzentriert sich auf das Projektgebiet „Grätzl 20 + 2“ als Teil des Stadterneuerungsprogramms WieNeu+ der Stadt Wien. Das Grätzl 20 + 2 befindet sich in den benachbarten Bezirken Leopoldau (2. Bezirk) und Brigittenau (20. Bezirk) in Wien und wurde Anfang 2023 als bezirksübergreifendes Programm ins Leben gerufen.[3] Ein besonderer Schwerpunkt in diesen Gebieten liegt auf der Umstellung des derzeit gasbasierten Energieversorgungssystems auf alternative erneuerbare Energiequellen und der Bewertung der Auswirkungen einer solchen Umstellung auf das Strom- und Wärmelastmanagement, insbesondere der damit verbundenen Spitzenlasten. Daher besteht der geplante Ansatz innerhalb von DigiTwins4PEDs darin, verschiedene Szenarien für die Umstellung der Energieversorgung in Stadtteilen mit Schwerpunkt auf Optionen zur Flexibilisierung der Energieversorgung unter Verwendung urbaner digitaler Zwillinge als Simulationswerkzeuge gemeinsam zu entwerfen, Lösungen zu entwickeln und gemeinsam mit Anwohnern und Entscheidungsträgern das Potenzial und die Möglichkeiten für die Umwandlung des Grätzel 20+2 in ein PEQ[4] zu bewerten.

Nachfolgend wird der automatisierte Workflow, der für das Abrufen, Integrieren und Verarbeiten groß angelegter Geodatensätze zu Gebäuden und Flächennutzung im Rahmen des DigitTwins4PED-Projekts implementiert wurde, beschrieben. Das Hauptziel besteht darin, einen räumlich konsistenten und attributreichen städtischen Datensatz für Wien zu erstellen, indem über einen Web Feature Service (WFS) abrufbare Open Government Data (OGD), sowie Daten aus dem nationalen Forschungsprojekt „GEL S/E/P“ und CityGML-basierten 3D-Stadtmodellinformationen kombiniert werden. Der Workflow ist so konzipiert, dass er die Reproduzierbarkeit, Skalierbarkeit und effiziente Verarbeitung großer Datensätze gewährleistet und damit nachgelagerte GIS-basierte Analysen und städtische Energiesimulationen ermöglicht. Der Prozess wurde in Python unter Verwendung von GeoPandas und OGC-konformen[5] Diensten implementiert und besteht aus zwei Hauptkomponenten:

(1) Datenerfassung: Autom. Batch-Abfrage von Geodatensätzen aus WFS-basierten OGD Endpunkten.

[3] https://wieneuplus.wien.gv.at/graetzl20plus2 getestet am 27.1.2026
[4] bzw. Annäherung an ein PEQ
[5] OGC Open Geospatial Consortium https://www.ogc.org/, getestet am 27.1.2026

(2) Datenaufbereitung: Integration auf räumlicher und Attributebene mit bereits bestehenden Planungs- und statistischen Grenzen.

Wie in Abbildung 3 dargestellt, besteht der Arbeitsablauf aus vier Hauptphasen: 1) Abfrage der Datenquellen zur Datenerfassung, 2) Datenaufbereitung, 3) Qualitätsprüfung und 4) SimStadt-basierte Simulationen.

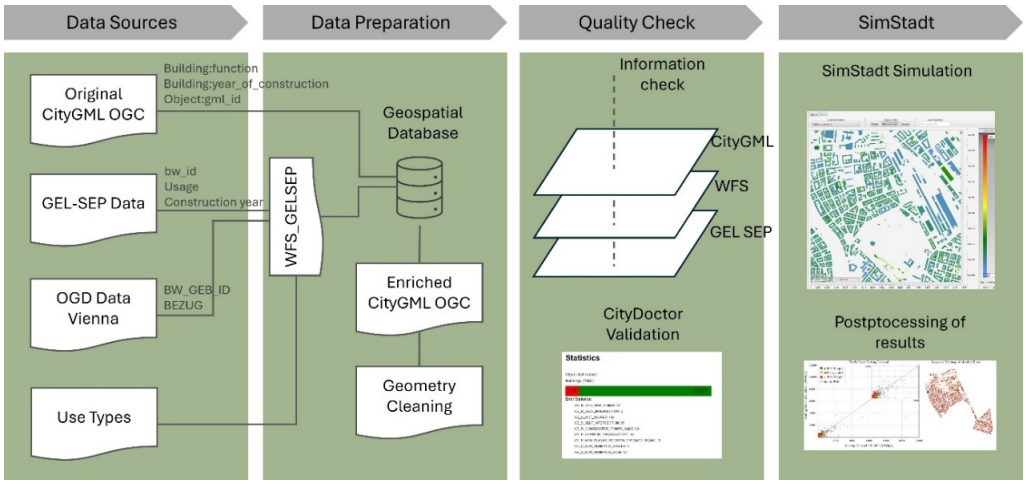


Abbildung 3: Übersicht über den automatisierten Daten-Workflow für die Anreicherung und Simulation von CityGML-Gebäuden. Der Prozess integriert mehrere Datenquellen (CityGML, Wien OGD (WFS) und GEL-SEP), führt die Datenaufbereitung und Geometriebereinigung durch, wendet Qualitätsprüfungen durch CityDoctor-Validierung[6] an und speist das angereicherte CityGML-Modell in SimStadt für die städtische Energiesimulation und Nachbearbeitung ein. ©AIT

Tabelle 1 fasst die in diesem Workflow verwendeten Datensätze, ihre Quellen, Formate und die aus jedem einzelnen Datensatz extrahierten Schlüsselinformationen zusammen.

Datensatzname	Quelle / Format	Beschreibung	Verwendete Informationen
GELSEP	MA20/ Geodatabase	Die im Rahmen des GEL S/E/P-Projekts7 zusammengestellten Datensätze umfassen Informationen zu Gebäudebeständen, Heizungssystemen, Sanierungsstatus und Energieverbrauchsverhalten	Gebäude-ID Baujahr Nutzungsart
CityGML	MA41/ CityGML	Semantisches 3D-Stadtmodell, das standardisierte Darstellungen von Gebäuden bereitstellt, einschließlich Geometrie, Gebäudefunktionen, Konstruktionsmerkmale und hierarchische Beziehungen für eine räumlich explizite Energie- und Stadtanalyse.	Gebäude-ID Geometrie (LoD1–LoD2) Geschosshöhe
GEBAEUDETYPOGD	OGD Wien8 / WFS	Gebäudetypologien	Nutzungstyp
FMZKGEBOGD	OGD Wien/ WFS	Die Flächen-Mehrzweckkarte zeigt die Bodennutzung (z.B. Gebäude, Fahrbahn oder Gehsteig) in einer flächigen Darstellung.	Gebäude-ID
GEBAEUDEINFOOGD	OGD- Wien/ WFS	Allgemeiner Gebäude Datensatz	Baujahr

Tabelle 1: Im Workflow verwendete Datensätze, Quellen und erforderliche Informationen

Um sowohl räumliche Konsistenz als auch Attributgenauigkeit zu gewährleisten, werden frei verfügbare OGD mit den GELSEP-Daten kombiniert. Während GELSEP stabile räumliche Identifikatoren bereitstellt, die für die Verknüpfung von Gebäuden über Datensätze hinweg und mit CityGML-Objekten unerlässlich sind, sind einige Daten der Attributfelder (z. B. Baujahr und Nutzungsart) veraltet. OGD liefert aktuellere und zuverlässigere Attributinformationen. Durch die Integration beider Quellen bleibt die räumliche Repräsentation erhalten, während der Datensatz mit aktuellen Gebäudeeigenschaften angereichert wird, wodurch die Zuverlässigkeit der Gebietsanalyse und der Energiemodellierung verbessert wird.

Die Datensätze GEBAEUDETYPOGD, FMZKGEBOGD und GEBAEUDEINFOOGD wurden iterativ in Batches von bis zu 400.000 Features abgerufen und zur weiteren Verarbeitung als Python GeoDataFrames gespeichert. Nach dem Abruf durchlaufen die Datensätze eine strukturierte Reihe von Bereinigungs- und

[6] https://simstadt.hft-stuttgart.de/related-softwares/city-doctor/ getestet am 27.01.2026

[7] https://www.researchstudio.at/projektkette-gel-s-e-p-erarbeite-methoden-fuer-die-energiewende/ getestet am 27.01.2026

[8] https://www.researchstudio.at/projektkette-gel-s-e-p-erarbeite-methoden-fuer-die-energiewende/, getestet am 27.01.2026; https://www.data.gv.at/datasets?publisher=Stadt+Wien&locale=de, getestet am 27.01.2026

Integrationsschritten, um die räumliche und semantische Konsistenz mit dem CityGML-basierten Stadtmodell sicherzustellen. Das Hauptziel dieser Phase besteht darin, 3D-Stadt-Objekten konsistente und aussagekräftige Gebäude-Identifikatoren zuzuweisen, indem räumliche Beziehungen und hierarchische Identifikatorstrukturen genutzt werden. Eine räumliche Verknüpfung (join) unter Verwendung des Prädikats „bedeckt" wird angewendet, um FMZK-Gebäude zu identifizieren, die räumlich von CityGML-Geometrien abgedeckt sind. Der resultierende Datensatz (joined_covers) kombiniert Attribute aus beiden Quellen, bei denen Geometrien eine aussagekräftige räumliche Beziehung aufweisen.

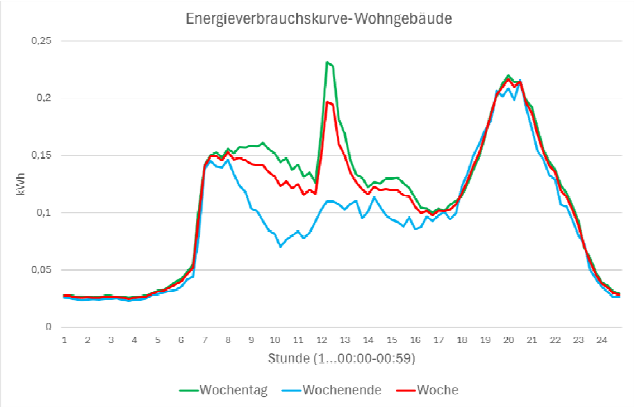


Abbildung 4: Standardlastkurve Tagesgang für Wohngebäude © DigiTwins4PEDs

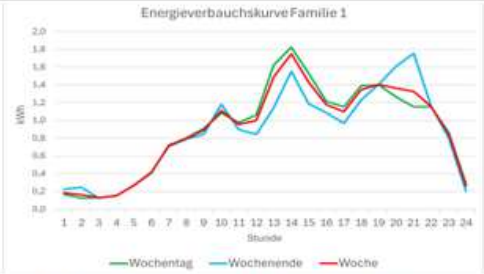
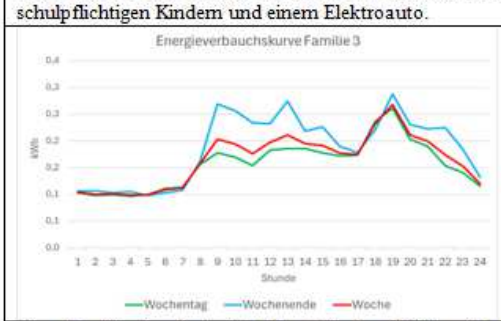
	
Eine Familie mit einem Elternteil zu Hause, zwei schulpflichtigen Kindern und einem Elektroauto.	Eine Familie, in der beide Elternteile berufstätig sind. Sie haben ein 10-jähriges Kind und zwei Elektroautos.
	
Eine Familie, in der beide Elternteile berufstätig sind. Sie haben ein 10-jähriges Kind und kein Elektroauto. Diese Familie hat einen sehr geringen Stromverbrauch	Eine alleinlebende Studentin. Sie hat ein Elektroauto.
	Erklärung: Die in der Tabelle dargestellten Energieverbrauchskurven für Familie 1, Familie 2, Studentin, und Pensionisten, wurden mit dem LoadProfile Generator (LPG)[9] generiert. Familie 3 wurde aus realen Smart-Meter-Daten und der unten unter 3.6 beschriebenen entwickelten Webapplikation erzeugt.
Zwei ältere Personen, die nicht mehr arbeiten. Sie haben kein Elektroauto.	

Tabelle 2: Verschiedene Energieverbrauchskurven.[9]

[9] LoadProfileGenerator (LPG) ist eine Anwendung zur Erstellung synthetischer Lastprofile für Wohngebäude. Sie nutzt eine wunschgesteuerte Agentensimulation, um das Verhalten der Bewohner detailliert zu modellieren und Lastprofile

3.5 Energieverbrauchskurven

Eine Energieverbrauchskurve (Lastkurve) ist die grafische Darstellung des Stromverbrauchs eines Haushalts, eines Unternehmens oder anderer Anlagen über einen gewissen Zeitraum. Verbrauchswerte stammen hierbei von Smart Metern oder anderen Messsystemen. Durch die grafische Aufbereitung kann der Stromverbrauch sowie Veränderungen des Stromverbrauchs in einem bestimmten Zeitintervall einfach abgelesen werden. Im Folgenden werden die Standardenergieverbrauchskurven (Jahreswerte), wie sie in SimStadt verwendet werden, dargestellt, sowie eine Möglichkeit zur spezifischeren standortbezogenen Erhebung mittels Onlinetool vorgestellt.

3.5.1 Standard-Energieverbrauchskurven

Abbildung 4 zeigt die Standard-Energieverbrauchskurve, die in SimStadt als Basis verwendet wurde. Sie zeigt deutliche Unterschiede zwischen Wochentagen (Werktagen) und dem Wochenende.

Die Energieverbrauchskurven in Tabelle 2 zeigen als Vergleich dazu spezifische Energieverbrauchskurven für verschiedene Haushaltstypen sowie eine kurze Beschreibung.

3.5.2 Lastverschiebung – Batterieelektrische Fahrzeuge

Durch den steigenden Marktanteil von batterieelektrischen Fahrzeugen (BEF) gewinnt die Schnittstelle zwischen Energieversorgung und Energiebedarf im Gebäudesektor und im Mobilitätssektor stark an Bedeutung. Dabei erhöhen BEFs nicht nur den lokalen Bedarf an Strom, sondern können durch ihre integrierten Energiespeicher auch entscheidende Beiträge zur Flexibilisierung des Energiesystems leisten. Die Nutzung von Flexibilitätspotenzialen ist hierbei insbesondere im Zusammenhang mit der Vermeidung von Lastspitzen im Stromnetz zu berücksichtigen, da erhöhte Marktanteile von BEFs zu starker Beanspruchung bestehender Infrastruktur führen können (Haidar et al., 2014).

Flexibilisierungspotenziale im Bereich von BEFs finden sich in mehreren Aspekten. Zum einen lassen sich Ladevorgänge, bedingt durch hohe Batteriekapazitäten im Vergleich zum typischen täglichen Mobilitätsbedarf, in Zeiten erhöhter Verfügbarkeit lokaler erneuerbarer Energieträger verschieben. Zum anderen kann diese Speicherkapazität durch bidirektionales Laden (Vehicle to home / grid) genutzt werden, um Zeiten geringerer erneuerbarer Versorgung im Stromnetz zu überbrücken oder auch netzdienliche Einspeisevorgänge vorzunehmen. Um die Effekte und Möglichkeiten der wachsenden Nutzung von BEFs innerhalb von PEQs zu untersuchen, wurde eine Methode zur stündlichen Modellierung des Ladebedarfs von BEFs in die UDT-Plattform eingebunden . Das Modell basiert auf einem Markov-Ketten-Ansatz, bei dem zwischen den Zuständen „Unterwegs“ und „zu Hause“ unterschieden wird, wobei das Nutzungsverhalten von BEFs basierend auf der aktuell verfügbaren Mobilitätsbefragung Österreich Unterwegs kalibriert wurde. Getätigte Fahrten (Zustandsänderungen) entladen Batterien in BEFs, im Zustand „zu Hause“, können diese im Modell geladen werden oder stehen für bidirektionales Laden zur Verfügung. Voraussetzung ist hier eine bestehende Möglichkeit zum Laden am Wohnort. Zur vereinfachten Anwendung dieses Ansatzes wurden in der UDT-Plattform zwei Ladeszenarien berücksichtigt und für eine typische Konfiguration einer möglichen Energiegemeinschaft in der Wiener Case Study modelliert. Dabei wird eine vollständige Nutzung lokaler Solarpotenziale und eine geringe Durchdringung von BEFs unterstellt. Das erste Szenario stellt das sogenannte „opportunistische Heimladen“ dar. Hierbei wird angenommen, dass BEFs im Zustand „zu Hause“ sofort geladen werden, ohne auf Netzparameter oder bevorstehende Photovoltaik-Einspeisung zu warten. Szenario 2 wird „antizipierendes Heimladen“ genannt. Hierbei werden Ladevorgänge bei Erreichen einer Batteriekapazität von 78% unterbrochen, sofern innerhalb der nächsten 24 Stunden ein lokaler Überschuss an PV-Erzeugung zu erwarten ist (instantane PV-Erzeugung abzüglich des erwarteten Strombedarfs im Gebäude). Der Schwellenwert von 78% wurde hierbei in Anlehnung an bestehende Befragungen zu Präferenzen von Nutzerinnen und Nutzern von BEFs gewählt . Die Bewertung lokaler PV-Überschüsse basiert hierbei auf dem SimStadt Modell zur Wiener Fallstudie. Die resultierenden Ladebedarfsprofile wurden für ein BEF normiert und in der UDT-Plattform bereitgestellt. Die maximale Ladeleistung wurde in beiden Szenarien mit 3,7 kW angenommen. Abbildung 5 zeigt den mittleren täglichen Ladeverlauf eines Tages im Juli für ein BEF innerhalb des angenommenen Pools an BEFs in der

mit einer hohen zeitlichen Auflösung von 1 Minute für den Energieverbrauch in Wohngebäuden, vor allem Strom und Warmwasser, zu generieren. Zusätzlich erzeugt sie Verhaltensdaten, Reise- und Standortdaten. https://loadprofilegenerator.de/

Energiegemeinschaft unter Berücksichtigung einer typischen jährlichen Fahrleistung in Wien (6500 km). Während durch opportunistisches Heimladen typische Bedarfsspitzen in den Abendstunden entstehen (überlappend mit bestehenden Bedarfsspitzen in der Nutzung von Haushaltsstrom), erlaubt antizipierendes Laden eine Verschiebung von Ladevorgängen in die Morgenstunden und den Vormittag, an denen lokaler PV-Überschuss erwartet wird. Es ist hierbei zu beachten, dass die normierte typische Ladekurve die Nutzung von BEFs in den Morgenstunden berücksichtigt, sodass viele Ladevorgänge im Laufe des Vormittags abgebrochen werden, weil die BEFs nicht mehr mit der lokalen Lademöglichkeit (zu Hause) verbunden sind. Durch diesen Effekt folgt die antizipierende Ladekurve nicht exakt dem typischen Verlauf der solaren Einstrahlung, und es ergibt sich während der Sonnenstunden um 12:00 eine im Vergleich zu den Morgenstunden reduzierte Ladeleistung. Die Diskrepanz zwischen der berücksichtigten maximalen Ladeleistung pro BEF (3,7 kW) und der maximalen Ladeleistung in Abbildung 5 ergibt sich aus der Mittelung der Ladeleistung über alle berücksichtigten BEFs. Durch die Annahme der vollständigen Nutzung des lokalen Solarpotenzials ergeben sich zudem in den Sommermonaten bereits in den Morgenstunden Überschüsse in der Solarproduktion, die durch die BEFs genutzt werden können.

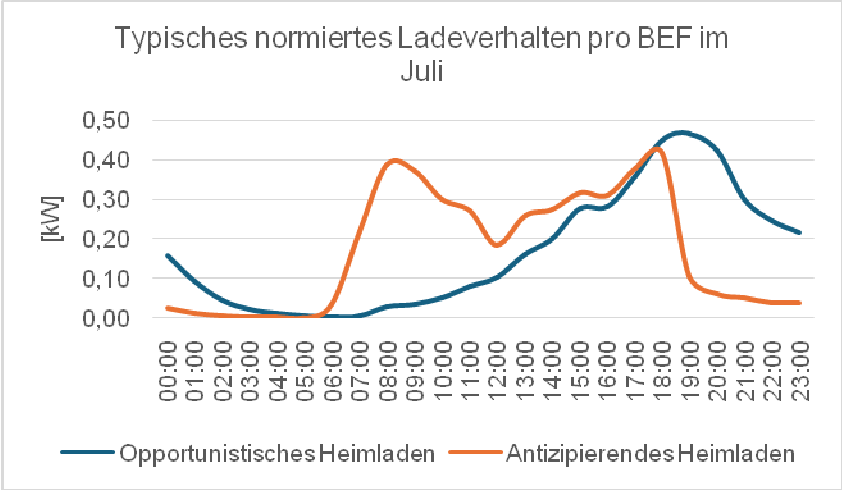


Abbildung 5: Normiertes Ladeverhalten eines BEFs für einen Tag im Juli anhand zweier Ladeszenarien. ©AIT

3.6 Partizipative Analyse der Smart-Meter-Daten

Wie im Kapitel 3.5 gezeigt variieren die Energieverbrauchskurven je nach Haushaltstyp stark. Dies war ein Grund dafür, dass im Rahmen des Projektes ein Online-Tool programmiert wurde, das es ermöglicht, die Smart-Meter-Daten der Wiener Haushalte zu laden und das folgende Analysen bietet:

- Allgemeine Analyse der 15min-Daten:
- Einteilung in spezifische Zeitgruppen
- Darstellung der Energieverbräuche je Zeitgruppe
- Ökonomische Analyse
- Mit spezifischen Tarifen für die Zeitgruppen und einem Ökotarif der für einen spezifischen -Zeitraum z.B. April bis August in den Stunden der Höchstleistung (Überschussproduktion) der PV-Stromerzeugung (12:00-16:00) einen eigenen Tarif simulieren lässt.
- Energieverbrauchsanalyse
- Generierung von aggregierten Energieverbrauchskurven (Wochentag, Wochenende und Woche)
- PV-Strom Energieanalyse
- Analyse einer fiktiven PV Anlage und Potenziale der Eigenstromnutzung im Vergleich zum Eigenverbrauch als Jahresbilanz, aber auch auf der Basis von Stundenwerten.

Die für die Analyse benötigten Daten können über das Smart-Meter-Portal der Wiener Netze als CSV-Dateien in 15-Minuten-Werten heruntergeladen werden.[10]

DSGV-konform werden keine Daten übertragen, sondern vom Online-Tool lokal auf dem Gerät des Benutzers verarbeitet. Es gibt jedoch die Möglichkeit, dass auf freiwilliger Basis aggregierte Tagesverläufe mit Stundenauflösung, zusammen mit einer Beschreibung der Haushalte übermittelt werden. Diese Daten können in weiterer Folge helfen, die lokale Analyse mit SimStadt für das Untersuchungsgebiet zu verbessern.

Abbildung 6 zeigt einen Screenshot des Tools. Im Block „DATEN“ können durch Drücken des Buttons „Browse“ (1) die csv-Daten in den Browser geladen werden. Daran anschließend wird die Analyse automatisch durchgeführt. Wenn unter (2) eine Änderung der Zeitgruppen oder der dazugehörigen Tarife eingegeben wird, werden die Berechnungen aktualisiert. Unter (3) kann vom Normaltarifsystem auf einen Ökotarif umgestellt werden, der es ermöglicht, einen spezifischen Zeitraum für den Ökotarif (z.B. April-August 12:00 – 16:00) und den Tarif selbst einstellen zu lassen. Die restlichen Tarife können wieder unter (2) verändert werden.

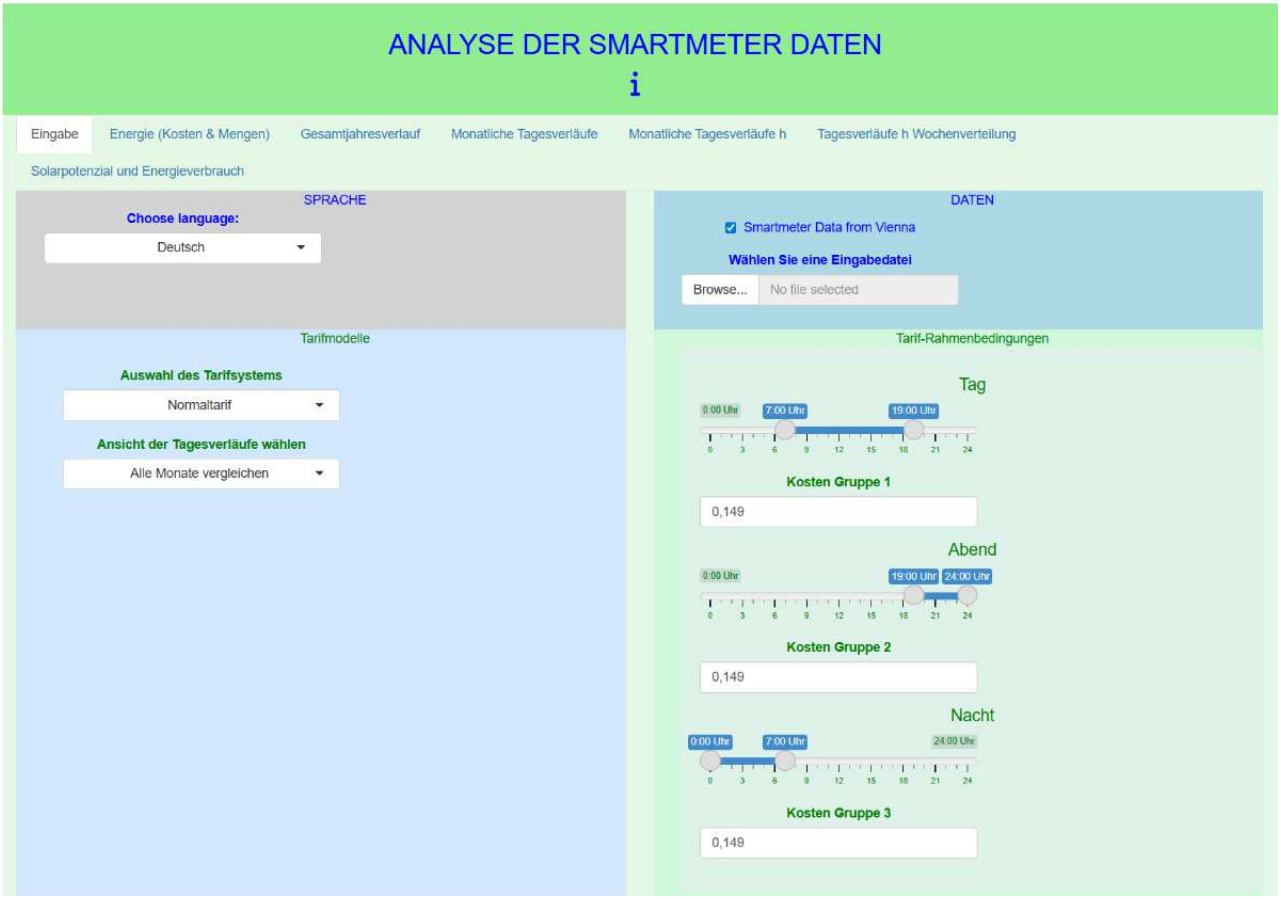


Abbildung 6: Screenshot der Powerflex-Webapplikation zur Smart-Meter-Datenanalyse https://cities.ait.ac.at/powerflex/ ©AIT

Die Abbildung 7 zeigt für die Monate Jänner (01) bis Dezember (12) die dazugehörigen Energieverbräuche und Kosten, die nach dem Datenimport automatisch berechnet werden.

[10] https://www.wienernetze.at/smart-meter-webportal, getestet am 27.01.2026. Anmerkung: Damit die 15-Minuten-Daten exportiert werden können, müssen sie im Portal aktiviert worden sein, denn erst ab der Aktivierung werden sie gesammelt und zum Download zur Verfügung gestellt.

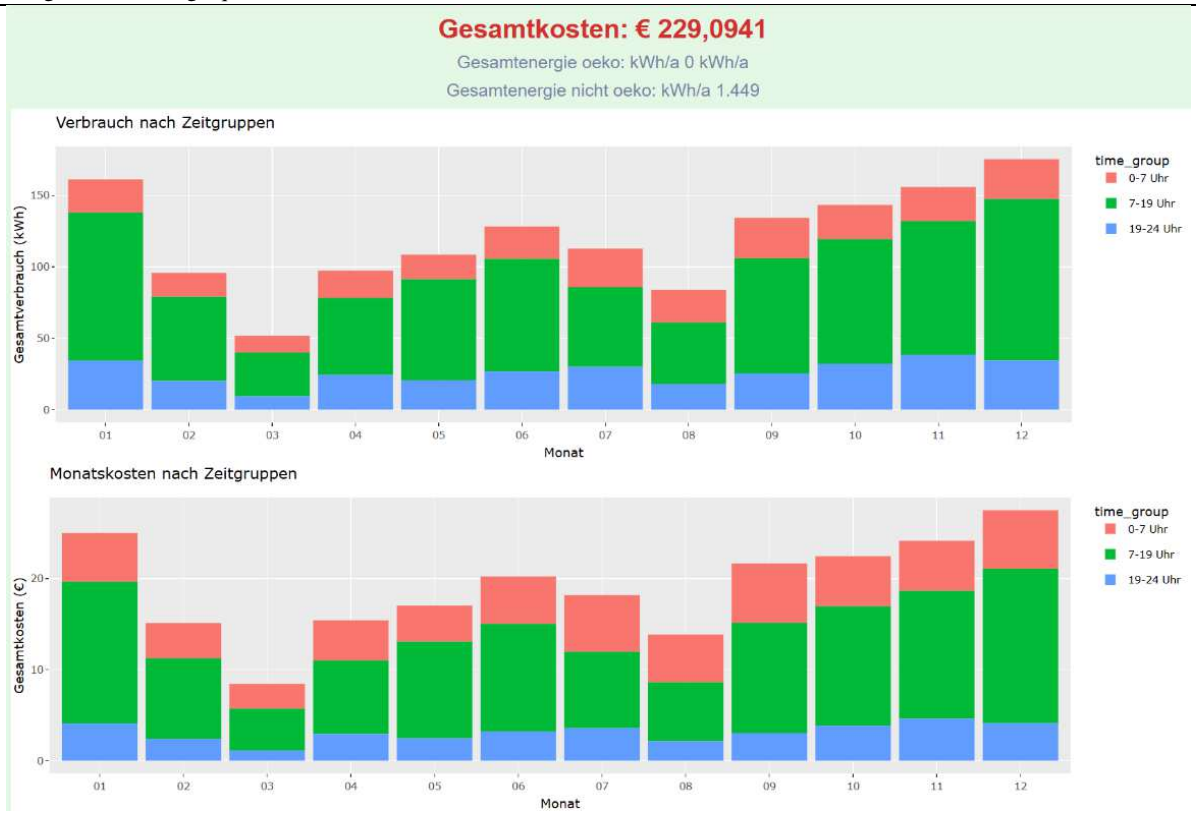


Abbildung 7: Verbrauch und Kosten nach Zeitgruppen ©AIT

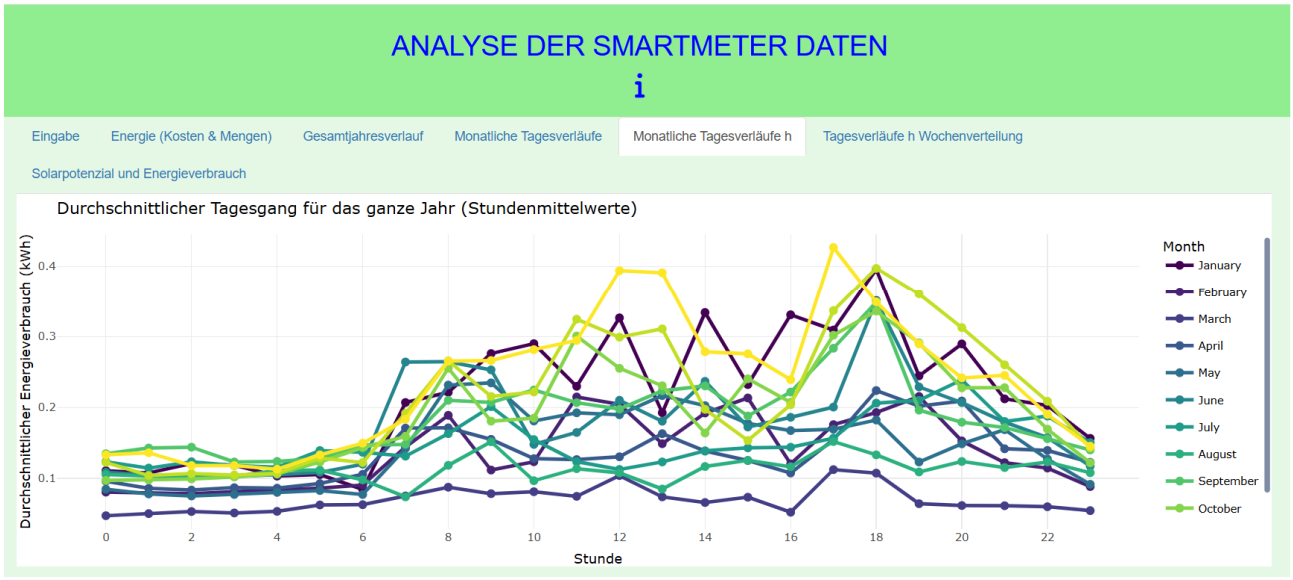


Abbildung 8:Analyse der Tagesgänge in den Monaten ©AIT

Das Online-Tool bietet zusätzlich die Möglichkeit, mittels einer fiktiven Solaranlage und deren stündlichem Strom-Produktionspotenzials[11] eine Analyse der direkten nutzbaren Stromproduktion durchzuführen (4 & 5). Dies ist zwar nur eine Näherung, aber im Vergleich zu einer jährlichen oder monatlichen Bilanzierung liefert dies eine viel genauere Abschätzung. Wie in Abbildung 9 dargestellt, ergibt sich für das vorliegende Beispiel ein 33% Eigenutzungsanteil des PV-Stroms, der von einer 1kWp Anlage produziert wird.

[11] Input dafür sind 10-minütige Solareinstrahlungsdaten im Jahr 2024 für Wien. Diese Daten wurden auf 8760 Stundenpro Jahr aggregiert und mit den stündlichen Verbrauchsdaten aus den SMART-METER-DATEN verglichen.

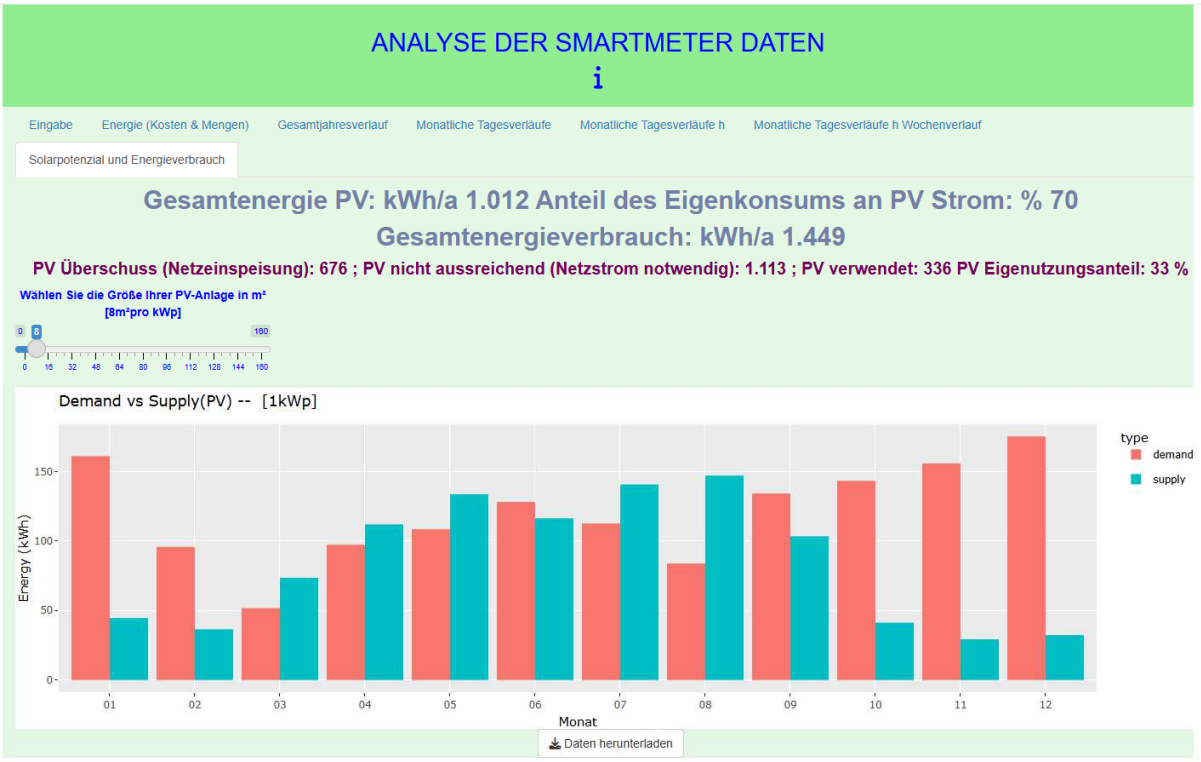


Abbildung 9: Analyse der Verbrauchsdaten gegenüber der Produktion einer fiktiven PV-Stromanlage ©AIT

Abbildung 10 zeigt die Energieverbrauchskurven, Stundenmittelwerte und die Unterschiede an Wochentagen (Werktagen) und am Wochenende sowie den Durchschnitt der Woche. Diese Daten können helfen das SimStadt-Simulationstool mit realen lokalen Daten zu parametrisieren und somit die oben angeführte Standardlastkurve (Abbildung 4) zu adaptieren. Dazu ist es notwendig, dass die Analysedaten (Stundenmittelwerte) inklusive soziodemografischer Angaben (Hauhaltsgröße, Haushaltstyp und Postleitzahl) übermittelt werden (siehe Abbildung 10). Die Soziodemographischen Daten ermöglichen eine Hochrechnung auf das gesamte Untersuchungsgebiet.

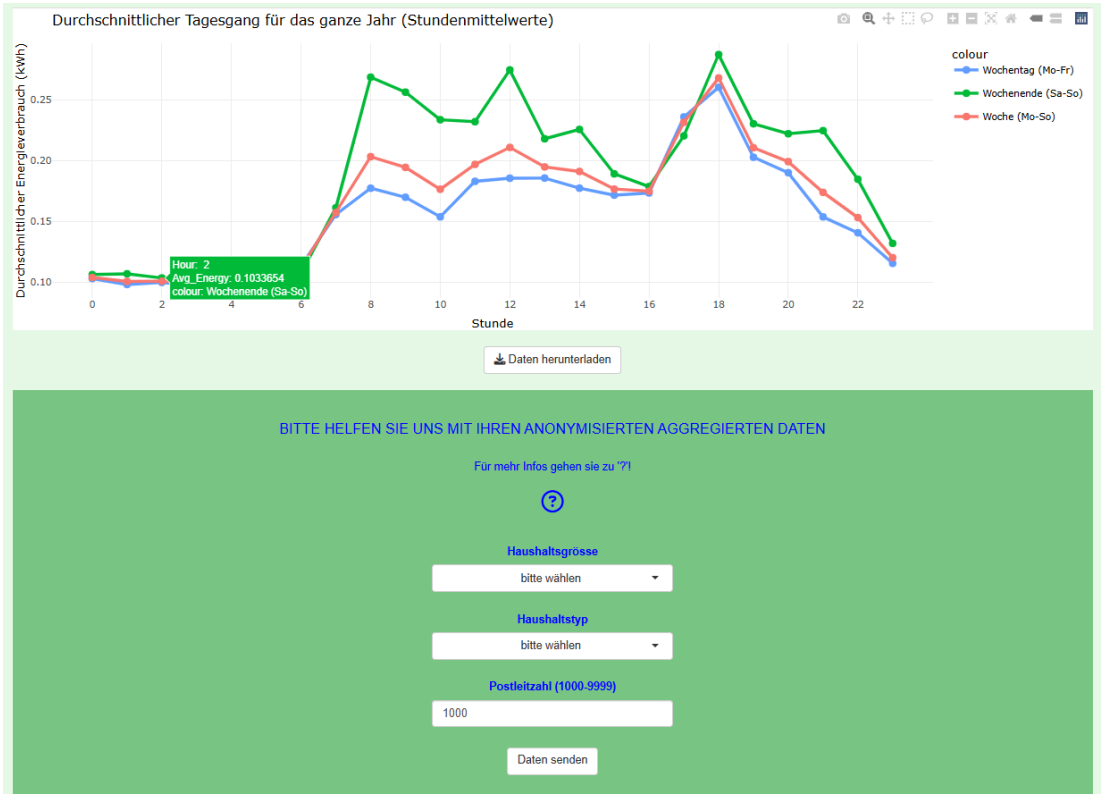


Abbildung 10: Durchschnittliche Tagesverläufe -Vergleiche Wochentage zu Wochenende ©AIT

4 FAZIT UND AUSBLICK

Die UDT-Plattform und Smart-Meter-Daten-Analysen ermöglichen eine ganzheitliche, transparente und partizipative Energiesystemanalyse auf Quartiersebene. Sie schaffen eine gemeinsam nutzbare Daten und Modellsicht, die technische Optimierung und gesellschaftliche Legitimation verbindet – eine notwendige Voraussetzung für die Realisierung von PEQs. Durch die Aufnahme normierter Ladeprofile für BEFs in die UDT-Plattform können die Auswirkungen eines roll-outs von BEFs auf die stündliche Strombilanz im betreffenden Planungsgebiet abgeleitet werden. Darüber hinaus wird die in beschriebene Methode zur Bewertung des Einflusses bidirektionalen Ladens genutzt. Die Simulationen werden im Februar 2026 für die Fallstudie Wien durchgeführt und dann im Stakeholder-Workshop im April präsentiert und diskutiert.[12] Die Webapplikation zur Analyse der Smart-Meter-Daten steht bereits als Prototyp zur freien Verwendung zur Verfügung und wird bis zum Projektende noch erweitert. https://cities.ait.ac.at/powerflex/.

5 DANKSAGUNG

Dieses Projekt wird vom BMIMI[13] und im Rahmen des Forschungs- und Innovationsprogramms „Horizon Europa“ der Europäischen Union unter der Fördervereinbarung Nr. 101069506 gefördert. Besonderen Dank möchten wir der MA20 und MA41 für die Projektunterstützung aussprechen, ferner unseren transnationalen Projektpartnern unter der Leitung der HFT Stuttgart.

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Placemaking an der Schnittstelle von Stadt- und Tourismusentwicklung

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1 ABSTRACT

Der Beitrag präsentiert die Ergebnisse einer interdisziplinären Kooperation, aus der zwölf Prinzipienfür Placemaking an der Schnittstelle von Stadt- und Tourismusentwicklung hervorgingen (Dlabaja, Werl, Höftberger, 2025). Diese basieren auf den Befunden des Forschungsprojekts „Learning Journey – Zufußgehen durch die Innere Stadt“ (Dlabaja, 2025a) sowie auf der institutionenübergreifenden Zusammenarbeit zwischen der Stiftungsprofessur für nachhaltige Stadt- und Tourismusentwicklung, der FHWien der WKW, dem Team Strategische Destinationsentwicklung des WienTourismus sowie der UIV Urban Innovation Vienna, deren Ergebnisse im Aktionsprogramm “Placemaking” von WienTourismus mündeten. Die gemeinsame Bearbeitung des Themas verknüpft Befunde aus Forschung, Tourismus und Stadtplanung. Das Forschungsprojekt „Learning Journey“ untersuchte anhand von vier Fallstudien (Schwedenplatz, Michaelerplatz, Albertinaplatz und Heldenplatz), wie bestehende Planungsprozesse für zukünftige Anforderungen in der Stadt- und Tourismusentwicklung erweitert werden können. Dabei gilt es vor allem, die Verknüpfung zwischen nachhaltiger Stadtplanung und Tourismusentwicklung zu stärken und dadurch Synergieeffekte zu erzielen. Ein Schwerpunkt lag auf der Analyse der Gestaltungs- und Planungsprinzipien für den öffentlichen Raum im Zusammenspiel mit den Besucherströmen im ersten Bezirk mit dem Ziel, die Qualität des Zufußgehens für die Bewohnerinnen und Bewohner zu erhöhen. Dadurch wurde eine solide, auf Prozesswissen und empirischen Erkenntnissen basierende Grundlage geschaffen, um das komplexe Netzwerk der beteiligten Akteurinnen und Akteure zu stärken und den Auswirkungen zunehmender Verdichtung und urbaner Hitze mittels integrativer Prozessplanung konstruktiv zu begegnen. Der vorliegende Beitrag befasst sich mit Placemaking an der Schnittstelle von Tourismus und Stadtentwicklung und konzentriert sich dabei auf Instrumente zur Schaffung resilienter, inklusiver, lebendiger, zugänglicher und lebenswerter Orte in der Stadt. Als wissenschaftliche Grundlage dienen Care-Konzepte, wie sie u.a. bei Joan Tronto (2013),Angelika Fitz und Elke Krasny (2019) sowie Cornelia Dlabaja (2021) entwickelt wurden. Im Hinblick auf das Verständnis von Tourismus knüpft der Beitrag an den Ansatz der Visitor Economy an und bezieht sich insbesondereauf die Visitor Economy Strategy des WienTourismus, die eine nachhaltige Stadt- und Tourismusentwicklung anstrebt und die Bedürfnisse von Besucherinnen, Besuchern, Einwohnerinnen und Einwohnern in Balance bringt. Sie zielt darauf ab, die Lebensqualität der Einwohnerinnen und Einwohner durch touristische Entwicklungen zu verbessern. Die 12 Prinzipien für die Gestaltunglebenswerter Orte umfassen Aspekte, die von Gestaltung und Design, über Ko-Kreation und Partizipation, bis hin zu Fragen der Governance und Steuerung reichen. Das „Vienna Playbook: The Places To Be“ (2025) zeigt, wie öffentliche Räume lebendig, inklusiv und zukunftsfähig mittels Governance- und Placemaking-Ansätzen gestaltet werden können.

Keywords: Placemaking, Tourismusentwicklung, Stadtentwicklung, Soziale Nachhaltigkeit, Öffentlicher Raum

2 HERAUSFORDERUNGEN DER NACHHALTIGEN TOURISMUSENTWICKLUNG

Um langfristige Entwicklungen und Herausforderungen wie die Verdichtung und Touristifizierung von Städten zu verstehen, ist es notwendig, die wirtschaftlichen Ankerpunkte lokaler Standortentwicklungen und die damit verbundenen strukturellen Verschiebungen zu analysieren. Ein verbindendes Merkmal vieler Kulturerbestädte ist, dass sie eine Geschichte als ehemalige Industriestandorte haben, die aufgrund komplexer Transformationsprozesse als solche an Bedeutung verloren, wie Venedig, Cagliari oder Hallstatt (Dlabaja, 2026). Dies führte zu Herausforderungen in der Standortentwicklung, die durch die Ausrichtung der Gebiete auf touristische Funktionen kompensiert wurden. Damit verbunden war die wirtschaftliche Fokussierung auf den Tourismus, die mit einer Umgestaltung und Neuordnung des öffentlichen Raums sowie der Erdgeschoßzonen entsprechend den Bedürfnissen der Besucherinnen und Besucher einherging. Diese Neuordnung hat Auswirkungen auf die Zusammensetzung der lokalen Wirtschaft und führt in Städten wie Venedig oder Lissabon in Teilen der Stadt zu einer wirtschaftlichen Monokultur (Van da Borg, 1997;

Russo, 2002), die sich auf das Alltagsleben ihrer Bewohnerinnen und Bewohner negativ auswirkt. Das Ergebnis sind überfüllte öffentliche Räume in der Hochsaison, die als Kulisse für Fotos dienen (D'Erasmo, 2017), die über soziale Medien verbreitet werden. Gleichzeitig entsteht eine Tourismuswirtschaft, die sich nicht an den Bedürfnissen der lokalen Bevölkerung orientiert, sodass Souvenirläden und Restaurants Geschäfte für Waren des täglichen Bedarfs ersetzen (Urry, 2002). Der Wohnungsmarkt wird durch Kurzzeitvermietungen verändert, was die Einwohnerzahl senkt. Familien ziehen aus den touristischen Stadtvierteln weg und Schulen schließen (Dlabaja, 2026; Russo, 2002). Dies wirkt sich negativ auf die demografische Struktur der Nachbarschaften aus. Diese Entwicklung wird in Städten wie Venedig, Hallstatt oder Salzburg durch die Imageproduktion in Filmen, Serien und sozialen Medien verstärkt (Urry, 2002). Zusätzlich beeinflussen touristische Mobilitätsinfrastrukturen, wie Häfen, (Bus)Bahnhöfe und Flughäfen die Touristenströme.



Abbildung 1: Arenen der Ausverhandlung in der Tourismusentwicklung. Grafik: Cornelia Dlabaja

Die Analyse von Kulturerbestädten, die von Tagestourismus transformiert werden, zeigt, dass es sieben zentrale Felder der Ausverhandlung gibt, die sie herausfordern (Dlabaja, 2025):

- Erhöhter Druck auf den öffentlichen Raum aufgrund von Dichte durch Tagestourismus und die damit verknüpfte Transformation der Erdgeschoßzone durch die Nutzungsansprüche von Besucherinnen und Besuchern.
- Herausforderungen des leistbaren Wohnens und privatisierter öffentlicher Infrastrukturen.
- Das Image der Städte mit kulturellem Erbe, das über soziale Medien verbreitet wird und Städte zu Fotokulissenmacht.
- Negative Effekte auf den Alltag der lokalen Bevölkerung, den Arbeits- und Schulalltag, die fehlenden öffentlichen Infrastrukturen bedingt durch Schließungen und Privatisierungen.
- Der demografische Wandel, ausgelöst durch Städtewachstum führt zu zunehmender Dichte und Konkurrenz um Wohnraum. Gleichzeitig Verdrängungseffekte und Alterungsprozesse, die in Zusammenhang mit den Phänomenen des Übertourismus stehen.
- Fehlendes Mobilitäts- und Besucherstrommanagement.
- Monozentrierte Standortentwicklung, die andere Wirtschaftsbereiche vernachlässigt und nur auf Tourismusentwicklung fokussiert (siehe Abbildung 1).

3 THEORETISCHE RAHMUNG – SORGETRAGEN FÜR DIE STADT

Care wird in diesem Beitrag als analytische Linse verstanden, um Placemaking in touristifizierten Stadträumen nicht nur als Gestaltungspraxis, sondern als demokratische Aushandlung von Räumen undnachbarschaftlichen Infrastrukturen zu untersuchen. Damit lässt sich sichtbar machen, wer Bedürfnisse

definiert, wer für die Folgen touristischer Entwicklung einsteht und wie Zugänge zu Raum und Infrastruktur verteilt werden.Die theoretische Rahmung des Beitrags baut auf den Arbeiten von Joan Tronto und ihrem Buch Caring Democracy (Joan Tronto, 2013), auf dem Buch Critical Care: Architecture and Urbanism for a Broken Planet (2019) von Elke Krasny und Judith Fritz sowie auf der Publikation Caring for the City (Dlabaja, 2021) auf.Mit ihrer Monografie „Caring Democracy: Markets, Equality, and Justice“ (Tronto 2013) hat Joan Tronto die interdisziplinäre Debatte um Care vorangetrieben. In ihrem Werk arbeitet sie heraus, dass Care-Arbeit keine private, sondern eine gesellschaftliche Aufgabe ist. Joan Tronto entwickelt in ihrem Buch vier Phasen von Sorgetragen: caring about (Bedarf wahrnehmen), taking care of (Verantwortung übernehmen), care giving (Sorge leisten), und care receiving (Resonanz). Der normative Rahmen dieser Praktiken bildet das Sorgetragen für die Stadt als Ganzes – wie im Falle Venedigsgegen die Verschmutzung der Lagune und der Sorge vor dem Untergang der Stadt, wegen des steigenden Meeresspiegels, oder das Sorgetragen für die Nachbarschaft, wie für ältere Bewohnerinnen nud Bewohner oder für gemeinschaftliche Infrastrukturen. Die Überlegungen in diesem Abschnitt basieren auf den Erkenntnissen der Forschung zu Venedig (Dlabaja, 2021, 2026). Daraus lassen sich verschiedene Formen von Fürsorge und solidarischer Praktiken für die Nachbarschaften durch lokale Initiativen beobachten. Am Beispiel der Vida-Bewegung zeigt sich, wer sich wie für die kommunalen und gemeinschaftlichen Infrastrukturen Venedigs einsetzt. Mitglieder der Initiative besetzten ab 2017 das ehemalige anatomische Institut (Antico Teatro di Anatomia di Venezia), am Campo San Giacomo dall’Orio (Dlabaja, 2021), das von der Stadt an einen privaten Investor verkauft wurde. Der Investor plant den Bau eines Restaurants. Dies ist für die Nachbarschaft problematisch, da in den letzten Jahren zahlreiche Restaurants eröffnet wurden und dadurch der ohnehin knappe öffentliche Raum weiter reduziert wurde. In einem Viertel, in dem viele Familien mit Kindern leben, ist das ein großes Problem, zumal es in der Nähe keine Spielplätze gibt. Der Effekt ist, dass die Bürgerinitiative sehr breit getragen wird und viele Bewohnerinnen und Bewohner des Viertels darin involviert sind. Teil der Bewegung sind Anwohnerinnen, Anwohner, Familien mit Kindern, ältere Menschen, aber auch Wissenschaftlerinnen, Wissenschaftler, ehemalige Mitarbeiterinnen und Mitarbeiter der Stadtverwaltung, Studentinnen und Studenten, die sich mit der Gruppe solidarisieren. Nachdem die Polizei die Besetzung beendete, verlagerte die Initiative ihre Aktivitäten in den öffentlichen Raum und gründet später eine weitere Nachbarschaftsinitiative und Food-Coop. Es werden regelmäßige Nachbarschaftsessen, Theateraufführungen, Flohmärkte, Lesungen und Interventionen im Stadtraum organisiert.Mit Bezug zu den von Joan Tronto (2013: 20) herausgearbeiteten vier Phasen des Sorgetragens, kannPlacemaking als Ansatz einer sorgetragenden Stadtplanung (vgl. Gabauer et al., 2022) für die Prinzipien des Placemaking an der Schnittstelle von Stadt- und Tourismusentwicklugn weiterentwickelt werden. 1) Eine Gruppe von Bewohnerinnen und Bewohnern erkennt die Notwendigkeit für die Stadt und ihre Gemeinschaft, Sorge zu tragen. Der Anlass ist in diesem Fall der Massentourismus in Form des Tagestourismus, der die Bewohnerinnen und Bewohner in ihren Alltagsräumen, sowie durch Kommodifizierung von Gemeingütern in ihren gemeinschaftlichen Infrastrukturengefährdet. 2) Es formiert sich eine aktive Nachbarschaft als Bürgerinitiative, die sich aus Familien mit Kindern, älteren Bewohnerinnen, älteren Bewohnern, Forscherinnen, Forschern und Studierenden zusammensetzt. 3) Diese Gruppe entwickelt verschiedene Formen des Sorgetragens für die Nachbarschaft. Sie umfassen: Treffen, die Organisation von Gemeinschaftsaktivitäten, Informations- und Medienarbeit und die Vernetzung mit anderen Organisationen. 4) Die Prozesserufen Reaktionen hervor, wie die Förderung von Nachbarschaftsinitiativen durch die Stadtverwaltung, die Entstehung weiterer Projekte, wie Nachbarschaftsgärten, Food Coops und selbstorganisierte Räume für die Nachbarschaft. Es entsteht eine Form der urbanen Resilienz – verstanden als Robustheit von Alltagsinfrastrukturen und Selbstorganisation – durch das Sorgetragen für die Gemeinschaft.Diese stärkt den stark touristisch genutzten Ort gegenübereiner singulären touristische Nutzung, da gemeinschaftliche Infrastrukturen sichtbar machen, dass eine Form von Placeownership durch die lokale Nachbarschaft besteht, die durch Ansätzedes Placemakingsunterstützt wird.Dazu bedarf es Ressourcen wie Nachbarschaftsbudgets oder Fördermodi, wie sie in Wien bereits im Rahmen der Lokalen Agenda21 in Form von Grätzloasen und Nachbarschaftsbudgets angewandt werden.

4 PLACEMAKING ALS INSTRUMENT FÜR URBANE RESILIENZ

Die Frage, wie negativen Dynamiken eines wachsenden Städtetourismus aus einer Care-Perspektive begegnet werden kann, verweist auf die Notwendigkeit eines integrierten Gestaltungsansatzes für den öffentlichen Raum. Placemaking bietet hierfür eine konzeptionelle und methodische Grundlage, da es

räumliche Gestaltung, soziale Aushandlung und institutionelle Koordination miteinander verbindet. Im Kontext nachhaltiger Tourismusentwicklung kann Placemaking zur qualitativen Aufwertung urbaner Räume beitragen und zugleich Resilienz gegenüber einseitigen Nutzungslogiken stärken.Die Wurzeln des Placemaking reichen in die stadtsoziologischen und planungskritischen Debatten der 1960er- und 1970er-Jahre zurück. Jane Jacobs (1992) betonte die Bedeutung lebendiger Straßenräume und sozialer Interaktion für Sicherheit und Gemeinschaft („eyes on the street“). William H. Whyte (1980) analysierte in empirischen Beobachtungen die soziale Nutzung öffentlicher Räume und zeigte, dass Aufenthaltsqualität wesentlich von menschlicher Interaktion abhängt. Aufbauend auf diesen Arbeiten entwickelte das Project for Public Spaces (PPS 2007; 2009) seit den 1970er-Jahren praxisorientierte Leitlinien für gemeinschaftsbasierte Stadtgestaltung. Zentral ist dabei die Annahme, dass Orte nicht allein durch Planung „gemacht“ werden, sondern durch Nutzung, Aneignung und lokale Verantwortung entstehen.

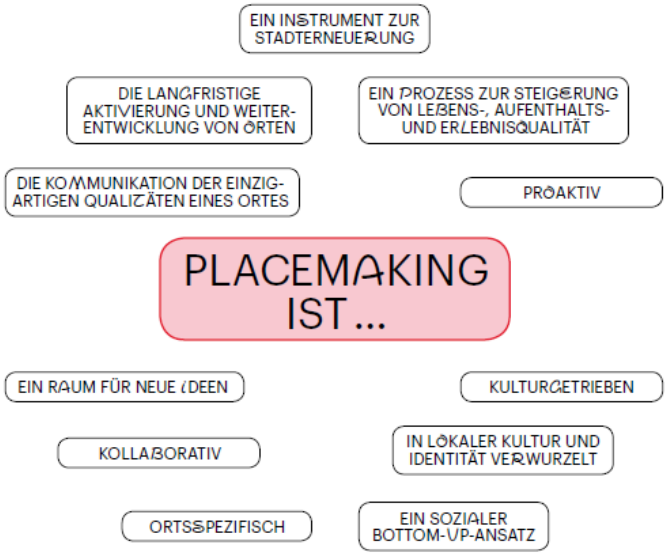


Abbildung 2: Placemaking ist ... , Grafik: seite zwei.

Im Sinne des Vienna Playbook (Dlabaja et al. 2025) verstehen wir Placemaking als kooperativen, bewohnerinnen-, bewohner- und ortszentrierten Ansatz (siehe Abbildung 2). Ziel ist die Entwicklung funktionaler, lebendiger und bedeutungsvoller Orte, die die Identität und Bedürfnisse lokaler Akteurinnen und Akteure widerspiegeln. Räume werden nicht als statische Strukturen begriffen, sondern als relationale Anordnungen (Löw 2001) und dynamische Lebensräume, die von Akteurinnen und Akteuren (vgl. Dlabaja et al. 2025), die mit unterschiedlichen Ressourcen ausgestattet sind und Möglichkeit zur Entscheidungsfindung (Adam& Vonderau, 2014) durch soziale Praktiken, kulturelle Ausdrucksformen und alltägliche Nutzung geprägt sind. Ähnliche Definitionen finden sich bei UN-Habitat (2015; United Nations, 2017), wo Placemaking als kollaborativer Prozess zur Gestaltung des öffentlichen Raums beschrieben wird, der gemeinschaftlichen Mehrwert schafft und physische, soziale sowie kulturelle Dimensionen integriert. Jan Gehl (2011) hebt in diesem Zusammenhang die Bedeutung partizipativer, inkrementeller Verbesserungen hervor, um lebenswerte Städte für unterschiedliche Nutzerinnen- und Nutzergruppen zu entwickeln. In der aktuellen Debatte wird zwischen kurzfristigen, experimentellen Interventionen und langfristiger Planung unterschieden. Tactical Urbanism setzt auf temporäre, kostengünstige Maßnahmen, die schnelle sichtbare Veränderungen ermöglichen und Beteiligung erfahrbar machen (Kaw et al. 2020). Solche Interventionen entfalten jedoch nur dann nachhaltige Wirkung, wenn sie in umfassendere Planungs- und Steuerungsprozesse eingebettet sind. Eine rein strategische, masterplanbasierte Planung hingegen riskiert mangelnde Flexibilität und fehlende lokale Verankerung. Placemaking verbindet daher beide Logiken: iterative, kleinräumige Impulse mit langfristiger struktureller Verankerung. Vor diesem Hintergrund wird zunehmend von „place-led development“ gesprochen (Kent 2013; Kent & Kent 2017). Gemeint ist ein Ansatz, der sowohl institutionelle Rahmenbedingungen als auch lokale Selbstorganisation berücksichtigt. Staatliche Akteurinnen und Akteure fungieren weniger als alleinige Entscheidungsträger, sondern als Ermöglicher und Moderatoren kooperativer Prozesse. Placemaking umfasst damit nicht nur räumliche Gestaltung, sondern auch Fragen von

Organisation, Kommunikation und langfristiger Betreuung. Es steht in engem Zusammenhang mit Place Marketing und Place Management. Während Place Marketing die Identität und Besonderheit eines Ortes kommuniziert, sichert Place Management dessen dauerhafte Pflege, Programmierung und Weiterentwicklung. Beide Dimensionen sind integraler Bestandteil eines umfassenden Placemaking-Ansatzes (Dlabaja et al. 2025), da sie verhindern, dass Orte entweder rein funktional gestaltet oder ausschließlich vermarktet werden. Für die Schnittstelle von Stadt- und Tourismusentwicklung ist zudem die Unterscheidung zwischen geplantem und organischem Placemaking zentral (Lew 2017). Tourismus folgt häufig marktorientierten Steuerungslogiken, in denen Orte strategisch positioniert werden. Gleichzeitig entstehen Orte durch alltägliche Praktiken von Bewohnerinnen, Bewohnern und Gästen ko-produktiv. Eine nachhaltige Tourismusentwicklung setzt daher voraus, dass formale Planungsprozesse mit informellen Aneignungsformen in Dialog treten. Aufbauend auf der Visitor-Economy-Strategie des Wien Tourismus (2018; 2025) versteht der vorliegende Beitrag Placemaking als Instrument, um touristische Wertschöpfung mit Lebensqualität, sozialer Infrastruktur und lokaler Identität zu verbinden. Vor diesem Hintergrund wird Placemaking als handlungsorientierter Ansatz verstanden, der im Rahmen der Fallstudien empirisch erprobt und in den zwölf Prinzipien für die Schnittstelle von Stadt- und Tourismusentwicklung operationalisiert wird.

5 DER FORSCHUNGSANSATZ

Um angewandte Grundlagen zur Untersuchung von Placemaking an der Schnittstelle von Stadt- und Tourismusentwicklung zu gewinnen, wurde das Forschungsprojekt „Learning Journey – Zufußgehen durch die Innere Stadt“ unter der Leitung von Stiftungsprofessorin Cornelia Dlabaja an der FH Wien der WKW konzipiert und umgesetzt. Ziel dieses Projekts war es, Herausforderungen und Gestaltungspotenziale des öffentlichen Raums in Wiens erstem Bezirk empirisch zu erfassen und mittels akteurszentrierter Methoden Perspektiven von Bewohnerinnen, Bewohnern, Entscheidungsträgerinnen, Entscheidungsträgern und weiteren Stakeholdern in die Analyse einzubeziehen. Die Learning Journey verbindet partizipative Methodik, Feldbeobachtungen, Spaziergänge sowie Workshops und bildet den methodischen Ausgangspunkt für die anschließende Ableitung empirischer Befunde. Zur Vorbereitung der Learning Journey erfolgte eine systematische Analyse aller öffentlich zugänglichen Planungsdokumente und Strategiepapiere zu den untersuchten Orten. Dazu zählten die Funktions- und Sozialraumanalyse Schwedenplatz/Morzinplatz (Breitfuss, 2013), der Masterplan 2.0 Innere Stadt (Wirtschaftskammer Wien, 2025), sowie Planungsgrundlagen der Stadt Wien wie der Managementplan Welterbe Historisches Zentrum Wien (Magistrat der Stadt Wien, 2021), die Analyse der Agenda 21 innere Stadt zum Zufußgehen (Lokale Agenda 21, 2024) und die Visitor-Economy-Strategie (WienTourismus, 2025). In der Vorbereitungsphase wurden außerdem 12 „Go-Alongs“ (Kusenbach, 2008) mit Bewohnerinnen, Bewohnern, Akteurinnen und Akteuren aus den Bereichen Tourismus und Verwaltung durchgeführt. Der Stakeholderprozess der Learing Journey begann mit einem Kick-off-Workshop, in dem das Projekt vorgestellt und gemeinsam mit relevanten Akteurinnen und Akteuren (Bezirksvertretung Innere Stadt, WienTourismus, Stadt Wien, WKW) Herausforderungen vergangener Planungsprozesse identifiziert wurden. Dieser Workshop wurde in Kooperation mit der Lokalen Agenda 21 (LA 21) Innere Stadt organisiert. Er bot den Teilnehmenden Raum für einen Perspektivenaustausch zu aktuellen Besucher- und Bewegungsströmen im ersten Bezirk und diente der Vernetzung im Sinne des Learning-Journey-Konzepts. Durch Kartierungen und Gespräche vor Ort sowie fünf Spaziergänge mit Stakeholdern (Stadtverwaltung, politische Vertreterinnen, politische Vertreter, Bewohnerinnen, Bewohner, lokale Initiativen, Reiseführerinnen, Reiseführer, Busunternehmerinnen, Busunternehmer, Destinationsmanagerinnen und Destinationsmanager) wurden Herausforderungen und Lösungsansätze erarbeitet. Besonders fokussiert wurden dabei Orte mit Dichtephänomenen und Klimaanpassungsbedarf (Albertinaplatz, Schwedenplatz, Michaelerplatz, Heldenplatz).Darüber hinausfanden vier Workshops und gemeinsame Go-Alongs mit bereits involvierten Akteurinnen und Akteuren (u.a. relevante Dienststellen der Stadt Wien, Bezirksvertretung, Lokale Agenda 21, Wirtschaftskammer Wien, Haus der Geschichte, WienTourismus, Bewohnerinnen, Bewohner, externe Expertinnen und externe Experten) sowie Interviews mit zwölf Bewohnerinnen und Bewohnern, Akteursgruppen (z.B. Fremdenführerinnen und Fremdenführer) und Entscheidungsträgerinnen und Entscheidungsträgern statt. Ergänzend wurde ein Geh-Café in Kooperation mit der Mobilitätsagentur Wien durchgeführt. Im Projektverlauf kamen Planspiel-Tools und interaktive Kartierungstechniken zum Einsatz, um Orte und Herausforderungen in der Inneren Stadt zu identifizieren und aufzubereiten. Ziel war die Ableitung von

Gelingensbedingungen, Herausforderungen und Strategien für zukünftige Projekte. Begleitend wurden acht internationale Expertinnen und Experten über zwei Lehrforschungsprojekte und im Rahmen des EU-geförderten Erasmus-Programms eingebunden. Das Erasmus-Programm ermöglichte den Austausch und die Kooperation zwischen internationalen Forscherinnen, Forschern und 45 Studierenden, die im Rahmen von zwei Intensivprogrammen an ausgewählten Themenfeldern und Problemstellungen in zwei europäischen Städten Lissabon und Wien arbeiteten. Im Sommersemester 2024 fand ein interdisziplinäres Forschungsseminar an der Universität Wien mit 20 Masterstudierenden der Geografie und internationalen Entwicklung statt, das von Heike Lütcken (HCU Hamburg) und Cornelia Dlabaja (FHWien der WKW) geleitet wurde. Die Studierenden untersuchten die Plätze mittels der Methoden der Sozialraumanalyse (Kessel et al. 2019; Omahna 2012) und arbeiteten Akteursperspektiven auf. Im Wintersemester 2024/25 wurde an der FH Wien der WKW ein Seminar mit 45 Masterstudierenden des Lehrgangs Urban Tourism & Visitor Economy Management, der Università Iuav di Venedig (IUAV) und Instituto Universitário de Lisboa (Iscte) durchgeführt, in dem Design-Thinking-Methoden in der Inneren Stadt getestet wurden. Im Sommersemester 2025 folgte ein Erasmus Intensivprogramm mit internationalem Teaching Team: Giovanna Marconi (IUAV), Alexandra Paio (Iscte), Donagh Horgan (Inholland University of Applied Sciences), Cornelia Dlabaja (FH Wien)sowie Yvonne Franz (Universität Wien). Im Fokus stand die Prozessmodellierung an der Schnittstelle von Stadt- und Tourismusentwicklung, wobei Placemaking, community-based Planning, taktile Ansätze und Leitbildentwicklung in komplexen Akteurssettings erprobt wurden. Als internationaler Experte im Rahmen der Kooperation mit WienTourismus nahm Ethan Kent von Placemaking X teil. Während des Erasmusprogramms konzipierten Cornelia Dlabaja und Ethan Kent gemeinsam mit Donagh Horgan die Grundzüge der zwölf Prinzipien für Placemaking an der Schnittstelle von Stadt- und Tourismusentwicklung. Ergänzt und überarbeitet wurden diese Prinzipien später gemeinsam mit Jana Werl (WienTourismus) und Katharina Höftberger (UIV). Im Zuge dieser kooperativen Bearbeitung fand auch ein Workshop mit Planungsexpertinnen und Planungsexperten der Stadt Wien statt, die über gelungenes und gescheitertes Placemaking in Wien reflektierten und so wertvolle Inputs zur finalen Ausarbeitung der 12 Prinzipien lieferten. Die Ergebnisse wurden den lokalen Akteurinnen und Akteure der Learning Journey (Bezirksvorstehung Innere Stadt, LA 21) vorgestellt. Außerdem wurden die 12 Prinzipien und mögliche weitere Handlungsansätze mit Expertinnen und Experten aus der Praxis von Architektur, Landschaftsplanung, Kunst und Stadtteilarbeit diskutiert.

6 ANALYSE DER VIER FALLBEISPIELE

In den vier ausgewählten Analysegebieten(Albertinaplatz, Schwedenplatz, Michaelerplatz, Heldenplatz) zeigen sich klar die Herausforderungen des Destinations- und Mobilitätsmanagements, wobei in jedem der vier Analysegebiete unterschiedlichen Aspekte hervortreten.

Der Albertinaplatz ist ein historischer Ort in der Stadt, der von der intensiven Nutzung diverser Nutzerinnen- und Nutzergruppen geprägt ist: Menschen, die im ersten Bezirk arbeiten und wohnen, Touristinnen, Touristen, Binnentouristinnen, Binnentouristen, Verkehrsteilnehmerinnen und Verkehrsteilnehmer, die den Straßenraum zu Fuß, am Fahrrad, mit den Hop-On-Bussen und dem PKW nutzen. Teile des Platzes wurden im Zuge der Umgestaltung des Neuen Marktes adaptiert und mit Möblierungen und Begrünungsmaßnahmen versehen. Bei der Learning Journey wurden vor allem die Aspekte der Wegeführungen und Möglichkeiten zur Entzerrung der Dichte durch die Nutzung bearbeitet. Fußgängerinnen, Fußgänger, Radverkehr, öffentlicher Verkehr, Reisebusse und Lieferverkehr konkurrieren um begrenzten Raum – insbesondere rund um die Operngasse. Die Reisebusse in der Operngasse nehmen sowohl Einfluss auf den Verkehrsfluss als auch auf die Wirtschaftstätigkeit der Geschäfte in den Erdgeschoßzonen. Das Entrée vor der Albertina wird dominiert von den Hop-on-Hop-off-Bussen – in Kombination mit längeren Warteschlangen vor einem Würstelstand und den Free-Walking-Touren, kommt es oft zu Dichteeffekten. Die Umgestaltung des Albertina-Platzes und seiner Ausstattung mit Sitzrondos und Bäumen hat die Aufenthaltsqualität erhöht und entzerrt die Dichte des Platzes. Ebenso wie die Verkehrsberuhigung, die mit der Umgestaltung des Neuen Marktes einhergeht, zu einer Entzerrung der Dichte führte.

Der Schwedenplatz bildet das Entrée in die Innere Stadt von der Seite des Donaukanals. Er ist in seiner Raumstruktur von seiner historisch belasteten Geschichte des Zweiten Weltkriegs geprägt und war Gegenstand diverser Planungsvorhaben und Sozialraumanalysen. Er ist ein zentraler Ort der städtischen Öffentlichkeit, Treffpunkt für die Wienerinnen und Wiener, in den Sommermonaten einer der Hotspots für

Eisliebhaberinnen und Eisliebhaber, aber auch von sozialer Kohäsion geprägt. Im Zuge der Learning Journey wurde untersucht, wie diese Nutzungsansprüche künftig in die Gestaltung einfließen können und wie die Dichte entzerrt werden kann. Ein zentrales Learning betrifft die Leitsysteme für Verkehr und Tourismus: Solange die Verkehrsleitsysteme und die Wegeführung unabhängig von der Dichte des Tagestourismus geplant werden, treten Probleme mit der Verkehrssicherheit sowie dem fehlenden Management unterschiedlicher Verkehrsteilnehmerinnen auf. Ein weiteres Themenfeld, das sich zeitig ist, ist die notwendige Koordination zwischen Stadtverwaltung, Bezirksvertretung und dem Wiener Tourismusverband (WienTourismus).



Abbildung 3: Schwedenplatz

Der Michaelerplatz liegt im Herzen des ersten Bezirks. Er ist einer der Hotspots, was touristische Bewegungsströme betrifft. Wesentliche Ansprüche der rezenten Umgestaltung 2024 waren Gendermainstreaming und Barrierefreiheit, sowie Aspekte der Klimaanpassung. Durch Baumpflanzungen und kühlender Gestaltungselemente sollte der Stadtraum klimaresilient gestaltet werden. Zusätzlich zur abgeschlossenen baulichen Neugestaltung bedarf es Überlegungen zur Entzerrung der Besucherströme sowie zur nachhaltigen Nutzung des Orts für die lokale Nachbarschaft und seine Unternehmerinnen und Unternehmer. Im Analysezeitraum kam das Thema des Welterbes und die kontroverse öffentliche Debatte hinzu. Proteste im Kontext von Stadtentwicklung und die Rolle von Protestbewegungen als Raumproduzentinnen und Raumproduzenten haben in Wien seit den 1970er-Jahren lange Tradition (Dlabaja, 2025).



Abbildung 4: Michaelerplatz und Heldenplatz

Der Heldenplatz ist historisch symbolträchtig und regelmäßig Gegenstand öffentlicher Debatten, was seine Gestaltung betrifft. In der öffentlichen Debatte wird die Nutzung der versiegelten Flächen, als Stellflächen für PKWs kritisch diskutiert. Gemeinsam mit diversen Stakeholdern, dem Haus der Geschichte, Akteurinnen und Akteuren der Verwaltung, dem Bezirk und der Burghauptmannschaft wurden Perspektiven einer klimaresilienten Umgestaltung, sowie das komplexe Akteurssetting, welches diese erschwert, diskutiert. Ergebnis der Analyseist eine Anzahl von Ankerpunkten für die Planung, die auf der Reflexion über zentrale Knackpunkte in den bisherigen Planungsprozessen des ersten Bezirks basieren. Dazu zählen Besitzverhältnissen, Rahmenbedingungen, Gestaltungsprinzipien und die Akteursanalyse (siehe Abbildung 3). Es hat sich gezeigt, dass diese Aspekte den Prozessverlauf maßgeblich prägen. Dabei wurde besonders

deutlich, dass Grundeigentümerinnen, Grundeigentümer, Pächterinnen und Pächter von Beginn an informiert und involviert werden müssen, damit ein Gestaltungsprozess umgesetzt werden kann. Ein weiterer Aspekt ist die vertragliche Absicherung von Planungsprozessen, sowie das Zusammenspiel politischer Entscheidungsträgerinnen und Entscheidungsträger. Es bedarf klarer Rahmenbedingungen, um die finanziellen Mittel abzusichern und abzuklären, wer für die Kosten aufkommt, sowie die Freigabe der notwendigen Mittel veranlassen kann.



Abbildung 5: Ankerpunkte für die Planung. Grafik: Cornelia Dlabaja

Befunde aus der Alltagspraxis der Bewohnerinnen zeigen, dass im Untersuchungsgebiet vor allem jene Elemente als konflikthaft wahrgenommen werden, die direkt auf ihre Alltagsmobilität, Orientierung und Aufenthaltsqualität Einfluss nehmen. Für die Bewohnerinnen und Bewohner ist in diesem Kontext eine Anpassung der Leitsysteme im Sinne von Verkehrssicherheit und einer klaren, für unterschiedliche Nutzerinnen- und Nutzergruppen lesbaren Orientierung notwendig. Diese Anforderungen gehen mit dem Thema Barrierefreiheit einher.Bodenbeläge beeinflussen gerade für ältere Bewohnerinnen, ältere Bewohner und Menschen mit körperlichen Einschränkungen die Barrierefreiheit, Nutzbarkeit und Sicherheit. Dies zeigte sich als durchgehendes Thema in der Learning Journey und an allen vier Untersuchungsorten. Gleichzeitig verdichten sich die Rückmeldungen rund um die spürbaren Effekte der Stadthitze. Hier wird deutlich, dass Begrünung und Schatten nicht als dekorative Add-ons fungieren, sondern als infrastrukturelle Voraussetzungen für klimaangepasste Alltagsräume. In diesem Zusammenhang rückt auch die Verweilqualität in den Fokus: Sie entsteht durch ein Zusammenspiel aus Mikroklima, Möblierungen und der Frage, wie Dichte räumlich organisiert wird – ob sie Überlastung erzeugt oder gesteuerter werden kann. Besonders das Zufußgehen wird dabei als zentrale Praxis sichtbar, die durch sichere Querungen, lesbare Wegeführungen und eine robuste, hindernisarme Gestaltung unterstützt werden muss.Ein spezifisches Problemfeld bildet das touristische Leitsystem: Die seit den 1980er-Jahren verbreiteten braungelben Schilder – die vom Bezirk über die MA 28 bestellt werden können – weisen aus Sicht der Praxis vor allem deshalb Defizite auf, weil eine Hierarchie in der Wegweisung fehlt und unterschiedliche Zielgruppen (Bewohnerinnen, Bewohner, Alltagsnutzerinnen, Alltagsnutzer, Gäste) nicht systematisch unterschieden werden. Als Orientierung für mögliche Weiterentwicklungen werden Good-Practice-Beispiele und Vorbilder wie Rotterdam und Edinburgh genannt, die zeigen, wie integrierte Leitsysteme, hochwertige Fußwege und klimaadaptive Gestaltung zusammen gedacht und in ein konsistentes Stadtraumkonzept übersetzt werden können.

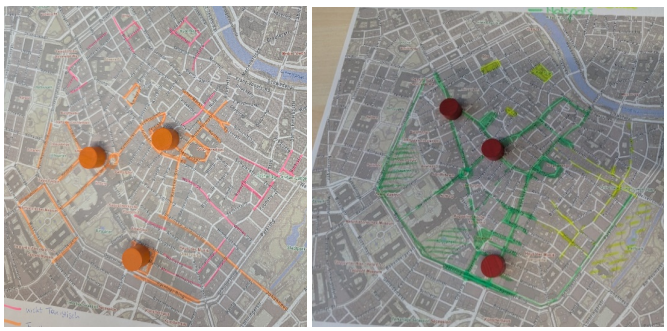


Abbildung 6: Kartierung der Vorder- und Hinterbühnen der Inneren Stadt.

In mehreren Stakeholder-Workshops wurden die Ergebnisse mit Akteurinnen, Akteuren, Bewohnerinnen und Bewohnern der Inneren Stadt diskutiert und für die Entwicklung des Playbooks zu Placemaking an der Schnittstelle von Stadt- und Tourismusentwicklung reflektiert. Ein Aspekt der aus Bewohnerinnen- und Bewohnerperspektive hervorgehoben wurde, ist das Bedürfnis "Raum für sich" zu haben. Die Bewohnerinnen und Bewohner bewegen sich im Stadtraum unter dem Eindruck, auf einer touristischen "Vorderbühne" zu wohnen. Die Bereiche, die für sie besonders wichtig und schützenswert sind, werden als "Hinterbühnen" im Stadtraum bezeichnet. Sie werden nicht so stark von Tagestourismus frequentiert und von der lokalen Bevölkerung als „ihr Raum" verstanden (siehe Abbildung 4). Dieses Phänomen lässt sich auch in anderen Städten beobachten (vgl. Dlabaja, 2021; Russo, 2002; Urry, 2002).

7 ZWÖLF PRINZIPIEN FÜR PLACEMAKING AN DER SCHNITTSTELLE VON STADT- UND TOURISMUSENTWICKLUNG

Die Erkenntnisse aus der Forschung wurden in die interdisziplinäre und institutionenübergreifenden Entwicklung der zwölf Prinzipien für gelungenes Placemaking integriert. Im intensiven Dialog wurden grundlegende Positionen zu den aktuellen Herausforderungen und Zielbildern in der Stadt- und Tourismusentwicklung herausgearbeitet. Dabei steht als gemeinsames Ziel im Zentrum, lebenswerte Orte für alle zu schaffen. Placemaking macht Orte robuster und resilienter gegenüber Dichtephänomenen, inklusiver und erlebbarer. Basierend auf den empirischen Befunden des Wiener Fallbeispiels und dem breiten internationalen Diskurs, soll die Debatte zur integrativen Planung im Bereich der Stadt- und Tourismusentwicklung befruchtet werden. Die Grundsätze für erfolgreiches Placemaking in der Stadtentwicklung und im Tourismus umfassen grundlegende Anforderungen, „How-to"-Schritte für Placemaking und Elemente der Stadt, also Eigenschaften des Raums, die erforderlich sind.

Lebenswerte Orte entstehen nicht zufällig – sie werden durchMenschen gestaltet, durch ihre Ziele, Werte und ihr tägliches Handeln.Nachdem zuvor erörtert wurde, was einen Ort bedeutungsvoll machtund wie Placemaking Gestaltung, Nutzung, Identität sowie die fortlaufende Aushandlung unterschiedlicher Interessen verbindet, folgtnun der Schritt von der Theorie zur Praxis.Dafür wurden die 12 Prinzipien für Placemaking im Kontext der verschränkten Stadt- und Tourismusentwicklungerarbeitet. Sie sollen den Dialog zwischen den Städten anregen und als Handlungsanleitung für die konkrete Umsetzung dienen. Ergänzt durch Good-Practice-Beispiele und Empfehlungen bieten sie eine Orientierung fürStadtplanung, Tourismus und Wissenschaft, um gemeinsam lebendige, polyzentrale Städte zu gestalten.

Placemaking erfordert eine integrative Perspektive und die Einbeziehung aller Interessengruppen mittels eines Ansatzes der kollaborative Governancevon Anfang an. Bevor ein Planungsprozess gestartet wird, sollten alle Interessengruppen einbezogen werden. So wird eine Brücke zwischen Stadtplanung, Tourismus, Einwohnern, lokalen Initiativen und lokaler Wirtschaft geschlagen.Derregelmäßige Austausch stärkt die Zusammenarbeit zwischen Stadtplanung, Tourismusentwicklung und den lokalen Interessen. Für die ortbezogene Entwicklung ist es wichtig lokale Netzwerke von „Kümmerern" oder „Caretakers" für den Ort aufzubauen und diese über Ansätze der Co-Creation zu stärken. Daraus leiten sich die folgenden zwölf Prinzipien ab:

(1) Strategische Allianz zwischen Tourismus und Stadtentwicklung

Placemaking erfordert eine integrative Gesamtperspektive und die Einbeziehung aller Interessengruppen von Anfang an. Bevor ein Planungsprozess begonnen wird, sollten alle notwendigen öffentlichen und privaten Interessengruppen einbezogen werden. Die Schaffung eines strukturierten Rahmens für den regelmäßigen Austausch stärkt die sektorübergreifende Zusammenarbeit zwischen Stadtplanung, Tourismusentwicklung und kommunalen Interessen.

(2) Kooperative Governance: Alle an einen Tisch bringen

Die Schaffung eines Netzwerks von Caretakern für den Ort. Die Einbindung lokaler Nachbarschaften. Es wird ein Augenmerk darauf gelegt, dass die Einheimischen die wichtigsten Interessengruppen sind, die ihre Orte und Bedürfnisse am besten verstehen. Die Etablierung eines kommunal geförderten Nachbarschaftsbudgets mit der Möglichkeit, Aktivitäten über öffentliche Aufrufe und niederschwellige Finanzierungen einzureichen. Der Aufbau lokaler Eigentums- und Verantwortungsstrukturen für Instandhaltung, Programmgestaltung und langfristigen Erhalt dieser lokalen Strukturen.

(3) Place Management: Lokale Verantwortung durch Ko-Kreation

Die Zusammenarbeit mit lokalen Initiativen und Akteuren ist eine wichtige Grundlage, um Aktivitäten für das ganze Jahr entsprechend den Bedürfnissen des Ortes zu konzipieren, anzupassen und zu programmieren. Dies geschieht in einer ersten Phase durch kleine Anpassungen und taktische Stadtplanungsinstrumente. Es braucht Placemanagment umd die Orte langfristig bespielen zu können.

(4) Ortsbezogene Entwicklung: lokale Identität stärken

Die Bewohner prägen die Identität eines Ortes – ohne sie verliert er seinen Charakter und seine Anziehungskraft. Entwickeln Sie Räume, die von der Identität und den historischen Infrastrukturen des Ortes ausgehen und die lokale Identität, Kultur und Geschichte hervorheben und bewahren. Anstelle von standardisierten Tourismusprodukten ist es wichtig, Konzepte zu entwickeln, die in der Gemeinschaft verwurzelt sind. Die Einbeziehung von touristischen Impulsgebern kann den Placemaking-Prozess bereichern, da diese geschult sind, Geschichten über Orte zu erzählen. Die Analyse des kulturellen, historischen und sozioökonomischen Hintergrunds des Ortes ist hierfür wichtig. Placemaking verstärkt das, was einen Ort bereits einzigartig macht.

(5) Gemeinsames Narrativ: das Besondere sichtbar machen

Touristische Entwicklungen legen oft den Schwerpunkt auf Marketingaktivitäten, investieren jedoch vergleichsweise wenig in Forschung und Zusammenarbeit mit lokalen Initiativen. Doch genau das ist für eine nachhaltige Tourismusentwicklung erforderlich: ortsbezogene Entwicklung, die auf die spezifischen Bedürfnisse und Bedingungen eines Reiseziels eingeht. Ortsbezogenes Marketing wiederum sollte in der lokalen Identität und den lokalen Erzählungen verwurzelt sein und sich in kohärente Markenentwicklung übersetzen lassen, die eine zukunftsorientierte Entwicklungsvision verkörpern und einen sinnvollen Beitrag zur Lebensqualität der Einwohner leisten.

Die Schaffung eines nachhaltigen Images stärkt nicht nur die Geschichte eines Ortes, sondern unterstützt auch lokale Anbieter und fördert die langfristige Entwicklung von Ortsmerkmalen im Einklang mit den Werten und Bestrebungen der Nachbarschaft. Tourismus und insbesondere Tourismusmarketing sollten niemals Selbstzweck sein.

(6) Experimentieren und Entwickeln: Potenzial durch Tactical Urbanism freisetzen

In Anbetracht der Tatsache, dass Planungsprozesse viel Zeit in Anspurch nehmen, kann tactical urbanism genutzt werden um niederschwellige Interventionen zu setzen. . Eine Strategie ist es kurzfristige, kostengünstige Pilotprojekte umzusetzen, um Ideen zu testen, bevor Sie sich zu dauerhaften Veränderungen entwickeln. Beim Placemaking geht es um eine gemeinschaftsbasierte Entwicklung, die auf greifbaren und temporären Maßnahmen basiert. Dabei werden lokale Akteure als Placemaker einbezogen, die auf der Grundlage ihrer Initiativen mit den lokalen Gemeinschaften zusammenarbeiten. Diese Ansätze ermöglichen eine leicht zugängliche Aneignung von Raum.

(7) Öffentliche Räume als urbane Wohnzimmer gestalten

Der öffentliche Raum ist der Ankerpunkt der städtischen Öffentlichkeit und der Stadtgesellschaft. Er ist der Bereich, in dem sowohl Bewohnerinnen und Bewohner als auch Besucherinnen und Besucher zusammenkommen und den städtischen Raum gemeinsam nutzen. Daher muss der öffentliche Raum robust gestaltet sein, offen für vielfältige Nutzungen, leicht anpassbar und einladend, um ihn als urbanes Wohnzimmer zu nutzen. Räume, die durch lokale Initiativen und die Institutionen einer Stadt für gesellschaftliche Veranstaltungen und als Gemeingut genutzt werden, sind widerstandsfähig, da sie von der lokalen Nachbarschaft gepflegt werden. Öffentlich zugängliche Räume, die mit Stadtmobiliar ausgestattet sind, das vielfältige Nutzungen ermöglicht und durch gemeinsame Räume und kulturelle Veranstaltungen sinnvolle Interaktionen zwischen Besuchern und Einheimischen fördert.

(8) Erdgeschoßzonen aktivieren: Straßen von Innen beleben

Die Erdgeschoßzonenentwicklung kann durch die Förderung lokaler Unternehmen, die auf die Bedürfnisse der Bewohnerschaft und der Gäste bezug nimmt langfrstig erhalten werden. Aufbauend auf dem Konzept der polyzentrischen Stadt ist es eine Möglichkeit, Ressourcen in die Nachbarschaften abseits der touristischen Routen zu transferieren. Eine Grundlage dafür ist im Fall von Wien das Heartbeat-Street-Konzept, dessen Umsetzung ein Netzwerk lokaler Stakeholder erfordert.

(9) Investition in soziale Infrastruktur, die Gemeinschaft stärkt

Der soziale Zusammenhalt ist für das Gefüge einer Stadt von entscheidender Bedeutung, insbesondere wenn die touristische Entwicklung in die städtische Gemeinschaft integriert wird. Soziale Infrastrukturen innerhalb der Stadt fungieren als multifunktionale Knotenpunkte und bietenMöglichkeitsräume für Lernaktivitäten und gemeinschaftliche Interaktionen. Solche Räume mildern auch Herausforderungen wie städtische Hitze und sorgen so für Komfort und Resilienz für alle, insbesondere während der touristischen Hochsaison.

(10) Nachhaltigkeit als Design-Prinzip anstreben

Mobilitätsmanagement ist eine wichtige Grundlage für nachhaltige Tourismusentwicklung. Wenn Orte mit hoher touristischer Nutzung neugestaltet werden, ist die Umsetzung von Mobilitätsmanagement und einem touristischen Leitsystem eine zentrale Grundlage einschließlich der Steuerung von Besucherströmen. Dazu gehören barrierefreie öffentliche Verkehrsmittel, Mobilitätsmanagement für Besucherströme, grüne Infrastruktur, ganzjährige Programmgestaltung, Unterstützung lokaler Unternehmen, die Vermeidung der Abhängigkeit von einem einzigen Wirtschaftssektor sowie die Reinvestition der Umsätze in nachbarschaftliche Infrastruktur.

(11) Klare Regeln für Wohnen und öffentliches Leben setzen

Um die Lebensqualität in unseren Städten zu erhalten, bezahlbares Wohnen zu gewährleisten und touristische Monokulturen zu verhindern, ist ein klarer regulatorischer Rahmen unerlässlich. Dies erfordert eine enge Zusammenarbeit zwischen Bewohnerinnen, Bewohnern Politik, öffentlicher Verwaltung, Tourismusverbänden, lokalen Initiativen und Unternehmen. Solche Rahmenbedingungen müssen klar kommuniziert, konsequent umgesetzt und lokal angepasst werden, um ein nachhaltiges Zusammenleben zwischen Einwohnern und Besuchern zu fördern. Ein regulatorischer Rahmen mit klaren Regeln für Wohnen und öffentliches Leben ist unerlässlich, um die Rechte und die Lebensqualität der Einwohner zu schützen und gleichzeitig Besuchern gerecht zu werden. Die Politik muss bezahlbaren Wohnraum sichern, Wohnstrukturen erhalten und dafür sorgen, dass öffentliche Räume für die lokale Gemeinschaft lebenswert bleiben.

(12) Messen, was für Orte und Menschen wichtig ist

Datentransparenz und die Messung von Indikatoren können langfristig einen Beitrag für die Standortentwicklugn leisten.

8 FAZIT UND AUSBLICK

Placemaking kann einen entscheidenden Beitrag zu einer verträglichen Tourismusentwicklung leisten, wenn es als integrierter, strategischer Ansatz verstanden wird. Eine solche Perspektive verbindet Lebensqualität, Aufenthaltsqualität und Erlebnisqualität und berücksichtigt systematisch die unterschiedlichen Bedürfnisse und Perspektiven vielfältiger Nutzerinnen- und Nutzergruppen. Der empirisch fundierte Beitrag zeigt zentrale Herausforderungen und Aushandlungsfelder im urbanen Kontext auf und formuliert zwölf Prinzipien, die als konkrete Lösungsansätze für die Stadt- und Tourismusentwicklung dienen. In ihrer Anwendung entfalten diese Prinzipien ihr Potenzial insbesondere dann, wenn Placemaking als kooperativer Prozess verstanden wird, der Druckpunkte frühzeitig identifiziert, touristische Monokulturen vermeidet und die positiven Effekte des Tourismus räumlich und sozial ausgewogen verteilt. Entscheidend für eine solche Umsetzung ist die enge Koalition zwischen Stadtentwicklung und Tourismus, um lebendige, inklusive und resiliente Orte für alle zu schaffen.Die Ergebnisse der Learning Journey flossen in den Strategieprozess für den öffentlichen Raum in der inneren Stadt ein und wurden in einer Reihe von Workshops und Roundtables mit lokalen Akteurinnen und Akteuren der Planung diskutiert, u.a. der Agenda21 Innere Stadt, der Bezirksvorstehung Innere Stadt und der MA19.Darüber hinaus dienen die 12 Prinzipien künftig als strategische und konzeptionelle Grundlage, um fachlichen Input aus touristischer Perspektive zu stadtplanerischen Entwicklungsprojekten einzubringen. So etwa aktuell im Rahmen des Zielgebiets Gründerzeitviertel – Westgürtel der Magistratsdirektion Bauten und Technik.

Das Playbook wurde im Rahmen der internationalen Tagung „Caring for the city“ einem interdisziplinär zusammengesetzten Publikum aus Forschung, Tourismus, Interessenvertreterinnen, Interessenvertretern und Planung präsentiert. Es fand ein Praxisdialog statt, in dem gemeinsam mit Architektinnen und Planerinnen die Bezugspunkte und Potenziale weitergedacht wurden. Das Playbook wird außerdem auf definierten internationalen und nationalen Fachplattformen vorgestellt und disseminiert, um den Wiener Zugang zu Placemaking sichtbar zu machen und in den globalen Diskurs einzubringen.Einige der Prinzipien werden

bereits unmgesetzt indem sich der WienTourismus gemeinsam mit der Stadt Wien für verbindliche Rahmenbedingungen zum Schutz des öffentlichen Raums und des Wohnens einsetzt. Dies zeigt sich etwa in der Teilnahme an Arbeitsgruppen und der Unterstützung regulatorischer Maßnahmen zur Eindämmung gewerblicher Kurzzeitvermietung sowieder Kommerzialisierung des öffentlichen Raums. Auf Basis jährlicher Messungen der Tourismusakzeptanz der Wiener Bevölkerung werdentouristische Druckpunkte im öffentlichen Raum identifiziert und anhand der Ergebnisse Lösungen entwickelt.Das Playbook dient hierbei als Leitfaden und Instrument .

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Plan Now, Ride Later: Simulation-Based Fleet Optimisation and Inclusive Service Design for Cities

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1 ABSTRACT

Public transport systems of all sizes face a common dilemma in the mobility transition: introducing flexible, on-demand services to reduce private car dependency without incurring the financial risks of oversized fleets. While Mobility-on-Demand (MoD) promises efficiency, authorities often lack empirical data to determine the exact "tipping point" where service quality justifies the cost. The integration of MoD solutions is often hard to predict due to different city networks as well as supporting measures for the integration of MoD services. Furthermore, ensuring equitable access for vulnerable groups remains a critical challenge.

This paper presents a novel simulation framework to bridge a multidimensional planning gap. Based on the funded project FLIPFLOP (Flexible Line and On-demand Public transport) the simulation focuses on a representative real-world city network in Austria. Using an open-source agent-based python simulation dynamic transit operations have been modelled by applying the Alonso-Mora algorithm for on-demand high-capacity ride-pooling. The approach supports the theory that the generation of on-demand ride pooling solutions depend on the relevant public city network, population size, job availability, cultural locations and many more variables. The research further focuses on a quantitative sensitivity analysis of fleet sizes under peak-hour stress tests, distinguishing itself by embedding diversity-specific constraints – such as wheelchair accessibility and varying digital literacy levels – directly into the dispatching logic.

While project FlipFlop has focused on the city of Klagenfurt the wider simulation framework will in addition support the cities of Graz, Innsbruck, Linz and Vienna, where on-demand ride pooling can be integrated within public transport.

Simulations reveal a non-linear efficiency frontier and have identified a distinct operational "sweet spot" at a specific fleet density that sustains a good service rate with average wait times stabilizing at a few minutes. Reducing fleet capacity by just a few percent below this threshold causes rejection rates to spike disproportionately, rendering the service unreliable. Preliminary simulations suggest accessibility features can be operationally integrated without evident service collapse, contingent on validation with real demand patterns and target user populations.

Validating parameters through agent-based simulation facilitates providing a “Digital Twin” methodology that empowers planners to test service levels before procurement, offering modern mobility services that are tailored to user needs and cost-efficient. Suburban areas may be integrated seamlessly in the deployment design, as may be non- technical aspects, like compliance with the Austrian Transport Law, EU passenger rights, and equality laws. The results offer a validated roadmap for implementing inclusive on-demand transit that complies with modern service standards, ensuring that future investments are based on hard, dependable data rather than rough estimates.

Keywords: Ridepooling, Agent-Based Simulation, Urban Planning, Inclusive Mobility, Social Impact

2 INTRODUCTION

2.1 Challenges of medium-sized cities in Austrian in the field of mobility

In Austria, cities between 4500 and 250 000 inhabitants are classified as midsized cities, where Klagenfurt can be identified as one as well as Innsbruck (132.499) and Salzburg (156,852).(Veneri et al., 2025) The logistics of transport within these cities is based on private vehicle trafficespecially due to the fact that commuters come to the city during day time. For example, in Klagenfurt a lot of comuters travel from Villach or Wolfsberg to Klagenfurt, in Salzburg from the surroundings following six main corridors with hotspots as Mülln and Salzburg Süd, and in Tirol from the “Innsbruck-Land” district. These circumstances result in a much higher number of private cars than in larger Austrian cities such as Graz and Linz, and even twice as many as in capital cities with good public transport systems and/or high proportions of cyclists.

City	Number of citizens	Private cars/ 1.000 habitants	Year	Source
Bregenz	~ 29.000	396	2023	VCÖ(VCÖ, 2025)
Eisenstadt	~ 15.000	515	2023	VCÖ(VCÖ, 2025)
Graz	~ 300.000	391	2024/25	VCÖ(VCÖ, 2025)
Innsbruck	~ 132.000	333	2024/25	ORF (ORF, 2025)
Klagenfurt	~ 104.000	523	2023	VCÖ(VCÖ, 2025)
Linz	~ 210.000	414	2023	ORF (ORF, 2023)
Salzburg	~ 156.000	383	2024/25	VCÖ(VCÖ, 2025)
St. Pölten	~ 27.000	464	2023	VCÖ(VCÖ, 2025)
Wien	~ 1.980.000	284	2024/25	(W24, 2024)
Amsterdam	~ 882.000	250	2023	Gemeente Amsterdam – Mobiliteitsmonitor(GAS, 2024)
Berlin	~ 3.850.000	282	2022	Amt für Statistik Berlin-Brandenburg (AFB, 2023)
Copenhagen	~ 632.000	209	2020	Radkompetenz Dänemark (RDM, 2020)
London	~ 9.400.000	280	2021	Office for National Statistics (ONS) (ONS, 2021)
Paris	~ 2.165.000	270 – 330	2023	Atelier Parisien d'Urbanisme (APURa, APURb 2023)

Table 1: Comparison of cities – Ratio of population and number of private cars per 1,000 inhabitants

Public transport in Klagenfurt, as well as Salzburg and Innsbruck is mainly based on busses. Innsbruck is the only one of these three cities with a small tram network around the inner city.In Klagenfurt as well the bus network leads to the inner city. In Salzburg the bus line network is less focused on one place in the city center.

2.2 Mobility-on-Demand (MoD) in Austria and Europe

In Austria, Mobility-on-Demand is still in its early stages. Projects such as Postbus Shuttle(POST, 2024), ISTmobil(IST, 2023) and RegioFlink (REG, 2023) primarily serve rural and suburban areas, while in cities like Salzburg, Innsbruck, and Klagenfurt, the share in the modal split remains marginal (below 0.5%). These services complement traditional public transport but are largely pilot initiatives. Salzburg is testing flexible minibuses in peripheral zones, Innsbruck integrates on-demand services into the Tyrolean transport association (VVT, 2024) , and Klagenfurt relies on regional call-bus systems. In comparison, European metropolises such as London and Paris show slightly higher usage (1–2%), mainly through ride-hailing services like Uber and Bolt as well as city-run on-demand buses. (RIDE, 2022)(OECD, 2022) Overall, MoD's market share across Europe is still very small but is seen as a strategic complement for the "last mile" and to relieve private car traffic. Within this article we will focus on comuters that travel from the suburbs to the inner city center by using MoD such as demand-oriented transport.

2.3 Definition of MoD

Mobility-on-Demand (MoD) refers to flexible, user-centric transport services – such as ride-hailing, shared shuttles, and on-demand minibuses – that operate without fixed routes or timetables, and are dynamically dispatched based on real-time requests, typically via digital platforms. This model complements traditional public transit by offering customizable, point-to-point or stop-to-stop solutions, especially useful for first/last-mile connectivity and in low-density areas such as Graz, Klagenfurt, and Innsbruck. (UITP, 2024)

2.4 Potentials and advantages of MoD for cities

Mobility-on-Demand (MoD) offers cities a flexible and user-centric alternative to traditional public transport. Unlike fixed-route and fixed-schedule systems, MoD services are demand-responsive, providing tailored routing and dynamic dispatching based on real-time requests. This adaptability makes MoD particularly valuable for areas where conventional transit is economically or operationally challenging, such as low-density neighborhoods or during off-peak hours. While mass transit excels at moving large volumes efficiently, MoD complements it by improving coverage and accessibility, especially for first- and last-mile connections.

According to International Association of Public Transport(UITP) (UITP, 2023), shared and on-demand mobility solutions improve cities in five key ways:

- Reducing congestion – By pooling rides and optimizing routes, MoD decreases the number of single-occupancy vehicles on the road.
- Lowering emissions – Shared services and integration with electric fleets help cut CO_2 and air pollutants.
- Enhancing accessibility – MoD bridges gaps in public transport networks, serving areas underserved by fixed routes.
- Optimizing space – Fewer private cars mean less demand for parking and more space for people and green infrastructure.
- Supporting multimodality – MoD integrates seamlessly with public transport, cycling, and walking, creating a more sustainable urban mobility ecosystem.

Together, these benefits position MoD as a strategic complement to traditional transit, enabling cities to become more sustainable, efficient and inclusive. Being mobile is a measure of social inclusion nowadays.

2.5 Challenges for cities to introduce MoD

While Mobility-on-Demand (MoD) offers flexibility and improved accessibility, its implementation in cities comes with significant challenges. The integration of MoD solutions is often hard to predict due to different city networks as well as supporting measures for the integration of MoD services. Unlike traditional public transport, which benefits from economies of scale and established infrastructure, MoD requires complex digital platforms, real-time data integration, and dynamic fleet management. This technological dependency can be costly and demands strong coordination between operators, municipalities, and IT providers. Another major challenge is financial sustainability. MoD services often have higher per-passenger costs compared to mass transit, making them difficult to scale without subsidies or innovative pricing models. Cities must also address regulatory and legal frameworks, including licensing, insurance, and labor conditions for drivers, which vary widely across jurisdictions. Furthermore, space and traffic management pose issues: if MoD services are not well integrated with public transport, they risk increasing congestion rather than reducing it. Finally, user adoption and equity are critical – ensuring that MoD does not become an exclusive service for tech-savvy or affluent users, but remains accessible to all, including vulnerable groups. In summary, while MoD can complement traditional transit, cities must overcome barriers related to technology, cost, regulation, and social inclusion to make these services truly sustainable.

2.6 Project FlipFlop

FLIPFLOP (Flexible Line and On-demand Public transport)is a collaborative research project funded by the Austrian Research Promotion Agency (FFG) within the program AI for Green. The consortium brings together leading partners: AIT Austrian Institute of Technology, Tech Meets Legal GmbH, Landeshauptstadt Klagenfurt am Wörthersee, KMG Klagenfurt Mobil GmbH, pdcp GmbH and DatenVorsprung GmbH. Running from 2024 to 2026, FLIPFLOP addresses the challenge of integrating on-demand mobility into public transport systems for medium-sized cities. The project develops AI-driven algorithms and digital platforms to optimize dynamic routing, fleet management, and demand prediction, aiming to reduce operational costs and improve accessibility. By combining real-time data analytics with inclusive service design, FLIPFLOP seeks to create scalable, sustainable solutions that complement traditional transit and support multimodal urban mobility. (FLIP, 2024)

3 METHODOLOGY

3.1 Alonso-Mora-Algorithm and FleetPy

Using an open-source agent-based python simulation dynamic transit operations have been modelled by applying the Alonso-Mora algorithm for on-demand high-capacity ride-pooling. This algorithm, introduced by Alonso-Mora (Alonso-Mora et al.,2017), solves the dynamic trip-vehicle assignment problem for ride-pooling services. (Engelhardt et al., 2022) It works by generating all feasible combinations of passenger requests and vehicle routes under strict constraints such as maximum waiting time and detour limits. These combinations are then optimized using an Integer Linear Programming (ILP) approach to minimize system-wide costs, such as total travel time, while maximizing the number of served customers. The algorithm is particularly suited for high-capacity pooling scenarios because it efficiently handles large sets of requests and vehicles in real time.

To implement and test such algorithms, the FleetPy framework has been developed as an open-source, modular simulation tool for Mobility-on-Demand (MoD) services. FleetPy is written in python and designed for highly detailed modeling of user-operator interactions, including real-time request-offer decision processes. Its modular architecture allows researchers and operators to integrate multiple MoD providers, customize fleet control strategies, and simulate complex behaviors such as repositioning, dynamic pricing, and charging management. FleetPy supports different simulation flows – Immediate Decision Simulation (IDS) and Batch Offer Simulation (BOS) – to model either instant responses or batched optimization of requests. The framework also includes advanced routing modules, demand modeling, and infrastructure components, enabling realistic studies of operational efficiency and regulatory impacts. By combining these features, FleetPy provides a flexible environment for evaluating algorithms like Alonso-Mora's under various urban mobility scenarios, from small-scale pilots to large metropolitan networks.

3.2 Fleetpy for FLIP-FLOP and Use Case-Definition

Several use cases highlight the need for integrating diversity factors into on-demand mobility solutions. First, universities and educational institutions experience strong demand peaks at specific times, requiring flexible routing and dynamic fleet allocation to handle fluctuating volumes. Second, digital competence significantly influences accessibility: users with limited digital skills face barriers when booking rides via apps, which can lead to algorithmic bias favoring tech-savvy users. Third, families with multiple children need tailored solutions such as semi-flexible pickup points, longer boarding times, and predictive capacity planning to accommodate strollers and additional luggage. Across all scenarios, incorporating diversity features – such as age, mobility limitations, and socio-economic conditions – into simulation and forecasting models ensures fairer, more inclusive service design.

The approach used in FLIPFLOP supports the theory that the generation of on-demand ride pooling solutions depends on the relevant public city network, population size, job availability, cultural locations and many more variables. The research focuses on comparative scenario analysis of fleet sizes under peak-hour stress tests, modeling diversity through adjusted parameters – such as extended boarding times for wheelchair-accessible vehicles (60s vs. 30s), increased capacity requirements for strollers and wheelchairs (2 seats per unit), and varying digital literacy levels through different booking decision windows – which are integrated into the fleet control system's time and capacity constraints.The simulation in FLIPFLOP focuses on a representative real-world city network of Klagenfurt in Austria. The simulation framework has been uploaded in GitGub as a private repository and will be shared after the planned enhancement as a public repository.

3.3 Methodological Limitations and Ongoing Work

3.3.1 Current Limitations

The present analysis employs two network configurations across scenarios: One network for peak-hour simulations, and one network for all-day and accessibility use cases. This design decision, driven by computational constraints during rapid prototyping, confounds spatial and temporal effects, limiting causal inference about demand density impacts. Controlled re-runs isolating network topology from demand variables are planned for Phase 2.

Demand synthesis for Klagenfurt scenarios currently employs synthetic generation based on aggregate commuter flow data from Statistik Austria and gravity model principles. Validation against disaggregated trip diary data from planned 2026 Klagenfurt mobility surveys remains pending. Temporal demand distributions (uniform vs. clustered) have not been empirically validated; sensitivity analyses exploring alternative distributions are underway.

Accessibility modeling via "WaitingTimeSensitiveLinearDeclineRequest" represents a methodological innovation integrating user patience dynamics and decision times (20–300 seconds) directly into dispatch logic. Parameter calibration is based on literature estimates and preliminary stakeholder interviews; systematic validation with target user groups (seniors, persons with disabilities) is scheduled for Q2 2026.

Statistical limitations: Current results report single-run point estimates without confidence intervals. Multiple replications (n=10+ per scenario) with stochastic sensitivity analysis are planned but not yet completed due to computational resource constraints. Sample sizes for UC2/UC3 (5–7 served requests per 350 total) fall below thresholds for robust statistical inference.

These limitations motivate cautious interpretation of findings and do not invalidate the simulation framework's utility for comparative scenario analysis and threshold identification.

3.3.2 Empirical Demand Calibration via MOIA Partnership

To address synthetic demand uncertainties, the FLIPFLOP consortium is partnering with MOIA Mobility Analytics (Volkswagen Group) in Q1-Q2 2026 to acquire operational ridepooling data from Hamburg. MOIA's dataset (11M+ rides, January 2023-March 2024) represents the only European city-scale on-demand service with research-grade data granularity. MOIA operates 500+ electric vehicles (including 15 wheelchair-accessible) across a 270 km² service area with 12,500 virtual stops (10,000 wheelchair-accessible), serving 2.9M passengers annually (2023) and achieving 77% pooled trip rates with 11-minute average wait times.

Validation methodology:

- Temporal clustering verification: Compare Klagenfurt's peak-hour concentration (50 req/h over 2h) against MOIA Hamburg patterns scaled to population ratio (105k:1,900k). Test hypothesis that peak demand represents similar % of daily total across city sizes.
- Spatial hotspot validation: Benchmark synthetic origin-destination matrices against MOIA's district-level demand flows (e.g., suburban-urban asymmetries, university district peaks).
- User patience calibration: Replace assumed WaitingTimeSensitiveLinearDeclineRequest decision times (20-300s) with empirical distributions from MOIA's 445,000 users (2023). Stratify by demographics (students 20s vs. seniors 300s assumptions tested against reality).
- Demand sensitivity incorporation: Integrate MOIA's event-impact coefficients (6× baseline demand for transit strikes, 2-11% increase for sports/concerts, temperature/precipitation non-significant) into Klagenfurt scenario design.
- Accessibility benchmark comparison: Test UC2/UC3 assumptions (extended boarding times, fleet capacity impacts) against MOIA's real-world performance

3.4 Implementation beyond FLIP-FLOP

While project FLIPFLOP has focused on the city of Klagenfurt the wider simulation framework will in addition support the cities of Graz, Innsbruck, Linz and Vienna, where on-demand ride pooling can be integrated within public transport.

4 DATABASE

4.1 Dataset availability for MoD

The development and evaluation of Mobility-on-Demand (MoD) systems rely heavily on high-quality datasets that capture real-world travel demand, network conditions, and user behavior. In Europe, however, publicly available datasets for MoD research remain scarce compared to North America and Asia. Most European cities provide aggregated mobility statistics or open transport data portals (e.g., GTFS feeds for

public transport), but detailed trip-level datasets for ride-pooling or on-demand services are limited due to privacy regulations (GDPR) and fragmented data ownership among operators. Researchers often resort to synthetic demand generation or rely on non-European datasets (e.g., NYC TLC Taxi dataset) adapted for Amsterdam for simulation studies. Initiatives such as MaaS pilot projects and EU-funded programs (e.g., Horizon Europe) are starting to encourage data sharing, but standardized, open-access MoD datasets for European cities are still in early stages. (Gregurić et al., 2025)This lack of granular data poses challenges for algorithm development and scalability studies, making simulation frameworks and synthetic augmentation techniques increasingly important for research.

4.2 Used dataset

This study employs the FleetPy/FLIPFLOP simulation framework (Technical University of Munich, open-source) to analyze ridepooling deployment for Klagenfurt, Austria (105,000 inhabitants). The Klagenfurt transportation network (3,435 nodes, 6,870 edges, radiocentric structure) was extracted from OpenStreetMap. Given the absence of publicly available ridepooling operational data for Klagenfurt – a challenge common to most European cities – current simulations utilize synthetic demand scenarios to test fleet sizing and operational strategies under controlled conditions. These scenarios (e.g., 100-500 trip requests distributed over 2-16 hour periods with peak-hour concentrations) enable algorithmic performance evaluation and sensitivity analysis but are not calibrated to actual Klagenfurt travel behavior. While the spatial distribution of synthetic requests reflects urban structure (higher density near city center, university, and main station), the absolute demand volumes and temporal patterns are estimates rather than data-driven predictions, limiting their use for precise market sizing or adoption forecasting. Validation gap: Current demand synthesis lacks calibration against disaggregated trip-level data (actual origin-destination pairs, temporal clustering patterns, user demographics). Phase 2 MOIA partnership will provide empirical benchmarks for validation and recalibration

4.3 Planned Enhancement: MOIA Demand Transfer Model:

Future work will integrate evidence-based demand forecasts using the Spatial Regression Transfer Model developed by Zwick & Axhausen (Zwick & Axhausen, 2022) in collaboration with MOIA Mobility GmbH. This methodology addresses the data scarcity problem by transferring ridepooling demand patterns learned from cities with operational data to new deployment locations. Trained on 1.2 million real MOIA trips from Hamburg and 330,000 from Hannover (2019-2020, proprietary), the model uses SLX regression (Spatial Lag of X) to predict zone-level demand based on publicly extractable urban characteristics: population and employment (Statistik Austria), points of interest – restaurants/culture/shops (OpenStreetMap, with gastronomie explaining ~35% of variance), public transit accessibility (GTFS), and centrality measures (distance to main station, ~25% variance explained). The Hamburg→Hannover validation demonstrated 19% demand overestimation with spatially random errors. For Klagenfurt, we anticipate 30-60% forecast uncertainty due to: (1) larger extrapolation gap (Hamburg 1.9M → Klagenfurt 105k inhabitants = factor 18 vs. Hamburg→Hannover factor 3.5), (2) substantially higher car ownership (523/1,000 vs. ~400/1,000 – highest in Austria), (3) different transit structure (radial bus system vs. comprehensive metro/S-Bahn), and (4) tourism seasonality (Wörthersee lake proximity). Klagenfurt-specific calibrations will incorporate university demand cycles (Alpen-Adria-Universität: 12,000 students, semester on/off periods), regional commuter flows from Villach/Wolfsberg (ÖSTAT pendler data), and summer tourism adjustments (+30% May-September weekends). Simulations will employ ±40% demand variation scenarios to ensure fleet sizing recommendations remain robust across plausible adoption ranges. While MOIA's operational data is proprietary, the regression methodology is fully documented in peer-reviewed literature, and all predictor variables are extractable from public sources (OpenStreetMap, Statistik Austria, GTFS), enabling methodological reproducibility.

5 LEGAL FRAMEWORK

Implementing Mobility-on-Demand (MoD) s services in cities requires, among other things, the adaptation of operating procedures to national transport law, EU passenger rights, equality and anti-discrimination regulations, and the EU AI Act for AI-supported dispatching and forecasting systems. This overview provides only a superficial sketch, highlighting potential problem areas and challenges without claiming exhaustive coverage.

5.1 Austrian Transport Law

The organizational and financial framework for public passenger and regional transport in Austria is governed by the Öffentlicher Personennah- und Regionalverkehrsgesetz 1999 (ÖPNRV-G). The primary legal basis for passenger transport is provided by the Kraftfahrliniengesetz (KflG) and the Gelegenheitsverkehrs-Gesetz (GelverkG), which distinguish between scheduled and non-scheduled commercial passenger transport. The applicable legal basis in individual cases depends substantially on the specific design of the transport service. Mobility-on-Demand models (MoD) as Micro-PTV are fundamentally permissible as alternative operating forms under § 5 para 2 ÖPNRV-G, whereby depending on the design, both the KflG and the GelverkG may apply, though other models are also conceivable, leading to no concrete classification and creating legal uncertainties with corresponding need for action (Kahl, 2023).

5.2 EU Passenger Rights

Passenger rights thus vary significantly by category, from full protection for long regular journeys to reduced rights for short regular journeys and occasional services. Regulation (EU) No 181/2011 establishes passenger rights in bus and coach transport and clearly distinguishes between regular and occasional services, as well as between long and short journeys. According to Art 2 para 1, the regulation "shall apply to passengers travelling on regular services available to all users of the service where the boarding or alighting point is situated on the territory of a Member State and where the scheduled distance of the service is 250 km or more". In such cases, passengers have comprehensive rights, such as compensation for long delays or cancellations, support services like meals and accommodation, and extensive information and complaint rights. For regular services under 250 km, a limited set of passenger rights applies under Art 2 para 2, particularly the prohibition of discrimination, special protection for persons with disabilities and reduced mobility (including compensation for damaged mobility aids), and obligations for adequate information and an effective complaint procedure. For mobility services classified as occasional services, only minimal rights apply under Art 2 para 3, such as anti-discrimination rules, accident compensation, and assistance for persons with disabilities. In Austria, relevant regulations supplement EU passenger rights depending on the mode of transport by imposing additional operator obligations regarding fares, carriage conditions, accessibility, safety standards, and customer service. State-level rules or concessions often establish further protective layers, such as binding service quality requirements, accessibility provisions, replacement transport arrangements, and enhanced documentation and information duties. (APF, 2026) This creates a multi-layered framework. EU rights serve as the binding minimum standard, reinforced by national, transport-specific requirements that purposefully enhance passenger protection across Austria.

5.3 Equality & Accessibility (National and Länder level)

Mobility-on-Demand services must comply with Austrian anti-discrimination law, which is based on constitutional principles, international agreements such as the UN Convention on the Rights of Persons with Disabilities (CRPD) and EU-level foundations such as the Equal Treatment in Goods and Services Directive (2004/113/EC), the Employment Equality Directive (2000/78/EC) or the Racial Equality Directive (2000/43/EC). Anti-discrimination law, as a cross-cutting matter, is regulated by both the federal government and the states within their respective constitutional competencies, meaning there is no uniform regulatory authority (Greif & Ulrich, 2019).At the federal level, equal treatment acts such as the Gleichbehandlungsgesetz (GlBG) must be considered, while the Bundes-Behindertengleichstellungsgesetz (BGStG), the Behinderteneinstellungsgesetz (BEinstG) and the Bundesbehindertengesetz (BBG) ensure equality and specific protection for persons with disabilities. This is supplemented by the European Accessibility Act (2019/882/EC), whose transposition into the Barrierefreiheitsgesetz (BaFG) standardizes the digital accessibility of apps and platforms and obliges the private sector to ensure accessibility for users with disabilities. Depending on the circumstances, the equal treatment and anti-discrimination laws of the federal states may also be relevant. State-level anti-discrimination law is likewise inconsistent and encompasses varying scopes of application (Greif & Ulrich, 2019).

5.4 EU AI Act – obligations for AI-enabled MoD platforms

Dispatching based on artificial intelligence, demand prediction, or dynamic pricing could fall within the AI, the EU AI Act (in force since Aug 1, 2024, with staged applicability to Aug 2, 2026) (EU, 2024)imposes a risk-based framework. Furthermore, High-risk AI systems require:

- Risk management, data quality and representativeness, technical documentation, logging, transparency to downstream users, human oversight, and accuracy/robustness/cybersecurity measures (Art. 9–15).
- Organizational duties (registration, conformity assessment, CE marking, information and record-keeping, incident reporting, cooperation with authorities). Transparency duties may also apply to chatbot interfaces used in customer service. For foundation models/generative AI, specific obligations (Art. 28b) cover governance and data management.
- Fundamental Rights Impact Assessment for High-Risk AI Systems (Art. 27)

6 PRELIMINARY FINDINGS AND OPEN QUESTIONS

6.1 Validated Proof-of-concept: Peak-Hour Demand Concentration

Simulations of 100 requests over 2 hours (50 requests/hour, 07:00–09:00) on the Klagenfurt network demonstrate operationally viable service rates across fleet sizes of 20–40 vehicles (8 seats each, 30-second boarding time). Figure 1 containing four plots summarized this:

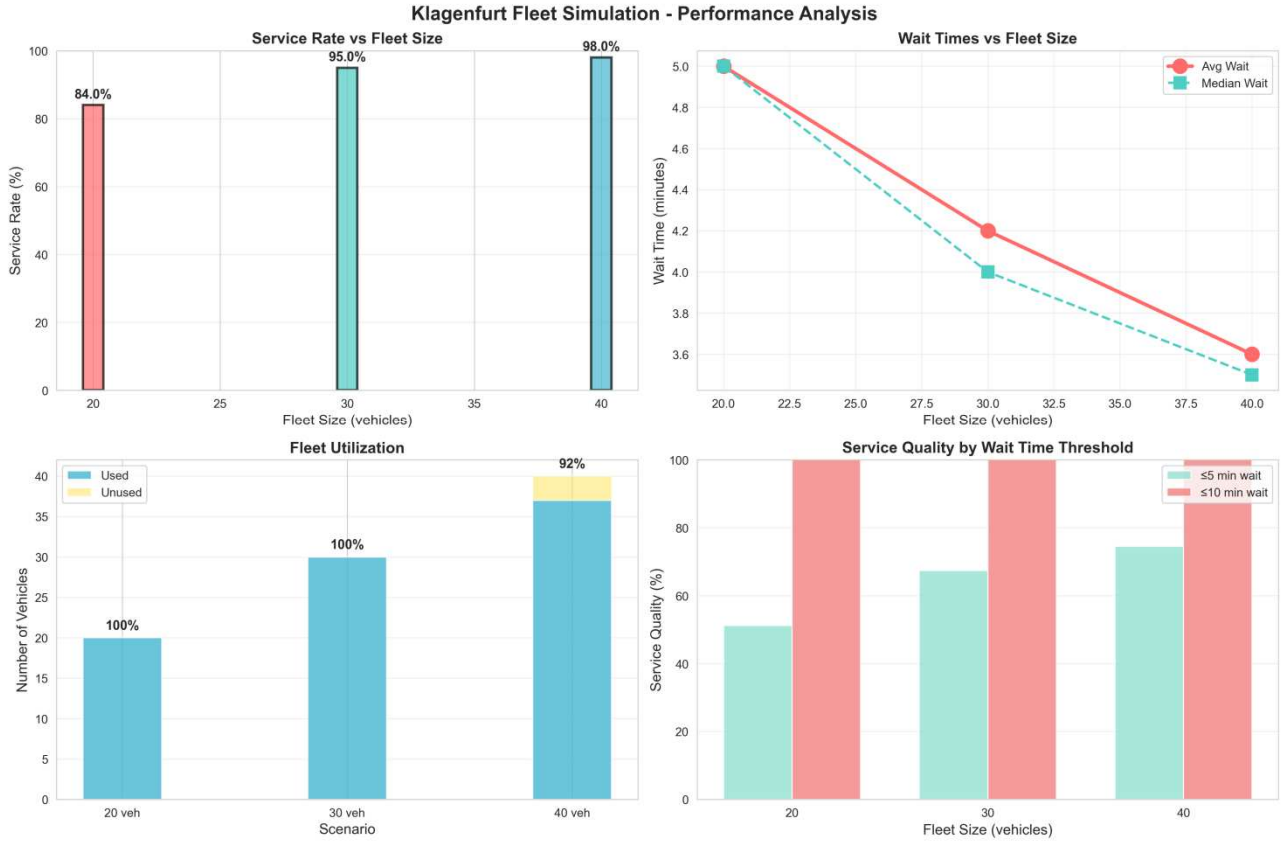


Figure 1 Left top: fleet size scaling from 20 to 40 vehicles. Left bottom: Fleet utilization from 20 to 40 vehicles. Right top; Average wait time in dependence of the fleet size. Right bottom: service quality in dependence of fleet size.

Critical density threshold: Fleet scaling from 20 to 30 vehicles (+50% capacity) yields a disproportionate service rate improvement (84%→95%, +13 percentage points absolute), suggesting a non-linear efficiency frontier consistent with ride-pooling literature. Below this threshold, vehicle supply constraints cause rejection rates to spike (16% rejection rate at 20 vehicles drops to 5% at 30 vehicles); above it, marginal returns diminish (30→40 vehicles: +3 percentage points improvement).

This pattern aligns with Mühle (2023), who demonstrate that fleet size N scales with demand according to a power law N ≈ Demand^1.15, implying increasing returns to scale until capacity saturation. The observed threshold suggests a critical fleet density of approximately 0.6 vehicles per req/h (30 vehicles / 50 req/h) to maintain >90% service rates.

Wait time performance: Average wait times decline from 5.0 minutes (20 vehicles) to 3.6 minutes (40 vehicles), remaining within user acceptability thresholds and comfortably below the 8-minute maximum wait

constraint. Vehicle utilization reaches 100% for constrained fleets (20–30 vehicles), confirming demand sufficiency during peak periods and indicating no idle capacity waste.

Planning implications: For mid-sized cities with comparable peak-hour demand profiles (~50 req/h morning commuter concentration), a fleet of ~30 vehicles (0.6 vehicles per req/h) represents a preliminary critical density benchmark for maintaining >90% service rates. This finding informs go/no-go decisions for pilot deployments targeting concentrated commuter demand.

6.2 Geographic Coverage vs. Capacity Constraints: Context-Dependent Fleet Sizing

Preliminary finding on capacity-fleet trade-offs: The study compares 8-seat vehicle configurations across 8, 16, and 24-unit fleets. While capacity increases (relative to previous consortium studies using 4-seat vehicles) provide operational benefits in some scenarios, the minimum viable fleet size for 92% service coverage in Klagenfurt's current 100 req/2h peak-hour demand (distributed across 6 zones) remains approximately 24 vehicles – requiring further investigation to determine whether this reflects genuine capacity-irrelevance or context-specific constraints.

6.3 Three competing hypotheses warrant investigation in Phase 2:

- Geographic coverage dominates (our initial interpretation): Zone-level service distribution requires minimum fleet size regardless of per-vehicle capacity. If true, this would diverge from high-density benchmarks (Alonso-Mora et al. 2017: NYC achieves capacity-fleet trade-offs at 12,000 req/h with 10-seat vehicles).
- Low pooling rates suppress capacity advantage: With only 50 req/h across 6 zones, vehicles rarely carry >2 passengers simultaneously (implying low pooling rates). At low simultaneity, increasing capacity from 4→8 seats provides minimal benefit, consistent with Zech et al. (2022): "capacity constraints reduce effective available vehicles... with low demand density, capacity advantage decreases as vehicles operate below capacity."
- Constraint interaction effects: If maximum wait time (8 min) or detour factor (40%) constraints frequently bind before capacity, then adding capacity provides no service rate improvement. This would be unique to Klagenfurt's network geometry and demand distribution.

6.4 Inclusive fleet configurations

The simulation framework enables testing of diversity-specific operational scenarios to address accessibility gaps for vulnerable user groups. Two use cases were modeled:

UC2 (Digital Competence): Elderly users with limited digital literacy face barriers when booking rides via apps. The simulation incorporates extended decision windows (allowing longer booking confirmation times), phone support alternatives (manual operator-assisted booking), and simplified interface pathways. These adjustments are modeled through parameter variations in the booking process rather than algorithmic modifications, testing whether service quality can be maintained when user response times vary by demographic group.

UC3 (Physical Accessibility): Families with strollers and wheelchair users require larger, barrier-free vehicles. The framework models mixed-fleet scenarios combining standard 8-seat vehicles (30s boarding time) with wheelchair-accessible 12-seat vehicles (60s boarding time). Accessibility requirements are represented through increased capacity allocation (wheelchair/stroller users occupy 2 seats vs. 1 for standard passengers) and extended boarding durations. Planned simulation scenarios test fleet compositions ranging from 0% to 50% accessible vehicles to identify the minimum proportion required to maintain service rates for the estimated 15% of demand requiring accessibility features.

Current Status: Quantitative results for UC2 and UC3 scenarios are subject to ongoing validation with improved demand synthesis. Initial framework testing confirms that diversity requirements can be incorporated through adjusted operational parameters (boarding times, capacity allocation, decision windows) without modifying core dispatch algorithms. Full sensitivity analyses comparing baseline performance to inclusive fleet configurations will be completed following integration of the MOIA demand transfer model, enabling robust recommendations on whether social equity requirements compromise operational efficiency or can be managed through intelligent repositioning and capacity planning.

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7 CONCLUSION

Validating parameters through agent-based simulation facilitates providing a "Digital Twin" methodology that empowers planners and cities to test various service levels before procurement, offering modern mobility services tailored to user needs and cost-efficiency. This research demonstrates the FleetPy framework successfully models Klagenfurt's real-world network topology and integrates accessibility constraints operationally, enabling scenario-based deployment design for suburban and urban areas alike.

Crucially, fleet sizing estimates will be calibrated against MOIA's 1.2M real Hamburg ridepooling trips using validated spatial regression methodology (Zwick & Axhausen 2022, 19% transfer accuracy proven Hamburg→Hannover), transforming synthetic predictions into empirically grounded forecasts. Compliance with the Austrian Gelegenheitsverkehrsgesetz, EU passenger rights (181/2011), and equality laws is statute-grounded and directly actionable (Section 6.4). While Klagenfurt-specific demand carries 30–60% forecast uncertainty due to structural differences from Hamburg, this bounded range is manageable through scenario planning and enables planners to stress-test deployment across multiple adoption curves.

Accessibility equity performance will be quantitatively validated by Q2 2026. Combined with a phased pilot approach (2026–27) and adaptive fleet sizing, this framework transforms theoretical feasibility into operational reality, ensuring that future investments in Klagenfurt's inclusive on-demand transit are based on hard, dependable data anchored in real ridepooling operational evidence rather than rough estimates or synthetic assumptions.

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Planning and Governance Model for AI Enabled Spatial Intelligence and New Urban Economics

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1 ABSTRACT

Across the world as well in India the cities are experiencing a structural shift witnessing how economic value is produced, distributed, and spatially organized. The rapid emergence of Indian cities like dense, walkable, and mixed-use urban enclaves where research institutions, start-ups, creative industries, and advanced manufacturing co-locate, are reshaping the urban landscape of contemporary urban economies.

Cities are generating vastly more spatially-tagged data than traditional planning systems were designed to handle. AI-enabled spatial intelligence like; the integration of machine learning, remote sensing, digital twins, and urban administrative data are transforming planning, service delivery and urban economics. But to realize these benefits, planners need to adopt a governance model that balances technical capability, institutional coordination, data ethics, and economic strategy. This article proposes an operational planning and governance architecture for AI-enabled spatial intelligence explaining its implications for "new urban economics," and illustrates lessons using recent Indian city experience. The present paper highlights how AI-enabled spatial intelligence can materially improve urban planning, operations and the economic functioning of cities, provided it is embedded within a robust governance framework that addresses data stewardship, transparency, privacy and institutional capacity.

The paper also highlights the Indian city experiments which offer practical lessons such as, start small, govern data, prioritize public trust, and align technical systems with fiscal and regulatory levers that shape new urban economics. Thus, the main focus of the paper is to integrate economic theory with digital tools and spatial justice principles, through which cities can create innovation districts that preserve cultural identity, reduce spatial disparities, and strengthen regional resilience. The present paper offers actionable pathways for urban planners and policymakers seeking to "cherish heritage, plan now, and create a better future".

Keywords: Innovation Districts, New Urban Economics, AI Driven Planning, Digital Twins, Metropolitan Governance

2 INTRODUCTION

Cities across the world are undergoing a structural transformation in how economic value is produced, distributed, and spatially organized. This transformation is driven by rapid technological change, intensified global competition, and increasing urbanization. In emerging economies such as India, cities are becoming dense, walkable, and mixed use environments where innovation, entrepreneurship, and advanced services increasingly concentrate. Research institutions, start ups, creative industries, and specialized manufacturing clusters are co locating in urban cores, reshaping traditional spatial hierarchies and altering the economic logic of cities.

At the same time, urban systems are producing unprecedented volumes of spatially referenced data. Sensors embedded in infrastructure, satellite imagery, administrative records, mobile devices, and citizen generated content continuously capture information about mobility, land use, environmental conditions, and economic activity. Traditional planning institutions were not designed to manage or interpret data at this scale or speed. As a result, many cities struggle to translate digital capacity into improved planning outcomes or inclusive economic growth.

AI enabled spatial intelligence presents a significant opportunity to address this gap. By combining machine learning, remote sensing, digital twins, and integrated administrative data, cities can generate real time and predictive insights into spatial dynamics. These tools can support more responsive planning, improve service delivery, and inform economic development strategies. However, technological capability alone is insufficient. Without robust governance frameworks, AI driven planning risks reinforcing inequality, undermining public trust, and privileging efficiency over democratic accountability.

The present paper proposes an operational planning and governance architecture for AI enabled spatial intelligence and examines its implications for new urban economics. Drawing on theoretical literature and

recent Indian city experiences, the paper argues that spatial intelligence must be embedded within institutional arrangements that prioritize data stewardship, transparency, privacy, and economic alignment. The central argument is that AI enabled planning should serve as a tool for inclusive growth, spatial justice, and long-term urban resilience rather than as a purely technocratic solution.

3 NEW URBAN ECONOMICS AND THE SPATIAL TURN

New urban economics emphasizes the role of agglomeration economies, knowledge spillovers, and spatial proximity in shaping productivity and innovation. Cities function as engines of economic growth because dense environments reduce transaction costs, facilitate labor market matching, and enable the exchange of ideas (Glaeser, 2011). Innovation districts, mixed use neighborhoods, and transit-oriented development exemplify this logic by clustering complementary activities within compact urban spaces.

However, the benefits of agglomeration are unevenly distributed. Rapid growth often produces spatial inequality, rising land values, informal settlements, and infrastructure stress. In many global South cities, economic dynamism coexists with fragmented governance and limited planning capacity. Angel (2012) notes that urban expansion frequently outpaces institutional adaptation, leading to inefficient land use and social exclusion.

In India, metropolitan regions such as Bengaluru, Hyderabad, and Pune illustrate both the promise and challenges of new urban economics. These cities host globally competitive technology and innovation clusters while simultaneously grappling with congestion, housing shortages, and environmental degradation. Traditional land use planning tools, often static and regulatory in nature, struggle to respond to rapidly changing economic geographies.

AI enabled spatial intelligence introduces a spatial turn in urban economics by allowing planners to analyze how economic activity responds to accessibility, land use regulation, infrastructure investment, and environmental risk. High resolution spatial data enables the identification of emerging economic clusters, informal activity patterns, and mobility flows. Digital twins allow planners to simulate alternative futures and evaluate the economic impacts of zoning reforms, transport investments, or climate adaptation strategies (Batty, 2018).

Yet the economic value of spatial intelligence depends on governance choices. If data and analytical capacity are controlled by private actors or used primarily for revenue maximization, digital tools may exacerbate exclusion and reinforce speculative development. A governance framework aligned with new urban economics must therefore prioritize public value, equitable access, and long-term productivity over short term efficiency.

4 AI ENABLED SPATIAL INTELLIGENCE IN URBAN PLANNING

AI enabled spatial intelligence refers to the integration of computational techniques with spatial data to support urban planning and governance. Key components include machine learning algorithms for pattern recognition, remote sensing for monitoring land use and environmental change, digital twins for scenario simulation, and integrated administrative databases for policy evaluation (Kitchin, 2014).

In urban planning practice, these tools enable a shift from reactive to anticipatory decision making. Predictive analytics can identify infrastructure stress before failure occurs. Real time mobility data can inform adaptive traffic management. Spatial models can assess how regulatory changes affect housing affordability, employment accessibility, and environmental outcomes.

Indian cities have begun experimenting with these tools through smart city initiatives and urban data platforms. Examples include real time command and control centers, satellite-based monitoring of urban expansion, and predictive systems for water and energy management. These initiatives demonstrate the technical feasibility of AI driven planning but also reveal institutional limitations.

Many projects operate in silos, driven by technology vendors rather than planning agencies. Data standards are inconsistent, and long-term governance arrangements are often unclear. As Datta (2019) argues, smart city initiatives can become symbolic projects that prioritize visibility over substantive planning reform. Without integration into statutory planning processes, spatial intelligence remains peripheral rather than transformative.

For AI enabled spatial intelligence to improve planning outcomes, it must be embedded within everyday institutional workflows. This requires capacity building within planning agencies, interoperable data infrastructures, and clear protocols for decision making. Technology should support professional judgment and public deliberation rather than replace them.

5 GOVERNANCE ARCHITECTURE FOR SPATIAL INTELLIGENCE

Effective governance of AI enabled spatial intelligence requires a multi layered architecture that integrates technical systems with institutional coordination and ethical oversight. This paper proposes four interrelated governance pillars.

The first pillar is data Stewardship: Cities must establish clear frameworks for data ownership, access, quality control, and accountability. Public agencies should act as stewards of spatial data, ensuring interoperability and long-term accessibility while protecting sensitive information. Open data policies can enhance transparency and innovation when combined with safeguards for privacy and security (Kitchin et al., 2015).

The second pillar is Institutional Coordination: Spatial intelligence spans departments responsible for planning, transport, housing, and economic development. Governance structures must enable data sharing and joint decision making across these domains. Metropolitan scale institutions are particularly important for managing cross boundary economic dynamics and infrastructure systems (OECD, 2020).

The third pillar is ethical governance: AI systems shape decisions that affect livelihoods, mobility, and access to services. Issues of bias, surveillance, and exclusion must be addressed through ethical guidelines, independent oversight, and public engagement. Zuboff (2019) warns that unchecked data extraction can undermine democratic institutions. Building public trust is therefore essential for the legitimacy of digital planning systems.

The fourth pillar is economic alignment: Spatial intelligence should inform fiscal and regulatory levers such as land value capture, zoning incentives, and infrastructure finance. By linking data driven insights to economic policy instruments, cities can actively shape innovation districts and inclusive growth corridors rather than simply responding to market forces.

6 LESSONS FROM INDIAN CITY EXPERIMENTS

Indian cities offer valuable lessons for operationalizing AI enabled spatial intelligence under complex institutional conditions. One key lesson is the importance of incremental implementation. Pilot projects focused on specific planning challenges allow agencies to build capacity, test governance arrangements, and demonstrate value without overextending resources.

A second lesson is the centrality of data governance. Cities that invested early in interoperable data platforms and standards were better positioned to scale digital initiatives. Fragmented data ecosystems, by contrast, limited the usefulness of advanced analytics and reduced institutional learning.

Public trust emerges as a critical factor. Citizen concerns around surveillance and data misuse can undermine digital initiatives, particularly in contexts with limited regulatory oversight. Transparent communication, participatory data practices, and clear grievance mechanisms help build legitimacy and social acceptance (Goodchild, 2007).

Finally, alignment with fiscal and regulatory systems determines long term impact. Spatial intelligence that informs zoning reform, infrastructure investment, and municipal finance has greater economic significance than isolated dashboards or monitoring tools. The Smart Cities Mission illustrates both the opportunities and limitations of digital urban reform when governance capacity varies across cities (Government of India, 2015).

Artificial Intelligence (AI) can improve planning only when it is embedded within a robust institutional, spatial, and ethical framework that aligns technological capability with public purpose. At its core, AI-enhanced planning depends on the principle of reliable and interoperable spatial data. Without high-quality geospatial datasets, like, land use records, infrastructure networks, mobility flows, demographic information, AI merely scales inaccuracies. India has begun strengthening this foundation through integrated spatial platforms such as the PM Gati Shakti National Master Plan, which overlays multi-sectoral infrastructure data

onto a unified geospatial interface. Unlike many Western cities where metropolitan agencies independently manage advanced GIS ecosystems (e.g., London or Singapore), India's approach emphasizes national-scale spatial coordination across ministries to reduce duplication, accelerate approvals, and improve logistics efficiency, hence, hereby lowering transaction costs in the urban economy.

A second principle is that AI must be problem-driven rather than technology-driven. Planning challenges, for example, congestion, informal growth, infrastructure deficits, climate vulnerability, should define by AI deployment. The Surat Smart City Development Limited offers a relevant example. Through its Integrated Command and Control Centre under the Smart Cities Mission, Surat uses data analytics for flood monitoring, traffic optimization, and epidemic response. During public health crises, real-time data mapping improved containment efficiency and minimized economic disruption, demonstrating how AI-supported spatial monitoring can stabilize urban productivity. In contrast, many global smart city models initially emphasized sensor deployment without sufficiently linking analytics to economic planning outcomes; Indian cities are increasingly integrating analytics with service delivery and disaster management to directly protect urban economic functions.

Third, institutional integration and governance alignment are necessary conditions. AI cannot function as a parallel technical experiment; it must be embedded in statutory planning and budgeting processes. In cities like Pune, data-driven property tax mapping and GIS-based revenue systems have enhanced municipal fiscal capacity. By improving assessment accuracy and reducing leakage, Pune strengthened its own-source revenue base, as demonstrating how AI-supported spatial intelligence can improve urban economic governance. Compared to many cities in the Global South where digital reforms remain pilot-based, Indian municipalities are gradually institutionalizing GIS-linked financial management systems that reinforce fiscal sustainability.

Transparency and explainability form another critical principle. Planning decisions influence land values, zoning rights, and infrastructure allocation; opaque algorithms risk eroding public trust. Indian cities are increasingly adopting dashboard-based public interfaces that display service metrics and project progress. For instance, the Bengaluru Smart City Limited publishes data-driven performance indicators, enabling greater administrative accountability. While global cities such as New York and Barcelona have pioneered open-data ecosystems, Indian cities are adapting these models within resource-constrained environments, often combining centralized dashboards with citizen grievance platforms to improve participatory governance.

Equity and spatial justice must also be deliberately programmed into AI systems. Optimization models may privilege high-return areas unless social vulnerability data are incorporated. In Hyderabad, geospatial analytics have been used to identify flood-prone informal settlements, enabling targeted resilience investments that protect economically vulnerable populations. This contrasts with purely market-driven smart infrastructure models seen in parts of East Asia, where technology-led urbanism has sometimes amplified land-value disparities. Indian experience suggests that AI can improve urban economies not only by increasing efficiency but also by reducing vulnerability and safeguarding labour productivity in low-income communities.

Human-in-the-loop governance remains indispensable. AI enhances analytical capacity but cannot substitute contextual planning judgment. The Delhi Development Authority, for example, has increasingly integrated digital land records and spatial analysis into master planning processes, yet final zoning and development control decisions remain subject to statutory review and public consultation. This hybrid model, like, algorithmic insight combined with professional oversight, reflects a necessary balance between computational precision and democratic legitimacy.

Finally, sustained political commitment, financial investment, and capacity building are preconditions for transformative impact. AI systems require continuous data updating, cybersecurity safeguards, and trained personnel. Indian cities differ from many global counterparts in that they often operate within tighter fiscal constraints; therefore, scalability and cost-effectiveness are critical. By leveraging national missions such as the Smart Cities Mission and integrating AI into broader infrastructure programs like PM Gati Shakti, India has attempted to reduce fragmentation and create economies of scale in urban data systems.

In summary, AI improves planning when it is grounded in reliable spatial data, embedded within statutory institutions, guided by clear public objectives, aligned with fiscal systems, designed for transparency, and

oriented toward equity. Indian cities demonstrate that even within developmental constraints, AI-enabled spatial intelligence can enhance logistics efficiency, strengthen municipal revenues, reduce disaster risks, and stabilize urban productivity. The lesson emerging from India, distinct from many purely technology-centric global experiments, is that AI's value lies not in automation alone, but in its integration with governance reform and urban economic strategy.

7 SPATIAL JUSTICE AND CULTURAL IDENTITY

While AI enabled spatial intelligence enhances analytical capacity, it must be guided by principles of spatial justice. Economic productivity should not come at the cost of displacement, exclusion, or cultural erasure. Innovation districts and redevelopment projects must respect local identity and support diverse livelihoods (Florida, 2017).

Digital tools can contribute to spatial justice by identifying vulnerable populations, monitoring displacement risks, and evaluating the distributional impacts of planning decisions. Participatory mapping and citizen generated data further democratize spatial intelligence and amplify marginalized voices.

In the Indian context, preserving heritage while accommodating growth is a central planning challenge. Spatial intelligence can help balance conservation and development by simulating alternative futures and making tradeoffs explicit. Governance frameworks must ensure that these tools empower communities rather than marginalize them.

8 CONCLUSION

AI enabled spatial intelligence represents a significant shift in the relationship between planning, governance, and urban economics. When embedded within robust institutional frameworks, these tools can enhance planning capacity, support innovation districts, and strengthen economic resilience.

This paper argues that the true value of spatial intelligence lies not in technical sophistication alone, but in governance design. Data stewardship, institutional coordination, ethical oversight, and economic alignment are essential for translating digital capacity into public value.

Indian city experiments illustrate both the promise and the risks of AI driven planning. By starting small, governing data carefully, prioritizing public trust, and aligning technology with economic policy, cities can harness spatial intelligence to create more inclusive, resilient, and economically productive urban futures.

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Planning for the Margins: A Stakeholder-Centred Legislative Analysis of Sustainable Human Settlements Policy in South Africa's Small Rural Towns

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1 ABSTRACT

South Africa's pursuit of sustainable human settlements is underpinned by a complex web of policies and legislative frameworks designed to redress spatial inequalities and promote inclusive development. Yet, small rural towns remain at the margins of planning and implementation, often constrained by weak institutional capacity, limited investment, and fragmented stakeholder coordination. This paper undertakes a stakeholder-centred legislative analysis to unpack how critical actors engage with, interpret, and implement sustainable human settlements policies within these rural settings. It examines the interplay between national frameworks, such as the Spatial Planning and Land Use Management Act (SPLUMA), the Housing Act, and the National Development Plan (NDP 2030), and local governance realities. Using a qualitative stakeholder analysis method, the study identifies and categorises stakeholders according to their influence and interest, ranging from national and provincial departments, district and local municipalities, traditional authorities, private developers, civil society organisations, and community-based structures. Secondary data from policy documents, planning frameworks, and implementation reports are analysed to determine stakeholder roles, responsibilities, and levels of collaboration in advancing sustainable human settlements in small rural towns. Findings reveal a fragmented institutional landscape characterised by limited coordination between state and non-state actors, inadequate inclusion of traditional leadership in planning processes, and misaligned accountability frameworks. The study argues that the current legislative environment lacks mechanisms for shared governance and participatory decision-making at the local level. Consequently, a rural-responsive stakeholder framework is proposed, one that clarifies roles, strengthens vertical and horizontal collaboration, and promotes legislative harmonisation to enhance collective implementation. This paper contributes to debates on inclusive governance and spatial justice by advancing a stakeholder-oriented approach to sustainable human settlements planning in South Africa's small rural town.

Keywords: rural development, policy coherence, SPLUMA, small towns, South Africa

2 INTRODUCTION

South Africa's post-apartheid planning agenda has been strongly shaped by the pursuit of spatial justice, equity, and the transformation of historically fragmented human settlements. Central to this agenda is the concept of sustainable human settlements, which extends beyond housing provision to encompass access to infrastructure, services, livelihoods, social facilities, and inclusive governance within well-located and integrated spaces (Department of Human Settlements [DHS], 2004; Republic of South Africa, 2012). Over the past three decades, the state has introduced an extensive suite of policy and legislative instruments, most notably the Housing Act 107 of 1997, the Spatial Planning and Land Use Management Act 16 of 2013 (SPLUMA), and the National Development Plan (NDP) 2030, aimed at restructuring settlement patterns and redressing entrenched spatial inequalities (RSA, 1997; RSA, 2013; National Planning Commission [NPC], 2012).

Despite these progressive frameworks, the translation of national policy ambitions into meaningful outcomes remains uneven, particularly within small rural towns. While much of the planning and housing literature in South Africa has focused on metropolitan areas, secondary cities, and informal settlements, small rural towns continue to occupy a marginal position in both policy interpretation and implementation. These settlements are often characterised by weak municipal capacity, limited fiscal resources, declining local economies, and complex governance arrangements involving traditional leadership structures. As a result, the implementation of sustainable human settlements policy in rural settings frequently diverges from legislative intent, reinforcing rather than alleviating spatial and socio-economic exclusion. Existing studies have highlighted persistent tensions between legislative frameworks and local implementation capacities, noting that policies designed at the national level frequently fail to account for the differentiated institutional,

spatial, and socio-cultural realities of rural settlements. In small rural towns, these tensions are exacerbated by limited stakeholder participation in decision-making processes, unclear accountability mechanisms, and weak horizontal and vertical collaboration between state and non-state actors (Pieterse et al., 2015). Consequently, sustainable human settlements initiatives are often implemented in a fragmented and project-driven manner, undermining their long-term sustainability and developmental impact. The paper argues that the current legislative environment inadequately enables shared governance and meaningful stakeholder participation in small rural towns. It contends that without clearer role definition, stronger intergovernmental coordination, and more inclusive engagement with traditional and community-based actors, the goal of sustainable human settlements in rural South Africa will remain elusive. Through proposing a rural-responsive stakeholder framework, the study contributes to debates on inclusive governance, policy coherence, and spatial justice, offering insights for strengthening the collective implementation of human settlements policy in marginalised rural settings.

3 LITERATURE REVIEW

The concept of sustainable human settlements has been widely discussed in South African planning and housing scholarship, with consensus that it extends beyond the physical provision of housing to encompass spatial integration, social inclusion, economic opportunity, environmental sustainability, and effective governance (Department of Human Settlements [DHS], 2004; Turok, 2016). Influenced by international frameworks such as the Habitat Agenda and the New Urban Agenda, South Africa's policy discourse frames human settlements as interconnected socio-spatial systems that require coordinated planning, infrastructure provision, and participatory governance (UNHabitat, 2016). However, scholars consistently observe a disconnect between this holistic conceptualisation and implementation practices, which remain dominated by output-driven housing delivery models, particularly in contexts with limited institutional capacity (Huchzermeyer, 2011). This implementation deficit is especially evident in rural South Africa, where the structural conditions shaping settlement development differ markedly from those in metropolitan areas. Rural towns are often characterised by weak and declining local economies, limited private sector investment, high levels of poverty, and heavy reliance on intergovernmental fiscal transfers (ScienceDirect, 2026). Unlike large cities, where sustainable human settlements debates focus on spatial restructuring and densification, rural towns face challenges related to service viability, low development thresholds, and spatial dispersion. As a result, policies and planning instruments developed within predominantly urban-centric paradigms often struggle to respond effectively to rural realities.

The marginal position of small rural towns within national development and planning frameworks has been well documented. Research shows that these towns are frequently treated as residual or administrative spaces rather than as strategic nodes of spatial and economic development (Asare Okyere et al., 2025). Planning capacity in rural municipalities is commonly constrained by shortages of skilled personnel, high staff turnover, limited technical support, and inadequate access to reliable spatial data. Consequently, statutory planning tools such as Integrated Development Plans (IDPs) and Spatial Development Frameworks (SDFs) often display weak strategic alignment with housing and land-use management functions, limiting their effectiveness in guiding sustainable human settlements development (Odendaal, 2007). Within this background, governance and stakeholder dynamics have emerged as critical determinants of planning and human settlements outcomes. SPLUMA explicitly promotes cooperative governance, spatial justice, and stakeholder participation, positioning collaboration across spheres of government and between state and nonstate actors as a central principle of spatial planning (Republic of South Africa, 2013). Despite this legislative intent, empirical studies reveal persistent institutional fragmentation and poor coordination in practice, particularly in rural municipalities where administrative capacity is weakest. Vertical coordination between national, provincial, and local government spheres remains inconsistent, while horizontal collaboration across sector departments involved in housing, infrastructure, land, and social services is often limited. The role of non-state actors in rural human settlements planning further complicates the governance landscape. Traditional authorities, in particular, play a significant role in land allocation and settlement development in many rural areas, yet their involvement in formal planning processes is frequently ambiguous or marginalised (Faboye, Gumbo & Sebola-Samanyanga, 2024). Studies indicate that the lack of clear legislative guidance on the integration of customary land governance systems into municipal planning

frameworks creates uncertainty, contestation, and delays in development implementation. This disjuncture undermines both planning legitimacy and the sustainability of human settlements initiatives in rural towns.

Community participation, although widely endorsed in policy, has similarly been critiqued for its limited influence on planning outcomes. Research suggests that participation in human settlements planning often takes the form of procedural consultation rather than substantive engagement, with communities rarely empowered to shape decisions regarding settlement location, design, or service provision (Terdoo, 2024). In rural settings, where communities may already experience political and spatial marginalisation, such tokenistic participation reinforces existing power asymmetries and weakens accountability mechanisms. A further strand of the literature interrogates the coherence of South Africa's legislative environment governing planning and human settlements. While SPLUMA, the Housing Act, and related policy instruments articulate broadly aligned objectives, scholars argue that their implementation is undermined by overlapping mandates, unclear role delineation, and inconsistent interpretation across government spheres. These challenges are particularly pronounced in small rural towns, where limited legal expertise and administrative capacity constrain municipalities' ability to navigate complex legislative requirements. As a result, planning practice often becomes compliance-driven rather than developmental, with statutory instruments produced to satisfy legislative obligations rather than to guide integrated and settingresponsive settlement development. Importantly, much of the existing literature examines policy frameworks, institutional capacity, or planning instruments in isolation, with limited attention to how legislation is mediated through stakeholder relationships in specific local aspects. Although there is growing recognition that planning outcomes are shaped by the interaction between actors, institutions, and regulatory frameworks, few studies explicitly analyse sustainable human settlements through a stakeholder-centred legislative lens, particularly in small rural towns. This represents a significant limitation, given that implementation success depends not only on policy design but also on how stakeholders interpret, negotiate, and operationalise legislative mandates within constrained and contested governance environments. This study responds to this deficit by foregrounding stakeholders as active agents within the legislative environment of sustainable human settlements planning. Through assessing how roles, interests, influence, and collaboration patterns shape implementation in small rural towns, the research advances a more comprehensive understanding of governance dynamics. It contributes to broader debates on inclusive planning, legislative coherence, and spatial justice in South Africa.

4 RESEARCH METHODOLOGY

This study adopts a qualitative, systematic policy and stakeholder review guided by the PRISMA framework to ensure methodological transparency, rigour, and replicability in examining sustainable human settlements governance in South Africa's small rural towns.

Rather than functioning as a statistical synthesis tool, PRISMA is applied as a structured reporting guide that clarifies how relevant legislative and policy documents were identified, screened, and analysed as indicated in Figure 1. The review focuses exclusively on the South African setting, with particular attention to small rural towns, allowing for a critical interrogation of governance arrangements that are frequently marginalised within urban-centric planning scholarship. A structured search strategy was implemented across academic databases, government repositories, and municipal planning portals, using carefully selected Boolean search terms related to sustainable human settlements, spatial planning, SPLUMA, rural development, and stakeholder governance. The search was limited to English-language documents published between 2013 and 2025 to align with the post-SPLUMA legislative period. In line with PRISMA guidelines, explicit inclusion and exclusion criteria were applied to ensure that only documents with substantive relevance to human settlements policy, spatial planning implementation, and stakeholder roles in rural or small-town contexts were retained, while metropolitan-focused, non-empirical, or opinion-based sources were excluded. Document screening followed a multi-stage process involving title and abstract review, full-text assessment, and the removal of duplicates, resulting in a curated dataset of legislation, policy frameworks, and implementation reports. Throughout the process, PRISMA principles enhanced transparency and credibility by ensuring a clearly documented search strategy, explicit eligibility criteria, a traceable screening process, and systematic data extraction, thereby strengthening the reliability and transferability of the findings to comparable rural planning and governance contexts.

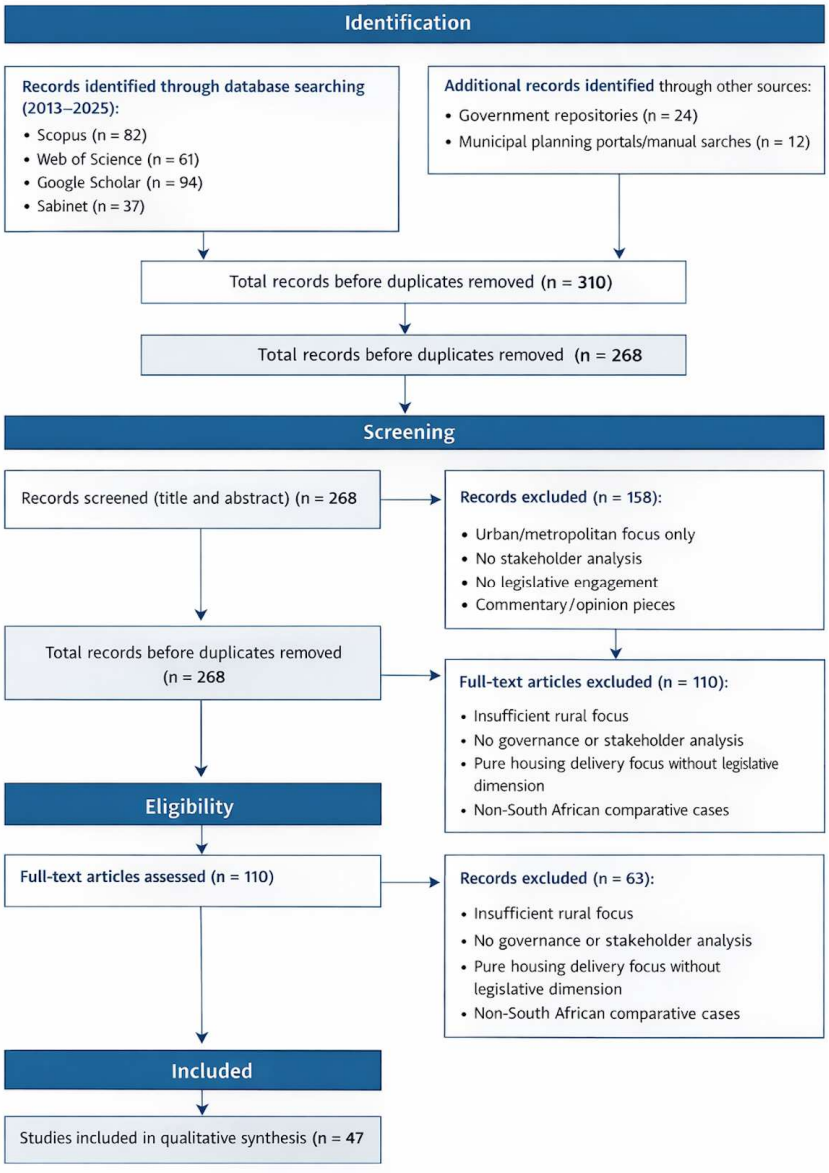


Figure 1: Research Process

5 ANALYSIS AND DISCUSSION

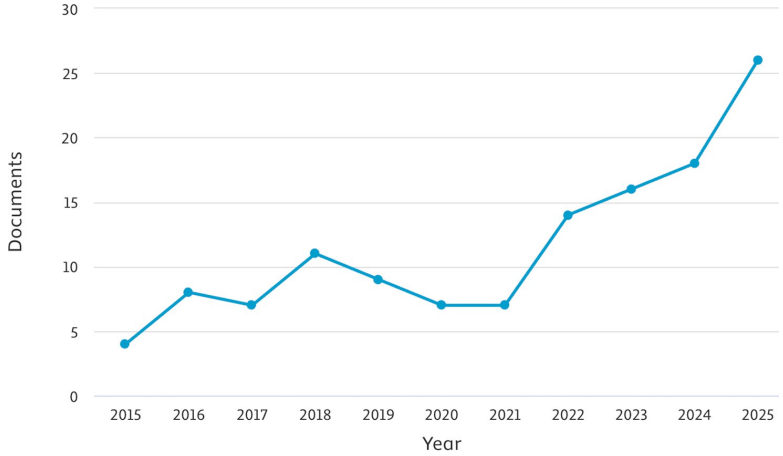


Figure 2: Publication Trend

Figure 2 illustrates the temporal distribution of documents related to sustainable human settlements, governance, and spatial planning between 2015 and 2025. The findings reveal a gradual but uneven growth trajectory, with relatively modest publication outputs between 2015 and 2020, followed by a marked

acceleration from 2022 onwards. The early period (2015–2017) reflects a foundational phase in which scholarly attention to sustainable human settlements was largely shaped by post2015 global policy shifts, particularly the adoption of the Sustainable Development Goals (SDGs) and the New Urban Agenda (NUA) (UN-Habitat, 2016). During this period, research was predominantly conceptual and urban-centric, with limited empirical engagement with rural and small-town settings in South Africa. This aligns with critiques that early sustainability discourses tended to privilege metropolitan regions while marginalising rural governance realities.

A noticeable increase in outputs occurs between 2018 and 2019, coinciding with growing scholarly interrogation of SPLUMA's implementation challenges and the persistent limitation between progressive planning legislation and on-the-ground outcomes. However, this momentum briefly stagnates between 2020 and 2021, likely reflecting disruptions associated with the COVID-19 pandemic and the redirection of research agendas toward emergency governance and public health concerns. The most significant finding is the sharp rise in publications from 2022 to 2025, peaking in 2025. This surge suggests a renewed and intensified interest in governance, spatial justice, and inclusive development, particularly within the Global South. Importantly, this period corresponds with increasing policy fatigue around implementation failures, growing service delivery protests in small towns, and heightened scrutiny of local government capacity in South Africa. The temporal trend thus supports the research's argument that sustainable human settlements have moved from a normative policy aspiration toward a contested implementation arena, especially in rural and small-town settings.

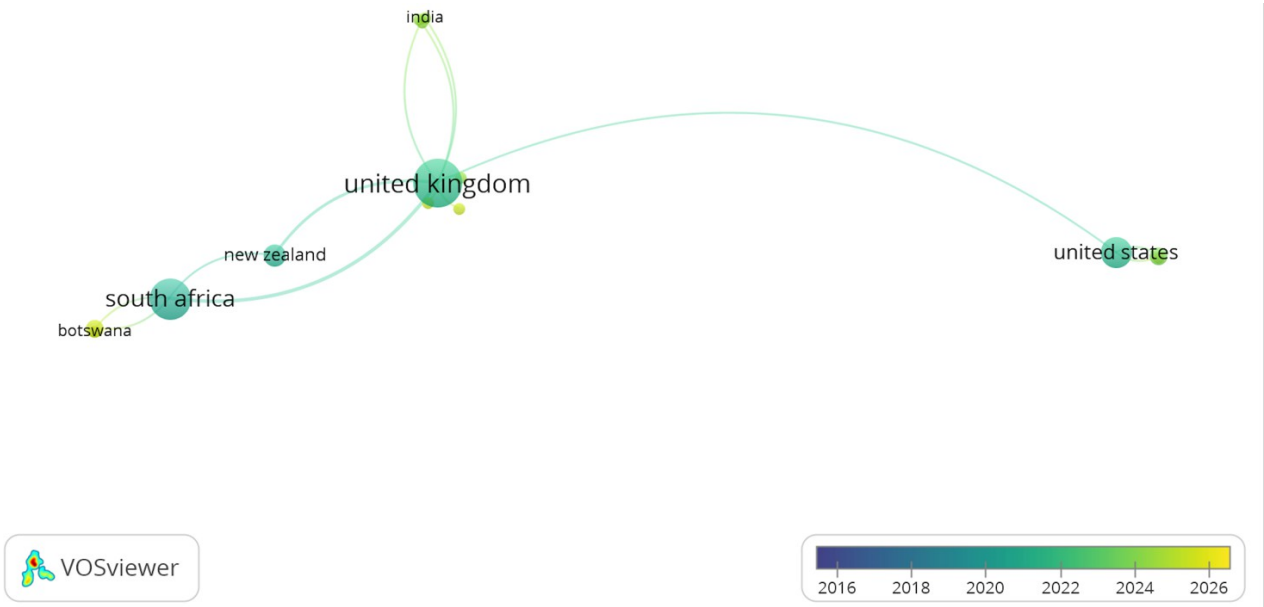


Figure 3:Countries

Figure 3 illustrates country-level co-authorship patterns, revealing distinct geographic asymmetries in the production of knowledge on sustainable human settlements. The United Kingdom emerges as the most prominent hub, exhibiting strong collaborative ties with South Africa, the United States, and New Zealand. South Africa occupies a secondary but significant position, while other African countries, such as Botswana, appear marginally connected. This pattern highlights a continued Global North–Global South knowledge hierarchy, where research agendas, theoretical frameworks, and methodological approaches are often shaped by institutions located in the Global North. While South Africa's relatively strong presence reflects its advanced planning legislation and academic infrastructure, the limited intra-African collaboration highlights the fragmentation of regional knowledge systems on rural human settlements. The dominance of the UK–South Africa axis suggests that much of the critical engagement with SPLUMA, governance, and spatial justice is mediated through external academic networks. While such collaboration can enhance theoretical rigour, it also raises concerns about the contextual grounding of policy prescriptions, particularly for small rural towns with unique socio-institutional configurations. Importantly, the marginal positioning of other African states reinforces the research's argument that small rural towns remain analytically peripheral, even within Global South scholarship. This finding strengthens the case for a stakeholder-centred and rural-

responsive framework that is grounded in local governance realities rather than imported planning orthodoxies.

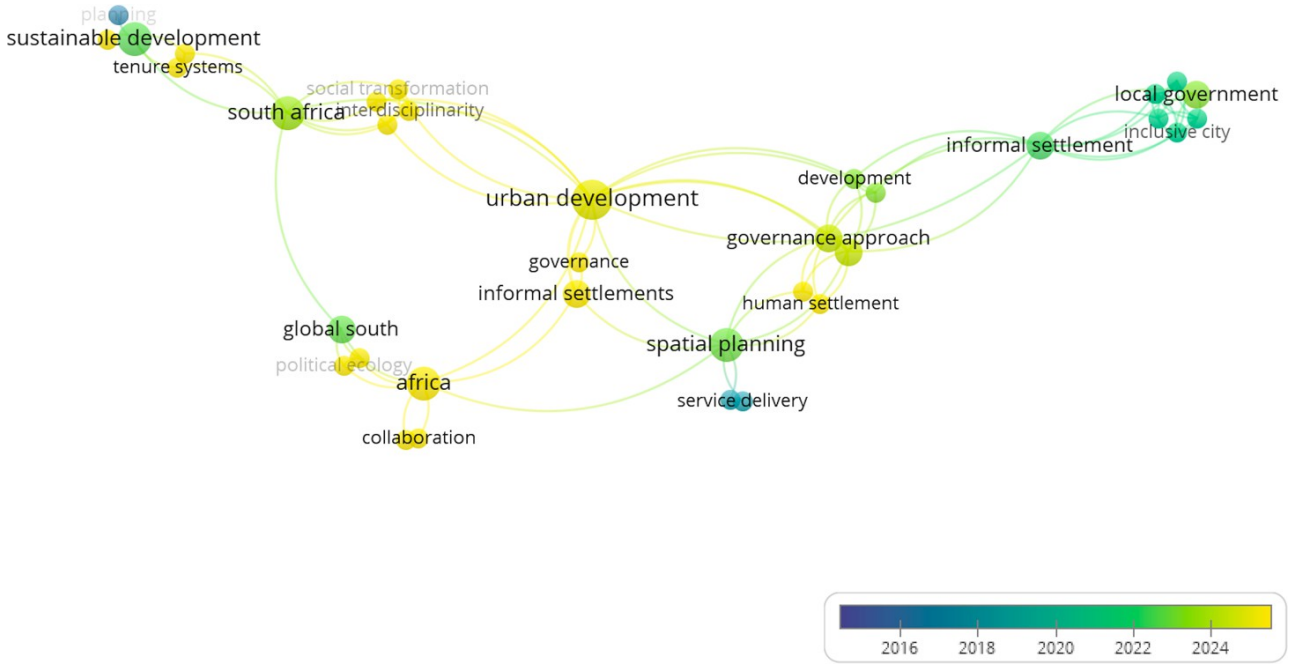


Figure 4: Keywords

Figure 4 presents a keyword co-occurrence network generated through VOSviewer, revealing the dominant thematic clusters shaping the discourse on sustainable human settlements. The analysis identifies urban development, spatial planning, and governance as central and highly connected nodes, highlighting their foundational role in the literature. Despite the works' focus on small rural towns, the prominence of "urban development" as the most central node reflects a persistent urban bias in planning research. This finding echoes longstanding critiques that policy frameworks such as the NDP and IUDF, while rhetorically inclusive, are underpinned by urban spatial imaginaries that inadequately translate to rural settlement dynamics. The strong linkage between urban development and governance further suggests that governance debates remain framed within urban administrative and institutional logics.

The cluster connecting spatial planning, human settlement, and service delivery reflects an applied policy orientation, particularly in relation to SPLUMA's objectives of spatial justice, efficiency, and sustainability (Republic of South Africa, 2013). However, the relatively weaker positioning of service delivery within the network signals a disjuncture between planning intent and lived implementation outcomes, a limitation widely documented in rural municipalities characterised by limited technical capacity and fiscal constraints. Notably, the presence of "informal settlement(s)", "inclusive city", and "local government" as interconnected but peripheral nodes suggests that informality and inclusion are treated as sectoral or thematic sub-issues rather than as central structuring conditions of human settlements. This is particularly problematic for small rural towns, where informality often takes hybrid forms linked to traditional land tenure systems and weak regulatory enforcement. The visibility of "tenure systems", "traditional leadership" (implicitly linked through governance and Africa-focused nodes), and "collaboration" further reinforces the work's argument that institutional complexity and overlapping authorities remain insufficiently theorised and operationalised in planning practice. The fragmented nature of these nodes reflects the absence of coherent legislative mechanisms for shared governance, especially in areas under traditional authority, despite SPLUMA's stated intent to promote inclusive and participatory planning.

6 TOWARDS THE INTEGRATED RURAL HUMAN SETTLEMENTS FRAMEWORK (IRHSF)

Based on the findings of this study, this section presents targeted recommendations aimed at strengthening the implementation of sustainable human settlements in small rural towns. The recommendations focus on addressing identified policy, institutional, and stakeholder-related gaps, with the intention of enhancing coordination, inclusivity, and practical effectiveness in planning and implementation processes.

The proposed recommendations, as shown innTable 1, collectively advance a shift from compliance-driven implementation toward collaborative governance of sustainable human settlements in South Africa's small rural towns. Rather than introducing new policy instruments, the framework stresses the reconfiguration of existing legislative and institutional arrangements to better reflect rural realities and multi-actor governance dynamics. Central to the framework is the strengthening of intergovernmental and cross-sectoral coordination, particularly at the district level where planning, housing, and rural development functions intersect. Through positioning district municipalities as coordination nodes, the recommendations respond directly to the fragmented institutional landscape identified in the findings and support more coherent vertical and horizontal alignment across governance spheres. This approach is consistent with SPLUMA's objective on integrated development but extends it by foregrounding operational collaboration rather than procedural compliance. A contribution of the framework lies in its explicit recognition of traditional leadership and community-based structures as integral governance actors. Through advocating for structured co-planning and strengthened participatory mechanisms, the recommendations move beyond symbolic inclusion toward meaningful engagement in decision-making. This responds to long-standing critiques of exclusionary planning practices in areas under traditional authority and reinforces the legitimacy and sustainability of settlement interventions. The framework also acknowledges that sustainable human settlements in small rural towns cannot be delivered by the state alone. Through promoting structured engagement with private and civil society actors, this work supports more diversified delivery models while maintaining public oversight. This balance between collaboration and accountability is essential for addressing capacity constraints without undermining developmental objectives. Overall, the recommendations reinforce the paper's central argument that achieving sustainable human settlements in small rural towns requires institutional alignment, stakeholder clarity, and rural-sensitive planning approaches, rather than new policy ambitions. Through offering a practical, stakeholder-centred framework grounded in existing legislation, the study contributes to debates on inclusive governance, spatial justice, and the localisation of planning policy in South Africa.

Finding	Recommended Action	Lead Stakeholders	Expected Outcome
Fragmented coordination among institutions	Establish a multi-stakeholder coordination forum at district level	National & Provincial DHS, District and Local Municipalities	Improved alignment and coordinated implementation
Legislative misalignment across planning and housing frameworks	Harmonise SPLUMA, Housing Act, and rural development policies through implementation guidelines	National DHS, COGTA,	Clear and coherent rural settlement implementation
Limited integration of traditional leadership	Formalise municipal– traditional authority co- planning arrangements	Local Municipalities, Traditional Councils	Inclusive and context- responsive planning
Unclear stakeholder roles and accountability	Clarify stakeholder responsibilities within municipal plans (SDFs and HSPs)	Local Municipalities, Provincial Planning Units	Stronger accountability and role clarity
Urban-biased planning approaches	Develop rural-specific planning guidelines for small towns	National DHS	Planning tools suited to rural realities
Weak engagement of private and civil society actors	Promote structured public– private–community partnerships	Municipalities, Private Sector, NGOs	Enhanced delivery capacity and innovation
Limited community participation in decision- making	Strengthen participatory mechanisms in settlement planning	Municipalities, Ward Committees, Communities	Increased local ownership and legitimacy

Table 1: Integrated Rural Human Settlements Framework (IRHSF)

7 CONCLUSION

This study demonstrates that while South Africa's legislative and policy frameworks for sustainable human settlements articulate progressive principles of spatial justice, inclusion, and cooperative governance, their implementation in small rural towns remains uneven and constrained. The findings highlight how institutional fragmentation, limited local capacity, weak stakeholder coordination, and ambiguous integration of traditional authorities undermine the translation of policy intent into practice. Through applying a stakeholder-centred legislative lens, the research shows that implementation outcomes are shaped not only by the design of policies and laws but by how diverse actors interpret, negotiate, and operationalise these mandates within complex rural governance environments. The proposed framework responds to these challenges by clarifying roles, strengthening vertical and horizontal collaboration, and promoting legislative alignment.

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reviewed paper

Positioning Bus Rapid Transit as a Catalyst for Accessible Urban Commons: Case of Pretoria

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1 ABSTRACT

The notion of urban commons has gained less attention in the planning and development of bus rapid transit systems across the world, meanwhile the city may be conceived as a shared studio for everyone. Preparing urban spaces to serve everyone requires extensive effort of considering what a city might look like if every individual has ease transfer, high speed and effective access to urban commons which are offered in terms of urban subcultures, governance, digital resources, civic infrastructure and street furniture. Theoretically, bus rapid transits in most cities are directed towards addressing issues of job-housing mismatch meanwhile sidelining direct connectivity to common tangible and intangible resources of urban spaces. Thus, practically bus rapid transit networks do not far reach the depth of cities commons, calling for multimodal transfer of commuters. This study adopts a pragmatic research approach to develop an understanding of how best can BRT systems be positioned as catalysts to bridge the gap between communities and urban commons. Moreover, this study builds on Howard's theory of urban value and relationality which provides centralised understanding of what constitutes the urban commons. The aim is to establish effective mechanisms that can be adopted during the planning and implementation of BRT systems to better bridge the gap between urban commons and public transport networks. The study findings particularly outlines that urban commons are more than just a right to access urban common resources rather individual right to enjoy, benefit and reach all resources offered by the urban built environment.

Keywords: Urban commons, bus rapid transit, accessibility, communities, built environment

2 INTRODUCTION

In modern times where urban spaces have assumed responsibilities of being habitable hosts to unfolding global challenges: social distress, unemployment, climate change, homelessness, poverty, dilapidating built environment, low quality of life, privatisation of public institutions and lack of service delivery; to name a few. Limited attention is drawn to effective planning mechanisms on how to preserve and manage urban space opportunities. Therefore, the regulated and accessibility of urban commons constitute a direct curiosity and interest to spatial planning scholars and activists. This thematic notion critiques the nexus of effective urban communing into dialogue with two critical areas: public transport and the built environment. How do the public transport ("connector") and built environment ("provision") entangle and facilitate effective accessibility of urban commons? What are the opportunities and setbacks of entangling these two systems, specifically in the metropolitan context? This paper explores the theoretical grounding of urban commons and bus rapid transit and provide a holistic overview of practical model that can enhance sustainable relationship between the two concepts. The "Urban commons" implies the everyday practise of sharing and enjoying resources and a cooperative ideology that surpass just state provision of adequate resources rather creation of social setting that enables active engagement, sharing based principles of inclusion and collaboration.

3 CASE STUDIES

The United Nations Sustainable Development Goal number 11 on "Sustainable Cities and Communities" advocate for urgent measures to transform human settlements and cities towards being safe, resilient, inclusive and sustainable (United Nations, 2015). Regardless of this global call, and the pressing sustainability objectives; socio-economic sustainability challenges emanating from welfare legislation and experienced by communities are far detached from realities of implementing inclusive, just and sustainable cities (Shirazi and Keivani, 2019). In most parts of the developed world, the implementation of bus rapid transit systems has been informed by rapid pace of industrialization and economic growth as such the introduction of bus rapid transit systems is driven towards promoting accessibility in economic nodes meanwhile neglecting accessibility of ecological commons (Rikhotso and Gumbo, 2023). From a classical

perspective, it is imperative to note that globalization and its force of privatizing "green urban commons" often perpetuate unequal share and distribution of urban commons. Moreover, it strengthens the disparities in social strata. Equally, the impact of urban green commons is tantamount to promoting fair natural resource distribution as advanced by SDG 11 (Lee and Webster, 2006).

Learning from experiences of Sweden, green commons has been a crucial issue in the mainstream of professional environmental management, community development and urban community planning for many years since early 1950s (Brusman and Turunen, 2018). According to Kennedy (2018), some recent experiments are being tested by the Swedish government to establish committee to review green sustainability; social services law and broader public transport accessibility, which has now led in the suggestion of new policy and legislative frameworks that prioritise accessibility of all urban commons particularly green commons by the general public (SOU 2020:47). In relative to Swedish approach, Finland present a different multi-disciplinary approach that drives active dialogue between public transport network and integration to urban commons. The first pioneering initiatives towards green commons work were initiated during the 1980s and systematically evolved through comparative research between Great Britain, Germany and Finland between the years 1997-2000 (Matthies et al.2000). In the case of Morocco, the view has always been prioritising green commons through placing them closer to where people stay and work, as such the role of BRT is limited.

4 CONCEPTUAL AND THEORETICAL ASSUMPTIONS

Urban green commons is a contested concept and dual-based, involving both normative and rational perspectives (Karlsson, 2013:2). The ideology of the commons is complex to various contemporary scholars because the concept "commons" appears to encompass endless definitions. This effect is rooted in both historical smear which laid basis for the "tragedy of the commons" fable also from legitimate utilization of a concept with multivalent definitions. In order to understand the traitorous, analytical power of the commons, then, it is imperative for one to begin with understanding the tangled modern application of the concept "commons". Prior to introducing the commons more scientifically, focus is directed towards outlining what commoners around the world in commons movement intends to achieve on reclaiming their "commonwealth" in both the political and materialistic context. Commoners seek to traverse the pervasive privatization and marketization of their common's natural resources- ranging from groundwater and land to knowledge and urban spatial zones; further reassert more participatory power over those resources and societal livelihoods. The commons notion frankly seeks to survive the unjust lived experiences of human society and social organization from the artificial regularities and global standard economics, bureaucratic dynamic and modernity. The complex reality is that a "commons" debate arises whenever a certain society is resolute on managing natural resources collectively with an intention on equal access, utilization and long-term sustainability.

On a parallel track, urban green commons are experienced as areas of nature in urban areas particularly towns, suburbs, cities and townships that are viewed as a common pool point by local residents (Colding and Barthel, 2013). The reality is that such commons are normally subjected to challenges of overuse and congestion, especially in cities, there is always an urgent call to device and enforce stringent regulations which are in the custody of legitimate network of stakeholders (Colding et al.2013). As such, beneficiaries of such urban commons may collectively draft and adopt their own regulations of use (local institutions) for the administration and management of common pool natural/artificial resources within the prescripts of society.

The theory of the commons speaks directly to the equal distribution and fair management of different forms of collective resources for wellbeing (Hardin, 1968). This theory is informed by the science article published by Hardin (1968) titled "The tragedy of the commons" which based its foundation arguments on the perspective that beneficiaries of a commons are found in a comprehensive process of which the common good will be vanished through efforts of self-interest goals that will in turn necessitate the destruction of the same resource upon which they rely on. This synopsis is applied to define the lines of misuse of any form of common resources including artificial or natural resources. This theory is vital to this paper as it provides a theoretical basis for the argument that bus rapid transit systems possess a central role to play in enhancing access to urban commons through bridging the gap between communities and urban commons.

5 METHODOLOGY

This study adopts a mixed method research approach to derive an in-depth understanding of the extent to which "REA VAYA" bus rapid transit system enables access to urban green commons in Johannesburg. The research integrates (interviews with municipal transport officials, questionnaires with residents in the city) and secondary data (BRT reports, academic literature and municipal integrated development plans) that are directly related with sustainable public transit and development goals. In a broader context, this research relies extensively on previous arguments and data results which are synced to a dialogue amongst themselves to derive common conclusions on broadened perspectives. Purposive sampling techniques were adopted to guide the study with the target population limited to a total of 50 respondents who responded to both interviews and questionnaires. Data collection procedures were observed through key informant and stakeholder interviews such as municipal departments (Spatial planning and economic development department; Environmental affairs and Transport department), as well as field observations of the urban green commons in Johannesburg. Secondary data sources consisted of public transport sector plans, annual reports, policies, scholarly publications and spatial development frameworks. Furthermore, thematic approach was adopted to analyse data collected which aimed on outlining key thematic areas, trends and patterns linked to bus rapid transit and green urban economy.

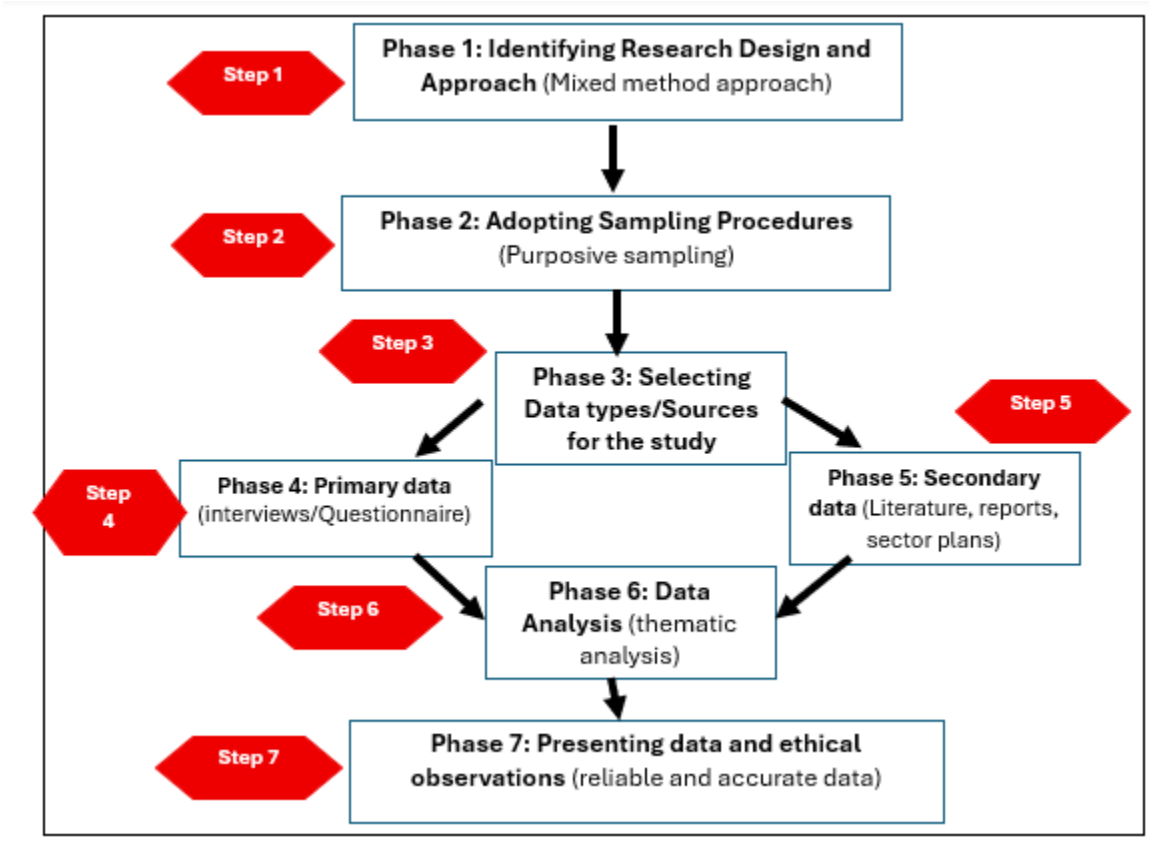


Figure 1: Research process and methodology. Source: authors.

6 THE SPATIAL EXTENT OF REA VAYA BRT TO URBAN GREEN COMMONS

In Johannesburg context, the bus rapid transit system is perceived as a catalyst to restructure urban form to promote optimum inclusivity and address the spatial inequalities that characterize the city. The city adopted the concept of transit-oriented development (TOD) which is traced from North American spatial planning, where the primary goal of this concept has always been to initiate neighbourhoods that are more supportive of public transport that bridges the gap between socio-economic opportunities of the city and places where the marginalized reside. The city of Johannesburg approach through bus rapid transit is placed on articulation that intends to enhance the livelihoods of the majority of communities in the city who make use of public transit system to navigate long distances between places of work and home; also to use this system as a

foundation for spatial transformation (Bickford and Behrens, 2015:377). Figure 6 below depicts the spatial extent of Rea Vaya bus rapid transit system in Johannesburg and how it relates to the urban green commons.

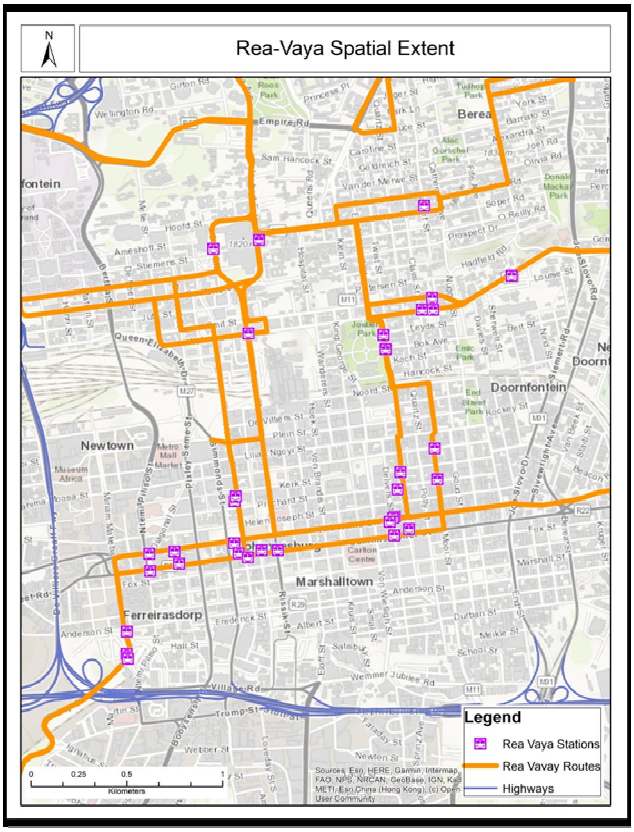


Figure 2: Spatial extent of bus rapid transit system and urban green commons in Johannesburg. Source: Author's construct (2026)

In figure 2 above, it is shown that the development of Rea Vaya bus rapid transit system is grounded around urban green commons, particularly in city centre. The BRT led to the mushrooming of more urban green commons which advances their roles on improving green sustainability, aesthetical appearance and green economy. However, the range of the distance between location of BRT stations and these green commons always derive controversies, if Rea Vaya BRT promote accessibility to these commons genuinely or the BRT network just found itself planned along green commons.

7 TOWARDS BUILDING CONSENSUS BETWEEN GREEN COMMONS AND BUS RAPID TRANSIT SYSTEM

In a spatial planning context, growing concerns are derived by the rapid increase of privatisation of urban land which in turn delimits the influence of policy directives and state intervention in creating a balanced consensus with government planning aspirations and private development visions. According to Ostrom (2015), the studies of urban green commons in Germany, Sweden and South African have proven that closing the spatial gap between public transport systems and urban commons is crucial to social, economic, political and environmental development. A hybrid of co-existence between BRT system and urban green commons create social conditions necessary for the efficient and inclusive management of local natural resources in cities (Tabane et al., 2021). According to Johannesburg SDF (2024), it is crucial to enhance the overall sense of community belonging and relevance along public spaces and routes where buildings are to be orientated towards open spaces and movement networks. To enhance accessibility of urban green commons extents beyond just physically being present in these spaces, but also the non-visible enjoyment of green benefits through balconies, side windows and building edges.



Figure 3: Configuration of Green commons and Bus rapid transit routes in Johannesburg. Source: Johannesburg Spatial Development Framework (2024)

In addition to figure 3 above, the urban design concepts adopted in Johannesburg are informed by guidelines that aim to advance urban life quality through proposing strategies that enhance public environment. As shown above, the scale is used to measure accessibility is rated from "typical to best"; from evidence presented, Johannesburg is striving to achieve the best case scenario of integrating bus rapid transit system with green commons however, due to shortfalls from spatial planning policies, the focus has been shift towards combing three case scenarios and locate opportunities within which the society will be able to benefit and enjoy the green commons. The challenges that were observed during data collection were: encroachment of green commons by homeless citizens; lack of security measures; dilapidated common infrastructure and lack of maintenance. These challenges may be addressed through building consensus and partnership between various stakeholders to maintain and manage the urban green commons in Johannesburg.

8 REA VAYA BRT NETWORK AND PROXIMITY TO CRITICAL GREEN COMMONS

The city of Johannesburg and JICP Inner City Think Thank conceptualised a pilot route which focused on key nodal areas and their proximity to urban green commons. The pilot route identified Main and Fox streets (East/West); Joubert and Rissik streets (North/South) as crucial configurations for activation of accessible urban green commons through Rea Vaya bus rapid transit system. The pilot network route is already characterized by a strong pedestrian presence and pedestrian oriented projects currently taking place in the precinct. The objective of pilot route network is to integrate and encourage to public transport and non-motorised transport usage (JICP Inner City Think Thank, 2020). In response to positioning Rea Vaya bus rapid transit system as a catalyst to accessible urban green commons, the above figure 8 identifies key nodes that need to be considered for strategic and

spatial transformational priorities (Metrocentre, Park station, Jeppe station, Ghandi square and Magistrates court). These nodes have been studied as absorbing points in the City of Johannesburg on daily basis, as such more green commons should be prioritised and developed along these key nodal areas.

9 CONCLUSION

The overall objective of this paper was to assess the extent of Rea Vaya bus rapid transit system in improving accessibility to urban green commons. The paper argues that the bus rapid transit system can be better positioned as a mechanism to improve how society interacts with green urban commons through facilitating ease and affordable urban mobility. The findings of this study reveals that the current BRT system in Johannesburg does not far reach majority of green commons as such may hinder the accessibility of such commons if not addressed. In conclusion, the study recommends that there should be a holistic approach through various stakeholder engagement between the Johannesburg planning department and city parks to facilitate smooth integration between the BRT system and urban green commons.

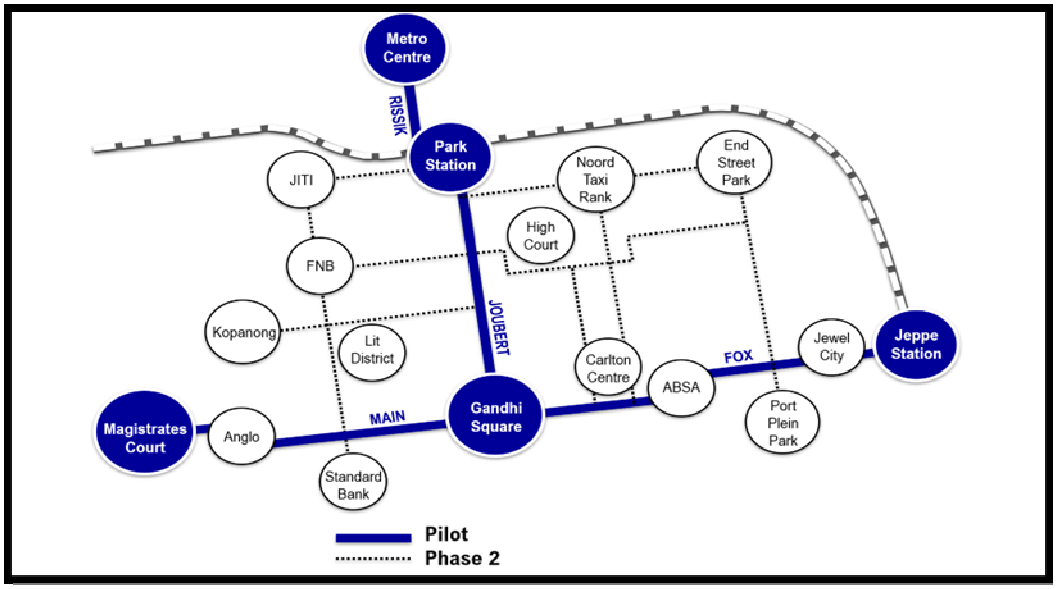


Figure 4: Pilot network aligning BRT to green urban commons (source: JICP, 2020)

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Positive Energy Districts and Energy Poverty

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1 ABSTRACT

Positive Energy Districts (PEDs) are promoted as tools for urban decarbonisation, combining high building efficiency, local renewable energy generation and smart energy management. By definition, they minimise operational energy costs and therefore have a strong structural potential to reduce energy poverty for residents. In Europe, energy poverty is driven by low incomes, high energy costs and inefficient housing, so these PED characteristics directly target core drivers. However, social inclusion and affordability are rarely central in current PED deployment, creating risks that vulnerable households remain excluded or displaced. This paper examines how PEDs can both alleviate and unintentionally exacerbate energy poverty through their impacts on income, energy costs, building efficiency and energy saving behaviour. It argues that PEDs will only contribute meaningfully to a just transition if affordability safeguards, targeted renovation of low efficiency districts and inclusive governance are integrated from the outset. Based on this analysis, the paper formulates policy recommendations to ensure that PEDs benefit low income households and support an equitable energy transition.

Keywords: Positive Energy District, Energy Poverty, Affordability, Social inclusion, Renovation

2 INTRODUCTION

Energy poverty has become a recognised socio economic and health challenge across Europe. It affects households that struggle to secure adequate heating, cooling, lighting and the use of basic appliances at an affordable cost. The issue is driven by a combination of low household incomes, rising energy prices and a large share of inefficient and aging residential buildings, particularly in dense urban areas where renovation backlogs are most pronounced (Bouzarovski, 2014). Energy poverty has important social and spatial dimensions, as it disproportionately affects vulnerable populations and contributes to unequal living conditions, excess winter mortality and a reduced quality of life (Walker, et al., 2016).

In parallel with this development, the concept of PEDs has gained increasing prominence in European research, funding programmes and urban planning strategies (JPI Urban Europe, 2020). PEDs are understood as urban areas that combine highly energy efficient buildings, local renewable energy production and smart control systems in order to achieve a positive annual energy balance (Bossi, et al., 2020). While they are primarily promoted as tools for decarbonisation and energy system innovation, an emerging discussion highlights their relevance for social equity and affordability. Because PEDs directly influence levels of energy demand, energy prices, building quality and the organisation of local energy systems, they are potentially relevant for addressing some of the structural drivers of energy poverty.

This paper examines whether and how PEDs can contribute to reducing energy poverty. It analyses both the mechanisms through which PEDs may alleviate energy poverty and the mechanisms through which they may unintentionally increase it, for example by raising housing costs or limiting access for vulnerable households. By considering these positive and negative pathways side by side, the paper highlights that the social effects of PEDs are not automatic but depend on how they are planned, financed and governed. Building on this analysis, the paper formulates policy recommendations aimed at improving the ability of PEDs to benefit low income households and contribute to a socially just energy transition.

3 METHODOLOGY

The analysis presented in this paper is based on a combination of literature research and expert input gathered within the DUT project RESPED (Ala-Juusela, et al., 2025). The literature research covered scientific articles, policy documents and technical reports on energy poverty and PEDs, with the aim of identifying relevant concepts, impact mechanisms and empirical observations. This provided the conceptual basis for analysing how PEDs may affect the drivers of energy poverty.

Four main dimensions of impact of PEDs on energy poverty were defined: household income, energy costs, building energy efficiency and energy related behaviour. These mechanisms reflect established drivers of energy poverty and enable a structured assessment of both positive and negative effects. In this paper, each mechanism is analysed separately in order to clarify how PED characteristics may alleviate or exacerbate energy poverty through these different causal pathways.

Complementing the desk research, insights were collected through workshops organised within the RESPED consortium and with selected external stakeholders, involving experts from research, municipal planning, housing and energy related fields to discuss affordability challenges, accessibility issues and potential social impacts associated with PED deployment.The findings informed the interpretation of the literature and helped identifying practical conditions under which vulnerable households may or may not benefit from PEDs. The combined approach allows the paper to address both theoretical mechanisms and practice oriented considerations relevant for the social implications of PEDs.

4 POSITIVE IMPACTS OF PEDS ON ENERGY POVERTY

The following subsections discuss how PEDs may reduce energy poverty by analysing their influence across four central dimensions of energy poverty: income, energy costs, building efficiency and energy saving behaviour.

4.1 Positive Impact through Income

In terms of income, the direct influence of PEDs on energy poverty is limited as PEDs do not provide additional revenues to households to boost their incomes. In some cases, electricity feed-in from surplus generation can create additional revenue streams, but these are typically modest (often well below €100 per month) and tend to accrue to building owners rather than tenants, who are more often affected by energy poverty. When such revenues do reach households, they function less as direct payment and therefore passive increase in income, but rather as a reduction of the net electricity bill, which makes them more appropriately understood within the impact mechanism through energy costs rather than income.

4.2 PositiveImpact through Energy Costs

The most significant way in which PEDs can mitigate energy poverty is by decreasing household energy costs. By producing more renewable energy than they consume, at significantly lower costs than the energy market or even near-zero costs, PEDs are able to substantially lower, or in some cases even eliminate, energy bills, which are disproportionately high for people experiencing energy poverty (Casamassima, et al., 2022). For energy-poor households, whose expenditures on electricity and heating amount to disproportionately high share of overall costs of living, these reductions can free up resources for other essential needs.

Furthermore, the enhanced capacity of PEDs to self-sufficiently cover energy demand from their own production provides resilience against energy price fluctuations. This might be particularly relevant in response to potentially rising prices for fossil fuels due to carbon pricing and geopolitical factors (Hearn, 2022). Energy poor households tend to have low savings, because they spend most of their available income on covering their everyday living expenses. Thus, energy poor households cannot buffer energy price fluctuations by themselves, but PED self-production may do so.

However, it is important to consider that if the high upfront investment costs of PEDs are passed onto residents through increased rents, the energy cost savings from PED self-production may be partly offset, limiting the overall impact on reducing energy poverty. Therefore it is important to combine the energy efficiency measures of PEDs with measures ensuring affordable housing to ensure that PEDs can considerably mitigate energy poverty.

Overall it can be assumed that in practice, if low-income households manage to take residence in a PED, they are no longer likely to be affected by energy poverty. This is because PEDs, by their very design, keep energy bills low. From this perspective, the impact mechanims of energy costs generally helps to reduce energy poverty inside PEDs. The bigger question, however, is not whether PED residents benefit, but whether people who are already struggling with energy poverty are actually able to find housing in these districts. If low-income households are excluded or pushed out, the positive effects of PEDs on energy poverty remain very limited. This issue will be discussed in Section 5, which focuses on the possible negative effects of PEDs on energy poverty.

4.3 Positive Impact through Building Energy Efficiency

Enhancing building energy efficiency is a key way in which PEDs can help alleviate energy poverty. By integrating highly efficient building envelopes, advanced insulation, and smart energy management systems, PEDs drastically reduce the amount of energy required for heating, cooling, lighting, and appliances (Bossi, et al., 2020). This inherent high efficiency minimises energy waste and lowers total energy demand, leading to substantial reductions in household energy consumption. Even if these efficiency gains are partially offset by larger floor areas (rebound effect), or because energy poor households no longer need to cut back on heating expenses and can now afford to heat to normal temperatures, the substantial reduction in energy demand still accrues to lasting benefits. For people affected by energy poverty, this means that even if energy prices rise, their efficient homes require significantly less energy to maintain comfortable living conditions, thereby buffering the impacts of increasing energy prices. However, while improved energy efficiency reduces operational costs, the high initial investment required for such advanced building standards may still pose barriers if not mitigated by targeted subsidies or financing schemes. PEDs also improve indoor environmental quality by providing more stable indoor temperatures, better humidity control, reduced noise, the absence of indoor air pollution from burning improvised fuels, and enhanced natural light. These factors directly support the health and well being of residents. Energy poor households often live in buildings with low indoor environmental quality, so moving into a Positive Energy District can significantly improve their living conditions.

PEDs are typically either new constructions or thoroughly renovated buildings built to the highest standards, their efficiency and comfort benefits are ensured by design. In summary, the high levels of building energy efficiency embedded in the PED concept naturally reduce energy demand and therefore contribute to lowering the risk of energy poverty. However, as with the energy cost mechanism, the main challenge is not whether PEDs are efficient, but whether energy-poor households are able to benefit from these efficiencies, either by affording to live in new PED developments or by having their existing, less efficient homes renovated to PED standards. Without addressing this accessibility issue, the efficiency gains of PEDs risk bypassing those who need them the most.

4.4 Positive Impact through Energy-Saving Behaviour

PEDs can influence energy poverty by fostering energy saving behaviour among residents. Through integrated smart systems, real-time energy monitoring, and user-friendly feedback technologies, PEDs raise awareness of personal energy consumption patterns and encourage behavioural changes to reduce unnecessary usage (Hearn, et al., 2021). This behavioural shift can lead to further energy savings beyond the building's inherent efficiency, empowering low-income households to learn about the main reasons for their energy consumption in order to actively manage and reduce their energy expenses. Educational programmes and community engagement initiatives often embedded within PED projects can further strengthen these behavioural impacts by enhancing knowledge and skills for long-term energy-aware living or by introducing social feedback among neighbours. However, it is important to recognise that behavioural change depends on user motivation, comprehension, and time availability, which may vary, limiting its effectiveness without adequate support.

5 NEGATIVE IMPACTS OF PEDS ON ENERGY POVERTY

PEDs may also exacerbate energy poverty through high investment costs and low accessibility of energy poor households. So, PEDs face several concerns that could hinder their role in alleviating energy poverty. The most pressing concern are the cost for constructing or renovating buildings and for installing the energy technologies that are characteristic for PEDs (Bouzarovski, 2014). The high initial investment required for PED implementation, particularly in economically disadvantaged areas, risks excluding energy vulnerable people and thereby increasing energy poverty (Bouzarovski, 2014; Hearn et al., 2021). The following subsections outline possible negative impact mechanisms of PEDs via the four dimensions of energy poverty. The issues regarding affordability and gentrification are discussed in the impact mechanism regarding energy efficiency (section 5.3).

5.1 Negative Impactthrough Income

PEDs have no meaningful direct impact on household income, as they neither raise wages nor provide additional earnings to residents. In this sense, no negative income effects are expected and the income dimension does not constitute a relevant impact mechanism for PEDs in relation to energy poverty.

5.2 Negative Impact through Energy Cost

Basically, PEDs reduce energy costs as outlined in the previous section. However, in some cases theseeffects could be rather limited as the advanced technologies and integrated systems of PEDs could leadto complex pricing structures and high maintenance costs, especially if PEDs are pilot projects whereunforeseen costs may emerge because of experimental technologies that require ongoing technicalsupport. These costs may be transferred to residents through elevated service charges or energy tariffswithin the district (Hearn, et al., 2021). Additionally, if the PED business model prioritises cost recovery or private returnson investment, locally produced renewable energy might be sold on the market, leading toconventional energy prices for all PED residents, including energy poor households.

PEDs typically have a positive net energy balance. This means that they generate more energy thanthey consume within a timespan of one year which should lead to low energy costs and therefore apositive effect on energy poverty. However, this presumes that feed in revenues are received byresidents and not only by investors or building owners.

Another negative impact mechanism that could undermine the positive effects could be a deliberately high energy price in PEDs. The PED project Hunziker Areal in Zurich has deliberately set high energyprices in order to avoid rebound effects, that is low energy costs, as they are typical in PEDs, incentivizinghigher energy use (Hearn, et al., 2021). While this is counter balanced by the highly energy efficient infrastructure, it maybe perceived as an energy injustice for lower income groups (Hearn et al., 2021).

In summary it can be said that all in all it is not expected that PEDs will increase energy costs forresidents due to their high energy efficiency and low energy consumption. However, the positive effectson energy costs could be limited in some cases by high service fees, maintenance costs or othercharges.

5.3 Negative Impact through Building Energy Efficiency

Households experiencing energy poverty typically live in dwellings with inadequate insulation, outdated heating systems and generally low energy performance. By definition, however, PEDs consist of highly efficient and well insulated buildings, which means that the negative effects of low energy efficiency do not apply within PEDs themselves. In this sense, PEDs do not directly exacerbate energy poverty through the efficiency mechanism. The central challenge instead lies in ensuring that energy poor households can access these highly efficient dwellings. This raises critical questions about affordability, the inclusion of existing low income housing in PED frameworks and how risks of gentrification and displacement can be minimised. Consequently, this subsection focuses on the interrelated issues of affordability, gentrification and accessibility of PEDs for energy poor households.

High energy efficiency comes with high upfront construction or retrofit costs. These costs may be passed on to tenants or owners through higher rents, service charges or purchase prices, potentially excluding lower income groups from accessing the benefits of energy efficient living (Walker, et al., 2016) (Hatz, 2021). Investments in renovating existing buildings to PED standard could even trigger the displacement of previous low-income residents who cannot afford an increased rent, a phenomenon sometimes referred to as renoviction, especially in areas where housing markets are already under pressure (Hatz, 2021). This affordability challenge is exacerbated by the heavy reliance on private sector investment in PED development. Unless regulatory frameworks enforce inclusivity, this dependence on investment from the private sector may prioritise profit over social equity (Hearn, et al., 2021). Studies have shown that retrofit policies relying on market-based mechanisms tend to have regressive effects, reproducing or even deepening existing energy inequalities (Rosenow, 2012) (Rosenow, et al., 2013). These considerations on affordability and social equity within financing are particularly relevant in the context of PEDs, as the European SET Plan for PEDs estimates that public investment of 0.74 billion euro will need to be matched by at least 100 billion euro from private investment and cities (JPI Urban Europe, 2020), highlighting the scale of private influence on implementation.

Beyond implementation costs, the post upgrade affordability of housing within PEDs also matters. As energy efficiency and renewable technologies raise property values, living spaces within PEDs may become unaffordable for lower income households. Without regulatory frameworks, PEDs are at risk of becoming exclusive domains for wealthier populations, resulting in gentrification and the potential displacement of energy poor households as they are pushed out to cheaper and less efficient housing (Hearn, et al., 2021).

Finally, energy poor households and their buildings may face structural exclusion from PED projects altogether. PEDs are often new private sector developments that target high efficiency standards in newly constructed buildings. As a result, existing buildings with poor energy performance, such as aging public or social housing stock where energy poverty is most prevalent, are less likely to be included. This exclusion reinforces spatial and social divides, as those who would benefit most from reduced energy demand and improved comfort lack access to highly efficient PEDs. Furthermore, energy efficiency upgrades in existing buildings, especially in older municipal housing, are often costly and complex, making them less attractive to private investors or PED planners. Integrating low performing affordable housing into PED frameworks must therefore be a priority if PEDs are to support rather than hinder a just energy transition.

5.4 Negative Impact through Energy-Saving Behaviour

PEDs may unintentionally deepen energy poverty through the impact mechanism of energy saving behaviour. Making effective use of dynamic pricing schemes and flexibility options, which are often key revenue streams within PEDs, requires a certain level of smart household devices, energy literacy, digital access and time availability that energy poor households may lack, preventing them from benefiting fully and potentially exposing them to higher costs during peak price periods (Hearn, 2022). Consequently, instead of lowering energy expenditures for vulnerable groups, PEDs could risk increasing them, thereby worsening energy poverty for residents already struggling to afford their basic energy needs.

Another relevant effect in this context is the so called rebound effect. This refers to situations where low energy costs in highly efficient buildings lead households to use more energy for comfort instead of saving it. In PEDs this may reduce the motivation for careful energy use and weaken behavioural measures aimed at lowering consumption. While this can improve indoor comfort for households that previously had to limit heating or cooling, it also limits the expected energy savings and can make behavioural interventions less effective for reducing energy costs.

6 POLICY IMPLICATIONS AND RECOMMENDATIONS

Drawing on the mechanisms identified in the previous sections, which highlight both the mitigating and exacerbating effects of PEDs on energy poverty, this chapter presents policy recommendations to ensure that PEDs support affordability and social inclusion and thereby contribute to reducing energy poverty over time.

6.1 Prioritise social housing and energy poor districts for PED retrofits

To ensure that energy poor households benefit from PEDs, renovation programmes should explicitly target social housing and low efficiency districts where energy poverty is most concentrated. Housing stock owned by the public or by non-profit housing cooperatives is often easier to retrofit systematically than mixed ownership buildings, making it a strategic entry point (Hearn, 2022). Large scale publicly funded deep renovations to PED standards in these areas would not only reduce energy bills and improve living conditions but also prevent the exclusion of the most vulnerable households from the energy transition.

6.2 Inclusion of low-income households in PEDs

Public authorities should require PED projects to meet clear social inclusion criteria, such as allocating a share of housing units to low income households or integrating energy poor buildings into the district's scope. Without binding inclusion mechanisms, PEDs risk becoming exclusive developments for wealthier populations. Planning regulations should link public funding or zoning approvals to measurable equity outcomes, ensuring that PED benefits extend to those most vulnerable to energy poverty.

6.3 Public financing for social housing

Public investments in PEDs should come with binding social conditions. Access to EU or national subsidies could be tied to inclusion criteria, such as allocating a fixed share of housing units for low-income

households, rent caps or anti eviction clauses. This ensures that the efficiency and comfort benefits of PEDs are not offset by rising rents or displacement. Long term affordability covenants should be required to maintain inclusivity over decades, not just at the point of construction or renovation.

This means that a portion of public PED funding should be ring fenced for retrofitting and integrating older, energy inefficient social and affordable housing within PED boundaries. Energy poor households are often concentrated in under maintained municipal housing, which is typically left out of high-tech PED projects. Targeted financial support is essential to overcome the technical and economic challenges of upgrading this stock and ensuring these residents are not structurally excluded from the energy transition. (Willand, et al., 2020) even find that a non targeted subsidy approach may be regressive and reproduce energy inequalities. Instead, interest free loans and full grants could improve participation and ensure that retrofitting initiatives reach vulnerable population segments (Willand, et al., 2020) (Hearn, 2022).

6.4 Protecthousingaffordability after renovation

Renovation driven gentrification poses one of the biggest risks to energy poor households. To counter this, policymakers should guarantee existing tenants the right to return after renovations at affordable rents. Legal mechanisms such as rent stabilisation, affordability guarantees or targeted tax incentives for landlords can help balance investment costs with tenant protection (Hatz, 2021). One such example is the Affito Condizionato in Milan which was implemented to avoid gentrification risk after retrofitting projects (Hearn, 2022). These safeguards are critical to ensure that deep renovations raise living standards without forcing low income residents out of their homes and pushing them to cheaper but low quality housing.

6.5 Empower municipalities and communities as PED developers

Municipalities should be supported to act as champions for PEDs in disadvantaged areas, ensuring that local needs and affordability remain central. Public ownership or cooperative models for PED energy systems can allow residents to share the financial benefits of surplus energy generation. By reinvesting revenues locally, for example into community services or further building renovations, municipal and community led PEDs can create a virtuous cycle of inclusivity and affordability that private market led developments often overlook. Municipalities may enter public private partnerships with private developers and energy providers to develop inclusive PEDs with guaranteed affordability measures (Hatz, 2021).

6.6 Develop tailored financing tools for low-income households

Energy poor households often lack the resources to invest in energy efficiency upgrades even when the long term return on investment is obvious. Financing tools such as zero interest loans, pay as you save schemes or on bill financing models with public guarantees can lower these barriers. State backed financing models and guaranteed returns on energy efficiency investments can mitigate this barrier (Hearn, 2022). By aligning repayments with actual energy savings and shielding households from upfront costs, these mechanisms ensure that vulnerable groups can access high efficiency living without additional financial burden. However, these financing tools must consider renter fluctuation and include rules for fair loan transfer if renters do not stay in the flat long enough for the entire payback period of loans.

6.7 Balance upscaling of PEDs with social policy

PEDs raise the overall efficiency standard of the building stock and therefore make an important contribution to reducing long term energy demand and costs. From this perspective, any measure that accelerates renovation rates or promotes new PED developments indirectly helps to reduce energy poverty in total, as other buildings must be renovated as well in order to be able to compete on the housing market.

However, it is neither realistic nor desirable to expect private investors and developers alone to shoulder the responsibility of solving energy poverty. Overregulation of the housing sector could reduce incentives to build or renovate, slowing down the overall transition. Instead, an Efficiency Plus Approach is needed (Hearn, et al., 2021). Policies should prioritise the most cost-effective structural efficiency gains while addressing affordability and energy poverty through parallel social measures such as targeted subsidies, income support or housing allowances. This combined strategy ensures that the benefits of PEDs are maximised without constraining investment or slowing down renovation momentum.

7 CONCLUSION

PEDs have a structurally high potential to mitigate energy poverty because they combine highly efficient buildings with local renewable energy production. By design this reduces or even removes operational energy costs and therefore effectively eliminates the energy spending behaviour that forces low income households to restrict heating, cooling or appliance use. Residents living in such districts are therefore unlikely to experience energy poverty, provided that housing costs remain affordable. However, the central question is not whether residents inside a PED are protected from energy poverty, but to what extent households who are currently affected by, or at risk of, energy poverty are able to access these buildings in the first place.

This challenge becomes even more urgent in light of Europe's renovation needs. The majority of buildings that will exist in 2050 are already built today, and a large share of them perform poorly from an energy perspective. If PEDs are intended to contribute meaningfully to the reduction of energy poverty, they must not remain limited to new, high end developments but need to be applied as a renovation strategy in those areas where energy poverty is actually present. Targeting social housing, municipal stock and low efficiency neighbourhoods is essential to ensure that the benefits of high efficiency and low energy costs reach vulnerable groups rather than bypass them.

The analysis has shown that PEDs do not automatically generate positive social outcomes. Without safeguards, they can increase rents, displace vulnerable households or become exclusive redevelopment projects. For this reason, complementary policy measures are required. Key priorities include linking public PED funding to affordability and inclusion criteria, protecting housing affordability during and after renovation, empowering municipalities and community actors as PED developers, and creating tailored financing tools that enable low income households to participate without upfront costs. These elements are consistent with the broader recommendation that upscaling PEDs must be balanced with social policy rather than driven by efficiency targets alone.

Under these conditions, PEDs can evolve from isolated technical demonstrators into a systemic instrument of the energy transition that improves living conditions, reduces energy expenditure, and ensures that vulnerable households are not left behind. Without such conditions, PED deployment risks reinforcing existing inequalities. Ensuring that PEDs contribute to a just transition therefore hinges on two simultaneous commitments: renovating where energy poverty exists, and creating access pathways so that those most in need can actually benefit.

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Qualität der Nachverdichtung in Österreich

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1 ABSTRACT

Der Klimawandel, die wachsende Bevölkerung sowie die stetige Bodenversiegelung stellen die Stadt- und Ortsentwicklung in Österreich vor neue Herausforderungen. In Anbetracht dieser Rahmenbedingungen liegt der Fokus auf einer nachhaltigen und ressourcenschonenden Stadtentwicklung. Die Nachverdichtung gilt als bodenschonender Ansatz, welcher in der Praxis jedoch häufig auf das quantitative Maß der Dichte reduziert wird. Weitere qualitative Aspekte werden gering adressiert und begrenzt berücksichtigt. Das Paper untersucht daher, wie „Qualität" in der Nachverdichtung definiert werden kann und welche Schwerpunkte als Dimensionen relevant sind. Methodisch basiert das Paper auf einer theoretisch-analytischen Literaturauswertung. Diese umfasst Grundlagen aus der Städtebautheorie sowie Publikationen aus der Praxis. Der Fokus liegt auf dem deutschsprachigen Raum mit dem Hauptschwerpunkt auf Österreich.

Die Analyse zeigt, dass Qualität in der Nachverdichtung aus unterschiedlichen Dimensionen besteht und interdisziplinär ist. Sie umfasst räumliche, funktionale, ästhetische, ökologische und ökonomische Dimensionen. Diese Dimensionen können teilweise messbar gemacht werden. Außerdem betont die Praxisliteratur, dass die Nachverdichtung im ortsspezifischen Kontext zu sehen ist und daher eine Verallgemeinerung nicht möglich ist. Es wird darauf verwiesen, dass Nachverdichtung maßvoll und integrativ gedacht werden sollte, um Dichte und Lebensqualität zu verbinden. Dieses Paper liefert eine theoretisch fundierte Grundlage zur Einordnung der Qualität bei der Nachverdichtung. Es soll zur Weiterentwicklung von planerischen Instrumenten dienen und einen Beitrag zum Diskurs in der nachhaltigen Stadtentwicklung in Österreich leisten.

Keywords: Qualität, Nachverdichtung, Stadtentwicklung, Ressourcenschonung, Dichte

2 EINLEITUNG

In den letzten Jahren sind Dringlichkeit und Herausforderungen, bedingt durch den Klimawandel, immer präsenter geworden. 2024 war laut Klimastatusbericht Österreich mit einem Jahresmittel von 8,8 °C Lufttemperatur das wärmste Jahr in der österreichischen Messgeschichte. Das Jahr verzeichnete starke Regenfälle und anhaltende Hitzeperioden im Jahresverlauf.[1] Aktuelle Daten aus dem Jahr 2025 (Stand 03.03.2026) zeigen, dass Österreich bei einer Gesamtfläche von 8.386.102 ha eine Flächeninanspruchnahme von 568.122 ha aufweist.[2] Seitens des Austrian Panel on Climate Change (APCC) wird im „Special Report: Landnutzung und Klimawandel in Österreich" darauf hingewiesen, dass Böden eine zentrale Grundlage für die Nahrungsmittelproduktion, für sauberes Trinkwasser und für Naturräume bilden. Der aktuelle Bodenverbrauch gefährdet daher zunehmend die regionale Ernährungssicherheit in Österreich.[3] Der Fokus sollte daher auf der Nutzung bereits bebauter Flächen für Siedlungsentwicklung und der Beschränkung weiterer Inanspruchnahme des endlichen Bodens liegen.[4]

Demgegenüber wird seitens der ÖROK mit Bezugnahme auf die Statistik Austria prognostiziert, dass bis 2050 die städtische Bevölkerung um 20% zunehmen wird. Ergänzend dazu veranschaulichen Grafiken (Statistik Austria) zur Wohnflächenentwicklung, dass die durchschnittliche Wohnfläche von 1995 bis 2024

[1] Vgl. CCCA u.a. 2025, 6, 25-26.
[2] Vgl. Soil Walks Dashboard: Dashboard zur Flächeninanspruchnahme und Versiegelung, 2025, https://secure.umweltbundesamt.at/powerbi-embed/start?reportName=soilwalks_oeffentlich&settings.navContentPaneEnabled=false, 03.03.2026.
[3] Vgl. APCC: Wissenschaftsbericht: Massiver Bodenverbrauch in Österreich stellt große Gefahr für Ernährungssicherheit, Artenvielfalt und Klima dar, 30.04.2024, https://www.ots.at/presseaussendung/OTS_20240430_OTS0127/wissenschaftsbericht-massiver-bodenverbrauch-in-oesterreich-stellt-grosse-gefahr-fuer-ernaehrungssicherheit-artenvielfalt-und-klima-da, 03.03.2026.
[4] Vgl. Bundeskammer der Ziviltechnikerinnen und Ziviltechniker 2024, 4.

stetig zugenommen hat. 1995 lag die durchschnittliche Wohnfläche (Hauptwohnsitz) bei 87,6m² und 2024 waren es 101,7m².[5]

2025 wurden von der Erste Group und s Real Immobilien Ergebnisse von der „Wohnstudie 2025“ veröffentlicht. Aus den Ergebnissen geht hervor, dass das Einfamilienhaus mit 38% die präferierte Wohnform in Österreich darstellt.[6] Dieses Ergebnis wird auch seitens der Printmedien wie beispielsweise von „der Standard“ oder „Die Presse“ bestärkt. Überschriften wie „Ein Leben ohne Einfamilienhaus? Für viele undenkbar“[7] oder „Einfamilienhaus: Der Traum vom Haus am Land“ verdeutlichen den Wunsch nach dieser Wohnform in Österreich. Zudem wird auf den dadurch verursachten Bodenverbrauch, auf weitere infrastrukturelle Konsequenzen und auf Herausforderungen in der Finanzierung hingewiesen. Dennoch geht hervor, dass der Wohntraumwunsch „Einfamilienhaus“ bestehen bleibt.[8]

Die Entwicklung der größer werdenden Wohnfläche und der bestehende Wohntraum „Einfamilienhaus“ verursachen, dass mehr Wohnraum, infrastrukturelle Maßnahmen und geplante Freiräume in städtischen Gebieten benötigt werden. Es soll seitens der ÖROK eine kompakte Stadtentwicklung mit einem sparsamen Umgang mit Boden zur Erreichung der Klimaschutzziele angestrebt werden. Zur Reduktion des Bodenverbrauchs, der Versiegelung und der Zersiedelung bedarf es einer ressourcensparenden und nachhaltig gedachten Stadtentwicklung. Eine wesentliche Entwicklungsart in diesem Kontext stellt die Nachverdichtung in bestehenden Strukturen auf gewidmetem Bauland dar.[9] Die reine Nachverdichtung beschreibt jedoch nicht die erzielbare städtebauliche Qualität, sondern wird im Allgemeinen als Erhöhung der vorhandenen Bebauungsdichte verstanden. Die reine Ausnutzung der Dichte und der Fokus auf den maximalen ökonomischen Ertrag leisten noch keinen Beitrag zu einer nachhaltigen Stadtentwicklung. Daher befasst sich dieses Paper mit der Forschungsfrage: „Nachverdichten – ja, aber was ist die Qualität? Wie kann Qualität definiert werden und was sind die Schwerpunkte?“

Als methodischer Ansatz wird eine Analyse von Fachliteratur und Leitbildern herangezogen. Die systematische Literaturrecherche setzt sich mit dem Begriff der Qualität kritisch auseinander. Ziel des Papers ist es, nicht einen Umsetzungsleitfaden zu entwickeln, sondern die systematische Einordnung von Qualitätsdimensionen. Zur sprachlichen und strukturellen Unterstützung wurden KI-Tools in Form von ChatGPT verwendet. Die wissenschaftlichen Argumentationen sowie die inhaltliche Verantwortung liegen vollständig bei der Autorin und wurden von dieser verfasst.

3 DIE NACHVERDICHTUNG: BEGRIFFSERKLÄRUNG UND NACHVERDICHTUNGS-FORMEN

In der Literatur wird vermehrt der Begriff der Innenentwicklung hervorgehoben und die Nachverdichtung stellt nur einen Teilaspekt davon dar. In diesem Zusammenhang ist zu erwähnen, dass vom deutschen Umweltbundesamt im Jahr 2023 eine Publikation unter dem Titel „Dreifache Innenentwicklung“ erschienen ist. In dieser wird argumentiert, dass die Innenentwicklung durch drei Dimensionen geprägt wird. Die Dimensionen bzw. Ebenen sind das Bauen, die blau- und grüne Infrastruktur und die Mobilität. Eine Überlagerung dieser drei Ebenen ergibt die dreifache Innenentwicklung und verdeutlicht den interdisziplinären Zusammenhang bei der nachhaltigen Stadtentwicklung.[10] Zudem wird die „Dreifache Innenentwicklung“ auch seitens der österreichischen Bundeskammer der Ziviltechnikerinnen und Ziviltechniker im Jahr 2024 gefordert.[11]

[5] Vgl. Statistik Austria 2025, 32.
[6] Vgl. Erste Group/s REAL Immobilien: Wohnstudie 2025: Traum vom Eigentum bleibt in Österreich fest verankert, 17.06.2025, https://www.erstegroup.com/de/news-media/presseaussendungen/2025/06/17/wohnstudie-2025-traum-vom-eigentum-bleibt-in-oesterreich-fest-verankert, 03.03.2026.
[7] Vgl. Die Presse: Einfamilienhaus: Der Traum vom Haus am Land, 20.08.2024, https://www.diepresse.com/18777509/einfamilienhaus-der-traum-vom-haus-am-land, 03.03.2026.
[8] Vgl. Redl, Bernadette : Ein Leben ohne Einfamilienhaus? Für viele undenkbar, 28.01.2024, https://www.derstandard.at/story/3000000204742/ein-leben-ohne-einfamilienhaus-fuer-viele-undenkbar, 03.03.2026.
[9] Vgl. Österreichische Raumordnungskonferenz 2021, 31-32, 65-67.
[10] Vgl. Umweltbundesamt 2023, 8.
[11] Vgl. Bundeskammer der Ziviltechnikerinnen und Ziviltechniker 2024, 5.

Dieses Paper beschränkt sich auf den Teilaspekt Nachverdichtung in der baulichen Ebene, jedoch werden Aspekte der blau- und grünen Infrastruktur berücksichtigt, da aufgrund der Komplexität der nachhaltigen Stadt- und Ortsentwicklung die Interdisziplinarität von hoher Relevanz ist.[12]

3.1 Definition „Nachverdichtung" in unterschiedlichen Dimensionen

Zentraler Bestandteil des Begriffs „Nachverdichtung" ist die Dichte bzw. die Verdichtung. In diesem Kontext ist die kompakte Stadt zu erwähnen. Eine eindeutige Begriffsdefinition ist nach der Literaturrecherche von Bibri/Krogstie/Käarrholm nicht möglich, jedoch liegt der Fokus auf einer Stadt mit hoher Dichte, großer Nutzungsdurchmischung und „keiner" Zersiedelung. Weiter argumentieren Bibri/Krogstie/Käarrholm, dass die kompakte Stadt nach 30 Jahren noch immer ein zentrales Paradigma des nachhaltigen Städtebaus darstellt. Forschungen zur kompakten Stadt verfolgen, ergänzend zur Raum- und Stadtplanung, Sozial-, Umwelt- und Wirtschaftsaspekte.[13] Aufbauend auf der vorangegangenen Forschung wurden für dieses Paper folgende relevante Schwerpunkte definiert:

Aspekte nach Bibri/Krogstie/Käarrholm[13]	**Gewählte Schwerpunkte**	**Anmerkung**
Raum- und Stadtplanung	Städtebau	Unterteilung aufgrund der unterschiedlichen Maßstäblichkeit
	Raumplanung/Bebauungsdichte	
	Architektur	
Sozialaspekt	Sozial/Gesellschaftlich	
Umweltaspekt	Ökologisch	
Wirtschaftsaspekt	Ökonomisch	

Tabelle 1: Relevante Schwerpunkte der Nachverdichtung

In der Literatur hat die Nachverdichtung, gegliedert in den gewählten Schwerpunkten, folgende Bedeutung und Relevanz:

Schwerpunkt:	**Zitat aus der Literatur**
Städtebau:	*„Der Begriff Nachverdichtung bezeichnet im Städtebau das **Nutzen freier Flächen** im Bereich **bereits bestehender Bebauung**. Sie erfolgt beispielsweise durch Hinterlandbebauung, Aufstockungen oder dem Andocken von Flächen."– **BauNetz Wissen**[14]*
Raumplanung/Bebauungsdichte:	*„Demnach umfasst Städtebauliche Nachverdichtung die **bauliche Nutzung** bisher **unbebauter oder mindergenutzter Flächen** innerhalb einer bereits bestehenden Bebauung." – **BBSR**[15]*
Architektur:	*„**Dichte als Möglichkeit** … für **Transformation**. Diese Konzeption von Dichte stellt Fragen … an die Architektur, die Räume im städtischen Kontext ordnet und gestaltet…" – **Tim Heide /Verena von Beckerath**[16]*
Sozial/Gesellschaftlich:	*„Die meisten … **Nachverdichtungen** finden **im (teil-)bewohnten Zustand** statt. Daher darf die soziologische Komponente eines solchen Projekts nicht unterschätzt werden. Berechtigte Ängste vor Veränderungen, Verdichtung …. Sollte …. Mit Informations- und … Partizipationsprogrammen begegnet werden." – **Martin Teigeler**[17]*
Ökologisch:	*„Angesichts der Nachverdichtung gewinnen **knapper werdende Grün- und Freiräume** an **Bedeutung** und sollen zunehmend mehr Funktionen erfüllen. Der Erhalt und die Begrünung freier Flächen und Gebäude haben unmittelbare Wirkung auf das Mikroklima. Vernetzt mit übergeordneten Grünzügen." – **Umweltbundesamt**[18]*
	Exkurs: Bodenversiegelung /Bodenschutz: Die Bodenversiegelung verursacht unter anderem den Verlust von Biodiversität, Agrarflächen für die Ernährungssouveränität und die Fähigkeit zur Speicherung von Treibhausgasen und Regenwasser. Der Aufruf zum Bodenschutz und zur Vermeidung weiterer Versiegelung auf unbebauten Wiesen wird seitens des Architekturzentrums Wien in der Publikation „Boden für Alle" lauter.[19]
Ökonomisch:	*„werden die Dichteindikatoren zwar als Instrumente verwendet, aber immer weniger als Tool der Raumplanung, sondern vielmehr als für **Grundstücksverhandlungen** und als Möglichkeit der **Profitmaximierung**."- **Degros u.a**.[20]*

Tabelle 2: Schwerpunkte mit Literaturzitaten

3.2 Formen der Nachverdichtung

Das Land Vorarlberg veranschaulicht und präzisiert in der 2018 erschienenen Publikation „Innenentwicklung und bauliche Verdichtung" unterschiedliche Formen der Verdichtung. Die verschiedenen Ausformungsarten können folgendermaßen definiert werden:

[12] Vgl. Region Köln/Bonn e.V. 2022, 13.
[13] Vgl. Bibri/Krogstie/Käarrholm 2020, 2-3.
[14] Baunetz: Nachverdichtung, o. J., https://www.baunetzwissen.de/glossar/n/nachverdichtung-1097483, 03.03.2026.
[15] BBSR 2014, 5.
[16] Griffin u.a. 2016, 54.
[17] Teigeler 2019, 15.
[18] Umweltbundesamt 2023, 14.
[19] Vgl. Mayer/Ritter/Fitz 2020 S. 139-146.
[20] Degros u.a. 2021, 102.

- Aufstockung auf Bestandsgebäude
- Zu- und Anbauten
- Dachausbauten und gegebenenfalls Umnutzungen von Nebengebäuden, wie Garagen
- Stellplätze für mobile Kleinbauten, z.B. in Form eines „Tiny“ Hauses
- Die Schließung von Baulücken
- Grundstücke mit Bedacht bebauen, sodass gegebenenfalls eine Grundstücksteilung möglich ist und der Bauplatz besser ausgenutzt werden kann
- Überlegungen zum Abriss bzw. Neubau von ausgewählten Gebäuden
- Bebauung im Hinterhof oder Garten durch die Errichtung eines zweiten Gebäudes
- Die Forcierung der verdichteten Bebauungsform, z.B. als Reihenhaus mit einer in die Umgebung passenden Geschossigkeit
- Die Bebauungsform der Blockrandbebauung
- Oder die vertikale Verdichtung durch eine größer dimensionierte Aufstockung, unter Berücksichtigung der statischen Voraussetzungen.[21]

4 QUALITÄT ALS MULTIDIMENSIONALES KONZEPT – MÖGLICHE INDIKATOREN

Die Qualität der Nachverdichtung ist ein multidimensionales Konzept mit strukturabhängigen Fokuspunkten, welche eng mit der Maßstäblichkeit und der gebauten Umgebung verbunden sind.

Diese These wird einerseits durch Literatur aus der Praxis, aus Vorarlberg und Deutschland, gestützt. Andererseits verweist auch Jan Gehl in seinem Buch „Städte für Menschen“ auf das vielschichtige Zusammenspiel. In der Praxis wird Qualität seitens des Landes und der Stadt/Gemeinde folgendermaßen gemessen: Das Amt der Vorarlberger Landesregierung leitet aus den Umfrageergebnissen zur gesellschaftlichen Wahrnehmung von Dichte folgende Aussage ab: „*Für die Planung bedeutet diese Erkenntnis, dass es keinen generell gültigen Maßstab für die Qualität einer verdichteten Bauweise gibt; vielmehr müssen die Qualitätsanforderungen ortsspezifisch und auf den konkreten Einzelfall bezogen herausgearbeitet werden.*“[22]

Dennoch werden in der Publikation drei Grundsätze für die Planung von verdichteten Bauweisen hervorgehoben:

- die „maßvolle Verdichtung“ als Planungsgrundsatz, um einen Mehrwert für die Bevölkerung zu ermöglichen und nicht den Fokus auf den maximalen Verdichtungsertrag zu richten.
- die „ortspezifische Verdichtung“, um auf die ortstypischen Gegebenheiten einzugehen und einen höheren Zuspruch bzw. eine höhere Akzeptanz zu erhalten.
- und das Austesten der „neuen Dichte“, um verdichtete Strukturen zu erproben und den Diskurs mit Menschen und deren Einbindung zu fördern.

Ergänzend dazu werden Qualitätskriterien herausgearbeitet, welche auf die Mehrdimensionalität des Qualitätsanspruchs der Nachverdichtung verweisen. Der Qualitätsanspruch stützt sich auf die unterschiedlichen Dimensionen der Planung. Einerseits wird auf infrastrukturelle und soziale Durchmischung verwiesen. Andererseits werden gestalterische Schwerpunkte in der Planung von Architektur, öffentlichem und halböffentlichem Raum hervorgehoben. Weitere Punkte sind die Planung des ruhenden, privaten und öffentlichen Verkehrs und der Umgang mit dem Klimawandel und der Knappheit der Ressourcen. [23]

Zudem wird im Agglomerationsprogramm „Dreifache Innenentwicklung“ der Region Köln/Bonn die Dichte in einen multidimensionalen Kontext gesetzt. Die Dichte darf nicht ausschließlich als quantitative Zahl mit Zielwerten verstanden werden. Es sollen weitere Aspekte zur funktionalen, sozialen und gestalterischen

[21] Vgl. Amt der Vorarlberger Landesregierung 2018, 14.
[22] Amt der Vorarlberger Landesregierung 2018, 16.
[23] Vgl. Amt der Vorarlberger Landesregierung 2018, 20.

Qualität bei der Nachverdichtung berücksichtigt werden. Die Entwicklung sollte integrativ gedacht werden und auf den Stadt- oder Gebietscharakter eingehen. Durch bauliche Ergänzungsmaßnahmen sollen positive Auswirkungen für die lokale Bevölkerung geschaffen werden. Dies kann beispielsweise durch weitere funktionale Ergänzungen, wie Einrichtungen für Gemeinbedarf und die Nahversorgung, erfolgen. Eine Durchmischung der Qualitätskriterien stellt einen höheren Aufwand dar. Langfristig betrachtet sind durchmischte Gebiete nachhaltiger, da sie einerseits robuster und andererseits anpassungsfähiger sind.[24]

Aus städtebautheoretischer Sicht argumentiert Jan Gehl in seinem Kapitel „Kompakte Stadt – lebendige Stadt?“, dass eine lebendige Stadt nicht ausschließlich auf die hohe Bebauungsdichte zurückzuführen ist. *„Lebendige Städte erfordern kompakte städtebauliche Strukturen, eine maßvolle Bevölkerungsdichte, annehmbar kurze Wege für Fußgänger und Radfahrer sowie einladende öffentliche Flächen. Bebauungsdichte (Quantität) muss mit gut gestalteten Stadträumen (Qualität) kombiniert werden.“*[25]

Für eine quantitative Messbarkeit können die städtebaulichen Qualitätskriterien, laut Reicher (Städtebauliches Entwerfen), ergänzend durch die Schwerpunkte aus Kapitel 3.1, in folgende Dimensionen zusammengefasst werden:

Gewählte Schwerpunkte	**Dimensionen laut Reicher**[26]	
Raumplanung/Städtebau	**Räumliche Dimension:**	Stadtstruktur, räumlicher Kontext, öffentlicher Raum
Raumplanung/Städtebau	**Funktionale Dimension:**	Nutzungen, Funktionsweisen, Erschließungen inkl. Verkehrswege
Architektur	**Ästhetische Dimension:**	Gebäude, Architektur
Ökologisch	**Ökologische Dimension:**	Landschaft, Ressource: Natur
Sozial/Gesellschaftlich	**Soziale Dimension:**	Soziokultur, soziale Verantwortung und Aneignung
Ökonomisch	**Ökonomische Dimension**	Wirtschaftlichkeit, Folgekosten

Tabelle 3: Dimensionen der Nachverdichtung laut Reicher inkl. Schwerpunkte

Dimension	**Magistrat Wien „Werkstattbericht 167 -Städtebauliche Kennwerte“**[27]	**Ergänzte Kennwerte**
Räumliche Dimension	Geschossflächendichte (GFD) netto	
	Bebaute Fläche in [m²]	
	Bebaute Fläche in Prozent [%]	
Funktionale Dimension	Anzahl der Erdgeschossnutzungen	Anzahl der Nutzungen[28]
	Erreichbarkeit (festgelegter Einzugsbereich [m])	Anbindung an Fuß- u. Radwegenetz[28]
	Einrichtungen für den täglichen Bedarf u. Versorgungseinrichtungen	Aufenthaltsdauer im öffentlichen Raum [h][29]
Ästhetische Dimension	Maximale Baublocklänge u. -breite [m]	
	Geschossanzahl ohne Dachgeschoss	
	Durchlässigkeit (max. 150 m ohne Durchgang) gewährleistet ja/nein	
	Raumhöhe im Erdgeschoss [m]	
Ökologische Dimension	Freifläche/unbebaute Fläche [m²]	drei sichtbare Bäume pro Einwohnerin oder Einwohner[30]
	Grün- u. Freiräume [m²/EW] (Einzugsbereiche: Grundstück, Nachbarschaft, Wohngebiet, Stadtteil)	30% Baumkronenbedeckung pro Nachbarschaft[30]
	Besonnung der bauplatzbezogenen Freiflächen [h]	300 m bis zum nächsten Park oder Grünfläche [m][30]
	Öffentliche Grünanlagen in unterschiedlichen Einzugsgebieten [m²/EW]	Grünflächenfaktor = (Σ Teilflächen x jeweiligen Faktor + Baumbonus) /Bauplatzfläche[31]
Soziale Dimension	Anzahl der Wohneinheiten pro Gebäude	Belegungsdichte [m²/Kopf][32]
	Bewohnerinnen- und Bewohnerdichte	Interaktionsdichte (Gegenseitige Einwirkungen der Bewohnerinnen und Bewohner, anonym o. nicht anonym)[32]
		Ø Haushaltsgröße[33]
		Ø m²/Bewohnerinnen und Bewohner[33]
Ökonomische Dimension	Bruttogeschossfläche [m²]	Beschäftigungsdichte[34]
		Baumassenzahl (BMZ)[34]

Tabelle 4: Dimensionen mit messbaren Kennwerten

[24] Vgl. Region Köln/Bonn e.V. 2022, 20.
[25] Gehl 2015, 87.
[26] Vgl. Reicher 2017, 214.
[27] Vgl. Magistrat Wien 2017, 28-32.
[28] Vgl. Reicher 2017, 10, 146.
[29] Vgl. Gehl 2015, 88.
[30] Vgl. Konijnendijk 2021, o. S.
[31] Vgl. Stadt Graz Grünflächenfaktor Verordnung, o. J. https://www.graz.at/cms/beitrag/10412985/9229427/Gruenflaechenfaktor_Verordnung.html, 03.03.2026.
[32] Vgl. Amt der Vorarlberger Landesregierung 2018, 12.
[33] Vgl. Gehl 2015, 84
[34] Vgl. Reicher 2017, 10.

Diese Dimensionen können teilweise mit messbaren Kennwerten in Verbindung gesetzt werden. Hierzu werden nachfolgend ausgewählte Kennwerte aus dem Werkstattbericht 167 „Städtebauliche Kennwerte“ des Magistrats Wien angeführt. Die Liste wurde durch Kennwerte aus den Publikationen „Innenentwicklung und bauliche Verdichtung“ (Amt der Vorarlberger Landesregierung), „Städtebauliches Entwerfen“ (Reicher), „Städte für Menschen“ (Gehl), „The 3-30-300 Rule for Urban Forestry and Greener Cities“ (Cecil Konijnendijk) und „Grünflächenfaktor Verordnung“ (Stadt Graz) ergänzt.

Die angeführten Kennwerte sind als quantitative Messgrößen zur Orientierung aus der Fachliteratur zu sehen. Die anzustrebenden Zielwerte sind von der vorhandenen Nachverdichtungssituation abhängig, welche an die örtlichen Gegebenheiten gebunden ist. Eine Pauschalisierung dieser Zielwerte ist daher ohne den Planungskontext und das Hintergrundwissen nicht möglich. Der Fokus dieses Papers liegt auf der Entwicklung einer konzeptionellen Einordnung und nicht auf der Entwicklung eines Bewertungsmodells. Zur Entwicklung eines Bewertungsmodells sowie eines Umsetzungsleitfadens bedarf es weiterer Forschung.

5 SPANNUNGSFELD: DICHTE VS. LEBENSQUALITÄT

Durch den multidimensionalen Ansatz der Nachverdichtung bzw. der Qualität in der Nachverdichtung entsteht ein Spannungsfeld zwischen „Dichte vs. Lebensqualität“. Das allgemeine Bewusstsein über die Vorteile von Nachverdichtungsmaßnahmen ist meist vorhanden, jedoch werden auch Bedenken oder Kritikpunkte über die Auswirkungen geäußert.[35] Die Dichte bzw. die Nachverdichtung trifft vermehrt auf Skepsis aus der Bevölkerung. Mögliche Maßnahmen sollen „niemanden“ betreffen. Dieses Phänomen wird auch als NIMBY – „Not In My Backyard“ – „Nicht in meinem Hinterhof“ bezeichnet.[36] Den städtebaulichen Entwicklungsmaßnahmen steht die Furcht einer möglichen Beeinträchtigung der Lebensqualität gegenüber. Diese Furcht stützt sich auf die Angst vor Wachstum und dem Unbekannten. Bauliche Maßnahmen könnten den Verlust von vorhandenen Stellplätzen und grünen Freiflächen zur Folge haben und gegebenenfalls auch die Aussicht einschränken.[37] Nachverdichtungsmaßnahmen betreffen in manchen Fällen die Grünflächen von Bewohnerinnen und Bewohnern, was als Hauptkritikpunkt gesehen wird.[38] Weiters kann es zu einem höheren Verkehrsaufkommen mit Lärmbelästigung kommen. Die Versiegelung, der erhöhte Verkehr und die fehlende Sozialverträglichkeit können negative Effekte auf das ökologische Stadtklima und das Zusammenleben verursachen. [39]

Demgegenüber kann die Nachverdichtung als Chance zur Verbesserung gesehen werden. Die unterschiedlichen Verdichtungsformen können die Ausnutzbarkeit des Bodens fördern und der Zersiedelung durch kompakte städtebauliche Entwicklungsmaßnahmen entgegenwirken.[40] Kompakte Siedlungen mit ausgewogener Nutzungsdurchmischung fördern die „10-Minuten-Nachbarschaft“. In dieser Nachbarschaft sind Wohnstandorte mit unterschiedlichen Einrichtungen für den täglichen Bedarf, wie Arbeitsstätten, Schulen oder Versorgungseinrichtungen, kompakt verbunden. Dies ermöglicht kurze Wege im Alltag.[41] Auf städtebaulicher Ebene wird zudem „die 15-Minuten-Stadt“ nach Carlos Moreno gestärkt. Die „15-Minuten-Stadt“ verfolgt das städtebauliche Ziel, dass Funktionen für den täglichen Bedarf innerhalb von 15 Minuten fußläufig bzw. per Fahrrad erreichbar sein sollen.[42] Durch die Schaffung von zusätzlicher Wohnfläche kann bezahlbarer Wohnraum gefördert werden. Weiters kann es zur Modernisierung von vorhandenen Bauwerken und zur Gebäudeerrichtung in ökologischer Bauweise kommen. Das Versorgungs- und Infrastrukturangebot kann verbessert und ausgebaut werden. Außerdem kann der Zuzug zu einer positiven Dynamik im gemeinschaftlichen Zusammenleben beitragen.[43]

[35] Vgl. Madureira/ Monteiro 2021, 2.
[36] Vgl. Poklewski-Koziełł 2025,11.
[37] Vgl. Region Köln/Bonn e.V. 2022, 28.
[38] Vgl. Säynäjoki/Heinonen /Junnila 2014, 6635.
[39] Vgl. Amt der Vorarlberger Landesregierung 2018, 15-16.
[40] Vgl. Amt der Vorarlberger Landesregierung 2018, 15-16.
[41] Vgl. Region Köln/Bonn e.V. 2022, 25.
[42] Vgl. BBSR 2025, 9.
[43] Vgl. Amt der Vorarlberger Landesregierung 2018, 15-16.

6 DISKUSSION

Die Analyse zeigt, dass die Qualität in der Nachverdichtung durch ihre Mehrdimensionalität bestimmt wird. Die Qualität wird nicht ausschließlich durch bauliche Maßnahmen und Kennwerte wie bauliche Dichte und Geschossflächen charakterisiert, sondern umfasst eine vielschichtige, interdisziplinäre Entwicklung. Diese Vielschichtigkeit setzt sich aus funktionaler Durchmischung, sozialem Zusammenleben, ökologischen Maßnahmen und der städtebaulichen Struktur zusammen. Die Literatur verdeutlicht, dass die Interessen der unterschiedlichen Zielgruppen gesamtheitlich und interdisziplinär gedacht werden sollten.

Jan Gehl erläutert dies mit der Aussage: *„Stadtleben entsteht nicht einfach von selbst oder allein aufgrund einer hohen Bebauungsdichte. Es benötigt zu seiner Entfaltung ganz unterschiedliche Konzepte und gezielte Maßnahmen.“*[44]

Dies hebt hervor, dass Nachverdichtung nicht automatisch zu einer lebendigen und städtebaulich funktionierenden Entwicklung beiträgt. Weitere zentrale Erfolgsfaktoren sind die interdisziplinäre Planung inkl. der Beteiligung der Bevölkerung. Die Integration ökologischer Planungsmaßnahmen kann zur nachhaltigen Stadt- und Gemeindeentwicklung beitragen und die Widerstandsfähigkeit gegenüber Wetterextremen erhöhen. Weiters werden neuer Raum und Wohnraum geschaffen. Dadurch können soziale und wirtschaftliche Mehrwerte angestrebt werden durch eine höhere Nutzungsdurchmischung und eine bessere Erreichbarkeit von unterschiedlichen Einrichtungen.

7 FAZIT UND AUSBLICK

Die Analyse verdeutlicht, dass Nachverdichtung über die bauliche Dimension hinausgeht und gestalterische, soziale, ökologische und funktionale Aspekte gleichermaßen berücksichtigen sollte. Die Qualität der Nachverdichtung setzt sich aus einem ganzheitlichen, interdisziplinären Planungsansatz zusammen. Dieser Ansatz ist in Verbindung mit den jeweiligen, spezifischen Gegebenheiten der Stadt oder Gemeinde in Österreich zu sehen. Nachverdichtungsmaßnahmen sollten daher die örtlichen Gegebenheiten, städtebaulichen Strukturen und die Interessen der Bevölkerung berücksichtigen, um eine nachhaltige und ortsverträgliche Entwicklung zu ermöglichen.

Für die zukünftige Stadt- und Gemeindeplanung in Österreich ergeben sich folgende Schlussfolgerungen:

Schlussfolgerung	Beschreibung
Interdisziplinäre Zusammenarbeit und Planung	Eine Förderung der interdisziplinären Zusammenarbeit und Planung kann zu integrativen Lösungsansätzen führen. Die Nachverdichtungsqualität adressiert, wie zuvor erwähnt, einen multidimensionalen Ansatz. Um die unterschiedlichen Dimensionen gleichermaßen zu berücksichtigen, benötigt es unterschiedliche Professionistinnen und Professionisten, welche als Team zusammenarbeiten.
Beteiligungsprozess	Die Beteiligung und die Miteinbeziehung der Bevölkerung sind essentiell, um eine höhere Akzeptanz zu erzielen und Konflikte zu reduzieren. Es gilt, bereits in der Planungsphase die unterschiedlichen Interessen abzuwägen und dadurch Konflikte vorzubeugen.[45] Obwohl ein Beteiligungsprozess die Planungsdauer verlängern kann, ist er relevant, um auch das öffentliche Bewusstsein über die Vorteile auf lange Zeit zu stärken. Weiters kann die Transparenz in der gemeinsamen Entscheidungsfindung das Vertrauen der Bevölkerung in öffentliche Institutionen verbessern.[46]
Nachhaltige und klimasensible Gestaltungsplanung	Durch eine nachhaltige und klimasensible Gestaltungsplanung kann die Klimaresilienz durch gezielte Maßnahmen gefördert werden. Blau-grüne Infrastrukturmaßnahmen sind in der Nachverdichtungsplanung zu berücksichtigen. Diese Maßnahmen können beispielsweise Stadtgrün, Parks, ökologische Korridore oder auch als Wassersysteme Ausformungen finden. Als integraler Bestandteil der Planung können sie die nachhaltige Stadtplanung verbessern und wirken schützend.[47]
Flexibilität fokussieren	Eine Verallgemeinerung der Nachverdichtungsqualität ist nicht möglich, da die Qualität ortspezifisch ist. Umsetzungsmaßnahmen der Stadtplanung berücksichtigen unter anderem vorhandene physische, geographische, sozialpolitische, wirtschaftliche oder historische Aspekte.[48]

Tabelle 5: Schlussfolgerungen mit Anmerkungen

Zusammenfassend kann gesagt werden, dass eine qualitätsorientierte Nachverdichtungsplanung in Österreich ein wirksames Instrument zur besseren Flächennutzung, Sicherstellung der Lebensqualität und Adressierung von Nachhaltigkeitszielen darstellt.

[44] Gehl 2015, 87.
[45] Vgl. Bibri/Krogstie/Käarrholm 2020, 13.
[46] Vgl. Poklewski-Koziełł 2025, 11.
[47] Vgl. Poklewski-Koziełł 2025, 11.
[48] Vgl. Bibri/Krogstie/Käarrholm 2020, 13.

Die Herausforderung in Österreich besteht jedoch darin, die unterschiedlichen Planungsvoraussetzungen der Bundesländer in die gleiche „Zielrichtung“ zu lenken und ein gesamtheitliches, österreichweites Ziel zu verfolgen. Die Steuerung hierbei müsste jedoch zentral sein, dies gestaltet sich schwierig, da jedes Bundesland eigene rechtliche Voraussetzungen zu erfüllen hat. Eine weitere Herausforderung kann auch die Finanzierung der Umsetzungsmaßnahmen sein, da neben der allgemeinen Finanzierung im Nachverdichtungsprozess auch weitere unvorhersehbare Ereignisse stattfinden können.[49]

Abschließend dazu sollte über eine gesellschaftliche Frage, welche bei der Fokusgruppenforschung von Säynäjoki/Heinonen /Junnila aufgekommen ist, nachgedacht werden:

“The question is, how to make people willing to live densely, close to each other.”- Group 3[50]

Deutsche Übersetzung „Die Frage ist, wie man Menschen dazu bringen kann, dicht beieinander zu leben?“- Gruppe 3

Diese Frage ist in Verbindung mit dem Traum bzw. dem Wunsch vom Einfamilienhaus in Österreich zu sehen. Zur Beantwortung bedarf es jedoch tieferer Forschung. Weitere zukünftige Forschungen könnten die Messansätze der Qualität weiter vertiefen, weitere Messwerte quantifizieren und Studien zur Vergleichbarkeit zwischen österreichischen Städten und Gemeinden untersuchen, um weitere Erkenntnisse aus der Nachverdichtungspraxis abzuleiten. Daraus könnte beispielsweise ein Umsetzungsleitfaden mit Umsetzungspaketen entwickelt werden.

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Quality Standards for XR Participation – Applications and Challenges in Smart, Participatory Urban Development

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1 ABSTRACT

The expanded communication, design and participation opportunities offered by XR technologies open up additional potential for participatory urban development. The spatial representation of planning variants can promote understanding of the planning object and informed opinion-forming among those involved (Brettschneider et al. 2017: 14; Wolf et al. 2020: 125f.; Rogoll, Sinning, Wolter 2024: 58). XR participation can be applied to various types of projects, such as redesigns of public spaces or urban development framework plans, as well as to various fields of urban development, such as open space planning, mobility and building construction planning.

The article addresses the following questions: What significance can XR technologies have for sustainable participatory urban development in the smart city? Which areas of application are particularly suitable? What are the potential benefits and challenges of using XR-supported participation formats? What quality standards can be identified for XR participation formats to supplement established participation guidelines for participatory urban development processes?

Quality standards for democratic participation have not yet been defined for the implementation of XR participation (using AR technology or in virtual space or the metaverse). Although citizen participation guidelines have now been established in many municipalities, there is a lack of supplementary guidelines for the use of digital participation with the support of XR technologies. In the context of the interdisciplinary and transdisciplinary BMFTR joint research project "XR-Part: XR participation spaces for expanded social participation in urban transformation processes" using the example of participatory planning processes in the model cities of Mannheim and Rostock, quality standards for XR participation were identified on the basis of empirical surveys during the testing of XR participation formats. They can contribute to the effective and sustainable design of XR-supported participation procedures in planning processes and ensure broad and committed participation. These quality standards range from targeted process design and time management, access equity, target group-oriented participation format design, legitimisation of visualisations, relevant visualisation of planning content, ethical, social and legal implications, to evaluation and continuous improvement of XR-supported participation formats.

Keywords: XR-Technology, Participatory urban development, Quality standards, Smart city, participation format

2 PARTICIPATION WITH XR TECHNOLOGIES – AR, VR AND METAVERSE

XR stands for Extended Reality and is an umbrella term for all immersive technologies that aim to expand human perception of reality. This includes digitally enhanced reality, such as VR (Virtual Reality), AR (Augmented Reality) or MR (Mixed Reality) (Dörner et al. 2019, among others). AR – Augmented Reality means “extended reality”. In augmented reality, virtual objects such as 3D models, images or text elements are digitally inserted into real space so that they are visible to viewers through mobile devices such as smartphones, tablets or AR glasses. Augmented reality also enables the placement of and interaction with digital content in the immediate physical environment (Wölfel 2023: 16, Dörner et al. 2019: 1ff.). The term VR – virtual reality refers to a completely computer-generated, three-dimensional environment. In VR, users have the feeling of being immersed in another world with which they can interact. Their perception of the real world is completely blocked out. The virtual environment is projected in front of the user’s field of vision using special multisensory devices such as head-mounted displays (HMDs) (Mystakidis 2022: 187). The “metaverse” is described as an immersive and interactive virtual space that can be considered the next generation of the internet. Currently, there are metaverse applications from various providers, such as

Decentraland, Second Life, Mozilla Hubs, TriCAT spaces and the Horizon Worlds platform from Meta. VR and AR technologies allow users to enter this virtual world and interact with it. Users of these virtual worlds interact with each other as avatars. (Weinberger 2022: 1; Fegert 2023: 2; Mertes et al. 2023: 8). The desktop application is currently easily accessible to users, while the application with VR glasses requires availability, which means a higher inhibition threshold. XR participation can enhance communication as well as spatial perception and imagination of planning variants, thus facilitating citizens and stakeholders to develop a founded opinion on the planning options (Brettschneider et al. 2017: 14; Wolf et al. 2020: 125f.; Rogoll, Sinning, Wolter 2024: 58).

3 POTENTIAL AND APPLICATION OF XR PARTICIPATION

3.1 Potential of XR-Participation

Next to its potential for expanded communication in planning projects, XR-supported participation offers a variety of benefits for participatory urban development processes. Inclusive and low-threshold participation can be promoted by the fact that XR formats increase motivation to participate and support the imagination of participants (Fegert et al. 2020: 2f.). Thanks to their immersive and interactive design, XR participation formats appeal to new target groups that have previously been largely overlooked by traditional formats, and their use is not restricted by time or location, thus enabling greater opportunities for participation.

Younger or tech-savvy individuals in particular are more easily won over to participation processes, which can increase the reach and diversity of participants (Rogoll, Sinning, Wolter 2024). In addition, the playful nature of many XR formats can increase overall motivation to participate (Simonofski et al. 2024: 10) and thus counteract the participation paradox, according to which there is little public interest in early planning phases despite a high degree of decision-making freedom (Berlin Senate Department for Urban Development and the Environment 2012: 82; Hirscher 2017: 323f.).

Immersive visualisations make it easier for citizens with varying levels of prior knowledge to access complex planning topics and to develop an informed opinion (Fegert et al. 2020: 1). 3D visualisations can counteract subjective interpretations, make it possible to experience things that are difficult to imagine, and increase transparency between the city and its citizens. In addition, XR participation formats enable flexible participation for different population groups, such as families, working people, or people with limited mobility. In addition to analogue formats, AR, VR and virtual collaboration spaces can open up alternative avenues for democratic participation and promote comprehensibility, collaboration and interaction in planning processes (Wolf et al. 2020: 125f.).

3.2 Areas of application for XR participation

Potential use cases for XR participation are manifold, ranging from the redesign of urban squares, green space planning, mobility and building construction planning to urban development framework plans. XR participation formats are particularly suitable in process phases in which 3D visualisations of development variants are possible or planned. These include mission statement processes, the establishment of framework plans, integrated development concepts (ISEK), scenario and alternative planning, and action planning.

In practice and research, XR technologies are already being used in numerous areas of urban planning. In transport planning, for example, AR and VR applications enable the simulation of alternative road layouts, the redesign of street spaces, or the visualisation of sustainable mobility concepts. This allows citizens to develop informed assessments of design options, as in the “VR-Planning” project in Vienna (Schrom-Freitag et al. 2018). XR technologies are also being used in the development of public spaces and the design of residential environments, for example in the “CoHeSIVE” project in Eindhoven, which investigated the potential of VR for healthy public spaces (Evers et al. 2023).

In addition, immersive visualisations can be used to clearly illustrate aspects of climate protection and climate adaptation, such as the shadows cast by buildings or temperature changes resulting from greening measures (GLARA-Forschungskonsortium 2021; Stadt Essen 2024). They also facilitate the evaluation of different structural development options in terms of their spatial impact (Brettschneider et al. 2017: 14). While AR is particularly suitable for blending new elements into existing urban space, VR also allows objects to be hidden or removed and enables the vivid simulation of effects such as shadow casting, parking space development or lighting concepts (Brysch 2023: 461ff.).

XR technologies are also used in city marketing to bring urban space to life for shoppers or tourists, for example through AR-supported city tours such as “Thuringia.MyCulture” in Erfurt or “MauAR” to visualise the course of the Berlin Wall (Topouzova 2021: 98f.).

XR technologies can be used in both formal, legally regulated participation procedures and informal processes. They are particularly suitable for procedures involving the creation of concrete 3D visualisations, such as in urban planning competitions. In terms of participation intensity, XR formats can be used for information, consultation and active participation, right through to cooperative procedures. They are particularly suitable in the early stages of the process for initiating discussions about development models or scenarios and identifying the needs of those affected. This allows citizens’ requirements to be taken into account at an early stage, for example when competitions are announced. With an appropriate cost-benefit ratio, XR participation opportunities can be used effectively for both large-scale projects spanning several years and small-scale projects.

4 RESEARCH CONTEXT: XR PARTICIPATION SPACES FOR EXPANDED SOCIAL PARTICIPATION IN URBAN TRANSFORMATION PROCESSES

4.1 Context Joint research project XR-Part

This article is part of the interdisciplinary and transdisciplinary BMFTR joint research project “XR-Part: XR participation spaces for enhanced social participation in urban transformation processes” using the example of participatory planning processes in the model cities of Mannheim and Rostock (Sinning et al. 2023). The objective of this project was to develop and evaluate participation formats based on XR technologies that comply with the quality standards of good citizen participation and can be integrated into cross-media participatory urban development projects. In line with this objective, the aim was to develop and design XR participation formats that enable flexible participation in terms of time and location, thus opening up new approaches to democratic planning processes. Based on trials in real participation processes in the model cities of Mannheim and Rostock, the extent to which the developed participation formats can improve the quality of participation procedures, both with AR technology (XR-Part participation tour) and in the metaverse (XR-Part participation space), was investigated. These formats can be used to overcome spatial and temporal constraints and enable citizens to participate in urban transformation processes through a comprehensive communication strategy that integrates both cross-media and analogue participation formats (Allianz Vielfältige Demokratie, Bertelsmann Stiftung 2017: 4 ff.; Le Blanc 2020: 4).

Digression: Cross-media participation offers a wide range of potential for more inclusive and broader participation processes: on the one hand, it offers a larger number of citizens the opportunity to participate (Le Blanc 2020: 9), On the other hand, cross-media participation can take into account target group-specific communication channels, individual preferences, and citizens’ opportunities and barriers to participation, such as varying degrees of digitalisation, family and life situations, and accessibility requirements (Allianz Vielfältige Demokratie, Bertelsmann-Stiftung 2017: 15, 19, 22). By combining analogue or traditional on-site participation events with digital or online participation and information offerings, which complement each other, the different requirements for target group orientation and accessibility can be taken into account (Le Blanc 2020: 12).

4.2 XR participation formats

The XR participation system developed in the XR-Part research project consists of an AR component, the XR-Part participation tour, and a metaverse application, the XR-Part participation room. These are presented below and explained in terms of their design and functionality.

XR-Part participation tour (see fig. 1): This is an AR application that allows users to display virtual models in the real environment on a tablet or smartphone in the relevant planning area. As part of the participation tour, three-dimensional visualisations of usage and design options are presented at designated stations, accessible via real world checkpoints, which can be viewed and commented on using the AR application. It is also possible to display information on the various development options in the form of text, images or video content. Additionally, a key feature of the app is the integrated survey tool. It allows participation questions to be posed to participants or opinions and usage requirements to be gathered via multiple-choice and single-choice questions.

The integrated 3D object catalogue also offers participants the opportunity to independently place virtual street furniture and greenery elements in the space. In this way, design proposals can be submitted and appropriation needs can be located in a specific area with georeferencing.



Fig. 1: XR participation tour (Source: TriCAT GmbH, ISP der FH Erfurt 2024)

XR-Part participation space (see fig. 2): This is a three-dimensional, virtually immersive communication and meeting space (metaverse). Citizens, representatives of the city administration, moderators and, if necessary, other stakeholders come together in the virtual space as avatars (virtual images) and can work interactively and collaboratively on the topics and issues of the planning project. The virtual space can be accessed online via desktop or browser application on a PC or laptop. The virtual immersive XR participation space offers the opportunity to hold various moderated participation events, such as workshops or dialogue formats, so that citizens can participate flexibly from home. Furthermore, it is possible to open the XR participation space persistently if required, for example to make 3D visualisations accessible to citizens without time restrictions in an interactive exhibition format. The XR participation space has various spatialities. The foyer is the starting point for all participants, as this is where the avatars enter the virtual space. The individual meeting rooms are available for (small) group work, while the auditorium with its seating tiers is a suitable space for presentations and lectures in plenary sessions. The adjoining spacious workroom is particularly suitable for presenting the 3D models of the planning area at different scales and bringing them to life. The three-dimensional replicas of the relevant planning areas can be viewed and explored from different perspectives, both as table models and as walk-in models on a scale of 1:1.



Fig. 2: XR participation space (Source: TriCAT GmbH, ISP der FH Erfurt 2024)

A 3D object catalogue (indoor and outdoor furniture, plants, play and sports equipment, etc.) and various interactive media walls enable a wide range of participation methods to be implemented in the XR participation room in a novel, playful form. These include, for example, map and point queries, mapping or modular methods, and participation methods such as World Café or Fishbowl. Detailed explanations can be found in the evaluation report (Rogoll, Sinning, Wolter 2024: 8f.).

The XR participationformats, XR-Part partcipationspace and XR-Part AR application weredeveloped conjointly, combining immersive visualisations of planning variants with the opportunity of collaborative exchange, surveys and commentfunctios. The latter make it possible to obtain qualitative feedback and quantitative opinions. The individual formats of the XR system shouldbe used independently of each other or

linked to-gether. Together with analogue and other digital participation formats, they form a broad and flexible range of participation options.

Both AR-supported participation and participation opportunities in virtual space (metaverse) offer various possibilities for implementing innovative and classic participation methods thanks to their integrated tools and functions. One advantage of XR participation applications over analogue formats is that they allow methods to be carried out with less preparation and thus more efficiently.

In addition to the technical XR applications developed, the project's key findings, which are discussed in this article, include recommendations for action and quality standards for the implementation and integration of XR participation, which were identified on the basis of empirical surveys conducted during the testing of XR participation formats (Sinning, Brandenburger, Kruse, Rogoll 2023; Rogoll, Sinning, Wolter 2024; Rogoll, Sinning, Wolter 2025a; Sinning, Rogoll, Wolter, Henn 2025).

5 QUALITY STANDARDS FOR IMPLEMENTING XR PARTICIPATION FORMATS

Conventional guidelines for effective and inclusive citizen participation in urban planning processes have already been widely established in municipal practice. However, the quality standards for citizen participation have not yet been adapted for XR-based participation, which his what the XR-Part research project aimed to accomplish. These quality standards range from targeted process design and time management, access equity, target group-oriented participation format design, legitimisation of visualisations, relevant visualisation of planning content, ethical, social and legal implications, to the evaluation and continuous improvement of XR-supported participation formats. All affected citizens should have a fair chance to participate and voice their opinion (cp. Nederhand, Edelenbos 2022: 526). In times of social transformation, it is the responsibility of local authorities to ensure the interests of democratisation by involving citizens in these processes (e.g. mobility transition, climate adaptation) and by taking into account their concerns over complex development procedures. Combining different formats geared towards diverse participation requirements ensures that a broad target group is addressed and opens up various (low-threshold) access points (Nederhand, Edelenbos 2022: 526). It is important that the different formats are equivalent in terms of their degree and quality of participation, so that citizens' opportunities to participate do not depend on the medium chosen or available to them (Fischer et al. 2020: 134; Steenbergen et al. 2003: 25).

The following section outlines the quality standards that have been identified for XR participation formats from the specialist literature and the findings of trials and evaluations conducted as part of the XR-Part joint research project (see Fig, 3), which supplement the established participation guidelines for participatory urban development processes (for more details, see Rogoll, Sinning, Wolter 2025b).

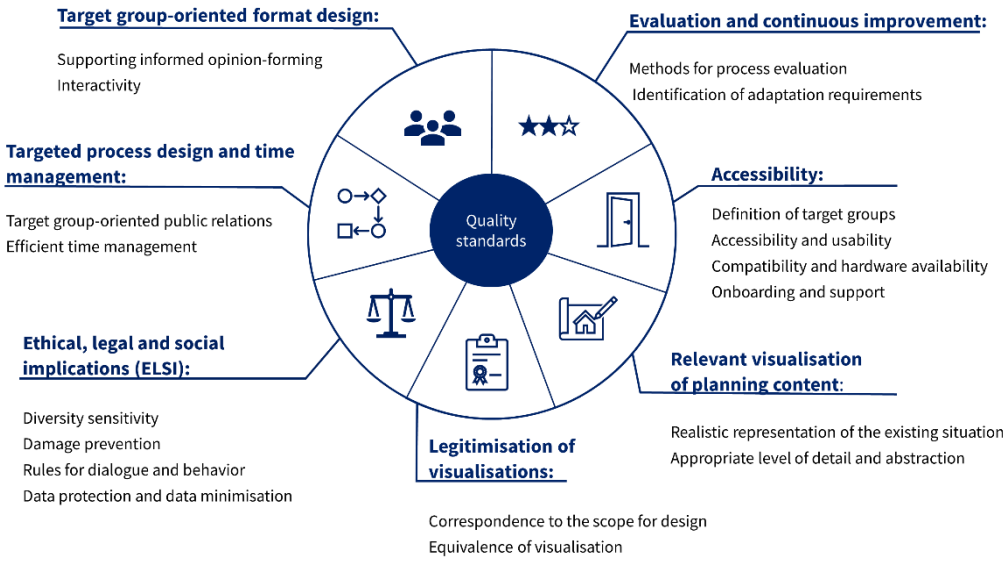


Fig. 3: Quality standards for XR participation (Source: ISP der FH Erfurt 2026)

5.1 Targeted process design and time management

The integration of XR-supported participation opportunities into a cross-media process requires an adapted procedural concept that takes additional work steps into account in the schedule. In addition, the success of XR-supported procedures depends on appropriate advertising and addressing the target citizens.

Target group-oriented public relations: In order to adequately introduce people with varying levels of prior knowledge in the field of technology to XR technologies, it is necessary for preparatory public relations work to promote XR participation formats in an easily comprehensible manner. Depending on the target groups addressed, promotion and information should be provided through various channels, such as press releases, social media posts, posters, postcards, etc. (Goldschmidt 2014: 325f.; Nanz, Fritsche 2012: 28; Stiftung Mitarbeit 2021). The use of visual media makes it possible to arouse curiosity about the XR-supported participation formats and allows participants to familiarise themselves with the planned XR formats in advance. “Teaser images” in press releases or social media posts provide an insight into how XR technologies are used in participation. Video tutorials teach citizens how to use XR applications, making it easier for them to access XR technologies and dispelling any reservations they may have in advance.

Efficient time management: Management should allow sufficient time to incorporate feedback and contributions from the XR participation events into the planning project (DIN EN ISO 9241-210: 41). The time frames for planning, implementing and evaluating the participation formats need to be estimated realistically so that a concrete schedule for the realisation of the development project can be drawn up (Goldschmidt 2014: 273).

5.2 Accessibility

Accessibility in citizen participation is essential in order to give all members of society, regardless of their individual circumstances, a fair opportunity to participate in the process of shaping society. This is not only a matter of providing diverse opportunities for participation, but also of breaking down existing barriers, whether physical, linguistic, cultural or digital.

Definition of target groups: When defining target groups in the context of planning the participation process, it is necessary to describe both the groups of people who are to be specifically reached with the XR participation formats and those who are excluded from using XR technologies or whose access to these technologies is significantly restricted (Huning 2014: 39f.; Orthmann 2017: 12f.). In the interests of equal access, it is necessary to offer alternative participation options to people with limited access to XR technologies, such as people with motor impairments (DIN EN ISO 9241-210: 22; ISO 9241-112: 2017, 3.15; BITV 2.0).

Accessibility and usability: Ensuring that XR participation formats are accessible to as large a user group as possible is a key objective. This can be achieved by implementing a barrier-free design, such as the integration of subtitles or the provision of alternative input methods (Dirks, Bühler 2018: 8f.).

The user interface of the XR application used should be intuitive, easy to understand and clearly laid out to enable easy navigation. It must be ensured that users can quickly learn how to use XR technologies. The text-to-speech function allows information about the process, participation questions, etc. to be read aloud in the applications. A speech-to-text function should be included to facilitate the entry of comments. This is particularly relevant for user groups who are less practised or limited in their ability to type manually on the device keyboard. Furthermore, the language choices available must be suited to migrant populations affected by the subject of participation to ensure equal participation opportunities (Goldschmidt 2014: 194). Appropriate graphic, performance and technical quality is guaranteed, ensuring an immersive and realistic experience (Molich, Nielsen 1990).

A successful augmented reality (AR) application depends on several technical and environmental criteria. Firstly, the recognition and tracking of real objects in the environment is crucial. This requires precise registration and calibration so that digital content can be embedded stably and accurately in the physical world (Azuma 1997: 360; Billinghurst et al. 2015: 89; Sutherland 1968: 759). The user experience and interactivity also play a central role, especially in terms of the visual and cognitive load on users. Aspects such as latency, overlay accuracy and application response speed are crucial to the success of an AR application (Azuma 1997: 361; Milgram, Kishino 1994: 133; Zhou et al. 2008: 2).

Compatibility and hardware availability: Ensuring that XR participation formats function on different devices and platforms is an essential criterion for achieving a broad user base. XR applications should be compatible with various common software solutions (Android, iOS, Windows, macOS) and hardware components (tablets, smartphones, PCs). It must be ensured that the content is displayed responsively (optimised for different end devices) so that the target group can participate using their private end devices (PC, laptop, mobile phone, tablet) (Koch et al. 2014: 142).

In order to enable target groups with limited access to digital transformation to participate, end devices (laptops, tablets, smartphones) should be provided free of charge or available for loan by the initiators. This can be seen as a response to the first level digital divide.

In particular, VR and AR glasses are not currently part of standard household technical equipment and should therefore be provided free of charge for participation (Bitkom e.V. 2022). Additionally, free Wi-Fi is an important prerequisite for access, especially for on-site applications.

Equipment for AR applications often includes head-mounted displays (HMDs), mobile devices such as smartphones or tablets, and special cameras and sensors. These technologies must ensure high precision and stability when superimposing digital content, while also being robust enough to be used in difficult weather conditions (Azuma 1997: 370; Billinghurst et al. 2015: 105; Sutherland 1968: 762). They must also be light and comfortable enough for long-term use so as not to impair the user experience (Billinghurst et al. 2015: 108; Henderson, Feiner 2011: 543).

Onboarding and support: When using XR participation formats, it is important to provide a clear explanation of how these applications work and how they can be used in the overall process from the outset (see, among others, Initiative D21 e.V. 2020). This leads to comprehensive education and enables a larger group of people to access the benefits of these innovative technologies.

It is advisable to provide participants with appropriate and adaptive onboarding methods and interactive tutorials tailored to their different degrees of knowledge and technical skills in order to ensure successful integration (Koch et al. 2014: 151). Examples include explanations with visual and acoustic presentations or interactive tutorials that promote “learning by doing”. People with little prior knowledge should be able to take advantage of comprehensive support services. Support can be provided, for example, by means of a help button, an FAQ page, technical support or a virtual guide. People who are very tech-savvy, on the other hand, should be empowered to use XR technologies more independently by receiving only the most necessary information and being able to skip tutorials.

5.3 Target group-oriented format design

Designing participation formats tailored to specific target groups is essential for ensuring inclusive and effective citizen participation. This requires coordinating participation opportunities and communication channels in order to address the specific needs of different target groups within the population. XR participation formats offer the opportunity for interactive participation on the one hand and, on the other hand, can encourage the formation of opinions on the subject of participation.

Supporting informed opinion-forming: When designing an XR participation format, it is particularly important to take into account the level of knowledge and information of the participants, which can vary greatly depending on the respective circumstances (Goldschmidt 2014: 108). The provision of content that is characterised by high quality, relevance and careful research is crucial in order to enable those involved to evaluate and prioritize visualisations of planning projects or variants in a differentiated manner. The use of XR technologies can help to promote knowledge acquisition and imagination through 3D visualisations, thereby limiting the scope for interpretation by those involved (Goudarznia et al. 2017). In order to prevent individual misinterpretation of presented content or concepts, transparent, appropriate communication is essential to bring all stakeholders to the same level of knowledge (Rockmann et al. 2015).

Interactivity: Active user participation is encouraged through the integration of interactive features, including polls, surveys, discussion forums, virtual tours and simulations. The methodological design of the participation formats can take on a playful character, which can increase the users’ motivation (“joy of use”) (Masser, Mory 2017: 57; Rohde et al. 2010: 345f.; Hoffmann 2023: 10ff.). A station concept in the real-world planning area or its virtual model, for example, proves to be suitable for carrying out small group work in the style of a World Café or for subdividing the event thematically.

Social interaction is a fundamental need for participants (Bennett et al. 2021: 30). When designing XR participation formats, it is therefore important to ensure that exchange between the various stakeholder groups (and within the stakeholder groups) is facilitated. Guided tours with an AR app are one example of how this approach can be implemented. Another option is a moderated dialogue format, such as idea workshops, which can be held in the virtual space.

In addition to choosing suitable participation formats and methods, it is important to select a virtual space with appropriate features (large conference room, small work rooms, outdoor area, naturalistic colour scheme, neutral ambience, audio rooms, etc.) that is appropriate for the target group when organising events in the metaverse.

5.4 Legitimisation of visualisations

A fundamental prerequisite is that, in addition to the participation process itself, visualisations presented to citizens and other stakeholders must also be politically and administratively legitimate. Authorisation or legitimisation depends on the following parameters:

Correspondence to the scope for design: The visualisations created within the XR application, which include 2D or 3D models and object catalogues, reflect the basic scope for design and show only those scenarios that are theoretically feasible from the perspective of the specialist departments and planners involved. In order to check the feasibility of development variants, a feasibility study can be carried out in advance, for example.

Equivalence of visualisation: Manipulation of the viewer is avoided by presenting different development options in an equivalent and representative or typical manner. The selected 3D visualisations should therefore have a uniform style (shape and colour scheme, texturing, level of detail) and be equally abstract.

5.5 Relevant visualisation of planning content

To ensure that the 3D visualisations shown in the XR participation formats are relevant, two conditions must be observed. On the one hand, the current state must be depicted realistically, and on the other hand, an appropriate degree of abstraction and level of detail must be selected.

Realistic representation of the existing situation: The creation of models of the built environment and the use of 3D city models requires a factually correct representation. The 3D city model should depict the current actual state of the participation object in a manner that is appropriate to reality and recognisable, as well as correct dimensions, proportions, shapes and colours (Brettschneider et al. 2017: 39). The 3D model should depict the defined participation object in its entirety and include relevant context of the surrounding area. In certain cases, an exemplary sub-area may also be visualised, provided that there is a corresponding justification for this. For example, a map should be used to show participants how the model is spatially limited and to which area the participation project relates (ibid.: 30f.).

Appropriate level of detail and abstraction: When creating 3D representations of planning projects and the object catalogue, they must have an appropriate level of abstraction, conveying complex, crucial and understandable information about the object, highlighting the general conditions and limitations of the planning project or the objects depicted, yet not making concrete design proposals (Höhl, Broschart 2015: 23). Therefore, when creating 3D models, it is important to refrain from integrating irrelevant details that could impair or distract from the discussion of content (Brettschneider et al. 2017: 39).

The degree of abstraction and the level of detail of 3D development variants and objects should be selected depending on the progress of the participatory planning process and the associated objectives. In the early phases of planning and participation, for example, rough cubatures of building volumes and interpretable 3D pictograms can be used to visualise development themes and requirements. In advanced planning phases, on the other hand, a high level of detail in the presentation of development variants is recommended in order to enable participants to make a comprehensive assessment.

5.6 Ethical, legal and social implications [ELSI]

The overarching goal is to use technology responsibly, with a focus on successful human-technology interaction. It must be ensured that the use of XR technologies is ethically acceptable and does not have any adverse consequences for users (Gressel et al. 2019: 11).

Diversity sensitivity: In order to make XR applications more inclusive and reflect the diversity of society, it is advisable to pay attention to diversity-sensitive issues when choosing a software provider and designing XR participation formats:

People with physical or mental impairments should have equal opportunities to participate. In addition to the accessible design of the XR application, the participation concept can define what support services are available for these target groups, e.g. through needs-based support or special workshop formats.

The visual representation as an avatar and the associated effect has a significant influence on the interaction between the actors (citizens, administration, politicians, moderators). Avatars should therefore be individually customisable in order to reflect characteristics such as gender identity, skin colour, different body shapes or physical impairments. It is also advisable to avoid stereotypical and discriminatory representations in public relations work. Images of conversation situations should depict people at eye level (Goethe University Frankfurt am Main, Equal Opportunities Office 2016: 22ff.).

Diversity-sensitive communication, in particular through multilingualism, plain language or gender-neutral language, can ensure that all target groups are addressed in the participation processes and can adequately contribute their wishes and ideas.

All these aspects can be summarised under the heading of diversity-sensitive technology design. Key questions for assessing diversity-sensitive technology design and thus the equal participation of target groups in XR-supported participation processes are: "For whom is the technology being designed? [...] Who actually benefits from the technology and who might be harmed, marginalised or even “erased” from an epistemic perspective due to its design or implementation? What features are missing to meet the needs and preferences of diverse users [...]?" (Heesen et al. 2021: 137f.).

Damage prevention: The use of mixed reality technologies must not result in undesirable effects or health risks for those involved (ibid: 11). This also implies the prevention of psychological, physical and economic damage. Furthermore, the prevention of motion sickness, anxiety and panic situations is of essential importance. Ensuring the safety of participants is a primary requirement when using immersive technologies (DIN EN ISO 9241-210: 38).

When using VR headsets in particular, the heightened immersive experience means that users need to be accompanied and supervised in order to reduce fears and uncertainties and to provide support in the event of negative sensations such as motion sickness, fear of heights or anxiety. When using AR technology, it is also necessary to alert users to potential hazardous situations (both during onboarding and during use). Dangerous situations can arise, for example, when walking with the device, due to a focus on the display and a resulting impairment of perception of the real environment, with a risk of tripping or falling, overlooking vehicles or other objects.

Rules for dialogue and behaviour: Compliance with established rules for dialogue and behaviour is ensured by preventing manipulation and inappropriate contributions by participants (e.g. sexist, racist contributions or misinformation). This can be achieved through (trained, sensitised) moderation or technical measures, such as filtering contributions (Goldschmidt 2014: 163).

Data protection and data minimisation: It must be ensured that XR applications meet data protection compliance requirements (creation of and adherence to a data protection concept). Transparent communication about data use and obtaining user consent are essential in this regard. In the interests of privacy, personal data is to be collected purposefully and economically in the participation process (German Ethics Council 2017: 132; Kuhnert, Grimm 2020: 255), carefully weighing options such as pseudonymised participation against possible negative consequences like manipulation or distortion of the participation results.

When installing AR applications on private devices, users must be informed about the possibility of location data tracking in accordance with data protection regulations. In order to enforce data protection and maintain an open, deliberative discussion atmosphere, it is also necessary to detect recordings and screenshots and protect the XR application from them. Alternatively, loan devices with pre-installed applications can be provided as part of accompanied participation tours.

5.7 Evaluation and continuous improvement

Continuous optimisation of XR participation formats is achieved through regular reviews and adjustments. Therefore, mechanisms such as evaluation forms need to be implemented. Both user feedback and technological developments should be taken into account.

When evaluating XR participation formats, it is necessary to identify technical adaptation requirements in addition to procedural aspects for embedding them in the overall process. This includes the design of user interfaces, compatibility with hardware and software, and the precision of content localisation. These requirements must be communicated to the technology provider (developer). Aspects of the evaluation of XR participation formats can be integrated into already established evaluation procedures for analogue or cross-media participation processes by the municipality. By defining evaluation criteria and derived questions, the success and effectiveness of the participation format can be assessed.

6 CONCLUSION: QUALITIES FOR XR PARTICIPATION FORMATS IN CROSS-MEDIA STRATEGIES

As shown, XR technologies expand the possibilities for communication, design and participation and open up additional potential for participatory urban development in the smart city. The spatial representation of planning variants promotes understanding of the planning object and enables participants to form well-founded opinions (Brettschneider et al. 2017: 14; Wolf et al. 2020: 125f.; Rogoll, Sinning, Wolter 2024: 58). XR participation is suitable for different types of projects – such as redesigns of public spaces or urban development framework plans – as well as for various fields of action such as open space planning, mobility and building construction planning. While AR technologies are particularly suitable for visually supplementing real spaces (e.g. building extensions or design elements), participation formats in the metaverse enable more comprehensive and fundamental interventions in the project area, for example in terms of space distribution or morphology.

With regard to the expanded opportunities for participation, there was a generally positive response to XR participation formats across different age groups and among participants with varying levels of technical knowledge. Even those who were initially inexperienced were able to achieve significant learning success in a short period of time.

Through functional enhancements such as text-to-speech, speech-to-text and multilingualism, XR technologies can also break down barriers and facilitate the participation of people with visual or hearing impairments and those who speak foreign languages (Rogoll, Sinning, Wolter 2024: 64).

A key challenge is that XR participation formats for administrations are currently still time-consuming and costly. This makes it all the more important to ensure that the results can be applied in municipal practice, for example by reusing the 3D models in later planning phases and everyday work processes. Examples of this include implementation planning with Building Information Modelling (BIM), which enables precise visualisation of complex plans and can reduce planning errors (Wong et al. 2018: 108, 114), as well as working with urban digital twins. The latter can be used by different departments for monitoring, management and planning. The Connected Urban Twins research cluster of the cities of Hamburg, Leipzig and Munich demonstrates a wide range of possible applications – from monitoring traffic flows, social displacement effects and air quality via a municipal energy atlas to civil engineering and transport planning from a first-person perspective (Keler et al. 2023; Winter 2023; Schubbe et al. 2023: 16, 19; Lindner et al. 2022).

In order to exploit the potential of urban digital twins as a real-time data environment, planning tool and participatory space, local authorities must create appropriate organisational structures and integrate digital and XR-supported methods into their everyday workflows. This requires time, financial and human resources, as well as the relevant expertise for data preparation, maintenance and integration. In addition to technological openness, fault tolerance is also necessary in order to create space for technological developments.

Support for local authorities from the federal and state governments is essential in order to pool and disseminate knowledge and promote networking opportunities. In order to involve citizens in digital municipal (participation) processes, media education in schools and adult education should be promoted,

especially for socially disadvantaged population groups, which are often underrepresented in participation processes.

Despite their high potential, XR participation formats should always be used as a supplement to analogue and other participation formats so that no one is excluded from democratic participation. This requires cross-media communication strategies and participation concepts in which the interfaces between analogue and digital formats are considered from the outset.

The quality standards developed contribute to the qualified use of XR technologies in communicative planning processes. They complement existing municipal participation guidelines and regulations and can support municipalities, administrations, service providers and other users in consolidating and professionalising the use of XR technologies.

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reviewed paper

Reimagining South African Urban Planning Education: Aligning Digital Skills with Professional Demands

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1 ABSTRACT

The Fourth Industrial Revolution (4IR) demands a fundamental shift in educational institutions, aligning with Sustainable Development Goal 4's call for inclusive, equitable quality education and lifelong learning. This study examines how digital skills are integrated into South African urban planning education in response to evolving professional demands. Using qualitative content analysis and a four-step review, the study assesses the alignment between taught digital competencies and industry expectations shaped by 4IR. Findings reveal an increasing demand for proficiency in digital technologies and analytical tools for data-driven decision-making and innovative urban problem-solving. However, gaps remain in curriculum integration, access, and preparedness. A conceptual framework is proposed, encouraging capacity building, leadership development, module-curriculum alignment with industry, and ongoing upskilling/reskilling. This framework supports a more responsive planning education system that prepares students and professionals for roles shaped by digitisation, automation, and the complex realities of urban transformation in South Africa.

Keywords: Education, 4IR, GIS, AI, Bibliometric Analysis

2 INTRODUCTION AND BACKGROUND

Emerging urban planners must acquire relevant digital competencies to effectively navigate today's increasingly complex and uncertain urban challenges. As stated by Braun and Kropp (2023), ongoing transformations present opportunities for innovative solutions to the multifaceted crises facing planning and architecture. In this context, digital transformation has become a critical driver of effective and responsive planning (Kuppler & Fricke, 2024). Embracing this shift holds the potential to strengthen educational institutions by enabling them to meet evolving professional demands, while also preparing learners and practitioners to engage with complexity and seize emerging opportunities with confidence. Global frameworks such as the United Nations Sustainable Development Goal 4 (SDG 4) further emphasize the importance of skills development, particularly in technical and vocational domains therefore to enhance employability and promote entrepreneurship (UNESCO, 2017). These imperatives have contributed to the growing demand for integrating digital technologies into everyday planning practices. Understanding the trajectory of industrial revolutions provides an important context for digital transformation in urban planning education. The Third Industrial Revolution, spanning from the 1980s to the early 2000s, introduced information and communication technologies, leading to widespread computer use and the emergence of early internet systems (Vickers et al., 2019). During this era, planning research focused on advances in telecommunication (Batty, 1991; Graham & Marvin, 1999) and the development of planning support systems such as Geographic Information Systems (GIS) (Gill et al., 1999). The Fourth Industrial Revolution has since shifted attention toward smart city initiatives (Batty, 2013; Carter, 2017) and the evolution of planning support science (Geertman & Stillwell, 2020). Despite these advancements, efforts to digitalize planning practices remain constrained by various challenges. As Daniel and Pettit (2021) argue, there is often a persistent gap between the digital skills taught in universities and those required in real-world professional contexts. This misalignment has significant implications not only for how students learn and apply

knowledge but also for how educators conceptualize and deliver teaching in an increasingly digital environment. As the Fourth Industrial Revolution continues to reshape professional expectations, the integration of digital technologies into urban planning education is no longer optional, it is essential. This transformation should extend beyond the superficial use of software to the strategic and intentional incorporation of emerging technologies into the planning, design, and governance of urban environments. Such an approach fosters innovation, resilience, and adaptability in both education and practice. In response to these demands, educational systems must transition from traditional, instructor-centered approaches to more learner-centered and digitally enhanced pedagogies (Osmundsen et al., 2018). This paper examines the extent to which digital skills currently embedded in selected South African urban planning curricula align with the requirements of professional practice. The objective is to develop a framework for curriculum reform that addresses this digital divide, equipping future urban planners with the technological competencies needed to navigate and shape the rapidly evolving urban landscape.

3 DIGITAL TRANSFORMATION IN URBAN PLANNING EDUCATION

The Fourth Industrial Revolution (4IR) represents a transformative period marked by the fusion of technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics, and big data analytics. This revolution is reshaping knowledge production, dissemination, and use across all sectors, including higher education. Adelekan et al. (2023) highlight the urgency of adapting educational frameworks to produce graduates who are digitally fluent, innovative, and adaptable. In South Africa, this imperative is heightened by the dual challenges of addressing historical educational inequalities and preparing students for a competitive global workforce. The digital divide, while a persistent barrier, also presents opportunities for innovation through strategic investments in digital infrastructure and curriculum reform.

Moodley (2021) stresses that integrating 4IR tools into university education is more than a technological upgrade; it involves socio-pedagogical transformation. Higher education institutions must adopt digital pedagogies that foster ethical awareness, critical thinking, and relevance to local contexts – particularly vital in disciplines like urban planning. Traditional instructional methods are being challenged by the need for virtual learning, simulation-based instruction, and online collaborative platforms. These shifts align with Sustainable Development Goal 4 (SDG 4), which advocates for inclusive, equitable, and quality education. UNESCO (2021) further asserts that digital-age education should cultivate digital citizenship and adaptability alongside technical skills. Urban planning, as a discipline, increasingly depends on digital tools for spatial analysis, forecasting, and stakeholder engagement. Technologies such as Geographic Information Systems (GIS), remote sensing, 3D modeling, and digital twins are reshaping planning practices (Chigbu et al., 2021; Letsoko and Pretorius, 2025). Despite this, their integration into South African planning curricula remains inconsistent. Rukato et al. (2024) found that while theoretical instruction on digital tools exists, students often lack practical experience, leading to a skills mismatch in the labour market. This disconnect hinders the readiness of planning graduates to manage the data-driven demands of modern urban development.

Moreover, digital tools carry epistemological significance. Giles and Bhurosy (2023) argue that beyond technical proficiency, planning students must understand how these tools influence urban imaginaries, governance, and public participation. Critical digital literacy, understanding how digital technologies mediate power and knowledge, must be a core element of planning education (Letsoko and Pillay,2019). Lwasa et al. (2023) emphasize that digital thinking should be integrated across the curriculum rather than confined to isolated modules. Curriculum reform is therefore essential to align graduate outcomes with industry needs. UNESCO (2021) recommends strong partnerships between academia and industry to ensure educational responsiveness to evolving professional standards. In South Africa, SACPLAN and the CHE regulate curriculum development, with SACPLAN recently introducing digital proficiency requirements (Mabaso & Mahlangu, 2022). Nonetheless, implementation is uneven. Maphisa et al. (2024) advocate for a theory-of-change approach to curriculum design, one that defines expected outcomes, stakeholder roles, and enabling policy conditions. They recommend modular, flexible, and interdisciplinary curricula featuring topics like smart cities, digital ethics, and e-governance. Experiential learning – through internships, studios, and collaborative platforms – bridges theoretical learning with practical skills, enhancing both digital literacy and soft skills such as collaboration and problem-solving.

4 METHODOLOGY

The study employed a four-step review approach as applied in previous studies (Jiang et al., 2021) was used to examine digital skills alignment with urban planning (see Figure 1). The study aimed to investigate the state of digital transformation culture, emerging digitalisation strategies, challenges, and future trajectories for digital transformation with urban planning.

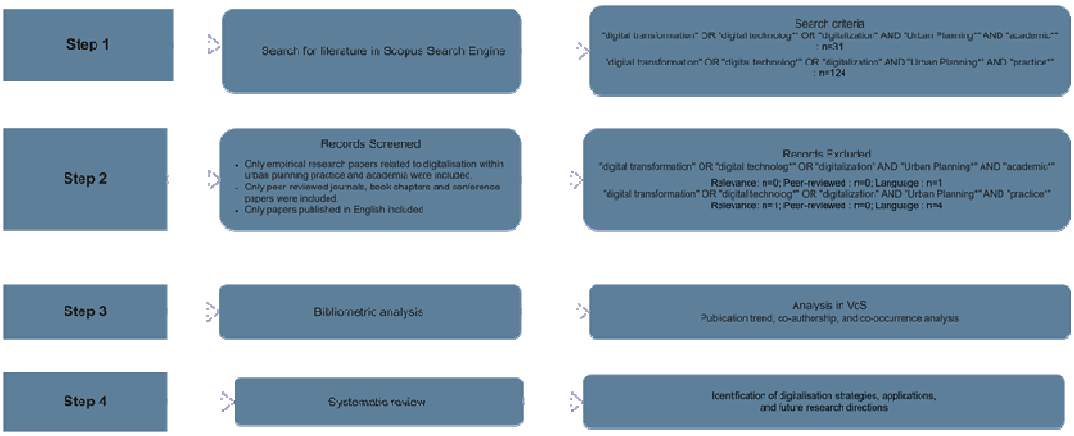


Figure 1: Review Approach.

Step 1 involved defining the review's scope, setting the stage for an in-depth exploration of digital transformation's role in urban planning. The study sourced academic articles from Scopus Search Engine, comprising peer-reviewed journal articles, conference papers, and book chapters. Two search strings were employed, namely:

"digital transformation" OR "digital technolog*" OR "digitalization" AND "Urban Planning*" AND "academic*"

"digital transformation" OR "digital technolog*" OR "digitalization" AND "Urban Planning*" AND "practice*"

Step 2 was the inclusion and exclusion of literature. The selection criteria were the title, keywords, or abstract, and peer-reviewed articles published in English, without restrictions regarding the study domain, due to the relevance in a wide range of disciplines. Only empirical research papers related to digitalisation within urban planning practice and academia were included. Following data acquisition, the subsequent steps encompassed data collection and quality assessment, ensuring the inclusion of reliable and pertinent resources. In Step 3, a quantitative analysis was undertaken. A Bibliometric analysis was undertaken using the Visualization of Similarities (VoS) Viewer package, namely publication trend, co-authorship, and co-occurrence analysis. In Step 4, a systematic review was conducted to identify digitalisation strategies, applications, and future research directions. The findings were then used to develop a framework for the digital transformation of urban planning.

5 ANALYSIS AND FINDINGS

In pursuit of global rankings and academic excellence, universities worldwide are increasingly prioritizing competitiveness and elevated academic standards. Similarly, the private sector is compelled to sharpen its competitive edge in response to global demands. As universities navigate this complex landscape, they encounter a range of institutional challenges foremost among them is the imperative to improve organizational efficiency. At the heart of this drive lies digital transformation, widely regarded as a cornerstone for institutional advancement. More than a mere technological upgrade, digital transformation serves as a strategic enabler, integrating Fourth Industrial Revolution (4IR) technologies into teaching, learning, and professional practice. This integration not only enhances operational performance but also redefines pedagogical and research paradigms, positioning institutions for long-term relevance in a rapidly evolving knowledge economy.

5.1 Publication trend

Figure 2 shows the developmental trend in digital transformation within urban planning academic and practise between the period 2010 to 2025. The timeline pre-2010 presents a period 4IR tools were either in

their infancy or not yet coherently defined under the 4IR framework. However, several precursor technologies and foundational digital tools such as Geographic Information Systems, Computer-Aided Design (CAD), and Remote Sensing were actively used in urban planning practice and academia. Pre-2010 academia and practice faced challenges in software integration and high implementation/usage costs, which resulted in a disconnect in technology uptake in planning policy and regulation.

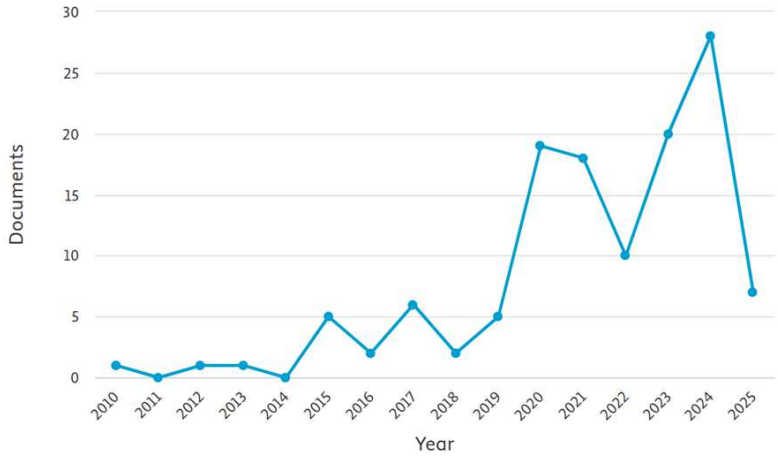


Figure 2: Publication Trend.

The period 2010 to 2015 represents the transition period from static digital tools to more dynamic, data-driven systems, marking the early integration of Fourth Industrial Revolution (4IR) technologies with urban planning. While publications were still low, this period was pivotal in bridging the gap between legacy systems and intelligent urban technologies. Between 2015 and 2020, urban planning entered a transformative phase characterised by the mainstreaming of 4IR tools. As evident with an increase in research, this era saw the accelerated institutionalisation of smart city initiatives, real-time data, and Internet of Things in both planning practice and academic research. At the same time, the period triggered critical debate on the role of planners in the implementation of emerging technologies with a focus on governance and equity. Post-2020, urban planning entered a more mature and contested phase of engagement with Fourth Industrial Revolution (4IR) tools. The global disruptions caused by COVID-19 served 2as a catalyst for the digital transformation of planning education and infrastructure planning. Publications in this period of increased documenting usage of 4IR technologies such as GIS and BIM integration, digital twins, and artificial intelligence within planning.

5.2 Network Analysis

The network visualisation represents co-occurring keywords in academic or thematic literature related to urban planning and digital transformation. Each node represents a keyword, and each link shows a relationship or co-occurrence between keywords in documents. In view of Figure 3 outlining thematic clusters of digitalisation with urban planning, it is evident that the most important part of the digitalisation in education is that students, teachers, and administrators have to take the necessary training for digital transformation.

Cluster 1: Core of Urban Planning

The blue cluster, anchoring the entire network, represents the traditional and evolving dimensions of urban planning, including technical tools, governance processes, and emerging urban forms. As planning systems are maturing and becoming increasingly indispensable in the planning process, they contribute to the paradigmatic (re-)emergence of technocratic planning as a science (Geertman and Stillwell, 2020). This instrumental rationality, currently re-emerging, involves digital and big data, smart technologies and software that frame the planned landscape as objectively known, accurately measured, analysed, modelled or visualised (see Ash et al. 2018, Cook and Karvonen, 2023, 12). However, Potts (2020) points out that the use of ICT and the emergence of Web 3.0 does not lead to a merely positivistic ontology of planning as a physical, scientific process due to its reliance on data, but is accompanied by a shift towards self-organisation.

Cluster 2: Governance Strategies

The purple cluster outlines varies governance strategies such as local participation, stakeholder engagement, improved communication links, and citizen engagement. This cluster engages with governance structures that underpin digital and sustainable planning. It focuses on how decisions are made and who controls technological urban futures. Teixeira et al (2021) also stated the importance of governance for facilitating the digitalisation vision at the management ministerial level and the institutional level. The support services to be provided during the digital transformation process will facilitate the adaptation of teachers and students.

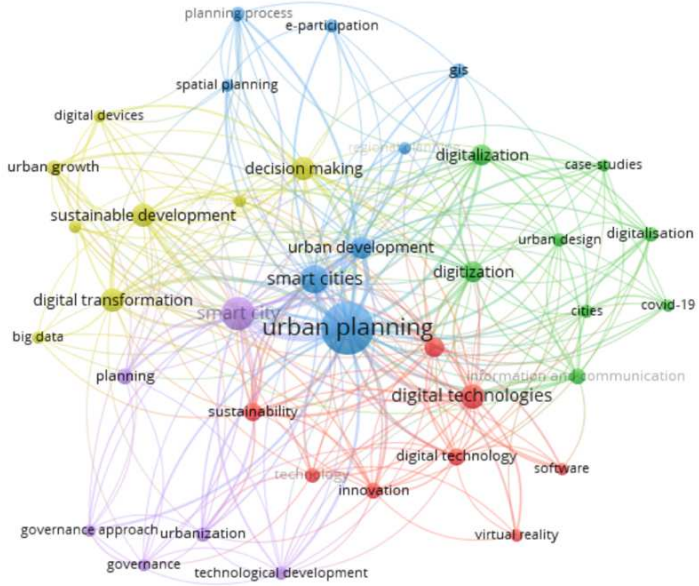


Figure 3: Network Analysis.

Academics have expressed the need for relevant educational policies for the design of innovative learning environments and for the transformation of schools. With education, digital transformation needs to be conceptualized and internalized. The emphasis is on ensuring the necessity of providing suitable infrastructure (Alenezi, 2021). Likewise, the development of the infrastructure and the development of the digital contents, learning environments should be informed by factors suitable for the partnership and learning characteristics of the shareholders are important, and the participation.

Cluster 3: Digital Transformation Culture

The yellow cluster represents the views of academicians and views on how digital transformation culture is to be formed in the direction of determined themes, and how to carry out learning in this culture should be combined with education in particular, and that the research and project work should be done from higher education institutions to industry. This cluster captures the macro-policy and ethical implications of urban digitalization emphasising sustainability and transformative goals. Furthermore, Oliveira et al. (2022) stated that in-service training should be done continuously, and they should act in the direction of strategic planning for digital transformation. This is supported by Bravo et al. (2020) articulation that there should be effective leaders who will make an evaluation on the issues, such as the monitoring and evaluation of training, the contribution of curriculum, and the level of institutional digital transformation. McCarthy et al. (2023) outlined that besides conscious consumption of emerging technologies, there should be strategies to address how efficiently technology merges with the professional culture.

Cluster 4: Technological enablers

The red cluster represents the technological enablers or infrastructure driving digital transformation in urban contexts. In addition, planning research focuses on smart cities and digital solutions, and oftentimes, on emblematic cases of digital planning in European Nordic countries such as Denmark (Fertner et al., 2019). Only a few scholars address the challenges of implementing ICT on the ground (Geertman and Stillwell, 2020) in the oftentimes ‘manual, paper-based, and tedious’ (Sabri and Witte, 2023, 1) planning practices. Others compare planning practices in different contexts, such as Potts and Webb’s (2023) survey on the use and challenges of ICT in the UK and Australia, or Christmann and Schinagl’s (2023) comparison of global planning offices in three locations. Kitchin and colleagues (2021) study how planning professionals in local

administrations use 3D spatial media in their day-to-day planning processes. Their results underline the challenges and the uneven adoption of 3D media in planning, with the private sector and architects more readily engaged than public sector planning. These scientific studies emphasise challenges to digital transformations, indicating a lagging adoption (Kitchin et al., 2021) and systemic barriers to integrate ICTs in public planning. These tensions lead to a considerable implementation gap between available technologies and data suggested by planning support science and digitalised everyday practices (Daniel and Pettit, 2021).

In addition, academics have expressed, along with the digital transformation, that their digital skills gains can be added in addition to the existing achievements (Geertman and Stillwell, 2020). In order to be able to evaluate the achievements identified, academicians have indicated that there may be product evaluation, peer assessment, portfolios, rubrics, and skill-based evaluation, usually from assessment methods. They also stated that curriculums should be rearranged in this direction and they stated that step-by-step, program-based, sub-learning-centered methods should be included according to the student's level (Geertman and Stillwell, 2020).

Cluster 5: Usage of emerging technologies

The green cluster focuses on case studies of the usage of emerging technologies to address urban challenges. Akhmedova and Vavilonskaya, (2019) have articulated the envisioned benefits from digital transformation as a solution to planning under uncertainty and complexity, while demanding new skills from and posing challenges to professionals. Several studies address the digital transformation of public and private planning practices in different contexts, not only based on forerunners of digital planning (Fertner et al., 2019), but also by drawing attention to mundane, in many local contexts often still manual, and non-digital planning practices (Sabri and Witte, 2023). Planning research focuses on key information and communication technologies (ICT), such as computer-aided design (CAD) (Kuppler and Alpermann, 2022) and other types of 3D spatial media (Kitchin et al., 2021) and how they have impacted plannings' content and form (Potts, 2020). Several studies emphasise challenges of digital transformations, indicating a lagging adoption (Kitchin et al., 2021), a 'digital skill gap in planning practice and education' (Yang, 2024, 39) as well as systemic barriers to integrate ICTs in planning practice. These tensions lead to a considerable gap between the potential transformation and everyday planning practices (Daniel and Pettit, 2021).

6 DISCUSSIONS

The Fourth Industrial Revolution (4IR) demands a global fundamental shift in educational institutions and calls for embedding relevant technology that are specifically designed for certain disciplines. Such adaptation aligns with the Sustainable Development Goal (SDG 4) call for inclusive and equitable quality education. It has been realized that there are various technical modules using technological software's that are taught within urban planning programmes. These tools are very critical to be sufficiently taught in the Urban Planning discipline providing support to rational decision-making on spatial analysis and planning. There are strongly grounded modules to technological innovations in Urban Planning which include (i) Geographic information systems and urban information systems where students are taught to analyze real-time data of urban spaces, mapping and monitor change to inform design decisions. (ii) Architectural and Planning design, and (iii) Advanced computer applications in AutoCAD affording digital design tools where students are taught basics operations of the softwares and advanced technological softwares that include 3D modelling to create digital representation of urban environments which assist in spatial analysis providing enhanced development proposal of existing spaces and new development proposals. However, there are various challenges faced by successfully having enhanced technological innovations in teaching and learning. With this mentioned, there is a lack of obtaining most updated softwares and provision of license software's to ensure that students are equipped with the necessary skills required in the industry. Accordingly, in certain instances there is a lack of data access that could be used to aid learning. Consequently, even with these technological modules that are taught, they are not dominant in the curricula. Such modules are taught on a semester basis, specifically, once a semester in a year. This does not provide sufficient time for learning and allows students to properly grasp the skills. Therefore, leading to students not having a concrete background of such planning perspectives creating a huge gap when they are presented to professional practice. Subsequently, there is a lack of continuous training for educators to stay up to date with new technological programs compromising the delivery of such technological modules.

Further, there is a lack of sufficient collaborations between industry and academia which compromises the alignment between the two. There are on-going projects where digital tools are deployed in the industry. With strong collaboration, this could afford an opportunity for accessibility to adequate data to be used for learning which at times is not easily accessible, and there could be alignment between most updated projects that are taking place and allow an opportunity to be taught in universities promoting lifelong learning opportunities applicable to evolving professional demands. For South African urban planning programmes, it is critical to align curricula and teaching models with the digital skills essential for graduate employability and effective engagement with real-world urban challenges. This could assist to prepare future urban planners with the technological competencies needed to navigate and shape the rapidly evolving

7 RECOMMENDATIONS AND FRAMEWORK

To adequately respond to the identified digital skills gap and misalignment between planning education and professional practice in South Africa, this section presents recommendations through a conceptual framework to guide curriculum transformation. These are structured around pillars essential for building a digitally competent, inclusive, and industry-relevant planning education system, as shown in Figure 3.

Curriculum innovation and digital integration are the first and most foundational recommendations. Digital tools such as GIS, AI, remote sensing, and 3D modelling must be embedded into the very core of planning pedagogy. Rather than offering these as electives or post-hoc certifications, planning programmes should incorporate them into foundational modules. Research by Batty (2018) shows the importance of digital spatial literacy for planners operating in increasingly data-driven urban environments. Co-teaching arrangements with computer science and engineering faculties can enhance the interdisciplinarity of urban problem-solving and expose students to diverse computational methods (Basnet and Basnet, 2018). This aligns with international trends in planning education, where digital urban labs and real-time data are used to simulate policy interventions (Kontokosta, 2018). Academic capacity building is the second pillar and addresses the systemic bottleneck of digital proficiency among planning educators. Without digitally skilled faculty, even the most well-designed curricula will falter. Institutions should therefore create structured upskilling programmes and continuous professional development (CPD) pathways, including industry secondments and attendance at digital planning conferences. SACPLAN (2015) has already called for accredited CPD courses, and universities should align their staff development initiatives with these standards.

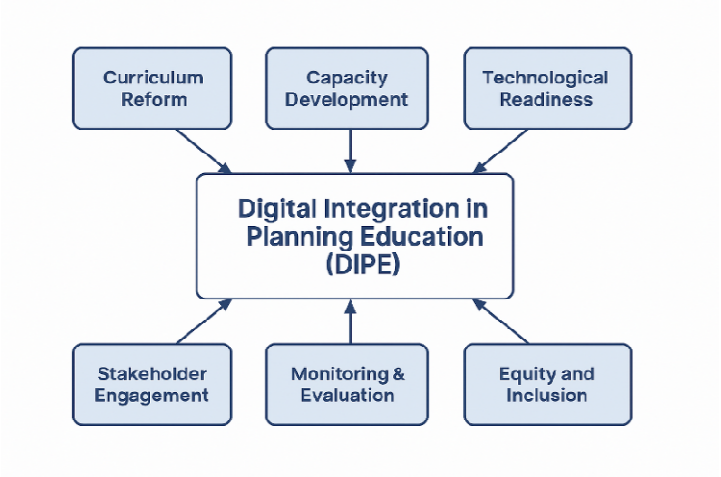


Figure 4: Digital Integration in Planning Education (DIPE).

Thirdly, strengthening university-industry partnerships is essential to anchor academic instruction in real-world practices. Collaborations between universities and municipalities, private firms, and professional councils can facilitate the co-creation of digital course content and ensure students are exposed to applied digital methods during their training (Esangbedo et al., 2023). Capstone projects addressing problems using digital solutions can serve as both a pedagogical tool and a service-learning opportunity (Shurin, Davidovitch, and Shoval, 2021). The fourth recommendation involves investing in technological infrastructure, especially in historically disadvantaged institutions. Digital equity cannot be achieved without equitable access to high-speed internet, licensed software, and computing hardware (Liu, Tschinkel, and

Miller, 2024). Institutions must invest in spatial planning labs and leverage cost-effective tools such as QGIS, R, Python, and Blender. Equity, inclusion, and digital justice constitute the fifth recommendation and underpin the ethical dimension of digital transformation. As digital divides often mirror broader socio-economic inequalities in South Africa, planning schools must adopt inclusive strategies. Device loan programmes, subsidised data, and foundational digital skills workshops can democratise access to digital learning (United Nations Development Programme,2024). Finally, the importance of monitoring, evaluation, and feedback mechanisms cannot be overstated. Regular curriculum reviews, graduate tracer studies, and stakeholder feedback loops can ensure planning education remains aligned with evolving market demands and technological trends (Kapala, 2024). The framework offers a roadmap for aligning South African planning education with the demands of the 21st century, and this framework can enhance not only the employability of graduates but also the social responsiveness of planning interventions in a digital era.

8 CONCLUSION

In conclusion, this study explored the intersection of digital transformation, planning education, and professional practice within South Africa's urban planning sector. It highlighted how global academic and professional competitiveness has reshaped expectations on universities, with digital transformation emerging as both a strategic necessity and a disruptor in pedagogy. Through an analysis of publication trends and keyword network visualisation, the study showed the evolution of Fourth Industrial Revolution (4IR) technologies, GIS, BIM, AI, and digital twins within planning theory, education, and practice. While interest in these technologies is growing, their implementation remains uneven. Five thematic clusters were identified, reflecting the growing complexity of digitalisation across planning systems. The analysis identified significant structural barriers, and the study proposed the Digital Integration in Planning Education (DIPE) framework to address these gaps. Therefore, aligning planning education with digital demands will better prepare future planners to shape equitable and sustainable urban futures.

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reviewed paper

Rethinking Complementary Land Uses for Early Childhood Development Centres in Johannesburg's CBD

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1 ABSTRACT

As Johannesburg's inner city densifies and increasingly accommodates low- and middle-income families, Early Childhood Development (ECD) centres have become essential complementary land uses within the Central Business District (CBD). However, many centres operate in high-rise and mixed-use buildings not designed for childcare, raising concerns about spatial justice, child-friendly urbanism, and the adaptability of planning systems. This paper examines the alignment between planning and regulatory frameworks for ECD provision and the spatial realities of ECD centres operating in Johannesburg's CBD. Using a qualitative explanatory case study approach, the study combines non-participant observation of selected ECD centres with analysis of zoning schemes, national norms and standards, policy documents, and demographic data. Findings reveal a persistent mismatch between regulatory expectations largely premised on low-density, purpose-built assumptions and the constrained, vertical environments of the inner city. While regulations aim to safeguard child wellbeing, their rigid application often hinders compliance and contributes to informality. At the same time, ECD centres demonstrate adaptive spatial practices that respond to urban densification but remain weakly recognised within formal planning systems. The paper argues for child-sensitive, context-responsive planning approaches that recognise ECD centres as integral urban social infrastructure and align regulatory frameworks with the realities of dense city centres.

Keywords: Spatial justice, Complementary land uses, Early Childhood Development (ECD), Inner-city planning, Child-friendly urbanism

2 INTRODUCTION, BACKGROUND, AND CONCEPTUAL FRAMING

2.1 Urban Densification, Childcare Demand, and the Inner-City Context

Rapid urban densification within Johannesburg's inner city has reshaped household structures, residential patterns, and everyday service needs. Once dominated by commercial and administrative land uses, the Central Business District (CBD) has increasingly become a space of permanent residence for low- and middle-income families, migrants, and informal households seeking proximity to employment and transport networks. This demographic shift has generated growing demand for spatially neighbouring social infrastructure, particularly Early Childhood Development (ECD) centres, which are essential to supporting care, learning, and early childhood wellbeing in dense urban environments (Ashley-Cooper, Van Niekerk & Atmore, 2019; Moses & van der Berg, 2023). However, ECD provision in South Africa has historically been conceptualised through a low-density, suburban lens, where facilities are assumed to operate within purpose-built, ground-level structures with access to outdoor play space and relatively flexible land availability. This assumption sits uneasily with the spatial realities of inner-city environments, where ECD centres increasingly operate within repurposed high-rise residential buildings, subdivided flats, and mixed-use blocks not originally designed for childcare functions. Similar trends have been observed in other African and Global South cities, where informal and semi-formal ECD provision has emerged as a response to unmet demand rather than as a product of proactive urban planning (Ndengo & Richard, 2022; Van Der Walt, De Beer & Swart, 2014).

2.2 Policy Intentions and Regulatory Frameworks for ECD Provision

South Africa has developed an extensive legislative and policy framework aimed at regulating and supporting ECD provision. These include the Children's Act and Children's Amendment Act (Republic of South Africa, 2010), national norms and standards for ECD infrastructure, municipal zoning schemes, and more recent strategic shifts placing ECD under the Department of Basic Education (Matlala & Molokwane, 2024). In principle, these frameworks are designed to ensure minimum standards of safety, accessibility, learning quality, and child well-being. Empirical evidence, however, consistently highlights a substantial gap between policy intentions and implementation outcomes. Studies across urban and peri-urban contexts reveal

that many ECD centres struggle to meet infrastructure, zoning, and compliance requirements, not due to neglect or unwillingness, but because regulatory standards are poorly aligned with the socio-economic and spatial conditions in which centres operate (Atmore, Van Niekerk & Ashley-Cooper, 2012; Aina & Bipath, 2022; Madyibi & Bayat, 2021). High compliance costs, fragmented governance responsibilities, and rigid land-use controls have contributed to the proliferation of unregistered or informally operating centres, particularly in dense urban areas (Kika-Mistry & Wills, 2022; Sello et al., 2024).

In Johannesburg's CBD, this misalignment is especially pronounced. Zoning schemes often restrict ECD facilities to specific land-use categories or require consent-use approvals that are difficult to secure in high-rise buildings. Fire safety regulations, outdoor space requirements, parking standards, and building design specifications frequently assume horizontal layouts and private land ownership, conditions largely absent in inner-city residential towers. As Ally (2023) argues, regulatory 'red tape' in the ECD sector often functions less as a safeguard for children and more as a structural barrier to service provision in precisely the areas of greatest need.

2.3 Misalignment Between Planning Frameworks and Spatial Realities

The tension between planning regulation and lived spatial reality constitutes a central challenge for ECD provision in dense city centres. Literature from South Africa and comparable contexts demonstrates that ECD centres operating in constrained urban environments frequently adapt spaces in creative but non-compliant ways. Examples include the use of internal corridors or rooftops for play, shared sanitation facilities within residential buildings, and vertical circulation systems that complicate safe child movement and emergency access (Madyibi & Bayat, 2021; Visser et al., 2021). On the other hand, research on ECD infrastructure quality further illustrates that spatial constraints disproportionately affect centres serving low-income communities, reinforcing patterns of inequality in early childhood environments (Ashley-Cooper et al., 2019; Aubrey, 2017). While international literature emphasises the importance of outdoor play, environmental affordances, and spatial flexibility for child development (Frost & Sutterby, 2017; Yogman et al., 2018), these principles are difficult to realise within vertically dense urban forms without adaptive planning approaches. Recent Johannesburg-based studies comparing ECD centres across socio-economic contexts highlight stark disparities in access to play space, equipment, and environmental quality, with inner-city and lower-income centres consistently disadvantaged (Clarkson, Botha & Van der Linde, 2025).

2.4 Conceptual Framing: Spatial Justice and Child-Sensitive Urban Planning

This study is conceptually framed by principles of spatial justice and child-sensitive urban planning. Spatial justice foregrounds the equitable distribution of resources, services, and opportunities across urban space, drawing attention to how planning systems can unintentionally reproduce exclusion when regulations fail to account for lived realities (Soja, 2010). Applied to ECD provision, a spatial justice lens highlights how children's access to safe, appropriate care environments is shaped not only by educational policy but also by land-use planning, building regulations, and urban governance structures.

Child-sensitive planning further emphasises children as legitimate urban citizens whose needs should be explicitly considered in spatial decision-making. International frameworks, including the United Nations Convention on the Rights of the Child (2013), assert children's right to safe play, care, and development-supportive environments. Yet, as several scholars note, these rights are often weakly operationalised within urban planning practice, particularly in high-density and low-income contexts (Bianchi et al., 2022; Lester & Russell, 2010). Through integrating these conceptual lenses, the paper positions inner-city ECD centres not as regulatory anomalies but as critical indicators of how planning systems respond to urban densification, social reproduction, and everyday care needs. The Johannesburg CBD thus provides a compelling case through which to interrogate whether existing planning frameworks enable or constrain equitable access to early childhood services in dense urban environments.

This paper aims to examine how Early Childhood Development (ECD) centres are accommodated within Johannesburg's Central Business District under conditions of increasing urban density. The specific objectives include assessing the extent of alignment between planning and regulatory frameworks and the spatial realities of ECD centres operating in the Johannesburg CBD, with particular attention to zoning, consent-use provisions, and national norms and standards. Examine how built environment conditions in high-rise and mixed-use buildings affect the safety, accessibility, and inclusivity of ECD centres, considering

infrastructure such as circulation, sanitation, emergency access, and play space. Develop planning-oriented recommendations that support ECD centres as essential complementary land uses in dense city centres, promoting child-sensitive, spatially just, and context-responsive urban planning. This study thus contributes to urban planning and early childhood development scholarship, advances spatial planning debates on complementary land uses by situating ECD centres within discussions of urban densification, mixed-use development, and spatial justice areas where ECD provision remains under-theorised in South African planning literature.

The introduction situates the study within debates on urban densification, complementary land uses, and early childhood development, and outlines the conceptual framing grounded in spatial justice and child-sensitive urban planning. The methodology section then details the qualitative explanatory case study design, including the study area, data collection through non-participant observation, and analysis of planning and policy documents. The findings and discussion section presents empirical insights from Johannesburg's CBD, examining demand pressures, spatial constraints, and misalignments between regulatory frameworks and everyday ECD practices. This is followed by a section on planning implications, which reflects on how ECD centres can be more effectively accommodated as complementary land uses within dense inner-city environments. The paper concludes by summarising key findings and highlighting broader implications for inclusive, context-responsive urban planning.

3 METHODOLOGY

This study adopts a qualitative, explanatory research approach to examine the spatial and regulatory conditions under which Early Childhood Development (ECD) centres operate in Johannesburg's Central Business District (CBD). A case study design is appropriate for exploring complex, context-specific interactions between planning regulations, built form, and everyday practices within dense urban environments (Yin, 2018). The Johannesburg CBD provides a critical empirical setting due to its high residential density, mixed land uses, and increasing demand for childcare services within buildings not originally designed for ECD purposes.

The research is based on multiple case studies within the CBD. The studied areas include Hillbrow, New Doornfontein, Maboneng, and the inner-city suburb of Johannesburg near Eloff. These areas were selected due to their historical transformation from a once well-resourced urban neighbourhood into one of the most densely populated areas in the city, characterised by overcrowding, deteriorating building conditions, and increasing pressure on social infrastructure (CUBES & Planact, 2007). This context provides a critical setting for examining the emergence and persistence of ECD centres within buildings not originally designed to accommodate childcare services. An explanatory case study design was employed to understand how historical processes of urban decline, demographic change, and policy responses have shaped present-day spatial realities. Tracing Johannesburg's broader urban development trajectory allows for an interpretation of how uneven population growth, building degradation, and insufficient social facilities have converged to affect the provision of ECD services in the inner city.

Primary data were collected through non-participant observation of selected ECD centres in high-rise and mixed-use buildings in Johannesburg's CBD. Observations focused on spatial and environmental attributes relevant to planning and ECD standards, including building access, circulation, safety features, play and sanitary facilities, and surrounding land uses (Madyibi & Bayat, 2021; Breakwell, 2000). Notes were systematically recorded to capture consistencies and deviations from national and municipal norms. The study also assessed immediate external environments, considering proximity to social amenities, exposure to noise or health hazards, safety conditions, and transport access used by children and caregivers. Informal interactions with caregivers provided additional contextual insight into daily experiences navigating ECD provision. This approach enabled the researcher to evaluate how ECD centres function within constrained urban spaces and how planning regulations translate into lived realities.

Secondary data were analysed to contextualise and triangulate the observational findings. This included a review of municipal zoning schemes and land-use management regulations relevant to the Johannesburg CBD. The City of Johannesburg's municipal by-laws include specific regulations related to land use and zoning, distinguishing between suburban and township areas, alongside fire safety (SANS 10400-T) and environmental health requirements. Furthermore, the 2024 Children's Services Policy provides a guiding framework for the registration and compliance of Early Childhood Development (ECD) sites in

Johannesburg, with a strong emphasis on ensuring the health and safety of children. Additional documents reviewed included national ECD norms, standards, and policy guidelines (Department of Basic Education, 2023; Republic of South Africa, 2010); legislative and regulatory analyses concerning ECD registration and compliance (Ally, 2023; Sello et al., 2024); and demographic and population data from Statistics South Africa to evaluate the demand pressures for childcare services in the inner city. This documentary analysis allowed for a critical comparison between regulatory expectations and the actual spatial conditions observed on the ground.

Data were analysed using thematic qualitative analysis, focusing on recurring patterns of spatial compliance, adaptation, and constraint. Key analytical themes included zoning alignment, infrastructural adequacy, safety and accessibility, and the impact of urban density on ECD provision. The analysis emphasised identifying points of misalignment between planning frameworks and everyday ECD practices within the CBD.

This study adhered to ethical principles applicable to research in sensitive urban contexts, particularly involving Early Childhood Development (ECD) centres. To minimise potential harm or regulatory exposure, data collection was conducted without direct engagement with children, and observations were non-intrusive, focusing on spatial characteristics rather than individual identities. However, informal conversations were held with caregivers dropping off children and individuals using the building and surrounding the facility. Photographic documentation was considered but not used, as consent was not granted. Thus, revealing facility locations could compromise participant and centre confidentiality. The study relied on observational methods and publicly available secondary data, ensuring ethical compliance while capturing the spatial and operational context of ECD provision. As a qualitative case study, the analysis is context-specific and not intended for statistical generalisation. Nevertheless, the methods employed provide transferable insights relevant to other dense urban centres facing comparable planning and regulatory challenges

4 FINDINGS AND DISCUSSION: RETHINKING COMPLEMENTARY LAND USES FOR ECD CENTRES IN JOHANNESBURG'S CBD

4.1 Rising Demand for ECD Centres in High-Density Areas

Observations across Hillbrow, New Doornfontein, Maboneng, and the inner-city suburb near Eloff indicate a growing demand for Early Childhood Development (ECD) services. Caregivers frequently rely on centres within walking distance due to limited transport options. Secondary data from the 2021 ECD Census (DBE, 2022) confirm Gauteng as the province with the highest number of Early Learning Programmes (ELPs), totaling 10,376 centres, representing 25% of all ELPs in South Africa. Six out of ten ECD programmes in Gauteng are located in urban areas, matching the urban proportion of enumeration areas in the census (StatsSA, 2022).

This data illustrates the pressure on urban ECD facilities, especially in Johannesburg's CBD, where population density has increased significantly due to in-migration and high-rise residential development. Informal observations in the CBD show centres creatively using corridors, rooftops, and subdivided apartments for play and learning, demonstrating adaptive responses to urban densification (Ashley-Cooper et al., 2019; Moses & van der Berg, 2023).

4.2 Spatial Constraints and Infrastructure Adaptation

CBD Early Childhood Development (ECD) centers encounter spatial and infrastructural challenges that hinder their ability to meet municipal and national standards. The limitations below highlight the disparity between regulatory expectations and the realities of urban environments. Aligning with (Visser et al., 2021), which discusses the creative, yet constrained solutions found in densely populated African cities.

- Vertical circulation and safety: Hillbrow centres often rely on a single elevator or narrow stairwells, creating safety risks during peak drop-off/pick-up.
- Outdoor play: Maboneng rooftop adaptations provide limited space (<2 m² per child) compared to the DBE National Norms and Standards (2023).
- Sanitation and hygiene: Shared bathrooms in high-rise buildings frequently do not meet prescribed child-toilet ratios (Children's Act, RSA, 2010).

- Accessibility: Centres near transport nodes mitigate travel burdens but remain exposed to noise, pollution, and traffic hazards (Clarkson et al., 2025).

4.3 Misalignments Between Planning Regulations and Practice

Analysis of zoning schemes, municipal by-laws, and observed CBD conditions highlights systemic misalignments, reinforced by provincial-level data:

Zoning and land-use restrictions: Johannesburg's Land Use Management By-law (2016) permits ECD centres mainly in "Community Facility" zones, yet many observed centres operate in residential or mixed-use high-rises. One Hillbrow centre reported waiting over two years for formal consent-use approval, reflecting barriers highlighted in Ally (2023). Fire and safety compliance: SANS 10400-T requires accessible emergency exits, yet narrow stairwells and obstructed corridors in New Doornfontein centres prevent full compliance. The Children's Services Policy (CoJ, 2024) calls for inspections, but enforcement remains uneven. Outdoor and play area requirements: DBE norms require 2 m² per child for outdoor play. In high-density CBD settings, rooftop or balcony play spaces often provide only 1–1.5 m², illustrating misalignment between standards and inner-city realities. Parking and transport requirements: Zoning requires on-site parking for staff and drop-off, often unavailable in high-rise buildings. Centres rely on street parking, increasing traffic risks. Registration status and governance challenges: The 2021 ECD Census shows that in Gauteng, 50% of ELPs are not registered, 40% are registered, and 16% are in the process of registration. This confirms that many centres operate informally or semi-formally, navigating overlapping municipal, provincial, and national approvals (DBE, 2022; Sello et al., 2024). These misalignments reveal structural barriers that disproportionately affect low-income centres, reproducing spatial inequities and limiting access to quality care in the CBD (Soja, 2010; Clarkson et al., 2025).

On the other hand, there are positive practices and opportunities for adaptive planning. Despite regulatory misalignment, CBD centers are showcasing innovative adaptations, such as utilising rooftops and internal corridors for play and strategically scheduling to maximize limited outdoor access. Additionally, their proximity to transportation and amenities helps alleviate caregiver burdens. Resource-sharing networks among centers also enhance service continuity. These strategies exemplify child-sensitive, context-responsive approaches that could inform formal planning adjustments, aligning urban densification realities with the provision of safe and equitable early childhood development (ECD) services (Lester & Russell, 2010; Bianchi et al., 2022).

5 PROVISION IN JOHANNESBURG'S CBD PLANNING IMPLICATIONS AND PATHWAYS FOR CONTEXT-RESPONSIVE ECD

The findings point to a critical planning implication: ECD centres are no longer peripheral or exceptional land uses in Johannesburg's CBD but constitute essential urban social infrastructure embedded within everyday residential life. The persistence of ECD centres in high-rise and mixed-use buildings, despite regulatory misalignment, demonstrates that demand-driven spatial practices have outpaced planning frameworks. This directly speaks to the study's final objective to develop planning-oriented recommendations that support ECD centres as complementary land uses within dense city centres.

The evidence suggests the need for formal recognition of ECD centres as legitimate complementary land uses within inner-city residential and mixed-use zones. Current zoning schemes in Johannesburg continue to treat ECD facilities as specialised or conditional land uses, requiring consent-use applications that are often impractical in high-density contexts. Aligning with arguments by Ally (2023) and Matjokana and Bipath (2024), the findings support a shift towards as-of-right inclusion of small-scale ECD facilities within residential and mixed-use zoning categories in the CBD, subject to context-appropriate safety criteria. Comparable approaches have been adopted in cities such as Bogotá and São Paulo, where childcare centres are integrated into mixed-use zoning as part of neighbourhood social infrastructure strategies, particularly in high-density, low-income areas (Bianchi et al., 2022).

The study highlights the necessity of flexible, performance-based design standards rather than rigid, spatially prescriptive requirements. Observed adaptations such as rooftop play areas, internalised play spaces, and shared sanitation indicate that centres are capable of meeting child development needs creatively, albeit often in technically non-compliant ways. International literature on child-friendly urbanism emphasises that the quality of play and supervision may be as important as spatial size alone, especially in dense urban

environments (Frost & Sutterby, 2017; Yogman et al., 2018). In the Johannesburg context, this suggests revising national and municipal ECD infrastructure guidelines to allow context-sensitive interpretations of outdoor play, circulation, and sanitation, supported by clear safety benchmarks rather than minimum spatial thresholds alone.

Furthermore, findings regarding registration and compliance challenges reinforced by the 2021 ECD Census showing that approximately half of Gauteng's ECD centres remain unregistered or semi-formal underscore the need for planning-led support mechanisms rather than punitive enforcement. Rather than framing non-compliance solely as regulatory failure, the findings align with Sello et al. (2024) in illustrating how fragmented governance and unrealistic standards push centres into informality. A Johannesburg-specific response could include inner-city ECD support programmes, combining land-use guidance, fire safety assessments, and phased compliance pathways. Similar incremental compliance models have been piloted in Kenya and India, where urban childcare centres are supported through technical assistance and conditional licensing tied to gradual spatial improvements (Ndengo & Richard, 2022). The findings reinforce the importance of interdepartmental coordination and planning awareness. ECD provision in the CBD intersects with planning, building control, fire services, environmental health, and children's services, yet these functions remain institutionally siloed. Embedding ECD considerations into inner-city precinct plans, social infrastructure frameworks, and urban regeneration strategies would enhance coherence. International examples from Barcelona and Rotterdam demonstrate how child-sensitive planning is operationalised through cross-sector urban governance structures, ensuring that children's needs are explicitly considered in densification and regeneration projects (Lester & Russell, 2010; Bianchi et al., 2022). From a spatial justice perspective, the findings suggest that failure to adapt planning frameworks risks reproducing early childhood inequalities, particularly for low-income and migrant families concentrated in the inner city. Recognising ECD centres as integral to urban social reproduction aligns with Soja's (2010) conception of spatial justice, where access to care, safety, and developmental environments is understood as a spatially mediated right. Raising planning awareness around ECD provision through professional guidelines, municipal training, and planning education can help shift perceptions of ECD centres from regulatory anomalies to critical indicators of inclusive, child-sensitive urban governance.

In summary, the Johannesburg CBD case illustrates that adaptive planning, regulatory flexibility, and institutional awareness are non-negotiable if ECD centres are to function effectively as complementary land uses in dense city centres. These insights contribute to broader debates on urban densification, mixed-use development, and social infrastructure provision in the Global South, offering transferable lessons for cities grappling with similar socio-spatial pressures.

6 SUMMARY

This paper examined how Early Childhood Development (ECD) centres are accommodated within Johannesburg's Central Business District (CBD) under conditions of increasing urban densification. Framed through spatial justice and child-sensitive urban planning, the study addressed the growing mismatch between planning and regulatory frameworks for ECD provision and the spatial realities of high-rise and mixed-use inner-city environments. Using a qualitative explanatory case study approach, the research combined non-participant observation of selected ECD centres with analysis of zoning schemes, municipal by-laws, national ECD norms and standards, and demographic data.

The findings demonstrate a strong and growing demand for ECD services in the CBD, driven by demographic change, in-migration, and the transformation of the inner city into a space of permanent residence for low- and middle-income households. While regulatory frameworks articulate clear intentions around safety, quality, and child wellbeing, they remain largely predicated on low-density, purpose-built assumptions that are poorly aligned with vertical, space-constrained urban environments. As a result, many CBD-based ECD centres operate through adaptive and creative spatial practices such as rooftop play areas, internalised learning spaces, and shared facilities that enable service provision but often fall outside formal compliance requirements.

The study highlights how rigid zoning categories, prescriptive infrastructure standards, and fragmented governance processes unintentionally marginalise ECD centres in precisely the areas where they are most needed. At the same time, the findings reveal opportunities for adaptive planning, regulatory flexibility, and institutional learning, positioning ECD centres as essential complementary land uses embedded within

everyday inner-city life. By foregrounding children's needs within urban planning debates, the paper contributes to under-theorised discussions on social infrastructure, mixed-use development, and spatial justice in South African cities.

7 CONCLUSION

This study set out to evaluate the extent to which planning and regulatory frameworks align with the spatial realities of Early Childhood Development (ECD) centres operating in Johannesburg's CBD. The findings confirm a persistent and systemic misalignment between regulatory intent and lived spatial practice. While existing policies and standards aim to safeguard children's well-being, their rigid and spatially prescriptive application fails to accommodate the realities of dense, vertical urban environments. Consequently, ECD centres are frequently rendered informal or semi-compliant, not due to disregard for child safety, but because planning systems have not adapted to changing socio-spatial conditions.

The Johannesburg CBD case demonstrates that ECD centres are no longer peripheral or exceptional land uses but constitute critical urban social infrastructure that supports everyday care, labour participation, and social reproduction. Treating ECD facilities as conditional or marginal land uses risks reproducing spatial and social inequalities, particularly for low-income and migrant families concentrated in the inner city. From a spatial justice perspective, access to safe, appropriate early childhood environments must be understood as a spatially mediated right that planning systems are obligated to enable rather than obstruct.

In alignment with the study's objectives and the paper's abstract, the conclusions emphasise the need for a shift towards child-sensitive, context-responsive planning. This includes recognising ECD centres as legitimate complementary land uses within residential and mixed-use zones; adopting flexible, performance-based design standards that prioritise safety and developmental quality over rigid spatial thresholds; and strengthening interdepartmental coordination to support phased and supportive compliance pathways. Without such reforms, regulatory frameworks risk undermining both early childhood development outcomes and broader goals of inclusive, compact, and socially just urban development.

Ultimately, rethinking ECD provision in Johannesburg's CBD offers wider lessons for cities in the Global South grappling with densification, informality, and uneven access to social infrastructure. Embedding children's needs into urban planning practice is not optional but fundamental to the creation of equitable, liveable, and resilient city centres.

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Rethinking Public Space in the Global South: A Secondary Analysis of Spatial Justice in South African Cities

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1 ABSTRACT

Public spaces are critical sites through which spatial justice is enacted and experienced in everyday urban life. In South African cities, however, public space provision and governance continue to reflect deep socio-spatial inequalities shaped by colonial and apartheid planning legacies, despite progressive post-apartheid reforms. This paper examines how spatial justice principles embedded in the Spatial Planning and Land Use Management Act (SPLUMA) are realised in practice through a comparative case study of two public parks in Johannesburg: Joubert Park in the inner city and Zoo Lake in an affluent suburban area. Using a qualitative research design that combines secondary policy analysis with non-participant field observation, the study evaluates each case against SPLUMA's spatial justice mandate and established principles of good public space. The findings reveal pronounced class-based differences in access, safety, diversity of use, maintenance, investment and governance. While Joubert Park performs well in terms of proximity and intensity of use, it underperforms in experiential access maintenance, and participatory governance. In contrast, Zoo Lake delivers high-quality public space outcomes for its primary users, largely due to sustained investment and aligned civic influence. The paper argues that spatial justice in public space planning cannot be assessed through proximity or formal access alone, but must be understood as a lived condition shaped by care, safety, recognition and power. It concludes by calling for differentiated, redistributive and participatory public space strategies to realise SPLUMA's transformative intent.

Keywords: Spatial justice; Public space; SPLUMA; Johannesburg; Urban inequality

2 INTRODUCTION AND BACKGROUND

Public spaces play a central role in shaping the social and democratic life of cities, functioning as everyday sites of mobility, interaction, and belonging (Low, 2000; Madanipour, 2010). In cities marked by deep socio-economic inequality, public spaces are particularly significant as they often represent the most accessible urban resources available to marginalised communities (UN-Habitat, 2016). In the Global South, however, access to safe, well-maintained, and inclusive public spaces remains uneven, reflecting colonial and postcolonial planning legacies that have entrenched spatial segregation and unequal investment along lines of race, class, and location (Watson, 2009; Robinson, 2016). South African cities exemplify these dynamics. Under apartheid, public space was racialised, controlled, and unevenly distributed, with Black communities systematically excluded from quality civic environments (Christopher, 2001; Harrison et al., 2008). Despite the transition to democracy and the introduction of progressive spatial planning reforms, these inequalities persist in contemporary urban landscapes. While post-apartheid policy has emphasised integration and redress, public spaces in many South African cities continue to reflect stark disparities in quality, safety, and investment, particularly between inner-city and township areas and affluent suburbs (Mabin & Smit, 1997; Todes, 2012; Bénit-Gbaffou, 2018). The Spatial Planning and Land Use Management Act (SPLUMA) of 2013 represents a key legislative attempt to address these inequalities by embedding spatial justice as a core planning principle (Republic of South Africa, 2013). Although SPLUMA does not regulate public space directly, it shapes public space outcomes through municipal planning instruments. Yet the extent to which its spatial justice mandate translates into equitable everyday public space experiences remains under-examined, as existing scholarship has focused largely on land use management and housing rather than lived public space outcomes (Todes et al., 2020; Van Wyk, 2021). Against this backdrop, this paper examines how public spaces in different socio-economic contexts within Johannesburg respond to SPLUMA's spatial justice principles and the extent to which they align with established criteria for good public space. Through a comparative analysis of two contrasting public parks, one in an affluent suburban area and the other in the inner city, the study explores how class, governance, and institutional priorities mediate the implementation of spatial justice in practice.

3 LITERATURE REVIEW AND THEORETICAL FRAMEWORK

3.1 Public Space, Inequality and the South African Urban Context

Public spaces are widely understood as central to urban life, functioning as sites of social interaction, mobility, leisure, and democratic engagement (Jacobs, 1961; Madanipour, 2010). Critical urban scholarship has shown, however, that public spaces are not inherently inclusive. Instead, they are shaped by planning decisions, design norms, and governance practices that reflect and reproduce broader social and spatial inequalities (Mitchell, 2003; Low & Smith, 2006). In cities characterised by high levels of socio-economic inequality, public space quality and accessibility are unevenly distributed. Affluent areas tend to benefit from sustained investment, active management, and strong civic advocacy, while public spaces in low-income neighbourhoods are more likely to experience neglect, securitisation, and under-resourcing (Watson, 2009; Low, 2017). These dynamics are particularly pronounced in cities of the Global South, where colonial and postcolonial planning legacies have produced fragmented urban forms and deeply unequal access to urban amenities (Robinson, 2016; Myers, 2011). South African cities exemplify these patterns. Under apartheid, public spaces were deliberately racialised, controlled, and unevenly distributed, with Black communities systematically excluded from quality civic environments (Christopher, 2001; Beavon, 2004). Despite post-1994 policy commitments to spatial transformation, contemporary public spaces continue to reflect stark class- and location-based inequalities (Mabin & Smit, 1997; Todes, 2012). Inner-city and township public spaces frequently face challenges related to safety, maintenance, and governance, while parks and recreational spaces in affluent suburbs tend to be better resourced and managed (Bénit-Gbaffou, 2018). These enduring disparities raise important questions about how spatial justice is operationalised in practice.

3.2 SPLUMA and Spatial Justice in Planning

The Spatial Planning and Land Use Management Act (SPLUMA) constitutes a central pillar of South Africa's post-apartheid planning framework. By positioning spatial justice as a core development principle, SPLUMA seeks to address historical spatial inequalities through redress, equitable access, and the prioritisation of disadvantaged communities in planning decision-making processes (Republic of South Africa, 2013). Scholars have highlighted SPLUMA's potential to reorient planning towards a more normative and justice-driven agenda (Todes, 2014; Van Wyk, 2015). At the same time, critical assessments caution that the Act's effectiveness depends heavily on interpretation and implementation at the municipal level (Todes et al., 2020). Much of the existing literature has focused on SPLUMA's implications for land use management and housing delivery, with comparatively limited attention given to public space as a key site through which spatial justice is experienced in everyday urban life. This gap is significant given the central role of public spaces in shaping mobility, safety, and social interaction, particularly for low-income and marginalised residents.

3.3 Theoretical and Analytical Framework

This study adopts an integrated framework that combines spatial justice theory, SPLUMA's normative planning principles, and established criteria for evaluating public space quality. This approach enables a comparative analysis that considers both policy intent and lived spatial outcomes. Spatial justice theory provides the normative foundation for the analysis by foregrounding the unequal distribution of spatial resources and the power relations embedded in planning processes (Soja, 2010). Drawing on Lefebvre's concept of the right to the city, spatial justice emphasises the right of all urban residents to access, use, and shape urban space, including public spaces that support everyday life and democratic participation (Lefebvre, 1996). Within the South African context, SPLUMA operationalises these ideas by embedding spatial justice as a statutory planning principle. In this study, SPLUMA is treated as a normative benchmark against which public space outcomes can be assessed. Although the Act does not regulate public space directly, it shapes public space provision through municipal planning instruments, spatial priorities, and development controls. To evaluate how public spaces perform in practice, the study draws on principles of good public space articulated by Carmona et al. (2010). These principles include accessibility and connectivity, safety and comfort, diversity of use and users, quality of design and maintenance, and governance and management. When read alongside SPLUMA's spatial justice mandate, Carmona's framework provides a practical evaluative tool for assessing whether public spaces are functional, well-designed, equitable, and inclusive. By integrating spatial justice theory, SPLUMA's normative commitments, and public space evaluation

principles, the framework allows for a structured comparison of public spaces across different socio-economic contexts. It enables the study to examine how class, location, and governance mediate the translation of planning legislation into lived urban experience, and to assess the extent to which public spaces contribute to or undermine spatial justice in Johannesburg..

4 RESEARCH METHODLOGY

This study employs a qualitative comparative case study design to examine how public spaces in different socio-economic contexts respond to spatial justice principles within South Africa's planning framework. Two public parks in Johannesburg were purposively selected for a class-based comparison: Joubert Park in the inner city, serving predominantly low-income and transit-dependent users, and Zoo Lake in an affluent suburban area, functioning primarily as a leisure and recreational space. Both cases fall under the same municipal and legislative framework, enabling meaningful comparison of how socio-economic context mediates public space outcomes. The study draws on secondary data and non-participant field observation. Documentary sources include national planning legislation, particularly SPLUMA, municipal planning instruments, public space audits, and peer-reviewed literature. Field observations documented patterns of use, accessibility, maintenance, safety, and everyday activities through structured field notes. Data were analysed thematically using spatial justice principles derived from SPLUMA and evaluative criteria for good public space articulated by Carmona et al. (2010). A comparative analysis was then undertaken to identify key contrasts and patterns across the two cases. As the study relied on publicly available documents and observational data only, formal ethical clearance was not required.

5 FINDINGS AND DISCUSSION

5.1 Access and Connectivity: Proximity Versus Effective Access

Both Joubert Park and Zoo Lake are formally accessible public spaces, yet the nature and quality of access differ markedly when examined beyond locational criteria. Joubert Park is highly accessible in spatial terms, situated within walking distance of dense residential neighbourhoods and major public transport routes. Field observations confirmed continuous and diverse use throughout the day, particularly by commuters, informal traders, caregivers, and children. From a SPLUMA perspective, the park appears to perform well against principles of access, integration, and proximity, aligning with the Act's emphasis on locating urban amenities close to disadvantaged communities. However, a closer examination reveals that spatial proximity does not translate into equitable or sustained access. Effective access to Joubert Park is constrained by safety concerns, uneven maintenance, and limited amenities that shape who can use the space, when, and for what purposes. Women and caregivers were observed to use the park predominantly during peak daylight hours, with noticeably reduced presence in the early morning and late afternoon. This temporal pattern reflects what feminist urban scholars describe as the conditional and negotiated nature of women's access to public space, where safety perceptions, care responsibilities, and fear of harassment restrict spatial and temporal mobility (Koskela, 1999; Fenster, 2005; Phadke et al., 2011). From a spatial justice perspective, this raises critical questions about how access is conceptualised in planning policy. SPLUMA's emphasis on physical access and integration risks privileging measurable, locational indicators while overlooking experiential dimensions of access rooted in gender, age, and vulnerability. As Soja (2010) argues, spatial justice requires attention not only to the distribution of resources, but also to the conditions under which space can be meaningfully used. In this sense, Joubert Park's accessibility is partial and uneven, offering access in principle but not consistently in practice.

Zoo Lake presents a contrasting case. The park is less accessible in conventional spatial planning terms, relying more heavily on private vehicle access and serving lower-density, affluent neighbourhoods. Yet, for its primary users, Zoo Lake offers high levels of effective access. Well-maintained pathways, consistent lighting, clear sightlines, and the presence of other users support extended use across different times of day. These conditions align with Carmona's argument that access is not solely a function of location, but is produced through design quality, management practices, and ongoing investment (Carmona et al., 2010). Critically, the comparison exposes a classed dimension of access that is often obscured in policy discourse. While inner-city public spaces such as Joubert Park may satisfy access objectives through proximity and density, affluent-area public spaces often outperform them in experiential and functional access. This reflects broader critiques of urban planning in unequal cities, where formal equality in policy masks substantive

inequality in lived outcomes (Mitchell, 2003; Low, 2017). In this context, access becomes less about who can reach a space and more about whose presence is anticipated, supported, and normalised. The findings therefore point to a fundamental tension within SPLUMA's spatial justice mandate. If access is assessed primarily through spatial indicators such as location and connectivity, planning outcomes may appear equitable while reproducing everyday exclusions. A more transformative interpretation of SPLUMA would require planners to incorporate experiential, gendered, and temporal dimensions of access into public space planning and evaluation. Without such a shift, public spaces in marginalised areas risk remaining accessible in theory but exclusionary in practice.

5.2 Diversity of Use and the Politics of Inclusion

Joubert Park supports a wide diversity of uses and users, including informal trade, social gathering, play, waiting, resting, and transit-related activities. Field observations indicate that the park functions as an essential everyday space for inner-city residents whose livelihoods, mobility, and social lives are closely tied to public space. From the perspective of Carmona's public space framework, such diversity would ordinarily be interpreted as a marker of success, as it reflects adaptability, intensity of use, and responsiveness to varied urban needs (Carmona et al., 2010). However, this diversity is not unambiguously valued in planning and management practice. Field observations and secondary sources suggest that the multiplicity of activities in Joubert Park is frequently framed within municipal and public discourse as disorderly, unsafe, or indicative of decline. These representations often trigger episodic securitisation, increased surveillance, and attempts to regulate or remove informal activities. This dynamic reflects what Mitchell (2003) describes as the paradox of public space, whereby spaces that are genuinely public in use become sites of conflict precisely because they accommodate groups and practices that challenge dominant norms of order and civility. This tension is well documented in South African urban scholarship. Bénit-Gbaffou and Oldfield (2011) argue that informality in public space is routinely treated as a governance problem rather than as a legitimate mode of urban life. In inner-city contexts, informal trade, social congregation, and non-consumptive uses of space are often perceived as incompatible with urban regeneration agendas oriented towards safety, cleanliness, and economic competitiveness. While SPLUMA formally promotes inclusion, redress, and equitable access, its implementation at the level of public space is frequently mediated by managerial logics that prioritise control, risk mitigation, and aesthetic order over social justice.

From a spatial justice perspective, this raises fundamental questions about whose presence is recognised as legitimate in public space. Lefebvre's concept of the right to the city emphasises not only access to urban space, but also the right to inhabit, use, and produce space according to everyday needs (Lefebvre, 1996). In Joubert Park, the everyday practices of informal traders, migrants, and low-income residents represent active claims to urban space. Yet these claims are often marginalised through regulatory practices that privilege abstract notions of order over lived realities. Zoo Lake presents a contrasting configuration of diversity and inclusion. The park supports a narrower range of uses focused primarily on leisure, recreation, and exercise. While less diverse in functional terms, these activities are socially sanctioned, institutionally supported, and aligned with middle-class norms of public space use. Governance practices at Zoo Lake work to protect and enhance these uses through maintenance, event programming, and informal civic oversight. As Low and Smith (2006) note, such spaces often appear inclusive precisely because exclusion operates subtly through social norms rather than overt regulation. The juxtaposition of the two parks illustrates how diversity in public space is unevenly valued. In affluent contexts, limited diversity is interpreted as order and quality, while in inner-city contexts, functional diversity is often reframed as disorder requiring intervention. This asymmetry reflects broader classed and racialised hierarchies embedded in urban governance, where certain ways of occupying space are normalised and others are problematised. The findings therefore suggest that spatial justice in public space planning cannot be achieved through tolerance alone. Accommodating diversity without legitimising it leaves marginalised users vulnerable to ongoing regulation and displacement. A more transformative interpretation of SPLUMA would require municipalities to explicitly recognise informal and non-normative uses of public space as integral to urban life, and to shift public space governance away from control towards care, recognition, and inclusion.

5.3 Maintenance, Investment, and Governance: Uneven Priorities and Spatial Justice

Differences in maintenance, infrastructure quality, and governance arrangements emerged as some of the most visible and consequential contrasts between Joubert Park and Zoo Lake. Zoo Lake consistently

exhibited high levels of upkeep, including clean pathways, functional amenities, regular landscaping, and clearly maintained recreational infrastructure. These material conditions were supported by active governance arrangements and sustained municipal attention. By contrast, Joubert Park, despite experiencing heavy daily use and serving a population with limited access to alternative recreational spaces, displayed uneven maintenance, deteriorating amenities, and limited infrastructural investment. This unevenness reflects long-standing critiques of post-apartheid urban investment patterns, in which historically marginalised areas continue to experience infrastructural neglect despite formal policy commitments to redress and equity (Todes, 2012). From a SPLUMA perspective, this pattern signals a dilution of the spatial justice mandate. Although the Act calls for the prioritisation of disadvantaged communities, resource allocation in practice often continues to favour spaces already embedded within affluent and politically influential urban areas. The result is a planning landscape in which equality of policy coexists with inequality of outcome.

The distribution of maintenance and investment is closely linked to governance and participation structures. Zoo Lake benefits from strong civic engagement and informal partnerships involving resident groups, recreational users, and event organisers whose interests align closely with municipal priorities. While these forms of participation are not always formally institutionalised, they exert significant influence over management decisions and resource allocation. This form of governance reflects what Healey (1997) describes as collaborative planning operating within relatively equal power relations, where participants possess the social capital, organisational capacity, and institutional access required to shape outcomes. In contrast, governance at Joubert Park remains largely top-down and managerial. Although the park is intensively used, everyday users, including informal traders, migrants, caregivers, and low-income residents, have limited influence over planning and management decisions. Participation, where it occurs, tends to be procedural rather than substantive, fulfilling statutory requirements without meaningfully redistributing decision-making power. This gap between formal participation and lived influence reflects critiques of participatory planning that emphasise how participatory processes often privilege actors with greater social, economic, and institutional capital (Cooke & Kothari, 2001).

From a spatial justice perspective, these dynamics highlight that redistribution and participation are deeply intertwined. As Soja (2010) argues, spatial justice is ultimately realised through the redistribution of both material resources and political power. In the absence of sustained investment and inclusive governance mechanisms, public spaces in marginalised areas remain subject to cycles of neglect, securitisation, and reactive intervention. Legislative intent, including SPLUMA's emphasis on redress and equity, therefore risks remaining symbolic rather than transformative. The comparison between Joubert Park and Zoo Lake demonstrates that maintenance and governance are not merely technical issues, but deeply political ones. Decisions about where to invest, whose voices are heard, and which spaces are valued reveal underlying priorities that shape urban inequality. Achieving spatial justice in public space planning requires more than uniform policy application. It demands differentiated investment strategies, proactive redistribution of resources, and governance models that amplify marginalised voices and recognise everyday users as legitimate stakeholders in the production and care of urban public space.

6 CONCLUSION AND RECCOMMENDAITONS

This study has demonstrated that while SPLUMA provides a robust normative framework for advancing spatial justice, its transformative potential in public space planning is unevenly realised in practice. Through a comparative analysis of Joubert Park and Zoo Lake, the paper has shown that public space outcomes in Johannesburg are shaped not only by legislative intent, but by how planning principles are mediated through class, location, governance, and investment priorities. Inner-city public spaces may meet access objectives in spatial terms, yet continue to underperform in experiential, functional, and governance dimensions. In contrast, public spaces in affluent areas often deliver high-quality experiences, not because of deliberate redress, but due to sustained investment, institutional attention, and aligned civic influence. These findings suggest that spatial justice cannot be assessed through proximity, formal access, or uniform policy application alone. Instead, it must be understood as a lived condition shaped by safety, care, maintenance, and the legitimacy of everyday uses. The persistence of uneven maintenance, selective governance, and the problematisation of informality highlights a gap between SPLUMA's redistributive mandate and municipal practice. Without targeted investment and inclusive governance mechanisms, spatial justice risks remaining symbolic rather than materially transformative.

For urban planning practice, the implications are significant. Public space planning must move beyond technocratic compliance towards differentiated, redistributive strategies that prioritise historically marginalised areas. Inner-city and low-income public spaces should be treated as essential urban infrastructure, requiring sustained maintenance, improved amenities, and care-centred design approaches that respond to gendered and everyday mobility needs. Informal and non-commercial uses of public space should be explicitly recognised and supported, rather than managed through episodic securitisation and control. Equally important is the need to strengthen substantive participation in public space governance. Procedural consultation alone is insufficient to address entrenched inequalities. Planning practice must support co-governance models that enable everyday users, particularly marginalised groups, to shape decisions about design, maintenance, and programming. This requires not only institutional reform, but also investment in facilitation, capacity-building, and long-term place-based engagement. Finally, the study underscores the value of public spaces as tangible indicators of spatial justice. Embedding equity-focused public space audits and monitoring mechanisms within SPLUMA-aligned planning instruments would enable municipalities to assess whether policy commitments translate into lived urban equity. In this sense, public spaces function as both outcomes and measures of planning effectiveness. Advancing spatial justice in South African cities therefore requires repositioning public space at the centre of urban planning, not as a residual design concern, but as a critical site where redistribution, recognition, and participation are made visible in everyday urban life.

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reviewed paper

Rethinking Spatial Potential Analysis with New Data: Integrating Supply, Demand, and Implementation Criteria in Municipal Heat Planning

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1 ABSTRACT

The ongoing energy transition is reconfiguring socio-technical structures and places particular pressure on the heat sector, where decentralized, building-integrated systems and district heating networks must increasingly replace fossil-based infrastructures. Municipal Heat Planning has therefore emerged as a central, though nonbinding, planning instrument for translating national climate targets and legal frameworks into spatially explicit strategies at the local level, yet current practice still relies predominantly on generic, model-based potential estimations that offer limited decision support for feasibility-oriented implementation. Existing potential analyses often emphasize theoretical and technical potentials, lack a clear distinction between source and demand, and insufficiently integrate spatial feasibility criteria such as distances, environmental constraints, land availability, and property rights, which contributes to a persistent gap between potential studies and subsequent feasibility analyses. This study examines how potential-based approaches in Municipal Heat Planning can be conceptually and methodologically refined to more accurately reflect real-world implementation conditions. It combines a systematic literature review with a document analysis of existing municipal heat plans. Furthermore, semi-structured expert interviews are conducted to deepen the understanding of data-related challenges, potential analyses, and barriers in heat planning.

Building on these insights, the study develops a two-stage, potential analysis framework in which a generic, preselection using open geodata provides a transparent spatial screening of heat sources, while a second, municipality-oriented stage systematically integrates local data, ownership structures, obstacles, and project synergies to prepare feasibility studies. By structuring the potential taxonomy, screening spatial criteria, and embedding them in a reproducible geoprocessing workflow, the framework shifts Municipal Heat Planning from generic potential estimation toward a feasibility-oriented, data-driven, and context-sensitive methodology that strengthens the methodological foundations of municipal heat planning, supports evidence-based prioritization of interventions, and improves transparency and comparability across municipalities.

Keywords: Energy Transition Planning, Renewable Energy Potentials, Spatial Feasibility Assessment, Multi-Criteria Decision Analysis (MCDA), Transformation Governance

2 INTRODUCTION

Energy supply constitutes the structural backbone of modern societies, yet for a long time it has been shaped by centralized fossil and nuclear resources. This configuration is increasingly under pressure, as it is neither environmentally sustainable nor resilient in the long term. The required transition extends far beyond technological innovation; it also necessitates a fundamental rethinking of institutional routines, infrastructural path dependencies, and political steering mechanisms (PRAEGER 2025; BECKER et al. 2022). In the scholarly literature, this restructuring is conceptualized as a comprehensive transformation process unfolding within the tension between established regime structures and emerging niche solutions. Spatial dimensions play a central role in this process. The energy transition not only alters technologies but also reshapes spatial patterns of energy provision, shifting from large-scale power plants toward decentralized systems, thereby constituting a paradigmatic change in spatial organization (ENGELMANN et al. 2021).

In addition, the transformation is characterized by a mismatch across spatial scales, as federal targets impose requirements that often conflict with municipal realities marked by limited financial resources and a shortage of qualified personnel. At the same time, governance structures are changing, leading to an expansion and reconfiguration of local action spaces. This governance shift is increasingly reflected in planning processes that involve multiple stakeholders coordinating their actions toward shared objective (ROHRACHER 2022).

The heat transition is particularly critical and challenging in this context. First, the heat sector accounts for the largest share of total energy consumption in Germany, exceeding 50 % of overall demand

(BRUECKMANN and EIGENDORF 2025). Second, the transformation of highly localized, fragmented, and building-specific infrastructures toward renewable heat sources constitutes a complex and resource-intensive endeavor. Especially in urban contexts, district heating networks are considered a key infrastructure for integrating such renewable heat sources. In this process, technical challenges intersect with organizational, economic, and social tensions, rendering heat supply a systemic focal point of the broader energy transition (ENGELMANN et al. 2021; SIEBEKING et al. 2025). Following MOELDERS 2022, derived from WBGU 2011, Municipal Heat Planning (MHP) can be epistemologically assigned to Transformation Planning (ToP), incorporating elements of Transformative Planning (TvP), as illustrated in Figure 1.

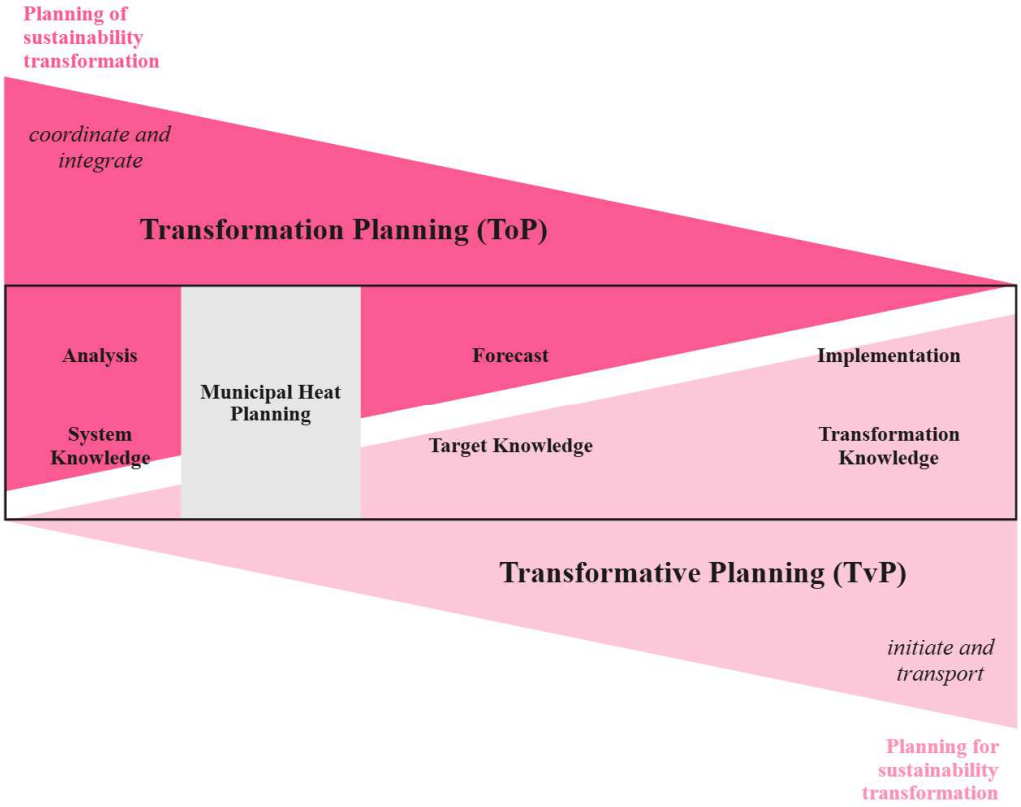


Fig. 1 MHP in transformation planning (ToP) and transformative planning (TvP) adapted according to MÖLDERS (2022)

Accordingly, it corresponds to the planning type described by MOELDERS (2022) as transformation planning. This approach is understood as a goal oriented restructuring process. It relies on analyses, scenarios, a defined transformation pathway, and an action plan. Genuinely transformative elements emerge only selectively through participation and co-production formats. However, they do not constitute the conceptual core. MHP establishes strategic guiding principles; yet, it achieves transformative effects only when supported by robust quantitative decision making foundations.

Municipalities play a central role in this context. Their proximity to local conditions and structures enables the targeted management and translation of climate objectives related to emissions reductions in the heat sector into spatially relevant infrastructure considerations. At this point, municipal heat planning, which functions as an informal planning instrument, becomes relevant. Its purpose is to systematically identify and assess suitable potentials and convert them into viable supply solutions, balancing technical feasibility, spatial suitability, and local or aesthetic acceptance. The results produced form the strategic framework for a municipality's heat transition, which, since early 2024, has been supported by two pieces of legislation: the Building Energy Act (Gebäudeenergiegesetz – GEG) and the Heat Planning Act (Wärmeplanungsgesetz – WPG) (GEG 2020; WPG 2024). The WPG, and in particular its regional implementations, establishes a legal framework with indirect legal effect, representing a hybrid planning instrument: it is not formally binding like zoning plans, but it carries indirect legal influence through the GEG (§ 71), which links new construction standards to municipal heat planning outcomes (BRUECKMANN and EIGENDORF 2025). Within this process, municipal heat planning functions as a planning interface, connecting overarching policy objectives with concrete local implementation.

One of the central components for addressing future energy challenges is potential analysis. Potential analysis refers to the process of systematically assessing the potentials for heat generation from renewable energy sources within a planned area (ORTNER et al. 2024). Currently, such analyses are conducted based on guidelines that provide only a general description of area screening, technology-specific information sources, and potential calculations. In other words, there is currently no methodologically consistent framework that ensures the quality of potential analyses. Initial findings indicate that it is increasingly effective to focus less on comprehensive, model-based quantification of all theoretical potentials and more on the assessment of heat sources that are realistically accessible and implementable (FUCHS et al. 2025; HERING et al. 2025). This paper addresses this gap and focuses on the following research questions in the field of spatial transformation and governance studies within municipal heat planning:

(1) Conceptual: How can potential-based approaches be refined and operationalized to account for source, demand, and spatial feasibility in real-world applications?

(2) Governance: How do key stakeholders perceive the tension between theoretical potential and practical feasibility, and which criteria do they consider most critical for the successful implementation of projects?

The literature reveals a predominant focus on theoretical-technical potentials, while the distinction between source and demand potentials often remains unclear. Moreover, most heat plans lack a consistent methodological integration of spatial criteria, such as vertical and horizontal distances, obstacles, suitable corridor spaces, soil and subsurface constraints, or property rights. The linkage between spatially available energy resources and heat demand areas has also been insufficiently addressed. Current analytical practices are largely shaped by individual generic models, which offer limited transparency due to non-uniform baseline parameters (AMMON and THIELE 2025) and frequently exhibit significant discrepancies between potential analyses and feasibility studies. Against this backdrop, the present study aims to develop a methodological advancement of potential analyses and their taxonomy for transformative planning, grounded in current literature and based on expert knowledge.

3 METHODS

To address the research questions, the study employs a qualitative method design, based on four core components: a literature review including document analysis of gray literature, existing municipal heat plans and potential assessments, semi-structured expert interviews, data evaluation, and the development of a Potential Analysis Framework (PAF) (BOGNER 2014; CRESWELL and CRESWELL 2022). The aim is to classify the potential concepts and spatial potential scales discussed in the literature, identify common methodological practices, and compare them with empirical insights from planning practice. The following figure illustrates the methodological workflow:

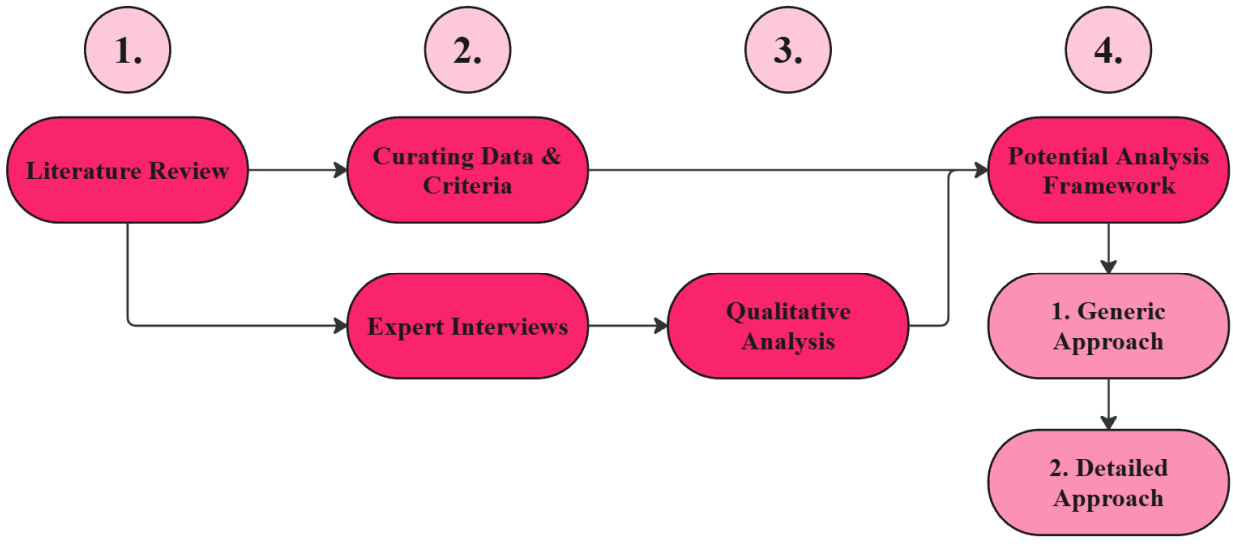


Fig. 2 Graphical representation of the methodological approach

In a first step, relevant literature was reviewed to disentangle different concepts of potential and their hierarchical organization (taxonomy), including theoretical, geographical, technical, ecological, temporal,

and spatial potentials, as well as the distinction between source and demand potentials. Based on this review, a tabular overview of potential levels was created, accompanied by a figure illustrating their spatial differentiation. In parallel, a document analysis was conducted on gray literature, municipal heat plans, and additional potential assessments to capture the method sets, model structures, and data requirements employed in practice.

Second, semi-structured expert interviews were conducted with stakeholders from municipalities, engineering firms, energy providers, and state authorities. The interview design combined a pre-structured guide, with open-ended follow-up questions to capture technical, procedural, and interpretative dimensions of knowledge (BOGNER 2014; HELFFERICH 2022). A purposive expert sampling strategy was applied, selecting the participants based on predefined competency domains derived from an independent review of professional role profiles, with demonstrated expertise in the municipal heat planning process and potential analysis (BOGNER 2014). The participants were primarily from the Bavarian region. Thematic saturation was reached following the completion of the interviews, as no additional argumentative patterns emerged. Furthermore, the pairwise comparisons indicated only minor deviations in the resulting weights. All interviews were conducted online, recorded with participants' consent, and transcribed verbatim. Qualitative data analysis was performed using MAXQDA (version 24.6.0) following the simplified procedures proposed by DRESING and PEHL (2018) and KUCKARTZ et al. (2008). To validate the category structure, a trial coding was conducted before the entire interview corpus was analyzed deductively and subsequently enriched with inductive subcategories (KUCKARTZ and RAEDICKER 2024).

In parallel, the open data landscape of Bavaria was systematically examined with regard to data findability and accessibility, in accordance with the FAIR principles (Findability, Accessibility, Interoperability, and Reuse of digital assets) (WILKINSON et al. 2016; GO FAIR 2026). The evaluation focused on the following spatial criteria: (1) spatial distribution of heat demand, (2) horizontal distance between heat sources and demand, (3) proximity to the electrical grid, (4) vertical gradient between heat sources and demand, (5) protected areas and landscape conservation, (6) land-use planning regulations, and (7) heat sources, as detailed in Table 2 (BAVARIAN ENVIRONMENT AGENCY 2026; OPEN BYDATA 2026).

The findings from the literature review, document analysis, and expert interviews form the basis for developing a two-stage geoprocessing workflow within the framework of a potential analysis. Stage 1 focuses on a robust, generic pre-selection of promising heat sources – through semi-automated GIS-based modeling – using the defined criteria 1–7. Open data structures are employed for this purpose. This first stage, referred to as the pre-selection, aims to provide a transparent, quantitative justification for excluding certain sources.

In Stage 2, the heat sources identified as promising are analyzed in greater detail and enriched with local knowledge, existing data structures, and additional spatial parameters. These include obstacles along potential routes, property rights, synergies with planned construction projects, and surface- and subsurface-related constraints. The objective is to establish a realistic and well-documented foundation for subsequent feasibility studies of district heating networks, thereby enabling a methodological refinement of the potential analysis within municipal heat planning processes.

4 LITERATURE REVIEW

"The theoretical potential of a renewable energy source is the starting point for a potential assessment, but it is not practical for decision-making and planning." This statement forms the conceptual foundation for contemporary renewable energy potential analyses (ARIAS-GAVIRIA et al. 2020, p. 308). In the literature, renewable energy potentials are commonly differentiated into theoretical, geographical, technical and economic levels. Theoretical potential describes the maximum energy flux inherent in a resource, without considering spatial, ecological or technological limitations. Geographical potential reduces this value by excluding areas that do not meet minimum biophysical requirements, for example minimum wind speeds or solar radiation thresholds. Technical potential reflects additional constraints arising from conversion efficiencies, site-specific conditions and environmental regulations, while economic potential represents the fraction of the technical potential that is cost-competitive relative to relevant alternatives (ARIAS-GAVIRIA 2020; DE VRIES et al. 2007). DE VRIES et al. (2007) highlight that potential values often appear "objective", although they strongly depend on assumptions regarding average conditions, technological

development and socioeconomic trends. Furthermore, geographical, environmental, social and economic restrictions can reduce theoretical potentials by up to two orders of magnitude, which underscores the need to rely on realistic potentials for planning processes (MORIARTY and HONNERY 2016). In thermal energy studies, this hierarchy is complemented by definitions of usable or practical potentials, which in this study are summarised as the realizable potential. This level accounts for ecological and legal constraints as well as the spatial and temporal match between the availability of thermal resources and the actual heating demand. It therefore reflects the share of the economic potential that can be integrated into real energy systems under existing regulatory conditions and demand patterns. The following table presents selected references that address these different potential levels and illustrates how the individual conceptual layers are applied across the literature.

Reference	JUNG et al. 2022	FUCHS et al. 2025	KALTSCHMITT et al. 2020	ORTNER et al. 2024	ARIAS-GAVIRIA 2020	DE VRIES et al. 2007
Application source	Single-Source	Multi-source	Macro-scale	Multi-source	Single-Source	Macro-scale
Theoretical potential	√	√	√	√	√	*
Geographical/Spatial potential	√	√		√	√	√
Environmental potential	√	√		√	√	
Technical potential	√	√	√	√	√	√
Temporal potential	√	√		√		
Legal potential		√				
Sustainable potential			√			
Economical potential			√	√		√
Realizable Potential			√	√		√
* ”has not much practical value so we leave it out here” DE VRIES et al. 2007, p. 2591						

Table 1: Different uses of potential terms in literature.

The literature review indicates that partially different terminologies are used to describe the same analytical levels. Therefore, Figure 3 should be understood as a synthesis and regenerate the taxonomy of the underlying semantics. It illustrates the pathway of potential assessment from an initial theoretical concept or potential toward practical, realizable relevance in spatial and planning contexts.

A review of German-language literature shows that it increasingly incorporates the more differentiated potential layers established in international research. The theoretical potential of a renewable energy resource defines the maximum energy that could be harnessed within a specific region during a given time period, constrained only by physical laws. Within this context, it is important to distinguish between source and demand potentials. Theoretical source potential refers to the portion of this energy that could be provided under technical-structural constraints on the source side. In contrast, demand potential represents the fraction of this energy that can realistically be utilized by end-users, considering temporal mismatches between resource availability and heating demand, as well as distribution losses (KALTSCHMITT et al. 2020). Although these aspects are sometimes implicitly addressed through generic criteria, they are not yet systematically conceptualised in studies. Moreover, no consensus has emerged in the literature regarding how potential assessments should be conducted, which hierarchical levels they should include and where the methodological boundary to feasibility studies lies. Moreover, the interactions and feedbacks between the different potential levels have so far received little attention, and a clear delineation between these levels remains difficult to establish. This lack of standardisation continues to challenge comparability across studies and highlights the need for clearer methodological frameworks in future research.

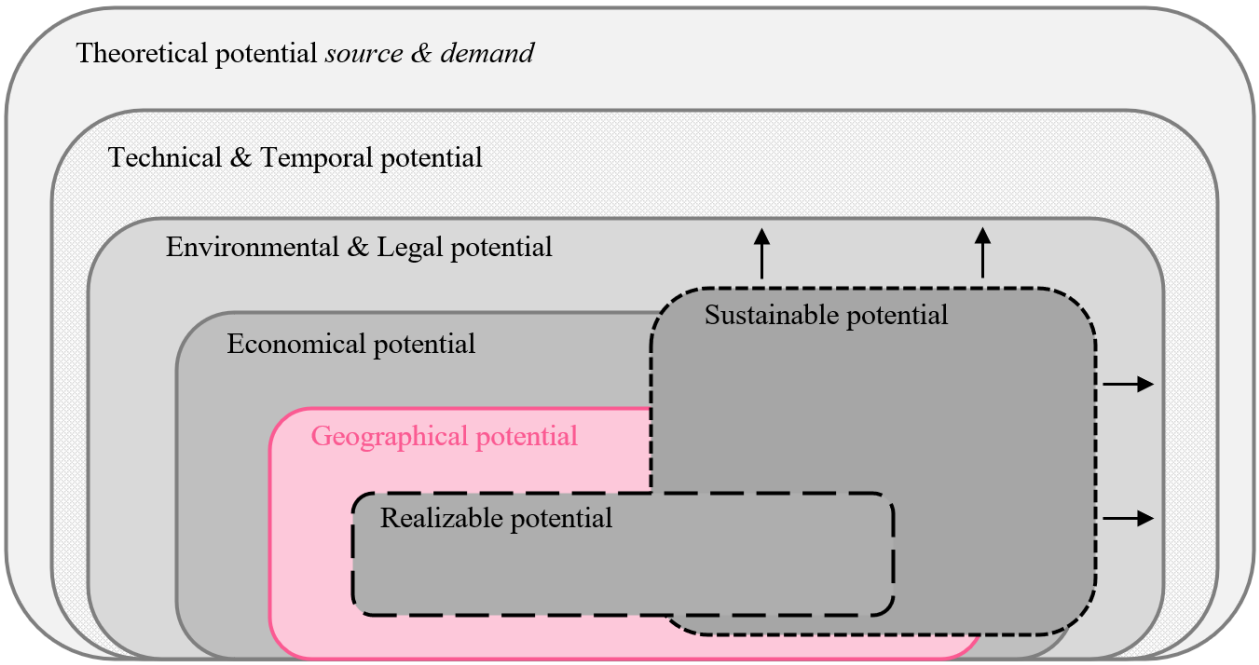


Fig. 3: Distinction between the different concepts of potential layers based on KALTSCHMITT et al. 2020.

The national heat planning guideline defines the analytical objective as "a sufficiently accurate estimation of the potentials for heat generation from compatible energy sources, as well as the potentials for energy savings through the reduction of heat demand within the designated planning area" (ORTNER et al. 2024, p. 58). In line with this objective, the available potentials are to be quantified separately by energy carrier and represented in a spatially differentiated manner, thereby providing an evidence base for subsequent scenario development and zoning. To this end, municipalities are advised to conduct an initial spatial screening that identifies areas subject to regulatory or land-use constraints (for example, nature conservation or water protection zones) and, where necessary, areas requiring explicit land reservation (for instance, for open-field solar thermal systems), in order to delineate viable options at an early stage. Building on this screening, the guideline recommends the systematic analysis of the following options: deep and shallow geothermal energy, groundwater and environmental heat, wastewater heat recovery, open-field solar thermal, biomass, locally produced hydrogen, and the utilization of unavoidable waste heat; options for central thermal energy storage; and potentials for reducing building and process heat demand through efficiency and demand-side measures (ORTNER et al. 2024).

5 RESULTS

The key findings from the literature, expert interviews, and data/criteria curation are systematically presented, analyzed and transferred to the PAF:

Renewable energy studies consistently distinguish between theoretical, geographical, technical, and economic potentials, yet these levels vary widely depending on underlying assumptions and contextual constraints. Recent literature also highlights the growing relevance of realizable potentials, which incorporate legal, ecological, and demand-related factors to better reflect real-world system integration. However, the lack of standardized definitions, limited treatment of source-demand distinctions, and minimal attention to feedbacks between potential levels continue to hinder methodological consistency across studies.

Document analysis indicates that more than half of German municipalities have now initiated municipal heat planning, and a growing share is explicitly planning to expand or newly develop district heating networks as a central pillar of future heat supply. At the same time, many plans assume significantly higher annual renovation rates than observed historically, typically around 2 % instead of the previous level of below 1 %, which underscores the key role attributed to building refurbishment in reducing heat demand that must subsequently be supplied by renewable sources identified through potential analyses. However, the comparability of existing heat plans remains limited, as there is no binding standardization and even fundamental indicators are reported in divergent ways, making it difficult to assess ambition levels and

outcomes across municipalities. This highlights the importance of systematic plausibility checks that scrutinize assumptions and results and help reveal potentially unrealistic or erroneous data (AMMON and THIELE 2025).

The qualitative findings from the interview formats confirm that Bavaria has a good geodata base for creating a municipal heating plan (RACK et al. 2025). However, there is still room for improvement in individual areas of potential data. This is particularly due to the fact that the open data strategy in Bavaria are making more and more data freely available (STMD 2025).

“The potential data sets are simply too sparse ...” [municipal utilities company]

In particular, it was pointed out that the greatest potential lies in the standardization of procedures, data formats, and criteria catalogs with threshold values.

“Variable quality due to lack of specification” [public stakeholder]

Moreover, the interviews indicate that heat planning documents increasingly report theoretical and technical potentials, which offer little practical value as decision-support for future scenarios.

“Often, only a ‘maximum load’ is reported, which effectively represents the technical potential alone.” [engineering firm]

This reinforces the perception among experts that many of the existing outputs are in fact partial potential estimations rather than full analyses in the strict methodological sense. In practice, some planners attempt to supplement openly available datasets with real-world operational data to strengthen the plausibility of the results and provide a more feasibility-oriented foundation.

“But when it comes to analyzing potential, we try to collect as much real data as possible because we place a strong emphasis on feasibility. […] For instance, in the case of biogas plants, we cannot simply rely on a generic dataset and assume that all existing installations are captured, that they will remain in long term operation, or that their technical condition is adequate, for example in terms of maintenance backlogs.” [engineering firm]

In summary, key criticisms in the interview format include insufficient data quality, high methodological heterogeneity, and a lack of spatial criteria integration. Critically, the dynamic interplay between source and demand potentials is rarely addressed, while the conceptual boundary between potential assessments and feasibility studies remains poorly defined. These ambiguities create significant challenges for aligning research outcomes with policy objectives and funding requirements, as essential data are often omitted or reported inconsistently, undermining the reliability and applicability of findings.

Based on the interview findings, a criteria catalog (see table 2) was developed that integrates insights from both the literature and expert discussions and combines them with accessible datasets.

While the initial literature-based criteria established a comprehensive framework for spatial assessment, expert consultations expanded this foundation by identifying five additional implementation-relevant criteria that depend on municipal-level data and thus cannot be systematically addressed through automated processes. These criteria include (8) property rights to required land, particularly open spaces, where feasibility is often constrained by ownership structures that lack publicly available datasets; (9) physical or administrative barriers between source and demand, such as conflicts with existing infrastructure or densely built environments that limit technical implementation; (10) synergies with ongoing construction projects, where coordination with planned initiatives (e.g., scheduled roadworks) could optimize resource use but requires access to non-public planning documents; (11) surface and substrate conditions, which differentiate between undeveloped land, sealed surfaces, or technical constraints like groundwater impacts or compatibility with heat infrastructure; and (12) social structures, encompassing socio-economic factors such as income distribution, demographic patterns, and community engagement, which significantly influence planning processes and public acceptance.

Based on the problem statements identified in the literature and in structured stakeholder dialogue formats, a two stage modeling framework was developed that explicitly accounts for the current state of data availability and the perspectives of relevant actors. The primary objective was to improve the robustness of baseline parameterization and the transparency of spatial potential assessments. The criteria catalog comprises seven core spatial criteria, which are assigned to the dimensions of heat source, demand structure,

land availability, and spatial constraints. In this way, it provides a conceptual link between the theoretical levels of potential discussed in the literature and the practical constraints and planning related boundary conditions that are relevant in applied contexts.

Nr.	Criterion	Basic Data Type	Open Data Findability – Accessability	Potential Analysis Framework – PAF
1	Spatial distribution of heat demand	Raster	**F** √ | **A** √	1. Generic Approach
2	Horizontal distance between heat source and demand	Raster/ Vector	**F** √ | **A** √	
3	Proximity to electrical grid	Vector	**F** √ | **A** x*	
4	Vertical gradient between heat source and demand	Raster	**F** √ | **A** √	
5	Protected areas and landscape conservation	Vector	**F** √ | **A** √	
6	Land-use planning regulations	Vector	**F** √ | **A** √	
7	Heat source	Vector	**F** √ | **A** √	
8	Property rights to required land – Open Spaces	Vector	**F** √ | **A** √	2. Detailed Approach
9	Barriers between source and demand	Vector	**F** √ | **A** x/√	
10	Synergies with construction projects	Vector	**F** x | **A** x	
11	Surface and substrate condition	Raster	**F** √ | **A** x/√	
12	Social Structures	Raster/ Vector	**F** √ | **A** x/√	
	*Due to data protection concerns, access to grid data is severely restricted | √ = Yes; x = No			

Table 2: Potential analysis criteria in connection with data availability.

Certain criteria were deliberately excluded from the catalog because they are either not available at a sufficient spatial resolution, not generally accessible as geospatial data, or only indirectly represented through other indicators. This is particularly true for the technical dimension. Heat pump specifications, the efficiency of deployed technologies, temporal performance dynamics, and environmentally relevant threshold values cannot be consistently captured using a generic spatial approach due to limited availability of open data and the highly location-specific nature of the required information. The criteria catalog is based on a transparent and reproducible scoring approach derived through pairwise comparison, which accounts for both data availability and the relevance of each criterion with respect to municipal heat planning.

Based on the availability of open data, a spatial potential analysis is conducted as an initial step using a generic approach in order to identify and filter the most relevant heat sources. Wherever possible, the open input datasets are ground-truthed and refined using municipal data to enhance the validity and robustness of the results.

Subsequently, a second step is carried out using a more detailed but time-consuming data collection and verification approach. In this phase, local knowledge and locally available information on promising heat sources that are not accessible through open data are systematically integrated and quantitatively assessed. Based on this enhanced data basis, targeted strategic recommendations are derived within the framework of municipal heat planning.

Figure 4 illustrates the two-stage PAF. The municipal, implementation-oriented stage is highlighted using a more saturated color, whereas the generic, spatially aggregated approach is represented with a less saturated color.

The proposed two-stage PAF directly addresses the gaps identified in current practice by providing a structured pathway from generic assessments toward more context-specific feasibility considerations. The implications, limitations, and regional transferability of this approach are examined in the subsequent section.

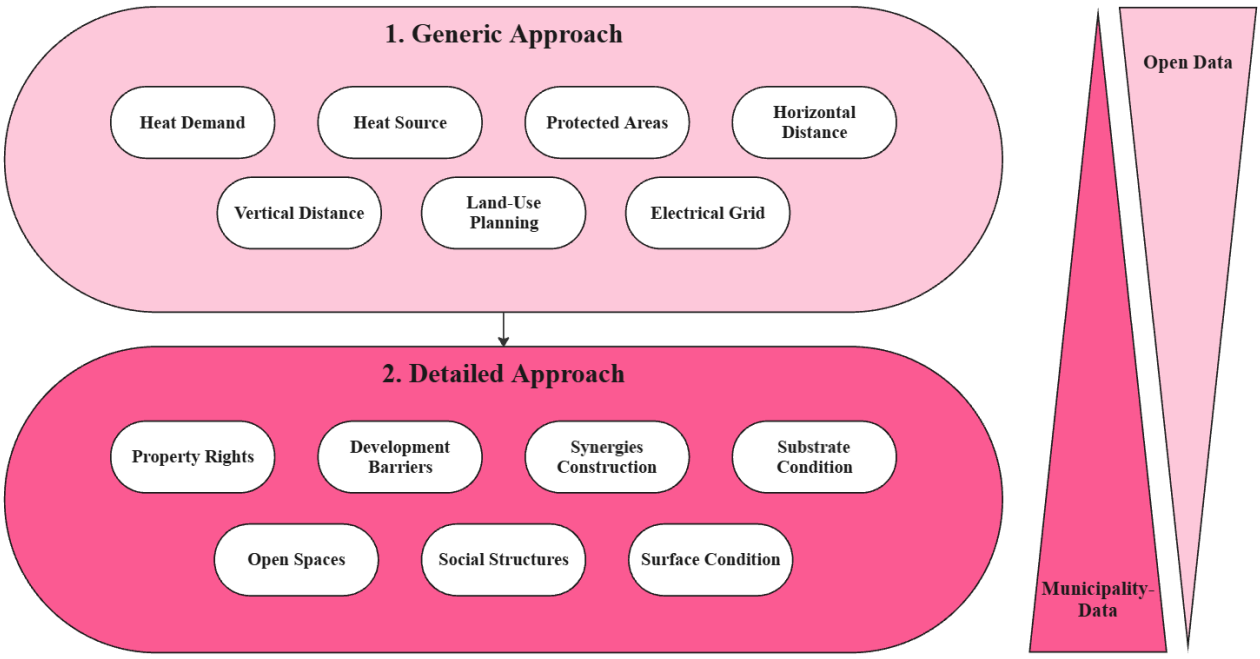


Fig. 4: Potential Analysis Framework – PAF with a focus on spatial criteria and geodata.

6 DISCUSSION

Municipal Heat Planning is a new, nonbinding planning instrument in Germany that aims to support the targeted transformation of local heat supply systems through analyses, scenarios, and transformation pathways combined with an action catalog at a strategic planning level. Certain components, such as participatory formats and the integration of target knowledge, can be clearly assigned to the field of transformative planning. However, the literature review indicates that the guidelines accompanying the legislation do not provide a structured roadmap explaining how municipalities are expected to arrive at informed decision processes for specific energy sources or potentials. Similar findings were reported by FUCHS et al. (2025), who show that the methodological toolkit for potential analysis is not systematically represented within the current legal framework. In view of the tight timeline for Germany's decarbonization targets, it is therefore essential to structure the development of low temperature heat sources in a transparent, traceable, and feasibility oriented manner. FUCHS et al. (2025) proposed an independent concept that evaluates low temperature heat sources using a simplified indicator based approach, focusing on technical potential combined with initial cost assumptions. While this approach primarily addresses technical aspects, it does not explicitly capture the feasibility oriented dimension of geographic potential. This is where the present article contributes by integrating open geodata with municipal data and local knowledge to enable a more holistic analysis. The objective is to move beyond currently applied potential estimations and to actively support transformative planning processes. The methodological framework builds on the spatial criteria proposed by JUNG et al. (2022), KAMMER (2018), LUND and PERSSON (2016), as well as NEUGEBAUER et al. (2015), who address the relationship between heat demand and heat sources through horizontal and vertical distance measures in combination with minimum heat demand thresholds for district heating systems and settlement structures. The criteria catalog was deliberately expanded to include environmental planning aspects and additional factors that are highly relevant from an implementation perspective.

The expert interviews conducted in this study substantiate the ongoing discussion surrounding MHP potential analyses and their discrepancy with subsequent feasibility studies. The experts critically assess completed heat plans, emphasizing that they often lack sufficient spatial and technical resolution. This shortcoming reveals a fundamental tension between the intended strategic steering function of MHP and the actual decision-making capacity derived from current potential analyses. As a consequence, additional feasibility studies are frequently initiated to perform final evaluations and to prioritize heat source options. However, this step should represent a core outcome of the potential analysis itself, indicating that the original objective of the analysis is not fully achieved. Moreover, the experts highlight the insufficient consideration

of interdependencies between heat sources and heat demand. In this context, a stronger cross-energy-carrier harmonization of data foundations with relevant federal guidelines and regulations would be a viable first step. While some data are available through public portals, the accessibility of municipality-specific data, particularly those essential for implementation-focused planning, remains limited. Similar findings were reported by HERING et al. (2025), AMMON and THIELE (2025).

With respect to the research questions posed, the results indicate that the previous potential analysis approach can be further optimized using the two-stage PAF. Furthermore, the use of automated geodata processes enables a targeted optimization of resource allocation and allows focus on relevant planning questions while incorporating real-world data. Initial guidelines, such as the MHP-Guideline, have already identified preliminary structures and weaknesses (ORTNER et al. 2024). However, overarching elements such as the definition of criteria thresholds or the systematic embedding within a taxonomy-based framework, remain incomplete and require further methodological refinement. Building on these findings, several avenues for subsequent methodological development can be identified. At the same time, improving the underlying data requires the harmonization of existing models and the development of standardized procedures to enhance the comparability and transferability of results. In particular, digitalization opportunities, such as the deployment of a Digital Urban Twin, offer potential to increase the efficiency of planning processes and enhance support for diverse stakeholders (LEHTOLA et al. 2022). Current research demonstrates that novel heat planning digital twin frameworks can only realize their full potential if municipalities possess a clear understanding of their data structures and maintain adequate in-house expertise (DREIER et al. 2026).

Our findings provide evidence that methodological approaches need to be further refined. This particularly involves investigating feedbacks between different potential layers and evaluating weightings through development processes in case studies. Additionally, refining numerical criteria based on existing heat and energy usage plans, as well as implemented projects, is essential to derive robust functional benchmarks. A similar need exists for cooling and electrical urban planning, enabling these domains to be more strongly integrated in a data- and criteria-driven manner in the future. Overall, the transferability of these approaches to other federal states or municipalities outside Bavaria should be carefully evaluated, particularly with respect to data availability.

7 CONCLUSION

In this study, a two-stage potential analysis framework was developed through a combination of literature review, expert interviews and geodata curation. The application of this two-stage quantitative framework transforms the previously generic approach into a feasibility-oriented methodology. By systematically using spatial criteria, the framework captures the complex interplay between heat sources and heat demand in relation to district heating networks. The integration of site and context-specific expert knowledge in the second stage provides empirically grounded decision support for municipal planning actors. This enables municipal heat planning to shift from a reactive coordinating function to a proactive initiating role in the transformation toward climate-neutral heating systems.

By combining spatially explicit data with qualitative expert insights, the framework supports a structured, transparent, and reproducible approach to identifying feasible heat sources. This addresses a key gap identified in previous studies, where potential analyses often lacked sufficient spatial resolution, requiring additional feasibility studies. By focusing on both geographical potential and contextual feasibility, the proposed framework strengthens the methodological foundation of municipal heat planning, enabling evidence-based prioritization of interventions and efficient allocation of planning resources.

8 ACKNOWLEDGEMENTS

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reviewed paper

Rethinking the Smartness of Cities: Microclimatic Performance of Public-Private Transition Spaces in Dense residential Areas of Tokyo

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1 ABSTRACT

Urbanization and climate change demand new forms of urban resilience to promote livable environments. Many cities respond with Smart-City strategies that prioritize digital efficiency and data-driven optimization. Even citizen-oriented approaches remain largely technology-mediated, overlooking the ecological potentials embedded in daily life and underestimating how directly residents contribute to environmental performance.

This research highlights Public–Private Transition Spaces (PPTS) in low-rise & high-density residential areas of Tokyo as a human-centered alternative. Situated between private homes and the public street, these small spaces emerge through everyday actions of residents, such as positioning plants, objects and various boundary elements. Together, these practices and the material elements produce spatial forms that foster ecological performance as well as social interaction.

A case study combining detailed mapping of PPTS and their components with surface-temperature measurements under humid subtropical conditions reveals measurable cooling effects. These findings show that simple practices by residents can generate tangible ecological benefits without relying on digital tools.

By demonstrating the ecological value of plants within PPTS, this research reframes everyday spatial production as a form of vernacular climate practice. The study thus expands Smart-City discourses from standardized and technology-oriented solutions toward a human-centered, bottom-up urbanism and supports planning strategies that recognize small everyday spaces as vital components of livable urban environments.

Keywords: transition spaces, microclimate, smart-city, low-tech, everyday practice

2 INTRODUCTION

The smart city is presented as a solution to urban challenges such as climate change and densification, promising more sustainable, inclusive, and resilient environments that improve quality of life. Measures such as optimizing mobility flows, improving waste management, conserving resources, and reducing energy consumption are intended to reduce the environmental impacts and make life more convenient. However, the emphasis on the “smart” use and networking of technologies has been criticized for remaining technology-centric and focusing on digital infrastructures and data-driven solutions, while ignoring the needs and agency of residents. When people are included at all, they appear mainly as users of apps or consumers of the city, without a meaningful active role in shaping urban life.



Fig.1: Examples of PPTS in T1 (own photographs)

By questioning the limitation of urban smartness to technological systems, PPTS in dense residential areas of Tokyo present a human-centered alternative. As products of everyday practices, ecological and social qualities become visible in the material composition and continual adaptation of these spaces through use and care.

In this research PPTS are defined as: "the area between the façade of the building with the front door and the property boundary to the street" (Kurz, forthcoming). As private area belonging to the building plot that is visible to the public, PPTS are vital urban links mediating between private and public realms with social and spatial meaning. Their composition includes various boundary objects such as walls or fences, daily items like household and gardening tools, bicycles or cars and above all vegetation and potted plants with ecological potentials.

In the extremely dense urban fabric of Tokyo, where the heat island effect is pronounced and green space is scarce, PPTS can act as ecological resources on the microscale. Emerging from everyday spatial practices, these spaces demonstrate how low-tech, resident-managed configurations can contribute to microclimatic regulation without relying on technological infrastructures.

Against this backdrop, this article poses the following question:

To what extend do public-private transition spaces generate ecological value in dense residential areas of Tokyo as practice-based low-tech urban smartness?

This paper highlights the ecological performance of small, often underestimated spaces resulting from everyday spatial practices. By making microclimatic contributions of daily actions visible, it presents PPTS as a form of bottom-up, low-tech urban smartness that does not depend on digital infrastructures. Situated within the broader discussion of smart cities, the paper aims to broaden current views on urban smartness by demonstrating that the capacities for resilient urban environments are already present in these informal and hybrid spaces.

3 THEORY, STATE OF THE ART

There is no universal definition of what constitutes a smart city. This opens up the possibility to rethink prevailing perspectives that focus on the "intelligent" use and networking of technologies and digital systems as a key response to contemporary urban challenges. Townsend (2014) emphasizes the potential of digital tools, but simultaneously warns against a mindless implementation of smart technologies. Instead of efficiency and control, focus should be put on people and communities as central actors in urban development.

Building on this, Radulova-Stahmer (2020) introduces "smart spaces" arguing that energy efficiency and the qualitative experience of urban environments depend not only on digital infrastructures but fundamentally on spatial organization and design. However, the considerations remain structural and top-down without thinking of human agency.

Research on the postdigital city criticizes the impact of technology on urban everyday life. The subordination of urban space and human activity to automated, system-driven processes results in a homogenization and abstraction of space, where residents are additional data sources rather than active producers of space (Alvaro-Sanchez, 2022; Lefebvre, 1991). This suggests a need to reconsider where digital technologies are necessary and where they can have a counterproductive impact on future urban development.

In their study of participatory smart city initiatives Cardullo and Kitchin (2019) find that inclusive and empowering citizen involvement remains difficult to achieve in practice. Rather than as active decision-makers with authority, citizens are often integrated as contributors within technologically predefined governance frameworks. In contrast the city of Barcelona is presented as best-practice-example for its open and participatory city model that involves citizens in decision-making processes through a digital platform (Galič, Schullenburg, 2021). While this represents a shift toward citizen-oriented governance, participation is still embedded in digital structures, limiting the consideration of human agency in everyday practice.

Regarding the continuing dependence on technological systems, Saxe (2019) draws attention to the high resource consumption required to manage the increasing complexity of smart cities. By questioning the necessity of ever more new technologies she calls for a refocus on established, low-tech principles and practices as response with challenges of today.

Urban interfaces have been identified as significant mediators of spatial transitions (Dovey and Wood, 2015), where social practices contribute to placemaking processes, personal belonging and the creation of spatial identity (Muminovic, 2014). Previous studies in Japan demonstrate that the appropriation of street

edges by residents, through the placement of objects and plants (Aoki, Yuasa, 1993), contribute to fostering social cohesion and improving the quality of the built environment (Jonas, 2007).

In contrast, research on greened balconies in (sub)tropical India demonstrates the effectiveness of potted plants in contributing to thermal regulation and improved indoor climate conditions (Ahmed and Rahman, 2024).

Current smart city research frames urban climate resilience as a mainly technological and data-driven challenge, that is largely directed from top-down, with little human agency. While micro-scale urban greening and everyday spatial practices have been studied separately, it remains underexplored how residents actively shape urban space and its ecological potential through low-tech, everyday interventions. This paper addresses this gap by examining how resident-managed, low-tech spatial practices in PPTS in dense residential areas of Tokyo contribute to local temperature regulation, thereby thinking microclimatic performance as a form of everyday urban smartness.

4 METHOD AND CASE STUDY

To assess the ecological performance of PPTS a detailed spatial mapping with focus on plants and floor surface materials was conducted in the first step. The results were subsequently combined with surface temperature measurements and analyzed using heat maps to make microscale cooling effects and thermal patterns visible.

The case study is carried out in 3-chome Taishido, a residential neighbourhood in the livable district of Setagaya in western Tokyo, and builds on a prior study by the author (Kurz, forthcoming). This earlier study presented a typology of PPTS and their distribution across the neighbourhood. Based on this analysis, areas with a high concentration of vital PPTS, characterized by frequent occurrences of plants and objects, were selected as focus areas for the in-depth investigation due to their presumed potential for ecological effects. As active PPTS mainly occur in connection with single-family houses, other residential building types were not considered.

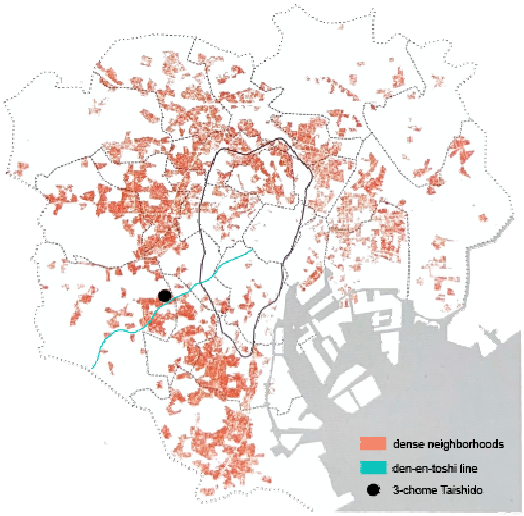


Fig. 2: Map of Tokyo + 3-chome Taishido (own illustration based on Almazan, 2021)

4.1 Spatial Mapping

The focus spot T1 comprises 18 PPTS of varying sizes and shapes, associated with houses of different ages. Only a few PPTS are empty, but the majority is actively used and show clear signs of everyday life. A comparison with older images from Google Maps during the investigation period reveals a decline of bigger trees over time, reflecting ongoing redevelopment processes in which older houses are replaced by newly built structures. Due to the high building density, trees of all sizes tend to appear individually rather than in extensive stands. Bushes and shrubs are highly prevalent, primarily as hedges. Potted plants are the most common feature, appearing in a wide range of configurations, including single pots, small and large clusters or mixed arrangements with in-ground vegetation.

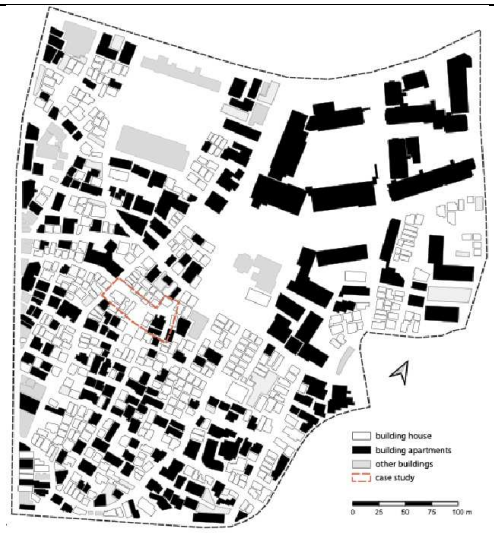


Fig. 3: Map of 3-chome Taishido with focus spot T1 for case study (own illustration)

Ground surfaces are predominantly sealed, with concrete, plaster, or tiles being the most common materials. In contrast, permeable surfaces such as gravel and unsealed ground, including grass and soil, are rare



Fig.4: Configurations of PPTS in T1 (own illustration)

4.2 Surface-Temperature

To ensure comparability, surface temperatures of different materials were measured both in the immediate vicinity of plants and in areas without vegetation using a laser infrared thermometer. The previously prepared spatial map of the PPTS was overlaid with the measured temperature points in QGIS and evaluated as a heat map using interpolation. As the focus is on the effectiveness of plants and the visualization is based on interpolated values, the interpretation of the heat map primarily considers individual measurement points with their immediate surroundings, and does not assume extensive thermal transitions.

The measurements were conducted on a hot and humid late-summer day on August 25th, 2024 between 11:20 and 12:10 with very sunny weather condition. Air temperature and relative humidity measured 27.4 °C and 80% at the beginning of the survey and increased to 37.5 °C with a relative humidity of 54% by the end of the measurement period.

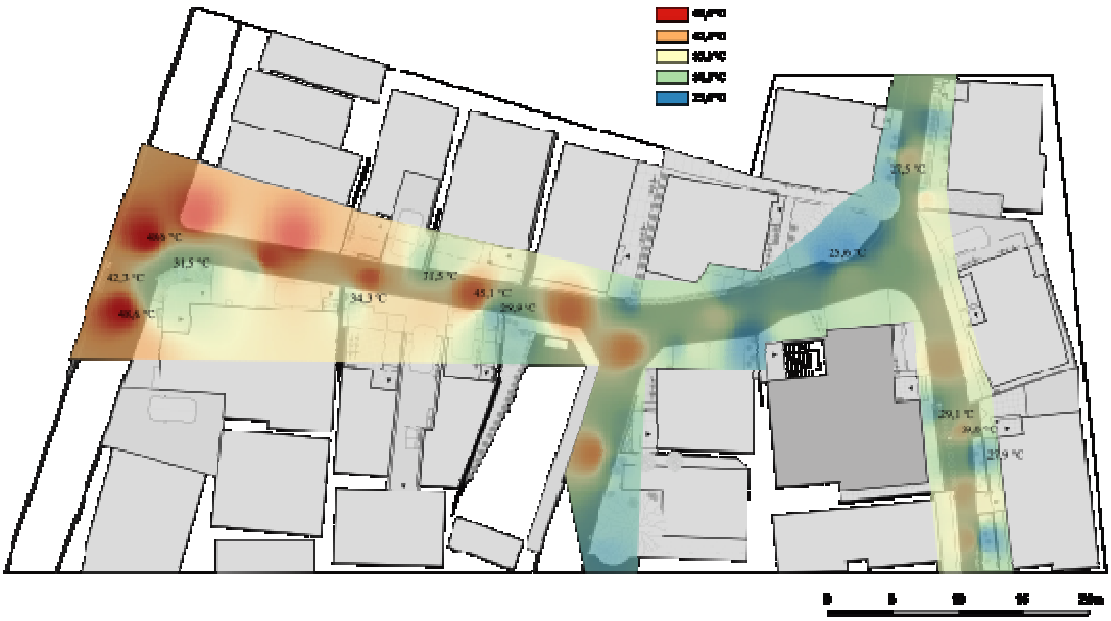


Fig.5: Configurations of PPTS in T1 with Heatmap (own illustration)

The map reveals distinct clusters of warm and cool areas. Particularly high surface temperatures occur where vegetation is entirely absent. The highest measured temperature reached 48.6 °C on the asphalt roadway, while the lowest temperature of 25.6 °C was recorded in the shade of a large tree. In areas with planted vegetation, clear temperature differences become apparent. Notably, even small clusters of potted plants exhibit distinctly cooler surface temperatures.

Although a difference is not directly evident from the map, an asphalt surface located in the shade of a potted plant measured 42.3 °C, whereas the immediately adjacent asphalt surface exposed to direct solar radiation heated up to 48.6 °C. The absence of a clearly defined cool spot on the map may be due to the extremely heated surrounding, which is still cooled by almost 4.5 degrees in the shade of the potted plants.

Surface materials also respond differently to solar exposure. Sealed surfaces show broadly similar response patterns, with asphalt and white gravel reaching the highest temperatures. Concrete, paving stones, and tiles exhibited slightly lower surface temperatures, while small areas of spontaneously growing grass were significantly cooler. Nevertheless, in combination with potted plants cooler temperatures could be recorded with any material.

In areas with a higher presence of in-ground vegetation, a spatial extension of cooler zones can be observed, even if these effects are not immediately perceptible to pedestrians. In contrast, the cooling effect underneath a large tree was clearly noticeable during the measurements due to their dense foliage. The cooling impact on the street and its immediate surroundings was measurable and is also visible in the map. The surrounding vegetation also seems also seems to further extend the cooling effect

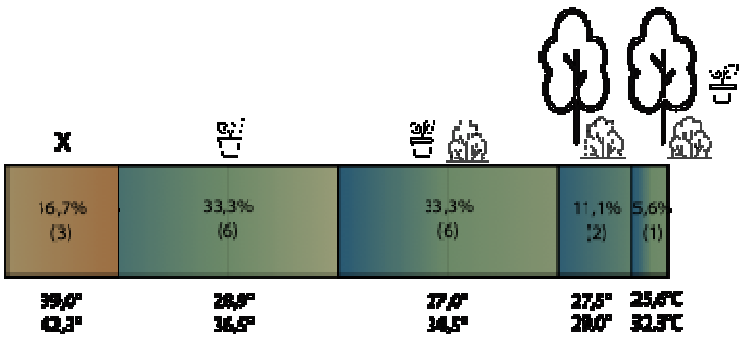


Fig.6: Combinations of plants in PPTS and temperature ranges in T1 (own illustration based on icons)[1]

[1] Icons made by DinosoftLabs and Freepick from www.flaticon.com

asphalt	48,6	42,3
concrete	39,0	34,3
asphalt	39,0	34,0
earth		29,1
weed	31,5	

Table 1: Surface-temperature table (own table based on icons)[2]

As can be seen from the heat map, the diagram (Fig. 5) also shows temperature differences between PPTS depending on the presence of plants. It is not surprising that the coolest temperatures were recorded in zones with in-ground vegetation, especially with trees. However, the coolest surfaces in the shade of potted plants did not show a large temperature difference to surfaces of in-ground vegetation.

The temperature range is very low in empty spaces and areas with in-ground vegetation, presenting a consistency of temperature. Whereas the highest temperature range occurred at PPTS with potted plants, pointing out a lower effect and consistency of temperature. In terms of the heat map, areas with lots of plants also have more consistent and cooler temperatures.

The effect of potted plants becomes also visible in the table (Table 1), presenting temperature differences on different surfaces exposed to sun radiation or shaded of potted plants.

5 CONCLUSION

By illustrating the microclimatic capabilities of public-private transitional spaces, this article positions PPTS as a human-centered alternative to technology-oriented approaches to urban resilience in the context of the smart city discourse. The results not only show measurable surface temperature reductions in areas with in-ground vegetation, but also temperature differences of up to 5–6 °C on identical materials in the presence of potted plants. This reveals that even small, resident-managed arrangements of plants contribute to localized thermal regulation in dense residential environments. PPTS are thus not merely decorative extensions of the private realm, but spaces in which human action creates tangible ecological value through maintenance, care and decision-making.

While the gained information is based on a single case study conducted on one hot summer day and the focus is primarily on surface temperature, they point to promising directions for future research. Comparative studies across different neighborhoods and measurements as well as the integration of spatial configurations could further deepen the understanding of PPTS as socio-ecological systems.

By making their microclimatic performance visible, this research recognizes PPTS as integral components of climate-responsive and livable cities and encourages a shift in perspective toward simple, existing solutions grounded in everyday care and use.

6 ACKNOWLEDGEMENTS

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reviewed paper

Rising Costs, Stagnant Incomes in Johannesburg: Understanding Affordability Mismatch in Low-Income Households

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1 ABSTRACT

Access to affordable housing remains a critical challenge in Johannesburg, where low-income households struggle to meet rising housing costs. This affordability contradiction has resulted in increased housing insecurity, overcrowding, informal settlements, and poor living conditions. While national policy emphasises affordability and inclusion, limited empirical evidence exists on how these cost burdens are experienced at the household level. This study addresses this gap by examining the lived realities of affordability strain in low-income communities in Johannesburg, focusing on the social, spatial, and financial dimensions of housing-related stress. Using empirical data drawn from household interviews and field-based observations, the study explores how residents navigate rising costs such as rent, municipal service charges, transport expenses, and informal expenditures. The qualitative data were thematically analysed to reveal patterns in coping mechanisms and household strategies. Findings indicate a growing mismatch between household incomes and the cost of maintaining basic living standards. Participants reported reliance on shared accommodation, informal backyards or temporary structures, inconsistent service payments, and unsafe or illegal service connections. While these practices support short-term survival, they expose households to heightened risks, with spatial location further shaping affordability pressures on households on the urban periphery as they face compounded burdens. Based on these findings, the paper proposes a framework to guide future research and policy interventions, offering socially responsive approaches to addressing affordability challenges and supporting more responsive housing outcomes.

Keywords: Housing Affordability, Low-Income Households , Cost Burden, Income Stagnation, Urban Inequality

2 INTRODUCTION

Rising housing costs alongside stagnant or precarious household incomes have become defining features of contemporary urban housing systems (Crook & Kemp, 2019; Haffner & Boumeester, 2021). Although affordability challenges affect a wide range of urban residents, low-income households are disproportionately exposed to housing stress, displacement risk, and residential instability (Stone, 2006; Ma & Wu, 2021). Traditional affordability assessments, commonly based on the ratio of housing costs to income, remain dominant in policy and academic discourse but have been widely critiqued for failing to capture the lived realities of affordability in diverse socio-economic and spatial contexts (Whitehead, 1991; Hulchanski, 1995). Housing affordability research is geographically uneven. The bulk of empirical and theoretical contributions originate from North America, Europe, Australia, and parts of East Asia, while African urban contexts remain underrepresented (Parnell & Robinson, 2012; Watson, 2020). This imbalance has implications for policy transferability, as affordability frameworks developed in formalised housing markets often inadequately reflect informality, income precarity, and spatial inequality prevalent in Global South cities (Gilbert, 2016). In South Africa, post-apartheid housing policy has prioritised ownership through subsidised housing delivery, with comparatively limited attention to rental housing provision (Charlton & Kihato, 2006; Turok, 2012). Demand for affordable rental accommodation has therefore been absorbed through informal and semi-formal markets, particularly backyard rentals within townships such as Soweto (Shapurjee & Charlton, 2013; Turok & Visagie, 2021). Johannesburg presents a compelling case for examining affordability mismatch due to persistent spatial segregation, high transport costs, and labour market informality (Klug, Rubin & Todes, 2013; Visagie & Turok, 2022). Housing affordability research from the Global South consistently highlights three dominant themes, which are Informality as a Structural Housing System (Gilbert, 2016), Spatial Mismatch and Transport Burdens (Dodson & Sipe, 2008; Visagie & Turok, 2022), and Governance Gaps in Regeneration and Upgrading (Arbab & Shabani, 2023; Watson, 2020). Unlike Global North contexts where financialisation and mortgage markets dominate affordability debates, Global South research foregrounds incremental rental systems, state capacity constraints, and spatial

inequality legacies. This paper contributes to this body of scholarship by situating Johannesburg within these broader structural patterns.

This paper addresses two research questions:

(1) How is global housing affordability scholarship structured thematically and geographically?

(2) How does housing affordability mismatch manifest for low-income rental households in Soweto?

3 LITERATURE REVIEW

3.1 Conceptualising Housing Affordability

Housing affordability is most commonly measured using the ratio approach, which defines housing as affordable when housing-related costs do not exceed 25–30 per cent of household income (Hulchanski, 1995; Andrews, 1998). This metric has been widely adopted in policy and comparative research due to its simplicity and ease of application. However, scholars have increasingly criticised the ratio approach for its inability to account for household size, income stability, non-housing expenditures, and spatial variations in living costs (Whitehead, 1991; Stone, 2006). As a result, households with similar rent-to-income ratios may experience very different levels of material hardship.

The residual income approach addresses these limitations by assessing whether households retain sufficient income after housing costs to meet basic living needs (Stone, 1993; Stone, 2006). This approach is considered more sensitive to the experiences of low-income households, particularly in contexts characterised by income precarity and fluctuating expenditure patterns. More recent scholarship has further expanded affordability frameworks by incorporating transport expenditure, recognising that housing location interacts with labour market access and commuting costs to shape overall affordability (Dodson & Sipe, 2008; Suzuki et al., 2013). This broader conceptualisation is particularly relevant in spatially fragmented cities such as Johannesburg.

3.2 Rental Housing and Low-Income Households

Low-income households are more likely to depend on rental accommodation due to constrained access to credit, land, and homeownership opportunities (Crook & Kemp, 2019; Ma & Wu, 2021). Rental affordability challenges have intensified globally as rents increase faster than incomes and labour markets become more insecure. In high-income contexts, academic debates have focused on rent inflation, housing financialisation, and displacement linked to urban restructuring and gentrification processes (Lees, 2012; Aalbers, 2020). In contrast, rental housing in the Global South frequently operates outside formal regulatory frameworks and is shaped by incremental construction, informal landlordism, and hybrid tenure arrangements (Gilbert, 2016). These informal rental markets play a critical role in providing access to housing for low-income urban residents but are often excluded from formal policy and statistical systems. As a result, affordability pressures within informal rental markets remain under-analysed and inadequately addressed in housing policy.

3.3 The South African Township Rental Context

In South Africa, housing policy has historically prioritised ownership through state-subsidised housing delivery, with comparatively limited institutional support for rental housing (Charlton & Kihato, 2006). As a result, township areas have experienced significant growth in backyard rental accommodation, which has become a critical housing subsystem for low-income households (Shapurjee & Charlton, 2013; Lemanski, 2017). Backyard rentals provide relatively affordable housing options and social embeddedness within established communities but are frequently associated with overcrowding, insecure tenure, and pressure on household and municipal infrastructure (Turok & Visagie, 2021). Affordability pressures in township rental markets are intensified by structural and spatial factors. Many township residents remain spatially disconnected from major employment centres, resulting in high transport costs that compound housing-related expenses (Klug et al., 2013). In addition, the widespread use of prepaid electricity and shared service connections places a disproportionate burden on low-income tenants, contributing to inconsistent service payments and informal coping strategies (Rust, 2020). These dynamics highlight the need for affordability frameworks that reflect the combined social, spatial, and financial realities of township rental housing.

3.4 Knowledge Gaps

Two key gaps emerge from the literature. First, housing affordability scholarship remains dominated by Global North perspectives, with the majority of empirical studies and theoretical frameworks developed in contexts characterised by formal housing markets, stable income structures, and well-established welfare systems (Parnell & Robinson, 2012; Watson, 2020). While these contributions have advanced understanding of affordability measurement, rental stress, and policy intervention, their applicability to cities in the Global South is limited. African urban contexts are shaped by high levels of informality, income precarity, and hybrid housing arrangements that challenge the assumptions underpinning conventional affordability frameworks. Consequently, affordability metrics and policy models derived from Global North experiences often fail to adequately capture the lived realities of low-income households in African cities.

Second, within African urban research, there is a limited empirical focus on township rental markets, despite their growing importance as a primary source of affordable housing for low-income households. Existing studies have largely prioritised housing delivery, ownership, and informal settlements, with less attention given to everyday rental experiences within townships, particularly backyard and informal rental arrangements. As a result, there is insufficient understanding of how affordability pressures are negotiated at the household level, including the role of utilities, transport costs, and informal service arrangements in shaping housing-related stress. This study contributes to addressing these gaps by providing a household-level examination of affordability strain in Johannesburg's low-income communities, foregrounding the social, spatial, and financial dimensions of housing affordability in a township context and offering empirically grounded insights to inform more context-sensitive housing policy interventions.

3.5 Towards a Context-Sensitive Conceptual Framework on Housing Affordability

While conventional housing affordability approaches have relied primarily on ratio-based and residual income measures (Stone, 2006; Hulchanski, 1995), emerging scholarship from the Global South calls for multidimensional and spatially grounded frameworks. In rapidly urbanising cities characterised by informality, peripheralisation, and income precarity, affordability must be understood as the interaction between income stability, cumulative housing-related costs, spatial accessibility, and governance systems (Parnell & Robinson, 2012; Watson, 2020).

Research from the Global South emphasises that affordability is not solely a function of rent levels, but is shaped by land-use policy, informal rental markets, service delivery structures, and spatial segregation. For example, Arbab, P. and Shabani, Z. (2023), in their study of affordable housing within urban regeneration plans in Isfahan, demonstrate that affordability outcomes are strongly influenced by planning governance, land value escalation, and the degree to which regeneration programmes actively integrate low-income groups. Their findings show that without deliberate affordability safeguards such as inclusionary mechanisms, land-use regulation, and subsidy targeting urban regeneration can inadvertently exclude vulnerable households despite policy rhetoric emphasising inclusion.

Drawing from both Global South literature and the present empirical findings, this paper proposes a Housing Affordability Mismatch Framework comprising five interrelated dimensions:

(1) Income Stability and Labour Market Position

(2) Direct Housing Costs (Rent)

(3) Indirect Housing Costs (Utilities and Services)

(4) Transport and Spatial Accessibility

(5) Governance and Planning Interventions

This framework conceptualises affordability mismatch as a structural condition produced through the interaction of economic precarity, cumulative cost burdens, and spatial inequality, mediated by planning systems and institutional responses.

4 METHODOLOGY

4.1 Study Design

This study adopts a dual-method research design that integrates a bibliometric analysis of global housing affordability literature with an empirical investigation of low-income rental households in Soweto, Johannesburg. The bibliometric component provides a structured overview of dominant themes, knowledge clusters, and geographic patterns within housing affordability scholarship, while the empirical component captures household-level affordability experiences within a South African township context. Combining these approaches enables the study to situate local affordability dynamics within broader global research trends, thereby strengthening analytical depth and contextual relevance (Moher et al., 2009).

4.2 Bibliometric Procedure

Bibliometric data were extracted from the Scopus database for the period 2000–2025, selected for its comprehensive coverage of peer-reviewed literature across housing, urban studies, planning, and related disciplines. The search was limited to English-language journal articles, review papers, conference proceedings, and book chapters. Document screening followed PRISMA guidelines, involving the removal of duplicate records and the exclusion of documents not directly related to housing affordability or urban contexts. This process resulted in a final dataset of 142 documents retained for analysis (Moher et al., 2009).The bibliographic dataset was exported in CSV format and analysed using VOSviewer. Full counting was applied to ensure equal weighting of publications, authors, and keywords across the dataset. Manual keyword harmonisation was undertaken to address spelling variations, plural–singular forms, and synonymous terms, thereby improving the reliability of thematic clustering and network visualisations.

4.3 Empirical Survey

The empirical component focused on Soweto, one of the largest township settlements within the City of Johannesburg Metropolitan Municipality, characterised by a high concentration of low-income rental households and a diversity of formal and informal rental arrangements. The study targeted low-income tenants residing in backyard rental units and formal rental accommodation, while owner-occupiers were excluded to maintain analytical consistency. Data were collected on monthly rental payments, household income, utility and municipal service charges, transport expenditure, and household coping strategies. The analysis employed descriptive techniques to assess affordability pressures, using rent-to-income ratios as a primary indicator supplemented by additional cost measures related to utilities and transport (Bogdon & Can, 1997; Gabriel et al., 2005). This approach enabled a more comprehensive assessment of affordability by capturing cumulative housing-related cost burdens rather than focusing on rent in isolation.

5 RESULTS

5.1 Bibliometric Results

This section presents the results of the bibliometric analysis, illustrating publication trends, dominant research themes, intellectual foundations, key publication outlets, and geographic patterns of collaboration and research output in global housing affordability scholarship.

5.1.1 Analysis of Publications by Year

The annual publication trend (Figure 1) shows a steady increase in housing affordability research from the early 2000s, with a marked acceleration after 2010. This growth corresponds with heightened global concern around housing affordability following the global financial crisis, rising urbanisation, and widening socio-economic inequality. The upward trend indicates increasing scholarly attention to affordability as a central urban policy challenge, although the distribution of this research remains uneven across regions.

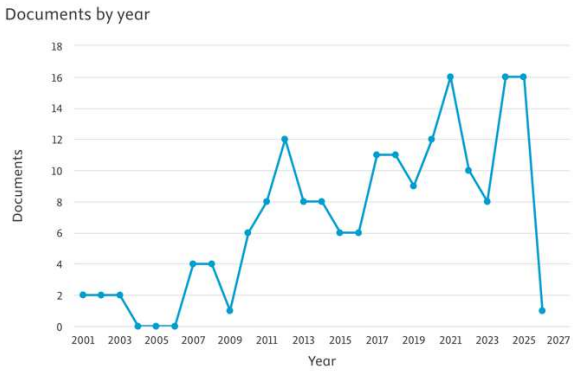


Figure 1: Graph depicting the publication trend of the research area between 2001 and 2026.

5.1.2 Conceptual Structure: Keyword Co-occurrence Analysis

Figure 2 presents the keyword co-occurrence network, revealing three dominant thematic clusters within the housing affordability literature. The first cluster centres on affordability metrics and housing policy, with high-frequency keywords such as affordable housing (80 occurrences), housing policy (38), social housing (39), and public housing (20). This cluster reflects a strong policy-oriented focus on affordability measurement, housing provision, and state-led interventions. The second cluster relates to rental housing and low-income populations, highlighted by keywords including low-income housing (30), rental sector (28), rental housing (14), rent burden (3), and poverty (19). This cluster indicates growing recognition of rental markets as a critical affordability concern, particularly for vulnerable and low-income groups.

The third cluster captures urban spatial dynamics, with keywords such as urban housing (30), urban planning (15), neighbourhood (21 combined), gentrification (6), and accessibility (3). These terms point to the spatial dimensions of affordability, including neighbourhood change, displacement, and access to urban opportunities. Notably, keywords explicitly related to informal rental systems and African urban contexts, such as informal sector, informal settlement, South Africa, and Johannesburg appear infrequently and exhibit weak link strengths. This suggests that while affordability is widely studied, informal rental markets and African cities remain marginal within the dominant global research agenda (Watson, 2020).

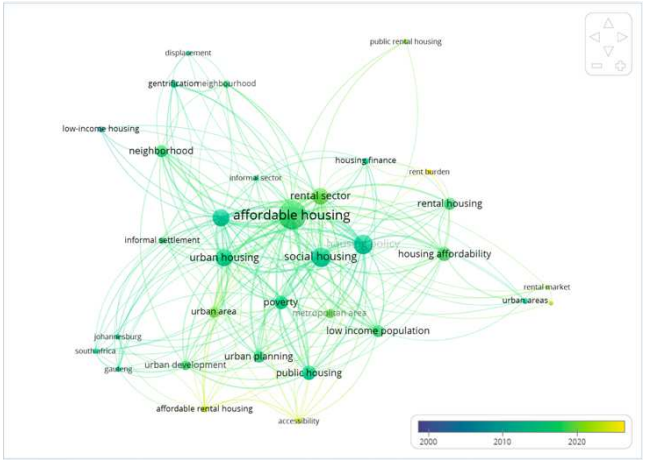


Figure 2: Visualised network map of research themes, overlay between 2000 and 2020 20 year period) to understand the trajectory of research themes.

5.1.3 Author Co-citation Analysis

The author co-citation network (Figure 3) illustrates the intellectual foundations of housing affordability research. Highly cited authors include Atkinson, Arthurson, Ball, and other scholars primarily associated with housing economics, spatial inequality, and urban restructuring. These authors are frequently co-cited, indicating a shared theoretical lineage grounded in Global North housing debates. The dominance of Global North scholars reflects the theoretical orientation of the field, which prioritises residual income approaches, market-based analyses, and gentrification-related displacement (Stone, 2006; Whitehead, 1991; Aalbers,

2020). The limited visibility of African scholars within the co-citation network further reinforces the marginal position of Global South perspectives in shaping mainstream affordability theory.

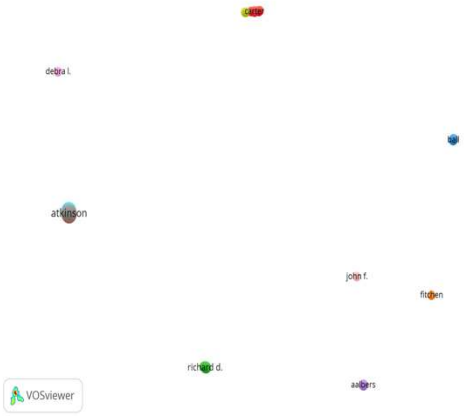


Figure 3: Visualisation of co-author network.

5.1.4 Source Bibliographic Coupling

Figure 4 presents the bibliographic coupling of journals, highlighting the primary outlets through which housing affordability research is disseminated. Core journals include Housing Studies, Urban Studies, Cities, Habitat International, and the Journal of Housing and the Built Environment. These journals exhibit high document counts and citation link strengths, indicating their central role in shaping affordability discourse. The concentration of publications within these established Western journals reflects institutional and geographic clustering of knowledge production. While a small number of regionally focused journals such as Urban Forum appear, their lower link strength suggests limited integration into the dominant global research networks (Chiodelli et al., 2022).

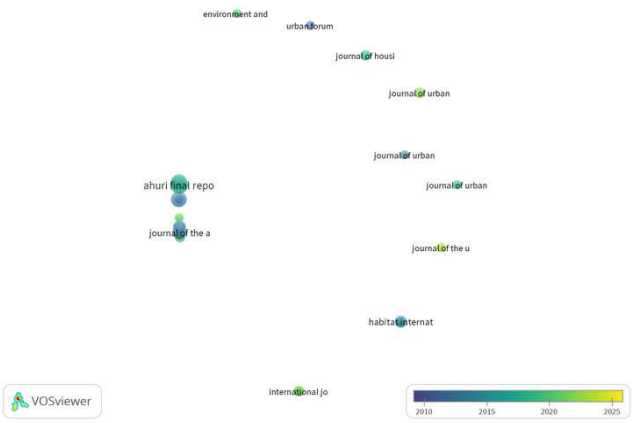


Figure 4:Visualisation of source bibliographic coupling

5.1.5 Country Co-Authorship Networks

Figure 4 illustrates international co-authorship patterns in housing affordability research. Dense collaboration networks are evident among high-income countries, particularly the United States, the United Kingdom, Australia, Canada, and parts of Europe. These countries demonstrate both high publication volumes and strong collaborative linkages. In contrast, African countries, including South Africa, appear weakly connected and largely peripheral within the global collaboration network. South Africa's relatively low document count and limited link strength indicate constrained integration into international research partnerships, reinforcing long-standing concerns about uneven global knowledge production (Parnell & Robinson, 2012).

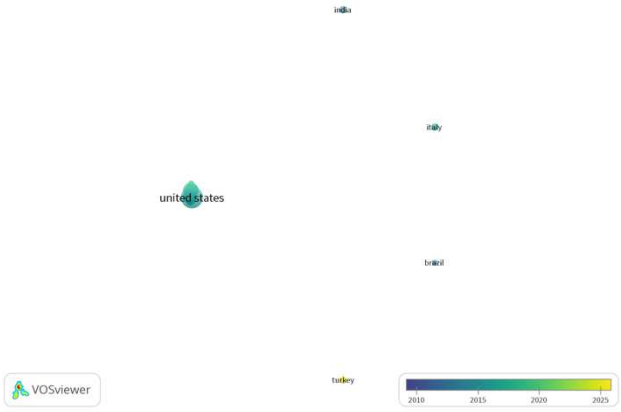


Figure 5: Visualisation of country collaboration and contribution network

5.1.6 Country Research Output

Figure 5 further confirms the geographic imbalance in housing affordability scholarship. Research output is heavily skewed towards high-income countries, with the United States accounting for the largest share of publications, followed by Australia, the United Kingdom, Canada, and China. African countries contribute a small proportion of the overall literature, despite facing acute affordability challenges. This imbalance highlights a disconnect between where affordability problems are most severe and where academic knowledge is produced. The under-representation of African urban contexts underscores the need for locally grounded, empirical studies that capture affordability dynamics beyond formal housing markets (Watson, 2020).

5.2 Survey Findings: Affordability in Soweto

The survey findings reveal significant housing affordability pressures among low-income rental households in Soweto, driven by a persistent mismatch between household incomes and cumulative housing-related costs. Monthly rental payments for backyard rental units ranged from approximately R1,000 to R2,500, while formal room or flat rentals ranged between R2,200 and R4,000. Household incomes largely fell between R3,200 and R6,500 per month, reflecting reliance on informal employment, casual labour, domestic work, and low-wage service-sector jobs. These income levels resulted in rent-to-income ratios ranging from 32 to 57 per cent, substantially exceeding the conventional affordability threshold of 30 per cent (Bogdon & Can, 1997; Gabriel et al., 2005). Affordability pressures were not limited to rent alone. Utility costs, particularly prepaid electricity and shared water connections, represented a significant additional burden, with households reporting monthly expenditures that fluctuated unpredictably. Seasonal increases in electricity usage, especially during winter months, further intensified financial strain.

Transport costs also emerged as a critical affordability driver, as many households remained spatially disconnected from employment centres, requiring daily commuting over long distances. These findings align with previous research highlighting the compounded impact of transport and service costs on affordability in township contexts (Rust, 2020; Visagie & Turok, 2022). To cope with these pressures, households adopted a range of strategies, including shared accommodation, informal borrowing from social networks, delayed or partial service payments, and expenditure trade-offs that often compromised food security and household wellbeing. Some households reported reliance on informal or unsafe service connections as a survival mechanism. Importantly, these strategies were not temporary responses to short-term shocks but reflected sustained structural affordability stress embedded within everyday household practices (Gilbert, 2016).

5.2.1 Addressing Research Question 2 in Greater Depth

The findings confirm that housing affordability mismatch in Soweto is not merely a rent burden issue but a multi-layered cost accumulation problem. While rent-to-income ratios exceeded the conventional 30% benchmark (Stone, 2006), the inclusion of transport and utility costs reveals effective housing expenditure often surpassing 45–60% of disposable income. This supports arguments by Gilbert (2016) that informal rental systems function as survival infrastructures rather than affordability solutions. Similar to findings in Isfahan by Arbab and Shabani (2023), affordability challenges are embedded within broader urban

governance structures. In Johannesburg, spatial legacies of apartheid planning and limited well-located affordable rental supply compound cost pressures, particularly transport-related expenditure (Visagie & Turok, 2022). Furthermore, the data show that coping strategies such as shared accommodation and delayed utility payments are not transitional behaviours but long-term structural adaptations. This reflects what Stone (1993) terms "shelter poverty," where housing costs crowd out essential non-housing expenditure.

6 DISCUSSION

6.1 Rethinking Affordability Beyond Conventional Metrics

The findings underscore a critical disconnect between dominant housing affordability frameworks and the lived realities of low-income households in Johannesburg. Conventional affordability metrics, particularly rent-to-income ratios, fail to capture the cumulative burden imposed by utilities, transport costs, and income instability in township environments (Stone, 2006; Dodson & Sipe, 2008). While ratio-based measures suggest unaffordability, they obscure the everyday strategies households employ to remain housed under conditions of persistent financial strain.

6.2 Backyard Rentals as a De Facto Affordability Mechanism

Backyard rentals emerge as a central, albeit informal, affordability mechanism within Soweto's housing system. These rental arrangements provide relatively lower-cost accommodation and access to established social networks, allowing households to remain within familiar neighbourhoods. However, their informal nature exposes tenants to overcrowding, tenure insecurity, and infrastructural inadequacies (Shapurjee & Charlton, 2013; Gardner, 2018). Despite their importance, backyard rentals remain marginal in formal policy frameworks and underrepresented in affordability scholarship.

6.3 Structural Nature of Affordability Stress

The persistence of affordability stress across households indicates that affordability challenges are structural rather than episodic. Stagnant incomes, labour market informality, and spatial inequality interact to constrain household choices and limit upward mobility. The reliance on informal coping strategies reflects systemic gaps in rental support and urban planning, rather than household-level failure or poor financial management.

Affordability Dimension	Key Challenge Identified	Proposed Intervention / Policy Response	Intended Outcome
Economic (Income)	Low and unstable household incomes; informal employment	Link housing strategies with local economic development, skills programmes, and employment hubs	Improved income stability and reduced rent-to-income pressure
Housing Costs	High rent relative to income in both backyard and formal rentals	Introduce targeted rental support mechanisms and guidelines for affordable rental thresholds	Reduced rental burden for low-income tenants
Service Costs	High and unpredictable utility costs due to prepaid systems and shared connections	Reform municipal tariff structures and provide service subsidies for low-income rental households	More predictable and affordable service expenditure
Spatial Location	Peripheral location leading to high transport costs	Integrate housing and transport planning; promote well-located, higher-density rental options	Reduced transport expenditure and improved access to employment
Household Coping Strategies	Reliance on informal borrowing, overcrowding, and unsafe service connections	Strengthen social protection measures and support safe incremental upgrading	Reduced household vulnerability and health risks
Policy & Governance Context	Limited recognition of backyard rentals and rental housing in policy	Formal recognition and regulation of backyard rentals with incremental upgrading support	Improved tenure security and service quality without displacement

Table 1: A Proposed Policy and Planning Framework for Addressing Housing Affordability Mismatch

7 POLICY IMPLICATIONS

The findings point to the need for a shift towards more context-sensitive and integrated affordability interventions. First, affordability assessments should move beyond rent-focused metrics to incorporate transport and utility costs as integral components of housing affordability, particularly in spatially fragmented cities such as Johannesburg. Second, backyard rentals should be formally recognised as a permanent and significant component of the urban housing system. Policy recognition could enable targeted infrastructural support, improved service provision, and incremental upgrading without displacing low-income tenants (Turok & Visagie, 2021). Third, targeted rental support mechanisms such as rental subsidies

or service-cost relief for low-income tenants should be explored to address affordability pressures directly. Finally, improved coordination between housing and transport planning could reduce commuting costs and enhance access to employment opportunities, thereby alleviating affordability stress (Pawson & Wilcox, 2013; Rust, 2020).

7.1 A Proposed Policy and Planning Framework for Addressing Housing Affordability Mismatch

Based on the empirical findings, this study proposes a framework for understanding housing affordability mismatch in township rental environments (Table 1).

This framework illustrates how affordability mismatch is produced through the interaction of income constraints, cumulative housing-related costs, and spatial inequality, mediated by informal coping strategies and policy gaps. It provides a basis for future empirical research and policy design focused on low-income rental markets in Global South cities.

8 CONCLUSION

This paper demonstrates that housing affordability mismatch in Johannesburg is driven by the interaction of stagnant incomes, rising rental and service costs, and entrenched spatial inequality. By integrating bibliometric mapping with household-level empirical evidence, the study advances a context-sensitive understanding of affordability that moves beyond conventional metrics. The findings highlight the central role of informal rental systems, particularly backyard rentals, in sustaining low-income households, while also exposing the vulnerabilities associated with policy neglect. Addressing housing affordability in Johannesburg and similar Global South cities requires inclusive, locally grounded interventions that recognise lived realities and integrate housing, transport, and service provision within a coherent policy framework (Parnell & Robinson, 2012; Watson, 2020).

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Roll Out of Sustainable Solar Energy in Spatial Planning: A Focal Lens of Maseru, Lesotho

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1 ABSTRACT

The global energy crisis disproportionately affects Sub-Saharan Africa, with Maseru, Lesotho, facing rising urban energy demand, unregulated spatial growth, socio-economic inequalities, and reliance on imported electricity. Despite high solar potential, solar energy remains underutilized and poorly integrated into urban planning. This study employs a PRISMA-guided systematic review and VOSviewer bibliometric analysis to identify research trends, policy gaps, and best practices in solar energy and spatial planning. Findings highlight the potential of decentralized solutions, including rooftop solar and solar-powered public infrastructure, to enhance local energy resilience. The study offers evidence-based recommendations to inform policy frameworks aligned with SDG 7 and SDG 11, promoting renewable energy adoption and advancing a just and sustainable urban energy transition in Maseru.

Keywords: Climate change, State Owned Enterprises, Just Energy Transition, Fossil fuel Dependence, Public engagement

2 INTRODUCTION

Global energy demand is projected to increase by 56% by 2040, largely driven by industrial growth in developing regions (Muhammad et al., 2016; Kayima et al., 2023). Rapid population growth and urbanization in Sub-Saharan Africa are outpacing energy infrastructure development, leaving 568 million people without electricity (IEA, 2020). Urban areas contribute nearly 80% of global CO_2 emissions (IEA et al., 2022), and reliance on unsafe energy sources such as biomass disproportionately affects women and marginalized communities.

Maseru, the capital of Lesotho, illustrates these challenges. Only 57% of households are connected to the national grid, with national electrification at 33.7% (Energy Catalyst, 2020; Mpholo et al., 2021). High electricity tariffs encourage reliance on kerosene and biomass, increasing health risks and environmental degradation (WHO, 2016). The city shown below on diagram 2,depends heavily on imported electricity from South Africa and Mozambique, exposing it to supply vulnerabilities (Mpako & Ndoma, 2024).

Although renewable energy policies exist, implementation remains limited due to financial, institutional, and infrastructural constraints.Solar energy offers a strategic solution to Maseru's energy insecurity. However, adoption is hindered by fragmented urban planning, inadequate policy alignment, and limited technical capacity. This study investigates the potential of integrating solar energy into spatial planning to advance energy security, sustainability, and equity. By focusing on Maseru, the study contributes to achieving SDG 7 and SDG 11 through a just energy transition.

3 CONCEPTUALIZATION

3.1 Urban Energy Challenges

Spatial planning organizes land use to balance competing interests, promote sustainable development, protect the environment, and involve local communities (Nowak, 2022). Key elements include land use management, infrastructure development, environmental protection, public participation, and spatial justice. Historically, energy planning has emphasized techno-economic efficiency (Osorio-Aravena, 2020), but integrating spatial planning can enhance energy efficiency and fairness by mediating site development, mitigating inequalities, and aligning energy infrastructure with urban growth (Kooij, 2025; Marsden et al., 2025).

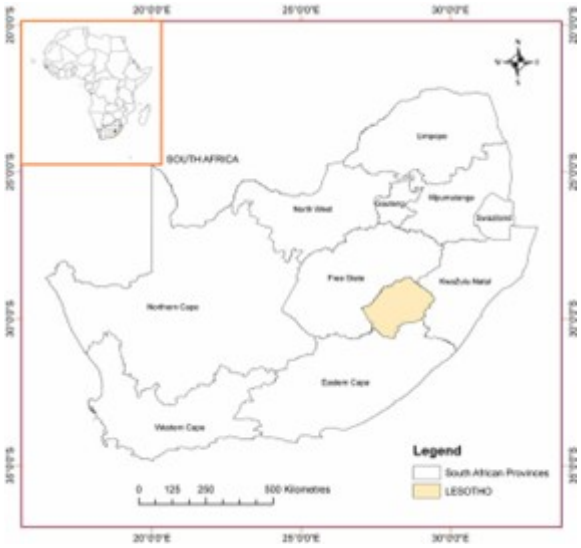


Diagram 1. Location Map of Lesotho (Source: Mukwanda 2020)

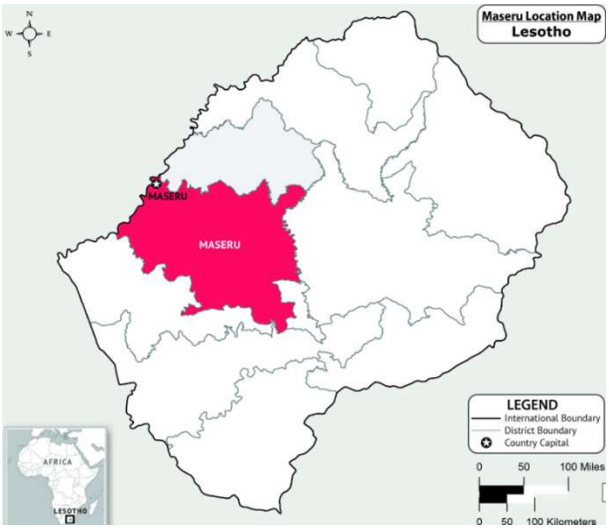


Diagram 2. Location Map of Maseru

3.1.1 Energy as a Planning Concern

Energy production, distribution, and consumption are shaped by urban form, land use, and infrastructure. Recognizing energy as a spatial governance challenge allows for strategic urban design that supports renewable energy deployment, energy-efficient buildings, and resilient public infrastructure (Rydin & Turcu, 2019).

3.2 Energy Demand and Supply

Global energy consumption has increased nearly twentyfold since 1850, driven by economic activity, urbanization, and technology adoption (Al-Yasiri, 2021). Developing countries face challenges in forecasting demand due to grid limitations and diverse consumption patterns (Arnob et al., 2023). In Maseru, supply fails to meet growing demand, leaving informal and peri-urban areas underserved. Aging infrastructure, low investment, and weak governance exacerbate access disparities (Moturi et al., 2024).

3.2.1 Just Energy Transition (JET)

A Just Energy Transition involves a fair, inclusive shift from carbon-intensive to low-carbon energy, emphasizing social equity, job protection, and community welfare alongside environmental goals (Yang et al., 2024). Global reliance on fossil fuels has driven climate change, compelling nations to adopt renewable energy under frameworks such as SDG 7. By 2030, SDG 7.1 targets universal access to reliable energy, while SDG 7.2 promotes the global share of renewables. Yet, nearly 3 billion people still depend on fossil fuels for cooking and heating (Patrick et al., 2025).

3.2.2 Theoretical Underpinnings

Dependency Theory

Prebisch and Singer's framework explains how historical and structural inequalities limit local autonomy in energy development (Romaniuk, 2017). Lesotho exemplifies this dependence through reliance on imported electricity and donor-driven renewable projects, often prioritizing external interests over local needs. Addressing this requires investment in local capacity, policy reform, and domestically driven solar projects.

Smart City Theory

Smart City Theory frames cities as data-driven systems integrating ICT, human capital, and governance for sustainability (Liu & Wu, 2023). Smart energy systems – smart grids, IoT, and AI – can optimize solar adoption, enhance energy reliability, and reduce emissions (Gracius et al., 2023). For Maseru, smart city strategies offer a pathway to affordable, carbon-neutral solar energy deployment.

4 METHODOLOGY

This study employs a mixed-method research design combining a systematic literature review with bibliometric analysis. A PRISMA-guided systematic literature review was conducted using the Scopus database to ensure transparency, replicability, and academic rigour. Peer-reviewed literature published between 2015 and 2026 was screened based on relevance to spatial planning, solar energy, energy demand, and sustainability transitions. The diagram depicts how PRISMA protocol was followed in the study.

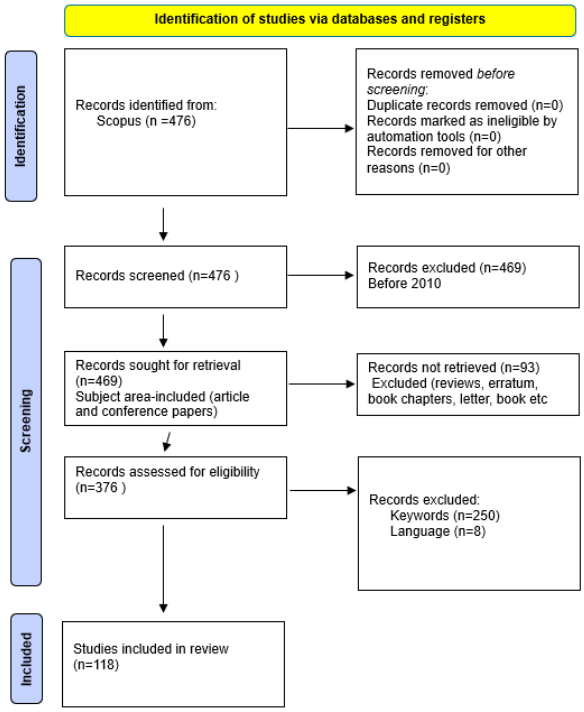


Diagram 3. PRISMA flow diagram (Source: Author: 2025)

Complementing the review, a bibliometric analysis using VOSviewer mapped keyword co-occurrences, thematic clusters, and geographic research trends. This approach enabled the identification of dominant research themes, policy gaps, and the relative absence of African urban case studies particularly from smaller cities such as Maseru within the global renewable energy planning discourse.

5 RESULTS AND DISCUSSION

5.1 Global and Regional Research Trends

The bibliometric analysis identified 761 publications related to renewable energy planning and energy transitions, with 394 English-language sources meeting the inclusion criteria. Research output is heavily concentrated in Europe, Asia, and North America, with comparatively limited representation from African

cities. Thematic clusters reveal a shift from narrowly focused technical energy modelling toward more integrated approaches encompassing governance, spatial planning, infrastructure, and social justice.

Key clusters include carbon emissions and energy infrastructure, smart cities and digital innovation, clean energy transitions in developing countries, micro-grids and disaster resilience, and solar energy deployment in urban areas. These trends reflect growing recognition that renewable energy transitions are not solely technological processes but deeply embedded within planning, governance, and socio-spatial systems.

5.2 Energy Insecurity and Planning Constraints in Maseru

Findings indicate that Maseru's energy insecurity is shaped by a combination of ageing infrastructure, limited generation capacity, high electricity tariffs, and continued reliance on coal-powered imports. Weak spatial planning practices characterised by unregulated settlement growth, infrastructure backlogs, and fragmented sectoral policies further constrain the integration of renewable energy.



Picture 1. An Informal Settlement in Maseru

Despite high solar irradiation and substantial rooftop photovoltaic potential across residential, commercial, and public buildings, the absence of mandatory planning guidelines for example-in the picture 1 shown above, financial incentives, and technical standards limits systematic adoption. Additional barriers include limited technical expertise, low public awareness of solar benefits, weak governance structures, and insufficient private-sector investment.



Picture 2. Old Electrical poles destroyed by extreme weather

5.3 Decentralised Solar Systems and Urban Resilience

Decentralised solar systems emerge as a critical pathway for addressing energy access and equity gaps, particularly in peri-urban and informal settlements where grid connectivity remains limited. Rooftop solar installations and solar-powered public infrastructure such as street lighting, clinics, schools, and transport interchanges offer opportunities to improve service delivery, enhance safety, and reduce pressure on the national grid.

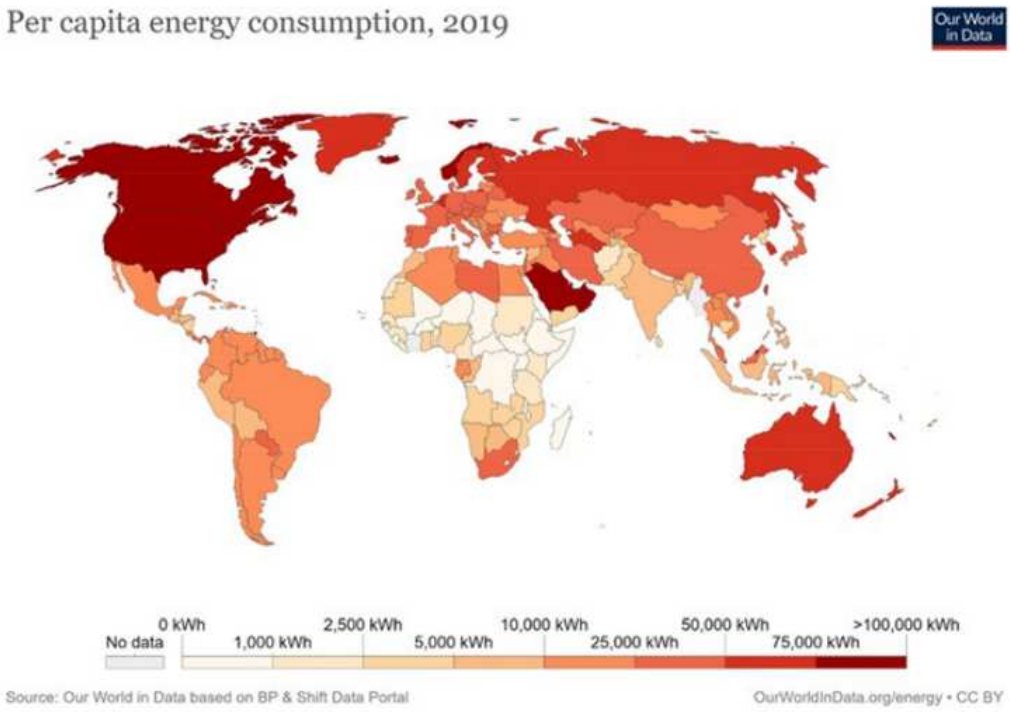


Figure 1: Global Distribuion of solar energy (Our World in Data, 2020)

International experience demonstrates that cities which align spatial planning instruments with renewable energy policies through zoning regulations, building codes, and incentive frameworks achieve faster and more inclusive solar adoption. In Maseru, adopting similar approaches could significantly strengthen urban energy resilience while supporting broader sustainability objectives.

6 TOWARD SOLAR-INTEGRATED SPATIAL PLANNING

Based on the findings, the study proposes a planning-led framework for integrating solar energy into Maseru's urban development processes. Key pathways include:

- Updating building regulations to mandate solar-ready design in new developments;
- Designating renewable energy zones and micro-grid innovation hubs within urban and peri-urban areas;
- Introducing targeted financial incentives, including subsidies and feed-in tariffs, to encourage household and commercial solar adoption;
- Strengthening public-private-community partnerships aligned with SE4ALL, UNDP, and World Bank frameworks;
- Piloting solar-powered public infrastructure as demonstration projects to build institutional and public confidence.

7 CONCLUSION

This study demonstrates that Maseru possesses substantial untapped potential for integrating sustainable solar energy into its spatial planning frameworks. While technical feasibility is high, institutional fragmentation, weak policy alignment, and limited planning-led incentives continue to constrain progress.

Addressing these challenges requires a deliberate shift toward integrated urban energy planning that prioritises decentralised solar solutions, social equity, and environmental sustainability.

By embedding renewable energy within spatial governance processes, Maseru can reduce dependence on imported fossil-fuel-based electricity, enhance urban resilience, and advance a just energy transition aligned with global development goals. The findings contribute to the limited body of Global South urban energy planning literature and offer transferable lessons for similarly positioned cities across Sub-Saharan Africa.

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Smart Health Measurements on Urban Air for Smart Cities and Regions Matter

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1 ABSTRACT

In this article, we aim to present some of the possibilities for monitoring and quantifying the diverse influences of urban air (i.e. aerosoles, gases, and odors) in both indoor and outdoor spaces. These effects on citizens can also be monitored using unobtrusive methods. Based on literature, regulatory information and experiments, we present a somewhat fluid boundary between technologies that are already available on the market today, technologies that exist in principle in the scientific community but have not yet been incorporated into medically approved devices, and technologies that are expected to function within the next few years. We also do not claim to be exhaustive but rather aim to provide a selection of ways in which people's sense of well-being in relation to air quality in cities can be monitored, thus offering insights into potential manipulation.

Keywords: Smart City, Health Management, Urban Air, Measurement Technology, Sensor Networks

2 THE COMPONENTS OF URBAN AIR

Urban air is not a single “entitity”; vice versa, it is a dynamic complex mixture of suspended particles, liquid droplets, reactive and inert gases, and an immense variety of volatile organic compounds (VOCs). If one wants to monitor health-relevant external influences in cities – continuously, unobtrusively, and at scale – then particulate matter, aerosols, and gases are not optional topics but the measurement backbone. The technical challenge is not primarily that these quantities are unmeasurable. Rather it is that they vary rapidly in space and time, are driven by multiple intertwined sources, and require interpretation that is both physically sound and operationally useful for city management and indoor environments.

Particulate matter (PM) is commonly defined by its aerodynamic diameter and reported as PM10 and PM2.5 (and increasingly PM1). In cities, PM arises from combustion (traffic, heating), mechanical abrasion (tires, brakes, road wear), resuspension of deposited dust, construction activity, and secondary particle formation from gaseous precursors. The health relevance follows from deposition in the respiratory tract: PM2.5 can penetrate deeply into the alveolar region, and ultrafine particles (<0.1 µm) can, under certain conditions, cross biological barriers. For practical monitoring, it matters most that concentrations can change within seconds: for example, a cyclist leaving a congested arterial road for a side street may experience a pronounced step change in exposure, i.e., the “micro-geography” of exposure that regulatory stations, by design, can only approximate.

The European Union (EU) already provides a strong regulatory and analytical framework for PM. The EU Ambient Air Quality Directive sets binding limit values and introduces population-exposure concepts for PM2.5, explicitly shifting the discussion from point compliance to population-level exposure indicators (European Commission, 2008; EEA, 2008). The European Environment Agency (EEA) routinely assesses PM2.5 and other pollutants against both current EU limits and even stricter WHO guideline levels. In this context, the EEA’s recent “Air quality status” analyses underline that PM remains Europe’s largest environmental health risk despite long-term improvements (EEA, 2025a; EEA, 2025b). At the German level, the Umweltbundesamt (UBA) provides population-health indicators (e.g., DALYs attributable to PM2.5) and emission and exposure trend analyses that are directly usable for urban policy evaluation and for prioritizing interventions (UBA, 2023a; UBA, 2023b; UBA, 2023c).

Aerosols, in the strict physical sense, are suspensions of solid or liquid particles in a gas. The term becomes particularly consequential when we move from “ambient PM” to bioaerosols and respiratory aerosols. Human exhalation produces liquid droplets and droplet nuclei over a broad size spectrum, and these droplets can transport pathogens. The decisive point for monitoring is not a generic statement that “aerosols exist,” but that aerosol concentration, size distribution, and persistence depend on ventilation, humidity, room geometry, and human behavior. This is where small popularizations are not a stylistic luxury but an

explanatory necessity: anyone who has entered a poorly ventilated meeting room and immediately noticed "stale air" has experienced the macroscopic correlate of microphysical processes – accumulating exhaled CO_2 and co-emitted respiratory aerosols. The scientific literature on indoor airborne transmission and mitigation strategies supports the view that minimizing indoor risk is primarily a question of ventilation, filtration, and time-dependent occupancy patterns (Morawska et al., 2020).

Gases complete the picture and, in practice, often provide the most actionable signals. CO_2 is not toxic at typical indoor concentrations, but it is an excellent surrogate for ventilation quality, occupancy, and the dilution capacity of a room. Elevated CO_2 levels are usually the earliest quantitative sign that an indoor environment is drifting into a regime where exhaled aerosol accumulation becomes plausible. CO, in contrast, is directly toxic even at low concentrations and indicates incomplete combustion. NO_2 and O_3 are key oxidants, with pronounced diurnal cycles and strong coupling to traffic and photochemistry. VOCs are a heterogeneous class that ranges from innocuous metabolic emissions to compounds of toxicological concern; importantly, VOC mixtures are central to what humans perceive as odors.

2.1 Measurement technology and validation: From reference methods to scalable sensor networks

A technically defensible monitoring concept must separate three layers: (i) reference measurement for comparability and legal robustness, (ii) dense indicative sensing for spatial/temporal resolution, and (iii) data fusion and interpretation for decision support.

For particulate matter, the reference anchor in Europe is gravimetric sampling with standardized inlet characteristics and filter weighing. EN 12341:2014 specifies the standard gravimetric method for PM10 and PM2.5 mass concentrations (CEN, 2014). Whilst these methods are slow (typically 24-hour sampling), they provide traceability. In contrast, most compact low-cost PM sensors rely on optical scattering. They infer particle number and size proxies from scattered light and convert these signals into mass concentrations using assumptions about particle density and refractive index. This is not "wrong" and a different measurement model with known limitations. It is well suited to mapping variability and detecting events when properly calibrated, quality-controlled, and interpreted with humility about absolute accuracy.

Aerosol measurement overlaps technically with PM sensing but often shifts the objective: relevant metrics include number concentration, size-resolved dynamics, and – particularly for infection-relevant contexts – the ability to distinguish liquid respiratory aerosols from predominantly solid ambient particles. The ProxiCube® NX3 provides a representative example of an applied research-to-product trajectory in this domain. The device integrates two optical particle counters within a single housing. One particle counter measures the total particle population, while the second samples air that is guided through a heating element. This heating step evaporates liquid aerosols, so that only solid particles remain. By evaluating the differential signal between both particle counters, liquid and solid particle fractions can be distinguished within one device. This concept addresses a central ambiguity in indoor monitoring: elevated particle counts may arise from harmless dust resuspension or from human-generated liquid aerosols that are relevant for infection risk. While uncertainty is not eliminated, interpretability is significantly improved compared to a single undifferentiated particle metric (Westphal, 2021; Westphal et al., 2022).

For gases, sensor choice depends on the target compound and the required confidence level. Nondispersive infrared (NDIR) sensors provide robust CO_2 measurements and are a practical baseline for occupancy/ventilation inference. Electrochemical sensors cover CO, NO_2, and O_3 with good sensitivity but require attention to cross-sensitivities and sensor aging. Metal-oxide semiconductor (MOS) sensors provide broad VOC responsiveness (often reported as TVOC) but are, by nature, non-specific and strongly influenced by humidity and temperature. The key engineering point is that multi-sensor fusion – CO_2 plus particles plus TVOC plus humidity/temperature/pressure – often outperform any single "hero sensor", because it constrains interpretation.

Indoor "problem detection" is a specific, high-value use case. Mold, for instance, is rarely detected directly by a single gas sensor. Instead, risk emerges as a pattern: persistently high relative humidity, poor ventilation (CO_2), temperature profiles that enable condensation, and the appearance of characteristic odor signatures or elevated microbial VOCs. German guidance documents on mold prevention, investigation, and evaluation highlight the necessity of combining building physics, hygiene, and measurement – an approach aligned with smart monitoring as an early-warning system rather than a single-parameter alarm (UBA, 2017). A similar

logic applies to spoiled food or decomposition: what is measured are VOC patterns and secondary indicators; confirmation then requires targeted inspection or sampling.

Any sensor network worth deploying in a city or region must address comparability and quality assurance. Practical approaches include co-location with reference stations for calibration transfer, drift monitoring, plausibility checks (e.g., CO_2 should correlate with occupancy), and transparent uncertainty reporting. The air-pollution monitoring community has long emphasized the paradigm shift (Snyder et al., 2013) from sparse, highly accurate stations to hybrid systems that combine reference methods with dense indicative sensing (Morawska et al., 2020).

2.1.1 Cutaneous and Transcutaneous Measurements

A currently developing air related area of concern is transcutaneous skin measurement. Here, sensors monitor the skin's surface without penetrating it (without pricking). This allows for the detection of oxygen deprivation or subsequent, incipient damage caused by oxygen deprivation, particularly in endurance sports. Diseases such as kidney failure or impairment, as well as liver malfunction, can also be monitored using transcutaneous sensors. In our increasingly aging population, age-related illnesses and the effects of improper behavior on bodily functions are becoming ever more significant.

A promising approach for the precise recording and successive optimization of the health status of an urban population lies in the implementation of large-scale, public monitoring stations based on cutaneous and transcutaneous diagnostics. The term "cutaneous" (derived from the Latin "cutis" for skin) refers to methods that directly examine the condition of the epidermis. In contrast, transcutaneous measurement methods refer to those non-invasive procedures in which physiological parameters are detected within or below the skin layers without violating the anatomical integrity of the tissue through penetration. Detrimental cutaneous effects of air quality are reflected, for example, in deteriorating values as to inflammation, oxidative stress, skin barriers, or microvascular changes. Detrimental transcutaneous effects , i.e. via lungs or blood circulation, triggered by air polution are reflected by worsening oxygen or carbon dioxide related values. Various transcutaneous technologies are already used in current clinical practice and everyday life:

Infrared thermometry: The non-contact measurement of thermal radiation to determine core body temperature.

Pulse oximetry: The optical determination of arterial oxygen saturation (μ) using light absorption in a photometric method (often implemented as a “finger clip”).

In modern medical technology, there is a significant drive to replace conventional, invasive blood analyses with innovative transcutaneous measurement methods. While the laboratory analysis of blood samples is methodologically standardized and relatively easy to validate scientifically, every invasive sampling procedure – due to the risk of infection and tissue trauma – represents a burden for the subject. Transcutaneous methods, on the other hand, are characterized by a minimal risk profile. This lack of risk makes them ideal for use in public spaces to generate large-scale datasets. By correlating and algorithmically calculating this biometric data with other environmental factors, a valid picture of urban health can be generated.

2.1.2 The role of Raman spectroscopy – an experiment

Raman spectroscopy, an analytical technique used to identify and possibly quantify air pollutants, is a technologically highly potent method that has not yet been sufficiently used for public screening. This method, the fundamentals of which were already discussed in the relevant specialist literature for transcutaneous diagnostics at the beginning of the 21st century (around 2001), is based on the inelastic scattering of light on molecules.

While Raman spectroscopy in combination with light microscopy is already a gold standard in modern laboratory analysis, its transfer to the public sphere has so far proved complex. The primary challenge lies in the use of laser radiation as an excitation source. However, the associated safety concerns regarding eye protection and skin exposure have been largely resolved through advanced technical protective measures and the development of lower-class laser systems (with the same sensitivity). Raman spectroscopy is thus on the verge of being used as a precise, non-invasive tool for real-time biochemical analysis in urban areas.

Raman is a method for obtaining chemical information. This allows molecule-specific information to be obtained. Three very promising analytes are urea, lactate, and bicarbonate. These have specific peaks in the Raman spectrum and are present in the skin and blood. To evaluate the validity of transcutaneous Raman spectroscopy under controlled conditions, measurements were performed on skin phantoms in experimental series. The aim of these investigations was to simulate the determination of urea concentrations depending on different dermatological tissue properties.

The construction of these phantoms was based on a complex matrix of water and gelatin, which was supplemented by a specific scattering medium in order to realistically replicate the optical properties of human dermis (light scattering and absorption). Within the various phantoms, both the concentration of the analyte (urea) and the melanin content were systematically varied. The variation in melanin content is of crucial importance here in order to ensure the transferability of the method to different skin types (phenotypes), as pigmentation has a significant influence on the optical penetration depth and the signal-to-noise ratio.

2.1.3 Production of the phantoms

First, the solid ingredients are weighed on an analytical balance and mixed. After everything has been ground in a mortar until no titanium oxide lumps are visible, the mixture is transferred to a 50 ml beaker. The water is weighed into a 100 ml beaker and heated to approximately 60°C on a hot plate. Once the water has reached the desired temperature, add the solid ingredients while stirring with a flat spatula. Continue stirring until there are no more gelatin crumbs visible and the mixture has a homogeneous consistency. It had to be made sure that the mixture does not burn. The mixture is then poured into a silicone mold and sonicated in an ultrasonic bath for 10 minutes. After sonication, the mold can be removed from the ultrasonic bath. The molds are covered with aluminum foil to allow them to harden completely and stored in the refrigerator until measurement. The measuring head shown in figure 1 is designed as a compact optical setup for Raman spectroscopy with an excitation wavelength of 785 nm and integrates beam guidance, sample excitation, and detection in a coaxial geometry. The monoch 1 romatic excitation laser is first collimated and coupled into the optical path via a suitable beam shaping element. The laser radiation then hits a dichroic beam splitter, which is highly reflective for the excitation wavelength, while exhibiting high transmission for longer wavelengths. This deflects the laser beam toward the focusing optics and focuses it on the sample, generating a sufficiently high power density on the measurement sample to excite Raman scattering.

The scattered light emitted by the sample, consisting of elastically scattered Rayleigh component and inelastically scattered Raman component, is collected by the same focusing optics and returned along the original excitation path. Due to the spectral properties of the dichroic beam splitter, the returning scattered light with wavelengths greater than 785 nm is transmitted and coupled out of the excitation beam path.

To effectively suppress intense Rayleigh scattering, a spectral blocking filter is integrated into the detection path, which strongly attenuates the laser line (here: spectral line, not geometric line) and allows only the Raman-shifted wavelengths to pass through.

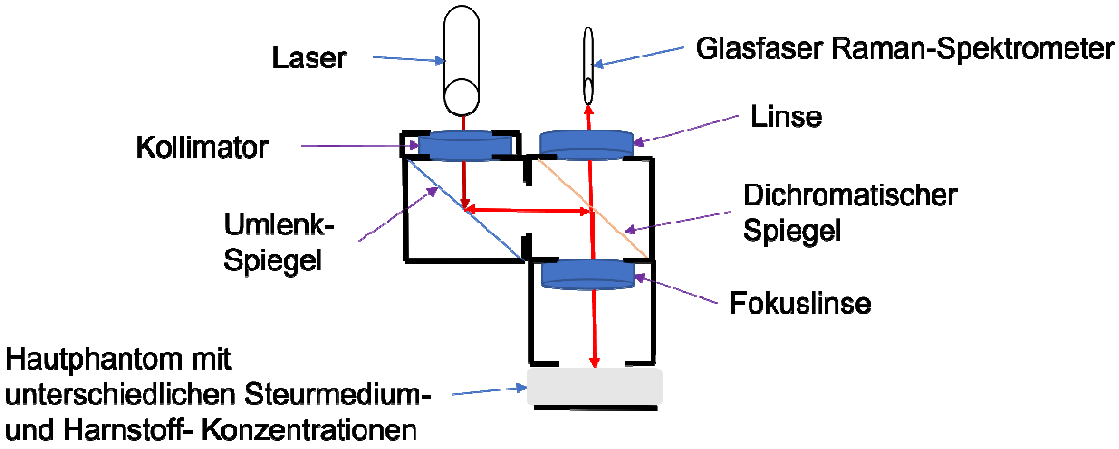


Figure 1: Illustration of Raman Spectroscopy Experiment

The filtered Raman light is then focused onto the entrance to an optical fiber via a further imaging optic. The geometric arrangement of the optical elements ensures that excitation and detection overlap spatially and that high collection and coupling efficiency is achieved. Overall, the design shown allows for stable, backscatter-based Raman measurement with good suppression of the background signal and is particularly suitable for compact, fiber-coupled measurement systems in the near-infrared excitation range.

Figure 2 clearly shows a linear relationship between the Raman peak at 1050 cm^{-1} and urea content. The two lines show the signals for two different skin types.

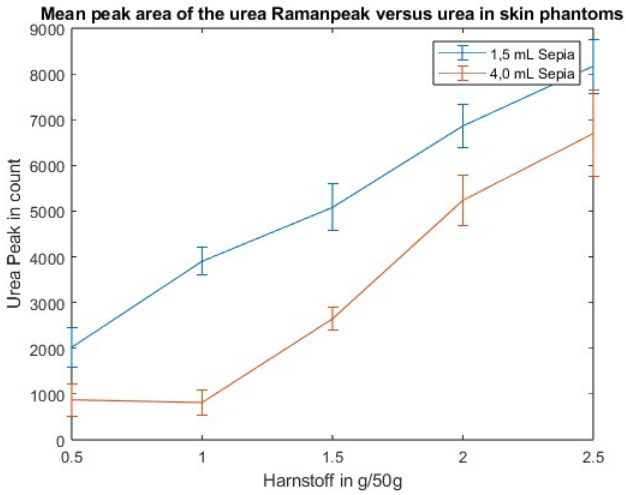


Figure 2: Ramanpeak versus Skin Phantoms

3 SMART-CITY AND SMART-HEALTH INTEGRATION AND CITIZENS' INCLUSION

Air-quality measurement data become infrastructure intelligence by being operationally integrated. "Smart Health Measurements" is not the act of producing numbers; it is the creation of feedback loops that connect environment, behavior, and interventions, at multiple scales.

At the city scale, dense PM and NO_2 data can support adaptive traffic management, evaluation of low-emission zones, and targeted enforcement or incentives. At the neighborhood scale, identifying exposure corridors (e.g., school routes, cycling networks) allows urban design to reduce chronic exposure without requiring citizens to change behavior. At the building scale, CO_2 and aerosol metrics can control ventilation and filtration in real time – demand-driven rather than schedule-driven – thereby achieving both health protection and energy efficiency. Latter city scenarios are illustrated by an experiment with the aforementioned ProxiCube® NX3 applied at five parallel outdoor measurement points of the city of Mannheim at a high data rate (Kaufmann et al., 2023).

Standards and professional guidelines in the German-speaking context explicitly target healthy indoor environments and the hygiene requirements of ventilation and air-conditioning systems (e.g., VDI 6022) and the broader European framework (e.g., DIN EN 16798-3 replacing the older EN 13779) (VDI, 2018; DIN, 2017).

Two operational principles are worth stating plainly. First, resolution beats averages for many health-relevant questions: a 24-hour mean PM2.5 value is important for epidemiology, but it does not tell a citizen or a facility manager whether an indoor space is currently drifting toward an avoidable risk regime. Second, interpretability beats raw sensor count: a smart city does not need "more sensors" as an end in itself. It needs measurement designs that map to actions – ventilate, filter, reroute, warn, investigate – and that provide auditable rationales.

This domain is also comparatively favorable regarding privacy and ethics. Environmental sensing can be designed as passive, non-invasive observation: the city and the building are measured, not the individual. Exposure assessment can then be personalized only if the citizen opts in, while public policy can act on aggregate patterns.

In the context of a concerted smart city stakeholder inclusion, a bridge must be created between science, economy and society. This is the mission of the TransforMA project, a joint endeavor of the Mannheim

University of Applied Sciences and the University of Mannheim (https://www.hs-mannheim.de/die-hochschule/forschung-und-transfer/transforma.html). Technologies from the fields of AI, sensor technology, and robotics are presented, designed to make otherwise complex topics more accessible. The project is structured into five areas of action: “Communication”, “Cooperation”, “Technology”, “Impact and Responsibility” and “Cooperation and Evaluation”. The sub-project "Communication" aims to establish channels, for example in the area of social media, and thereby promote the transparent exchange of information between science and society. In the area of cooperation, networks with a wide variety of institutions are being established and expanded to foster stronger collaboration within the region. Additionally, events are being organized within this framework, inviting people from diverse backgrounds to engage in dialogue. The technology component of TranforMA involves the Technical University and the University jointly presenting various technologies to the public in the context of demonstrators. Technologies from the fields of AI, sensor technology, and robotics will be showcased, making otherwise complex topics more accessible.

4 CONCLUSION

Particulate matter, aerosols, gases, and odors form a technically coherent measurement domain that connects directly to smart-city operation and smart-health outcomes. The required technologies already exist – from EN-standardized reference methods to integrated devices such as the ProxiCube® NX3 or increasingly transcutaneuous measurements. The order of the day is to deploy, validate, interpret and communicate measurement data as part of an intelligent control loop, information and communication system. In terms of the impact on humans, the first possibilities for contactless, continuous monitoring are emerging through image analysis methods additionally evaluated by AI and novel methods of spectroscopy. Even if there is still a long way to go, with the required detection limit not yet being achieved or cross-sensitivities heavily influencing or falsely altering the results, the technological path has been laid out and will lead to commercial and affordable devices in the coming years. Finally, awareness building and inclusion of citizens is recommended to come to the fore.

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reviewed paper

Social Equity in Housing: Addressing Systemic Barriers in Johannesburg, South Africa

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1 ABSTRACT

Johannesburg continues to grapple with entrenched spatial inequality, which is deeply rooted in the apartheid era, resulting in uneven access to housing that is affordable, adequate, and well-located. While significant research exists on South Africa's housing challenges, there is limited systematic analysis of how scholarship on housing equity, particularly within the city of Johannesburg, has evolved. In this study, a literature review is combined with a bibliometric analysis from 1997 to 2024 to gain a broader understanding of the themes, authors, and patterns within this field. The results show that global scholarship on housing equity has expanded substantially since 2006, driven by urbanisation, the Sustainable Development Goals, and post-pandemic research interest. However, Johannesburg remains significantly underrepresented in global housing equity literature, with South Africa producing only two publications in the analysed dataset. Keyword clustering reveals strong attention to affordability, inequality, and policy themes globally, but limited focus on city-specific issues. Based on the findings, the study proposes a conceptual framework to guide future research and policy development on housing equity in Johannesburg, identifying opportunities for strengthening local knowledge production, improving policy responsiveness, and advancing socially just housing outcomes.

Key Words: Social Equity, Housing Policy, Spatial Inequality, Affordable Housing, Urban Development

2 INTRODUCTION

Social equity in housing is a critical component of sustainable urban development, particularly in cities grappling with historical injustices and socio-economic inequality. Johannesburg, South Africa's largest city and economic powerhouse, exemplifies the enduring impact of apartheid-era policies that entrenched spatial segregation and economic disparities. These systemic barriers have left marginalised communities, particularly low-income earners and informal settlement dwellers, without equitable access to adequate housing, infrastructure, and services (Turok, 2016). According to McKay, Fakudze and Gunter (2022), the disparities in housing and human settlements manifest as spatial inequalities and, persistent socio-economic challenges, further exacerbating exclusion and limiting upward mobility for vulnerable populations. Despite substantial policy reforms, including the Reconstruction and Development Programme (RDP) and Breaking New Ground (BNG), the city continues to experience unequal access to adequate and well-located housing, particularly for low-income households and residents of informal settlements (Turok, 2016; Huchzermeyer, 2011). The concept of social equity in housing encompasses fair access to adequate, affordable, and quality housing for all parts of society, regardless of socio-economic status, race, or ethnicity (Hochstenbach et al., 2025). In the setting of Johannesburg, achieving social equity in housing is crucial for addressing historical injustices and promoting inclusive urban development (Makalima, 2024). Addressing these challenges requires a nuanced understanding of the intersection between historical legacies, contemporary urban policies, and the lived realities of affected communities.

While housing inequality in South Africa has been widely studied, there is a notable insufficiency of studies that map the evolution, structure, and influential contributors to research on housing equity in Johannesburg. Existing scholarship is fragmented, largely qualitative, and seldom assessed for thematic evolution or conceptual patterns. This presents a critical knowledge gap given the city's prominence and the complexity of its housing challenges. This research explores the systemic barriers to housing equity in Johannesburg, focusing on access, affordability, and quality. Through employing a mixed-methods approach, including a thorough literature review and bibliometric analysis, this study identifies policy gaps, highlights socio-economic constraints, and proposes actionable solutions. The findings may offer some insight into ongoing discussions on enhancing inclusive urban development and addressing spatial inequality through holistic and community-driven strategies.

Beyond documenting housing inequality, this study positions Johannesburg within broader global housing equity debates by interrogating the intellectual and collaborative structures that shape knowledge production in this field. The limited visibility of Johannesburg within global housing equity scholarship is not merely a geographic gap but reflects broader epistemic imbalances in urban research, where Global South cities remain underrepresented in dominant conceptual frameworks. By combining bibliometric mapping with contextual analysis, this study therefore contributes not only to understanding housing inequality in Johannesburg but also to examining how knowledge hierarchies influence urban policy discourse and research priorities.

3 AIM AND RESEARCH QUESTIONS

This research aims to investigate the landscape of social equity in housing within Johannesburg, South Africa, aiming to unpack the structure of knowledge of this multifaceted field. Guided by the overarching goal of understanding the systemic barriers and potential solutions, the study addresses the following questions:

- What are the dominant conceptual frameworks used to understand social equity in housing in this scenario?
- What constitutes the intellectual structure of this field, as evidenced by crucial publications and influential authors?
- How is the social structure of research on this topic configured, including collaborations and networks?
- How does the body of knowledge specifically addressing Johannesburg contribute to broader understandings of social equity in housing?

4 LITERATURE REVIEW

The literature review for this study aims to reinforce the rationale, support the investigation of the research question, and locate the study's variables within the existing body of knowledge. It examines the concept of social equity in housing, explores historical and contemporary challenges in Johannesburg, and critically analyses policy interventions and their effectiveness in addressing spatial inequalities. Through synthesizing important academic discussions, this review identifies gaps in current research and highlights potential strategies for enhancing inclusive urban development.

4.1 Historical Background of Housing Inequality in Johannesburg

According to Kamana, Radoine, and Nyasulu (2024), the apartheid era in South Africa institutionalised racial segregation and spatial planning, resulting in deeply entrenched inequalities in housing and urban development. Policies such as the Group Areas Act of 1950 designated specific residential areas based on race, forcibly relocating black communities to the urban periphery and relegating non-white populations to underdeveloped areas with limited access to resources and opportunities (Francis and Webster, 2019; Harrison et al., 2008). This deliberate spatial planning entrenched socio-economic disparities, creating a legacy of unequal access to resources, services, and economic opportunities that continues to shape Johannesburg's urban landscape, perpetuating spatial and socio-economic disparities. The apartheid-era policies systematically entrenched spatial segregation, limiting access to adequate housing for non-white populations (Turok, 2016). Under the Group Areas Act (1950), non-white communities were forcibly relocated to peripheral townships, restricting their economic opportunities and access to essential services (Mabin & Smit, 1997). This historical displacement created enduring spatial divides that persist in contemporary Johannesburg (Bremner, 2000). Post-apartheid efforts, such as the Reconstruction and Development Programme (RDP) and Breaking New Ground (BNG), aimed to address housing shortages and rectify spatial inequalities. However, these initiatives have faced criticism for their limited impact on transforming entrenched patterns of segregation and addressing systemic barriers. Persistent challenges include inadequate infrastructure, insufficient service delivery, and the slow pace of housing provision, particularly for low-income households (Charlton & Kihato, 2006).

4.2 Conceptualising Social Equity in Housing

Social equity in housing refers to the fair distribution of housing resources, opportunities, and services, ensuring that all socio-economic groups have access to adequate shelter (Fainstein, 2014). Fundamental dimensions of housing equity include access, affordability, and quality, each playing a crucial role in determining the inclusivity and sustainability of urban housing systems. Access refers to the ability of marginalised communities to secure housing in well-located urban areas with proximity to economic opportunities, social amenities, and public transportation (Turok, 2016). Many low-income households in Johannesburg face exclusion from such areas due to high land costs, restrictive zoning policies, and historical spatial inequalities (Parnell & Pieterse, 2014). Affordability is another critical dimension, highlighting the financial feasibility of obtaining adequate housing without compromising other essential needs such as food, healthcare, and education (Bredenoord, Van Lindert & Smets, 2014). The persistent housing backlog, rising property prices, and limited access to financing options further exacerbate affordability challenges, leaving many households reliant on informal settlements or substandard rental housing (Charlton & Kihato, 2006). Quality encompasses the physical condition of housing, including infrastructure, safety, and access to basic services such as water, sanitation, and electricity (Huchzermeyer, 2011). According to Marais and Ntema (2013), poorly constructed dwellings, inadequate service delivery, and overcrowding contribute to deteriorating living conditions, particularly in townships and informal settlements. These dimensions collectively provide a framework for assessing Johannesburg's housing challenges, emphasising the need for integrated policies that address spatial inequality, enhance affordability mechanisms, and improve the overall quality of housing for low-income and marginalised populations.

4.3 Contemporary Housing Policies and Their Effectiveness

Post-apartheid housing policies were designed to address the legacies of apartheid by providing affordable housing and rectifying historical injustices. Among the major initiatives was the Reconstruction and Development Programme (RDP), launched in 1994, which aimed to deliver mass housing to low-income households. While it was a significant attempt to provide housing for the previously disadvantaged, the RDP has been criticised for promoting peripheral urban expansion, creating low-density developments on the outskirts of cities, and failing to promote social integration or meaningful economic opportunities within these areas (Charlton & Kihato, 2006). In response to some of these challenges, the Breaking New Ground (BNG) Initiative was introduced in 2004 with the goal of creating integrated, sustainable human settlements. This initiative was more progressive than its predecessor, placing emphasis on sustainability, infrastructure, and social inclusion. However, despite these improvements, the BNG has faced implementation challenges, including limited success in overcoming spatial segregation, with many housing developments still reinforcing patterns of inequality and exclusion (Harrison, Todes, & Watson, 2008). Both the RDP and BNG illustrate the tension between achieving immediate housing delivery and addressing broader spatial, social, and economic inequalities in South Africa's urban landscape.

4.4 Systemic Barriers to Housing Equity

Several interconnected barriers hinder equitable access to housing in Johannesburg, perpetuating spatial inequality and socioeconomic disparities. Economic constraints, such as high unemployment rates and low wages, severely limit affordability, excluding a significant portion of the population from formal housing markets (Huchzermeyer, 2011). This is compounded by spatial segregation, where affordable housing developments are often located on the urban periphery, distant from economic opportunities and essential services, thus reinforcing apartheid-era spatial divides (Todes, 2012). Infrastructure deficiencies in informal settlements, characterised by a lack of adequate sanitation, water, and electricity, further exacerbate precarious living conditions (Del Mistro and Hensher, 2009). According to Zhou (2023), market dynamics play a crucial role, as the private sector tends to prioritize middle- and high-income housing developments, resulting in a limited supply of affordable housing options. These factors create a complex web of challenges that must be addressed holistically to promote equitable access to housing in Johannesburg.

4.5 Informal Settlements and Housing Insecurity

Informal settlements continue to accommodate a significant proportion of Johannesburg's low-income population and play a central role in the city's housing landscape. Despite several policies aiming to upgrade these areas, challenges such as insecure land tenure, inadequate access to basic services, and occasional

forced evictions still persist (Huchzermeyer, 2004). These conditions contribute to ongoing housing insecurity and highlight some of the practical difficulties in achieving more equitable housing outcomes. Some scholars suggest that more participatory and community-driven planning approaches could be useful in addressing these issues, as they may allow affected communities to play a stronger role in shaping their living environments (Watson, 2009).

4.6 Emerging Strategies for Inclusive Housing

In order to achieve social equity in housing, various strategies have been proposed. Community-driven approaches, emphasising participatory planning and involving local communities, enhance housing outcomes by ensuring that development aligns with residents' needs and preferences (Gerrits, 2012). Mixed-income developments, integrating low-income housing within middle- and high-income areas, foster social inclusion and break down socioeconomic segregation (Landman and Badenhorst, 2014). Affordable rental housing offers greater flexibility for low-income earners by expanding rental options and reducing the financial burden of homeownership (Lonardoni and Bolay, 2016). Lastly, infrastructure investment plays a crucial role in bridging spatial inequalities by improving transportation and service delivery in low-income areas, connecting residents to opportunities and essential amenities (Geyer & Geyer, 2015). These strategies, implemented comprehensively, can contribute to a more equitable and just housing landscape.

5 METHODOLOGY

For this study, a mixed-methods approach was used, incorporating both a comprehensive literature review and a bibliometric analysis. The literature review served to contextualise the historical and contemporary challenges of housing equity in Johannesburg, South Africa, exploring systemic barriers, policy limitations, and socio-economic constraints impacting equitable access to adequate housing, particularly for marginalised communities in informal settlements and low-income areas. The bibliometric analysis, a rigorous quantitative approach for analysing large datasets, was used for the purpose of exploring the knowledge structure and visually mapping and analysing the field of "social equity in housing," focusing on Johannesburg. Bibliometric analysis offers a robust approach for understanding the evolution and current structure of a research field, providing valuable insights into its key themes, influential authors, and emerging trends (Van Eck & Waltman, 2010). Data related to “social equity in housing”, “Johannesburg”, and related terms such as “affordable housing Johannesburg”, “housing policy”, “housing inequality Johannesburg”, “housing Johannesburg” between 1997 and 2024 were exported using Scopus. Figure 1 is a representation of the years that were used to identify, select, and include relevant publications in this bibliometric analysis.

5.1 Literature Review

The qualitative component involved a systematic review of scholarly publications on Johannesburg’s housing landscape. The review aimed to synthesise existing knowledge on social equity and housing, highlighting historical, policy, and contemporary dimensions of inequality. The areas of scope included:

- Historical Inequality: Examining the spatial and social legacies of apartheid and colonial-era planning that continue to shape urban housing disparities.
- Policy Evolution: Reviewing major housing policies, programmes, and interventions in Johannesburg, including public housing initiatives, low-cost housing projects, and mixed-income developments.
- Contemporary Systemic Barriers: Identifying structural, economic, social, and institutional factors that impede equitable access to housing for low-income and marginalised groups.
- Emerging Strategies for Social Equity: Evaluating recent interventions and innovative approaches aimed at promoting inclusion, integration, and affordability in the city’s housing market.

This literature review provided the theoretical and conceptual foundation for the bibliometric analysis, helping to contextualise patterns in research outputs, collaborations, and thematic focus areas. Furthermore, it informed the identification of relevant keywords, search terms, and inclusion criteria for the bibliometric component.

5.2 Bibliometric Analysis

The bibliometric analysis was conducted to quantitatively assess the scholarly landscape on housing equity in Johannesburg, examining patterns of authorship, collaboration, and thematic development over time.

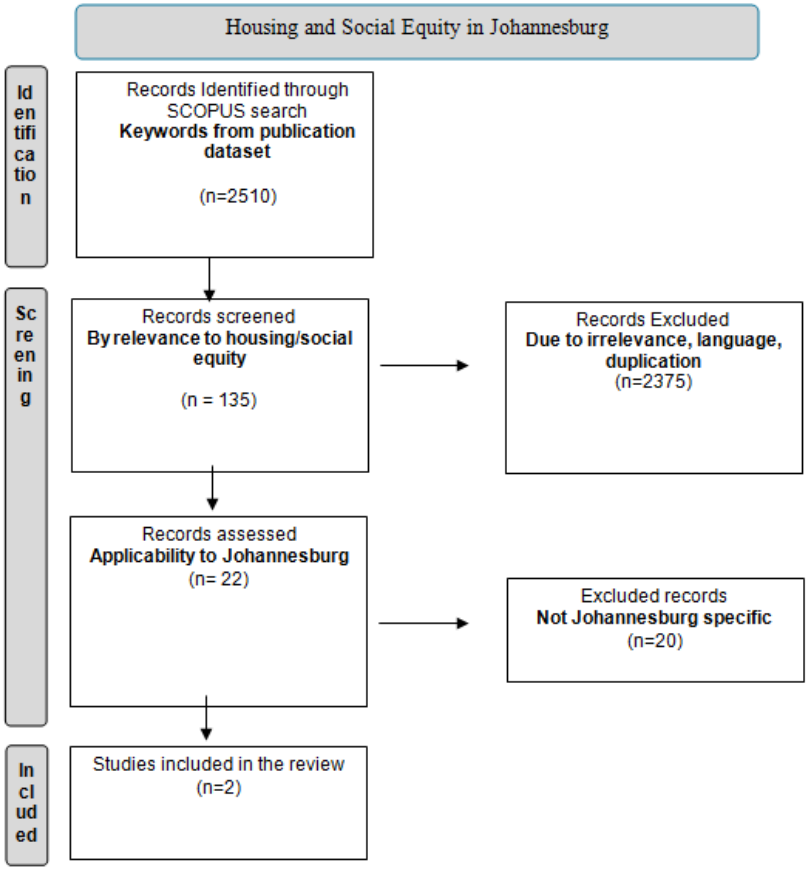


Figure 1: PRISMA flow diagram. Source: Authors

Figure 1 illustrates the systematic process used to identify and select relevant academic publications for the study. An initial 2510 records were retrieved from Scopus using keywords connected to housing, social equity, and Johannesburg. During the first screening stage, 2375 records were excluded due to duplication, irrelevance to the subject, or language restrictions, leaving 135 records for further evaluation based on thematic relevance to housing and social equity. In the second screening stage, those 135 publications were assessed for specific applicability to Johannesburg. This screening resulted in 22 studies that discussed housing and equity concerns within broader South African and urban studies frameworks. A final screening was done, and only 2 studies directly addressed Johannesburg-specific issues related to social equity in housing. These 2 studies were found to be relevant and were included in the bibliometric analysis.

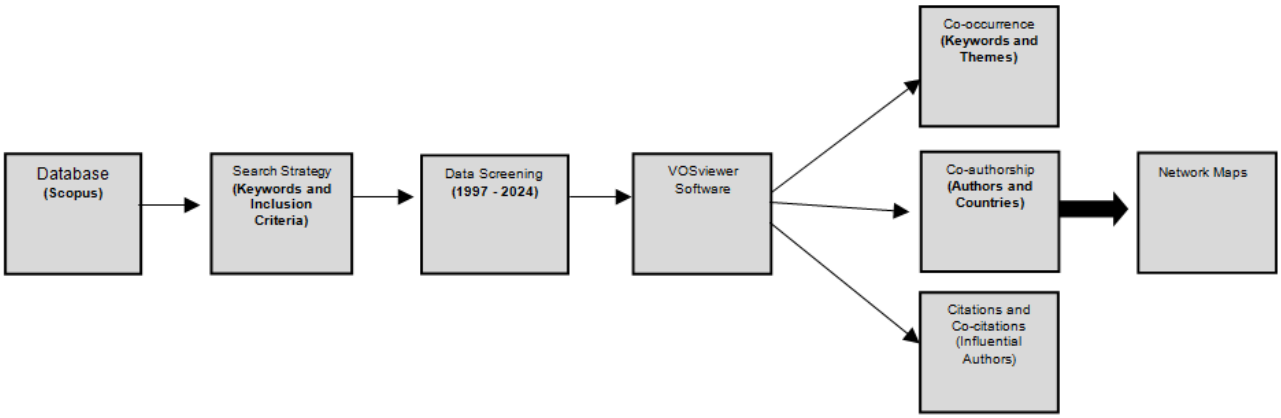


Figure 2: A bibliometric analysis guide. Source: Authors

Figure 2 summarises the systematic process used to analyse literature on social equity in housing and systemic barriers in Johannesburg. Data was extracted from Scopus using specific keywords and inclusion criteria, screened for relevance and quality using the years1997–2024, and analysed in VOSviewer through three steps: (i) co-occurrence analysis to identify critical themes such as spatial integration, affordability, social cohesion, and policy interventions; (ii) co-authorship analysis to explore collaboration patterns; and (iii) citation and co-citation analysis to highlight influential scholars and foundational knowledge. The resulting network maps visually represent the thematic structure, collaboration networks, and knowledge base informing housing equity research in Johannesburg.

6 RESULTS, ANALYSIS, AND DISCUSSION

VOSviewer was employed to conduct the bibliometric analysis, generating keyword co-occurrence maps, country co-authorship networks, author co-citation networks, and temporal visualisation overlays. Threshold settings were applied to ensure meaningful results, with a minimum keyword occurrence of 5, a minimum citation threshold for co-citation of 3, and units of analysis including authors, keywords, and countries. From the exported dataset of 2,510 keywords, 225 met the threshold for inclusion in the analysis.

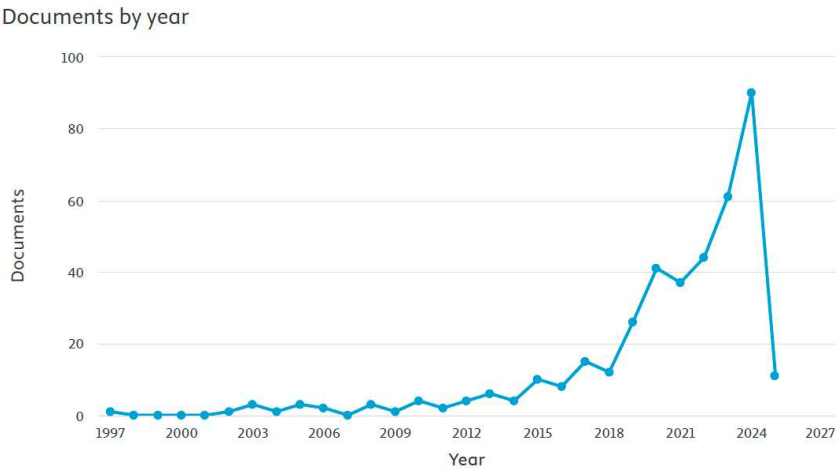


Figure 3: Graph depicting the publication trend of the research area between 1997 and 2024.

6.1 Analysis of Publications by Year

Between 1997 and 2000, the publication rate on housing issues was notably low, likely due to a transition period where researchers focused on other pressing topics. From 2000 to 2006, a mixed trend emerged, with both increases and decreases in publications, indicating a growing but inconsistent interest in housing equity. From 2006 to 2012, there was a significant rise in housing-related publications, driven largely by the aftermath of the 2008–2009 Global Financial Crisis. This period also saw rapid urbanization, especially in developing countries, which increased housing demand. Concurrently, several countries, including the United States, the United Kingdom, and China, introduced new housing policies, further stimulating research in the field. The period between 2015 and 2018 witnessed a gradual upward trend in publications, fuelled by the emergence of funding opportunities, technological advancements, and the enforcement of the United Nations Sustainable Development Goals (SDGs), particularly Goal 11 on Sustainable Cities and Communities, which highlights housing as a critical area of. Between 2018 and 2021, the trends of heightened awareness of housing issues, the influence of the SDGs, and continued rapid urbanization persisted. However, the COVID-19 pandemic, beginning in 2020, introduced a significant inflection point. The pandemic highlighted housing as a critical determinant of health and well-being, as lockdowns and stay-at-home orders exposed vulnerabilities, particularly for those living in inadequate or overcrowded housing in informal settlements and marginalised communities. Finally, the period from 2021 to 2024 saw an increase in housing-related publications, driven by the long-term impacts of the pandemic, including economic disruptions, increased inequality, and shifts in work patterns, such as the rise of remote work. These factors intensified existing housing challenges and prompted research into their lasting effects. Furthermore, government policies and international programs aimed at addressing the housing crisis spurred research evaluating the effectiveness of these interventions. The intersection of housing with social justice movements focused on racial and social equity gained prominence, stimulating research on housing disparities and their

broader societal implications. However, despite increased global publication output, Johannesburg remains underrepresented, indicating a critical research gap. Figure 3 clearly depicts the publication trend of the research area between 1997 and 202.

6.2 Intellectual Knowledge Structure of the Field

This section of the research employs a bibliometric analysis and science mapping to depict the intellectual landscape of social equity in housing, focusing specifically on Johannesburg. This exploration directly responds to the first three research questions and advances the study's overall aim is to develop a comprehensive knowledge to enable conceptualisation and a great emphasis on social dimensions of the field which is being investigated. Starting with a broad overview of the global scholarship on housing equity, the analysis then narrows its scope to the specific case of Johannesburg. Consequently, the intellectual framework, consisting of critical publications and influential researchers, provides a foundation for the subsequent analysis.

6.2.1 Conceptual Structure: Keyword Co-Occurrence Analysis

The top 5 preferred keywords from the data are listed in Table 2. Compared to the total publications that were exported, it is evident that housing is tied to the complexities that have to do with inequality, affordability, policy, exclusion, and spatial inequality within the city of Johannesburg. The blue area, with housing being dominant, is an area of research that is of great interest, whereas the smaller red, green and blue parts are yet to be explored and researched on within the society of global knowledge, it is important to understand how the collaboration of countries can be unpacked where the prominent authors come from as well as their ties globally.

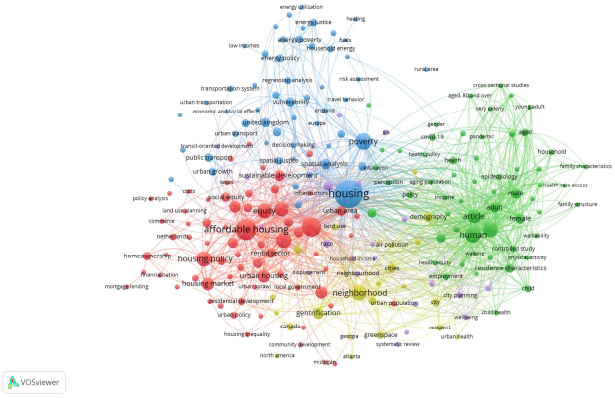


Figure 4: Visualised network map of research themes, overlay between 2014 and 2024 (10-year period) to understand the trajectory of research themes.

The analysis in Figure 4 revealed three distinct but interconnected clusters defining the mixed-income housing literature landscape. The largest group, Cluster 1 (Blue), forms the central axis of global housing research, tightly integrating core themes of housing, affordable housing, urban development, and inequality, signifying its critical and foundational nature in the scholarly conversation. Cluster 2 (Red) focuses on the institutional dynamics and instruments that shape housing outcomes, encompassing themes such as planning, policy reform, and governance strategies, which illustrate the pragmatic application of political will. Finally, Cluster 3 (Green) highlights the growing attention to justice-oriented frameworks, focusing on the critical dimensions of spatial inequality, segregation, exclusion, and informality, reflecting a necessary shift toward analysing social barriers and systemic marginalization within urban settings.

Keyword	Occurrences	Total Link Strength
Housing	175	1323
Affordable Housing	97	590
Urban Development	51	333
Housing Policy	53	298
Housing Inequality	7	43

Table 1: The top 5 keywords in the research network

6.2.2 Country Contribution and Collaboration

Figure 5 is an illustration of a country collaboration map. The map reveals a highly centralised research network dominated by the United States (161 documents), which has the highest productivity and centrality, and China (60 documents), which maintains strong co-author ties with the US, alongside active contributions from the United Kingdom and Canada. However, South Africa produced only two publications that met the inclusion criteria and expressed weak collaboration links with these global centres. This underrepresentation points to weak global integration of housing research, which is focused on Johannesburg, proving that there is a need for local academic output that pays attention to social equity in housing, reinforcing the importance of this study and emphasising the need for stronger international research collaboration involving South African scholars.

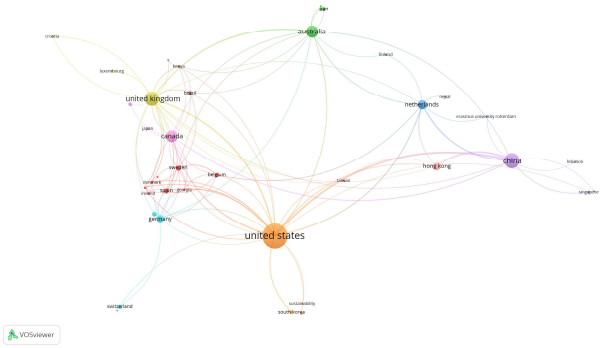


Figure 5: Visualisation of country collaboration and contribution network.

Country	Documents	Citations	Total Link Strength
United States	161	4431	65
China	60	898	43
Canada	35	646	30
Canada	35	646	30
South Africa	2	12	0

Table 2: A table of the top 5 countries and their publication numbers

6.2.3 Social Structure

The final data set focuses on the co-citation, which in turn determines the body of knowledge in which authors have found their niche. Authors have established a concrete understanding of their chosen area of interest.

Author Co-citation Analysis

Figure 5 and table 2 reveal a highly centralised research network dominated by the United States (161 documents), which exhibits the highest productivity and centrality, and China (60 documents), which maintains strong co-author ties with the US, alongside active contributions from the United Kingdom and Canada. Critically, South Africa produced only two publications meeting the inclusion criteria and exhibits no strong collaboration links with these global hubs. The minimal visibility of Johannesburg-centred housing equity research within global networks demonstrates a clear gap in scholarly engagement, further validating the aims of this study and emphasising the importance of building stronger global research links. Furthermore, table 3 illustrates that authors such as Anguelovski, Cole, García-Lamarca, Shokry, and Triguero-Mas form a cohesive cluster representing the environmental justice and urban equity school of thought. Their criteria, including the same number of publications (three each), citations (96 each), and total link strength (31 each), suggest an equally high-standing influence and shared conceptual foundation in justice-oriented urban studies within the dataset. However, the complete absence of any South African scholars among this influential group highlights the lack of Johannesburg-centred intellectual leadership in global scholarship.

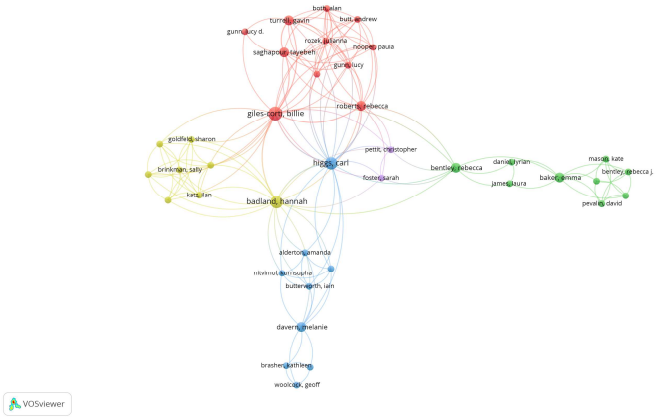


Figure 6: Visualisation of co-author network.

Author	Documents	Citations	Total Link Strength
Anguelovski I.	3	96	31
Cole H.	3	96	31
García-Lamarca M.	3	96	31
Shokry G.	3	96	31
Triguero-Mas M.	3	96	31

Table 3: Author co-citation analysis indicating the main authors within the network.

7 RECOMMENDATIONS

Based on the findings of this study, a practical framework in Table 4 has been proposed to advance social equity in housing within Johannesburg. The framework is structured around five central dimensions, which are Spatial Justice, Affordability and Financial Inclusion, Infrastructure and Service Equity, Governance and Participation, and Research and Knowledge Production. Each dimension focuses on targeted actions that address systemic barriers, strengthen policy implementation, and enhance the lived experiences of low-income and marginalised residents. Together, these strategic components aim to reduce spatial and socio-economic disparities, improve access to well-located and affordable housing, foster inclusive governance, and promote knowledge generation that reflects local realities, ultimately contributing to more equitable and sustainable urban development.

Dimension	Strategic Focus	Actions & Interventions	Expected Outcomes
Spatial Justice	- Addressing deeply-rooted spatial segregation and exclusion	- Providing housing which is affordable and within close-proximity to amenities - Increasing mixed-income housing projects for the purpose of supporting social and spatial integration (Hofner et al., 2022)	- Reduced urban sprawl - Improved access to services and jobs (World Resources Institute, 2018)
Affordability and Financial Inclusion	- Increasing the access to secure tenure and different housing options catering to different income brackets	- Increasing affordable rental options - Increasing subsidies for low-income households - Use inclusionary housing policies to ensure private developments include more affordable units (Madell, 2025) - Improving tenure security	- Improved access to affordable housing for low-income earners (Madell, 2025) - Various housing options beyond home-ownership (SpringerLink)
Infrastructure and Service Equity	- Upgrading informal settlements and improving basic service delivery	- Incremental upgrading of informal settlements - Improving tenure security - Integrating amenities with transportation routes	- Healthier and safer environments - Reduction of spatial inequality with better access to amenities (Bettencourt and Marchio, 2023).
Governance and Participation	- Improving community participation and accountability	- Improving coordination between government departments - Working closely with communities in housing decision-making - Strengthening transparency and reducing corruption in housing processes	- Improved accountability from the government - Improved public participation in decision-making (SpringerLink) - Reduced forced relocation
Research and Knowledge Production	- Contribution more towards local knowledge while learning from global experience	- Creating research networks focused on Johannesburg's housing issues - Providing more financial support for local housing research - Encouraging international collaboration and sharing of data to strengthen knowledge	- Improved influence from a perspective which highlights local realities which will provide more data for the purpose of contributing towards future interventions (Watson, 2009)

Table 4: A proposed Framework for addressing systemic barriers to social equity of housing in Johannesburg.

8 CONCLUSION

This study provides the first integrated literature review and bibliometric mapping of research on social equity in housing with a specific focus on Johannesburg. The findings show that although global scholarship

on housing equity has grown substantially, particularly after 2015, Johannesburg remains significantly underrepresented in the broader academic landscape. Existing literature consistently highlights the city's deep-rooted spatial inequalities, persistent socio-economic challenges, and the lingering effects of apartheid-era segregation, all of which continue to undermine efforts toward equitable housing. While post-apartheid housing policies have introduced various mechanisms to expand access to affordable housing, they have often fallen short in addressing social integration, economic disparities, and long-term sustainability. As such, the systemic barriers to achieving genuine social equity in housing remain multidimensional, spanning economic, social, and institutional domains.

The bibliometric analysis unequivocally underscores these concerns by demonstrating the limited Johannesburg-specific scholarship within global debates on housing equity, with central thematic clusters revealing conceptual gaps, particularly in relation to social integration, community participation, and spatial justice. The country collaboration map highlights a highly centralised research network dominated by the United States (161 documents) and China (60 documents), while critically, South Africa is severely underrepresented (two documents) and exhibits no strong global collaboration links. This lack of integration is mirrored in the co-citation network, where authors forming the influential environmental justice school of thought (Anguelovski, Cole, García-Lamarca, Shokry, and Triguero-Mas) possess equally high-standing influence but none are South African. This complete absence of Johannesburg-centric intellectual leadership in global scholarship reinforces the need for this study, which contributes by identifying these critical research and intellectual gaps, mapping the collaborative structures shaping current scholarship, and offering a vital baseline for future urban housing studies in South Africa.

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reviewed paper

Spatial Determinants of Urbanisation in Debre Markos, Ethiopia: Modelling Building Footprint

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1 ABSTRACT

Urbanization puts pressure on socio-economic and environmental aspects worldwide. Spatial factors play a pivotal role in driving this urbanization; for instance, geographical features, proximity to socio-economic services, and government zoning regulations are spatial determinants discussed in the literature. The purpose of this study is to understand the spatial determinants of urbanization based on building footprints.

The Google Open Building Dataset has been used for retrieving building footprints. Additionally, 26 dependent variables were collected from various sources. Road networks were extracted from OSMnx, and geographical data were collected from Google Earth Engine. Points of interest for proximity estimation were gathered from the Debre Markos municipality, and some socio-economic data were collected through a survey of 385 respondents, which were then interpolated to the entire area. The independent variables are categorized as geographical, proximity, socio-economic, and governmental regulation factors. About 25,000 training samples were extracted from each variable to train the models.

Two methods were employed in this research: the binary logistic regression and the machine-learning model of XGBoost. Binary logistic regression was employed for its interpretability, while XGBoost was employed for its superior data management and prediction accuracy. According to the results of the area under the curve (AUC) for accuracy measurement, logistic regression achieved 0.73, and XGBoost achieved 0.82. However, the data fit the model in both cases. Distance from road, building height zone, road network density, and slope are among the top factors determining urban building footprint. This implies that the likelihood of building has increased near roads. The results of building-height zoning show that local government regulations affect the likelihood of building, and a model result on slope also indicates that topography is a significant determinant of urbanization.

Keywords: XGBoost, logistic regression, urban expansion, building presence, urban modeling

2 INTRODUCTION

The primary drivers of urbanization are natural population growth and rural-to-urban migration (Arif & Gill, 2023; Ayele & Tarekegn, 2020). Location, development level, country size (Arif & Gill, 2023), topographic, planning and policy constrients (Wu et al., 2015), and economic level determine the level of urban expansion (Dutta et al., 2020). Urbanization is a global concern, exerting pressure on social, economic, and environmental issues in both the global North and the global South (Arif & Gill, 2023; Braimoh & Onishi, 2007). The fast-growing and uncontrolled expansion causes nuanced problems (Angel, 2023), such as environmental degradation, unplanned urban housing and lack of infrastructure (Karimi et al., 2021). It has also consumed agricultural land, leading to food insecurity, soil erosion, social injustice, and high housing burden (Chen et al., 2016).

Although cities can serve their residents through densification or horizontal expansion, the focus in recent years has been predominantly on horizontal urban expansion (Angel, 2021). In Africa, urban centers have expanded into peri-urban areas, where infrastructure is limited and social services are inaccessible. The residents become poor, and the areas become sources of various environmental pollutants (Braimoh & Onishi, 2007). Ethiopia experienced such a rapid urbanization. Inadequate planning or problems in its implementation generally characterize this kind of urbanization. The result of such a velopment are cities lacking the necessary infrastructure and services (Ayele & Tarekegn, 2020).

Spatial determinants of urbanization are driving factors that emphasize the spatial dependency between geographic features (Chen et al., 2016). The spatial determinants of urbanization used by previous studies are:

- Social infrastructure accessibility (Community space, place of worship, social business, and parks) (Fraser et al., 2024),
- Proximity of road, land value, proximity of an education center, proximity of a utility service center, elevation, proximity of the old city, distance to the canal, elevation, distance from rivers, and distance from a forest (Sarkar & Chouhan, 2020).
- Transportation networks and proximity to the city center (Sarkar & Chouhan, 2020),
- Topological factors, neighborhood factors, socio-economic factors, and spatial planning policies (Mustafa, et al., 2018)
- Accessibility and topographic features (Christensen & McCord, 2016),
- Market access and terrain slope (Christensen & McCord, 2016),
- Proximity variables, topological variables, density, banks, company offices, stores, and transportation services (Chen et al., 2016),

In Debre Markos, rapid urbanization and spatial expansion are transforming non-urban land uses into urban uses. This expansion is driven by natural population growth and by rural-to-urban migration for expectation of better life and work opportunity, which increases demand for housing and infrastructure. Ultimately, this leads to challenging urban planning and development.

Policy interventions are essential to mitigate the destructive impact of built-up developments on the environment, natural resources, and human health (Mustafa, Heppenstall, et al., 2018). Thus, a good understanding of the factors of urbanization is vital for developing strategies for various purposes, such as development planning (Hofmann & Wan, 2013). This study aims to understand the spatial factor of urbanization and this knowledge will contribute to the city's spatial planning.

Although there are several studies on urban growth in Debre Markos, most rely on land-use land-cover classification and boundary expansion (Agegnehu et al., 2015; Abebaw, 2017; Temesgen & Huseyin, 2019). However, the spatial determinants of urban growth, including proximity factors, government regulations, socio-economic, and geographical factors, remain insufficiently studied. Analyzing these factors and their implications can significantly enhance urban planning and development in the city.

Besides, the authors recognized a shortage of studies that utilize building footprint data and employ both XGBoost spatial machine learning and econometric binary logistic models. The research is based on Angel's proposed future research ideas (2023). Among the many suggested questions, the authors were particularly motivated by two key questions: What are the determinants of urban footprints in cities? And what are the drivers of urban expansion? Based on these research questions, the following research questions were developed, considering the availability of data:

- What physical, socio-economic, and policy factors determine the likelihood of building footprint?
- How are the spatial factors correlated with each other?

3 RESEARCH METHODS AND MATERIALS

3.1 Description of the study area

Debre Markos, illustrated in Figure 1, the capital of the East Gojjam Administrative Zone, is located 300 kilometers northwest of Ethiopia's capital, Addis Ababa, and 265 kilometers from Bahir Dar in the Amhara National Regional State. The city's population has grown significantly in the last years due to rural-to-urban migration and natural increase. It was about 92,500 in 2014, and is estimated to be about 161,000 in 2025 (https://ess.gov.et/).

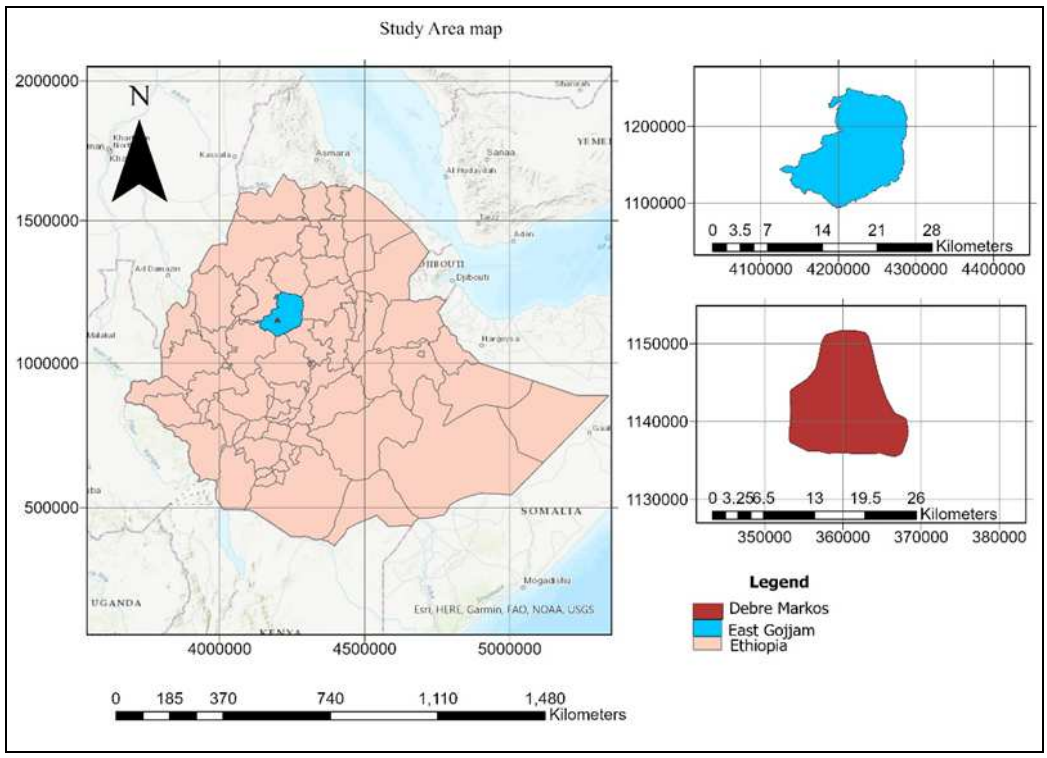


Figure 1: Study area map; source: "Rental housing affordability and spatial variation in rapidly growing urban areas of Ethiopia: evidence from Debre Markos city" submitted to the "International Journal of Housing Markets and Analysis (IJHMA)" by Moges Wubet Shita et al.

3.2 Data Source

The source for building footprint presence is open buildigs. It is a temporal annual dataset with an effective resolution of 4 meters, detailing building presence, fractional building counts, and building heights. The data are used in the fields of urbanization, environmental science, population mapping, public health planning, humanitarian, and disaster response (https://sites.research.google/gr/open-buildings/). The region-of-interest data for the building footprint can be downloaded from Google Earth Engine. In developing nations, alternative data sources are often based on remotely sensed data (see, for example, Sirko et al., 2021). The Figure 2 visualizes the difference in building footprint presence around the center of Debre Markos and it's perphery.

The independent variables are classified in four categories (Table 1): Government regulatory variables, socio economic variables, geographical variables, and proximity variables.

Land value grade and building height zoning are government regulatory variables selected for this study. The source of the variables is Debre Markos municipality (2024). Land value grades were provided in the DWG (AutoCAD drawing file) format and then converted into raster format for the simplicity of extracting the pixel value. Building height zone data is provided in raster format already. Land value, rental price per unit, household income, household affordability, and household size are socio-economic data. The land value per square meter is determied by interpolating from the price of 769 parcels from the Debre Markos municipality, wich were adjusted to make it in the same year. After adjustment, Inverse Distance Weighted (IDW) interpolation was used to obtain a continuous value field for the entire area. The other socio-economic variables were obtained by a survey of 385 households.

The geographical variables, elevation, slope, aspect, and hill shade are obtained from an image collection of CGIAR/STRM90_V4 throgh Google Earth Engine (GEE). Initially, the resolution was 90 meters; it was then resampled to 10 meters, to obtain a similar cell size to the other factors. To estimate proximity to the road network and road density, the road network was extracted from OSMnx, and then the proximity to the road network and road density were computed. The drainage line network, primary schools, secondary schools, streetlights, police stations, market centers, health centers, playing grounds, and green areas were collected from the Debre Markos municipality. Areas of worship and the city center pointwere extracted from Google Earth maps. Finally, the Euclidean distance of each pixels to each point of interest was computed.

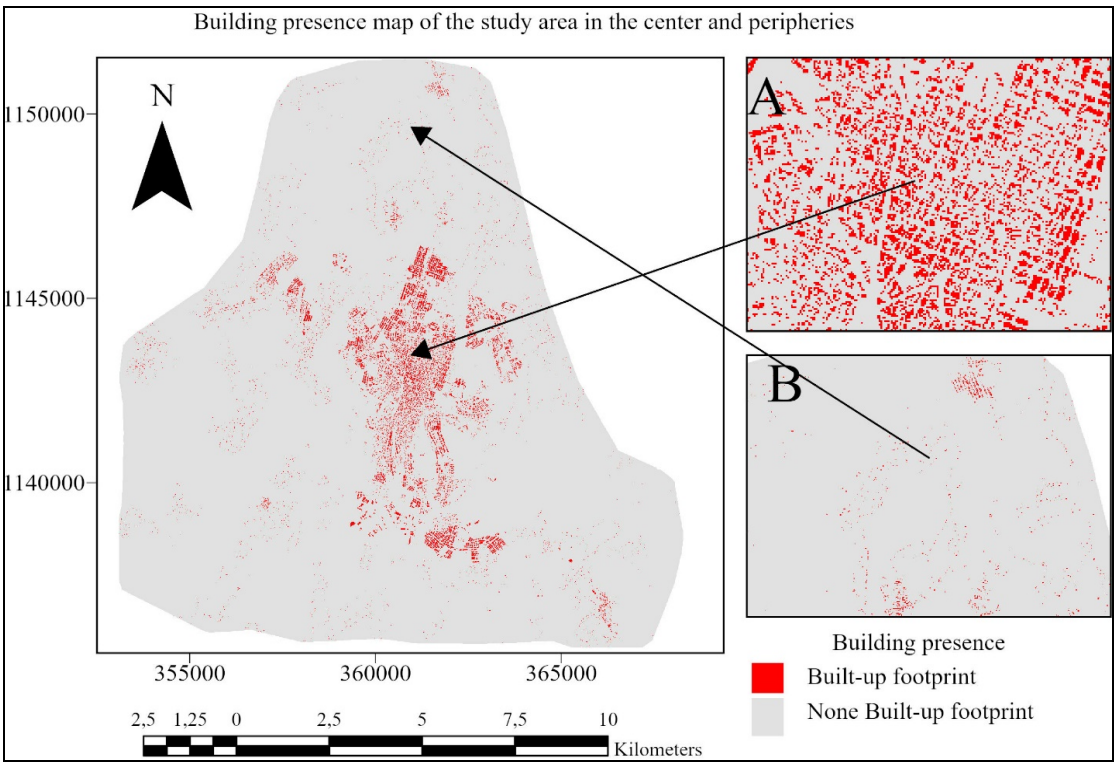


Figure 2: Building footprint presence of Debre Markos extracted open buildings collections using GEE.

Finally, about 25,000 random points were generated within the Debre Markos city map. The values of all 26 variables are extracted for these poins to create training data.

Variable Category	Representation	Variable name	Type of data	Source
Dependent Variable	BP	Building presence	Binary	Open buildings
Government regulatory variables	LVG	Land value grade	Discrete	DM municipality
	BHZ	Building height zoning	Discrete	DM municipality
Socio-economic variables	LV	Land value	Contentious	DM municipality*
	RPPU	Rental price per unit	Contentious	From 385 survey data*
	HHI	Household income	Contentious	From 385 survey data*
	AHH	Household Affordability	Contentious	From 385 survey data*
	HHS	Household size	Contentious	From 385 survey data*
Geographical variables	Slope	Slope	Contentious	DEM from GEE
	Elevation	Elevation	Contentious	DEM from GEE
	Aspect	Aspect	Contentious	DEM from GEE
	Hill shade	Hill shade	Contentious	DEM from GEE
Proximity and accessibility variables	DWA	Distance from worship areas	Contentious	From Google Earth**
	DfD	Distance from drainage line	Contentious	DM municipality**
	DPS	Distance from primary school	Contentious	DM municipality**
	DSS	Distance from secondary school	Contentious	DM municipality**
	DSL	Distance from street lite	Contentious	DM municipality**
	DRN	Distance from road network	Contentious	OSMnx**
	DPLS	Distance from police stations	Contentious	DM municipality**
	DMC	Distance from Market Center	Contentious	DM municipality**
	DHC	Distance from the Health Center	Contentious	DM municipality**
	DfG	Distance from green spaces	Contentious	DM municipality**
	DPG	Distance from playing ground	Contentious	DM municipality**
	DCC	Distance from the city center	Contentious	Google Earth **
	WLD	Water line density	Contentious	DM municipality ***
	RND	Road network density	Contentious	OSMnx***
	DD	Drainage line density	Contentious	DM municipality ***
Note: After collecting the raw data, we preprocessed it. *Indicates the variable in which the values were interpolated to have a continuous value in the map area. ** indicates that the Euclidean distance has been computed to the point of interest. *** indicates line density was calculated. All data were resampled to a raster width of 10x10 meters.				

Table 1: Variables selected for this study based on literature review and classified in four categories.

3.3 Model specification

This research aims to identify the determinants of urbanization by modeling the presence of building footprints. Since our data indicate that the presence of a building footprint is binary, logistic regression was adopted for the econometric model and extreme gradient boosting (XGBoost) for machine learning. Logistic regression is a generalized linear model, based on the assumption of linearity. It models the probability of

observing binary responses (0 or 1) for the response variable (Starbuck, 2023; Shahri et al., 2021). XGBoost performs well even with unbalanced data. Logistic regression on the other hand performs poorly on unbalanced datasets (Shahri et al., 2021). However, interpreting the logistic regression model results is easier that interpreting the XGBoost model (Pesantez-Narvaez et al., 2019).

Hyper parameter	Search space	Description
No. of estimators	200, 300, 500, 800, 750, 1000, 1500, 2000	Number of boosting rounds
learning rate	0.001, 0.01, 0.025, 0.05, 0.075, 0.2, 0.3, 0.4, 0.5, 0.6	Learning rate of model
Max depth	9, 10, 11, 12, 13, 14, 15, 16	Maximum depth of the trees
Min child weight	4, 5, 6, 7, 8, 9	Minimum sum of instance weight in a child
Gamma	0.1, 0.2, 0.3, 0.4	Minimum loss reduction for further partitioning
Subsample	0.5, 0.6, 0.7, 0.8, 0.9	Ratio of training data used per tree
Colsample bytree	0.6, 0.7, 0.8, 0.9, 1.0	Ratio of columns subsampled per tree
Objective	binary: logistic	Objective function for optimization
Booster	gbtree, gblinear	Boosting method used
Eval metric	Auc	Area under the curve from the AOC curve for data validation

Table 2: Search space for hyper parameter for XGBoost Model (source: Kmen et al., (2024)

Both models were implemented in Python. In binary logistic regression, data were transformed using the standard scalar method. Then, the multicollinearity test was performed using the Variance Inflation Factor (VIF). Based on the VIF results, several variables are highly correlated. The VIF values above 10 are dropped from the model (Cheng et al., 2022). For XGBoost training, the data was split into test and training sets at 30% and 70%, respectively. A 10-fold validation with a randomized search was employed, with 500 iterations used to tune the hyperparameters.

After training of the model the best parameter were estimated as “subsample”: 0.6, “objective”: “binary: logistic”, “n_estimators”: 2000, “min_child_weight”: 8, “max_depth”: 11, “‘learning_rate”: 0.01, “gamma”: 0.3, “colsample_bytree”: 0.7, “booster”: “gbtree”.

3.4 Model Performance Evaluation

There are several performance measurements, such as R2, mean squared error, and Receiver Operating Characteristic (ROC) curve. However, its usage depends on the nature of the model. Since our model is a binary prediction, the ROC curve and AUC are selected to evaluate the model's performance, as Nakas et al. (2023) elaborated. Ideally, the ROC curve should touch the top-left corner, increasing the area under the curve and indicating better accuracy (Nakas et al., 2023). ROC curves have been used to compare different models (James et al., 2023). ROC is an outstanding method for estimating a model's quality by comparing a binary map (actual) with a probability map for the likelihood of change (Mustafa et al., 2018).

The AUC is a direct and convenient overall measure to evaluate the model’s performance (Zou et al., 2012). Eventually, it is summarized into a single number (Nathalie Japkowicz & Mohak Shah, 2011). If AUC is less than or equal to 0.5, the performance is no better than chance (James et al., 2023). If it is 1, it indicates perfect classification (Mustafa et al., 2018). Therefore, the value of RUC should lie between 0.5 and 1, howver a value approches to 1 have best performance, indicating that the model is better than random discrimination.

According to Nathalie Japkowicz & Mohak Shah (2011), RUC is defined as,

$$RUC = \frac{\sum_{i=1}^{|Tp|}(Ri-i)}{|Tp||Tn|} \quad (1)$$

where Tp ⊂ T and Tn ⊂ T are, respectively, the subsets of positive and negative examples in test set T, and Ri is the rank of the i^{th} example in Tp given by classifier f.

4 RESULT

Figure 3 shows the correlational analysis of the spatial variables. Red numbers indicate a strong relationship, blue numbers a weak relationship. Obviously, the proximity variables are strongly correlated. The proximity distances increase or decrease simultaneously. This is because infrastructure and social services are concentrated around specific locations. For instance, health centers, water lines, market centers, schools, and worship areas are built near roads, street lights, playing grounds, and the city center. Green spaces are established near roads in the city center.

Figure 3 also depicts the correlation between building presence (BP) and the predictor variables. Building height zoning (BHZ), land value (LV), rental price per unit (RPPU), household affordability (AHH), elevation, water line density (WLD), road network density (RND), and drainage density (DD) are positively correlated. The remaining variables, for example, land value grade (LVG), household income (HHI), household size (HHS), slope, distance from market center (DMC), distance from health center (DHC), distance from playing ground (DPG), and distance from the center of the city (DCC) are negatively correlated.

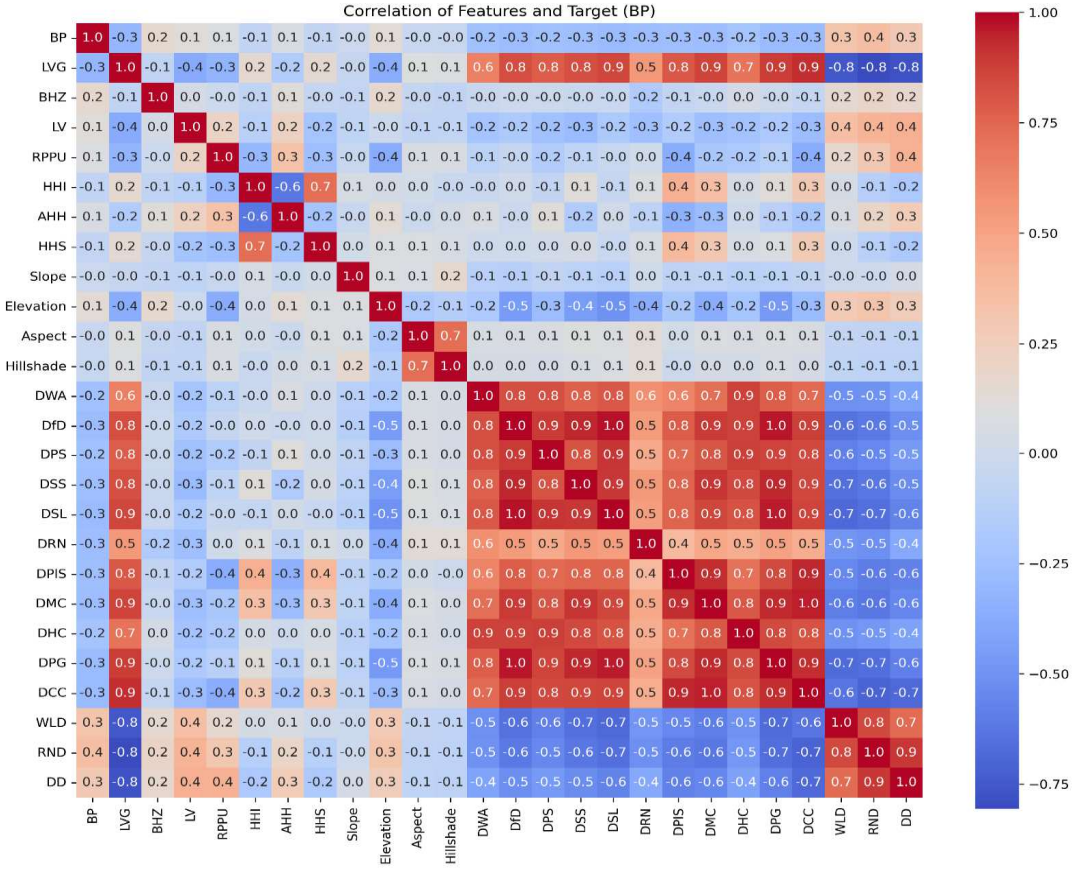


Figure 3: Correlation of variables.

As illustrated in Figure 3 of the ROC curve, the performance measures for the two models are: XGBoost scores 0.82 and logistic regression scores 0.73. In both models, AUC exceeds 0.5, which means the models perform better than random guessing. However, XGBoost performs better than a binary logistic regression in this case.

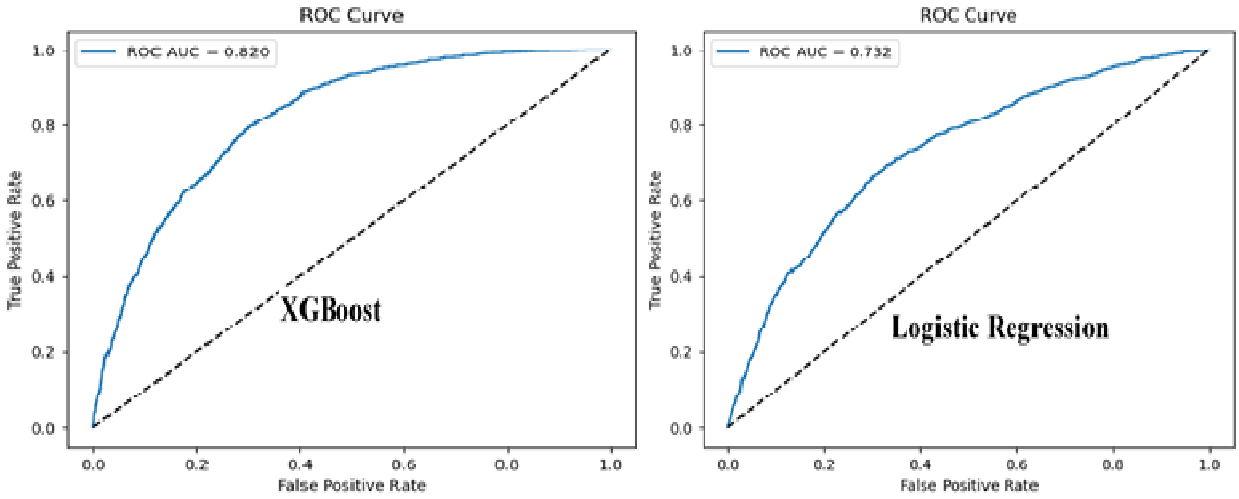


Figure 4: ROC curve of the two models.

Feature	Coefficient	Odds Ratio	Marginal Effect	p-value
Constant	-1.567	0.209		0.000*
DRN	-0.572	0.564	-0.046	0.000*
DPlS	-0.321	0.725	-0.012	0.000*
BHZ	0.284	1.328	0.000	0.000*
WLD	0.234	1.263	0.014	0.000*
DSS	0.149	1.161	0.082	0.001*
AHH	-0.109	0.897	-0.010	0.000*
HHI	-0.087	0.917	-0.016	0.005*
DWA	-0.086	0.917	-0.004	0.039**
Slope	-0.085	0.918	-0.010	0.000*
DHC	-0.083	0.920	-0.033	0.082***
Elevation	0.071	1.073	0.001	0.016**
HHS	0.071	1.073	0.012	0.009*
DPS	0.029	1.029	0.021	0.577
Hill shade	0.013	1.013	0.012	0.643
Aspect	0.004	1.004	0.002	0.888
LV	-0.002	0.998	-0.000	0.914
RPPU	-0.002	0.998	-0.012	0.921

Table 3: Logistic regression result, which shows the significance of variables (*represents variables that are significant at p <0.01, and ** represents variables that are significant on p<0.05, and *** represents variables that are significant at p<0.1)

Nine of the 26 variables were dropped from the model due to multicollinearity. Table 3, shows the results of the logistic regression. DPlS, BHZ, WLD, DSS, AHH, slope, and HHS are significant variables at (p<0.01), DWA and elevation are significant at (p<0.05), and DHC is substantial at (p<0.1). However, DPS, hill shade, aspect, LV, and RPPU are not significant determinants of building footprint presence. An increase of DRN, DPlS, AHH, HHI, DWA, Slope, and DHC affect the likelihood of building presence by reducing the probability of a building footprint. However, increasing values in BHZ, WLD, DSS, Elevation, and HHS raise the likelihood of a building footprint.

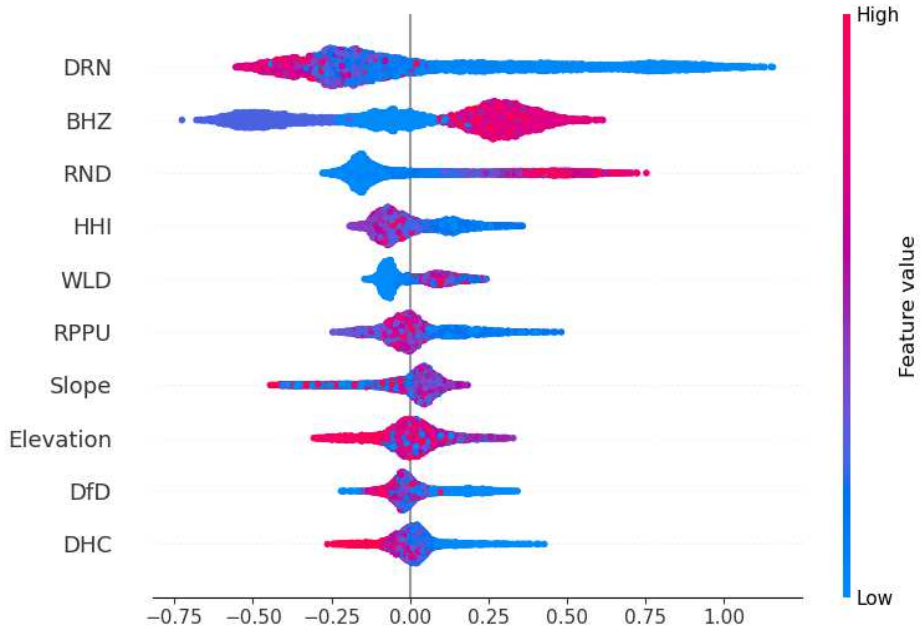


Figure 5: Top ten Shapley values of a feature that shows the impact of the variable on the model output from XGBOOST

”Shapley Additive exPlanations (SHAP) adds global and local interpretability to ML-based models by computing the marginal contribution of each feature” (Movsessian et al., 2022). This SHAP value is used to understand the feature contribution to the result. According to the SHAP values of XGBoost (see Figure 5), distance from road (DRN), building height zoning (BHZ), road network density (RND), household income (HHI), water line density (WLD), rental per unit price (RPPU), slope, elevation, distance from green spaces (DfG), and distance from health center (DHC) are the ten variables that influence the likelihood of building presence most. DD, LVG, DCC, DMC, AHH, DWA, DSS, hill shade, DPG, and DPS are contributing the least to the model output.

5 DISCUSSION AND IMPLICATIONS

The purpose of this study is to identify the spatial determinants of urbanization using building footprints. To meet the objective of this study, econometric logistic regression and the machine-learning model XGBoost were employed. The results reveal that XGBoost outperforms binary logistic regression.

Off-government regulatory variable building height zoning (BHZ) is one of the significant variables in the binary logistic regression, with a positive association with the likelihood of building presence. An increase in building height increases the likelihood of building availability. The XGBoost result also confirms that the BHZ is the second most contributing factor for determining the building presence. From this, we can see how local government regulations affect urbanization, shaping and expanding cities. The effect of policy on urbanization is also documented (Braimoh & Onishi, 2007).

Household income (HHI), household housing affordability (AHH), and household size (HHS) are significant socio-economic variables in a binary logistic regression model. Household income is inversely correlated with the presence of a building footprint and is the fourth contributing factor in the XGBoost model. As income increases, the household needs more space and can afford the commuting costs to the city center. Thus, they can search spaces outside the city center. Housing affordability is a significant factor affecting the probability of a building footprint, with the likelihood decreasing as household affordability increases. However, there are high commuting costs. For many, houses are only affordable outside the city center, where buildings are relatively compact. Household size has a positive coefficient: an increase in household size increases the likelihood of building presence. From these, it can be inferred that socio-economic factors are determinants of urbanization in shaping the presence of buildings, whether compact or sparse.

Among the topographical variables, elevation and slope are significant factors that affect the likelihood of building in urban areas. According to this study, these two variables are among the top contributors to the XGBoost model. Similarly, in the binary logistic regression model, elevation is positively associated with the presence of a building footprint. A slope negatively affects the likelihood of building and urbanization is expanding at the plateau of the city. As the slope increases, it exposes the site to runoff, increases maintenance and construction costs, and makes infrastructure expansion difficult. Therefore, topography has an effect on urbanization by shaping the urban expansion.

Among the proximity variables, DRN, DPlS, AHH, HHI, DWA, and DHC affect the likelihood of building presence; a one-unit increase lowers the probability of a building footprint. However, WLD and DSS, have increased the likelihood of a building footprint. In addition, the results from XGBoost indicate that DRN and RND are the most influential variables for the likelihood of building footprint.

Urbanization depends on the expansion of road infrastructure and the distribution of social services, such as markets, health centers, and places of worship. The effect of distance to roads on urbanization and urban expansion has been documented in several studies (e.g., Mustafa, Heppenstall, et al., 2018; Chen et al., 2016; Sarkar & Chouhan, 2020). The effects of policy and proximity variables are documented in Braimoh & Onishi (2007). Furthermore, the topography of the land, such as slope and elevation, and socio economic facors has also determined the urbanization that shapes the pattern of buildings and the city's directional growth. As it has also been documented by Jing et al. (2022). The effect of road density on urban expansion was explained by Hofmann & Wan (2013). Therefore, urbanization is determined by the interplay of government policies and regulations, geographical features, accessibility to infrastructure and social services, and socio-economic factors.

6 CONCLUSION

In this study, correlational analysis of the variables was employed. Several variables were found to be strongly correlated with each other. This analysis extended to examine the relationship between building presence and 26 independent variables. Binary logistic regression was employed to assess the statistical significance of the independent variable and to facilitate a more straightforward interpretation. The XGBoost machine learning method was used for its predictive power and to draw the contribution of the variables to the model using SHAP values. According to the model's performance metrics, XGBoost performs better than logistic regression. Of the independent variables, distance to road, building zoning, and road network density are the most determinate factors of urbanization.

This study has the following limitations:

- Due to the availability of open building data, this study is cross-sectional. However, it would be more generalizable if it included different periods.
- The socio-economic data are interpolated from the survey of 385 respondents; the result would be good if the data is based on the detailed survey of the population
- The land value data is interpolated from the hundreds of parcel values

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Spatial Manifestation of Planning Culture in Graz: Understanding Planning Processes and their Influence on Public Space Design

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1 ABSTRACT

The design of public space plays a central role in the fight against the climate crisis. The growing number of public space transformation projects in European cities reflects their potential to increase urban quality of life, drive forward the mobility transition and make the built environment climate-fit. These three aspects are interconnected through the notion of design quality. Considering the climate crisis, incorporating climate adaptation measures is no longer optional in good public space design. At the same time, such measures can enhance the user experience and improve the quality of stay. – two characteristics encouraging active forms of mobility.

However, public space transformation projects often undergo intensive, complex and long-lasting planning phases, that frequently involve substantial design changes. To prevent these changes from diminishing design quality, it is necessary to understand them precisely – particularly how and why they occur.

In this study, we further develop existing research on decision-making processes within the city administration of Graz by examining the design implications of these decisions. We approach an in-depth understanding of design changes during the planning phase by investigating the development of eight public space transformation projects in Graz – from competition to implementation. This investigation is based on students work from the elective course "Spaces of Mobility" in the Architecture program at Graz University of Technology. In this course, students analyzed planning documents (in particular competition entries) and the implementation of the corresponding projects.

By comparing the results of these analyses, we identified patterns in the changes to the designs that reveal key design-relevant elements of the local planning culture, such as priority setting and action routines in the planning process. Consequently, we were able to identify measures to prevent loss of design quality during the planning phase. Applying these measures can contribute to developing a planning culture that enables climate-resilient and adaptive design of public spaces, promoting the mobility transition.

Keywords: public space, design, urbanism, transformation, planning culture

2 INTRODUCTION

As the central field where climate-related challenges and urban transformation intersect, the design of public space holds huge potential in addressing the climate crisis.

Firstly, climate adaptation and mitigation can be integrated into public-space design in many ways. Combining technical solutions with thoughtful design enables reducing heat island effects through additional greening (Oláh 2012), decreasing risks from heavy rainfall events through permeable surfaces (Kron et al. 2019), and facilitating efficient rainwater utilization through sponge city elements (Arbeitskreis Schwammstadt 2024) – to name only a few. At the same time, all these measures are capable of improving microclimate and providing attractive meeting places. In this way, they can help to reduce the shortage of consumption-free recreational areas – a problem not exclusive to Austria (IBA Vienna 2022; Grün Stadt Zürich 2019). Yet there is an (international) tendency to cut back on green infrastructures when public spaces are redesigned (Mel 2017, Hansen and Pauleit 2014), and landscape architecture expertise is underrepresented in Austrian competition and planning procedures (IBA Vienna 2022).

Secondly, public space design strongly influences behaviors linked to environmental harm. It shapes the use of public spaces and thus has a direct impact on mobility behavior (Papagiannakis and Vitopoulou 2015; Banister 2007). Monofunctional road spaces designed solely for motorized private transport permit only this one – particularly environmentally harmful – form of mobility. Furthermore, they generate additional mobility flows, as everyday activities such as social contact, local recreation, leisure activities or sports require a change of location to facilities built specifically for this purpose. By contrast, public spaces with high quality of stay offer a place for all these functions, thus reducing the number and length of daily

journeys and promoting the use of active – and climate-friendly – forms of mobility such as cycling and walking. Once people are accustomed to using them, they are also more likely to maintain this habit in less inviting spaces (Blitz and Lanzendorf 2020). These spaces thus contribute to achieving the Austrian and European goal of a mobility transition (City of Vienna 2019; BMK 2021; European Commission 2020).

Thirdly, the design of public spaces influences consumer behavior. Public spaces with a high quality of stay contribute to a healthy local economy as they increase visitor frequency and length of stay (ZAM et al. 2025) and thus the use of local consumer services. In doing so, they strengthen local production, small-scale businesses and short supply chains (Bendiks and Degros 2019).

Given this multitude of advantages, it is hardly surprising that the number of public space transformation projects is increasing. However, many innovative (re)design concepts fail to be realized or lose much of their ambition during the planning process. As a result, the goal of changing the use of public spaces is not achieved to its full potential. At the same time, understanding what led to that particular outcome is difficult due to the complexity and length of these planning processes (Wolfram et al. 2019). It remains unclear where, why and how quality is lost in the process. This knowledge is nevertheless crucial to develop countermeasures.

A first step towards identifying the moments of and reasons for the quality loss in planning processes of public space transformation was taken by a previous study investigating the transformation of Kaiserfeldgasse in Graz (Bauer 2025). Building on research on planning culture in German-speaking countries (Helmholz 2023; Klammer 2022; Sondermann 2016), the study examined changes in actor constellations and the distribution of decision-making powers in the planning process, as well as the resulting changes in the design. The results showed that, in the process, a reduction in public space design quality occurred, and that barriers and obstacles in the planning process arose equally from technical, legal, and administrative side. In addition, the study revealed elements of planning culture (namely action routines and thought patterns – cf. ARL 2018) of the city administration that led to the identified quality-reducing design changes.

The present study builds on and further investigates the insights generated by this existing analysis. It examines the nature of design changes that occur in a larger set of public space (re)design projects in Graz, and thus deepens the understanding of planning processes and how planning culture influences public space design. It focuses on finding patterns in design changes, which enable the development of measures to prevent loss of design quality.

3 METHODOLOGY

The study results described below are based on a statistical and content analysis of data generated during a course at the Institute of Urbanism at Graz University of Technology in the winter semester of 2025/26, under the direction of Sabine Bauer. Together with 15 students from the Architecture program, we examined a total of eight public space transformation projects in Graz.

3.1 Project selection

All eight projects are located in the city of Graz. They were designed between 2011 and 2023 and implemented between 2012 and 2024.

The project selection was based on the following criteria: timeliness, relevance and visibility (e.g., recognizable by media presence), relation to mobility and availability of planning material. To depict the spatial effects of the negotiation process regarding the details and implementation of a (from designer's perspective) finalized design, we aimed to use material from an early yet well-developed design stage.

Half of the projects were conducted through public planning competitions.[1] For this group of projects, the competition-winning plans formed the dataset for the analysis. Only when the available competition material lacked detail, did we use planning documents from later planning stages. The other half of the projects were

[1] Annenstraße (Competition: Neugestaltung Annenstraße, 2011, Winner: Mettler Landschaftsarchitektur), Margarete Hoffer Platz (Wohnbebauung Graz Wiener Straße, Bebauung inkl. Platzgestaltung, 2015, Schwarz.Platzer.Architekten.ZT GmbH), Nikolaus-Harnoncourt-Platz (Smart City Graz Mitte – Baufeld Nord, 2018, Nussmüller Architekten ZT GmbH) and Bertha von Suttner Platz (Graz City Gate, 2014, Scherr + Fürnschuss Architekten & Groszstadt Architekten with DI Waltraud Körndl)

carried out without a competition process and were assigned directly.[2] The extent to which the project implementations differed from the competition results or planning documents varied by case, regardless of whether a competition had taken place or not.

3.2 Spatial Analysis

The analyses comprised several parts. First, the planning materials were examined using structured content analysis. Then, the built spaces were mapped and compared with the planning documents. The comparison enabled us to identify and visually represent the differences between planning and implementation. All visual representations followed strict graphical guidelines to facilitate comparison. The resulting plans show all elements of the public space design grouped into the three categories Green and Blue Infrastructure (represented in green), Mobility Infrastructure (blue), and Quality of Stay and Aesthetics (orange; including seating and leisure furniture, lighting, flooring, litter bins, etc.). The focus of each plan is to show the changes between the design in the analyzed planning document and the built (implemented) design.

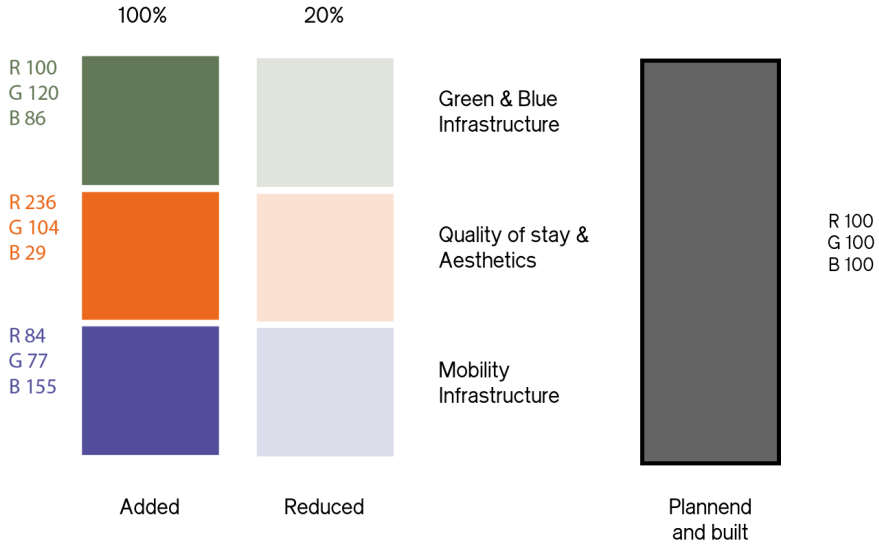


Fig. 1: Graphical guideline for the spatial analysis

To highlight these differences, a second graphical code was used in addition to the color scheme (green, blue, orange): elements added to the design stage captured on the analyzed planning documents were shown in dark colors (dark green indicates added green and blue infrastructure, dark blue added mobility infrastructure and dark orange added elements that increase quality of stay and/or aesthetics). Elements that were planned but not implemented were shown in light, transparent colors (light green, light blue and light orange). Elements that were included in the planning document and were also implemented were shown in dark gray (see Figs. 1 and 2).

3.3 Public Space Quality Assessment

The students then conducted a design evaluation of the versions shown in the analyzed planning materials and of the implemented projects using a catalog of public space quality criteria. This catalog is based on the Public Space Quality Index developed at the Singapore-ETH Center[3] in 2020 (He et al. 2020; Herthogs 2025) and consists of the following 16 criteria: Aesthetics, Orientation, Human scale (and reference), Light/lighting, Smell, Sound, Space for active use, Space for passive use, Space for social interaction, Flexibility (flexible use), Inclusivity, Pollution, (Traffic) Safety, Security, Thermal comfort and Ecology/metabolism (see Table 1). The assessment was carried out using an anonymous online questionnaire

[2] Lendplatz (plan author: verkehrplus, 2020), Obere Neutorgasse (Artgineering, 2023; integral, 2024), Leonhard Superblock (ZWOPK Landschaftsarchitektur Rode Schier Wagner OG, 2023/2024) and Zinzendorfgasse (bauchplan, 2023; bauchplan & verkehrplus 2022)

[3] Work done by P. He and P. Herthogs, (Future Cities Laboratory, Singapore ETH Centre, ETH Zürich, Singapore), M. Cinelli (Future Resilient Systems, Singapore ETH Centre, ETH Zürich, Singapore), L. Tomarchio and B. Tunçer at Future (Singapore University of Technology and design, Singapore), described in (He et al. 2020) and shared in personal correspondence with Pieter Herthogs in 2025 (Herthogs 2025)

with a school grading scale of 1 to 5 (1 = very good, 2 = good, 3 = satisfactory, 4 = sufficient, 5 = insufficient). The results thus reflect the participating students' perceptions of how the projects' quality developed during the planning processes across all 16 criteria.

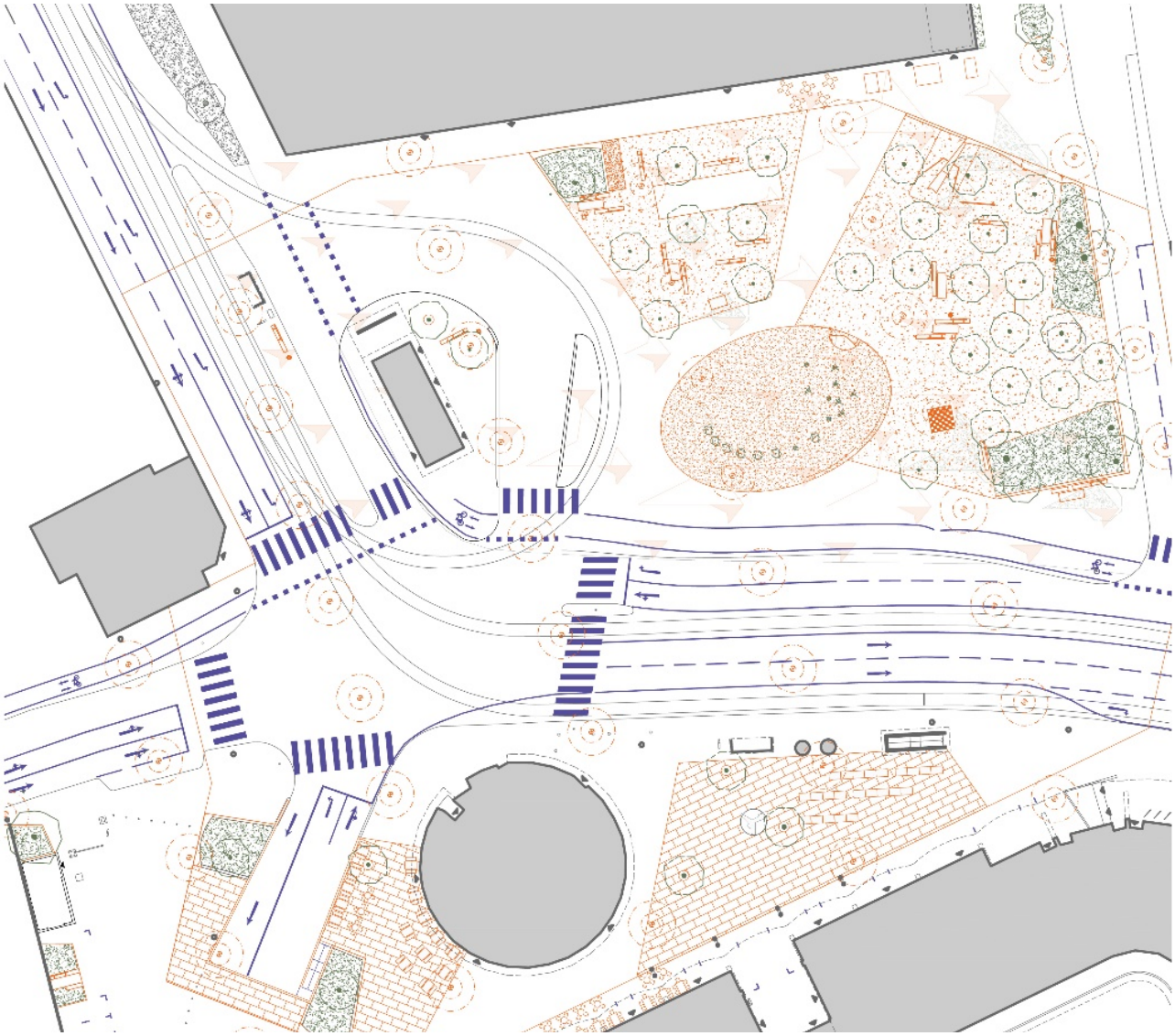


Fig. 2: Graphic example: Spatial analysis plan for Bertha von Suttner Square; The dark blue color of the ground markings indicate that they were added to the design in the process. The same applies to the surfaces structure, furniture, and overhead lights in dark orange and the green areas in dark green. The triangular pattern on the pavement of the square has not been implemented and is therefore shown in very light orange. Plan authors: Matija Pekic, Daniel Unterrainer

3.4 Identification and categorization of main changes

In the final step, main changes in the design of each project were distilled, listed, and categorized. The data provided an overview of all main changes in the analyzed projects during the planning phase grouped into the categories Greenery, Surface material, Mobility, Parking, Furniture, Form, and Accessibility (see Fig. 4). Cross-referencing these categories with the public space quality criteria (see Fig. 5) generated additional insights into the consequences of the identified changes. The resulting data allowed comparisons between individual projects and enabled us to draw conclusions about the full sample of public space transformation projects in Graz. On this basis, we were able to identify patterns in design changes. These patterns revealed four central issues, each indicative of key design-relevant elements of the local planning culture, such as priority setting and action routines in the planning process (see Fig. 5).

	Public space qualities criteria	Description
1.	Aesthetic	• low effort maintenance • location specific design, fitting overall project appearance, materials, furniture and vegetation form a whole • simple design, spatial clarity, haptics
2.	Orientation	• signs and marking for different users and modes of transport • remarkable points of reference that help wayfinding and meeting
3.	Human scale (and reference)	• Proportions of the dimensions of the space, sense of enclosure • walkability and human centered street design • presence of heritage
4.	Light(ing)	• Balance between level of light and light design, light distribution • Appropriateness of the lighting for the function of the respective space and its function and users • Natural light: pleasant consideration of orientation and seasonal sun path • Artificial light: pleasant consideration of light color and temperature
5.	Smell	• Presence and balance of sources of pleasant smells (such as greenery, water features, natural materials) • Reduced unpleasant smells (e.g. organization and distribution of smelling and smell sensitive functions, vegetation as natural barriers, placement and design of garbage areas / pins, natural ventilation and air flow)
6.	Sound	• Distance to traffic • fountains that smother noises / conversations
7.	Space for active use	• Supports active engagement of people and invites to physical activities (areas and equipment for sports / play / exercise, interactive water features, interactive green features such as climbing trees, sand, gras, furniture for multifunctional use)
8.	Space for passive use	• Comfortable seating (not only benches, implies surfaces that are raised from the ground) • Opportunities for „people watching"/interesting views • Presence of trees, green, water • Shelter from the elements
9.	Space for social interaction	• Grouping of seating • Shelter from the elements • Opportunities for cummunal / group activities / play / eating or drinking together • Opportunities for exchange of goods / market
10.	Flexibility (flexible use)	• Space for different activities, not strictly predefined • users can improvise and uses or rearrange urban furniture
11.	Inclusivity	• opportunities for play and learning, places to rest and for social interaction, spaces without compulsion to consume, walkability • accessability; Tripping hazards, walkability of surfaces, with of walkways, quality and safety of paths and crossings
12.	Pollution	• Protection from (traffic) pollution – air quality, smells and noise
13.	(Traffic) Safety	• Prevention of accidents occuring • Enough space for different users of the space, no barriers or tripping hazards on cycling paths or walkways • Where different modes of transport meet: enough, safe crossings and clear orientation and guidance especially for fast modes of transport • Puffer between different modes next to each other (e.g. cycling path next to a parking strip)
14.	Security	• Knowledge or evidence of past crime, Knowledge or evidence of measures to protect security • Presence of fear spaces (dark, empty, poorly maintained, overly eclosed spaces)
15.	Thermal comfort	• Temperature, humidity, exposure of the space • Presence and balance of shading, greenery, water elements, infiltration surfaces, materials and colors
16.	Ecology / metabolism	• infiltration surfaces and systems, rain water management • Biodiversity – diverse plants and possible habitats for different kinds of animals • Use of low-ecological-footprint materials, Materials and systems that enable the circular economy

Table 1: Criteria used for the public space quality assessment.

4 FINDINGS

The results described below were distilled from all analyses described above and represent the main findings of the study.

4.1 Public Space Quality Assessment

Looking at the Public Space Quality Assessment for all eight projects analyzed, we found that some aspects were more likely to improve during the planning process, while others were more likely to worsen (see Fig. 3). The most frequent decline in quality between the analyzed planning material and implementation was observed in the aspects of Sound, Pollution, Spaces for passive use, Inclusivity and Aesthetics. In contrast, positive developments were more frequently diagnosed for the aspects of Spaces for active use, Flexibility, Traffic safety, Security, Light/Lighting and Ecology/Metabolism.



Fig. 3: Results of Public Space Quality Assessment.

As the two aspects Sound and Pollution are related to traffic volume and type, their poor rating suggests that the conditions for motorized traffic were frequently enhanced in the planning process. The decline in the quality for the aspects of Spaces for passive use and Inclusivity can be interpreted as a trend towards reducing non-consumer-oriented collective areas. The decline in Aesthetics scores is probably due to the reduced use of high-quality materials for furniture and flooring. Three out of the four projects that received negative Aesthetics ratings were found to have undergone main design changes related to material choices.

These noticeable trends can be classified as indicators regarding priority setting and action routines in the planning and implementation process. Also, the improvement of the three aspects of Traffic safety, Security and Light/Lighting likely reflect a prioritization of safety aspects in the planning and implementation process.

The positive assessment of the development of Ecology/Metabolism is surprising, as it contradicts the findings of the spatial analysis of main design changes within the same projects (see 4.2.1). This discrepancy may be attributed to the fact that this component of the study relies on subjective evaluations by individuals (the students participating in the course), which may be influenced by personal bias (see 5.1.2). It is also possible that the assessment of this aspect has been influenced by the fact that (looking at the built space) the

implementation of all projects resulted in an increase of green infrastructure compared to the situation before the redesign – even if the amount of implemented green infrastructure was less then originally planned. Disproportionately positive perception of (in fact minor) improvements to green infrastructure would also be in line with public-perception studies that indicate broad support for urban greenery at street level, even if the greenery is limited to small interventions (eg., Wolf 2005).

4.2 Main Design Changes

In total 37 design changes were identified across all projects, which were then categorized and examined in detail. The following findings were distilled:

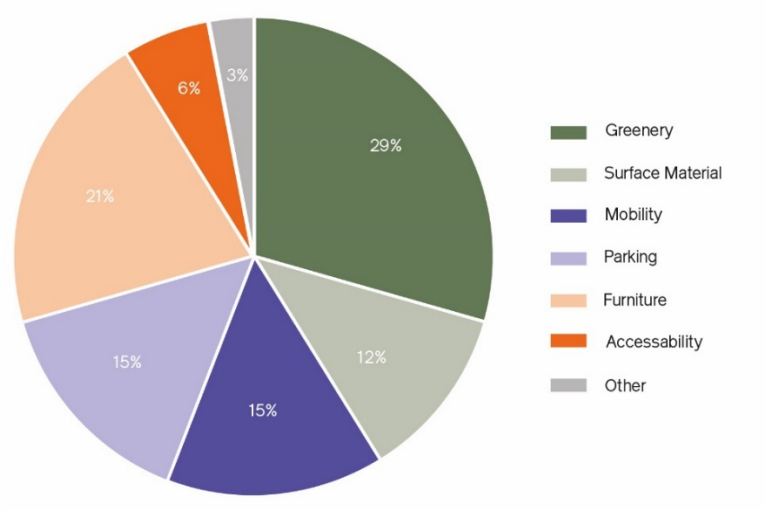


Fig. 4: Categorization of identified main changes.

4.2.1 Green infrastructures

It is significant that each project examined showed at least one main change relating to green infrastructures. Nearly one third of all identified design changes relates to the category of Greenery. The majority (almost three quarters) of these changes entailed reductions in green infrastructures such as trees, green/unsealed surfaces and biodiverse vegetation. One out of five changes in the planning process of the projects examined represent reductions in green infrastructures. The most frequently mentioned change was “fewer (grounded) trees”. A smaller share (8%) of all main changes increased green areas („more/bigger green areas“).

4.2.2 Mobility

15% of all identified changes related to Mobility concern mobility circulation (including prioritization of modes, routing, and route guidance). Half of these resulted in prioritization of motorized individual transport. All projects with circulation changes showed lower scores in Inclusivity suggesting that ambitions to invert the mobility pyramid were reduced during the planning process, with implications for perceived inclusivity.

One out of three projects examined showed circulation changes, indicating that this aspect is frequently adjusted during the planning process. Given that most public space redesign projects in Graz are led by the transport planning department (Bauer 2025), a focus on mobility during the planning phase and implementation is to be expected. At the same time, the evidence suggests that traffic planning – like open space planning – is often involved relatively late and not consistently integrated into conceptual design from the outset. This appears particularly common in competition based projects, as three quarters of the projects with circulation changes belong to this group.

4.2.3 Parking

As with mobility, results related to Parking show that a substantial share of design changes have reassigned space to motorized private transport. Although most changes in this section added bicycle parking spaces, more than one third increased the number of car parking spaces.

4.2.4 Surface material

Surface material changes accounted for 12% of all identified design modifications. In most cases, specified materials were replaced by less expensive alternatives (e.g., asphalt). In two out of three of such projects, the quality assessment indicated a reduction in Aesthetics, while one project showed no change. None of the identified modifications replaced a surface with a higher quality alternative. Overall, these findings indicate that surface related changes were predominantly used as a cost saving instrument and were generally associated with an aesthetic downgrade.

4.2.5 Furniture

Approximately 21% of all design changes concerned Furniture. Nearly half of these changes reduced seating elements. Smaller shares added seating elements, altered their design or reduced waste facilities. All projects with reduced seating recorded lower scores in Spaces for passive use and Spaces for social interaction, indicating a reduction in the quality of stay.

4.2.6 Accessibility

Less frequently mentioned changes concerned Accessibility. These changes were evenly split between decreases and increases in accessibility.

5 LIMITATIONS AND FURTHER RESEARCH

To contextualize the findings of this study and their transferability, we discuss its limitations and outline areas for future research.

5.1 Heterogeneity of the analyzed material

The empirical analysis drew on eight projects from Graz. While the sample size is adequate for an exploratory study within the 2010–2025 timeframe (see Section 3.1), the underlying planning materials varied across cases (e.g., competition entries vs. design development plans) and in their level of detail. These differences may reduce comparability between cases and introduced variation in the assessment of design quality, which may qualify the breadth of inference.

Future research could minimize heterogeneity by relying on planning documents from a single planning phase to ensure a consistent level of detail. For instance, a sample composed exclusively of open space competition submissions would reduce variability. Given that such competitions in Graz are relatively rare, broadening the geographic scope to include small and medium-sized towns across Austria (and potentially beyond) would support stronger comparative analysis.

5.2 Size and composition of the assessment panel

The quality assessment was conducted by a relatively small group of 15 architecture students (bachelor's and master's levels) at TU Graz (see Section 3). Although the participants were trained in architecture and spatial design, the modest sample size may limit the robustness of the results; individual rater bias cannot be ruled out, and the academic profile of the panel may not fully reflect professional practice perspectives. We partially addressed this by using a standardized instrument.

Increasing both the number and diversity of assessors – and including practitioners with expertise in public space design (e.g., urban designers and landscape architects) – would allow testing and verification of the findings. Complementary approaches such as qualitative expert interviews or moderated workshops could further triangulate the results.

5.3 Spatial limitation and generalizability

The study focuses exclusively on cases from Graz, which suggests limits of the transferability of the findings to other urban contexts. Replicating the study in other medium-sized Austrian or European cities would build a comparative dataset to assess how local planning cultures and regulatory frameworks influence public space design outcomes.

Additional insights on national and international transferability could be obtained through qualitative expert interviews or moderated workshops that compare interpretations across contexts.

6 DISCUSSION

The analysis of design changes revealed the following central issues and related indicators of priority setting and action routines in the planning process of public space transformation projects in Graz. In general, all the projects examined improved the quality of the space relative to the situation before the redesign. However, the data also shows that most projects lost ambitious improvements that were originally planned during the planning process. The data clearly shows which categories are at particular risk of losing quality during the planning process and enables the following central issues to be identified that form the basis for developing countermeasures.

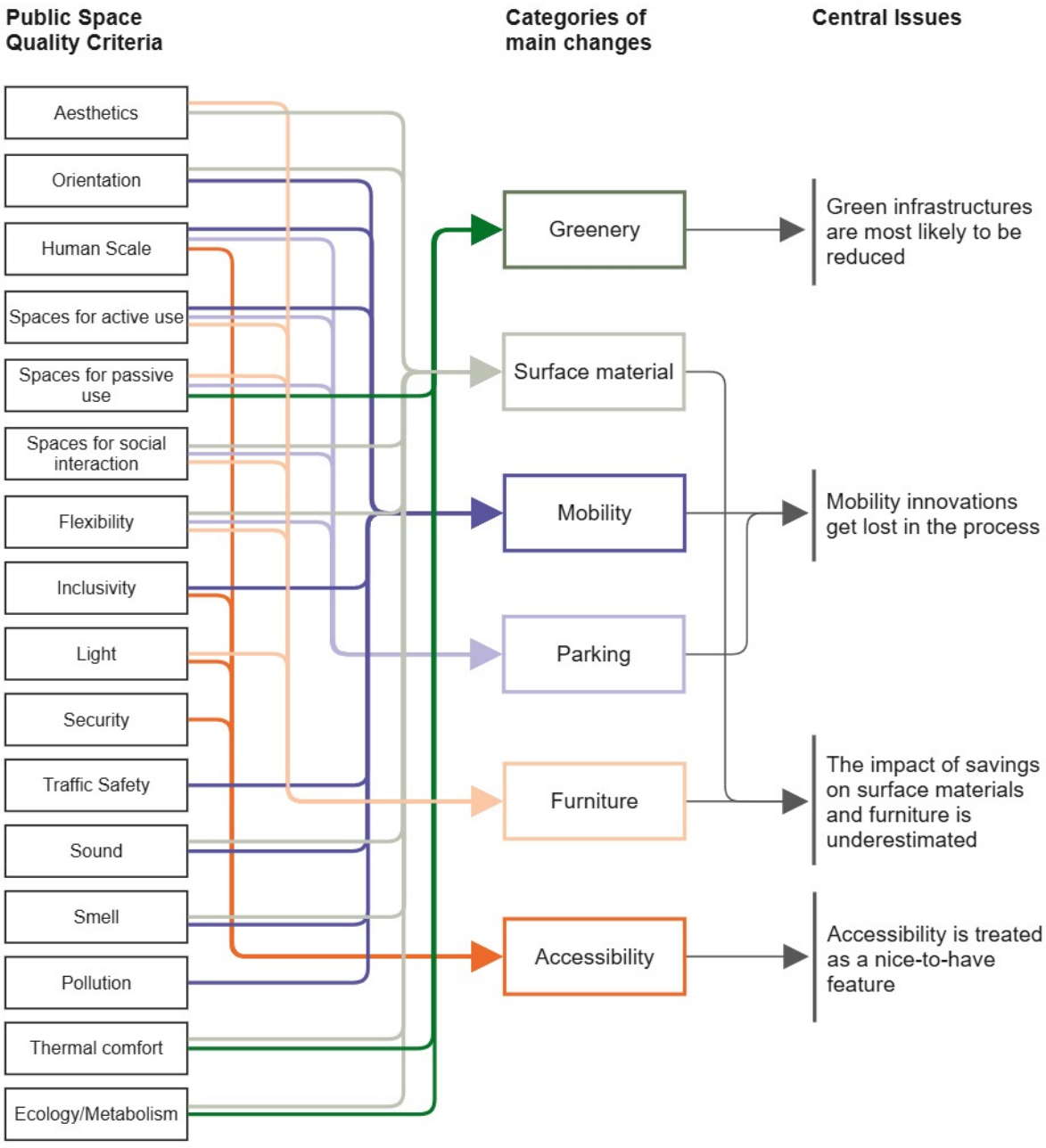


Fig. 5: Cross-referencing: Public Space Quality Criteria, Categories of changes and Central Issues.

6.1 Green infrastructures are most likely to be reduced

The large share of design changes affecting green infrastructure suggests either a lack of planning in the early design stage (as when the examined planning documents were drawn, many aspects of the green infrastructures had not yet been decided or specified) or that green infrastructures are particularly often subject to cutbacks during the planning process.

Both possibilities can be seen as indicators of priority setting in the planning process that disadvantages green infrastructures and thus conflicts with climate protection goals. This is consistent with international studies, that identify the same trend towards the reduction of green infrastructure in international transformation processes and highlight the risk of a resulting loss of quality. (Mel 2017, Hansen und Pauleit 2014).

Another possible reason for this is a lack of awareness of the need to plan open spaces and particularly green infrastructures. This is reflected in the fact that competitions were held for only half of the projects considered for this study. In three out of four of these, buildings and open spaces were included in the competition. However, in none of these cases public space was designed to the same level of detail as the architecture. In one case, there was hardly any identifiable design for it. In only one of the analyzed projects the competition focused on the public space, reflecting the underrepresentation of landscape architecture expertise in Austrian competition and planning procedures, and the late or lack of involvement, even in tasks relevant to open space throughout Austria (IBA Vienna 2022).

6.1.1 Recommendation

A greater focus on open space competitions and greater involvement of landscape architects in the process would be desirable to address the above mentioned imbalance. However, greater involvement must be backed up by an appropriate budget for planning and implementation of green infrastructures. These adjustments to the planning process align with the recognition of the importance of squares and streets as places for living, rather than “just” spaces of mobility (Bauer 2025; Bendiks and Degros 2019).

6.2 Mobility innovations get lost in the process

In the context of the general commitment to the mobility transition (City of Vienna 2019; BMK 2021; European Commission 2020), design changes towards more motorized individual traffic are no longer justifiable. Every opportunity to reduce climate-damaging forms of mobility and promote active ones must be used. Nevertheless, the data shows that a considerable proportion of projects undergo such changes that are often justified by technical and legal norms. However, the case of Kaiserfeldgasse shows that those responsible within administrative processes have the power to break long-established action routines within the applicable guidelines (Bauer 2025).

6.2.1 Recommendation

In „Try it out... Transformation! Learning from experiments and temporary interventions” (Degros et al. 2025), Barbara Russo and Eva Schwab emphasize the potential of temporary trials, pop-ups, and in-depth participation to empower administrative staff to change outdated planning routines. Following this idea, we recommend to introduce an administrative procedure that enables the simple and fast temporary testing of innovative mobility solutions (with structured stakeholder involvement) in order to enable their long-term implementation.

6.3 The importance of surface materials, furniture and accessibility is underestimated

We also found that seemingly minor changes and savings, such as the number of seating elements or surface materials used, can be decisive for the quality of the design, particularly with regard to the quality of stay. The results of the quality assessment for the criteria Spaces for passive use and Spaces for social interaction for projects with reduced material quality and/or furniture highlight their influence on this issue, which is closely related to the lack of high-quality, consumption-free areas in Austria and beyond (IBA Vienna 2022; Grün Stadt Zürich 2019). The data also shows that the issue of accessibility is not currently receiving sufficient priority or attention to create livable spaces for all. To make public spaces attractive and usable for as many people as possible, accessibility and quality of stay must be prioritized.

6.3.1 Recommendation

To achieve this, it is recommended that experts in design, inclusivity, and participation are involved throughout the entire planning process. In the long term, establishing an independent supervisory body to evaluate the designs with regard to specific issues such as accessibility, quality of stay and climate resilience would be a way to ensure quality.

The „Stadt Grün" Department of the City of Zürich can be used as a role model for such a quality assurance institution. Within the city of Zürich "Stadt Grün" reviews public space designs and must be consulted on all transformation projects. Before a design for a public space in Zurich is implemented, it must be approved by "Stadt Grün" to ensure that it aligns with the "Zürich Grüner" vision (Stadt Zürich 2026).

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Spatial Variability of Urban Land Price in Addis Ababa, Ethiopia

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1 ABSTRACT

Land value results from the site's desirability and economic value, as well as the availability of essential facilities. Understanding the spatial variation and determinants of prevailing land prices is crucial for urban planners and policymakers, given that land value, infrastructure availability, and proximity to public services are interrelated. To this end, we used 938 datasets of land lease prices per square meter from an online source. Additionally, geographic coordinates for each neighborhood association, the lowest level of city administration (Woredas), were collected from Google Earth. The data was analyzed using both statistical and geostatistical methods. The results of the Hedonic Pricing Model (HPM) indicate that plot area, land zone, land grade, building height, lease benchmark price, advance payment, and distance from the city center significantly influence the land prices. On the other hand, the spatial autocorrelation analysis revealed clusters of similar lease prices across various geographic areas of the city. High lease prices were concentrated in the city center, while the clusters of low land prices were randomly distributed at the periphery. The insights from this study contribute to the capture of land value resulting from public actions. Besides, the findings have practical implications for urban planners in making site-selection decisions for urban development projects and in fostering equitable and sustainable infrastructure provision. Moreover, real estate buyers, developers, and appraisers have different interests in land marketing. Thus, the study's findings are also crucial for understanding potential hot and cold areas of land value, as well as the driving factors of land value variability across the city.

Keywords: Spatial variation, Spatial autocorrelation, Land value, Urban planning, Hedonic regression

2 INTRODUCTION

Land is a source and a foundation for a city's development. The value of land, therefore, reflects its development potential and the availability of the neighborhood amenities (Sharma et al., 2024). On the other hand, land is a scarce and heterogeneous asset. Each plot of land is unique in its features, which drives the spatial variability of land values and makes the land market complex. Understanding the spatial patterns and determinants of urban land prices has become critical for urban planners to reallocate land resources and ensure equitable distribution of development activities (Binoy et al., 2022; Ma et al., 2020; Sharma et al., 2024; Ozalp & Akinci, 2017).

Prior studies have examined factors influencing land values worldwide using parametric and non-parametric methods. Agosto (2017) found that economic agglomerations, government policies, and neighborhood characteristics influence land value in Cebu City, Philippines. Bv et al. (2020) demonstrated that access to roads, closeness to nuisances, and disaster vulnerability significantly influence land value in Kerala, India. Neighborhood characteristics, particularly access to the main road of a plot, have affected land values in Gujarat, Pakistan (Aziz et al., 2021). On the other hand, Uju & Iyanda (2012) conducted a comparative analysis of locational and non-locational factors affecting land value in Onitsha, Nigeria. They found that non-locational factors are the most determinative factors of land value, and that land value does not decrease with distance from the city center. In contrast, Thiwanka & Wickramarachchi (2022) found that location, neighborhood characteristics, accessibility, and topographic features significantly influence the land value in Colombo, Sri Lanka. Overall, the above findings lead us to conclude that land value is affected by various locational and non-locational factors, underscoring the complexity of the land market. Besides, the country's socio-economic contexts and market conditions influence land values. The demand for urban land, especially in developing countries, has increased rapidly due to rapid urbanization and population growth (Tambe, 2025). For instance, in Addis Ababa, the capital of Ethiopia, urban land values are excessively high and unaffordable for a large share of the population, driven by rapid

urbanization and population growth (World Bank Group, 2019). As the country's capital, Addis Ababa hosts 25% of the country's urban population (Erena et al., 2017). According to the World Population Review (2024), the city's population is projected to increase by 4.44% annually, reaching 5.9 million by 2025. Furthermore, the influx of people into cities seeking employment and a better life has increased, placing a burden on the city administration to meet land and housing demand (Kebu et al., 2023).

In response to rapid population growth and urbanization, as well as the efficient use of urban land, the Addis Ababa City Administration Land Development Bureau has commenced land lease auctions. The Lease Proclamation No. 721/2011 aimed to ensure the equitable, efficient, and transparent delivery of scarce urban land to city residents. As a result, tender documents have been opened to the public, and interested parties can purchase them and compete on arm's length terms. As of today, six rounds of land lease auctions have been publicly conducted since 2023. Even if the land lease auction reflects the actual land price, resulting from competition among interested parties, the lease price still escalates rapidly (Miles, 2023). The land lease price is unaffordable, with pricing gaps and management challenges (Takele, 2018). Besides, the performance and implementation of the lease auction practice have been widely criticized for failing to meet the demand for urban land. As a result, informal settlements and squatting become the primary option for most urban dwellers in the city (Belete, 2017).

The vast portion of previous studies in the study area investigated the factors contributing to the escalation of urban land prices (Adamu, 2014; Belete, 2017; Takele, 2018; Weldegebriel et al., 2022), while few studies highlighted the determinant factors of urban lease prices in Ethiopia (Gebrihet & Pillay, 2020; Shita et al., 2022). However, there is limited research on the factors contributing to the spatial variability of land prices in Addis Ababa. Therefore, this study explores the determinants and spatial heterogeneities of land prices in Addis Ababa using both statistical and geostatistical techniques.

3 STUDY AREA DESCRIPTION

The study was conducted in Addis Ababa, the capital city of Ethiopia. Addis Ababa is characterized by rapid urbanization and population growth. According to the World Population Review (2025) report, Addis Ababa's population is estimated at 5.9 million. The city comprises 11 sub-cities: Gulele, Yeka, Lemi Kura, Akaki Kality, Bole, Kirkos, Addis Ketema, Arada, Kolfe Keraniyo, Lideta, and Nifas Silk Lafto, as shown in Figure 1.

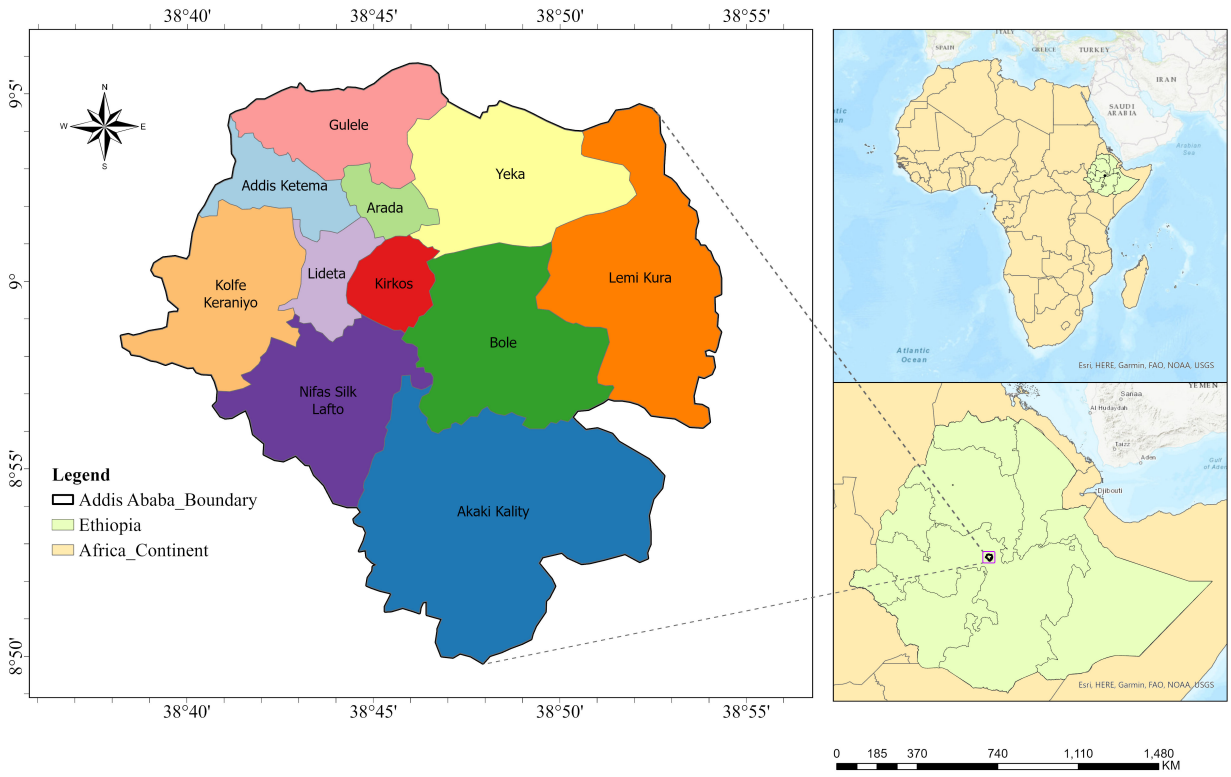


Figure 1: Locational map of the study area

4 METHODOLOGY

4.1 Data Sources and Method of Analysis

The study aims to identify and analyze factors affecting land prices in Addis Ababa using the hedonic pricing method (HPM). The study uses online data published by the Addis Ababa Land Development and Administration Bureau . The data contains lease price per square meter, plot area, lease benchmark price per square meter, land grade, land zone, land use type, down payment, building height, grace period, lease period, payment period end, potential, and a bid security (CPO). After data collection, these data are coded and edited for further descriptive, spatial, and statistical analysis. Additionally, the geographic centroids' coordinates of each district's woredas (districts) were determined using Google Earth. Furthermore, the distance of each Woreda to the city center (Menellik Square) was computed using ArcGIS Pro 3.4.

4.2 Hedonic Pricing Method (HPM)

Real estate prices are highly heterogeneous and are affected by a combination of structural, locational, and neighborhood factors (Ozalp & Akinci, 2017). As a result, the HPM is widely used to analyze the effects of the multidimensional nature of influencing factors on real estate prices (Sopranzetti, 2015). We employed the HPM to examine the effects of independent variables on lease prices. The HPM is summarized as follows.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \cdots + \beta_n X_n + e \qquad (1)$$

Where

Y is the lease price per square meter,
β_0 is the intercept,
$\beta_1 \ldots\ldots \beta_n$ are coefficients (parameters),
$X_1 \ldots\ldots X_n$ are independent variables,
e is the error term

4.3 Spatial Autocorrelation (Global Moran's I)

Spatial Autocorrelation is a Spatial Statistics technique used to describe the spatial Autocorrelation of values, whether they are clustered, dispersed, or randomized, using Moran's I Index. In addition, the tool provides both z-scores and p-values for evaluating the significance of that index. Therefore, the Global Moran's I was employed to investigate the spatial pattern of land prices in Addis Ababa, assessing whether they are dispersed, randomized, or clustered. A Moran's I < 0 indicates a negative spatial correlation. The smaller the value, the greater the spatial difference; otherwise, the space is random when Moran's I = 0 (Esri, n.d.)

$$\text{Moran's I} = \frac{n}{S_0} \frac{\sum_i^n \sum_j^n w_{i,j} z_i z_j}{z_i^2} \qquad (2)$$

Where n is equal to the total number of features, $w_{i,j}$ is the spatial weights between feature i and j, z_i is the deviation of an attribute for feature i from its mean$(x_i - \bar{x})$, S_0 and is the aggregate of all the spatial weights:

$$S_0 = \sum_i^n \sum_j^n w_{i,j} \qquad (3)$$

The z_i score for the statistic is computed as:

$$Z_i = \frac{I - E[I]}{\sqrt{V[I]}} \qquad (4)$$

Where:

$$E[I] = -1/(n-1) \qquad (5)$$

$$V[I] = E[I^2] - E[I]^2 \qquad (6)$$

4.4 Spatial Statistics (Hotspot Analysis (Getis-Ord Gi*)) and Spatial Interpolation

The hotspot analysis is essential for identifying statistically significant clusters of high and low land prices across the entire city of Addis Ababa using the Getis-Ord Gi* method. The Gi* statistic returned for each feature in the dataset is a z-score. For statistically significant positive z-scores, the larger the z-score, the

more intense the clustering of high values (hot spots). For statistically substantial negative z-scores, the smaller the z-score, the more intense the clustering of low values (cold spots) (Esri, n.d.). The formula for Getis-Ord Gi* is given in equation 7.

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{[n\sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \quad (7)$$

Where x_j is the attribute value for feature j, $w_{i,j}$ where the spatial weight is between feature i and j. n is equal to the total number of features, $\bar{X}$ is the variable's mean across all locations (eq. 8), and S is the variable's standard deviation (eq. 9).

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{N} \quad (8)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (9)$$

After the hotspot analysis, the Inverse Distance Weighted (IDW) spatial interpolation technique were used for generating continuous data. Spatial interpolation is the process of determining unknown spatial data using known spatial data (Jia et al., 2018).

4.5 Variable Description and Measurement

The dependent variable is the lease price per square meter, and the nature of the explanatory variables is highlighted in Table 1.

Name of Variables	Variable code	Nature of Variables	Description and measurements of variables
Lease Price	LSE	Continuous	The amount bidders offered for a plot per m^2, measured in Ethiopian Birr.
Down Payment	DP_LSE	Continuous	It is an initial payment made by participants, measured in Ethiopian Birr. The minimum threshold payment made is 20% of the total price.
Area	AR	Continuous	Size of the plot measured in m^2
Land Zone	LZ	Categorical	Shows the location of the plot and is mainly related with availability of infrastructure and the land zone classified as Land Zone 1= center around central business district, Land Zone 2 = Transitional, Land Zone 3 = Peripheral
Land Grade	PG	Categorical	Shows the location of the plot related to proximity to main road and other infrastructure. Thus, Land grade of the plot is classified into five group's starts from Land Grade 1, up to Land Grade 5.
Land Use	LU	Dummy	The type of the Land Use (Mixed = 0, Business = 1)
Building Height	BH	Categorical	Land Use regulation for building heights, 1, for Maximum of G+1, 2, for Maximum of G+2, and n = Maximum of G+n)
Benchmark Price	BMP	Continuous	It's a minimum benchmark price set by the city administration to auction. It's measured by Ethiopian birr per m^2.
Down Payment of Benchmark Price	DP_BMP	Continuous	The down payment of the lease benchmark price is the initial payment set by the city administration, which is 40% of the bench mark price. It's measured by Ethiopian birr per m^2.
Grace Period	GPY	Continuous	It's a time frame given to the leaseholder after the payment of the benchmark price to relieve them from payment before the start of the annual lease payment.
Lease Period	LP	Continuous	The lease termination period, which is measured in years
Lease Payment Period	LPPP	Continuous	It's a time frame given for the completion of the lease in a year
Potential	PO	Continuous	A capacity to develop the plot and show it in terms of Ethiopian Birr (ETB)
A bid security	CPO	Continuous	A bid security deposited in a lessee's bank account
Distance from Central Business District	DCBD	Continuous	The distance from the district's centroid point to the central business district. Which is measured in kilometers.

Table 1: Description of Variables

5 RESULT

5.1 Description and Determinant Factors of Lease Price

As shown in Table 2, the minimum lease price per square meter is 8,720.51 Ethiopian Birr (ETB), equivalent to 56 US Dollars (USD), and the maximum price is 470,422.5 ETB, equivalent to 3,024.25 USD. The average lease price per square meter is 52353.77 ETB, equivalent to 337.439 USD. In addition, the average plot area is 339.3185 m². The average benchmark price for the plot per square meter is 1324.268, and the average advance payment is approximately 582.02. The mean values of the bidder's potential and bid security are both 1021,201 ETB. The average distance from each woredas centroid to the city center is 10.55 kilometres.

Measurements	LSE	AR	DP_LSE	BMP	DP_BMP	PO	CPO	DCBD
count	938	938	938	938	938	938	938	938
mean	52353.77	340.07	43023.45	1334.73	533.89	1021201	1021201	10.55
std	34808.51	398.84	20562.57	376.17	150.47	1746831	474691.5	4.51
min	8720.51	75	4648.4	904.77	361.91	175000	36643.19	1.37
25%	36099.25	150	30750	1027.84	411.14	350000	85129.32	8.76
50%	46500	200	41500	1221.18	488.47	522666.7	142514.3	8.96
75%	57975	350	51008.38	1531.91	612.76	1073333	251840.1	15.29
max	470422.5	4798	311000	2213.25	885.3	35126000	8329566	18.14

Table 2: Summary Statistics for continuous variables

For categorical variables, Table 3 shows that 39.55% of auction plots were located in the transition zone, and 39.13% in the city's central areas. In comparison, 21.32% of the lease auctions were situated in the city's outlying areas. Additionally, mixed land use accounted for 99.47% of all auction plot leases in Addis Ababa.

Variable	Dummy Class	Freq.	Percent	Cum.
LZ	1	367	39.13	39.13
	2	371	39.55	78.68
	3	200	21.32	100
	Total	938	100	
LG	1	132	14.07	14.07
	2	140	14.93	29
	3	316	33.69	62.69
	4	41	4.37	67.06
	5	309	32.94	100
	Total	938	100	
LUT	0	933	99.47	99.47
	1	5	0.53	100
	Total	938	100	
BH	5	23	2.45	2.45
	9	841	89.66	92.11
	11	2	0.21	92.32
	14	2	0.21	92.54
	19	70	7.46	100
	Total	938	100	

Table 3: Summary Statistics for Categorical Variables

To evaluate the effect of the explanatory variables on lease price, we used the HPM. First, we checked the basic assumptions for model computation, such as data normality, multicollinearity, and independence of observations. Multicollinearity among the variables was assessed using the Pearson correlation coefficient (r) to determine the strength and direction of their relationships. The results are displayed in the confusion matrix (Figure 2). The Pearson correlation coefficient varies from -1 to +1, with the extreme values indicating a perfect negative or positive relationship between variables. As shown in the correlation map in Figure 2, several variables are highly correlated; therefore, the four variables Ln_DP_LSE, Ln_CPO, Ln_PO, and Ln_DP_BMP were removed. Additionally, the three continuous variables GPY, LP, and LPPP were excluded because they have a fixed effect on lease price. The Variance Inflation Factor (VIF) was also used to reduce the number of explanatory variables further (Cheng et al., 2022). Only variables with a VIF value of 10 or less were included (see Table 4).

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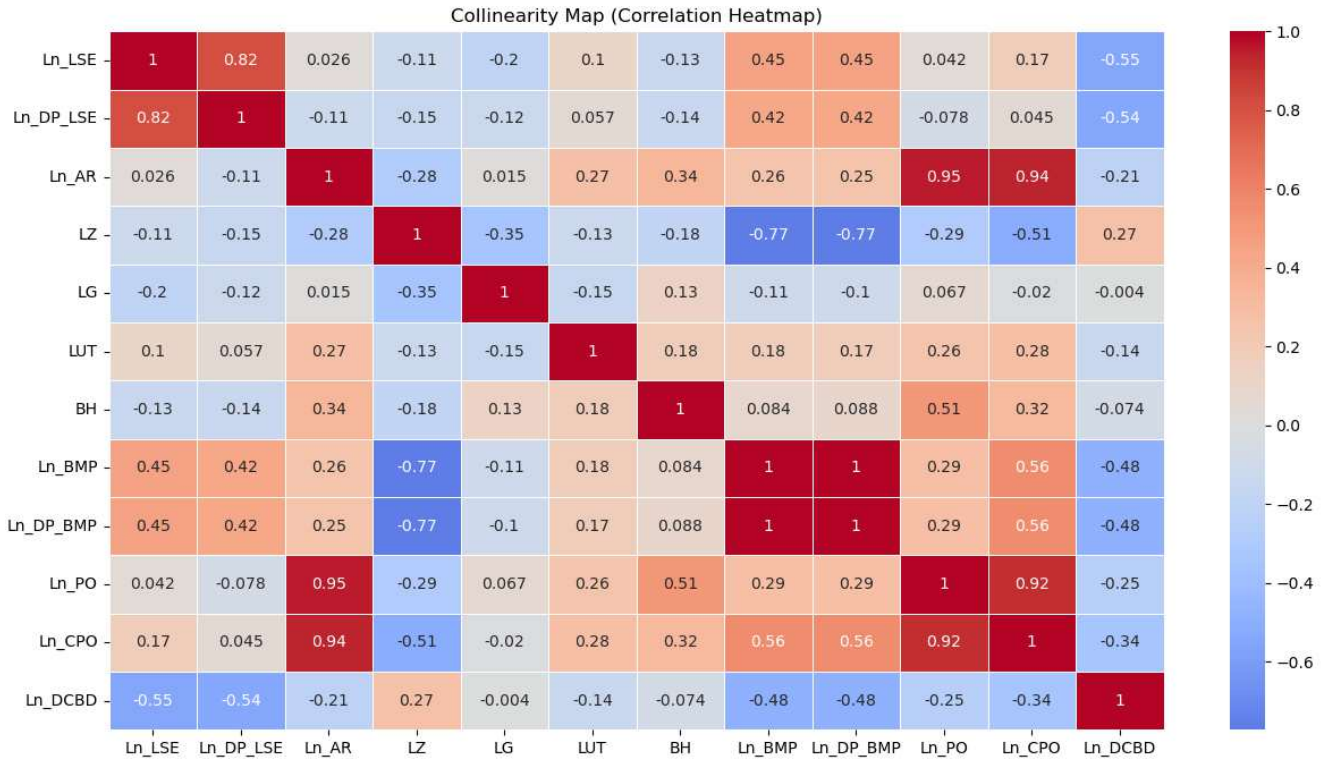


Figure 2: Collinearity Map (Correlation Heat)

Variable	VIF	1/VIF
Ln_BMP	5.78	0.172902
LZ	5.36	0.186737
LG	2.09	0.479242
Ln_DCBD	1.79	0.558529
Ln_BMP	1.78	0.562399
Ln_AR	1.38	0.725446
BH	1.19	0.840449
LUT	1.15	0.867915
Mean VIF	2.56	

Table 4: Variance Inflation Factor (VIF)

The normality test was performed after checking for multicollinearity. To do that, all continuous variables were converted to natural logarithms. This avoids the skewness and kurtosis effect of the variables. The residuals of the dependent variables, as shown in Figure 3, appear approximately normally distributed, and the points lie on the reference line in the Q-Q Plot, indicating normality of the data, even if a small deviation occurred on both upper and lower end tails. On the other hand, the residuals in the scatter plot of residuals (Figure 4) appear roughly normally distributed and look equally distributed on the x- and y-axes, which supports the test for heteroscedasticity.

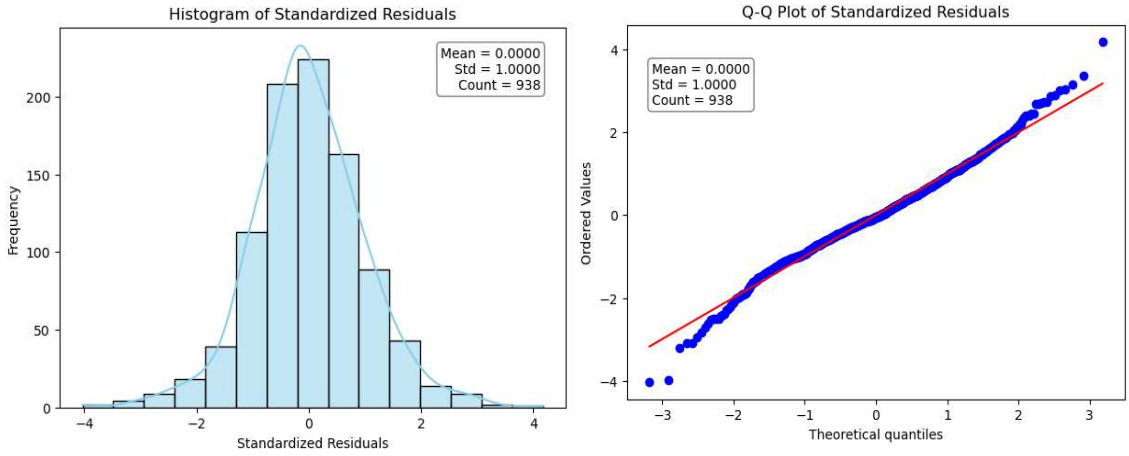


Figure 3: Normality Test: Histogram and Q-Q Plot

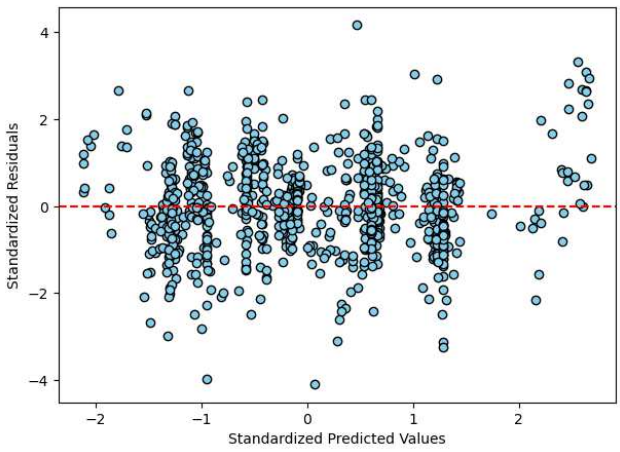


Figure 4: Scatter Plot of Residuals vs Predicted Values

The results of the HPM analysis indicate the statistical significance of the factors influencing lease prices. As illustrated in Table 5, all independent variables are significant factors influencing land prices in Addis Ababa: plot size, land grade, land use type, the level of building height (except BH with G plus 11), the benchmark price, and distance to the city center.

Source	SS	df	MS	Number of obs		938
				F(14, 923)		81.37
Model	126.7014	14	9.050097	Prob > F		0
Residual	102.6602	923	0.111225	R-squared		0.5524
				Adj R-squared		0.5456
Total	229.3616	937	0.244783	Root MSE		0.3335
Ln_LSE	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Ln_AR	-0.15406	0.020731	-7.43	0.000	-0.19475	-0.11338
LZ						
2	0.436006	0.052627	8.28	0.000	0.332724	0.539289
3	1.040004	0.081728	12.73	0.000	0.87961	1.200398
LG						
2	0.344578	0.054695	6.3	0.000	0.237237	0.451919
3	0.142654	0.039774	3.59	0.000	0.064597	0.220711
4	0.399349	0.069315	5.76	0.000	0.263316	0.535383
5	0.50691	0.056448	8.98	0.000	0.396128	0.617691
1.LUT	0.375203	0.110122	3.41	0.001	0.159084	0.591322
BH						
9	-0.72416	0.103004	-7.03	0.000	-0.92631	-0.52201
11	-0.33509	0.259049	-1.29	0.196	-0.84348	0.173306
14	-1.03825	0.249115	-4.17	0.000	-1.52715	-0.54935
19	-0.70989	0.100607	-7.06	0.000	-0.90734	-0.51245
Ln_BMP	1.536676	0.110314	13.93	0.000	1.32018	1.753172
Ln_DCBD	-0.37283	0.03023	-12.33	0.000	-0.43216	-0.3135
_cons	1.39728	0.899128	1.55	0.121	-0.36729	3.161853

Table 5: Hedonic Pricing Model

5.2 Spatial Variation of Lease Price in Addis Ababa

Land prices result from development activities and reflect urban structure. Therefore, land prices vary widely across space and are influenced by infrastructure availability, such as roads, and social factors (Tsutsumi et al., 2011). According to the second land lease auction in Addis Ababa, the highest land price of 470,423 ETB per square meter was recorded in Kirkos sub-city, near the city center. The Nefase Selk Lafto district had the lowest land lease price at 20,100 ETB per square meter. In the third round of the land lease auction, the highest price of 268,000 ETB per square meter was recorded in the Arada district. In contrast, the Akaki district had the lowest land lease price with 16,621 ETB per square meter. In the fifth round of land lease auctions, 265,000 ETB per square meter was recorded in the Kirkos district, while the Akaki Kality district recorded 8,720.51 ETB per square meter. Finally, in the sixth round of land lease auctions, the highest bid was 90,100 ETB in the Gulule and Nifas Selk Lafto districts, and the lowest, 23,721 ETB, was found in the Akaki Kality district. The results highlight the spatiotemporal and spatial variability of lease prices in Addis Ababa.

To understand the spatial patterns of land lease prices in Addis Ababa, we employed spatial analysis techniques, including spatial Autocorrelation and hotspot analysis, within a GIS. First, we adjusted the lease

price per square meter for inflation, accounting for the time value of money. This is because the second and third rounds of the lease auctions were conducted in 2024, while the fifth and sixth rounds were conducted in 2025. Next, we generated the centroid coordinates for each woreda (the smallest administrative district) of the city (see Figure 5). Afterwards, the adjusted average lease price per square meter was integrated for woredas. The spatial autocorrelation analysis (Figure 6) showed a cluster of similar lease prices in Addis Ababa. The Moran's I is 0.194618, which is greater than zero. The z-score value is 2.844184, and the p-value is 0.004453, which is less than 0.05. This indicates a concentration of similar values across the cities. Additionally, the statistical hot- and cold-spot areas of the lease price, highlighted on the spatial interpolation map, are shown in Figure 7. The Inverse Distance Weighting (IDW) hotspot analysis revealed significant hotspots around city centers, particularly in the Arada and Kirkos districts. In contrast, cold spots were identified in the city's periphery, in the Akaki Kality and Lemi-Kura districts. Moreover, the 3D visualization in Figure 8 shows the spatial distribution of the average lease prices of woredas in Addis Ababa. The city center shows higher land values than the peripheral areas, and the gap between the city center and the peripheral regions is larger.

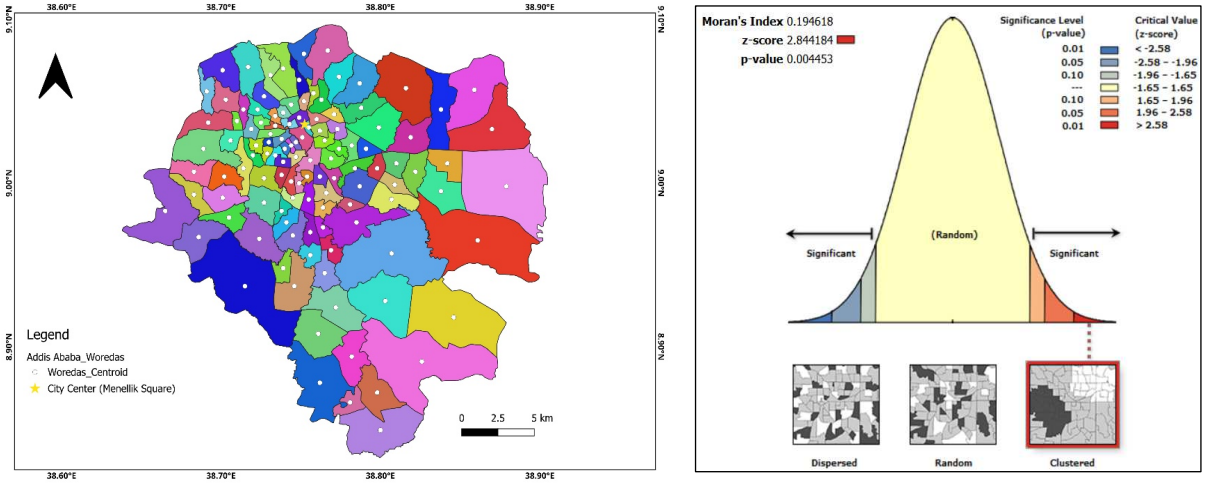


Figure 5: Addis Ababa's Woredas, Figure 6: Spatial Autocorrelation of Lease Price

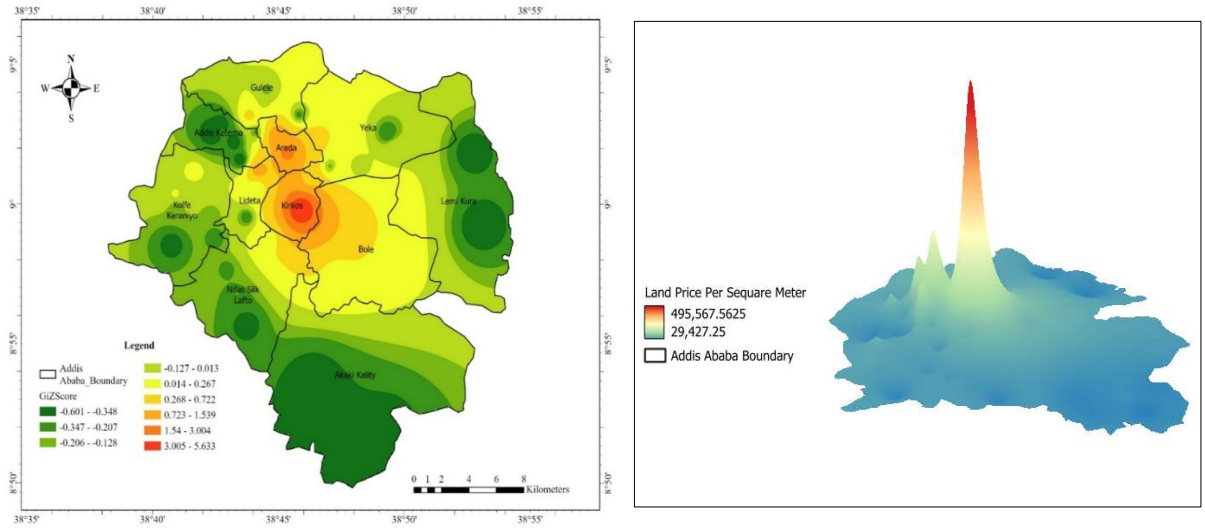


Figure 7: IDW Hotspot Analysis, Figure 8: 3D Visualization of Land Price

6 DISCUSSION AND POLICY IMPLICATIONS

This study investigates the determinants and spatial heterogeneity of land prices in Addis Ababa. The study found positive correlations between lease prices and plot area, land-use type, Compulsory Payment Order (CPO), Potential (PO), Lease Benchmark Prices, and Down Payments. Conversely, a negative relationship was identified between land zone, land grade, building height, and distance from the Central Business District (CBD), as shown in Figure 2. The results suggest that auctioneers are willing to pay more as the plot

size increases. However, bidders are less inclined to pay more for plots located farther from the city center, especially in transition and peripheral areas. Meanwhile, the Hedonic Pricing Model showed that plot size, land grade, land use type, building height, plot benchmark price, and location are key factors influencing land lease prices in Addis Ababa. This study's results align with a previous study by Weldesilassie & Gebrehiwot (2017), which suggested that the base price, plot size, location, grade, and auction period significantly impact land value. Similarly, Gebrihet & Pillay (2020) found a positive and significant relationship between the markup price and factors such as plot location, plot size, payment period, monthly income, access to basic services, land-use type, and the land-lease auction period. A study also indicated that distance to the city center, proximity to the main road, and access to healthcare facilities significantly influence land prices in Pekanbaru City, Indonesia (Pratiwi, 2025). Thiwanka & Wickramaarachchi (2022) demonstrated that locational factors, neighborhood characteristics, accessibility, and topographic features significantly affect land value in Sri Lanka. Moreover, the study findings showed the spatial variation of lease prices across different parts of the city. Significantly high land prices (hotspot values) were found in and around the city center, especially in Arada, Kirkos, and parts of the Bole and Lideta districts. In contrast, low values (cold spots) were seen in Addis Ketema, Akaki Kality, Lemi-Kura, Nifas Silk-Lafto, and Kolfe Keraniyo sub-cities. These spatial patterns indicate that location and accessibility influence price determination. The high land values in the city center may be due to infrastructure such as roads, parks, and essential amenities.

Understanding the determinants and spatial heterogeneity of land prices has practical implications for homebuyers, property developers, and urban planners. The study's findings help homebuyers make informed decisions about choosing neighborhoods by providing access to affordable land that meets their housing needs. Additionally, identifying hotspot and cold-spot areas of land value supports property developers in making evidence-based decisions regarding potential profits, development opportunities, and risk assessment (Miles, 2023). Moreover, the study's findings also support urban planners' understanding of how access to amenities and infrastructure development influence land value and the efficient use of urban land. This knowledge allows them to make decisions that promote equitable public infrastructure and capitalize on the increased land values generated by infrastructure projects, supporting sustainable urban growth and increasing urban revenue. Additionally, since urbanization in Ethiopia has been rapidly increasing over the past few decades, with an annual growth rate of 5.4%. The growth is expected to nearly double, reaching 40 million by 2030 (UN-Habitat, 2023). For example, according to the World Population Review (2024), the population of Addis Ababa is forecasted to increase by 4.44% annually, reaching approximately 5.9 million by 2025. Additionally, the influx of people into major cities seeking jobs and better opportunities has increased, putting more pressure on city governments to meet housing needs and exacerbating the challenge of providing urban land for housing (Kebu et al., 2023). Abubakar & Aina (2019) demonstrated that rapid urbanization in Nigeria requires the development of basic infrastructure, such as housing, roads, and public services. However, a funding shortfall remains a major issue in South African municipalities, impeding efforts to address infrastructure problems (Mazele & Amoah, 2022). Therefore, the government should create policies and strategies to allocate urban land effectively to meet housing needs and ensure the adequate and equitable provision of infrastructure for sustainable urban growth.

7 CONCLUSION

This study explores the determinants and spatial variations of land prices in Addis Ababa. The results from the Hedonic Pricing Model show that plot size, land grade, land use type, building height, benchmark price, and plot location are significant factors influencing land lease prices in Addis Ababa. The hotspot analysis indicates that land values are high in the city center and low in the city's outer areas. The plot's location significantly impacts its price. Plots near the city's Central Business District (CBD) are more expensive than those on the city's outskirts. The findings show the influence of both demand- and supply-driven factors on land lease prices. Auctioneers are willing to pay more for a plot in the city center than for one in peripheral areas, supporting the idea that location impacts price determination. Additionally, bidders take the plot's size into account when offering a premium.

Information about the main factors influencing land prices is essential for urban planners and policymakers to ensure efficient allocation of urban resources throughout the city. Additionally, understanding spatial differences can provide valuable insights into developed and undeveloped areas that require infrastructure,

helping optimize urban land use. The findings help urban planners understand the spatial variability and dynamics of lease prices, aiding decision-making for optimal resource allocation and development. However, the study has some limitations. We are not incorporating all woredas for analysis, and some have no lease auction prices because no plots in those woredas have been auctioned. This impacts the accuracy of the spatial interpolation maps in our results. Future research will address this gap by collecting additional data when new lease auctions become publicly available and by exploring the factors influencing lease prices and their spatial variabilities using advanced geospatial techniques, such as the Geographically Weighted Regression Model. Overall, based on the study's findings, the following recommendations are provided.

- Maximizing government revenue through land value capture. Information about land value maps is crucial for assessing the spatial variation in land values. Urban planners can gain insights into high and low lease prices and use them to inform decision-making to capture the increased value resulting from development activities.
- Expanding equitable access to public services and infrastructure. Urban planners should prioritize fair distribution of public services and urban infrastructure across different districts of the city to balance the attractiveness and accessibility of land.
- Enhancing land lease policies and ensuring that the lease system provides fair and transparent access of the urban land for residents from diverse backgrounds. Although lease prices result from arms-length transactions between parties, the system does not adequately address the needs of the majority of society seeking land. Therefore, the government should develop alternative methods to ensure access to urban land for low- and middle-income residents.

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🏆 reviewed paper

Stadtraumdiagnostik – Identifikation stressauslösender Faktoren öffentlicher Stadträume in Karlsruhe, Osnabrück und Würzburg

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1 ABSTRACT

Öffentliche Räume prägen seit jeher das Gesicht unserer Städte und bilden das Rückgrat des urbanen Lebens. In den vergangenen Jahrzehnten hat sich die Rolle des öffentlichen Raums jedoch stark verändert. Massive strukturelle Eingriffe und der steigende Verdichtungsdruck haben schließlich dazu geführt, dass der öffentliche Raum erheblich an Bedeutung verloren hat. Aus der menschlichen Perspektive wird er nunmehr vermehrt als negativ und stressintensiv wahrgenommen.

Um den Ursachen dieser negativen Wahrnehmung städtischer Räume nachzugehen, wurde mit der im Jahr 2022 begonnenen Studie „Stadtraumdiagnostik“eine Methode entwickelt, die es ermöglicht, Stressfaktoren in öffentlichen Räumen systematisch zu identifizieren und zu analysieren.Damit widmet sich der diagnostische Ansatz einem Themenfeld, das in der Stadtforschung bislang weitgehend eine Black Box geblieben ist. Die zentrale Innovation der Methode liegt in der Integration quantifizierbarer „harter“ Faktoren und qualifizierbarer „weicher“ Faktoren innerhalb eines einheitlichen analytischen Rahmens, der sogenannten „Stressorenmatrix”.

In diesem Beitrag werden die Untersuchungen der Stadtraumdiagnostik anhand von fünf Fallstudien dargestellt, die in den vergangenen drei Jahren in den deutschen Städten Karlsruhe, Osnabrück und Würzburg durchgeführt wurden.Darauf aufbauend präsentiert der Beitrag erste Erkenntnisse zu insgesamt zwölf untersuchten Faktoren, von denen sechs in den Fallstudien als Stressfaktoren identifiziert wurden:“EG-Zonen“, „Elemente“, „Straßenraumaufteilung“, „Verkehr“, „Ruhender Verkehr“ und „Akustik“.

Keywords: Stadtplanung, öffentlicher Raum, Stadtwahrnehmung, Neurourbanismus, Stressfaktoren

2 EINLEITUNG

2.1 Relevanz und Problemstellung

Der öffentliche Raum ist die tragende Struktur der europäischen Stadt: Er bildet die grundlegende Raumstruktur für das öffentliche Leben und prägt damit maßgeblich die städtische Kultur und Lebensqualität (Cozzolino et al., 2022; Deutscher Städtetag, 2006; Kostof et al., 1992). In den letzten Jahrzehnten hat sich seine Rolle jedoch stark gewandelt. Entwicklungen wie der autogerechte Stadtumbau der 60er-Jahre sowie derzunehmende Verdichtungsdruck haben den Charakter urbaner öffentlicher Räume erheblich verändert (Gehl, 2011). Aus dermenschlichen Wahrnehmung betrachtet haben diese Räume nicht nur erheblich an Attraktivität und Lebensqualität verloren, sondern sich sogar in die gegenteilige Richtung gewandelt (Krefis et al., 2018).Sie sind nunmehr lediglich Verkehrsflächen, die als „stressig” empfunden werden.

Um unsere öffentlichen Räume zurück zu menschengerechten Orten entwickeln zu können, ist es daher notwendig, die Problemlage aus der Perspektive des Menschen zu betrachten. In diesem Kontext konstatieren zahlreiche Forschungen, wie stark dieser Bedeutungsverlust mit negativen Wahrnehmungen und dem Empfinden von Stress zusammenhängt (Evans, 2003; Gado et al., 2024; Lederbogen et al., 2011; Mehran et al., 2024).Diese Phänomene sind klare Indikatoren einer ungesunden Stadt und verdeutlichen die Notwendigkeit, neuralgische, stressintensive Orte zu identifizieren und den Ursachen auf den Grund zu gehen.

Angesichts der hohen Komplexität sowohl der menschlichen Wahrnehmung als auch des urbanen Raums ist es in diesem Kontext unerlässlich, ganzheitlich zu arbeiten, und ein möglichst breites Spektrum möglicher Einflussfaktoren zu analysieren. Denn eine isolierte (z.B. verkehrsplanerische) Betrachtung von Einzelfaktoren kann immer nur eine Teilmenge der realen Situationabbilden und dementsprechend nicht ganzheitlich abbilden. Der vorliegende Beitrag nimmt sich dieser Aufgabe an und stellt die Methode „Stadtraumdiagnostik” vor, mit der die menschliche Stadtwahrnehmung systematisch erfasst werden kann. Die Methode verfolgt einen ganzheitlichen Ansatz, der verschiedene Umweltfaktoren analysiert und schließlich deren Einfluss auf die Wahrnehmung und das Stressempfinden ableitet.

2.2 Stand der Forschung

2.2.1 Identifikation negativer Stadtwahrnehmumgen („Stress")

Die Wahrnehmung seiner Umwelt ist tief in der ursprünglichen Lebensweise des Menschen verankert. Bei der Bewegung durch einen Raum ist der Mensch unterbewusst stetig damit beschäftigt, die auf ihn einwirkenden Umweltreize zu verarbeiten (Mehrabian, 1987). Demphysiologischen Stressmodellzufolge reagieren verschiedene Personendeshalb auf dieselben Reize (Stressoren) mit der gleichen körperlichen Reaktion (Selye, 1956). Im Verlauf dieser Stressreaktion setzt der Körper Stresshormone frei, die das autonome Nervensystem (ANS) aktivieren, um das Gleichgewicht der physiologischen Körperfunktionen (Homöostase) wiederherzustellen (Cannon, 1914). Messbare Veränderungen umfassen u.a. Modifikationen der Herzaktivität, der Schweißdrüsenaktivität sowie der Hauttemperatur(Boucsein, 1988; Chrousos et al., 1988).

Diese messbaren physiologischen Indikatoren einer Stressreaktion nutzt auch die hierangewandte Emotion-Sensing-Methode, umnegative Emotionen im urbanen Kontext zu detektieren und räumlich zu verorten.Die Methodewurde bereits in mehreren deutschen Städten sowohl beim Zufußgehen als auch beim Radfahren erfolgreich angewendet (N. Haug, Schmidt-Hamburger, et al., 2023). Das Verfahren zeichnet die beiden Indikatoren Hautleitfähigkeit und Hauttemperatur mithilfe eines Sensorarmbands (Empatica E4) auf.Die erfassten Daten werden dann über ein Smartphone mit dem entsprechenden GNSS-Signal (Global Navigation Satellite Systems) verknüpftund gespeichert (vgl. Abb. 1, links). In der anschließenden algorithmischen Auswertung der Messdaten wird Stress immer dann identifiziert, wenn die Hautleitfähigkeit kurzfristig ansteigt und die Hauttemperatur gleichzeitig abnimmt, also „kalter Angstschweiß" entsteht (Kyriakou et al., 2019). Die Ergebnisse werden anschließend in Form von Heatmaps visualisiert und zeigen anschaulich, an welchen Orten in der Stadt die Testpersonen Stress empfunden haben(vgl. Abb. 1, rechts).

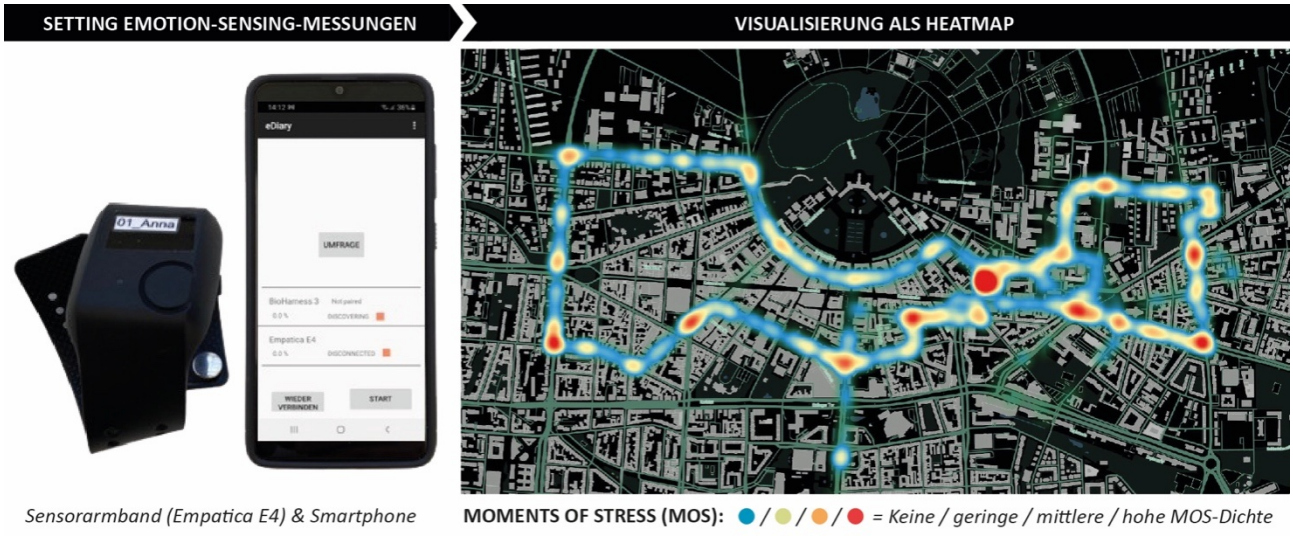


Abb. 1: Setting der Emotion-Sensing-Messungen und Visualisierung der Ergebnisse als Heatmap am Beispiel von Radfahrenden in Karlsruhe, Deutschland. Quelle: Eigene Darstellung nach Datenquelle Cape Reviso(HLRS, 2020).

2.2.2 Ursachenforschung & Einflussfaktoren

Im Kontext der Stressforschung befassen sich zahlreiche Arbeiten mit den Ursachen negativer Emotionen im urbanen Raumbzw. befassen sich im erweiterten Sinne mitdem Komfort im urbanen Rad- und Fußverkehr. Bei der genaueren Betrachtung fällt jedoch auf, dass dieses Forschungsfeld bislang stark von der Verkehrsforschung geprägt wird und sich deshalb primär auf die Analyse quantifizierbarer („harter") Faktoren konzentriert. Ein häufig angewendetes Verfahren für die Analyse solcher harten, messbaren Faktoren ist zum Beispiel das integrierte Erfassen von Verkehrsdichten und Bewegungslinien mithilfe intelligenter Kamera-Erfassungssysteme(Zeile et al., 2024). Mithilfe dieser Daten können stressintensive Orte innerhalb der Stadt identifiziert werden, an denen extreme Verkehrsdichten herrschen und bzw. oder es häufig zu sogenannten Beinaheunfällen, also dem Kreuzen von Bewegungslinien, kommt.

Qualifizierbare („weiche") Faktoren, deren Wirkung maßgeblich auf subjektiven Wahrnehmungen basiert und daher stark variiert, sind in der Ursachenforschung bislang hingegen wenig erforscht. Die existierenden

Arbeiten stammen hier größtenteils aus der Stadtforschung sowie der architektonischen und künstlerischen Praxis.Viele der Arbeiten aus diesem Kontext arbeiten unter der Annahme, dass diese weichen Faktoren meist zwar nicht im klassischen Sinne messbar sind, sich jedoch in Form von Mappings, Skizzen oder Fotografien dokumentieren lassen. Allen voran sind hier die frühen Wegbereiter Kevin Lynch und Robert Venturi zu nennen, die in den 1960er- und 1970er-Jahren verschiedene Formen des Mappings als zentrales Analyseinstrument zur Untersuchung wahrnehmungsprägender Faktoren öffentlicher Räume und Architekturen einsetzten(Lynch, 1960; Venturi et al., 1979).Weiterführend ist im Kontext der Analyse weicher Faktoren auch die Arbeit von Jan Gehl zu nennen (Gehl, 2011).In seiner Arbeit richtet Gehl den Fokus insbesondere auf die innerhalb des öffentlichen Raums ablaufenden Aktivitäten. Gehl beobachtet dabei, wie Menschen den öffentlichen Raum benutzen, und analysiert, welche Raumkonfigurationen, Möblierungen etc. welche Verhaltensweisen fördern oder hemmen. Seine Ergebnisse veranschaulicht er auf sehr visuelle Art und Weise in Form von fotografischen Dokumentationen und Skizzen.

2.3 Forschungslücke, Zielsetzung und Forschungsfragen

Der vorangegangene Abschnitt zeigt, dass negative Emotionen im urbanen Kontext anhandmessbarer physiologischer Indikatoren objektiv erfasst werden können. Die Ursachenforschung zu diesenurbanen Stresspunkten konzentriert sich jedoch aktuell noch sehr einseitig auf quantifizierbare („harte") Faktoren. Qualifizierbare („weiche") Faktoren, die ebenso prägend für die jeweilige Stadtwahrnehmung sind, werden nur selten miteinbezogen.

Die vorliegende Arbeit verfolgt deshalb das Ziel, erstmals quantifizierbare harte Faktoren sowie qualifizierbare weiche Faktorenin einem gemeinsamenGrundgerüst zu analysieren und damit vergleichbar zu machen.Hierfür bedient sich der Methodenansatz sowohl quantitativer als auch qualitativer Methoden. Damit setzt es sich der integrative Ansatz zum Ziel, Planende insbesondere in frühen Projektphasen mit einem Tool zu unterstützen, das die Bewertung der Situation aus der menschlichen Perspektive ermöglicht. Damit unterstützt die Methode die menschengerechte Transformation unserer Städte und fördert die Lebensqualität in urbanen Räumen.Vor diesem Hintergrund beschäftigt sich dieseArbeitmit den folgenden Fragestellungen:

(1) Was bedeuten negative Emotionen im urbanen Kontext, und wie können sie gemessen werden?

(2) Welche harten und weichen Untersuchungsfaktoren können die Komplexität realer öffentlicher Stadträume adäquat in einem Modell abbilden?

(3) Wie kann die räumliche Analyse unterschiedlicher quantifizierbarer und qualifizierbarer Faktoren gleichberechtigt in einem vergleichbaren Format abgebildet werden?

(4) Welche Faktoren stehen in Zusammenhang mit dem Empfinden von Stress?

3 KONZEPT

Das Konzept dieser Forschung basiert auf der Annahme, dass „Stress"im urbanen Kontext mittels sensorbasierter Messungen (Emotion Sensing) erfasst und räumlich lokalisiert werden kann. Entsprechend werden die Ergebniskarten einiger ausgewählter, vorangegangener Emotion-Sensing-Messungenals Grundlage herangezogen. Einige der dort identifizierten Stress-Hotspots werden als Fallstudien für die hier angestellte Ursachenforschung ausgewählt, sodass insgesamt fünf Fallstudien mit der „Stadtraumdiagnostik" untersucht werden.Die Fallstudien teilen sich auf drei deutsche Untersuchungsstädte wie folgt auf: K1 und K2 in Karlsruhe, O1 und O2 in Osnabrück undW1 in Würzburg.

Anhand dieser fünf Fallstudien analysiert der vorliegende Beitrag ein breites Spektrum quantifizierbarer „harter" und qualifizierbarer „weicher" Faktoren, was sich auch in der Vielfalt der eingesetzten Analyseverfahren und Erhebungsmethoden zeigt. Die Darstellung der Fallstudienuntersuchungen folgt einemneuartigen methodischen Ansatz, der den Vergleich der inhaltlich und methodisch heterogenen Analysen der Untersuchungsfaktoren ermöglicht. Dabei werden nicht nur quantitative und qualitative Aspekte, sondern auch datenbasierte und subjektive Dimensionen miteinbezogen und in einem gemeinsamen analytischen Rahmen zusammengeführt.

4 METHODENANSATZ

4.1 Datenerhebung: Untersuchungsfaktoren, Erhebungsansätze & Datenquellen

Die Zusammensetzung der Themenfelder und Untersuchungsfaktoren wurde mithilfe mehrerer experimenteller Testläufe in iterativen Schleifen erprobt.Eine detaillierte Beschreibung der Testläufe liegt in Form der Ergebnisdokumentationen der Studie „Decoding Stress" vor, die am Karlsruher Institut für Technologie durchgeführt wurde (Haug et al., 2023, 2024) und wird in diesem Beitrag nicht detaillierter Ausgeführt.Im ergebnis der Testläufe konnte der Analysegegenstand auf insgesamt 12 Untersuchungsfaktoren eingegrenzt werden, die sich in die fünf Themengebiete „Gebäude", „Freiraum", „Gestaltung", „Verkehr & Bewegung" und „Sensorik" gliedern. Mit dieser Auswahl soll ein möglichst dreidimensionales Bild der realen Situation abgebildet werden. Die fünf Themenfelder bündeln daher nicht nur Faktoren der gebauten Umwelt, sondern beziehen bewusst auch die olfaktorische und akustische Dimensionen der Stadtwahrnehmung mit ein.

Der Datenerhebungsplan gibt darauf aufbauend für jedes Themengebiet die zugehörigen Untersuchungsfaktoren, ihre Unterparameter, die Art des Analyseansatzes (quantitativ/qualitativ) und die zur Anwendung kommenden Erhebungsmethoden an. Tabelle 1 zeigt einen Ausschnitt des Datenerhebungsplans. Hinsichtlich der Erhebungsmethoden bzw. Datenquellen wurden mit den Testläufen drei grundlegende methodische Ansätze als zielführend identifiziert. In einigen Fällen wurden die Methoden auch miteinander kombiniert. Die drei Erhebungsmethoden sind:

A. Zweidimensionale Datengrundlagen:Ein Teil der Untersuchungsfaktoren kann mithilfe zweidimensionaler digitaler Datensätze aus der Vogelperspektive analysiert werden. Zu den primären Datenquellen zählen hier frei verfügbare OpenStreetMap-Daten, Luftbilder sowie Daten aus kommunalen Geoportalen.

B. Dreidimensionale Remote-Analysen:Für all jene Parameter, bei denen die Erfassung der dritten Dimension erforderlich ist, stellen dreidimensionale Remote-Analysen eine sinnvolle Erhebungsmethode dar. Hierbei wird vor allem auf Bildmaterialien aus der Straßenraumperspektive zurückgegriffen, die beispielsweise durch die Anbieter Apple Karten oder Google Street View bereitgestellt werden.

C. Vor-Ort-Begehungen:Ortsbegehungen stellen ein unverzichtbares Analyseinstrument für die Untersuchung der menschlichen Wahrnehmung verschiedener Parameter dar. Insbesondere gilt dies für die Analyse weicher Faktoren, die eine starke subjektive Komponente beinhalten (Gehl, 2011). Die Beobachtungen in den Begehungen werden mithilfe von Eintragungen in Karten, Skizzen und Fotografien dokumentiert. In den meisten Fällenstellen die Begehungeneine wichtige Kontrollebene dar und ergänzen die Methoden A und B.

Themengebiet	Untersuchungsfaktor	Unterparameter	Analyseansatz		Erhebungsmethode		
			quantitativ	qualitativ	A	B	C
I. Gebäude	1. Bauliche Dichte	1a. Geschosse	x			x	x
		1b. Parzellierung		x	x		
	2. EG-Zonen	2a. Nutzungen	x		x		
		2b. Räumliche Ausbreitung	x	x		x	x
(…)	(…)	(…)	(…)		(…)		
V. Sensorik	11. Olfaktorik	11a. Gerüche		x			x
		11b. Assoziationen		x			x
	12. Akustik	12a. Geräusche		x			x
		12b. Lautstärken	x		x		x
		12c. Wahrnehmung		x			x

Tab. 1: Auszug der definierten Themenbereiche, Untersuchungsfaktoren, Unterparameter, Analyseansätze und Erhebungsmethoden (A = zweidimensionale Datengrundlagen, B = dreidimensionale Remote-Analysen, C = Vor-Ort-Begehungen).

4.2 Methodenbausteine

Der vorgestellte Methodenansatz fußt auf drei grundlegenden Schritten (vgl. Abb. 2): der Datenerhebung (vgl. Abschnitt 4.1), der Übersetzung und der Visualisierung der Ergebnisse. Hierzu führt die Stadtraumdiagnostik zwei wesentliche Methodenbausteine neu ein: die „Stressorenabwicklung" und die „Stressorenmatrix".

4.2.1 Stressorenabwicklung

Der Methodenbaustein Stressorenabwicklung bietet die Möglichkeit, die räumliche Analyse verschiedener Untersuchungsfaktoren in ein vergleichbares Format zu übersetzen. Auf diese Weise wird die konventionelle

Trennung zwischen quantitativen und qualitativen Analysen überwunden.Die Erstellung einer solchen Stressorenabwicklung funktioniert wie folgt: Nachdem die Untersuchungsfaktoren, die zugehörigen Unterparameter und die Erhebungsstrategie definiert wurden (vgl. Tab. 1 und Abb. 2, linke Spalte), werden die Analysen zunächst in räumlichen Analyseplänen dokumentiert, wie sie in der Architektur und Stadtplanung gängig sind. In diesen Analyseplänen werden die definierte Bewegungslinie und die kreuzenden Straßen markiert (vgl. Abb. 2, mittlere Spalte). Dieses Grundgerüst ermöglicht es im späteren Übersetzungsprozess, die räumlichen Eigenschaften des realen Raums in ein abstraktes System zu übertragen. Dafür wird die Bewegungslinie wie in einem Koordinatensystem zur x-Achse „ausgeklappt" und die kreuzenden Straßen und Einmündungen als Fixpunktemarkiert. Die Ausprägungen des analysierten Untersuchungsfaktors werden dann auf der y-Achse nach einer vordefinierten Skala eingetragen.

4.2.2 Stressorenmatrix

Nachdem für jeden Untersuchungsfaktor eine solche Stressorenabwicklung erstellt wurde, werden diese in der Stressorenmatrix mit den Ergebnissen der Emotion-Sensing-Messungen zusammengeführt (vgl. Abb. 2, rechte Spalte). JedeAbwicklung nimmt dabei inder Matrix eine eigene Zeile ein. Die oberste Zeile ist in jeder Matrix den Ergebnissen der Emotion-Sensing-Messungen vorbehalten, die für diesen Zweck ebenfalls in eine Stressorenabwicklung übertragen werden. Die Stressorenmatrix bildet die Grundlage für die Auswertung der Untersuchungen. Denn anhand der übersichtlichen Visualisierung der 12 analysierten Faktoren in Kombination mit den gemessenen Stressmomenten ist es vergleichsweise einfach möglich, Zusammenhänge zwischen den untersuchten Faktoren und dem Auftreten von Stress zu identifizieren.

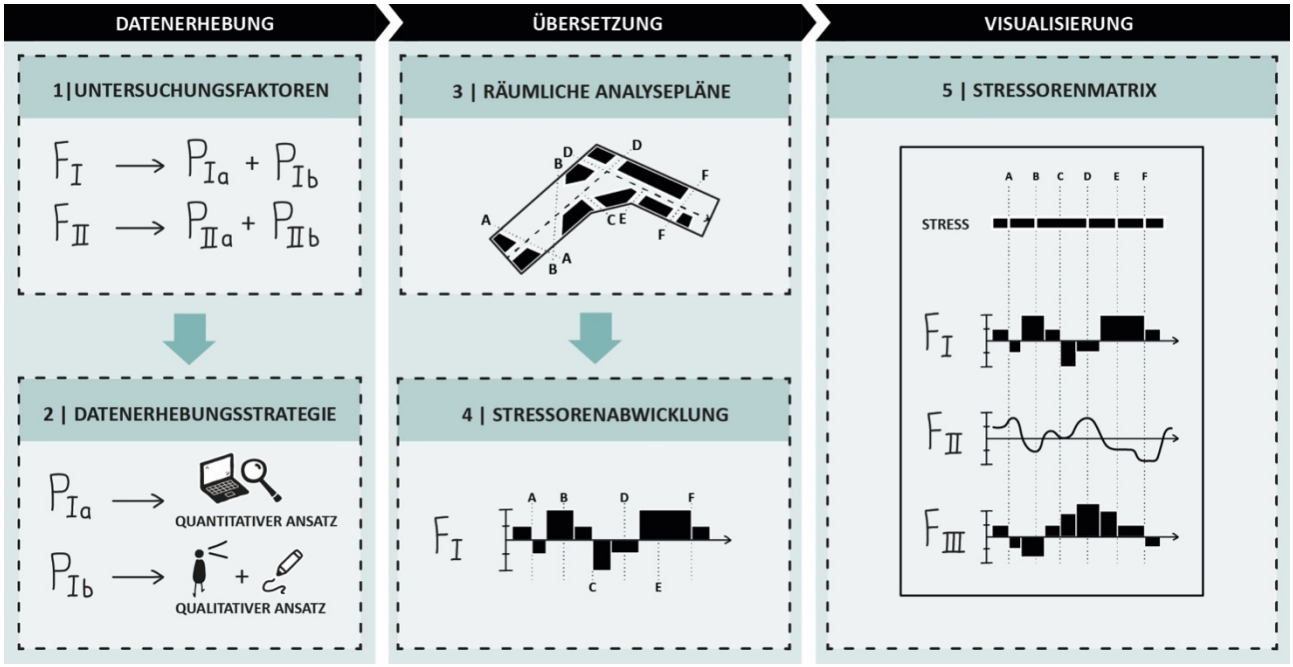


Abb. 2: Übersicht der Methodenentwicklung mit den beiden zentralen Bausteinen Stressorenabwicklung und Stressorenmatrix.

4.3 Auswertung der Stressorenmatrizen

Im Rahmen der Auswertung werden in den Stressorenmatrizen der fünf Fallstudien die Stressorenabwicklungen der jeweils 12 Untersuchungsfaktorenim ersten Schritt zunächst einzeln hinsichtlich ihrer Stresszusammenhänge ausgewertet. Dabei werden die Hotspots der Stressmessung (orange und rote Bereiche) mit auffälligen Bereichen(Hochpunkte, Tiefpunkte, Kategorienwechsel) in den Stressorenabwicklungen verglichen. Im Rahmen dieser Einzelauswertung wird dann jedem Untersuchungsfaktor gemäß seiner Übereinstimmung mit den Mustern der Stressmessungen ein Wert von 0 (kein Zusammenhang) bis 1,0 (starker Zusammenhang) zugewiesen. Bei fünf Fallstudien mit jeweils 12 Untersuchungsfaktoren ergeben sich folglich 60 Einzel-Stresszusammenhänge.

Im zweiten Schritt, der Gesamtauswertung, wird dann aus den Einzelwerten der fünf Fallstudien pro Untersuchungsfaktor die Gesamtsumme errechnet (also Fallstudie 1 + Fallstudie 2 + Fallstudie 3 + Fallstudie 4 + Fallstudie 5 = Gesamtsumme). Die resultierenden Werte reichen folglich von 0 bis 5,0 und geben den

Gesamt-Stresszusammenhang eines jeden Untersuchungsfaktors im Querschnitt der fünf untersuchten Fallstudien an.

5 ERGEBNISSE

Der entwickelte Methodenansatzwurde nach der vorgestellten Datenerhebungsstrategie in fünf Fallstudien (K1, K2, O1, O2, W1) in realen urbanen Stadträumenin den drei deutschen Städten Karlsruhe, Osnabrück und Würzburg angewendet. Die Ergebnisse aller fünf Fallstudien wurden gemäß der Systematik der Stadtraumdiagnostik in Form der Stressorenmatrizen dokumentiert und können der Arbeit von Haug (2025, S. 155 ff.) entnommen werden. Dieser Beitrag behandelt zum Zweck der Anschaulichkeit eine der Fallstudien exemplarisch und geht anschließend auf die Gesamtauswertung der Stresszusammenhänge ein.

5.1 Ergebnisauszug Fallstudie W1, Würzburg

Die Fallstudie W1 liegt im Stadtzentrum Würzburgs und dient exemplarisch zur Veranschaulichung der Ergebnisse der Fallstudien.

5.1.1 Datengrundlage Emotion-Sensing-Messungen &Grundgerüst

Die den Fallstudien W1 zugrunde liegenden Emotion-Sensing-Daten stammen aus dem Projekt „Super Testsite Würzburg". Die Messungen wurden im Sommer 2024 im Zeitraum vom 10. bis 21. Juni 2024 mit 41 Zufußgehenden in der Würzburger Innenstadt zu unterschiedlichen Tageszeiten durchgeführt (Super Testsite, 2024). Die Teilnehmenden bewegten sich frei durch die Würzburger Innenstadt und passierten dabei fünf festgelegte Kontrollpunkte in vorgegebener Reihenfolge. Damit sollte sichergestellt werden, dass sich die Teilnehmenden zwar so frei wie möglich bewegen konnten, sie zugleich jedoch auch die Kontrollpunkte in derselben Bewegungsrichtung passierten. Einer dieser Punkte befindet sich im Bereich der Eichhornstraße im Untersuchungsgebiet der Fallstudie W1.

Abbildung 3 zeigt auf der linken Seite die Heatmap der zugehörigen Emotion-Sensing-Messungen. Zwei Stress-Hotspots fallen in dieser Karte besonders auf: ein lokaler, kleinerer Hotspot im Bereich der Kreuzung Semmelstraße/Theaterstraße (1) sowie ein stark ausgeprägter Stress-Hotspot entlang der Eichhornstraße im Abschnitt zwischen Punkt 3 und Punkt 4, wo die Fußgängerzone in eine Platzsituation übergeht.

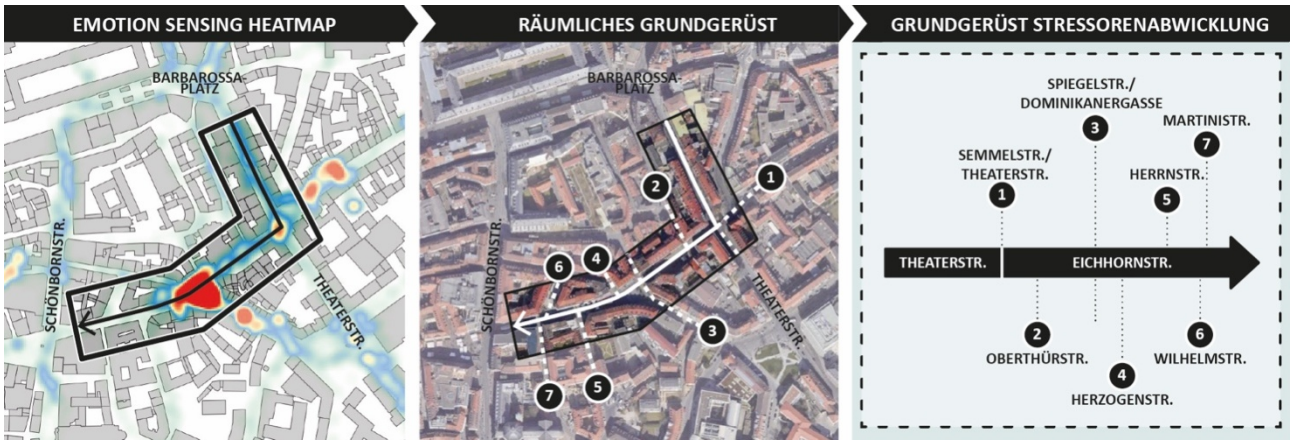


Abb. 3: Grundgerüst der Fallstudie W1, Würzburg.

Die mittlere und rechte Spalte in Abbildung 3 stellen das räumliche Grundgerüst im Luftbild sowie dessen Übersetzung in das abstrakte System der Stressorenabwicklung dar. Dieses Grundgerüst bildet die Basis für die Analyse der zwölf Untersuchungsfaktoren entlang der 400 Meter langen Bewegungslinie in Fallstudie W1.

5.1.2 Durchführung

Der Methodenansatz zur Identifikation stressauslösender Faktoren in dichten Stadträumen wurde nun mithilfe des definierten Grundgerüsts in der Fallstudie W1 implementiert. Zu diesem Zweck werden die zwölf Untersuchungsfaktoren und die ihnen zugeordneten Unterparameter (vgl. Tab. 1) unter Anwendung der definierten Analyseansätze und Erhebungsmethoden analysiert. Dafür wurden am Montag, den 28. Oktober 2024, vormittags und nachmittags, bei sonnigen Witterungsbedingungen, Vor-Ort-Begehungen durchgeführt. Im Zuge der Analyse der zweidimensionalen Datengrundlagen wurde primär auf Daten aus

OpenStreetMap und Luftbilder zurückgegriffen. Für die dreidimensionale Remote-Analyse wurden Bilddaten aus Apple Maps und Google Street View herangezogen. Die Analyseergebnisse der zwölf Faktoren wurden gemäß der Stadtraumdiagnostik-Methode jeweils in einer separaten Stressorenabwicklung dargestellt und anschließend in der Stressorenmatrix mit den Ergebnissen der Stressmessungen zusammengeführt.

5.1.3 Ergebnisse

Der folgende Abschnitt diskutiert die zentralen Ergebnisse der Einzelanalysen und setzt sie in Beziehung zu den Ergebnissen der Stressmessungen. Abbildung 4 zeigt einen Ausschnitt der Stressorenmatrix W1 und stellt fünf der insgesamt zwölf analysierten Faktoren dar, die aus jeweils einem der fünf Themengebiete stammen. Im oberen Bereich der Stressorenmatrixist die Abwicklung der gemessenen Stressmomente dargestellt.

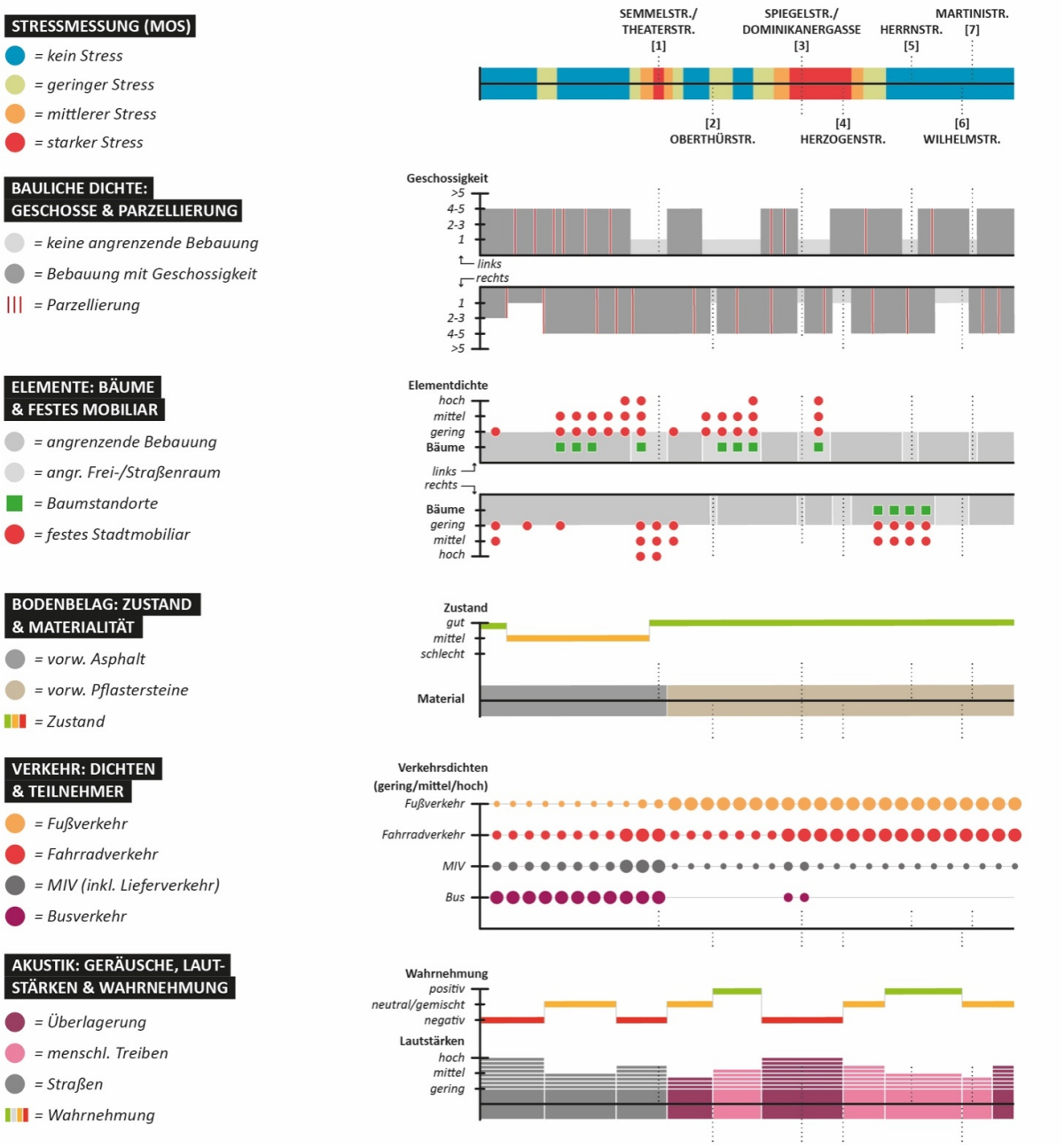


Abb. 4: Auszug der Stressorenmatrix aus Fallstudie W1, Würzburg mit den Untersuchungsfaktoren Bauliche Dichte, Elemente, Bodenbelag, Verkehr und Akustik.

A. Stressmessung: Wie bereits die Heatmap der Emotion-Sensing-Messungen (vgl. Abb. 3, linke Spalte) erkennen lässt, weist das Untersuchungsgebiet W1 zwei kritische Stress-Hotspots auf. Der erste Hotspot befindet sich an einem spezifischen Punkt in der Theaterstraße, an der Kreuzung

Semmelstraße/Theaterstraße (1), die zugleich den Übergang in die Fußgängerzone markiert. Der zweite Stress-Hotspot liegt in der Eichhornstraße zwischen Spiegelstraße/Dominikanergasse (3) und Herzogenstraße (4) und ist deutlicher ausgeprägt als der erste.

B. Bauliche Dichte: Hinsichtlich des Untersuchungsfaktors „Bauliche Dichte" zeigt sich Fallstudie W1 weitgehend homogen. Die Analyse ergab in diesem Fall keinen eindeutigen Zusammenhang mit den gemessenen Stresspunkten. Die Gebäude, die den Untersuchungsraum einrahmen, sind hier nahezu durchgehend viergeschossig, und überwiegend einheitlich parzelliert. Abgesehen von den Straßenräumen an den unmittelbaren Kreuzungspunkten zeigt die Bebauungsstruktur in W1 zwei markante Punkte: die Aufweitung der Fußgängerzone im Bereich von Punkt 3 sowie die Platzsituation zwischen Punkt 3 und 4.

C. Elemente: Das feste Stadtmobiliar („Elemente") erscheint in W1 über das gesamte Untersuchungsgebiet sehr kompakt und geordnet. Auf der linken Straßenseite befindet sich festes Mobiliar vor allem im Bereich von Punkt 1, innerhalb der Aufweitung der Eichhornstraße zwischen Punkt 2 und Punkt 3 sowie vereinzelt an der Platzsituation zwischen Punkt 3 und Punkt 4. Auf der rechten Seite konzentriert sich das Mobiliar insbesondere am Übergang zur Eichhornstraße (1) durch eine hohe Dichte an Fahrradabstellanlagen sowie im Abschnitt zwischen Herzogenstraße (4) und Wilhelmstraße (6). Die auffallendsten Cluster korrespondieren mit den identifizierten Stress-Hotspots. Die Bäume sind – mit Ausnahme der Theaterstraße im Bereich von Punkt 1 – in großzügige Stadtmöbel integriert und befinden sich links in den beiden Aufweitungen sowie rechts im Abschnitt zwischen Punkt 4 und Punkt 6.

D. Bodenbelag: Die Ausprägung des Faktors „Bodenbelag" gliedert sich im Untersuchungsgebiet in zwei Abschnitte: In der Theaterstraße dominiert Asphalt bis Punkt 1, während die Fußgängerzone in der Eichhornstraße mit Pflastersteinen gestaltet ist. Der Zustand des Belags in der Theaterstraße reicht von mittlerer bis guter Qualität. Der Belag in der Fußgängerzone wurde erst vor wenigen Jahren erneuert und befindet sich daher in einem sehr guten Zustand. In Bezug auf die Ergebnisse der Stressmessungen ist lediglich der Wechsel des Oberflächenmaterials am Stress-Hotspot bei Punkt 1 hervorzuheben. Am zweiten Hotspot (3/4) konnten hingegen keine Zusammenhänge festgestellt werden.

E. Verkehr: Der Untersuchungsfaktor „Verkehr" zeigt ausgeprägte Zusammenhänge mit den identifizierten Stress-Hotspots. Entlang der Theaterstraße bis Punkt 1 dominieren der MIV und der Busverkehr, wobei der motorisierte Individualverkehr eine mittlere Dichte und der Busverkehr eine hohe Dichte aufweist. Der auf derselben Fahrbahn geführte Radverkehr erreicht hier mittlere Dichten, während die Dichte des Fußgängerverkehrs in den Seitenbereichen gering bleibt. An der lichtsignalgeregelten Kreuzung zur Eichhornstraße (1) verdichten sich MIV und Radverkehr kurzfristig. Ab Punkt 1 ist die Eichhornstraße dem Fuß- und Radverkehr vorbehalten, verzeichnet in den Stoßzeiten jedoch auch ein nicht unerhebliches Aufkommen an Lieferverkehr. Bis zur Kreuzung Spiegelstraße/Dominikanergasse (3) zeigt sich eine hohe Frequenz an Zufußgehenden, eine mittlere Radverkehrsdichte sowie ein geringfügiger Lieferverkehr. An Punkt 3 kreuzt der MIV und der Busverkehr die Bewegungslinie, was zu kurzzeitigen Ausschlägen führt, während zugleich vermehrt Radfahrende in die Eichhornstraße einbiegen und der Radverkehr hinter Punkt 3 zunimmt.

F. Akustik: Der Faktor „Akustik" weist in W1 einen klaren Zusammenhang mit den nachgewiesenen Stressmomenten auf. Der erste Abschnitt bis Punkt 1 ist von lauten, negativ wahrgenommenen Straßengeräuschen geprägt. Daran schließt sich ein kurzer Abschnitt mit geringerer Geräuschkulisse an, die als gemischt bewertet wird. An der Kreuzung Semmelstraße/Theaterstraße (1) nimmt der Lärm erneut zu und wird negativ wahrgenommen. Am Eingang zur Eichhornstraße bleibt die Lautstärke bis zur Oberthürstraße (2) moderat und wird als gemischt kategorisiert, da sie situationsabhängig stark variiert. Ab Punkt 2 dominiert menschliches Treiben die Geräuschkulisse, was vermehrt positive Assoziationen hervorruft. Im Bereich zwischen 3 und 4 steigt die Geräuschkulisse erneut an und wird negativ bewertet. In den Abschnitten bis zur Martinistraße (7) tritt wieder verstärkt menschliches Treiben in den Vordergrund, während der Geräuschpegel sukzessive abnimmt und wieder positiver wahrgenommen wird. Im letzten Abschnitt nimmt der Straßenlärm entlang der Schönbornstraße leicht zu und wird negativ assoziiert.

5.2 Gesamtauswertung der Stresszusammenhänge

Im Rahmen der Gesamtauswertung wurden nun alle zwölf Untersuchungsfaktoren in allen fünf Fallstudien, also K1 und K2 in der Untersuchungsstadt Karlsruhe, O1 und O2 in Osnabrück sowie die Fallstudie W1 in

Würzburg, hinsichtlich ihres Stresszusammenhangs untersucht. Zentrale Fragestellung ist dabei: In welchem Zusammenhang stehen die untersuchten Faktoren mit den Ergebnissen der Stressmessung?

Abbildung 5 zeigt die berechneten Stresszusammenhänge der betrachteten Faktoren auf Grundlage der Stichprobe der fünf Fallstudien. In Übereinstimmung mit dem Forschungsziel, kausale Zusammenhänge zu identifizieren, konzentriert sich diese Arbeit auf Faktoren mit einem starken oder sehr starken Stresszusammenhang. Konkret handelt es sich hierbei um die Faktoren“EG-Zonen“, „Elemente“, „Straßenraumaufteilung“, „Verkehr“, „Ruhender Verkehr“ und „Akustik“.Diese Faktoren werden in den folgenden Abschnitten deshalb als Einflussfaktoren bezeichnet. Besonders hervorzuheben ist dabei, dass der Untersuchungsfaktor „Verkehr” in allen fünf Fallstudien ausnahmslos einen starken Stresszusammenhang aufweist. Das bedeutet, dass in den fünf Fallstudien ein erhöhtes Stressaufkommen vorrangig an solchen Orten nachgewiesen wurde, an denen eine hohe Verkehrsdichte herrscht und bzw. oder viele verschiedeneVerkehrsteilnehmer (MIV, Radverkehr, Fußverkehr etc.) aufeinandertreffen. Infolgedessen zeigt auch die Gesamtauswertung für diesen Faktor einen sehr starken Stresszusammenhang. Im Rahmen der Untersuchungen dieser Arbeit gilt „Verkehr” somit als der häufigste Auslöser für Stress.

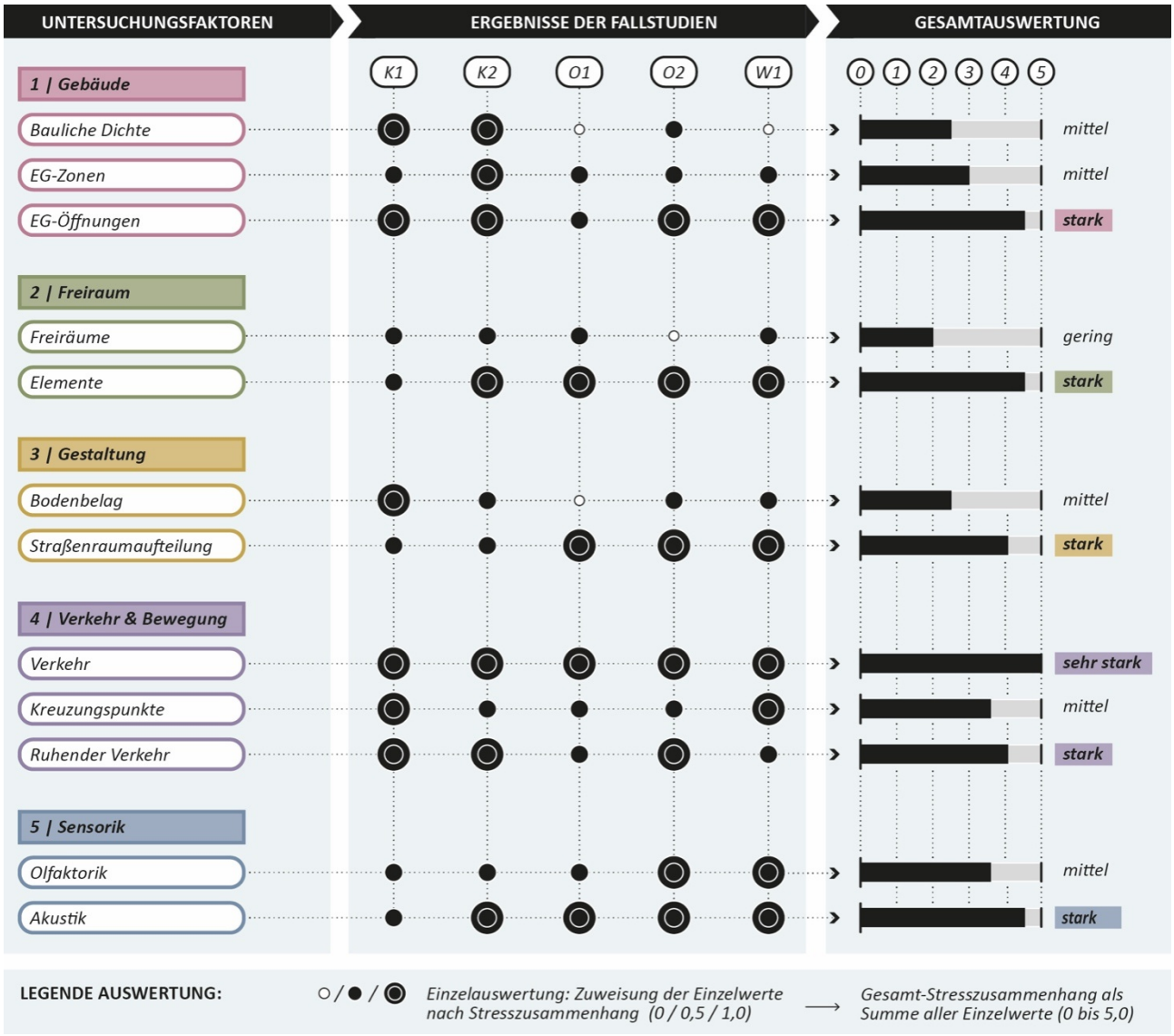


Abb. 5: Gesamtauswertung der Stresszusammenhänge aller zwölf Untersuchungsfaktoren in den fünf untersuchten Fallstudien K1, K2, O1, O2 und W1.

Im Gegensatz dazu weisen andere Faktoren im Querschnitt der fünf Fallstudien eine deutliche Variabilität auf. Dazu zählt beispielsweise der Untersuchungsfaktor „Bauliche Dichte, für den in der Gesamtauswertung ein mittlerer Stresszusammenhang identifiziert wurde. Während hier jedoch die Fallstudien K1 und K2 in Karlsruhe einen starken Zusammenhang zeigen, weist die Fallstudie O2 lediglich einen partiellen Zusammenhang mit Stress auf, und in den Fallstudien O1 und W1 konnte kein Zusammenhang festgestellt

werden. Ein ähnliches Muster zeigt sich auch bei dem Faktor „Straßenraumaufteilung". In der Gesamtauswertung wurde hier ein starker Stresszusammenhang errechnet. Die Verteilung über die Fallstudien zeigt jedoch, dass der Stresszusammenhang in den beiden Karlsruher Fallstudien nur partiell ausgeprägt war, während in den übrigen drei Fallstudien ein starker Zusammenhang mit Stress festgestellt wurde.

Demgegenüber identifizierte der Fallstudien-Evaluationsprozess lediglich einen schwachen Zusammenhang zwischen Stress und dem Untersuchungsfaktor „Freiräume". In den einzelnen Fallstudien K1, K2, O1 und W1 wurde jeweils ein partieller Stresszusammenhang festgestellt. In der Fallstudie O2 konnte kein Zusammenhang nachgewiesen werden. Das bedeutet, dass im Rahmen der untersuchten Fallstudien an öffentlichen Freiräumen (z.B. Stadtplätze, Grünflächen) seltener Stressreaktionen nachgewiesen werden konnten.

Die Gesamtauswertung zeigt damit, dass es durchausgeneralisierbare Faktoren wie z.B. „Verkehr" gibt, die nachweislich in allen untersuchten Fallstudien einen Einfluss auf das Empfinden von Stress haben. Darüber hinaus existieren allerdings auch zahlreiche weitere Faktoren, die nicht durchgängig, aber unter bestimmten Bedingungen, einen nachweisbaren Einfluss auf Stress ausüben.

6 DISKUSSION

Der folgende Abschnitt diskutiert den vorgestellten Methodenansatz und adressiert einige Limitationen.

Eine zentrale Einschränkung der Methodik liegt in dem Abstraktionsprozess, der mit dem Erstellen der Stressorenabwicklungen verbunden ist. Um die komplexen räumlichen Situationen in dem abstrakten Gerüst übersichtlich abbilden zu können, werden viele der Inhalte stark abstrahiert und reduziert. Diese Reduktion wird insbesondere an solchen Orten deutlich, an denen die räumliche Situation komplexer ist als die klassische Unterteilung in eine linke und eine rechte Raumkante entlang der analysierten Bewegungslinie. Das ist beispielsweise dann der Fall, wenn sich Gebäude hinter größeren, an die Bewegungslinie angrenzenden Freiflächen befinden, wie z.B. großen Vorplätzen vor öffentlichen Gebäuden. Diese Flächen werden nach der aktuellen Systematik der Methode dann lediglich als Freiflächen kategorisiert und das dahinterliegende Gebäude nicht berücksichtigt. Ebenso werden starke Krümmungen der Bewegungslinie in der Projektion der Stressorenabwicklung stark gestaucht abgebildet, was ebenfalls eine Informationsreduktion mit sich bringt.

Weiterhin ergibt sich auch durch die Zielsetzung der Ganzheitlichkeit des Methodenansatzes eine Limitation. Zwar unternimmt die Stadtraumdiagnostik diesbezüglich zweifellos einen wichtigen Schritt in Richtung der ganzheitlichen Analyse menschlicher Stadtwahrnehmungen, indem erstmals verschiedene quantitative und qualitative Faktoren sowie deren faktische und subjektive Dimensionen in einem gemeinsamen methodischen Rahmen zusammengeführt werden. Dennoch darf das entstandene Modell nicht als abgeschlossen betrachtet werden, sondern muss mit den zwölf analysierten Faktoren als Annäherung an das komplexe Forschungsfeld der menschlichen Stadtwahrnehmung verstanden werden. Es bleibt zu diskutieren, inwiefern die Auswahl der Untersuchungsfaktoren in zukünftigen Fallstudien adaptiert werden muss.

Eine weitere Einschränkung ergibt sich aus dem retrospektiven Charakter der hier durchgeführten Ursachenforschung. Hier ist darauf hinzuweisen, dass die vorliegende Forschung zum jetzigen Zeitpunkt keine eigenen Emotion-Sensing-Messungen durchführt, sodass die kausale Analyse in allen fünf Fallstudien mit einem gewissen Zeitversatz zu den Stressmessungen erfolgt. Innerhalb des bestehenden Untersuchungsaufbaus ist eine gleichzeitige Durchführung beider Erhebungen nicht möglich. Infolgedessen kann das Modell situationsabhängige Veränderungen bestimmter Variablen aktuell nur eingeschränkt abbilden. Der retrospektive Ansatz stellt aktuell somit lediglich einen Durchschnittswert der beobachteten Momentaufnahmen unterschiedlicher Jahreszeiten, Wochentage und Tageszeiten dar.

Darauf aufbauend muss die vorgestellte Methodezudem kritisch hinsichtlich ihrer allgemeinen Übertragbarkeit reflektiert werden. Eine grundlegende Herausforderung besteht hierin der Schwierigkeit, innerhalb des komplexen Gefüges Stadt überhaupt universell gültige Erkenntnisse abzuleiten. Denn klar ist: Die Stadt kann als Untersuchungsgegenstand allein aufgrund ihrer hohen Komplexität und Dynamik nicht mit Laborbedingungen gleichgesetzt werden. Aufgrund ihrer unterschiedlichen historischen, kulturellen und sozialen Prägungen – ihrer jeweiligen „DNA" – lassen sich die Ergebnisse aus Stadt A demnach nicht ohne Weiteres auf Stadt B übertragen. Entsprechend distanziert sich die Studie bewusst vom Begriff der

Korrelation, der kausale Zusammenhänge impliziert, und verwendet stattdessen den Begriff der Hypothese. Letztlich bleibt jedoch die Frage offen, ob im komplexen Forschungsfeld der menschlichen Stadtwahrnehmungüberhaupt eindeutig nachweisbare und übertragbare Kausalzusammenhänge identifizierbar sind.

7 SCHLUSSBETRACHTUNG

Die vorliegende Studie entwickelt eine neuartige diagnostische Methode, die mittels eines umfassenden Abstraktionsprozesses die menschliche Wahrnehmung verdichteter öffentlicher Stadträume decodiert. Durch die Analyse verschiedener wahrnehmungsrelevanter Faktoren adressiert der vorgeschlagene Ansatz einen Themenbereich, der in der Stadtforschung bislang weitgehend als „Black Box“ galt. Über rein qualitative Beschreibungen hinaus existieren bislang nur wenige methodische Zugänge, die sich mit den schwer fassbaren, subjektiven Komponenten der Stadt als Untersuchungsgegenstand befassen.

Aus dieser Motivation heraus führt die Stadtraumdiagnostik einen integrativen Ansatz ein, der das subjektive Erleben von Stadträumen mit objektiv messbaren Faktoren kombiniert betrachtet. Denn die Wahrnehmung öffentlicher Stadträume wird nicht ausschließlich durch objektiv erfassbare Merkmale bestimmt, sondern maßgeblich auch durch das individuelle Komfortempfinden, das den praktischen Erfolg stadtplanerischer Maßnahmen wesentlich beeinflusst.Um diese beiden inhaltlichen(und oftmals sehr unterschiedlichen) Dimensionen auch methodisch adäquat abbilden zu können, wird in dieser Arbeit eine neuartige Methodenkombination eingeführt. Sie vereint die Analyse von zweidimensionalen Datengrundlagen, dreidimensionalen Remote-Analysen und Vor-Ort-Begehungen in einem gemeinsamen System. Die Methodenbausteine Stressorenabwicklung und Stressorenmatrix ermöglichen es dabei, die Ergebnisse dieser Analysen – trotz ihres umfangreichen Inhalts und methodischer Unterschiede – vergleichbar darzustellen.

Mit dieser Zusammenführung der inhaltlichen und methodischen Ebenen ist es schließlich gelungen, die Analyseergebnisse aus den Fallstudien in einer Form aufzubereiten, die einen Vergleich der verschiedenen Untersuchungsfaktoren durch den hohen Abstraktionsgrad und die Visualität vereinfacht. Dadurch konnten in fünf Fallstudien mit jeweils zwölf Untersuchungsfaktoren sechs neuralgische Stressfaktoren identifiziert werden:“EG-Zonen“, „Elemente“, „Straßenraumaufteilung“, „Verkehr“, „Ruhender Verkehr“ und „Akustik“.

8 WEITERER FORSCHUNGSBEDARF

Obwohl der vorgestellte Methodenansatz bereits zum jetzigen Stand wertvolle Einblicke in die menschliche Wahrnehmung von Stadträumen liefert, wird zugleich auch der weitere Forschungsbedarf ersichtlich.

Allen voran besteht ein weiterer Forschungsbedarf in den als Grundlage verwendeten Stressmessungen. Der präsentierte Ansatz basiert auf der Identifikation von Stress-Hotspots mittels Emotion-Sensing-Messungen, die physiologische Indikatoren wie Hautleitfähigkeit und Hauttemperatur zur Erfassung von Stressreaktionen nutzen. In Hinblick auf die Vielzahl an Methoden, die es gibt, um Stressreaktionen nachzuweisen, wäre es in diesem Kontext von großem Interesse, den vorgestellten Ansatz in Kombination mit weiteren physiologischen Indikatoren (z.B. Herzratenvariabilität) und Settings, wie z.B. Elektrokardiogramm (EKG)-Brustgurten oder mobilen Elektroenzephalogramm (EEG)-Geräten(Aspinall et al., 2015; Roe et al., 2023; Tawil et al., 2024).

Der vorgestellte methodische Ansatz ist als erste Entwicklungsstufe eines Planungswerkzeugs zu sehen. So könnte die Stadtraumdiagnostik in der Planungspraxis eine echte Hilfestellung für die Planung menschengerechter Stadträume darstellen. Denn der große Vorteil dieses Ansatzes ist, dass sowohl Bestandssituationen als auch verschiedene Planungsvariantenvisuell miteinander vergleichbar gemacht werden können. Damit kanndie Anwendungzukünftig das Monitoring von Transformationsprozessen wirkungsvoll unterstützen und einen Beitrag zur ganzheitlichen Planung von Stadträumen leisten. Kombiniert mit der Implementierung in die kommunalen 3D-Stadtmodelle könnte dann mit der Stadtraumdiagnostik ein wichtiger Perspektivwechsel gelingen. Analog zur „Smart City Platform” vonRuohomäki et al. (2018), besteht hier das Potenzial, die digitalen Zwillinge um weitere Instrumente zu ergänzen und mit der Stadtraumdiagnostikim ganzheitlichen Sinne um eine reale, menschliche Bewertungsebene zu erweitern.Diesbezüglich erscheint es evident, dass die Systematisierung und Automatisierung der Methode einenzentralen Entwicklungsschritt darstellt. Erste Studien haben hierbereits gezeigt, dass reale Umgebungen durch die Auswertung von Street-Level-Aufnahmen analysiert werden

können(Seiferling et al., 2017). In der Weiterentwicklung der Stadtraumdiagnostik könnte somit ein Erfassungssystem konstruiert werden, das mit Machine Learning automatisiert die relevanten Objekte aus Bildmaterialienidentifiziert, und, basierend auf spezifischen Trainingsdaten, kategorisiert. Langfristig könnte eine solche maschinelle Objekterkennung die direkte Überführung der identifizierten Merkmale in die Stressorenabwicklung ermöglichen.

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🏆 reviewed paper

Stakeholder Mapping and User Perception of Mobility Management for Commuters and Students: A Comparison of 7 Case Studies in Central Europe – the GreenPATH Project

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1 ABSTRACT

The GreenPATH project is a collaborative initiative aimed at addressing sustainable commuting challenges in Central European Functional Urban Areas (FUAs). It focuses on students and employees, promoting innovative and green mobility solutions through co-designed strategies, action plans, and pilot projects. The project involves 11 public administrations, mobility agencies, operators, universities, and research bodies, along with 12 associated partners. Its primary goal is to reduce private vehicle dependency, improve air quality, and enhance commuter well-being by encouraging the use of sustainable transport modes such as public and shared transport, cycling, and walking.

GreenPATH emphasizes the importance of stakeholder mapping and engagement to ensure the success of its initiatives. Stakeholders, including commuters, local administrations, businesses, and public transport operators, are identified and mapped based on their power and interest. Commuters and local governments are the most frequently identified stakeholders, with influence levels varying across pilot regions. This mapping process helps tailor strategies to the specific needs and challenges of each region. Awareness-raising campaigns are accompanying activities of the project. These campaigns aim to educate communities about the benefits of sustainable transport and provide information on available transportation options. Real-time information and personalized travel options are also offered to improve the commuting experience and encourage the adoption of sustainable modes of transport.

Based on the results of the user surveys in the 7 pilot areas, the project highlights the need for improved infrastructure to support sustainable commuting. Key recommendations include better lighting, enhanced cycling paths, and pedestrian-friendly conditions to improve accessibility and safety. Gender-specific and accessibility-focused improvements are emphasized to reduce barriers for all commuters. Behavioral aspects, such as improving car drivers' attitudes towards cyclists and pedestrians, are also identified as areas for improvement. Despite a general willingness to adopt sustainable commuting behaviors, only a small percentage of respondents have participated in mobility management initiatives before the GreenPATH project kicked of. This indicates the need for customized activities such as challenges and to improve awareness of available services and infrastructure. GreenPATH promotes role modelling by encouraging frequent users of sustainable transport modes, such as cyclists and public transport users, to share their experiences. This approach aims to inspire others to adopt similar behaviors, contributing to reduced private car usage and lower CO2 emissions.

GreenPATH leverages transnational cooperation across countries like Italy, Germany, Austria, Slovenia, Hungary, and Croatia to develop scalable solutions and formal agreements for long-term implementation. This collaboration helps overcome national legislative barriers and ensures the development of applicable mobility management tools across the region. The project's outputs include collaborative solutions for sustainable mobility, a comprehensive strategy, and action plans for each FUA, which are expected to be endorsed by decision-makers to ensure their adoption and long-term impact.

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Keywords: mobility management, commuter, students, stakeholder mapping, planning

2 INTRODUCTION

GreenPATH develops an innovative approach to commuting in Central European Functional Urban Areas (FUAs). It aims at co-design smart and green mobility solutions with public and private stakeholders, benefiting students and employees by promoting sustainable transport. The project addresses the challenge of decarbonizing urban mobility through a set of tested solutions, strategies, and action plans. It involves 11

partners, including local administrations, mobility agencies, operators, universities, and research bodies. Transnational cooperation is key, bringing together expertise from Italy, Germany, Austria, Slovenia, Hungary, and Croatia. This cooperation contributes to overcome national legislative barriers and create applicable mobility management tools across the region. GreenPATH aims to deliver formal cooperation agreements, collaborative solutions for sustainable mobility, a comprehensive strategy, and action plans for each FUA. These outputs will be adopted by decision-makers to ensure long-term implementation and cooperation beyond the project's completion, benefiting a wide range of users, including local authorities, service providers, and educational institutions. The project is case study based, including seven pilot areas, which are: Berlin (Germany), Kecskemét (Hungary), Maribor (Slovenia), Monza (Italy), Osijek (Croatia), Ravenna (Italy), and Vienna (Austria), see also figure 1.

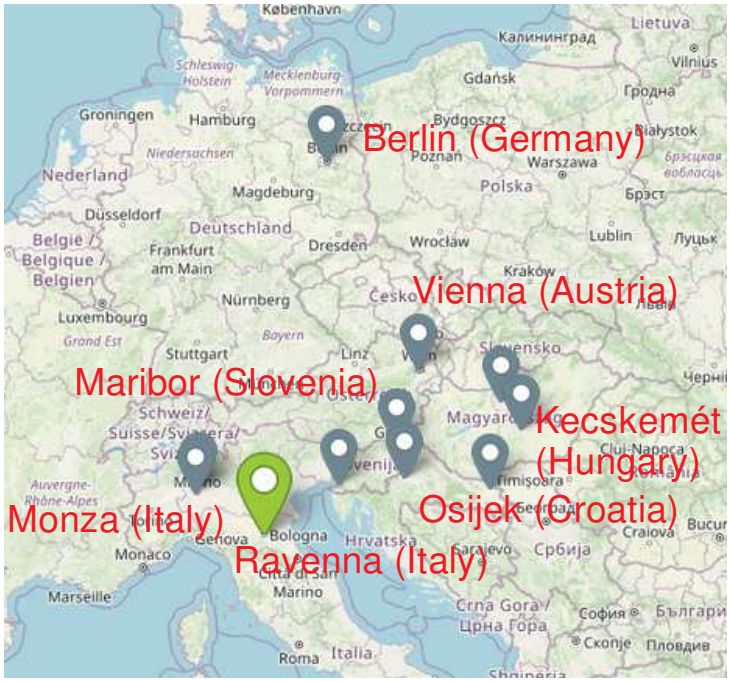


Figure 1: Case studies and partners of the GreenPATH project

An important first pillar of the project activities of the GreenPATH project is to map local stakeholders, governance and mobility management awareness in each pilot area to inform individuals and communities on the benefits and importance of sustainable modes of transportation such as public and shared transport, cycling, and walking. The activity comprises work with local communities, transport and mobility operators, and other stakeholders to develop and implement effective awareness-raising strategies. This includes developing educational campaigns, providing information on available transportation options, and promoting the use of sustainable modes of transportation to reduce the dependence on private vehicles and improve air quality in urban areas, while also improving the health and wellbeing of commuters. GreenPATH provides an overview of key stakeholders and their perspectives on the GreenPATH activities. Another important pillar is to learn about the users (employees and students), their behaviour, attitudes and perceiptions. Thogether with the stakeholder mapping, this forms the basis for a successful implementaiton of mobility management in the respective area, but knowledge gained can be used to transfer the methods and strategies as well.

3 METHODOLOGY

The methodology of stakeholder mapping consists of a multi-step process. Step one: A questionnaire was prepared and distributed among the pilot region leaders. Characteristics of the pilot area and FUA and the desired changes are to be identified in order to guide the pilot action leaders towards the identification of the relevant stakeholders for their pilot action. Based on the given framework conditions relevant stakeholders in the FUA and, in particular, in the pilot area are mapped. This approach is chosen to give pilot action leaders the possibility to reflect upon their activities and therefore to be able to identify the relevant stakeholders. Step two: Based upon the responses of the pilot action leaders stated, the stakeholder maps are analysed to prepare a follow-up Stakeholder Mapping Workshop with pilot action leaders to discuss similarities, and

differences among the identified stakeholders and relevant engagement strategies across the pilot actions. Step three: Approaches for the identification of strategies and plans like SUMPs but also policies for the FUA and pilot area are included to provide accordance of the pilot action with the relevant overarching goals in the region.

Regardless of the specific context of the project's pilot area, collecting comparable and reliable data about employees and students is a challenge. This is due to limited willingness of potential participants to participate in surveys, for example due to privacy concerns, but also limited time availability of participants which can cause incomplete answered questionnaires. Although these challenges exist, collecting mobility related data provides a strong basis for identifying needs of the user group and therefore gaps in the current situation which provides potential for action. Therefore, a user survey is essential to provide guidance on how to engage user via a survey to provide a common approach among all pilot areas and therefore enable a cross-case analysis of the results to gain insights across Central Europe. In GreenPATH students and employees are considered users of the pilot actions. They are crucial for the success of the pilot action implementation in the seven GreenPATH pilot areas. Questionnaires follow a strict structure: mostly but not always, closed questions are asked and therefore different options for answering are offered, which the participant has to choose from (predefined answers). An advantage is the quick performance and answers are mostly comparable. Structured questionnaires can be provided in written form or via an interviewer (Batiajew et al., 2019). In the case of the GreenPATH project, a written approach is chosen, but the survey can be conducted as personal face to face interview as well, where the interviewer enters the oral answers of the respondent.

4 RESULTS OF STAKEHOLDER MAPPING

In the questionnaire, pilot responsibles were asked to map the stakeholders based upon their power and interest. Commuters (employees and students) are mapped most often as stakeholder group (6 of 7 pilot regions). Administration on local level follows with 5 of 7 nominations. Business associations and business/companies are each mentioned in 4 pilot regions, followed by public transport operator and universities/research institutions (each mentioned by 3 pilot areas). Interest groups, public authority and transport sharing scheme operators follow by 2 mentions each. Other nominations mentioned by one pilot area only, are campus owner, NGOs, public transport users, administration on regional level, municipality/government and public transport authority.

Figure 2 shows an overview of the power and interest of different stakeholders per pilot action with regard to the the actions for mobility management for companies/universities. Regarding power: rather stakeholders were mapped with high to medium power (Ravenna, Monza, Maribor). Osijek mapped stakeholders with medium to high power. Vienna, Kecskemét and Berlin mapped along the whole spectrum from low to high power. Regarding interest: stakeholders with high, medium interest were mapped by Ravenna, Monza, Maribor Berlin, Osjiek, Kecskemét and Vienna identified stakeholders across the whole spectrum of interest. Stakeholders with high power and low interest can be critical decision-makers if agreements are needed. Such critical stakeholders occur in several pilot region, such as Osijek, with the city representatives, Ravenna with important companies to have on board and Vienna with the head of the university. It is important to inform, engage and convince these critical stakeholders at an early stage of the project. Contrary to this, stakeholders with high power and srtrong interest can be included in accompanying activities like the municiaplity in Ravenna and Monza, the local government in Kecskemet exisiting working groups in Vienna or the employees themselves in Maribor.



Figure 2: Stakeholder maps ranked according to their Interest

5 RESULTS OF USER SURVEY

The surveys were launched in the pilot areas from December 2024 to January 2025. The number of respondents, who filled in the survey, varied among the pilot areas: Monza stands out with 252, Osijek follows with 119, 118 in Vienna, Maribor with 100, Kecskemét with 71, 63 in Berlin, Ravenna with 59. Overall, 782 respondents filled in the questionnaire. Due to focus upon different target groups across the pilot areas, in Vienna, the participants were students. In Monza and Ravenna, mainly employees answered the questionnaire, in Berlin and Maribor roughly half of the respondents were students, half were employees. In Osijek, the majority were employees. Overall, 205 students answered the questionnaire, 542 employees and 34 who were both students and employees. The questionnaire was designed with non-mandatory questions, to provide the most possible participation. Therefore, the sample size varies across the answers.

Overall, private car usage as a driver is an (almost) daily mobility behaviour across the pilot areas (except for Berlin and Vienna with its focus on students). Private car commuters hold the potential to provide carpooling options for colleagues, which could support a reduction in CO2 emissions. Commuting in a private car as a passenger is less common across the pilot areas so far. But those, who commute as passengers in private cars, could be valuable role models for sharing their advantages (compared to driving by themselves) and therefore help reduce private car usage as a driver. Apart from car usage, active transport modes like cycling with a private bicycle and walking exist as commuting behaviours as well. Cyclists and PT users are potentially interesting to address as role models: eliciting their preferences for their daily mode choice and broadcasting their strategies to deal with barriers along their commuting trip with their mode of transport might encourage current car users to switch to public transport modes (if the personal circumstances match). Apart from role modelling, existing frequent mobility behaviour of cycling, walking and PT usage are essential to address via sustainable provision of infrastructure, e.g. cycle paths, improvements of infrastructure (surfaces, lighting etc.) to sustain the already existing sustainable commuting practise in the long-term. Therefore, promoting actions for addressing commuters' needs might raise awareness for sustainable transport modes which might lead to encourage further commuters, who might not commute by active transport modes yet. Regarding other activities than working in combination with commuting (like bringing/ picking up kids meet friends after work, do some shopping before arriving at work): high shares of the respondents state to include (almost) never or less frequently than monthly such activities in their commuting trips. This is an important information, as such activities make trip chains more complex and less flexible to be changed in the course of mobility management activities. Factors for mode choice: Overall, all discussed factors are considered important by the respondents but the factors price, comfort and environment vary regarding importance across the pilot areas. The factor health is considered as an important reason for choosing private bicycle for commuting. Addressing health related aspects of active mobility in mobility management campaigns can be a strong argument to shift modal split towards active transport modes. Figure 3 shows the results about the general experiences of commuting. Only a minority of a maximum of 27% really enjoy their commuting time, whereas up to 67% are not happy at all.

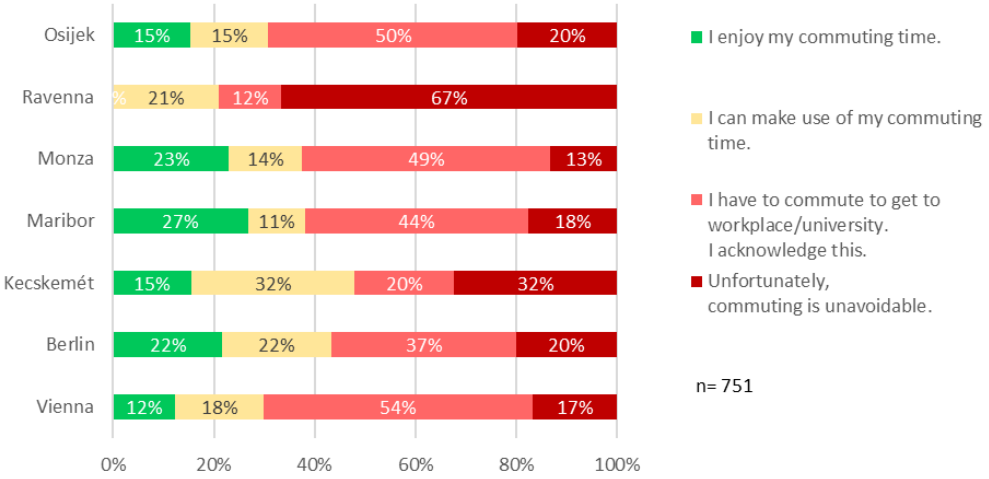


Figure 3: Attitude towards commuting per pilot area

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Road safety issues are experienced in all pilot areas but it varies in the pilot areas (9% in Maribor and 47% in Vienna, who experience this on regular basis). Stress is occurring by the majority of the respondents, but very little in Maribor (5%) where commuting by walking is used (almost) daily by a rather high share of the respondents. Conditions for walking in Maribor might be beneficial for their trip experience. Also, across all pilot areas it needs to be considered that between 2% to 20% of the respondents state to experience harassment/ cat-calling regularly, which might impact the overall trip experience and needs to be addressed. Gender-specific improvements: Addressing light conditions is crucial and can be a gender-specific obstacle if kept unaddressed, but also addressing bad road conditions (for walking and cycling) and car drivers' behaviour towards other road users have the potential to act as gender-specific barriers along commuting trips. Therefore, potentials for gender-specific improvements are seen by the respondents in better lighting, improving the conditions of sidewalks and cycling paths and improvements to reduce safety and security concerns. Accessibility-specific improvements: Providing sufficient infrastructure for cyclist and pedestrians and sufficient light is essential to improve accessibility for commuters, who arrive by bicycle or by foot to counteract existing safety concerns. Also, implementing measures that keep those infrastructures clear of undesirable objects that prevent the movement upon those (like trees, e-scootersm parked vehicles) but also regarding aesthetics (like dog excrements and trash) might improve accessibility. Infrastructure provision or improvements (light, cycle path, etc.) for pedestrians and cyclist are suggested by respondents to improve accessibility but also behavioural aspects were mentioned, like car drivers' behaviour towards cyclist and pedestrians is considered improvable.

The willingness to change behaviour by the respondents towards more sustainable modes exists throughout all the pilot areas between a third (30% in Berlin) and more than the half of the respondents (56% in Ravenna). The existing willingness to change the behaviour will be addressed within GreenPATH activities. On the other hand, survey results showed a lack of knowledge about existing infrastructure and services by some respondents (either stating not to know or state that it is not available, but it is). Information provision about available services and infrastructures might need be considered by the pilot areas to improve mobility related knowledge among employees or students in their pilot area. Additionally, only a little share of the respondents has actually joined/consumed a mobility management measure before. Knowledge about mobility management alone is not enough to actually join the mobility management initiatives. Respondents were asked if they know what mobility management is. Roughly half of the respondents in the pilot areas stated to know what mobility management are, except for Osijek, where only 19% stated to have knowledge about this matter. In Maribor (58%) and Kecskemét (55%), the majority stated to not know about concrete mobility management measures in their pilote area, whereas in Ravenna (59%), Berlin (52%) and Vienna (51%) the majority of respondents stated to have knowledge about such. However, the implementation of mobility management actions at their university or workplace is considered rather important by most of the respondents across all the pilot areas. Monza shows the highest agreement (83%), followed by Vienna (82%), Ravenna (76%), Maribor (67%), Berlin (66%), Osijek (65%). Kecskemét shows the lowest agreement with 48% only.

6 CONCLUSIONS

GreenPATH demonstrates that combining stakeholder mapping with user surveys provides a solid basis for targeted mobility management in Central European FUAs. Commuters and local administrations emerge as the most frequently mapped stakeholders, confirming their central role in shaping interventions. Power–interest analysis reveals critical high-power/low-interest actors; engaging them early is essential for pilot success and formal agreements. Awareness-raising, real-time information, and personalized travel options are complementary levers to shift commuting behavior toward sustainable modes. User surveys show dominant private car use (except student-focused areas), indicating potential for carpooling and role modelling by cyclists and PT users. Safety and comfort are decisive: better lighting, improved cycling and walking infrastructure, and addressing driver behavior are widely prioritized. Safety issues and harassment persist across pilots, varying by context, underscoring the need for gender- and accessibility-sensitive measures. Willingness to change exists (about 30–56%), but knowledge gaps about existing services hinder uptake; information provision should be intensified. Most respondents value mobility management at workplaces/universities, indicating strong acceptance and implementation potential. Overall, the project points to pragmatic next steps: engage critical stakeholders, close information gaps, and invest in user-

prioritized infrastructure to reduce car dependency. Formalized outputs (cooperative solutions, strategies, action plans) position GreenPATH for durable impact beyond the project term are now planned based on this output.

7 ACKNOWLEDGEMENT

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reviewed paper

Straßendorf, Angerdorf: Historische Dorfstrukturen als neue Pole in einem polyzentralen Wien

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1 ABSTRACT

Die Stadtrandbereiche Wiens sind charakterisiert durch historische Ortskerne, welche sich oftmals als lineare Siedlungsstrukturen identifizieren lassen und hauptsächlich typologisch als Straßen- oder Angerdorf klassifizierbar sind. Im Hinblick auf eine polyzentrale Stadtstruktur Wiens, bieten diese linearen Dörfer als historisch gewachsene Strukturen mit entsprechender Relevanz für die lokale Identität, ein Potenzial zur weiteren Entwicklung von Mikro- oder Quartierszentren. Diese Perspektive beschreiben auch die zuletzt veröffentlichten Stadtentwicklungspläne von Wien, ohne jedoch konkrete Aussagen zur zukünftigen räumlichen Entwicklung zu treffen.

Bei Betrachtung historischer Karten aus dem Beginn des 19. Jahrhunderts lässt sich ein umgebender Ring von linearen Siedlungsstrukturen außerhalb der Wiener Befestigungsanlagen erkennen, welcher essenziell zur Bewirtschaftung der agrikulturellen Flächen und für die Versorgung der Stadt war. Beginnend in der zweiten Hälfte des 19. Jahrhunderts führten verschiedene Stadtentwicklungsphasen zu einem gewissen Verlust von dörflichen Strukturen in neueren Stadtgefügen. Trotz des ebenso damit verknüpften stetigen Rückganges landwirtschaftlicher Aktivitäten, haben sich dörfliche Layouts und die typischen eingeschoßigen Hofarchitekturen in einigen Bereichen erhalten und wurden zu einer prägenden Komponente von Stadtbildern in Wien in peripherer Lage. Eingeführte Schutzzonen für ausgewählte dörfliche Strukturen limitierten zudem signifikante Transformationen. Dennoch stellt sich in einer stetig wachsenden und sich verändernden Stadt, die Frage nach der räumlichen Perspektive dieser historischen Ortskerne, hier im speziellen die Straßen- und Angerdörfer.

Anhand eines neu entwickelten Design Research Zuganges, adressiert dieses Paper die Zukunftsperspektive der Straßen- und Angerdörfer im Kontext Wien. Wie können diese linearen Siedlungsstrukturen mit ihren spezifischen räumlichen und morphologischen Qualitäten sowie ihrer geografischen Verteilung mit Abständen von ca. 30min Gehdistanz zueinander, in künftigen urbanen Entwicklungen integriert werden?

In einer Zeitspanne zwischen 2023 und 2025, wurde ein umfassender Datensatz an Studierendenprojekten zu dieser Frage am Forschungsbereich Städtebau der TU Wien gesammelt. Drei forschungsgeleitete Design Studios brachten insgesamt 60 Projekte hervor, welche die unterschiedlichen Entwicklungspotenziale der Straßen- und Angerdörfer erörterten. Innerhalb einer Verknüpfung von Ansätzen aus den Bereichen Research by Design und Research about Design, werden diese Projekte zunächst evaluiert und sollen angereichert durch wissenschaftliche Studien und Expertenwissen zu einem Design Guide führen. Dieser forschungsbasierte Guide soll eine fundierte Designstrategie zur Weiterentwicklung der Straßen- und Angerdörfer in Wien bieten. Neben der Zukunftsperspektive thematisiert der Beitrag auch die potenziellen symbiotischen Beziehungen zwischen Forschung, Lehre und Design.

Keywords: Research Through Design, Polycentrality, Urban Design, Historical linear settlements, Heritage

2 INTRODUCTION

Innerhalb der heutigen Stadtgrenze Wiens lassen sich im Franziszeischen Kataster (ca.1820) 71 dörfliche Strukturen bzw. Ortskerne ausmachen (Fig.1). Etwa zwei Drittel dieser Dörfer sind räumlich länglich organisiert und lassen sich auf einer typologischen Ebene hauptsächlich als Straßendorf oder Angerdorf identifizieren. (Tobisch et al. 2023: 113) Generell sind lineare Siedlungsstrukturen eine prägende Typologie für den Osten Österreichs (Klaar 1942), in den ehemaligen Einflusssphären der Habsburger in Osteuropa (Miller 1947; Miller 1950; Löschenbrand et al. 2023) sowie aber auch in anderen Teilen Europas (Miller 1950). Auch wenn im Kontext Wiens gewisse lineare Siedlungen in großen Stadterweiterungsphasen beinah

gänzlich durch spätere Stadtsysteme aus der zweiten Hälfte des 19. Jahrhunderts ersetzt wurden, haben sich lineare Siedlungsstrukturen als prägender Baustein im Wiener Stadtgebiet erhalten.

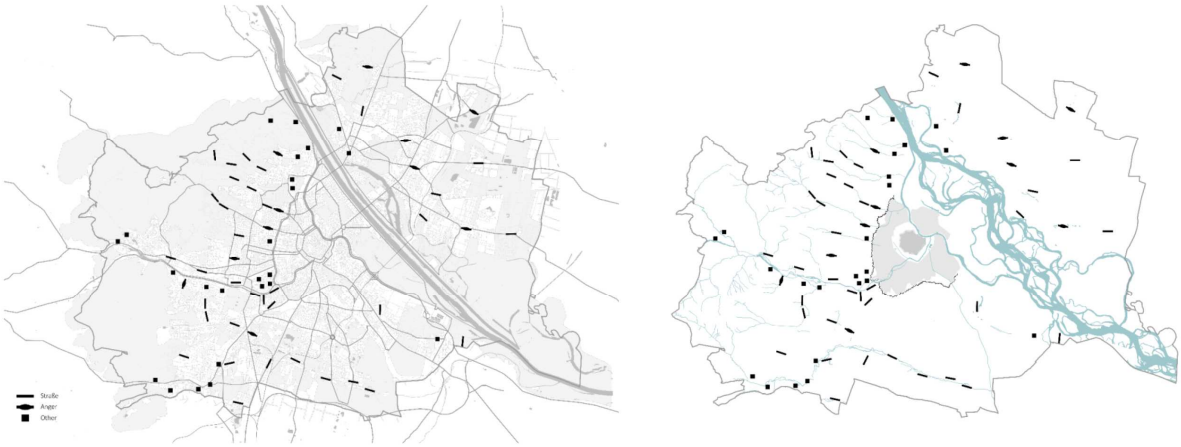


Fig. 1: Links: Übersicht und Typologisierung historische Ortskerne auf Basis des Franziszeischen Katasters (ca. 1820); Rechts: Beziehung Ortskerne zu historischer Wassersituation. © Tobisch, Löschenbrand, Psenner

Als gegenwärtig wachsende Stadt verfügt Wien seit geraumer Zeit über eine kontinuierlich steigende Bevölkerungsanzahl. Diese Bevölkerungszunahme spiegelt sich auch in einer Vielzahl von Stadterweiterungsprojekten außerhalb der konsolidierten Stadtbereiche. In der Perspektive einer räumlich wachsenden Stadt, stellt sich auch die Frage nach zunehmender Multipolarität bzw. Polyzentralität im Stadtgefüge. Ergänzend dazu bedingen aktuelle Strömungen im planerischen Diskurs wie beispielsweise die 15min Stadt oder Superblocks ebenso neue Zentralitäten auf Mikro- und Quartiersebene. Hierbei können die linearen Siedlungstypen in Wien mit ihrer räumlich geografischen Verteilung und ihren Abständen zueinander (Ref. 3.3.) eine bedeutende Rolle einnehmen. Diese Perspektive wird auch im Stadtentwicklungsplan 2025 (kurz: STEP, Stadt Wien 2014: 64) adressiert, indem die historischen Ortskerne mit einer „Stadt der kurzen Wege“ verknüpft werden (Ref. 3.4).

Wie die 15-min-Stadt in periurbanen Bereichen umgesetzt werden kann, ist die zentrale Thematik des DUT-Forschungsprojektes Evolutive Meshed and Compact City – EMC2 (Fusco et al. 2023). Die im Weiteren vorgestellte Lehrtätigkeiten sowie Teile dieser Forschung stehen im Zusammenhang mit dem Forschungsprojekt ECM2. [1] Der vorgestellte Research-by-Design-Ansatz betreffend der Weiterentwicklung der Straßen- und Angerdörfer versteht sich als eigenständige, weiterführende Forschungstätigkeit.

Wie können die historischen linearen Siedlungen in Wien zu einem integralen Bestandteil der periurbanen Stadtentwicklung werden und dabei einen Beitrag zu einer Stadt der kurzen Wege und zu urbanen Herausforderungen leisten? Für diese Zielsetzung braucht es zunächst ein methodisches Framework. Die Erarbeitung dieses Frameworks unter Hinzunahme von Zugängen aus dem Bereich Design Research ist der zentrale Bestandteil dieses Beitrages.

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[1] Im transnationalen Forschungsprojekt EMC2 – arbeitet und forscht ein Konsortium bestehend aus Partnern aus Frankreich, Italien, Schweden und Österreich an der Umsetzbarkeit der Implementierung von Carlos Morenos Konzept der 15-Minuten-Stadt in der städtischen Peripherie. Dabei werden die Stadtrandbereiche von Nizza, Lille, Göteborg, Wien sowie der Küstenstreifen in Massa und Viareggio vertieft behandelt. Auf einer nationalen Ebene in Wien wird schwerpunktmäßig auf einer morphologischen Ebene gearbeitet. Die entsprechende Forschungsgruppe unter der Leitung von Angelika Psenner ist am Forschungsbereich Städtebau der TU Wien beheimatet. Lin: https://urbanism-tuwien.at/forschung/projekt/emc2 und https://emc2-dut.org

3 BACKGROUND

3.1 State of the Art und Definition von Straßendorf und Angerdorf

Wie bereits eingangs erwähnt, finden sich diese linearen Siedlungstypen aufgrund historischer Konstellationen auch in östlich umgebenden Nachbarländern Österreichs und darüber hinaus. Die hier vorgestellte Betrachtung von Straßen- und Angerdörfern bezieht sich auf eine deutschsprachige Perspektive im österreichischen Kontext. Dabei gibt es wenig Primärliteratur zu diesen linearen Siedlungstypen.

Eine wichtige Grundlage zur Typologisierung von Siedlungs- und Flurformen in Österreich erfolgte durch die Arbeiten von A. Klaar (1942), der mitunter auch Definitionen zu den beiden Typen Straßen- und Angerdorf sowie zu den vielen verwandten Subtypen erstellte. Klaar definiert das Straßendorf als planvolle Siedlungsform, in derer sich entlang einer zentralen Straße regelmäßig rechteckige Grundstücke arrangieren (Klaar 1942: 18). Das Angerdorf, welches sich zusätzlich über eine zentrale Grünfläche „Anger" innerhalb der Siedlung definiert und Allmendegut war, ist ebenso eine planmäßige Siedlungsform (ebd.: 20-21). Unabhängig vom jeweiligen Basislayout, ob Straßen- oder Angerdorf in unterschiedlichen Formen, sind beiden Typen von denselben Hoftypologien geprägt, welche die rechteckigen in die Tiefe gezogenen Parzellen zur Straße bzw. Anger hin bebauen und dadurch der charakteristische geschlossene Straßenraum entsteht (Fig.2).

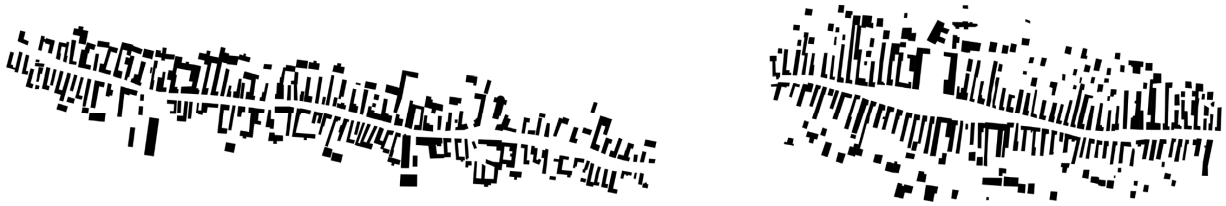


Fig. 2: Links Exemplarisches Straßendorf in Wien; Rechts: Exemplarisches Angerdorf in Wien © Tobisch, Löschenbrand, Psenner

In der zweiten Hälfte des 20. Jahrhunderts entstanden aus deutschsprachiger Perspektive im österreichischen Kontext noch Masterarbeiten (e.g. Zierhut 1975; Dungl 1988; Zehetgruber 2010) und Dissertationen (e.g. Poschacher 1967) mit Bezug zu Straßen- und Angerdörfern. Vertiefte spezifische Auseinandersetzungen oder Standardwerke zu diesen Siedlungstpyen aus einer urbanen oder raumplanerischen Perspektive finden sich nach aktuellem Wissenstand nicht. Mehr Beiträge und Publikationen finden sich bezugnehmend auf die unterschiedlichen Hofformen aus einer entweder Baukulturperspektive (e.g. Kräftner 1987) oder einer Regionalforschungsperspektive (e.g. Dachler 1909). Die Untersuchung und Recherche zu möglichen Standardwerken zu Straßen- und Angerdörfern aus einer beispielsweise ungarischen, tschechischen oder slowakischen Perspektive ist noch nicht abgeschlossen. Diese transnationale Perspektive linearer Siedlungsstrukturen wurde bereits in ersten Anaylsen untersucht (Löschenbrand et al. 2023) und enthält noch großes Forschungspotenzial.

3.2 Genesis der Typologie von linearen Siedlungsstrukturen in Wien

Die Ursprünge dieser planmäßigen Straßen- und Angerdorfformen in Österreich liegen im Mittelalter (Klaar 1942; Miller 1947; Miller 1950). Auch im Kontext Wien finden sich Nennungen für einige lineare Siedlungsstrukturen aus dem 11. und 12. Jahrhundert. Über die Jahrhunderte hinweg, erlebten diese Dorfstrukturen Naturkatastrophen, Feuer oder kriegerische Konflikte. (Klaar 1971; Hinkel 1994: 13, Hansen-Schmidt 1995: 5)

Mit ihren historischen agrikulturellen Ausrichtungen prägten diese linearen Siedlungsstrukturen das städtische Umland. H. Bobek & E. Lichtenberger (1978) unterscheiden hierzu im Wesentlichen zwischen größeren Dorfstrukturen gewidmet dem Ackerbau im Süden und Osten sowie Orten bzw. Dörfern, welche im Westen situiert, auch durch das Thema Weinbau charakterisiert waren (S. 254).

Als Wien in der Gründerzeit wesentlicher Stadterweiterungsphasen erlebte, wurden zunehmend zentrumsnähere lineare Siedlungen überformt (e.g. Ottakring). Weiters durchlebten im 20. Jahrhundert die linearen Siedlungen unterschiedliche Grade an baulichen Transformationen, was zu einem gewissen Verlust der historisch eingeschoßigen Hofarchitekturen führte. Dennoch konnten gewisse lineare Siedlungen ihren

ursprünglichen charakteristischen uniformen Dorfcharakter weitestgehend bis heute erhalten (e.g. Stammersdorf oder Oberlaa). Dies wurde auch gefördert durch eine Altstadterhaltungsnovelle 1972, welche erste Schutzzonen in ausgewählten Straßen- und Angerdörfern einführte. So finden sich heute im Wiener Stadtgebiet einer Vielfalt unterschiedlicher Situationen – von stark transformiert (e.g. Simmering, Stadlau) bis hin zum weitestgehenden Erhalt der ursprünglichen Charaktersitik (e.g. Stammersdorf, Leopoldau).

3.3 Geografische Verteilung von Straßen- und Angerdörfern in Wien

Trotz unterschiedlichen geografischen Situationen in Wien – die westliche hügelige Stadtseite geprägt von den Ausläufern des Alpenvorlandes und der südliche und östliche Teil als flache Ebene – finden sich lineare Siedlungsstrukturen historisch wie gegenwärtig ringförmig um die gesamte Stadt.



Fig. 3: Ausgewählte Lineare Siedlungen in Wien inklusive 15-min-Einzugsraum. © Löschenbrand, Tobisch, Psenner

In den Hügeln im Nordwestens Wiens, die geprägt sind durch parallele Richtung Stadtzentrum verlaufende Bäche, situieren sich die linearen Dörfer jeweils an den Talböden (Fig. 1). Die Hügel selbst wurden mitunter auch für den zuvor erwähnten Weinbau landwirtschaftlich genutzt. Der östliche Teil des heutigen Wiens, welcher auf der anderen Flussseite der Donau liegt, charakterisiert sich durch eine flache Ebene. Dabei fallen in diesem Kontext unter anderem die teilweise sehr regelmäßigen Abstände der Dörfer zueinander und eine beinah netzförmige Anordnung auf einer größeren Maßstabsebene auf. Die Verknüpfung zwischen Wasser und Siedlung, welche sich bereits in den westlichen Tallagen ausbildet, bildet sich im südlichen Teil Wiens noch auf eine neue Art aus. Hier orientieren sich einige Straßendörfer parallel versetzt zum Liesingbach.

Zieht man um die jeweiligen Straßen- und Angerdörfer in Wien einen 15-min-Einzugsraum, lassen sich die bereits erwähnten Aspekte von regelmäßigen Distanzen sowie einer gewissen Netzartigkeit nachvollziehen (Fig.3). Diese Logik der Verteilung steht in Relation zu geographischen Bedingungen und historischen agrikulturellen Praktiken, thematisiert aber auch zu Fuß begehbare Distanzen in einem räumlichen System.

3.4 Polyzentralitäten

Geprägt durch die Arbeiten von R. Rainer (Planungskonzept Wien 1962) und auch seiner Position als leitender Stadtplaner von Wien, wurde in der zweiten Hälfte des 20. Jahrhunderts in Wien zunehmend Polyzentralität gefördert. Die beiden Stadtentwicklungspläne (kurz: STEP) der Stadt Wien STEP 84 (Stadt Wien 1985) and STEP 94 (Stadt Wien 1995) förderten diese Entwicklung mit der Ausweisung von Subzentren und Entwicklungsachsen bzw. -korridoren. In diese Planungen wurden ausgewählte Straßen- und Angerdörfer in gewisse Achsen integriert. Ebenso wird in beiden Dokumenten mehrfach die Erhaltung ausgewählter historischer Ortskerne, welche auch die linearen Siedlungen abbilden, adressiert.

Wie bereits erwähnt, assoziiert der STEP25 (Stadt Wien 2014) erstmals die Ortskerne und Polyzentralität mit der Thematik „Stadt der kurzen Wege“. Ebenso umfasst der STEP25 ein Fachkonzept Mittelpunkte des städtischen Lebens – Polyzentrales Wien (Stadt Wien 2020), welches die alten Ortskerne als Versorgungszentrum auf einer kleinmaßstäblichen Ebene ausweist.

4 RESEARCH QUESTION AND METHODS

4.1 Forschungsfrage und Zielsetzung

Das hier vorgestellte Projekt repräsentiert einen komplexen experimentellen Zugang mit der Zielsetzung, perspektivisch eine spezifische Siedlungstypologie in Wien weiterzuentwickeln. Diese Zielsetzung soll durch Hinzunahme von Lehre, Forschung und Expertenwissen erfolgen. Der in diesem Beitrag beschriebene erste Schritt beinhaltet einen methodischen Fokus, wodurch sich gegenwärtig folgende Forschungsfrage ergibt:

Wie kann ein methodisches Framework, welches bekannte Zugänge aus dem Bereich Design Research und Lehre bündelt, organisiert sein, um wissenschaftlich fundierte Designstrategien zu entwickeln?

Auf diesem methodischen Beitrag aufbauend, wird das Potenzial der räumlichen Weiterentwicklung der linearen Siedlungsstrukturen in Wien im Hinblick auf eine 15-min-Stadt bzw. Stadt der kurzen Wege in kommenden Publikationen nach Abschluss der dazugehörigen Tätigkeiten veröffentlicht.

4.2 Research by Design

Zur Erarbeitung dieser wissenschaftlich fundierten Designstrategie wird Research by Design als zentraler Zugang gewählt. R. Roggema (2016) präsentiert für Research by Design ein methodisches Framework, in welchem er den Prozess in eine Pre-Design Phase, eine Design Phase und eine Post-Design Phase teilt und diesen auch mit Lehre und Design Studio verknüpft. Dabei versucht Roggema auch die sehr vielfältigen Definitionen von research into/about, through/by und for design zu ordnen – greift dabei auch die bekannte Dreiteilung mitunter stark geprägt durch C. Frayling (1993) zwischen Research into-/Research through-/ Research for Design auf – und stellt eine Definition für Research by Design auf:

“Research by design is a method, which uses design to research spatial solutions for a certain area, accommodating a design process, consisting of a pre-design phase, a design phase and a post-design phase, herewith providing a philosophical and normative basis for the design process, allowing to investigate the qualities and problems of a location and test its (spatial) potentials, meanwhile creating the freedom to move with the proposals in uncharted territory, and producing new insights and knowledge interesting and useful for a wide audience.” (Roggema 2016: 15).

Schreurs & Martens (2005) verknüpfen Qualitätssteigerung mit Research by Design und verstehen es als kein finales Produkt. „Research by Design fokussiert auf die Produktion einer Umgebung durch das Testen von Standorten, Programmen, Wahrnehmungen, Absichten, gutem Willen, Machbarkeit (…)“ (S. 4, Übersetzung durch Autorinnen und Autoren).

Für die hier präsentierte Research by Design Methodologie ist das Design Studio das zentrale Element. Die Verknüpfung von Research by Design und einem Design Studio wurde bereits mehrfach beschrieben (e.g. Roggema 2016). Das allgmemeine Design Studio ist in der Regel praxisorientiert und nicht forschungsbasiert (de Walsche 2021: 40). Dennoch kann ein Design Studio, beispielsweise im Kontext eines größeren Forschungsprojektes mit entsprechenden Forschungsfragen, über die Rolle eines Think-Tanks hinausgehen und zu einem Raum werden, wo themenbezogene Entwürfe untersucht werden und sich wertvolle Erkenntnisse ableiten lassen können (Armstrong 1999: 10).

Neben dem Design Studio als Hauptkomponente zur Erlangung der beabsichtigen fundierten Designstrategie für die Straßen- und Angerdörfer, wurden als weitere wesentliche Bauteine Analysis, Research, Evaluierung und Design Guide bestimmt.

4.3 Design Studio

Die bereits erwähnte geografische Verteilung der linearen Siedlungsstrukturen bildete auch die Grundlage in der Konzeption der forschungsgeleiteten Design Studios. Um die Gesamtheit der Straßen- und Angerdörfer auch in einer gewissen Tiefe in Wien zu behandeln, wurden drei Design Studios über drei Semester (1,5 Jahre) veranstaltet: Ein Design Studio, welches die Straßen- und Angerdörfer im Osten Wiens behandelt, eines für den Nordwesten sowie eines für den südlichen Teil.

Zielsetzung dieser jeweiligen Design Studios war es zu untersuchen, wie und in welcher Rolle diese linearen Siedlungsstrukturen in einer urbanen Weiterentwicklung der Stadtrandbereiche die Implementierung einer 15min Stadt fördern können. Neben der baulichen Weiterentwicklung und Verdichtung der Dörfer und ihrer Umgebung waren im Zusammenhang mit dem Konzept der 15min Stadt folgende Schwerpunktthemen

ausgewiesen: Angebote & Nutzungen, Förderung aktiver Mobilitätsformen, Reduktion Autoverkehr, Stadtökologie, Einbindung Stakeholder.

In jedem Design Studio wurde eine intensive Analysephase mit den Studierenden durchgeführt, indem linearen Siedlungsstrukturen in Wien nach einem semesterübergreifenden Prinzip vergleichbar untersucht wurden. Wie unter 4.4 erläutert, wurden Templates und klare Arbeitsweisen innerhalb der Analyse vorgeben, um einerseits qualitative weiterverarbeitbare Resultate zu erhalten sowie aber auch andererseits für die Studierenden eine gute Ausgangsbasis für den Entwurf zu schaffen. Jedes Design Studio wurde mit einem zusätzlichen Schwerpunkt behandelt: Netzwerkbezogener Schwerpunkt, Prozessbezogener Schwerpunkt, Konzeptioneller Schwerpunkt. Diese Schwerpunkte wurden auch gewählt, um zu erproben, ob sich diese unterschiedlichen Zugänge auch in einer späteren Benotung und Evaluierung sichtbar machen.

4.4 Analyse

Analytische Auseinandersetzungen zu den linearen Siedlungsstrukturen werden zweifach durchgeführt. Einerseits am Anfang in den Vorbereitungen und in der Beginnphase des Design Studio mit den Studierenden sowie andererseits in Form einer Aufarbeitung der ersten Analyseresultate inklusive ergänzenden Recherchen und Anlaysen für den späteren Design Guide.

Für den ersten Analysepart, welcher auch in Zusammenhang mit Lehre und Design Studios steht, lag ein Hauptfokus auf der Erstellung entsprechender Analysetemplates mit dazugehörigen Standards und Richtlinien für den Arbeitsprozess. Mit den Studierenden behandelte Analysenthemen in den forschungsgeleiteten Design Studios waren mitunter: Typologische Untersuchungen der Gebäude, Mapping der PoI (Points of Interest) und Mobilitätsanbindungen. Für diese Analysen galt es auch Feedbackschleife mit den Studierenden durchzuführen, um letztlich gewünschte Resultate zu erhalten.

In einer zweiten Analysephase gilt es die Resulte der Studierenden aufzuarbeiten, vereinzelt zu korrigieren und letztlich noch im Design Studio identifizierte fehlende Anaylsethemen zu ergänzen. Ziel ist eine harmoniserte gleichwertige Analyse für jedes behandelte Straßen- oder Angerdorf.

4.5 Ergänzende Forschung

Ausgewählte Inhalte betreffend der 15min Stadt von C. Moreno (2024) oder auch im Hinblick zur Straßenraumgestaltung von J. Gehl (2012, 2015) prägten bereits die Design Studios und sind auch für die weitere Erstellung des Design Guides relevant. Weiters gilt es auch netzwerkrelevante Konzeptionen wie die „400-m-Regel“ (Mehaffy et al. 2010) im Hinblick auf Qualitäten für zu Fuß gehende zu berücksichtigen.

Nach der Evalierung der Studierendenprojekte und im Hinblick auf den Design Guide gilt es entsprechende relevante Inhalte zu beispielsweise Historie, Stadtklimatologie, Soziologie oder Mobilität zu recherchieren und dadurch die im Guide enthaltenen Handlungsempfehlungen zu untermauern.

4.6 Evaluierung

Der Datensatz an Studierendendesigns aus dem Design Studio wird aufgearbeitet und qualitativ und quantitativ bewertet. Hierzu bedarf es eines Katalogs an Parametern (Ref. 5.4), anhand welcher diese Einschätzungen getroffen werden.

In der qualitativen Bewertung und Analyse der Studierendenprojekte gilt es auch die Note und die dazugehörige Ausarbeitung des jeweiligen Designs im Hinblick auf einzelne Parameter zu separieren und differenziert zu betrachten. So kann es sein, dass beispielsweise sehr vielversprechende konzeptionelle Ansätze, welche wertvolle Erkenntnisgewinne beinhalten, nicht immer überzeugende Ausarbeitungen durch Studierende erfuhren. Dementsprechend kann trotz keiner guten Note, theoretisch ein wertvoller Erkenntnisgewinn zu einem gewissen Parameter vorliegen, welcher wiederum einen Beitrag für den späteren Design Guide bilden kann.

Die Auswertung des jeweiligen Studierendendesigns erfolgt anhand einzelner Parameter und wird anhand 3 Kategorien bewertet: Für den weiteren Prozess nicht relevant; Parameter weiterverfolgbar behandelt; Parameter überzeugend behandelt.

4.7 Design Guide

Die Evaluierung der Studierendendesigns bildet die Grundlage für den Design Guide. Hierbei werden weiterverfolgbare und überzeugende Designansätze abgeleitet und nochmals auf ihre Anwendbarkeit und Umsetzbarkeit im Kontext Wien geprüft – auf einer normativen und regulatorischen Ebene sowie aber auch auf einer konzeptionellen Ebene. Anschließend werden auf Basis dieser untersuchten Designansätze mittels Expertinnen- und Expertenwissen konkrete Handlungsempfehlungen betreffend der transformativen Potenziale definiert. Ziel ist es eine Sammlung von Handlungsempfehlungen auf einer räumlich qualitativen und strategischen Perspektive im Bezug zur Weiterentwicklung der Straßen- und Angerdörfer in Wien zu kreieren.

Diese Handlungsempfehlungen sollen innerhalb des Design Guides auch anhand ausgewählter Straßen- und Angerdörfer exemplarisch angewendet werden, um die Potenziale für Entscheidungsträgerinnen, Entscheidungsträger und Stakeholder zu visualisieren.

5 RESULTS

5.1 Framework

Die unter 4.3–4.7 vorgestellten Teilbereiche wurden zu einem methodischen Framework zusammengeführt (Fig.4), welches es ermöglichen soll, Forschung und Lehre unter einem Research by Design Zugang so zu organisieren, um letztlich einen Design Guide zur Weiterentwicklung einer spezifischen Typologie zu generieren. Mit den wesentlichen Phasen Design Studio, Evaluierung und Design Guide wird eine klare chronologische und aufeinander aufbauende Abfolge beschrieben. Die dazugehörigen Analyse- und Researchtätigkeiten werden diesem linearen Prozess zugeführt.

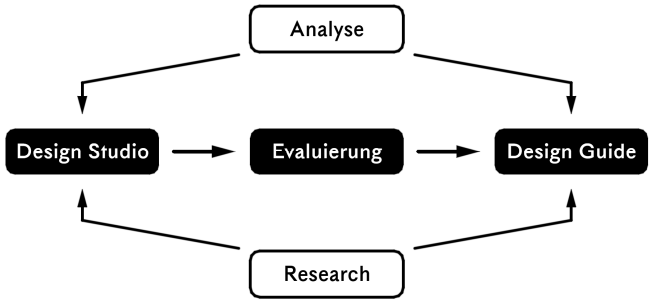


Fig. 4: Methodisches Framework. © Löschenbrand, Tobisch, Psenner

Die von Roggema (2016) erwähnte Dreiteilung (Pre-Design Phase, Design Phase, Post-Design Phase) lässt sich theoretisch auch auf dieses Schema übertragen. Dennoch sieht sich dieses Vorhaben auch als Vorstudie für entweder strategische Entscheidungen und stadtplanerischen Designs oder aber auch für tatsächliche Praxisdesignprojekte mit Umsetzung. So könnte man diese Untersuchung wiederum als Research for Design verstehen.

5.2 Analyse

Für jedes Straßendorf oder Angerdorf und der jeweiligen Umgebung wird im Hinblick auf den Design Guide eine umfassende Analyse anhand der Analysematrix (Table 1.) durchgeführt. Teile der Analysethemen werden durch die Analysetätigkeit mit den Studierenden innerhalb des Design Studios generiert. Die verbleibenden Themen werden in der Analysephase 2 erarbeitet.

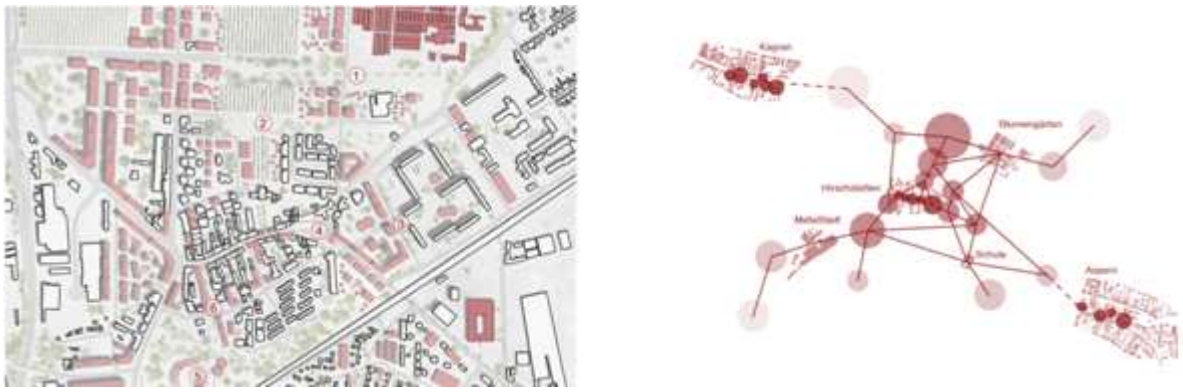


Fig. 5: Studierendenprojekt 1. © Reiner, Riedler.

Kategorien	**Analyseparameter**			
Gebaute Strukturen	Anteil hist. Obejkte (max 2 Geschoße, Fassade referenzierbar zu historische Hofarchitektur) vereinzelt; medium; signifikant	Erweiterung und Nachverdichtung Charakteristische Nach-verdichtung innerhalb Kern; Erweiterungen Kern mit niedriger Dichte; Erweiterung Kern mit hoher Dichte; großformatige Sonderbauten	Verbaute Fläche wenig; medium or intensive verbaute Fläche	Charakterisitische Typologien Offene Kleinstrukturen; Offene Großstrukturen; Geschlossene Kleinstrukturen; Geschlossene Großstrukturen; Großformatige Sondertypologien
Mobilität & Straßenraum	Anbindung der Hauptstraße an Primärnetzwerk Teil einer Hauptstraße Direkte Anbingung an Hauptstraße; Parallel zu Hauptstraße; nicht an Hauptstraßen angebunden	Mobilität Ausgebaute Fußgänger-infrastruktur; Ausgebaute Fahrradinfrastruktur; Busanbindung; Straßenbahnanbindung; Übergeordnete Anbindung	Charakterisitk öffentlicher Raum (im Zentrum der linearen Struktur) Autodominiert; Aufenthalts-flächen; Bäume; Gastronomie mit Schanigarten, Möbel	
Nutzungen	Platzsituationen – Potenzial für diverse Nutzungen (auch temporär) Ja/Nein	PoI (Points of Interests, relevant für die Erdgeschoßzone) Gastronomie; Handel; Hotel; Religion; Andere	Nähe zu übergeordneten Einkaufszentren, Gewerbeparks, Büroviertel etc. Ja/Nein	
Grün- und Freiraum	Nähe zu hochwertigen Grün- und Freiraum-flächen Ja/Nein	Nähe zu hochwertigen Freizeitangeboten Ja/Nein		
Geografie	Geografische Orientierung Nord-Süd; West-Ost; Nordwest-Südost; Südwest-Nordost	Charakteristische topografische Elemente Ja/Nein	Nähe zu Wasser (Fluss, Bach) ≤200m; ≤400m; ≥400m	

Tabelle 1: Überblick über die Analyseparameter.

Die Analysematrix enthält die 5 Überkategorien: Gebaute Strukturen, Mobilität & Straßenraum, Nutzungen, Grün- und Freiraum sowie Geografie. Die dazugehörigen Analyseparameter repräsentieren räumliche Eigenschaften in unterschiedlichen Maßstabsebenen und sind mit entweder ja/nein oder fixierten Auswahlmöglichkeiten (auch Mehrfachauswahl) zu beantworten. Diese definierten Auswahlmöglichkeiten sollen es ermöglichen, Muster zu identifizieren sowie auf Basis der Analyseparameter etwaige vergleichbare Typen von Straßen- und Angerdörfern zu bestimmen.

5.3 Design Studios

Von den etwa 30 linearen Siedlungsstrukturen, welche sich heute in unterschiedlichen Zuständen im Stadtgebiet Wiens finden, wurden 20 lineare Siedlungsstrukturen innerhalb der drei Design Studios behandelt. Die Zielsetzung der städtebaulichen Weiterentwicklung von linearen Siedlungsstrukturen und ihrer Umgebung im Hinblick auf eine 15min Stadt wurde in den einzelnen Design Studios differenziert umgesetzt. Um Einblicke zu den Resultaten zu geben, wurde ein jeweils exemplarisches Studierendenprojekt aus dem Design Studio ausgewählt, um gewisse Zugänge der Studierenden im Rahmen dieses Beitrages vorzustellen.

Der netzwerkbezogene Fokus aus dem ersten Design Studio, also das Verständnis für die jeweilige lineare Siedlungsstruktur und ihren umgebenden baulichen Kontext auf einer größeren Maßstabsebene zu behandeln und Synergien zu kreieren, war ein Zugang, der sich auch automatisch in vielen Projekten in den anderen beiden Design Studios durchsetzte. Diese Netzwerkschwerpunkte können sich auf mobilitätsbezogene oder auch auf programmatische Ebenen beziehen. Wesentliches Merkmal des exemplarischen Studierendenprojektes 1 ist es, lokale Stakeholder zu vernetzen und durch Aktivieren von ausgewählten vorhandenen Sonderbausteinen, neue programmatische Impulse zu setzen. In Kombination mit Nachverdichtung und Erweiterung von Bestandsstrukturen sollen dadurch Dichten und Frequenzen erhöht werden, welche sich wiederum bspw. positiv auf Erdgeschoßzonen auswirken soll (Fig. 5).

Neben dem unter 4.3 erwähnten prozesshaften Schwerpunkt auf einer methodisch pädagogischen Ebene[2], zeigte sich ein prozesshafter Zugang auch auf einer entwerferischen Ebene als überzeugend in Studierendenprojekten des Design Studio 2, in den Hügellandschaften im Wiener Westen. Das exemplarisch gewählte Projekt beinhaltet die langfristige Neuausrichtung vorhandener und neuer Wege bzw. Straßen. Diese Neuausrichtung umfasst die Umgestaltung von Straßen zugunsten von Fußgängermobilität und die Attraktivierung mittels thematisch geprägten Wegenetzwerken. Ergänzend dazu sollen innerhalb der linearen Dorfkerne thematisch passende Angebote geschaffen werden (Fig. 6).



Fig. 6: Studierendenprojekt 2. © Spieck.

Das dritte Designstudio integrierte die stark gewerbliche und landwirtschaftliche Prägung des Wiener Südens in Form von Kreislaufwirtschaft bzw. Circularity als ergänzendes Schwerpunktthema. Das exemplarische Studierendenprojekt 3 nahm diese Themen auf und übersetzte diese in thematische Hubs, welche die bestehenden Dorfstrukturen durch neue materielle und soziale Kreisläufe prägen sollen (Fig. 7).

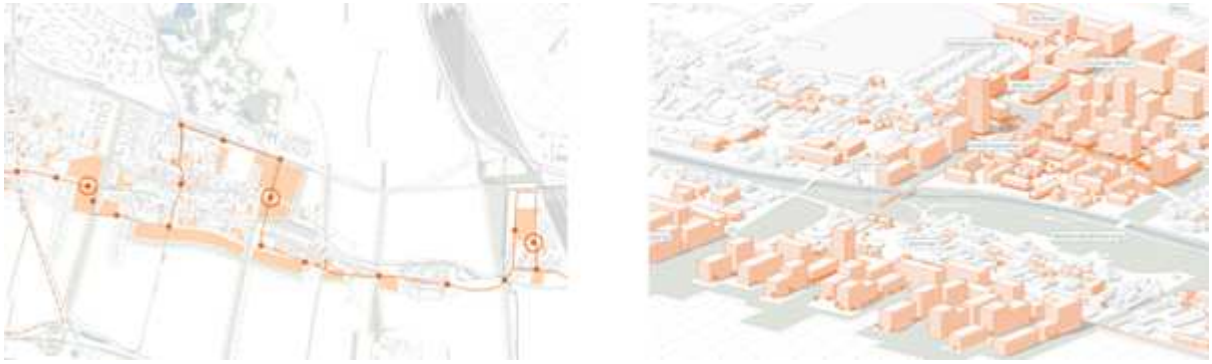


Fig. 7: Studierendenprojekt 3. © Heß, Tappe.

5.4 Evaluierung

Wie unter 4.6 erläutert, erfolgt die Auswertung der 60 Studierendendesigns nicht auf Basis einer Gesamtnote, sondern auf Basis einzelner Projektlayer. Diese umfassten die Kategorien: Umbauten und Erweiterungen der historischen Kernstruktur; Neubauten oder Umbauten im Kontext der hist. Kernstruktur; Infrastruktur (Angebote; PoI); Mobilität; Transformation halböffentlich oder öffentlich Raum; Grün- und Freiraumplanung; Soziale Durchmischung und inklusive Themen; Möglichkeiten Raumaneignung, Flexibilität.

[2] Die Studierenden wurden zu Beginn des zweiten Design Studios mittels Workshops gezielt in die Semesterplanung involviert.

Jedes Studierendenprojekt wird auf alle 8 Projektlayer geprüft, ob dieses Thema schwerpunktmäßig behandelt wurde und wenn ja, ob dies weiterverfolgbar oder überzeugend behandelt wurde. Diese Filterung bzw. Selektion erfolgt auf Basis von Expertenwissen und die weiterverfolgbaren und überzeugenden Ansätze bilden die Grundlage für die Handlungsempfehlungen und die weitere Erstellung des Design Guides.

6 DISCUSSION & CONCLUSION

Wie eingangs erwähnt, beschreibt dieses Paper das methodische Framework zu diesem Research by Design Ansatz. Die Evaluierung der Studierendenprojekte betreffend Straßen- und Angerdörfer in Wien, die Vervollständigung der Analysen und die letztendliche Generierung des Design Guides inklusive der Applikation an ausgewählten linearen Siedlungsstrukturen sind für das Frühjahr 2026 angesetzt.

Die über 3 Semester konzipierten Design Studios, welche elementarer Bestandteil dieses Vorhabens sind, boten nicht nur auf einer designtechnischen Ebene wertvolle Erkenntnisse, sondern führten auch auf pädagogischer Ebene zu einigen Aufschlüsse. Der subjektive Eindruck der Betreuenden war es, dass durch diese starke Verflechtung zu Forschung und die Einbettung des Design Studios in Forschungsvorhaben, eine vergleichswiese stärkere Beziehung zwischen Studierende und Aufgabenstellung entstand. Ebenso die anfängliche intensive Analysephase, welche auch in der Erstellung der Templates und Richtlinien für die Betreuenden zeitaufwendiger war, führte innerhalb des Semesters zu kontextuell besser verankerten Designprojekten.

Die in diesem Paper dargelegte Methodik, basierend auf den drei wesentlichen aufeinander aufbauenden Bausteinen Design Studio, Evaluierung und Design Guide sowie die dazu begleitenden Analyse- und Researchtätigkeiten mit den jeweiligen Kategorien bildet eine erste Skizze, welche sich im noch ausständigen Prozess adaptieren kann.

Neben dem methodischen Schwerpunkt sowie einer Darstellung der Genese von linearen Siedlungsstrukturen innerhalb der Wiener Stadtgrenze, war das generelle Ziel dieses Beitrages, das Bewusstsein für diese Typologie zu stärken und auf deren räumliche Eigenschaften und Potenziale von Straßen- und Angerdörfern hinzuweisen. Die räumliche Verteilung dieser dörflichen Strukturen mit den dazugehörigen Distanzen bietet eine potenzielle Basis für chronourbanistische Stadtplanungskonzepte.

Betreffend das Stichwort Polyzentralität, formulierte der STEP 94 im Kapitel „Räumliches Entwicklungskonzept – Leitbild“ für den Bereich: Stadlau/Aspern/Essling/Hirschstetten/Hausfeld/Altes Flugfeld/Aspern:

„Wesentliche Träger der künftigen Identität des Stadtentwicklungsbereiches werden die vorhandenen alten Ortskerne – als Kristallisationspunkte einer polyzentrischen Siedlungsentwicklung mit einem leistungsfahigen öffentlichen Verkehr als Rückgrat – und das übergeordnete System der imagebildenden Grünräume – in das die zukunftsweisend gestalteten neuen Stadtviertel flächenhaft eingebettet sind – sein.“ (Stadt Wien 1995, STEP 94: 140)

In etwa 30 Jahre später kann man gegenwärtig festhalten, dass die neu eingeführte Linie U2 diese polyzentrale Perspektive mit Fokus auf die historischen Ortskerne etwas konterkarierte und neue Zentralitäten sich entlang dieser Trasse an den Stationen gegenwärtig und perspektivisch bilden. Dennoch bleibt im Gebiet Stadlau/Aspern/Essling/Hirschstetten sowie aber auch auf gesamtstädtischer Ebene das Potenzial dieser historischen Dorfkerne bzw. linearen Siedlungsstrukturen bestehen, um das Netz an Mikro- bzw. Quartierszentren weiter zu verfeinern und dadurch eine Stadt der kurzen Wege bzw. eine 15min City in peripheren Lagen weiter zu fördern.

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The Bibliometrics Insight: Role of Spatial Planning in Just Energy Transition in South Africa

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1 ABSTRACT

In the Global South, the repurposing of decommissioned power stations offers a unique opportunity to address the energy crisis while advancing spatial justice. This paper explores the socio-spatial dimensions of energy transitions, with a focus on the role of spatial planning in facilitating a just energy transition that addresses the needs of historically marginalized communities through the equitable redistribution of resources and opportunities. Using PRISMA and bibliometric methods, the study examines the key themes and geographic trends shaping the discourse on spatial justice and renewable energy integration. The study also examines best practices in balancing socio-economic and environmental goals during the transition from coal to renewable energy, drawing on case studies from the Global South. The study's findings highlight strategic insights for a Just Energy Transition in South Africa, emphasizing the need for policies that align spatial equity and social inclusivity with technical innovation.

Keywords: Spatial planning, renewable energy, coal-fired power station, bibliometric analysis, energy transition

2 INTRODUCTION

In the discord of the global energy transition, the Global South faces a paradoxical challenge: the shift from coal to renewables is essential for climate resilience, yet it risks perpetuating spatial injustices if not well managed through inclusive planning (Rocco, 2022). According to Moeng (2024), in South Africa, decommissioned coal-fired stations, such as those in Mpumalanga, exemplify both the legacy of extractive economies under the apartheid regime and the potential for transformative spatial equity. Here, spatial planning emerges as a critical, yet underexplored tool for just energy transitions (Teng et al., 2025). In any case, the study investigates this gap by exploring how spatial planning can recalibrate energy landscapes to redress historical marginalization; this mechanism can ensure that the just energy transition is well supported by spatiality and ensures that renewable energy is well integrated, including its technical imperatives to deliver tangible socio-spatial equity. By harmonizing bibliometrics and PRISMA analysis with case studies from the Global South, the study reveals discrepancies between on-the-ground realities and policy rhetoric. Furthermore, this research aims to challenge the prevailing narratives that examine the infrastructural efficiency of energy distribution. Moreover, at the heart of this inquiry, this study underpins a bold proposition: that spatial planning is not only a logistical tool used by practitioners, but also a radical framework for reconfiguring power from both political and technical expertise. Drawing on the leading authors in the field of energy geographies and urban justice, this study disassembles the techno-centric principle of energy transitions. This paper proposes a logical discussion that harmonizes renewable innovation with spatial restoration. The study's narrative is suspended by its dual criticism: firstly, a methodology that charts out the socio-spatial contours of energy justice and uncovers the myopia of "just energy transition" policies that intend to forsake the spatiality of resource distribution. In the context of South Africa, a nation battling with the legacy of apartheid spatial planning, this paper offers not only an analysis but also a manifesto: energy just transitions must be spatially literate to be truly proclaimed as just.

3 LITERATURE REVIEW

3.1 Legacy of spatial Injustice in South Africa's Energy Landscape

Apartheid era spatial planning entrenched deep infrastructure and economic disparities, enforcing the Black communities to underdeveloped townships and vacant land while concentrating economic opportunities and infrastructure in white urban centers (Gambill, 2019; Ramatlo, 2021; Kararach, 2024). To date, this legacy is prevailing in coal-dominated energy systems. According to Frantál & Nováková (2014) and Perez-Sindin et al. (2022), mining regions continue to bear disproportionate environmental and health burdens, while urban centres are the primary beneficiaries; this spatial injustice is also reflected in the Global South. Notwithstanding the post-apartheid policies, such as the Renewable Energy Independent Power Producer

Procurement Programme (REIPPPP or REI4P), the policy seeks to optimize electricity capacity through private sector investment in renewable energy infrastructure. Herbst & Lalk (2015) & Wenzel (2016) advance the argument that energy poverty still dominates marginalized communities due to inconsistencies in electricity accessibility, load-shedding, and perpetuation of apartheid-era discrepancies. The transition efforts, according to Besada (2022) and Beires & Lincoln (2017), remain hindered by the lack of localized capacity and bureaucratic fragmentation, which leads to the failure to address the spatial inequities embedded in the energy infrastructure. Nevertheless, a just energy transition exceptionally demands spatially literate policies that can restructure the apartheid's geographic legacy, warrant renewable energy projects that adequately prioritize historically disadvantaged and marginalized communities, and integrate economic measures that seek to repair the fragmented spatial layout (Chandratreya, 2025).

3.2 The Limitations of Current Just Energy Transition Frameworks

The current Just Energy Transition frameworks often redirect the concepts to labour-centric and technical challenges, which has led to the continuous neglect of its spatial and socio-economic dimensions (Muinzer et al., 2024; Del Guayo & Cuesta, 2022). The findings by Garvey et al. (2022) and Topaloglou & Ioannidis (2022) underscore that policies, such as those in Greece and Western Macedonia, have utilized a top-down approach as a governance model, which frequently limits public participation by local communities. This has led to the exacerbation of spatial injustices, as the communities' needs are not being addressed. The experience of Global South case studies reveals that they also face the same pitfalls as South Africa's REIPPPP, as identified by Müller & Claar (2021) and Mirzania et al. (2023). Notwithstanding the growth of renewable capacity, REIPPPP is criticized for failing to address energy poverty and warrant local ownership. However, countries such as Bhutan, India, and Nepal bespeak the decentralization of community-driven projects, including microgrids, which demonstrates that decarbonization is aligned with democratization (Misra & Bhardwaj, 2024; Kirchhoff et al., 2016). In any case, the cases indicated underpin the call for redefining Just Energy beyond technocratic solutions to include spatial equity, multi-scalar justice, and participatory governance (Abram et al., 2022; Kanger & Sovacool, 2022). Without such integration, the energy transition stands at risk of the same inequalities it aims to resolve.

3.3 Spatial Planning as a Catalyst for Energy Justice

Spatial planning plays a vital role in the redistribution of both literal and political power, rooting energy justice into the fabric of sustainable development (Rocco, 2022; Wang & Gu, 2023). Furthermore, operationalizing spatial justice entails equitable access to resources and inclusive decision-making; this approach prompts questioning of historical energy marginalization patterns (Bouzarovski & Simcock, 2017). According to Rocco (2022), this method views planning as a socio-political institution, where public justification and reasoning serve as mechanisms for institutionalizing justice. Essentially, spatial planning serves as a tool for decentralizing energy systems, redirecting power from centralized entities to local communities through initiatives such as Renewable Energy Communities (RECs) (Teng et al., 2025). Wang et al. (2022) and Ardi et al. (2023) delineate that RECs symbolize redistribution; this is where the optimization of regional renewable resources is achieved to achieve energy self-sufficiency while democratizing governance through participatory frameworks. Wang et al. (2022) underscore that such models dismantle technocratic energy hierarchies and further address the conflict between greens by prioritizing the spatially mediated competing land uses. Ultimately, spatial planning must extend beyond infrastructure siting to actively restructure power dynamics in communities, necessitating energy transitions that enhance both social equity and sustainability.

4 METHODOLOGY

This study adopts a systematic literature review approach, led by the PRISMA framework, to investigate the integration between spatial planning and the just energy transition in South Africa. This method was utilized for this purpose in improving the reproducibility and transparency in the screening and selection process of academic literature. At first, the dataset of 204 peer-reviewed documents was extracted from the SCOPUS database using a combination of keywords such as "spatial planning," "spatial justice," "just energy transition," "coal transition," and "renewable energy". Using this method, duplicates were removed, and the screening process was based on document type, looking at the keywords and abstracts; this was to enhance the relevance of the documents. At the end of the process, 161 studies were selected as eligible for review.

VOSviewer was a tool used for the analysis of the dataset. Thus, the study infuses the bibliometric analysis. Moreover, this approach was utilized to map the scientific landscape, determine geographic trends, identify the key thematic clusters, and underpin the most influential authors and countries that excessively contribute to the discourse of spatial planning and just energy transition. The study visualized metrics such as citation analysis, co-occurrence of keywords, and publication trends to expose the social and intellectual structure of the field. By combining the two methodologies, the study provides both depth and breadth of critical gaps, best practices, and emerging themes related to spatial equity and renewable energy transition, focusing on the context of South Africa and the Global South.

5 FINDINGS

The bibliometric analysis, conducted using VOSviewer on the 161 PRISMA-selected studies, reveals an interconnected thematic landscape encompassing spatial planning, sustainability, and energy systems. As shown in Figure 1 below (Keyword co-occurrences and a link strength of 210, highlighting its essential role in integrating related fields. As visualised in Figure 1 (keywords co-occurrence network), "spatial planning" emerges as the central node with 85 occurrences and a link strength of 210, underscoring its pivotal role in integrating related fields. Closely integrated keywords include "sustainable development" (62 occurrences), "climate change" (48), "renewable energy" (45), and "energy planning" (38), reflecting the growing convergence of environmental and spatial concerns in energy transition research. The network identifies four key clusters: (1) urban transformation (e.g. "urbanization" "urban planning"); (2) marine spatial planning (e.g., "offshore wind farms," "marine environment," "fisheries'); (3) energy justice (e.g., "energy transition," "spatial justice"); and (4) policy framework (e.g., "land use," "governance"). Geographically, the analysis shows dominance by Global North countries like the Netherlands (32 publications), the United Kingdom (28), and Germany (25), with minimal representation from the Global South (e.g., South Africa: 8; India: 6). This bias underpins a critical knowledge gap in context-specific application of spatial planning to just energy transition in rejoins like South Africa, justifying this study's focus.

The below Figure1 illustrates the Keyword Co-occurrence Network, generated through VOSviewer; minimum keyword occurrence: 5; clusters colored for distinction.

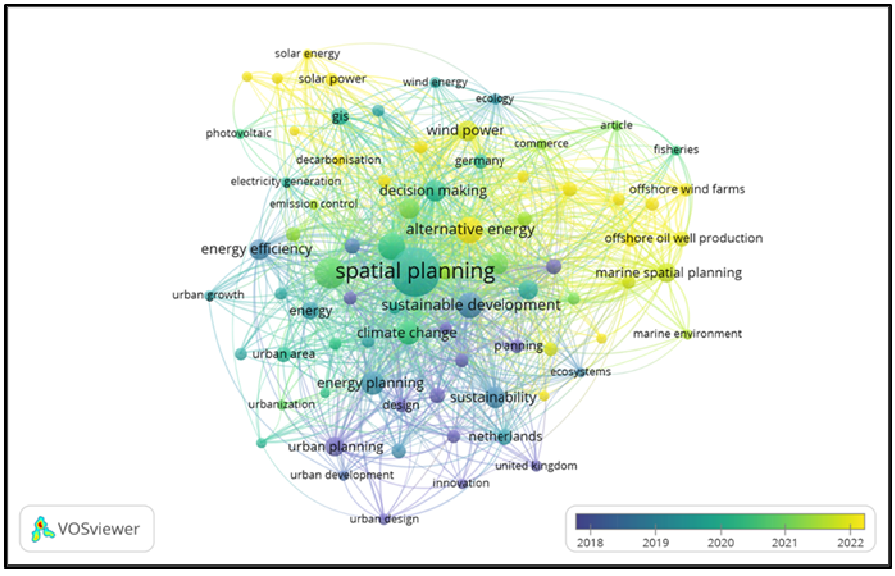


Fig. 1: Keyword Co-occurrence Network (generated via VOSviewer; minimum keyword occurrence: 5; clusters colored for distinction). This visual map reveals the interconnection, highlighting how renewables, such as solar and wind, are underrepresented in discussions of spatial justice.

To complement Figure 1, Figure 2 above represents publication trends over time. Of the 161 studies, only 28 (17%) have a clear integration of spatial planning with just energy transitions; this is often linked to policy frameworks, land-use optimization, and urban development for renewables. There are stresses that spatial planning is a tool for siting infrastructure and resolving land conflicts, while promoting equitable energy access to communities. Additionally, a key gap emerges in the siloed treatment of domains: 112 studies (70%) focus on the technical aspects of renewable energy or policies without considering spatial aspects, such as community participation in wind project zoning or addressing geographic disparities in solar access.

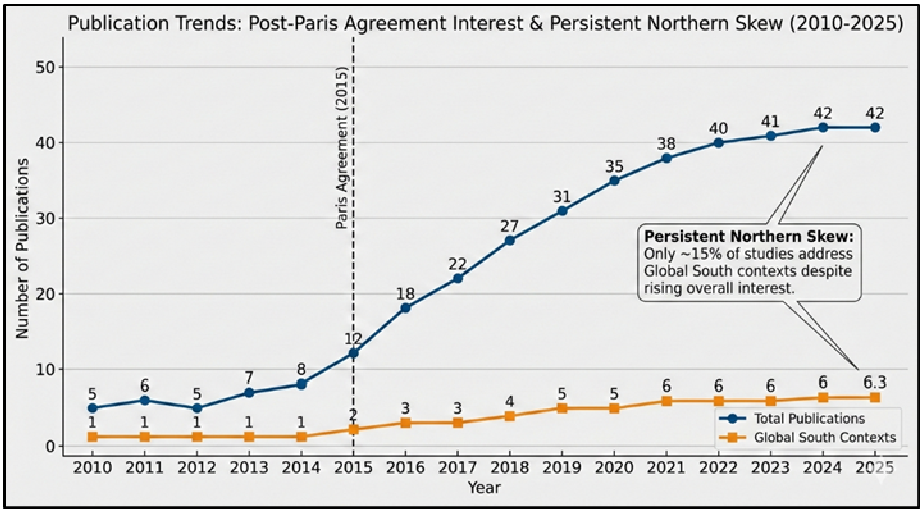


Fig. 2: Publication trends over time, showing a sharp increase in relevant studies from 2015 onward (post-Paris Agreement), peaking at 42 in 2024-2025

Figure 3 below, supports both Figures 1 & 2 by charting out the number of publications of developed, transitioning, and developing countries.

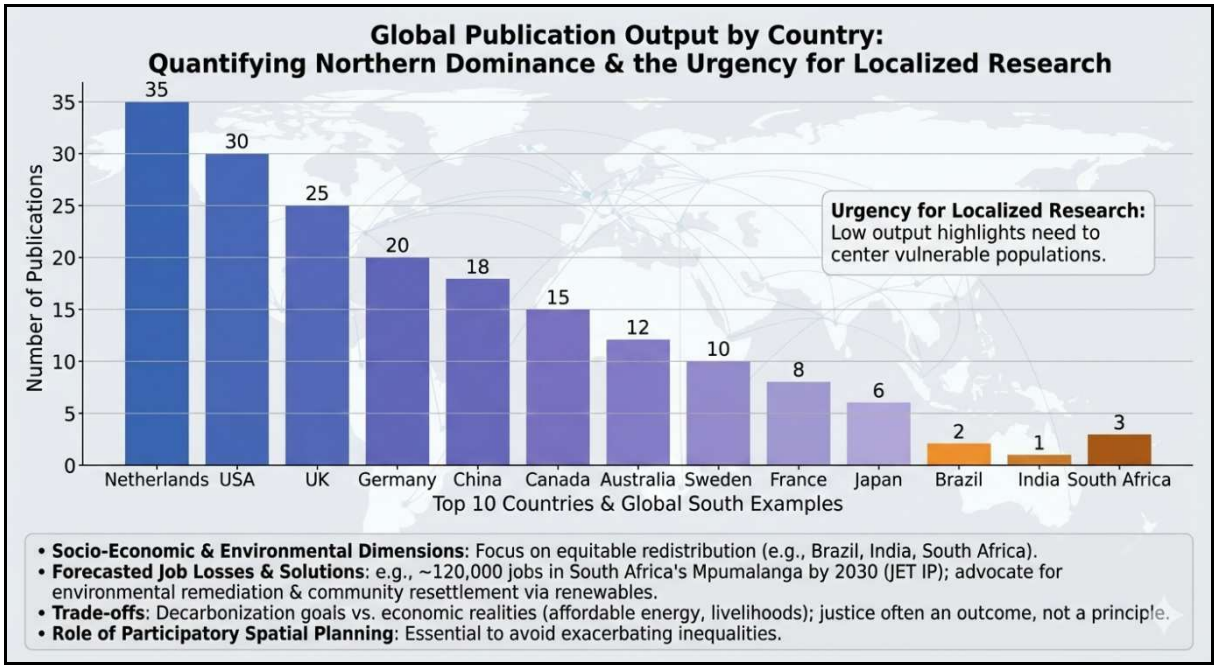


Fig. 3: Bar Chart of Country Contributions. This visual quantifies the dominance of the Global North (e.g., the Netherlands leading), contrasting with low output from the Global South, to emphasize the urgency for localized research.

In the context of the socioeconomic and environmental dimensions of energy transitions, countries such as Brazil, India, and South Africa clearly engage with the theme of equitable redistribution, underscoring the need to prioritize historically marginalized communities during the shift from fossil fuels to renewable energy sources. The study forecasts job losses in coal-dependent regions, but also advocates for the remediation of degraded environments and community resettlement. A remarkable pattern may emerge as a result of trade-offs between environmental goals, including decarbonization and emissions reductions, and the economic realities of affordable energy, accessibility, and local livelihoods (Müller & Claar, 2021). Withal, various studies treat justice as an outcome rather than a guiding approach principle of transition. This finding reinforces the significance of rooting participatory planning and spatial justice at the core of transition strategies, ensuring that vulnerable populations are not further disadvantaged in the process.

Figure 4 below. It is a radar chart of trade-offs in Energy Transition. The image effectively illustrates the role of spatial planning in countries of the Global South, highlighting both balanced and imbalanced approaches.

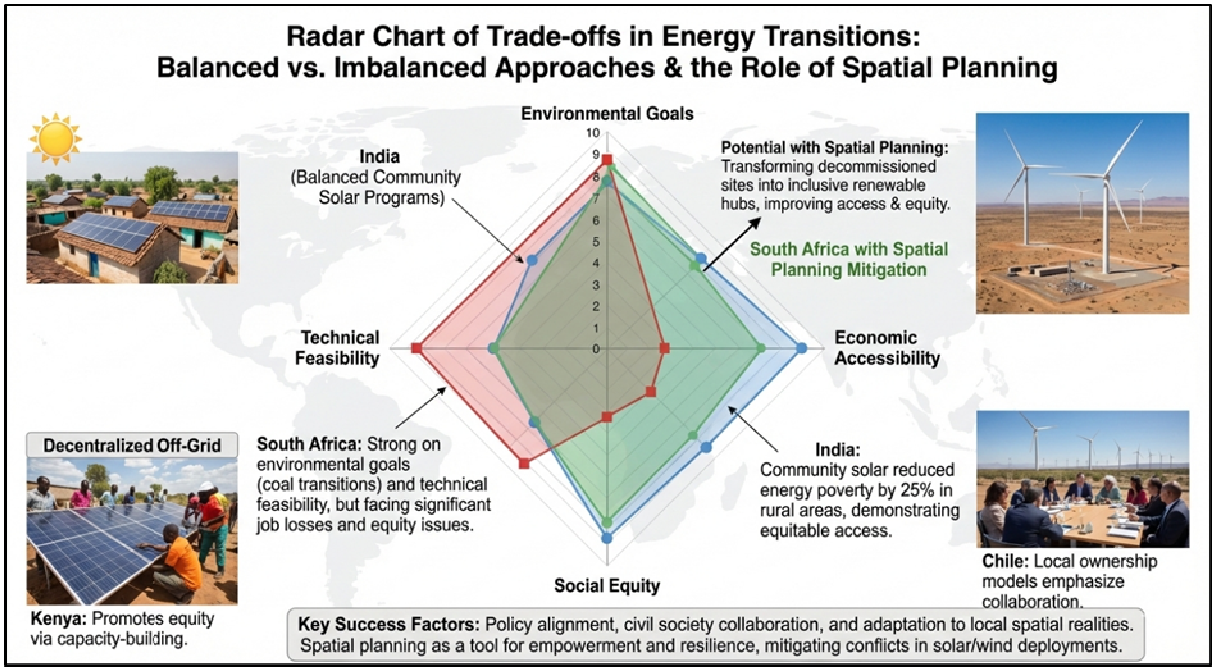


Fig. 4: Radar Chart of Trade-offs in Energy Transitions. This visual illustrates balanced vs. imbalanced approaches, showing how spatial planning can mitigate conflicts in solar/wind deployments.

Country	Key Initiative	Spatial Planning Role	Outcomes
India	Community Solar Programmes	Integrated with rural development strategies through strategic site selection and land suitability planning	Improved affordable energy access and enhanced energy equity for rural communities
Chile	Multi-stakeholder Wind Energy Models	Spatial zoning to manage land-use conflicts, coupled with participatory planning and local ownership frameworks	Increased community acceptance, reduced land-use disputes, and strengthened local capacity
Kenya	Decentralised Off-Grid Solar Systems	Spatial planning enabled equitable distribution through zoning for service coverage and community-based infrastructure siting	Expanded energy access, reduced spatial inequality, and improved local collaboration
South Africa (JEP / Renewable Energy Hubs – Potential)	Renewable Energy Hubs and Skills Transition Initiatives	Spatially targeted planning to repurpose coal regions, integrate energy infrastructure, and support regional economic diversification	Mitigated job losses, strengthened local resilience, and advanced an inclusive just energy transition

Table 1: Comparative Best Practices from Global South Case Studies. This tabular visual synthesizes transferability, enhancing actionable insights.

It is noteworthy to emphasize that several high-impact studies have provided practical examples of how regions in the Global South are navigating the dual directives of spatial justice and energy transition. Countries including India, Chile, and Kenya have a proven record of community-based solar programs, multi-stakeholder governance models, and decentralized energy systems that position equity at the centre of

energy planning (Wang et al., 2022; Ardi et al., 2023). The successful solutions are frequently underscored by local capacity-building, strong policy alignment across sectors, and collaborative frameworks between government and civil society initiatives that encourage sustainability and ownership (Rocco, 2022; Wang & Gu, 2023). Subsequently, these case studies emphasize the importance of context-specific planning, rather than a one-size-fits-all approach; needs are tailored to local conditions and spatial realities. The study considers these cases as the best practices, and potentially, they offer invaluable lessons to South Africa. The study emphasizes that the just energy transition is most feasible and will materialize when spatial planning is leveraged not only as a regulatory tool but also as an approach for inclusive development, community empowerment, and long-term resilience.

The table below, Table 1. Offers comparative best practices from case studies in the Global South. It demonstrates how context-specific spatial planning has successfully pioneered equitable renewable energy transitions in Kenya, India, and Chile, while offering transferable lessons to South Africa's Just Energy Transition Partnership (JETP) and energy hub initiatives.

6 DISCUSSION

By casting light on the critical yet underexplored themes, the study bridges the conceptual and practical gaps between spatial planning and just energy transition in the Global South, particularly in South Africa. Academically, the study advances the interdisciplinary discourse by mapping the convergence of spatial justice, socio-economic, and renewable energy equity using PRISMA and bibliometric methods. The study further highlights the limited opportunities for growth in integrating spatial dimensions into energy planning, thereby identifying key areas for future scholarly inquiry. For policy practitioners and industry, the study provides actionable insights into how the significance of spatial planning can be effectively utilized and leveraged to operationalize the just energy transition principle, including participatory planning, equitable redistribution, and localized energy systems. Therefore, by learning from the best practitioners in the world, the study affords a platform for designing context-sensitive frameworks and inclusive policies that adequately inform the repurposing of decommissioned power stations and other infrastructure projects.

7 CONCLUSION

This paper investigated the critical integration of spatial planning and a just energy transition in South Africa, deploying PRISMA and bibliometric methods to unearth key themes, identify best practices from the global South, and examine geographic biases. The analysis identified spatial planning as an essential node in the energy domain, yet the study indicates the uneven application, specifically in addressing societal equality in marginalised regions amid coal-to-renewable shifts. The study's findings highlight the critical gap: the energy transition risk reinforces apartheid era spatial injustice, unless planning actively redistributes the resources equally as per the Spatial Planning and Land Use Management Act (SPLUMA) policies. Countries such as India and Kenya are seen as key practitioners, with spatial planning as a node in the distribution of renewable energy resources. It is noteworthy to indicate that the study highlights that moving forward, spatial planning must evolve from regulatory to a catalyst for socio-spatial transformation; it should inform policies such as JETP to aid in successfully repurposing decommissioned power stations into equitable renewable hubs. By prioritising multi-scalar justice and community participation, the global south nations can pave the way for a transition that is truly just, equitable, and sustainable.

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reviewed paper

The Built Environment and Health Comorbidities in Urban Informal Settlements: Mechanisms, Evidence, and Interventions

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1 ABSTRACT

The built environment, encompassing housing quality, sanitation infrastructure, neighbourhood characteristics, and urban design, is a fundamental determinant of health and plays a critical role in shaping the burden of chronic diseases and multimorbidity in urban populations, particularly in informal settlements of low- and middle-income countries. This paper examines the complex relationships between built environment characteristics and the development of comorbidities (multiple coexisting chronic conditions) in residents of informal settlements. Drawing on extensive empirical evidence from diverse geographic contexts, we explore how poor housing conditions, inadequate water and sanitation infrastructure, environmental hazards, and neighbourhood disadvantages create pathways to chronic disease development and multimorbidity. The paper identifies key mechanisms linking built environment factors to comorbidity burden, including biological pathways (disease exposure, stress physiology), behavioural pathways (reduced physical activity, unhealthy food consumption), and psychosocial pathways (chronic stress, depression, social isolation). We examine evidence on housing conditions, neighbourhood safety, green space access, and environmental quality as determinants of comorbidity patterns. Finally, we propose integrated interventions addressing built environment improvements as a strategy for reducing comorbidity burden and health disparities. The paper concludes that addressing built environment deficits is essential for reducing the disproportionate burden of multimorbidity in informal settlement populations globally.

Keywords: Built environment, comorbidities, multimorbidity, informal settlements, health disparities

2 INTRODUCTION

The built environment, the physical structures, infrastructure, and spatial organisation of neighbourhoods and communities, profoundly shape human health and are increasingly recognised as a critical determinant of chronic disease development and multimorbidity (the simultaneous presence of multiple chronic conditions) (Weimann and Oni, 2019). The relationship between housing conditions, neighbourhood characteristics, and health outcomes has become particularly salient as cities in low- and middle-income countries experience rapid, often unplanned urbanisation, resulting in the proliferation of informal settlements characterised by severe infrastructural deficits (Priyadarshini and H. Gundimeda, 2024). Informal settlements are residential areas lacking durable housing, adequate living space, access to basic infrastructure, water, sanitation and other services, and secure tenure (Weimann and Oni, 2019). Residents of these settlements face profound health challenges, yet the mechanisms linking specific built environment characteristics to the development and clustering of chronic diseases remain incompletely understood. This paper synthesises evidence on how built environment factors in informal settlements contribute to comorbidity burden, identifies biological and social pathways connecting environmental exposures to multiple disease development, and examines intervention opportunities.

Understanding these pathways is critical because multimorbidity imposes substantial health, economic, and social costs. Research in urban slum populations demonstrates that multimorbidity is significantly prevalent, with rates as high as 62.5% among older adults aged 65 years in some urban slum settings (Yogesh et al., 2024). The burden of multimorbidity is strongly associated with poor health-related quality of life, reduced functioning, increased healthcare utilisation, and increased mortality risk (Yogesh et al., 2024). Yet populations most burdened by multimorbidity residents of informal settlements often have the least access to integrated healthcare and support services.

3 METHODOLOGY

This study employed a systematic literature review to examine research on the relationship between the built environment and health comorbidities in urban informal settlements. The Web of Science database served as the primary data source, ensuring the inclusion of peer-reviewed and high-quality scholarly outputs. Following a screening and eligibility assessment, 34 articles were retained for analysis. These articles were thematically analysed to identify key research trends, thematic areas, and the evolution of scholarship within this field.

4 FINDINGS AND DISCUSSION

Poor housing conditions represent one of the most direct pathways through which the built environment influences health and comorbidity development (Jabali et al., 2025). Housing quality encompasses multiple dimensions: structural integrity, moisture and mould presence, indoor air quality, crowding, access to utilities, and thermal comfort (Jabali et al., 2025). Each of these dimensions has distinct health consequences, yet residents of informal settlements typically experience multiple simultaneous housing deficits (Brown et al., 2018). Research examining the nexus between housing conditions and health outcomes reveals significant associations across physical, mental, and psychological well-being (Jabali et al., 2025). Palestinians living in smaller households, with higher family incomes, and in private homes report better health across all domains compared to those in overcrowded, rental, or refugee camp settings (Jabali et al., 2025). This relationship holds across multiple disease outcomes. In Swedish immigrant populations, poor housing conditions, particularly dampness and mould, were associated with current asthma and asthma medication use, while mould was associated with headache (Oudin et al., 2016). The presence of cockroaches was associated with emergency care visits, colds, headaches, difficulty falling asleep, and worse general health (Oudin et al., 2016). The mechanisms linking housing quality to chronic disease development are multifaceted. Damp housing promotes mould growth and dust mite proliferation, both of which are associated with respiratory disease and asthma (Nix et al., 2020). Poor ventilation in informal settlement housing contributes to the accumulation of indoor air pollutants and moisture, creating environments conducive to the development of respiratory infections and chronic respiratory disease (Mahadevia et al., 2024). Inadequate heating or cooling systems contribute to physiologic stress and temperature-related illness (Jabali et al., 2025). .

Thermal Environment and Cardiometabolic Morbidity

The thermal characteristics of housing, which are often severely compromised in informal settlements, directly influence cardiometabolic health and contribute to comorbidity development (Weimann and Oni, 2019). Informal settlement housing, typically constructed with heat-absorbing materials (corrugated metal, concrete blocks), minimal insulation, and poor ventilation, creates extreme indoor thermal conditions in hot climates and insufficient heating in cold climates (Sims et al., 2020). These thermal extremes impose direct physiologic stressors and contribute to the development of hypertension, cardiovascular disease, and metabolic dysfunction (Weimann and Oni, 2019).

Research on housing conditions and thermal comfort in informal settlements reveals widespread heat stress (Mahadevia et al., 2024). Indoor temperatures in informal dwellings frequently exceed 30°C during 50-60% of working hours, prompting residents to adopt maladaptive coping strategies such as increased window opening (compromising security), adjusting work schedules (reducing economic productivity), and utilising inadequate cooling strategies (Handayani et al. 2024). These environmental stressors, compounded with poor housing quality and overcrowding, create multiple cardiometabolic risk pathways.

Crowding, Infectious Disease, and Secondary Comorbidities

Housing density and crowding in informal settlements create conditions ideal for rapid disease transmission (Priyadarshini and H. Gundimeda, 2025). High household density and crowding were associated with increased risk of COPD incidence and were identified as significant environmental hazards (Brown et al., 2018). Beyond immediate infectious disease transmission, crowding creates chronic stress exposures and limits privacy, both of which contribute to mental health comorbidities (Handayani et al. 2024). Crowded households during the COVID-19 pandemic were associated with worse mental health outcomes, including loneliness, anxiety, and reduced life satisfaction (Colombo et al., 2023). The persistent threat of infectious disease in crowded informal settlement housing creates chronic vigilance stress, which has been linked to

cardiometabolic disease development, hypertension, and metabolic dysregulation through neuroendocrine and inflammatory pathways.

Water, Sanitation, and Hygiene Infrastructure: Pathways to Comorbidity

Waterborne Disease and Gastrointestinal-Associated Comorbidities

Inadequate water and sanitation infrastructure in informal settlements creates direct pathways to infectious disease and contributes to multimorbidity through multiple mechanisms (Jabali et al., 2025). Poor sanitation facility access was strongly associated with diarrheal infections in Abidjan, in Nairobi). Diarrheal disease in early childhood, a consequence of poor water and sanitation, is associated with impaired linear growth, cognitive development, and long-term chronic disease risk (Priyadarshini and Gundimeda, 2025). Beyond acute gastrointestinal illness, chronic exposure to contaminated water and sanitation creates opportunities for persistent parasitic infections, which contribute to malnutrition, anaemia, and reduced immune competence, compounding risk for other infections and chronic diseases.

Environmental Contamination and Multiple Disease Pathways

In informal settlements lacking adequate water, sanitation, and waste management, environmental contamination creates multiple simultaneous disease exposures (Nix et al., 2020). In urban Nigeria, inadequate housing and sanitation conditions were significantly correlated with communicable disease rates, including malaria (27.6%), typhoid (23%), and diarrhoea (10.3%), with inadequate water supply, unsanitary environments, and overcrowding identified as key drivers (Yusuf et al., 2025). These communicable diseases, particularly when occurring repeatedly or chronically, contribute to the development of immune-mediated chronic diseases, nutritional deficiencies, and secondary comorbidities.

Neighbourhood Disadvantage, Social Stress, and Mental Health Comorbidities

Neighbourhood-Level Determinants of Mental Health

Neighbourhood disadvantage operates as a powerful determinant of mental health comorbidities through multiple pathways. Research demonstrates that residential neighbourhoods with higher deprivation, lower safety perceptions, and reduced social cohesion are associated with substantially higher rates of depression, anxiety, and stress-related disorders (Wong et al., 2024). In Hong Kong, neighbourhood quality was significantly associated with common mental disorders over 3 years, and for participants in substandard housing, high neighbourhood quality significantly alleviated mental health impacts.

Environmental Hazards and Occupational Exposures in Informal Settlements

Air Pollution and Respiratory-Cardiometabolic Comorbidity Clusters

Informal settlements are frequently located adjacent to industrial facilities, waste sites, transportation corridors, and other pollution sources, exposing residents to severe air pollution (Brown et al., 2018). Neighbourhood environmental burden encompassing air pollution, hazardous sites, built environment deficits, transportation infrastructure, and water pollution was associated with significantly higher rates of hypertension, diabetes, and obesity in highly burdened versus minimally burdened neighbourhoods (Kulchar et al., 2024). The associations were strongest in socially vulnerable neighbourhoods, suggesting compounded effects of multiple disadvantages. Ozone exposure during pregnancy and in early life was associated with reduced birth weight (approximately 33g per 10 ppb increase) and increased development of respiratory disease later in childhood and adulthood (Lusk et al., 2024).

Occupational Exposures and Secondary Comorbidities

Residents of informal settlements often engage in informal sector occupations characterised by hazardous exposures waste picking, street vending, and informal construction work (Osrin et al., 2011). These occupations expose workers to chemical hazards, dust, infectious agents, and biomechanical stressors. Occupational exposures contribute directly to chronic respiratory disease, dermatological conditions, musculoskeletal disorders, and infectious diseases, which then interact with poverty-related comorbidities to create complex multimorbidity patterns (Fottrell et al., 2024).

Neighbourhood Access to Health-Promoting Resources

Green Space Access and Mental Health Protection

Access to neighbourhood green space provides protective effects against mental health comorbidities and appears to buffer against neighbourhood disadvantage effects (Brown et al., 2018). Higher block-level greenness was associated with 18% reduced risk of Alzheimer's disease and 28% reduced depression risk in older adults (Roe et al., 2020). Importantly, greenness effects were particularly pronounced in low-income neighbourhoods, where a 1 standard deviation increase in greenness was associated with 37% lower odds of depression compared to 27% and 21% in medium- and high-income neighbourhoods, respectively [20]. Walking in green versus grey (built-up commercial) urban environments showed significant positive effects on emotional well-being and stress physiology, with walking in green areas associated with improved happiness and lower stress activation as measured by heart rate variability (Heredia et al., 2021).

Walkability, Physical Activity, and Metabolic Disease Prevention

Neighbourhood walkability and availability of recreational facilities influence physical activity patterns and are inversely associated with obesity, diabetes, and cardiovascular disease risk (Khan et al., 2024). Lack of nearby shops was associated with 26% increased C-reactive protein values (indicating systemic inflammation) and lower odds of meeting physical activity guidelines (Brown et al., 2018). For older adults ageing with disability, residing in neighbourhoods with a greater density of recreational establishments and parks was associated with reduced risk of incident cardiometabolic disease (Khan et al., 2024).

Housing Insecurity and Eviction-Related Health Impacts

Eviction as a Comorbidity Driver

Housing instability and eviction represent acute disruptions to health and are associated with increased comorbidity development. Poor housing conditions and evictions are both independently associated with cardiovascular disease, depression, and injuries, yet the relationship between these two negative housing outcomes has received limited research (Sonik and Herrera, 2022). In New York City public housing, adjusted predicted probabilities of eviction increased from 34% to 43% with a rodent inspection and from 34% to 46% with an indoor environmental inspection, indicating that formal recognition of unsafe housing conditions preceded evictions (Khan et al., 2024).

Residential Instability and Long-Term Health Trajectories

Children who moved from high to low neighbourhood deprivation showed larger improvements in educational outcomes than those who moved between high-deprivation neighbourhoods, suggesting that residential moves to better neighbourhoods provide tangible health and development benefits (Bravo et al., 2024). However, residential instability itself, frequent moves, was associated with worse outcomes. These findings indicate that stable housing in adequate conditions is preferable to instability, even in disadvantaged environments, yet moves to improved environments provide the greatest health benefits.

Mechanisms and Pathways: Toward Integrated Understanding

Multiple Simultaneous Disease Pathways

The built environment influences comorbidity development through multiple simultaneous, often interacting pathways (Weimann and Oni, 2019). . A framework for understanding these pathways includes:

- Biological pathways: Infectious disease exposure (through poor sanitation); environmental hazard exposure (air pollution, lead, other toxins); thermal stress; nutritional deficiency; and immune dysregulation from chronic stress (Yogesh, et al., 2024).
- Behavioural pathways: Reduced physical activity opportunities; unhealthy food consumption reflecting food environment characteristics; tobacco and alcohol use patterns; and reduced healthcare-seeking behaviour (Patel, 2020).
- Psychosocial pathways: Chronic stress from neighbourhood violence and disadvantage; social isolation and reduced social cohesion; depression and anxiety related to housing insecurity and environmental conditions (Patel, 2020).
- Systems-level pathways: Limited access to healthcare resources; poor quality of available services; and health system fragmentation in serving informal settlement populations (Yogesh, et al., 2024).

Interventions: From Built Environment Improvements to Comorbidity Reduction

Housing Upgrading and Health Benefits

Housing upgrading interventions have been associated with health improvements, though the evidence is more developed for specific outcomes (infectious disease, respiratory disease) than for integrated comorbidity assessment (Weimann and Oni, 2019). Cool roof interventions in informal settlements reduced indoor temperatures by 1-1.5°C during peak summer, with potential for reducing heat-related illness and thermal stress-related cardiometabolic disease (Brown et al., 2018). However, longitudinal evidence on whether housing upgrades prevent or reduce multimorbidity development remains limited (Weimann and Oni, 2019).

Water, Sanitation, and Infrastructure Investments

Improving water and sanitation infrastructure prevents waterborne disease and reduces communicable disease burden, addressing one critical pathway to comorbidity in informal settlements (Priyadarshini and H. Gundimeda, 2024). Combined with hygiene promotion, comprehensive WASH interventions significantly reduce diarrheal disease incidence and provide protection against malnutrition-related immunodeficiency and secondary comorbidities (Priyadarshini and H. Gundimeda, 2024).

Neighbourhood Green Space Development

Expanding access to green spaces in informal settlement neighbourhoods offers co-benefits for mental health, physical activity, and social cohesion (Brown et al., 2018). Green space development can reduce depression and Alzheimer's disease risk while providing space for community gathering and social connection (Brown et al., 2018).

Participatory Planning for Built Environment Transformation

Effectively built environment improvements require participation of informal settlement residents in planning and design processes (Weimann and Oni, 2019). Participatory approaches ensure that interventions align with residents' priorities and constraints, increase the likelihood of sustainability, and strengthen community agency in addressing health determinants.

5 CONCLUSION

The built environment is a fundamental determinant of multimorbidity in urban informal settlement populations through multiple interconnected pathways, including infectious disease exposure, environmental hazards, chronic stress, and limited health-promoting resources. The evidence demonstrates that poor housing, inadequate water and sanitation infrastructure, neighbourhood disadvantage, and environmental hazards are not merely correlates of comorbidity but direct contributors to chronic disease development and clustering. Addressing built environment deficits represents a critical public health opportunity for reducing comorbidity burden and health disparities in informal settlement populations globally (Weimann and Oni, 2019). However, as the evidence also demonstrates, housing upgrades and infrastructure improvements must be comprehensive, participatory, and integrated into broader health system strengthening efforts to achieve sustainable health improvements (Weimann and Oni, 2019). Future research utilising longitudinal designs must assess whether built environment improvements actually reduce the incidence and progression of multimorbidity over time in informal settlement populations.

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The Role of Land Use Planning in Influencing the Placement of Logistics Firms near the Port of Cape Town, South Africa

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1 ABSTRACT

The institutional frameworks in maritime services and logistics functions, particularly in emerging markets like South Africa, are ever changing and need to be studied further. The study responds to the research gap in understanding the ever-changing economic activity in the port-city interface. The study aimed to analysethe role of land-useplanning and regulatory frameworks in influencing the location of logistics firms in the vicinity of the Port of Cape Town, South Africa. The study conducted content analysis of the zoning and applicable municipal spatial and management strategies. The results show that there is a land-use planning and regulatory framework creating a conducive environment for logistics operations, and this can be improved by implementing port-centric logistics clusters purposefully. The research concludes that there is an opportunity for strategic concentration of logistics firms in Paarden Eiland to enhance operational efficiencies through shared resources. The study recommends adaptive approaches that consider the impact of the growth and transformation of logistics and supply chain management and the operational strategies of logistics firms through effective land-use planning and port development to improve the interrelationships between port-centric cluster development and urban and regional planning in the City of Cape Town.

Keywords: Port of Cape Town, Paarden Eiland, spatial planning, land-use planning, port-city interface

2 INTRODUCTION

The spatial changes of maritime services offered near ports still remain under researched, particularly in emerging market economic regions (Ye and Jiang, 2021). As a result of the fourth industrial economy's globalisation and new technology revolution, the port's role is expanding and becoming more of an integration platform for production elements (Jacobs and Notteboom, 2011). The port's fundamental purpose is transformed into a hub for the 'factor flow' between the economic hinterland and other locations (Wenyuan et al., 2019; Zhang and Yun, 2019; Guo et al., 2020; Guo and Qin, 2022). The maritime shipping industry, which transports the movement of multiple industrial elements, is a crucial node in the construction of this circulatory network. It completes the network of cargo flows, capital, technology, skills, and information between the port and the urban area in which it is located, so creating the port urban region's 'flow space' (Zhang and Yun, 2019). After the ports have evolved into a system typified by port regionalisation, not only are there transit links between them, but there are also more non-port industries moving there, and urban agglomerations are progressively driving their expansion. However, the usage and purpose of land in port regions have not been delineated on land use maps for centuries. (Hesse, 2010; Hein, 2021). In this regard, further research is required. Using Paarden Eiland as a case study, the research contributes to the gap of knowledge pertaining to the land-use mix in the vicinity of ports.The aim of the research is to analyse the role of land-use planning and regulatory frameworks in influencing the location of logistics firms in the vicinity of the Port of Cape Town, South Africa. This provides insight on how these firms interact spatially and functionally within this strategic urban-port interface. The study seeks to contribute to the broader discourse on port-city dynamics by focusing on the land-use mix and spatial organisation of logistics activities in view of a rapidly evolving global economy and technological landscape. By doing so, the study not only aims to contribute to theoretical knowledge but also to provide practical insights into effective land-use planning and policy formulation for logistics planning related to ports and their surrounding regions.

3 METHODS

The study is based on a mixed methods and single-case study approach. Zoning data from the City of Cape Town Open Data Portal were analysed using ArcGIS to assess the alignment of logistics firms location with zoning regulations. Additionally, content analysis was conducted on the City of Cape Town's Spatial Development Framework (SDF) and District Plans to extract guidelines and visions relevant to logistics operations. To investigate the influence of land-use planning and regulation on the logistics firms' mix and placement, data on zoning and applicable spatial plans were collected. This included GIS shapefiles from the

City of Cape Town City Map Viewer, as well as district plans relevant to the Table Bay and Blaauwberg administrative areas. The analysis combined spatial analysis techniques with content analysis of the Paarden Eiland CID Business Plans to identify themes and regulatory frameworks impacting logistics operations. This approach enabled the identification of themes and policy directives shaping the spatial distribution and functional mix of logistics firms. The content analysis of municipal documents revealed how zoning classifications, such as industrial and mixed-use zones, influenced the placement of logistics firms. Frequency analysis was applied to categorise the logistics firms identified in the study area. This method quantified the presence of different types of logistics firms, highlighting their relative significance within the vicinity of the Port of Cape Town and provided basic statistical analysis of types of economic activities based on the mix of logistics firms. Using ArcGIS software, a spatial analysis was performed to look at how logistics companies were distributed and clustered throughout the research area. These techniques provided insights into the spatial logic of logistics operations by assisting in determining how close logistics companies were to important nodes, like the Port of Cape Town, industrial districts, and transportation networks.Figure 1 indicates the locality map locating the Paarden Eiland case study in the national and municipal context. It delineates the municipal administrative boundary, highlighting significant transport routes, including arterial roads and railway lines,logistics landmarks such as the Port of Cape Town and Cape Town International Airportwhich are crucial for understanding the connectivity in the region. Paarden Eiland is marked in red within the city, highlighting its location and relevance to the logistics landmarks and routes illustrated. Additionally, an inset map places Cape Town municipality within the broader geographical context of South Africa.

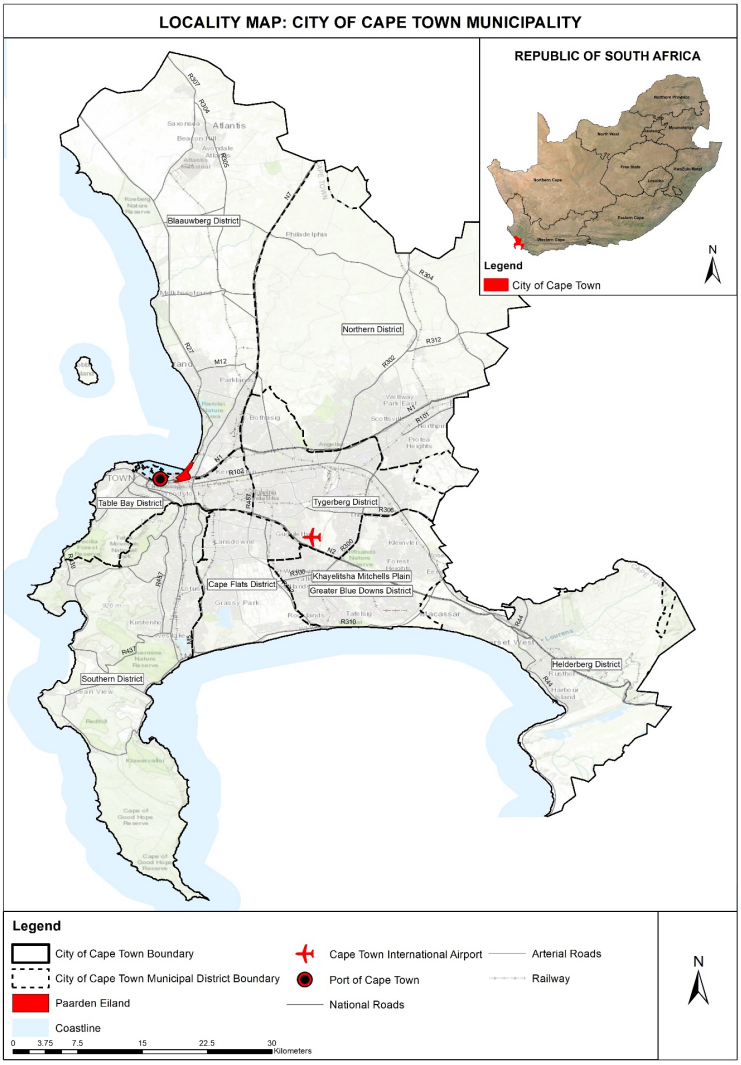


Fig. 1: Locality Map

4 EVOLUTION OF MARITIME ECONOMICS AND LOGISTICS SUPPLY CHAINS

As ports remain significant in global trade networks, understanding their economic and spatial dynamics is essential for planning and policy-making. The evolution of trends in maritime economics and port-centric logistics clusters provides the backdrop for exploring how logistics firms agglomerate in the vicinity of ports, contributing to the broader understanding of port-city interactions against the backdrop of technological and economic shifts. Port attributes include waterfront, estuary, and maritime bases, ship/shore and multimodal/intermodal interfaces, distribution and logistics centres, corridors and gateways, maritime industrial development areas (MIDAs) and trade and distribution maritime centres (TDMCs), industrial clusters and distriparks, free zones, trading hubs, and networks (Bichou and Grey, 2005).Economic activity taking place at ports and their vicinities are denoted by firms such as freight forwarders that serve as crucial intermediaries in the logistics network, managing the shipment process from origin to destination. They ensure compliance with regulatory requirements and address the complexities of global trade, particularly in high-traffic port areas. This role is increasingly supported by advanced technologies that facilitate efficient tracking and scheduling (Heitz et al., 2020). Third party logistics providers are also prominent economic activity near ports that enhance operational efficiency by outsourcing logistics activities, such as warehousing and transportation management, allowing businesses to focus on core operations (Chen et al., 2024). Transportation companies are dedicated to moving goods through various modalities and their proximity to ports is vital for improving operational efficiency (Vitellaro, 2021). The concentration of these firm types near the ports reflects the area's strategic importance as a logistics hub, further enhanced by agglomeration economies that promote shared infrastructure and collaboration among firms.

Freight forwarders are indispensable within the logistics framework, consolidating shipments and coordinating services such as customs clearance and insurance. Their functions are critical in mitigating delays and ensuring compliance with complex regulations. The reliance on modern technologies in this field allows for improved navigation of port congestion and optimised logistics operations (Cooper et al., 2024). Consequently, freight forwarders not only facilitate connectivity within supply chains but also contribute significantly to economic growth through efficient logistical coordination. The recent surge in the significance of third-party logistics providers stems from the evolutions of supply chain management; these providers offer comprehensive services that span the logistics spectrum, enabling firms to improve efficiency through outsourcing (Holl and Marrioti, 2017). The presence of warehousing plants and transportation services at logistics hubs like ports illustrates the pivotal role of these providers in ensuring smooth product flow. Although courier services, representing last-mile delivery, are less prevalent, they indicate adaptations to modern market demands such as e-commerce, showcasing an evolving logistics landscape (Tiupysheva et al., 2023).Research indicates that the strategic engagement of stakeholders boosts profitability and addresses risks in the maritime logistics environment (Vitellaro, 2021). Recognising the diverse roles of these firms allows for tailored strategies that leverage their strengths while addressing operational challenges, thus fostering a robust maritime logistics framework. Logistics firms act as essential facilitators in supply chain management, overseeing various activities such as inventory management and transportation planning. Their strategic location decisions indicate the importance of accessibility to ports, significantly affecting operational efficiency (Tiwari et al., 2003). As global trade dynamics evolve, these firms adapt to technological advancements and market demands, enhancing their capacities to optimise supply chain processes. Collaborative approaches among different logistics stakeholders are crucial in maintaining competitive advantages and addressing emerging logistical challenges, ultimately maximising responsiveness within the logistics network (Vitellaro, 2021).The literature highlights the importance of adopting innovative strategies to harmonise port and city development while addressing their shared challenges and maximising mutual benefits.This perspective emphasises the critical role of geographic dispersion and network effects in shaping the technological and operational dynamics of port systems, port industrial zones, and their interactions with urban centers.

5 RESEARCH FINDINGS AND DISCUSSION

5.1 The role of land-use planning and regulation

The zoning pattern in Paarden Eiland was identified using data from the City of Cape Town Open Data Portal (Figure 2).The predominant zoning in Paarden Eiland is “General Industrial 2”. Industrial zoning caters for manufacturing and general industrial land use which may affect the environment with hazardous or

noxious land uses which need to be managed cautiously. Industrial development has specific waste management needs and road infrastructure (City of Cape Town, 2024). “General Industrial 2” zoning different subzoningsconsisting of a variety of built firms and there is a provision for consent uses associated with industrial activities (City of Cape Town, 2024). The data indicates the presence of logistics firms in the Paarden Eiland are consistent with the zoning regulations. The second predominant zoning in Paarden Eiland is “Open Space 2 – Public Open Space”. This zoning mostly caters for the buffer zone along the coastal edge to cater for environmental considerations. The least predominant zoning in Paarden Eiland is “Mixed Use 2”. Mixed-use zonings accommodate industrial, business and residential development (City of Cape Town, 2024).



Fig. 2: Zoning Schemefor Paarden Eiland

5.2 Content analysis of municipal documents that influence land-use and spatial planning

According to the Blaauwberg District Plan (District B) a gradual change of land use is foreseen in Paarden Eiland. Although Paarden Eiland is historically an industrial area, the analysis from the Spatial Development Plans suggests that it is suited to mixed-use development, including retail, offices and residential use as a

result of its location attributes (City of Cape Town, 2023:276). According to the Table Bay District Plan (District A) general industrial development activity is retained in Paarden Eiland.

Document Name	**Document Content**	**"Paarden Island" Occurrences**	**"Maritime Cluster" Occurrences**	**"Logistics Cluster" Occurrences**
1. City of Cape Town City Map Viewer Open Data Portal	Zoning data	N/A	N/A	N/A
2. City of Cape Town Table Bay District Plan 2012	Socio-economic and spatial planning data	23	0	0
3. City of Cape Town District Blaauwberg District Plan 2012	Socio-economic and spatial planning data	9	0	0
4. City of Cape Town Table Bay District Plan Documents (Volumes) 2023	Socio-economic and spatial planning data	Total = 148	Total = 10	Total = 2
Volumes				
4.1 Volume I: Baseline and Analysis Report (BaAR)		13	0	0
4.2 Volume II: District Plan Main Technical Report		15	0	1
4.3 Volume II: Main Technical Report – Executive Summary		4	0	0
4.4 Volume III: Implementation Plan		2	0	0
4.5 Volume IV: Technical Annexures		114	10	1
5. City of Cape Town District Blaauwberg District Plan Documents (Volumes) 2023	Socio-economic and spatial planning data	Total = 44	Total = 0	Total = 1
Volumes				
5.1 Volume I: Baseline and Analysis Report (BaAR)		22	0	0
5.2 Volume II: District Plan Main Technical Report		15	0	1
5.3 Volume II: Main Technical Report – Executive Summary		2	0	0
5.4 Volume III: Implementation Plan		2	0	0
5.5 Volume IV: Technical Annexures		3	0	0
6. CID Application Report	Urban management data	63	0	0
7. Business Plan for the Management of the Paarden Eiland City Improvement District 01 July 2016 -30 June 2021	Urban management data	32	0	0
8. Business Plan for the Management of the Paarden Eiland City Improvement District 01 July 2021 – 30 June 2026	Urban management data	53	0	0

Table 1: Institutional Land-use and Spatial Planningin Paarden Eiland (Letsoalo, 2024: 69)

Table 1 lists the spatial plans and technical reports containing socio-economic and spatial data applicable to Paarden Eiland. Paarden Eiland suburb boundary spans across two Districts namely, Table Bay District and Blaauwberg Districts. The Paarden Eiland is mentioned the most in Table Bay District Plans than Blaauwberg District Plans for both the 2012 and 2023 Spatial Development Frameworks. In 2012, Paarden Eiland was mentioned 23 times in Table Bay District and only 9 times in Blaauwberg District. In 2023, Paarden Eiland was mentioned 148 times in total from the Table Bay District SDF documents compared to only 44 times in the Blaauwberg District SDF documents. This indicates that there was more intentionality in the planning and development of Paarden Eiland in Table Bay District than in Blaauwberg District. The 2012 SDFs do not mention "marine cluster" or "logistics cluster". This indicated that there was no intentional spatial planning concerning cluster development in 2012 unlike in 2023 where "maritime cluster" and "logistics cluster" are mentioned in the SDF documents. Table Bay District SDF mentions "maritime cluster" ten times and the "logistics cluster" twice. The logistics cluster is mentioned specifically in relation to proximity to the port (City of Cape Town, 2023:290). Blaauwberg District SDF makes no mention of "marine cluster" and mentions "logistics cluster" once. The content analysis shows that there is more land use planning related to cluster development in Table Bay which directly corresponds to the concentration of firms on the southern portion of Paarden Eiland unlike the northern portion of Paarden Eiland that falls under Blaauwberg District jurisdiction. The spatial plans highlight that that Paarden Eiland is strategically situated

next to the Port, about 6 km from the Central Business District (CBD) and around 15 km from Epping Industrial. It's positioning between the Port and the N1, Paarden Eiland serves as an entryway to the Blaauwberg District. Table Bay's 2023 SDF acknowledge the significance of Paarden Eiland's proximity to the port and confirms that the land use is predominantly used for light to medium industry that serves the port (City of Cape Town, 2023:271). The economic analysis from the 2023 SDF indicates Paarden Eiland's significance as an industrial node that serves as a key distributor to maritime-related industries (City of Cape Town, 2023:272).

Logistics firm in Paarden Eiland consist of a diversified mix of categories, including warehousing, freight, distribution, couriers, and other related activities.The spatial distribution of logistics firms shows a geographic concentration of logistics firms on the southern portion of the site, this is directly related to concentrated effort for promoting the Paarden Eiland as an industrial area and part of a Maritime cluster as per the Table Bay District SDF unlike in the Blaauwberg District SDF which is the northern portion of Paarden Eiland. According to the Table Bay District SDF, a significant percent of the industry in Paarden Eiland is centred around a Maritime Cluster (City of Cape Town, 2023: 278). The boat-building cluster is situated in Paarden Eiland due to its excellent access to the Port, which facilitates launching, testing, and shipping abroad. Additionally, its proximity to other components of the value chain and ease of accessibility for staff, whether by train or private vehicles, though less so by MyCity buses thus providing a significant advantage (City of Cape Town, 2023: 278). The Eiland City Improvement District (PECID) has a rich history rooted in community collaboration and a commitment to enhancing the industrial environment. Initially, the Metro Industrial Township joined in 1972, leading to the formation of the Paarden Eiland & Metro Association (PEMA). This organisation focused on maintaining and improving the area, but it soon became clear that the voluntary membership model placed a disproportionate burden on those who paid fees, while others benefited without contributing (Paarden Eiland, 2024). To address this issue, property owners proposed the establishment of a City Improvement District (CID), where all owners would share the responsibility of funding improvements (City of Cape Town 2005). This led to the transformation of PEMA into PECID in 2005, following the approval of a formal application to the City of Cape Town. The shift to a Section 21 Company ensured that all property owners contributed financially to the district's upkeep, fostering a more equitable approach to community improvement (City of Cape Town, 2005, 2015, 2020).The Paarden Eiland City Improvement District (PECID) was established in 2005 in terms of Section 8.1 of the By-law of the City of Cape Town following an application by property owners in the area (City of Cape Town, 2005). It was mandated by the Paarden Eiland and Metro Industria CID Steering Committee to establish a CID in the Paarden Eiland and Metro Industria area and that it be declared a CID subject to the approval of the Paarden Eiland and Metro Industria City Improvement District Management Committee (Section 21 company), in terms of Section 12 of the CID By-law (City of Cape Town, 2005). The PECID reflects the ongoing commitment of local stakeholders to enhance the economic and physical landscape of Paarden Eiland, building on a legacy with Paarden Eiland industrialists ratepayers in 1947 by influential local figure Louis Glassman (City of Cape Town, 2015).

5.3 Economic activity and types of firms located in Paarden Eiland

The observed mix of types of logistics firms in the case study aligns with the strategic significance of Paarden Eiland's location. Proximity to the Port of Cape Town facilitates freight and warehousing operations, which rely heavily on seamless connections to shipping routes (Letsoalo, 2024). The predominance of distributors validates the area's function as a bridge between the port and broader markets within the City of Cape Town and beyond. While smaller in proportion, Couriers reflect the adaptation of logistics clusters to contemporary market demands, such as e-commerce and time-sensitive delivery services. Firms' diversity also highlights agglomeration economies' role in Paarden Eiland. Businesses benefit from shared infrastructure, proximity to key transport routes, and synergies among firms, such as those between warehousing and freight operators. However, the relatively smaller representation of specialised services like packaging and movers points to potential areas for strategic development. According to the data presented in Table 2, the largest typology in Paarden Eiland is distributors, making up 36% of the total indicating a strong focus on distribution in the area. Suppliers also represent a significant portion at 31% (Letsoalo, 2024). Couriers account for the smallest percentage at 2%. Distributors and suppliers play crucial roles in the logistics ecosystem, indicating a focus on the supply and distribution side. An examination of the frequency of firms within each typology highlights a significant presence of distributors and freight firms in Paarden

Eiland. Couriers, while fewer in number, illustrate the growing importance of last-mile delivery, particularly with the rise of e-commerce. Packaging and movers, though minor contributors, enhance the cluster's overall service diversity. Logistics firms also play a significant role with 8 firms actively involved in managing supply chains.

Typology	Number of Firms per Typology	Percentage
Warehousing	2	3%
Freight	3	5%
Distributors	21	36%
Couriers	1	2%
Movers	3	5%
Packaging	2	3%
Logistics	8	15%
Suppliers	18	31%
Total Data Points	58	100%

Table 2: Logistic firms in Paarden Eiland(Letsoalo, 2024:54)

Figure 3represents firms within the case study using a typology legend, with colour-coded symbols representing various industries such as logistics, freight, distributors, packaging, warehousing, suppliers, movers, and couriers. The map illustrates the boundaries of Paarden Eiland site based on the City of Cape Town's land administration suburb boundaries. The Paarden Eiland site spans two planning districts, namely, Table Bay District and Blaauwberg District. The site is accessible through the N1 National Road and arterial roads providing transport links. Figure 3 below shows the port firms typology for Paarden Eiland in the City of Cape Town Municipality. It categorises different businesses within the area using a typology legend, with colour-coded symbols representing various industries such as logistics, freight, distributors, packaging, warehousing, suppliers, movers, and couriers. The maps also illustrate the boundaries of Paarden Eiland site based on the City of Cape Town's land administration suburb boundaries. The Paarden Eiland site spans two planning districts, namely, Table Bay District and Blaauwberg District. The site is accessible through the N1 National Road and arterial roads providing transport links.

The findingsindicate a diverse range of services provided by these firms. For instance, some locations combine logistics and warehousing capabilities, allowing them to manage both storage and transportation efficiently. Other businesses act as both distributors and suppliers, handling the flow of goods to various markets. Additionally, some entities manage freight operations while also providing courier services, thus accommodating both large-scale shipments and local deliveries. Having multiple typologies can reflect a flexible business model, allowing these companies to meet various customer needs, optimise operations, and adapt to market demands. It may also indicate a strategic advantage in Paarden Eiland, facilitating comprehensive service offerings in proximity to key transport infrastructure.

Based on the spatial representation of the mix of logistics firms in Paarden Eiland the data points located on one address were grouped as one firm consisting of typology combinations. This ensured that there was no overlap in the counts. Table 3 summarises the consolidation of combination and singular typologies indicating a total unique firm count of 48 when avoiding doubling counting in combination firms. Distributors are still the largest typology in the table, emphasising their significance in the supply chain of firms located in Paarden Eiland in proximity to the Port of Cape Town. In contemporary logistics, the role of Third-Party Logistics (3PL) providers has gained significant prominence due to the complexities of supply chain management. The integration of advanced technologies within 3PL services facilitates real-time tracking and inventory management, informing decision-making processes and enhancing service delivery (Verhetsel et al., 2015). Courier operators specialise in last-mile delivery, catering to e-commerce and time-sensitive logistics needs and are least prominent typology of logistics firms in Paarden Eiland. There is only one courier company in Paarden Eiland, thus confirming the global observations of shifts in logistics firms land use patterns near ports, e-commerce and decentralisation of delivery. The role of ports as logistics hubs is evolving, shifting from multinational functions to more regionally integrated activities (van de Lugt and de Langen, 2005). According to Fried and Goodchild's (2023) findings, certain e-commerce couriers serving last-mile deliveries are decentralised and opt to locate closer to end-user consumers than upstream distribution platforms to improve the time it takes to fulfil customers' time demands.Decentralisation of delivery includes shifts in regulatory frameworks and decentralisation of transport to air and sea. The evolution of logistics concepts delineates logistics markets for distribution areas and consolidation areas(van de Lugt and de Langen, 2005).

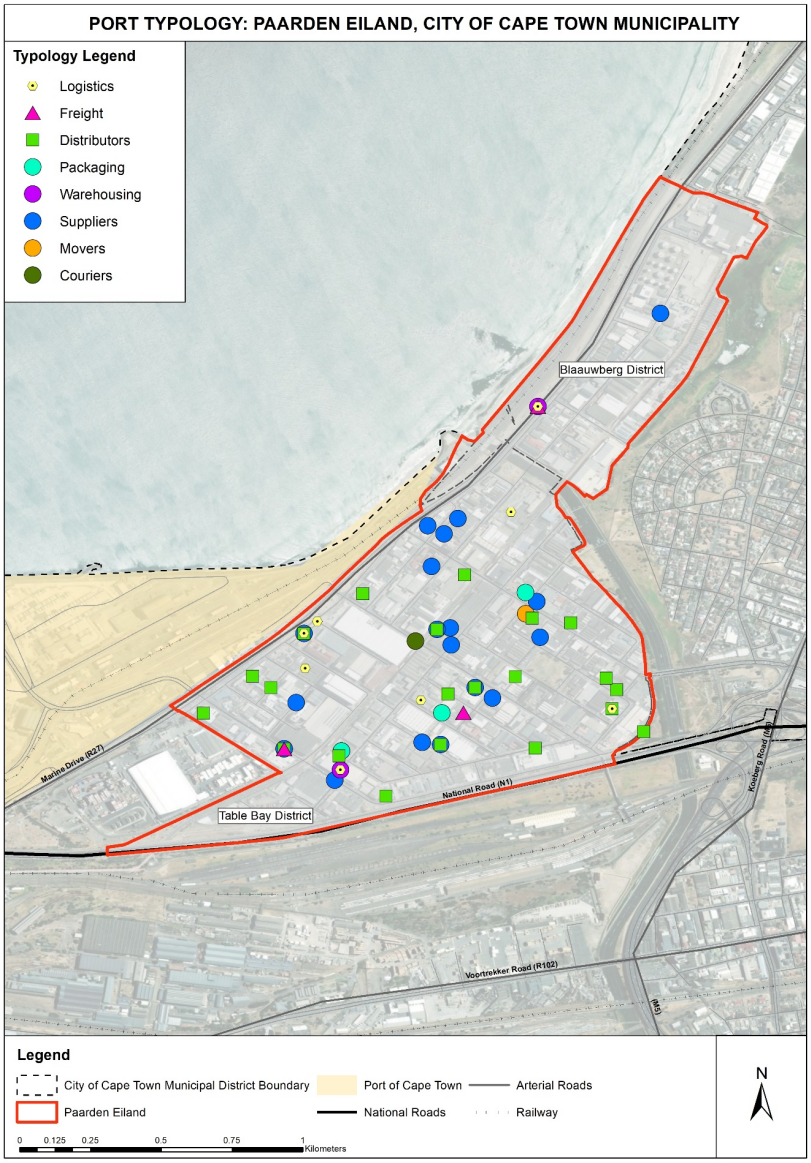


Figure 3: Spatial representation of the mix of logistics firms in Paarden Eiland

Consolidated Typologies	Number of Firms	Description
1. Logistics, Distributors and Suppliers	1	Firms that supply products and oversee distribution networks, ensuring products reach various markets effectively.
2. Logistics, Freight and Warehousing	1	Firms that manage both the storage and transportation of goods, providing an integrated service for efficient supply chain management.
3. Logistics and Warehousing	1	Firms that integrate logistics operations with warehousing, providing comprehensive storage and management of goods
4. Logistics and Distributors	1	Firms that combine logistics functions with distribution services to ensure effective delivery and supply chain efficiency.
5. Logistics, Freight, Suppliers	1	Firms combining elements of logistics and freight services with a focus on supplying products, facilitating both storage and transportation
6. Distributors and Suppliers	3	Firms that focus on handling larger shipments while also managing more localised delivery services to meet diverse customer needs.
7. Logistics	4	Firms involved the planning and management of the flow of goods, services, and information throughout the supply chain.
8. Distributors	16	Firms focused on supplying products and large-scale distribution.
9. Freight	1	Firms that specialise in the transportation of goods in bulk, typically involving trucks, ships, or trains.
10. Couriers	1	Firms involved in fast delivery services for small parcels and documents based on end-user demand.
11. Movers	3	Companies that specialise in relocating household goods or office contents.
12. Packaging	2	Firms that specialise in the process of preparing goods for transport, storage, and sales, ensuring safety and presentation.
13. Suppliers	13	Firms that provide raw materials or products to manufacturers or other businesses.
Total unique firm count	48	

Table 3: Summary of logistics firms in Paarden Eiland (Letsoalo, 2024: 58)

6 CONCLUSIONS AND RECOMMENDATIONS

The study shows the significance of land-use planning and regulatory frameworks in fostering a conducive environment for logistics operations. This was shown by analysing the zoning patterns in Paarden Eiland, explanatory content analysis of institutional land use and spatial strategies by the City of Cape Town. The findings also established that institutional regulatory instruments such as City Improvement Districts, can facilitate improved safety, cleanliness, and operational standards, ultimately enhancing the attractiveness of the industrial hub, and making it an ideal location for logistics firms despite changing global trends. Land use planning regulations play a significant role in shaping the logistics landscape, particularly in proximity to ports, which are characterised by multimodal transportation and economic nodes. land use regulations serve as both a framework for planning and a catalyst for fostering a competitive and sustainable logistics sector adjacent to major ports, thereby enhancing regional economic vitality. According to the City of Cape Town land use zoning scheme, the predominant zoning in Paarden Eiland is industrial use. Land use planning regulations facilitate the optimal locations for logistics firms, particularly near ports where proximity to transport hubs can significantly influence operational efficiency. These regulations not only facilitate the allocation of land for various logistics activities but also ensure that such activities align with broader urban development goals.Consequently, well-structured land use regulations can help balance the needs of logistics firms with community and environmental interests, promoting sustainable development while ensuring that firms benefit from strategic locations that enhance their competitiveness in the global market. The research contributed to understanding how logistics firms located near the port in the case of Paarden Eiland drive economic development and urban growth in the vicinity of ports while addressing contemporary challenges of spatial integration, land-use management, and sustainable development. They are influenced by zoning and land use planning. The study recommends that agglomerations near the port can be further supported by spatial development frameworks recommending and facilitating cluster development and strengthening agglomeration.

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reviewed paper

The Role of State-Owned Enterprises (SOEs) in Advancing a Just Energy Transition in South Africa

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1 ABSTRACT

South Africa's transition to a low-carbon energy system is essential to combat climate change and reduce reliance on fossil fuels. Given coal's dominance, State-Owned Enterprises (SOEs) such as Eskom and SANEDI are key to guiding an inclusive, sustainable transition. This study, based on collaborative planning and conflict management theories, views JET as a multi-actor governance process. It explores PPP models to attract investment and foster social inclusion. Using qualitative methods, including institutional analysis and bibliometric mapping, the research identifies policy progress and ongoing challenges, including infrastructure issues, fragmented coordination, gaps in community engagement, and difficulties with technology integration. The study proposes a SOE-focused Just Energy Transition Framework, highlighting stronger PPPs, participatory planning, accountability, and conflict-sensitive governance as essential for meeting climate goals and ensuring social and economic equity.

Keywords: Climate Change, State Owned Enterprises, Just Energy Transition, Fossil Fuel Dependence, Public Engagement

2 INTRODUCTION

Energy production from fossil fuels remains a primary driver of global climate change (Liu and Wang, 2025). Rising carbon dioxide (CO_2) emissions have led to record increases in global surface temperatures, intensifying environmental degradation and socio-economic vulnerabilities (Kabir et al., 2023; Zhang, 2024). Urbanization further compounds these challenges: while it accelerates economic growth and innovation, it simultaneously contributes to ecological deterioration through rising energy consumption in transportation, industries, and buildings. Indeed, urban activities account for nearly 70% of global energy-related carbon emissions (Tong et.al, 2025). In many regions, particularly in Africa, continued reliance on traditional biomass such as wood and charcoal undermines health, livelihoods, and environmental sustainability (Njenga et al., 2022).

Mgwangi et. al 2023 state that ensuring equitable access to modern energy is critical for both poverty alleviation and long-term development. Yet South Africa faces a complex dual challenge, which includes meeting increasing energy demand while tackling ongoing supply shortages and reducing climate risks. Since 2007, insufficient generation capacity has caused widespread disruptions, resulting in prolonged daily blackouts in 2023 (Molepo, Aboalez and Mathaba, 2025). These crises reveal deep institutional and infrastructural weaknesses and underscore the urgency of transitioning toward renewable and sustainable energy sources such as solar, wind, hydropower, and geothermal.

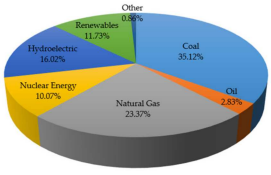


Figure 1: World electricity mix by source (Supapo 2021)

Globally, economic development and population growth continue to be supported largely by carbon-intensive energy systems, with fossil fuels dominating electricity generation, underscoring the persistent reliance on unclean energy sources and the urgent need for a cleaner and more sustainable global energy mix. Figure 1 shows the global electricity mix, with coal (35.12%) and natural gas (23.37%) dominating. Fossil fuels collectively generate over 60% of electricity, underscoring their significant contribution to

Carbon dioxide emissions and climate change. Low-carbon sources, renewables, hydro, and nuclear, remain comparatively small, highlighting the gap in meeting global climate targets (Supapo, 2021). This dominance of fossil fuels in the global electricity mix implies an urgent need to reorient urban development pathways towards low-carbon and energy-efficient models, integrating renewable energy systems alongside green and blue infrastructure frameworks to decouple economic growth from carbon emissions and align with global climate targets.

The notion of a just energy transition emphasizes that decarbonization must extend beyond climate objectives to integrate equity, inclusivity, and social justice. In South Africa, this imperative is particularly urgent given the legacy of apartheid, where a fossil-based energy system entrenched social and environmental injustices (Annecke, 2012; Magazzino et al., 2020). Communities dependent on coal economies risk being disproportionately affected by the transition unless deliberate safeguards, redistribution mechanisms, and participatory governance processes are implemented.

At the global level, the 2015 Paris Agreement reaffirmed the urgency of reducing carbon emissions, yet coal still accounted for more than one-third of global electricity generation as recently as 2021 (United Nations, 2015; Todorov et al., 2024). For South Africa, where coal dominates the energy mix, achieving a just energy transition requires not only technological innovation but also institutional reform. In this regard, state-owned enterprises (SOEs), most notably Eskom, the country's largest electricity utility, and the South African National Energy Development Institute (SANEDI), play a pivotal role. With mandates to provide public goods, these SOEs are uniquely positioned to shape investment patterns, enable renewable energy integration, and ensure that the transition delivers both environmental sustainability and social equity.

This study, grounded in collaborative and advocative planning theory and informed by conflict management perspectives, conceptualizes the Just Energy Transition (JET) in South Africa as a negotiated, multi-actor governance process. Focusing on Eskom and SANEDI, it addresses fragmented literature on how SOEs navigate trade-offs between energy security, climate action, and social justice. A systematic review and bibliometric analysis synthesize existing studies, identify knowledge gaps, and highlight persistent SOE challenges, including infrastructural constraints, limited coordination, uneven renewable energy integration, and weak community engagement. The study proposes a practical SOE-centred JET Framework emphasising participatory planning, strengthened PPPs, institutional accountability, and conflict-sensitive governance to advance socially equitable, economically inclusive, and climate-aligned energy futures.

3 METHODOLOGICAL CONSIDERATIONS

This study adopts a mixed-method systematic review, integrating both qualitative and quantitative techniques to examine the role of SOEs in advancing a just energy transition in South Africa. The methodology combines systematic literature review, bibliometric analysis, and empirical data analysis.

3.1 Systematic Literature Review

A systematic literature review was conducted using Scopus-indexed articles, following the PRISMA protocol, to capture scholarly insights into SOEs, just energy transitions, and energy governance. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement, published in 2009, was designed to help systematic reviewers transparently report why the review was done, what the authors did, and what they found (BMJ, 2021). Scopus was chosen for its comprehensive coverage of peer-reviewed literature across multiple disciplines, high-quality indexing standards, and advanced search functionalities, which enable a systematic, transparent, and reproducible approach to literature retrieval. The review focused on publications from 2015 to 2025 and covered subject areas including the social sciences, energy, environmental science, and the humanities. The review aimed to identify trends, knowledge gaps, and evidence supporting the role of SOEs in the energy transition.

Procedure:

(1) Keywords: "just energy transition" AND "South Africa" – 40 documents retrieved (limited to 38 relevant publications after screening).

(2) Keywords: "state-owned enterprise" AND "South Africa" AND "energy" – 13 relevant documents retrieved.

(3) Keyword: "Collaborative Planning" AND "Advocative Planning"

3.2 Bibliometric Analysis

Bibliometric Analysis of Learning Models Research Using Vosviewer (Nova et al., 2023). Bibliometric analysis was conducted using VOS viewer software to visualize research patterns, including knowledge clusters, keyword co-occurrence, and trends in the literature. To ensure data quality, PRISMA Protocol was used. Moher 2010 states that PRISMA Statement is to help authors improve the reporting of systematic reviews and meta-analyses. This analysis identified critical research gaps and emerging areas of inquiry related to just energy transitions and the role of SOEs in South Africa.

3.3 Thematic Data Analysis

Thematic Analysis (TA) is one of the most widely utilized methods for analyzing qualitative data, offering a structured yet flexible framework for identifying, analyzing, and interpreting patterns of meaning within datasets (Ahmed et al., 2025). For this study, thematic synthesis is applied to identify recurring themes, such as the challenges faced by South African SOEs, including Eskom and SANEDI, in implementing a Just Energy Transition.

3.4 Study Area

The study area for this research is South Africa (Figure 2). South Africa offers a unique context for examining the Just Energy Transition due to its position as Africa's largest economy and its relatively advanced institutional and planning systems.



Figure 2: Map of South Africa

The country's coal-dominated energy sector, combined with its cultural diversity and historical inequalities, presents complex social, economic, and technical challenges for energy transition. Examining the role of SOEs in this context provides practical insights into how state-led institutions can manage these challenges, and the lessons learned can inform energy transition strategies in other African countries and the broader Global South.

3.5 Rationale for Methodology

A convergent mixed-methods approach was selected to triangulate evidence from multiple sources, enabling a comprehensive understanding of both theoretical and practical dimensions of the Just Energy Transition. By integrating quantitative bibliometric analysis with qualitative thematic synthesis, the study captures both publication trends, key actors, and research networks as well as insights into challenges, opportunities, and governance practices of SOEs. This approach strengthens the validity and reliability of the findings, ensures a holistic perspective, and addresses the fragmentation of the existing literature on state-led energy transitions in South Africa.

4 RESULTS AND DISCUSSIONS

4.1 Energy Justice and Just Transition

A just energy transition refers to the shift from fossil fuel–based systems to sustainable and renewable energy sources in a fair and inclusive manner (Ndlovu, 2025). At the heart of this is the principle of energy

justice, which emphasizes equity, fairness, and ethics in energy governance, ensuring that low-carbon transitions redress historical inequalities and place marginalized groups at the center (Taghizadeh-Hesary et al., 2021). Across Africa, where millions still lack access to modern energy, energy justice is a cornerstone of sustainable development (Abe & Azubike, 2025). In South Africa, high electricity costs compel many households to rely on unsafe and polluting fuels, intensifying health risks and environmental degradation. Achieving a truly just transition, therefore, requires providing affordable, reliable, and clean energy for all.

Globally, coal-fired power remains the dominant source of electricity and a major contributor to carbon dioxide emissions (EIA, 2019), driving international commitments such as the UN's Sustainable Development Goal 7, which calls for universal access to clean and affordable energy (UNDP, 2019). However, despite South Africa's abundant wind and solar resources, renewable energy uptake has been sluggish, leaving coal entrenched as the backbone of the energy system and perpetuating socio-environmental vulnerabilities (Molepo et al., 2025). Addressing these challenges demands not only technical solutions but also institutional reforms, particularly through State-Owned Enterprises (SOEs), whose governance frameworks critically shape access, affordability, and the pace of South Africa's clean energy transition.

4.2 State-Owned Enterprises and Governance

State-owned enterprises (SOEs) have traditionally played a key role in infrastructure and service provision across sectors such as energy, water, and transportation (Ferdiana & Sugiyarto, 2022). Globally, SOEs are increasingly acknowledged as important players in sustainability transitions because of their presence in energy-producing and energy-intensive industries (Curi et al., 2025; Meelen & Sluijs, 2025). However, their contribution to energy transitions, particularly in emerging economies, remains underexplored (Zhu et al., 2023). The origins of SOEs are connected to evolving political-economic paradigms since the 1970s, influenced by neoliberal reforms and state interventions (Harvey, 2005; Papenfuß, 2014; Lee et al., 2022). Although they were intended to improve efficiency, productivity, and service delivery, many SOEs encounter governance issues, political interference, and fiscal challenges (Mbo & Adjasi, 2017). In South Africa, these issues are especially acute in the energy sector.



Figure 3: Hendrina Power Station (Eskom, 2025)

4.3 South Africa's Energy Landscape

South Africa generates over 80% of its electricity from coal, making it one of the world's top ten greenhouse gas (GHG) emitters (Fitzgerald et al., 2024; Akinbami et al., 2021). Eskom, the national power utility, is responsible for more than 90% of electricity production and contributes about 45% of Africa's total electricity generation capacity. It ranks among the world's top 20 utilities by size. However, its reliance on coal has entrenched environmental and climate challenges.

Eskom's operational difficulties, including rising debt, mismanagement, corruption, ageing infrastructure, coal shortages, and frequent load shedding, have severely undermined energy security and economic stability (Pramjeeth, 2021; Eskom, 2022). These failures highlight the urgent need for reform.

Figure 3 shows an example of a large Eskom power station used for electricity generation, which has negative environmental impacts.

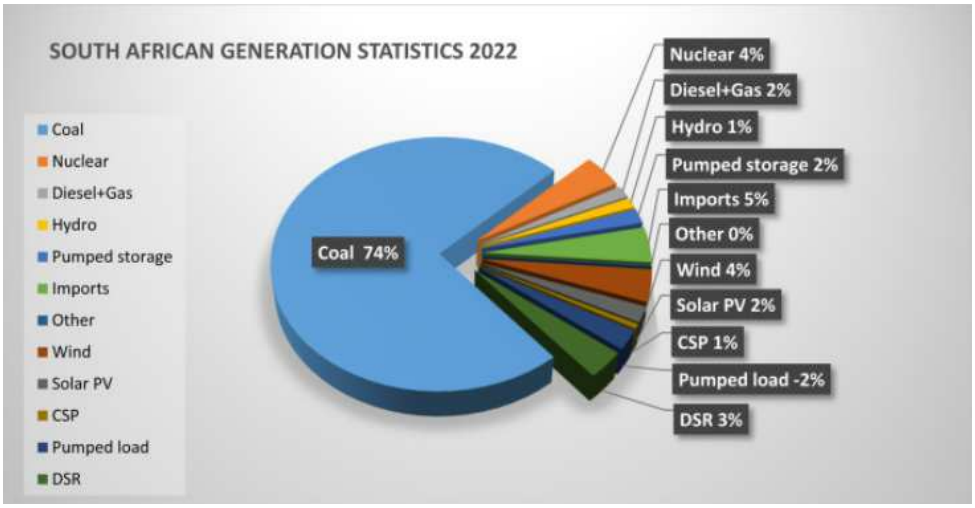


Figure 4: South African Energy generation distribution (Ndlovu, 2025)

Figure 4 illustrates South Africa's energy generation profile, showing its continued heavy reliance on coal and highlighting the role of state-owned enterprises, such as Eskom and SANEDI, in facilitating a Just Energy Transition. Despite global shifts toward cleaner energy in line with the United Nations Sustainable Development Goals, coal remained the dominant energy source in South Africa in 2022, emphasizing the urgent need for a shift to sustainable alternatives. Across the African continent, energy is produced from diverse sources, including oil, coal, wind, solar, geothermal, hydro, and natural gas, with countries such as Zambia, Mozambique, Madagascar, Tanzania, and the Democratic Republic of Congo generating a substantial share of electricity from renewable sources (IRENA, 2021).

4.3.1 ESKOM

According to the Constitution of the Republic of South Africa (1996), the allocation of certain public goods and services to State-Owned Enterprises (SOEs) is mandated to benefit citizens, subject to the availability of financial resources (Mashilo & Kgobe, 2024). However, South Africa's energy capacity has been negatively impacted by an inadequate, unreliable, and unpredictable electricity supply (Eskom, 2022). As a result, Eskom, the national electricity utility, has become both a key part of the country's economic activity and a symbol of its systemic energy challenges. Eskom plays a significant role across the African continent, contributing approximately 45% of Africa's electricity generation and ranking among the 20 largest utilities worldwide by generation capacity. Despite this scale, most of its electricity is generated from coal, making South Africa one of the top ten global emitters of greenhouse gases (GHG) (Akinbami et al., 2021). This dependence on coal presents a major obstacle to the country's decarbonisation and just energy transition agenda.

Scholars have noted that SOEs such as Eskom impose unnecessary financial burdens on governments by increasing taxes and inefficiencies (Nhleko & Inambao, 2021). Eskom faces numerous difficulties, including rising debt, mismanagement, governance issues, coal shortages, labor unrest involving infrastructure damage, poor staff performance, and aging power plants. These problems lead to frequent load-shedding, higher operational costs, and concerns over the utility's long-term viability (Pramjeeth, 2021). To address these issues and align with South Africa's Just Energy Transition (JET) goals, Eskom has initiated several reforms (Msimango and Orffer, 2022). These include breaking the utility into separate generation, transmission, and distribution units to enhance efficiency and accountability, as well as encouraging private sector involvement in renewable energy projects (Kemabonta, 2025). Eskom also plays a central role in implementing the Just Energy Transition Investment Plan (JET-IP), aiming for "Net Zero" carbon emissions by 2050 (Steed et al., 2025), focusing on attracting public and private investments to shift from coal to cleaner energy sources, support affected workers, and promote social and economic inclusion (Karg et al., 2025). These energy reforms demonstrate a strategic effort to stabilize electricity supply while supporting a socially just and environmentally sustainable energy transition in South Africa (Mirzania et al., 2023).

4.3.2 SANEDI

The South African National Energy Development Institute (SANEDI) is a government research agency tasked with advancing energy innovation, technology development, and policy support across the renewable, bioenergy, fossil-based, and energy-efficiency sectors to promote sustainable and secure energy systems (Academy of Science of South Africa, 2014). SANEDI is a South African state-owned entity that conducts energy research, development, and innovation, and promotes energy efficiency. It supports the country's energy transition by optimizing energy resource use, developing technologies, building capacity, and providing advice, funding, and technology transfer across the energy sector (HSRC, 2022). Therefore, it is quite notable that, Complementing Eskom, the South African National Energy Development Institute (SANEDI) plays a more specialized role in research, innovation, and piloting renewable projects. Policy frameworks such as the Integrated Resource Plan (IRP) and the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) have created opportunities for renewable expansion, though implementation has been uneven (Eberhard et. al 2016).

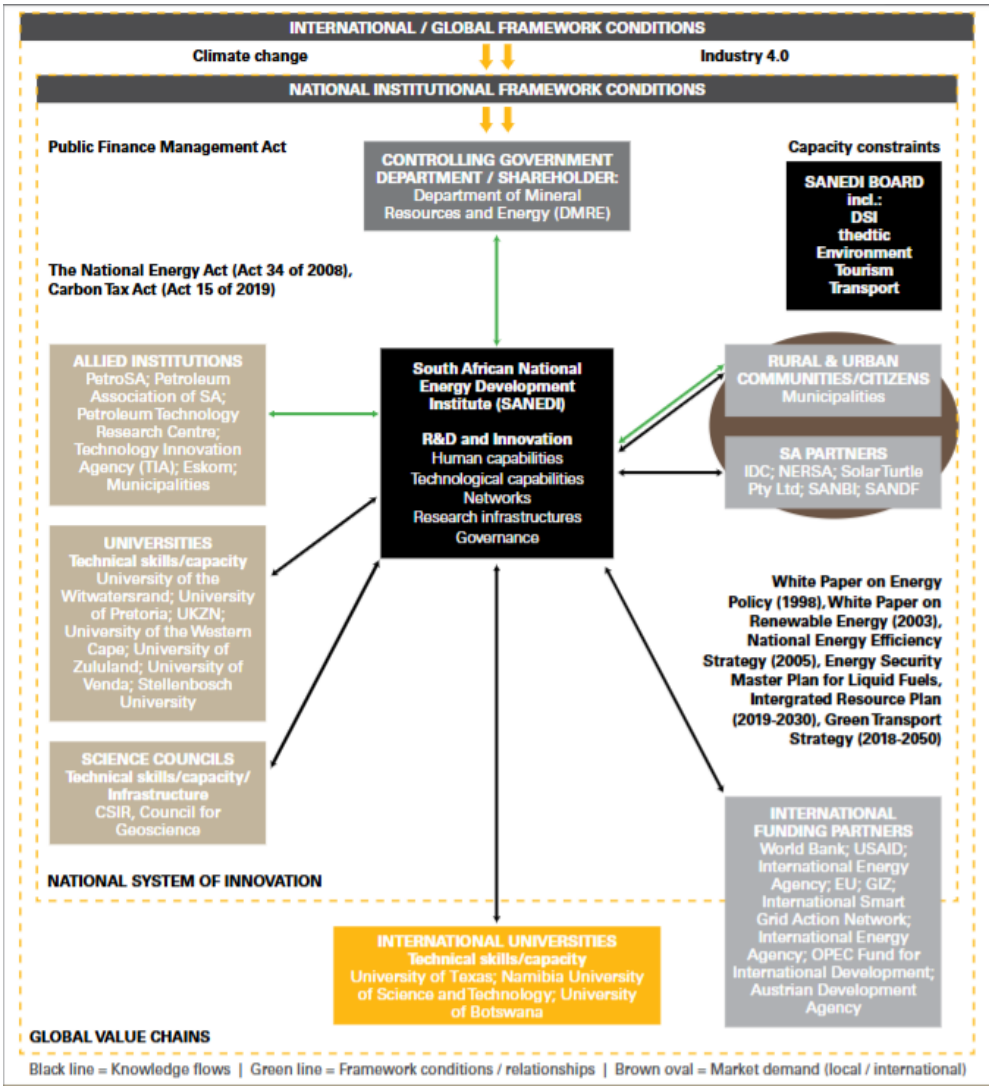


Figure 5: An illustrative mapping of the sectoral R&D and innovation system (HSRC, 2022)

4.4 Land Use Planning and Energy Integration

In the context of the energy transition, integrating land use considerations into energy planning can yield significant benefits (Mosso et al., 2024). Renewable projects often need large land areas, community approval, and thorough environmental assessments. Vanclay (2016) notes that, regardless of purpose, large-scale developments, whether initiated by governments or private entities, usually require extensive land, sometimes very large areas. Poor integration of spatial planning into energy strategies has led to conflicts, delays, and uneven distribution of benefits. Todes and Turock (2017) also argue that strategic installations and national research institutes often face inequalities, highlighting the need for new planning principles to

promote more integrated approaches. In South Africa, aligning land-use governance with energy planning is crucial to ensure that renewable energy deployment supports not only decarbonization but also social equity and inclusive growth. The country's energy sector is in a critical phase of transformation, addressing challenges related to access, environmental sustainability, and modernization. This study critically explores South Africa's energy landscape, focusing on policy implications, renewable energy adoption, and the impact of Fourth Industrial Revolution (4IR) technologies reshaping the sector.

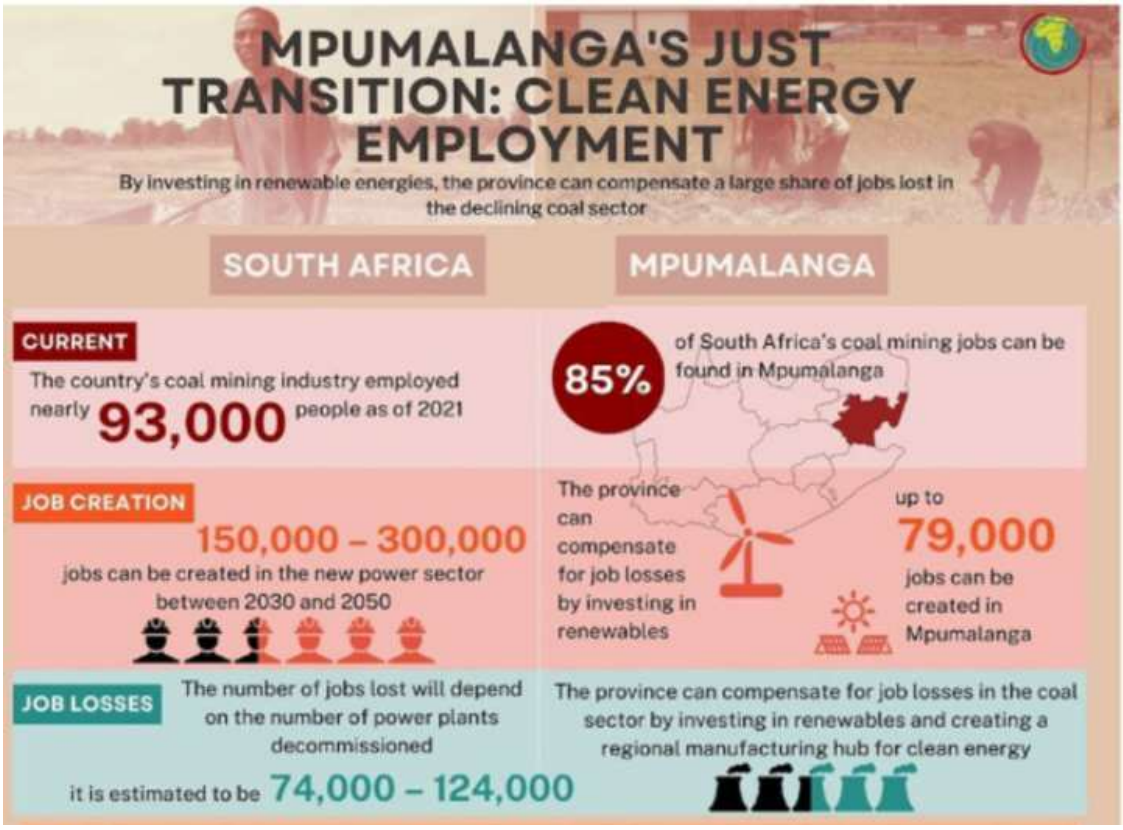


Figure 6: Energy Transition Strategy for Mpumalanga Province in South Africa (Molelekwa, 2023)

4.5 Challenges to a Just Energy Transition

Achieving a just energy transition in South Africa is estimated to require approximately US$99 billion in investment, along with capacity-building initiatives such as workforce upskilling and the implementation of the 2019 carbon tax (Abe & Azubike, 2025). However, progress faces many obstacles, such as low public engagement, limited community backing, insufficient infrastructure, and issues with accountability challenges.

4.5.1 Public Engagement and Social Inclusion

In Africa, vulnerable groups, including women, youth, and indigenous communities, are often marginalized or excluded from energy transition processes. Issues such as uncompensated land seizures and the absence of gender-aware policies exacerbate social inequities and pose significant justice concerns (Abe & Azubike, 2025). Addressing these concerns requires proactive stakeholder engagement, community consultation, and participatory planning to ensure equitable outcomes.

4.5.2 Policy and Stakeholder Coordination

Global frameworks, including the Paris Agreement and the Glasgow Climate Pact, reinforced by the 2023 United Nations Climate Change Conference (COP28), continue to guide efforts to reduce carbon emissions below 2°C and achieve net-zero targets. National policies must balance commercial objectives with government oversight, often creating tensions between private investment goals and public accountability (Abe & Azubike, 2025).

4.5.3 Energy Production and Environmental Challenges

Cities worldwide are responsible for nearly 80% of greenhouse gas emissions, making urban energy systems key targets for climate efforts (Supapo et al., 2021). In the Global South, especially within the SADC region, reliance on coal, economic disparities, and institutional challenges hinder the shift to clean energy. South Africa continues to depend heavily on coal for electricity, significantly contributing to national GHG emissions and environmental harm. Although renewable energy development is increasing, it still falls short of achieving climate and social equity objectives.

4.5.4 Infrastructure and Governance Constraints

Besides technological and financial issues, the energy shift faces hurdles like aging infrastructure, limited grid capacity, and underinvestment in renewable energy. Poor governance and accountability further obstruct effective action, highlighting the necessity for integrated policies, planning, and reform of institutions to ensure sustainability and social inclusion. Tackling these challenges enables South Africa to pursue a fair energy transition that cuts carbon emissions while fostering equity, public involvement, and socio-economic growth in both urban and rural areas.

4.6 Implications and future research

International climate frameworks are increasingly emphasizing the importance of a just transition, especially for workers and communities reliant on high-emission industries. Before COP22 in Marrakech, the UNFCCC published a technical paper on workforce transitions, integrating this concept into the Paris Agreement's preamble and highlighting it in climate talks from COP21 to COP27. In 2021, UN Secretary-General António Guterres emphasized the need to phase out coal power while providing locally tailored support to coal-dependent communities, such as reskilling, economic diversification, and social protection (Mirzania et al., 2023).

Despite multiple government initiatives to transition from fossil fuel–based electricity generation, the effectiveness of these interventions remains uncertain. Merzic (2022) highlights that many energy transition scenarios lack explicit validation or are only applicable under very specific circumstances. South Africa's approach has often focused on privatizing electricity generation, yet there is no clear, overarching framework that integrates renewable energy deployment, social equity, and spatial planning considerations. Questions remain regarding how to transition effectively, how to measure success, and how to align private investment with public goals for a socially just and sustainable energy system. Addressing these gaps is crucial for guiding SOEs, policymakers, and stakeholders toward evidence-based, inclusive strategies that advance the country's just energy transition agenda.

4.7 Conclusion

In conclusion, while state-owned enterprises are central to South Africa's just energy transition, governance gaps, fragmented coordination, and limited community engagement constrain their effectiveness. Applied research and practical frameworks are needed to evaluate SOE interventions and identify strategies that accelerate equitable, sustainable energy transitions.

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The Slave

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1 ABSTRACT

As great modern thinkers have noted, contemporary society faces serious challenges that threaten its identity in our familiar historical sense. One of the greatest challenges is the danger of the return of slavery at this new stage of historical development. All the signs of this return are present. Moreover, this new slavery promises to be far more brutal than previous forms of this social vice and threatens not only physical limitation but also encroaches on the most intimate part – the very soul of man.

In this article, we highlight the signs of modern humans becoming slaves and all the objective and subjective conditions that contribute to this transformation. We also identify the signs of destructive influences on individuals and ways to protect against this state of slavery.

The main subject of our article is the problem of the loss of individuality. We suggest that this is a fundamental component of the process of modern man's transformation into a new kind of slave.

Keywords: philosophy, slavery, digital twins, freedom, digital society

2 INTRODUCTION

We have repeatedly returned to the issue of slavery in our previous works [PIETRO Elisei, at all], analysing available sources on this topic. We have not addressed the opinions and judgments of many researchers, sociologists, and ordinary journalists. We were interested in research with a purely philosophical focus, as we are not simply interested in people's "impressions" or "emotions", although these are also very important. We are primarily interested in analytics, i.e., scientific knowledge, which is typically inherent in classical philosophical scholarship. Today, we're seeing the same effect in society we recently observed in computer science: practice outpaces theory. In reality, this isn't true, but that's the appearance. The reason for this is the incredible acceleration of business, the pursuit of profit, which blurs the lines between the classic stages: scientific development, experimental prototype, testing, series production, modernization, and so on. Fierce competition virtually eliminates scientific discussion, as new ideas are intercepted and quickly adopted. Those with fewer morals and familiar human principles gain an advantage. Stealing ideas and copying other people's technology is practically uncritical; it's becoming the norm. Such chaos in business and social life creates a "muddy water" effect, in which those who are simply looking for profit achieve their goals, while the majority does not see or understand what is really going on.

As a result of these new circumstances, we experience two phenomena: the loss of individuality and, based on this, the emergence of slavery at a new stage in the development of civilization. Let's examine these phenomena in more detail.

3 LOSS OF INDIVIDUALITY

In our opinion, this idea (the loss of individuality) was well articulated in E. Fromm's work "Escape from Freedom." The enormous pressure that the social environment places on the individual renders them inert to all important challenges that affect them personally. Let's briefly examine the cycle of modern human development, which creates the platform for their transformation into a slave.

3.1 Childhood

Modern families offer little care for their children; parents must work intensively to stay afloat in modern social life. Job loss is practically the end of everything, as modern people are entangled in insurance and loans calculated based on their current employment status for decades to come. In other words, families are held hostage by a bank. Being born into a hostage family is not the happiest childhood. A family that is relatively successful in a slave community has no chance of raising a child who is not a slave, as they have already lost the ability to identify themselves as free people. Numerous examples can be cited here, one of

the most famous being the conflict between the South and the North in the American Civil War. Many slaves fought in the Southern army because they were satisfied with their servitude. They were afraid of losing the meager wealth they had. When serfdom was abolished in the Tsardom of Muscovy in 1861, the former serfs were left lost; they simply didn't know how to live without a master. They were not ready for freedom, for an independent existence.

3.2 Nursery, kindergarten

These are the first social organizations focused on creating social pressures for the ruling class (the top brass). Intensive brainwashing of children begins here. The struggle against individuality begins here. Children are taught to obey blunt orders, not to seek answers, but simply to obey. They are shown that disagreement with the teacher is harshly punished and that it's easier not to think, but to blindly follow what the adult says. There is no point in trying to figure out whether the adult is right or wrong.

3.3 High school

Intensive ideological indoctrination begins. Education is based on approved textbooks, approved by government agencies. In some cases, religious figures and officials are brought in. Children begin to learn to lose not only their freedom but also their souls. Social behaviour patterns are instilled: "the boss is always right", bosses are appointed by superiors, etc. Children are taught to behave in a group based on strict obedience to superiors. They are taught to write denunciations and complaints against their friends and colleagues.

3.4 University

The final stage in creating a social type for society. A student, learning from tests, learns to guess the desires and opinions of his superiors. Knowledge is unnecessary, as it can lead to doubts, which are severely punished. There is no dialogue between students and teachers, as the teachers are former students, uneducated people with slave instincts.

3.5 Job

There are two fundamentally different paths here. The first, and most important, is state corporations that masquerade as business entities. In such state-owned companies, hierarchy degenerates instantly. The manager is "one of our own" and only "one of our own"! Otherwise, how can one control finances? "One of our own" similarly chooses "one of our own". And so it goes, right down to the last official. Competence, education, and experience are purely for show, just to tick a box in one's personal file. A frenzy of power struggles ensues, both horizontally and vertically. Depending on one's "origin", each official's vertical ceiling is determined. The second category, rapidly declining, are private companies with businesses independent of state corporations. These companies are a liability to state corporations, but due to their small financial size and inability to attract large financing, they naturally disappear from business undetected, although, due to certain legislation, they are often created or "acquired" (i.e., taken over) to allow senior officials to dissipate funds and steal, without their superiors noticing.

4 THE EMERGENCE OF SLAVERY

People who have lost their individuality are practically ready-made slaves. The absence of individuality is practically a loss of freedom, since it is of no use to a person who has not identified themselves as an individual. They are members of a herd, not a wild one, but an artificially created one, a domestic one, where everything depends on the master. Very little remains to fix the slave's position. It's also worth noting that instead of a slave-owning system, today we have states where there are no slave owners: everyone is a slave. Regardless of their formal governmental roles – the president, members of the government, and other officials – they are all just as much slaves as the general population. This is due to the fact that the real owners are not always located within the state; their location, like their names, is carefully concealed. Thus, we have a state whose citizens own nothing. And even if they do formally own something, it can easily be taken away due to the lack of effective legislation and corresponding state institutions for which private property is a sacred concept. In other words, a modern slave society is a unique formation, one that many in power strive for, not realizing that such a state is only beneficial to them when they represent power. However, since they are essentially "overseers" and do not represent real power, as they lack it, they can at

any moment become the most reviled slaves, with all the ensuing consequences. For a slave state to exist, basic but immutable elements are necessary: provision of food necessary for survival and basic social amenities: housing, primitive medicine, and the semblance of entertainment. Periodic "executions" (frequent announcements of the exposure of corrupt officials, traitors, foreign agents, etc.) are also a necessary attribute. The population must be afraid; many people must be imprisoned and sent to concentration camps. The number of people with higher education should be reduced, because they pose a potential danger – freethinking.

5 POTENTIAL DANGERS OF MODERN SLAVERY

Modern slavery transforms humans into primitive creatures, worse than any other animal. The modern slave loses their pre-established, natural instincts, inherent to animals, and gains nothing meaningful in return. Such a being becomes a completely unexpected phenomenon, possessing a whole host of unexpected properties.

5.1 Simple logic

The absence of simple logic at the level of first-order predicates. A slave cannot establish cause-and-effect relationships. He cannot understand the connection between phenomenon and essence. Thus, he can only follow commands. A slave society requires instructions from outside. It (society) cannot exist on its own, as it quickly degrades.

5.2 Orders

The slaves' tendency to follow orders exclusively is greatly appreciated by their top managers. But this joy is short-term. Following orders exclusively quickly takes the form of an "Italian strike". A lack of initiative and creativity kills all social and production processes. Slaves are incapable of producing even the most basic things. They can only repeat, and even then, only with the help of competent supervisors and a brutal repressive machine.

5.3 Main motto

The slave's main motto – "I'm like everyone else" – creates a disregard for their own lives. Slaves can die en masse during repressions or military operations, without much thought to what's happening. It is enough for the phenomenon to be widespread.

5.4 Delayed effect

The appearance of calm and control in society inevitably leads to a social explosion, characterized by exceptional cruelty and even more massive, senseless repression, this time by rebellious slaves. The main prerequisite for such an explosion is the absence or sharp decline of basic living conditions: affordable food, relatively comfortable living conditions (water, electricity, heat).

5.5 The learning disability effect

This effect is increasingly common among young people under 40. It essentially means that after a certain age, a person loses the ability to learn. Having climbed a simple social ladder (family, kindergarten, school) based on repetition, guessing, and testing, a person is no longer able to learn as was previously the case. Textbooks and literature are no longer a source for developing such qualities as understanding. A person simply memorizes, but is unable to interpret the information and knowledge they receive. They can study instructions, but they need someone to show them how to act using an example. Then they will remember the example. Change the conditions slightly, and they are unable to apply their knowledge.

5.6 Artificial Intelligence

The widespread use of technologies collectively known as AI has had a profound impact on the entire modern industrial manufacturing industry. As with any large-scale phenomenon, there are positive and negative aspects. The positive aspect is a significant increase in the speed and quality of creating new computer products. There has been a significant reduction in the number of unskilled employees, software developers, and so-called "coders". The negative trend manifests itself in the illusion that AI can do everything. People begin to blindly believe everything generated by a neural network. Critical analysis is

impossible for the reasons discussed above. Thus, modern AI burrows modern people even deeper into the quagmire of slavery. There is no need to think, just ask. Considering the fact that neural networks can be "corrected" as easily as Wikipedia, for example, the extent of the danger becomes obvious.

6 CONCLUSION

We have very briefly examined the problem of slavery in the modern world. Signs of this shameful phenomenon were ubiquitous in the past, and they persist in modern society. The extent of this presence varies greatly both historically and by region and historical traditions. The natural question arises: "What is to be done?" In our opinion, the main lever for influencing humanity's slide into a new era of slavery is raising the level of education, moving away from test-based learning, and weakening the pursuit of profit. The first point is raising the level of education. Easy to say, but difficult to do. The first reason for the difficulty is where to find teachers? When you have easy access to information, it is very difficult to motivate people to acquire new knowledge independently and learn to think. Business requirements also arise here. Problems must be solved faster than competitors. A whole system of contradictions arises. Even now, leading companies are demanding the use of AI in software development, as it has a number of advantages. The AI subsystem seeks ready-made solutions that have already been tested and proven. A modern programmer (not a coder) needs to select a suitable option that is insured against gross errors and inaccuracies. But over time, the programmer will increasingly lose their skill in choosing the appropriate option, as they will have no basis for their choice, as they have not done it themselves and do not fully understand what is going on. Eventually, they themselves will become irrelevant. Thinking that AI will be able to offer you a suitable option in every case is a grave misconception. Such a system is even theoretically impossible (see K. Gödel's theorem on the incompleteness and inconsistency of axiomatic theories containing natural arithmetic). The obvious conclusion is that such global AI networks will inevitably degrade and ultimately lead to complete collapse. There will be no one to fix or edit them. The second thesis is to stop the relentless pursuit of profit. This is a very difficult question, since it means introducing some kind of artificial regulation into business, which in turn is fraught with negative consequences. This cannot be achieved without coordinated cooperation among key players in the global economy. Despite the obvious difficulties, there is no doubt that decisions will be made and the problems outlined in this article will be resolved.

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The Social and Economic Development Implications of 4IR Technologies in African Housing Production Systems: Review of 3D Printing

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1 ABSTRACT

Digital transformation, associated with the Fourth Industrial Revolution (4IR), is reshaping planning paradigms across Africa, signaling a departure from traditional housing delivery mechanisms toward digitally enabled and data-driven systems. This transition has prompted intensified scholarly interest in how automation, artificial intelligence, geospatial intelligence, and digital land administration may alter housing access, production models, and governance relations. However, the pace of technological innovation far exceeds the evolution of social development systems, creating a tension between digital optimisation and social equity. This research is motivated by the growing disparity between technological capabilities and socially inclusive housing outcomes. While 4IR demonstrates potential to enhance transparency, streamline land-use planning, strengthen tenure security, and support participatory decision-making, the absence of rights-based frameworks risks reproducing existing socio-spatial inequalities within digital infrastructures. The study aims to interrogate how 4IR technologies can be leveraged to advance, not undermine, socially just housing outcomes in African cities. A combined bibliometric analysis and qualitative systematic review was employed to map patterns, identify conceptual gaps, and analyse governance and implementation dynamics through cases in South Africa due to the no-representation of other African countries. The findings reveal three distinct trends: increasing technological experimentation without adequate regulation, insufficient institutional capacity to manage digital transformation, and growing potential for tech-driven co-creation of housing solutions. The research proposes a Digital Social Innovation Housing Framework centred on ethical governance, community empowerment, and institutional readiness.

Keywords: Digital housing systems, Fourth Industrial Revolution, Social development policy, Bibliometric analysis, Africa.

2 INTRODUCTION

Rapid urbanization and population growth, informal settlements form a major part of the urban fabric globally (Mndzebele & Gumbo, 2023). Africa continues to grapple with a multifaceted and persistent housing crisis marked by a severe shortage of affordable housing, substandard living conditions in informal settlements, and rapid urban population growth. The continent's housing challenge is further compounded by poor construction quality, slow delivery rates, and high material wastage, particularly within the low-income housing sector (Bah, Faye, & Geh, 2018). These challenges are exacerbated by limited technical capacity and inadequate awareness of innovative construction technologies, which have constrained the construction industry's ability to respond effectively. Consequently, the sector has been slow to adopt technological innovations capable of addressing the inefficiencies inherent in conventional construction methods, resulting in low levels of sustainability and delayed housing delivery across many African countries. Against this backdrop, this study interrogates the social and economic development implications of Fourth Industrial Revolution (4IR) technologies, specifically 3D printing, within African housing production systems. It seeks to move beyond techno-optimistic narratives by critically assessing how emerging construction technologies intersect with issues of governance, institutional capacity, and social equity. Through a combined bibliometric analysis and qualitative systematic review, the study maps existing scholarly trajectories, identifies conceptual and empirical limitations, and examines selected case experiences from South Africa, Morocco, and Kenya. In doing so, the research contributes to debates on digitally enabled housing delivery by proposing a Digital Social Innovation Housing Framework that foregrounds ethical governance, community empowerment, and institutional readiness as essential conditions for inclusive and sustainable adoption of 4IR technologies in African cities.

3 CONTEMPORARY DISCOURSES ON 4IR IN HOUSING

Conventional housing delivery models, largely dependent on labour-intensive, material-heavy construction techniques, have proven incapable of meeting demand at scale, particularly for low-income and marginalised households (Moghayedi & Awuzie, 2025). As a result, informal settlements have become a dominant mode of urbanisation across the continent, often characterised by insecure tenure, inadequate infrastructure, and exposure to environmental risks (Ouma et al., 2024). Within this discourse, technological transitions, particularly those associated with the Fourth Industrial Revolution (4IR), are framed as potential disruptors capable of transforming housing delivery processes, improving efficiency, and reducing costs (Lopes & Silva Filho, 2024). However, the uneven diffusion of technology across African settings raises concerns about deepening socio-spatial inequalities if innovation is not embedded within inclusive development frameworks. The Fourth Industrial Revolution is defined by the convergence of digital, physical, and biological systems, driven by advances in automation, artificial intelligence, robotics, big data, and additive manufacturing (Alarcón & Alarcon, 2025). In the Global South, including Africa, scholars note that 4IR technologies offer opportunities to enhance transparency in land-use management, improve coordination across planning institutions, and enable more participatory forms of urban governance (Mbatha, 2025). Despite these opportunities, critical literature cautions against technological determinism. Without adequate regulatory oversight, institutional readiness, and social safeguards, 4IR-driven systems risk reinforcing exclusion by privileging technically skilled actors and formalised property regimes. This tension highlights the need to interrogate not only the technical capabilities of 4IR technologies but also their governance, ethical, and distributive implications, particularly in housing systems serving low-income communities.

4 METHODOLOGY IMPERATIVES

This study employed a qualitative-dominant mixed-methods research design that integrates bibliometric analysis with a qualitative systematic review to explore the trajectories, governance considerations, and socio-institutional debates surrounding the application of Fourth Industrial Revolution (4IR) technologies in African housing production systems. This methodological combination was intentionally selected to capture both the macro-level structure of knowledge production. Such as publication trends, collaboration networks, and geographic concentration, and the micro-level thematic content shaping discussions on 3D printing, additive manufacturing, and socially just housing delivery. Peer-reviewed journal articles were systematically retrieved from indexed academic databases using carefully constructed search strings that combined terms related to 4IR, 3D printing, additive manufacturing, housing, and construction. To ensure analytical consistency, only English-language publications were included. The resulting dataset was analysed using bibliometric mapping software to generate visual representations of temporal publication patterns, co-authorship networks, and country-level collaboration dynamics, enabling the identification of dominant research clusters, asymmetries between Global North and Global South knowledge production, and shifts in scholarly focus over time.

In parallel, a qualitative systematic review was conducted to interrogate how 4IR technologies, particularly 3D printing, are conceptualised, governed, and operationalised within housing production systems. This review extended beyond academic literature to include policy documents and documented pilot projects that explicitly engaged with social, economic, governance, and institutional dimensions of digital construction technologies. Studies were screened based on their relevance to housing delivery processes, governance frameworks, and social development outcomes, with particular emphasis placed on implementation realities rather than purely technical innovation. A thematic analysis approach was applied to synthesise recurring concepts, constraints, and enabling conditions, paying close attention to issues of regulatory readiness, institutional capacity, social inclusion, and the uneven spatial diffusion of technological innovation within African settings. Given the limited empirical documentation of 3D printing housing initiatives across the continent, selected experiences from South Africa were used to contextualise the findings. South Africa was selected due to its relatively advanced research infrastructure, emerging experimentation with digital construction technologies, and greater availability of publicly accessible documentation. These cases were not positioned as representative of Africa as a whole but were instead treated as illustrative lenses through which governance preparedness, institutional arrangements, and socio-economic implications of 4IR-driven housing interventions could be critically examined. Insights generated from both the bibliometric analysis

and the qualitative systematic review were subsequently integrated through a qualitative synthesis process that informed the development of the Digital Social Justice Housing Framework (DSJHF).

5 ANALYSIS AND DISCUSSIONS

This section presents and interprets the empirical results of the bibliometric analysis, examining temporal trends, collaboration patterns, and geographic distributions in scholarship on 4IR technologies and housing production. The discussion situates these findings within broader debates on governance, institutional capacity, and social justice in digitally enabled housing systems from an African perspective.

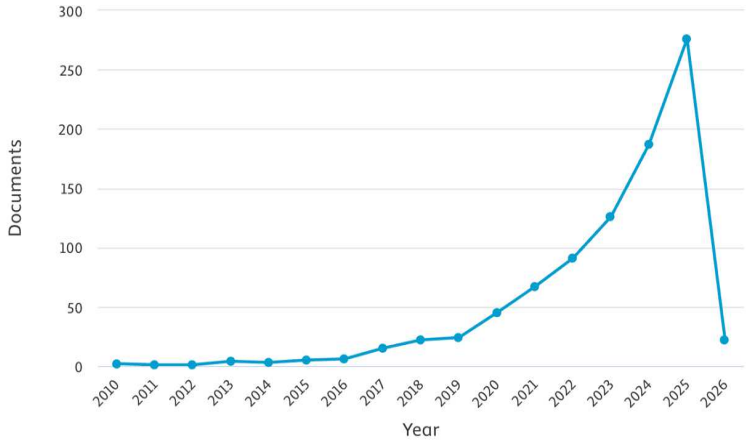


Figure 1: Publication trend

The bibliometric analysis reveals a clear, accelerating growth trajectory in scholarly output on 4IR-related technologies for housing production between 2010 and 2025 (Figure 1). From 2010 to approximately 2016, publication activity remained relatively low and fragmented, indicating that additive manufacturing and digital construction were still positioned as niche or experimental topics within the broader construction and housing literature. This early phase aligns with global accounts that position 3D printing in construction primarily as laboratory testing and pilot demonstrations rather than as applied housing systems (Lyu et al., 2021). A notable inflection point occurs from 2017 onwards, with a sharp increase in publications accelerating further after 2020. This surge corresponds with the global consolidation of Fourth Industrial Revolution discourse following Schwab's (2016) formalisation of the 4IR, as well as growing industry interest in automation as a response to housing shortages, climate pressures, and construction inefficiencies. The exponential rise between 2021 and 2025 suggests that 3D printing and digitally enabled housing production have transitioned from speculative innovation to a recognised research frontier within the built environment domain (University of Johannesburg, 2023). The apparent decline in 2026 should be interpreted cautiously, as it likely reflects incomplete indexing rather than a substantive reduction in scholarly interest. Overall, this temporal pattern confirms that the field is rapidly expanding yet remains emergent, reinforcing the relevance of this study's critical interrogation of social and governance implications, which often lag behind technological development.

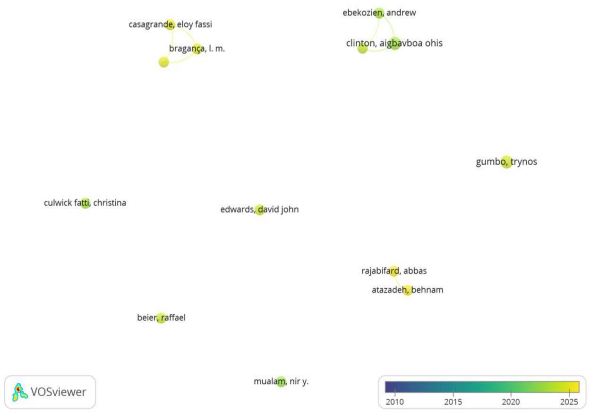


Figure 2: Co-authorship (Authors)

The co-authorship network analysis (Figure 2) reveals a relatively fragmented scholarly landscape characterised by small, loosely connected author clusters. Several micro-clusters, such as those involving Casagrande and Bragança, Rajabifard and Atazadeh, and Clinton and Aigbavboa, indicate strong collaboration within specialised subfields, including digital land administration, construction innovation, and smart infrastructure. However, the limited interconnection between these clusters suggests weak cross-fertilisation between technical, planning, and social development research streams. This fragmentation reflects a broader pattern in 4IR scholarship, where engineering-led research often advances independently of urban governance and social policy debates. The relative isolation of scholars working on housing justice, participation, and informality from those focused on additive manufacturing highlights a critical limitation: technological innovation is progressing faster than integrative frameworks capable of addressing social equity outcomes. The presence of African scholars, most notably Trynos Gumbo, within the network is significant but limited in scale, indicating that African perspectives remain underrepresented in global debates on digitally enabled housing systems. This finding supports existing critiques that Global South settings are frequently treated as sites of technological experimentation rather than sources of theory and normative guidance. The results, therefore, highlight the need for more interdisciplinary and transregional research collaborations that foreground African housing realities within 4IR innovation discourses.

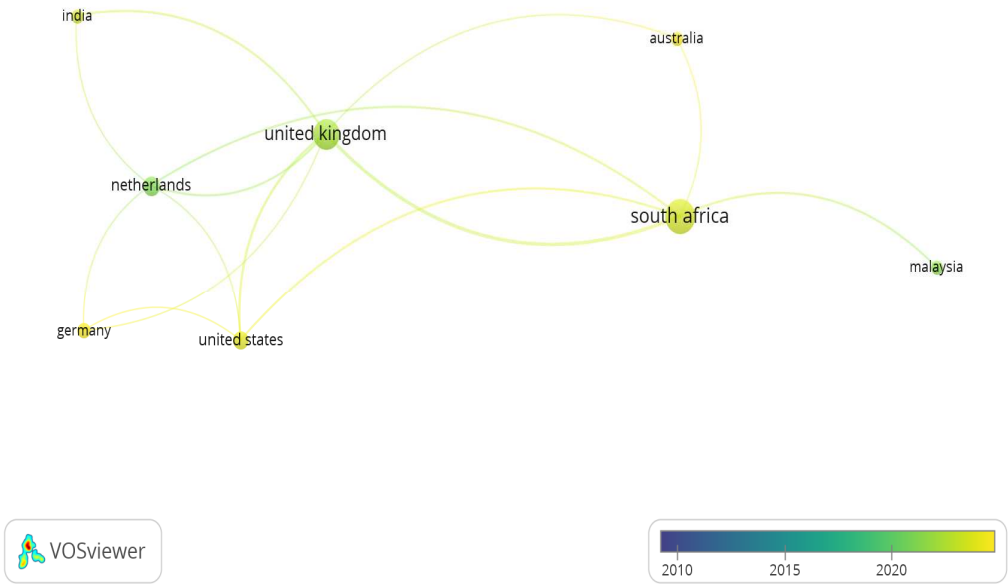


Figure 3: Co-authorship (Countries)

The country co-authorship network (Figure 3) demonstrates a pronounced concentration of research output and collaboration in the Global North. These countries function as central nodes within the network, facilitating transnational knowledge flows and shaping dominant research agendas in digital construction and housing technologies. South Africa emerges as the most prominent African contributor and the primary bridge between Global North research hubs and the African continent. The limited representation of other African countries suggests that research on 3D printing and 4IR housing remains geographically uneven, despite the continent's disproportionate exposure to housing deficits and informal urbanisation (UN-Habitat, 2020). This asymmetry raises critical questions about epistemic justice and technological transfer. While African cities are frequently framed as ideal testing grounds for rapid, low-cost housing technologies, the conceptualisation, regulation, and evaluation of these technologies are largely driven externally. The findings thus reinforce concerns that without strong local institutional capacity and participatory governance, 4IR housing interventions risk reproducing neo-colonial development dynamics rather than enabling locally grounded innovation.

6 TOWARDS THE DIGITAL SOCIAL JUSTICE HOUSING FRAMEWORK (DSJHF)

This section outlines targeted recommendations to support the socially just adoption of Fourth Industrial Revolution (4IR) technologies in African housing production systems. The recommendations respond directly to observed limitations in governance, institutional capacity, knowledge production, and community

engagement, and are structured to inform planning practice and future research. Collectively, they operationalise the principles of the proposed Digital Social Justice Housing Framework by translating important findings into actionable guidance for stakeholders involved in digitally enabled housing delivery.

Findings	**Implications for African Housing Systems**	**Targeted Recommendations**
Rapid growth in publications on 4IR and 3D printing since 2017, with accelerating interest post-2020	Technological development is advancing faster than governance, regulation, and social safeguards	Develop proactive, rights-based regulatory frameworks that guide the adoption of 3D-printed housing, ensuring alignment with social equity, housing rights, and sustainability objectives
Dominance of techno-centric research with limited engagement on social development outcomes	Risk of technocratic housing delivery models that marginalise community needs and lived realities	Embed social development indicators (equity, participation, tenure security, livelihoods) into digital housing policies and project evaluation frameworks
Fragmented author collaboration networks with weak interdisciplinary integration	Limited cross-learning between engineering, planning, and social policy disciplines	Promote interdisciplinary research and implementation teams combining planners, engineers, social scientists, and policymakers in 4IR housing projects
Concentration of knowledge production in the Global North, with South Africa as the main African node	African settings risk being sites of experimentation rather than knowledge generation	Strengthen African-led research, South–South collaboration, and locally grounded innovation agendas in digital housing systems
Limited institutional capacity to regulate and scale 3D-printed housing	Difficulty transitioning from pilot projects to large-scale implementation	Invest in institutional readiness through digital literacy training, regulatory reform, and updated building codes accommodating additive manufacturing
Potential labour displacement due to construction automation	Risk of job losses in low-skilled construction sectors	Integrate inclusive skills development and labour transition programmes linked to 3D printing and digital construction technologies
Weak community participation in digital housing innovation	Housing solutions may fail to reflect socio-cultural and spatial needs	Institutionalise community co-creation and participatory digital tools in housing design and delivery processes
Experimental nature of most African 3D-printed housing projects	Limited empirical evidence on long-term social and economic impacts	Support setting-sensitive pilot projects with stout social, economic, and environmental impact assessments

Table 1: Digital Social Justice Housing Framework (DSJHF)

As indicated on table 1, there is a need to reposition digital housing innovation within rights-based and ethically grounded governance frameworks that prioritise social equity, accountability, and inclusivity alongside efficiency gains. Across all recommendation areas, institutional readiness emerges as a critical enabling factor. Strengthening regulatory capacity, updating planning and building control systems, and investing in digital competencies within public institutions are necessary to move beyond isolated pilot projects towards scalable and sustainable implementation. Equally important is the alignment of technological innovation with inclusive skills development strategies, ensuring that automation in housing production contributes to employment transition and local economic development rather than labour displacement. Meaningful engagement of end-users in design and decision-making processes enhances contextual relevance and social legitimacy, while mitigating the risks of technocratic and exclusionary housing outcomes. Importantly, the recommendations highlight the need for African-led and interdisciplinary knowledge production to address existing geographic and conceptual asymmetries in 4IR housing research. Strengthening South–South collaboration and locally grounded innovation is essential for advancing socially just, digitally enabled housing systems aligned with the principles of the Digital Social Justice Housing Framework.

7 CONCLUSION

This study examined the social and economic development implications of Fourth Industrial Revolution (4IR) technologies, specifically 3D printing, within African housing production systems. Through combining bibliometric analysis with a qualitative systematic review, the research demonstrated that while digital construction technologies are rapidly gaining scholarly and policy attention, their integration into housing delivery remains uneven, fragmented, and insufficiently attuned to social equity concerns. The findings reveal a persistent disconnect between technological experimentation and the governance, institutional capacity, and participatory mechanisms required to support inclusive housing outcomes in African cities. The analysis highlights that 3D printing should not be understood as a standalone solution to Africa's housing crisis, but rather as part of a broader socio-technical transformation that demands deliberate institutional and ethical alignment. Without rights-based governance frameworks, inclusive skills development, and meaningful community engagement, digitally enabled housing initiatives risk reproducing existing socio-

spatial inequalities within new technological infrastructures. The study advances the Digital Social Justice Housing Framework as a normative and analytical contribution that re-centres social equity, ethical governance, and institutional readiness in debates on digital housing innovation. The framework provides a basis for guiding policy, planning practice, and future research towards housing systems that harness technological advancement while remaining grounded in African urban realities. Future research should build on this foundation by empirically evaluating long-term social outcomes of 3D-printed housing projects and further exploring locally driven models of digital housing innovation across diverse African settings.

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reviewed paper

Tools for Transformative Social-Ecological Infrastructure

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1 ABSTRACT

The social-ecological transformation of mobility systems poses major challenges for local and regional governance, as entrenched institutional structures, political incentives, and vested interests often impede change beyond technical solutions. This paper presents findings from the exploratory research project "LEIWAND – Lokale Entscheidungen für den sozial-ökologischen Infrastrukturwandel" (Local decisions for social-ecological infrastructure transformation), which develops a governance-oriented toolbox for decision making with regard to infrastructure decisions. Based on two case studies in Austria and a review of international good practices, the project analyses political-economic decision-making dynamics in transport and land-use planning. Building on these insights, the paper introduces tools that propose new and adapted process elements – such as transparency mechanisms, funding and alternative deliberation – to support more inclusive, transparent, and transformation-capable decision-making in mobility governance.

Keywords: sustainable mobility, governance, transport infrastructure, spatial planning, urban development

2 INTRODUCTION & METHODOLOGY

The transition towards sustainable and socially just mobility systems can be seen as a key element of broader social-ecological transformation processes, which are defined as long-term, multi-level and disruptive change processes (Brand and Wissen, 2017). Such transformations require more than technological innovation or spatial reconfiguration; they also depend on fundamental changes in political and institutional decision-making. Although many regions formally commit to sustainable mobility and integrated land-use planning, transformative change is frequently impeded by path dependencies, vested interests, and institutional constraints (Gössling and Cohen, 2014, Mattioli et al, 2020, Getzner et al., 2025).

Research on transport and land-use planning has largely focused on the linkages between policy design, technological options, and user behaviour. Comparatively little attention has been paid to the political dynamics and decision-making processes that shape whether well-known and effective measures are actually implemented (Kębłowski et al., 2022, Sang et al., 2026). This gap is critical, as the impacts of many mobility policies are well understood, yet their translation into practice often fails due to political, administrative, and institutional barriers.

The research project addresses this gap through an exploratory study focusing on decision-making processes in Austria with regard to land-use and transport infrastructure. The empirical basis consists of three parts: (1) two qualitative case studies (the redesign of a public square in a large city and the construction of a bypass road in a small municipality), where semi-structured interviews were conducted with political and administrative actors as well as with scientists, entrepreneurs and civil society[1], (2) two expert workshops with the aim to identify barriers and drivers and discuss tools and instruments to adapt decision making processes and (3) a review of international good practices in transformation-oriented governance, conducted as non-systematised desktop research, drawing on academic literature, grey literature, existing tools and policy instruments.

The development of the toolbox was mainly driven by the second expert workshop involving 13 participants. The group included transport planners from local planning companies, representatives from the federal

[1] While the empirical findings of the case studies informed the development of the toolbox, they are not the primary focus of this paper and are reported elsewhere (Gallian, Hauschild et al., under review).

transport ministry (BMIMI), academics from political science and mobility research, practitioners from intermediary organisations such as KEM regional managers, members of civic initiatives, and local politicians. After an introduction to the project, participants worked in small groups of four to five people. Each group was first presented with two proposed tools and invited to provide structured feedback. Subsequently, participants discussed additional tool ideas, drawing both on their own experience and on suggestions collected by the project team. The workshop concluded with plenary presentations and joint reflection, allowing participants to comment on the proposed tools and provide feedback on further development.

Based on the workshop outcomes, the case study insights, and the literature review, the project team conducted an internal synthesis to identify those tools most relevant and suitable for inclusion in a governance-oriented toolbox for social-ecological infrastructure transformation. The focus was on tools that introduce new or adapted process elements in political and planning practice – particularly those that increase transparency in decision-making, clarify roles and responsibilities, and enable the inclusion of actors and perspectives that are typically underrepresented. Many tools also aim to create deliberative spaces that foster learning, mutual understanding, and the integration of diverse forms of knowledge into mobility and infrastructure decisions.

3 TOOLS

In the following, we shortly present exemplary tools included in the toolbox.

3.1 Transparency Register

Our analysis indicates that decision-making processes in mobility and land-use infrastructure planning are often insufficiently transparent. Affected individuals and groups frequently lack information about the status of projects, the structure of decision-making processes, and the basis on which decisions are taken. To address these shortcomings, the introduction of a transparency register at the project level could provide a valuable governance instrument.

Such a register would systematically document and make publicly accessible who participates in infrastructure decision-making processes, including organisations, interest groups, consultancies, and individual actors. In addition, it could record meetings, formal submissions, and other forms of influence related to specific infrastructure projects, thereby increasing the visibility of political and administrative interactions throughout the planning process.

Comparable transparency instruments already exist in other governance contexts. A prominent example is the EU Transparency Register[2], which documents lobbying activities at the European level. Moreover, Odparlik and Köppel (2013) review project-related registers in the context of Environmental Impact Assessment, highlighting their role in enhancing transparency and public participation in planning procedures.

3.2 Transformation Fund

The concept of a transformation fund aims to provide targeted financial support for measures required to advance social-ecological transformation. Such a fund could be established at the federal level and designed to create dedicated funding opportunities for municipalities and provinces. Access to funding would be conditional on projects meeting clearly defined criteria aligned with social, and sustainability objectives, thereby enabling public finance to actively steer transformation rather than merely support isolated investments. Achieving climate neutrality in Austria until 2040/2050 requires additional investments of 1.1 to 1.9% of GDP; about one third of investments would be undertaken by the public sector, especially municipalities (Weyerstraß et al., 2024). A specific funding opportunity for these investments could be an important mobilizer for carbon neutrality.

In Austria, several existing funding instruments already link public co-financing to the fulfilment of specific criteria, such as the “Kommunales Investitionsprogramm"[3] or the “Klimapartnerschaft”[4], through which the

[2] https://transparency-register.europa.eu/index_en

[3] https://www.bmf.gv.at/themen/budget/finanzbeziehungen-laender-gemeinden/kommunales-investitionsprogramm.html

federal government supports regional railway infrastructure. A transformation fund could build on these experiences while broadening their scope and strategic orientation. Financing for such a fund could be drawn from multiple sources, including revenues generated through "polluter pays" instruments such as congestion charges, road pricing schemes, increased parking fees, or CO_2 pricing mechanisms. Similar approaches are discussed in recent studies on financing future-oriented transport systems, for example in the German context (Agora Verkehrswende and Dezernat Zukunft, 2025).

Germany has already established a "Klima- und Transformationsfonds" as a special federal fund (Sondervermögen), illustrating how earmarked financial instruments can be used to support structural transformation across sectors. At the same time, the design of a transformation fund raises important challenges, particularly with regard to defining robust and transparent criteria to assess whether funded projects genuinely contribute to climate goals and social equity. If investments are leveraged, efficiency and distributional problems would have to be addressed (Damjanovic et al., 2024). Addressing these challenges is crucial for ensuring the credibility and effectiveness of such a funding instrument.

3.3 Participatory and Deliberative Formats

Participatory processes and public deliberation have become increasingly important instruments in infrastructure and climate-related decision-making. These formats aim to enable citizens to express their views on projects and policies, contribute local knowledge, and engage in collective problem-solving. In Austria, however, political decision-making is primarily organised through representative democratic institutions, while participatory procedures are generally not mandatory. Binding participation rights mainly exist in specific legally regulated context, particularly in environmental decision-making processes subject to EU law and the Aarhus Convention.

Beyond conventional consultation formats, there is growing international interest in deliberative participation methods designed to support climate action and long-term transformation. These include citizens' assemblies, citizens' councils, and other structured deliberative formats that aim to facilitate informed discussion rather than opinion polling. In Austria, an important example is the Klimarat der Bürgerinnen und Bürger, which was convened by the federal climate ministry and developed recommendations for the Austrian parliament (ARGE Klimarat, 2022). Such formats are increasingly discussed as complements to representative decision-making, particularly in complex and contested policy areas such as mobility transformations.

Citizens' councils (Bürgerinnen- und Bürgerräte) are a particularly institutionalised form of deliberative participation. They typically consist of randomly selected citizens who deliberate on socially relevant issues and develop recommendations for public administration, political decision-makers, and planning authorities. Their key strength lies in fostering trust and mutual understanding by enabling dialogue beyond organised interests, as well as in allowing early articulation of concerns that might otherwise emerge later as conflicts in formal planning procedures. In addition, such formats have a learning function, contributing to the development of deliberative culture and institutional learning within public governance. At the same time, citizens' councils also have clear limitations. Their recommendations are politically but not legally binding, and implementation depends largely on the willingness of decision-makers. Without systematic feedback mechanisms, participation risks remaining symbolic. Moreover, due to the small number of participants, representativeness is necessarily limited. Despite these constraints, institutional experience shows their potential. Since 2013, they have been anchored in regional law in the Austrian province of Vorarlberg, where Article 1(4) of the regional constitution explicitly promotes additional forms of democracy. Notably, citizens also have an initiative right: a citizens' council can be requested with a minimum of 1,000 signatures.

3.4 Information Fact Sheets

Information fact sheets are a transparency-oriented governance tool aimed at creating a shared knowledge base among all actors involved in decision-making processes. By condensing complex planning, environmental, and policy-related information, such fact sheets seek to make relevant facts, arguments, and implications of projects or policy proposals accessible to a broad audience. They are typically produced by public authorities and are often used in the context of contested decisions, such as infrastructure projects.

[4] https://www.bmimi.gv.at/themen/verkehrsplanung/ausbauplan/klimapartnerschaft.html

A prominent example is the official voting booklet (Abstimmungsbüchlein) used in Switzerland. These booklets are sent to all eligible voters and made available online. They are issued by the federal government and prepared by the Federal Chancellery in cooperation with the relevant ministries. Their content includes the full wording of the proposal, explanations by the Federal Council, arguments from supporters and opponents, as well as voting recommendations from both the government and parliament. The primary objective is to fulfil an information obligation rather than to ensure strict neutrality.[5]

As a governance tool, information fact sheets can support more inclusive and informed decision-making by reducing information asymmetries, clarifying trade-offs, and making arguments transparent. At the same time, their design raises important questions regarding accessibility, authorship, balance, and institutional independence. If carefully designed, such fact sheets can complement participatory and deliberative processes by providing a common factual reference point and thereby improving the quality of public debate in mobility and land-use decision-making.

4 CONCLUSION

Drawing on two Austrian case studies, expert workshops and international good practice, this paper identifies governance tools that can help address persistent transparency deficits, power asymmetries, and implementation barriers in mobility and land-use infrastructure planning. The toolbox focuses on decision-making processes and highlights how such instruments can broaden the range of perspectives considered and strengthen the integration of social and ecological concerns. At the same time, the analysis underscores that such tools are not neutral: their effectiveness depends on political commitment, institutional embedding, and careful design to avoid symbolic participation or selective implementation. By combining political-economic analysis with practice-oriented governance tools, the paper contributes to debates on regional governance, just transitions and illustrates how regions can enhance their capacity to actively steer sustainable mobility and land-use transformations.

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reviewed paper

Training of Experts for Sustainable Use of Land

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1 ABSTRACT

A key objective of spatial planning is the sustainable management of the resource 'land', which requires balancing competing interests such as housing, infrastructure, wildlife protection, food production, and industry. In regions with no or limited spatial planning traditions, land is often underutilized or inefficiently managed. Addressing this challenge requires specialist in spatial planning, but also experts for the acquition of geodata needed for decision-making.

Therefore, training people in data acquisition is essential for many countries. This paper shares experiences from two capacity building initiatives in Ethiopia. Both projects aim to provide materials for (in attendance, online, and hybrid) teaching with the thematic focus on geomatics. This includes the purchase of equipment such as UAVs (Unmanned Aerial Vehicles) equipped with RTK/GNSS (Real time Kinematic/Global Navigation Satellite System), a GNSS base station, a CORS (Continously Operating Reference Station), and multi-media equipment for producing educational videos and online-teaching. Teachers at four Ethiopian universities are trained in the usage of these instruments to gain competences and skills to subsequently educate their students and national professionals. In addition, joint courses were also offered. Both initiatives emphasize capacity development through hands-on field exercises, competency-based teaching approaches, and institutional collaboration. This approach ensures the long-term integration of modern geospatial tools in academic and professional practice.

Keywords: Training, Data Acquistition, UAV, Ethiopia, Land Administration

2 INTRODUCTION

A primary objective of spatial planning is the responsible and sustainable use of the resource 'land'. This requires balancing conflicting interests; aspects such as housing, infrastructure, wildlife protection, food production, and industry must all be considered. Countries with no or limited spatial planning traditions face a heightende risk of inefficient land use and resource degredation. A typical consequence of these planning gaps – frequently observed in the Global South – is the proliferation of informal settlements, which emerge when land is not allocated or managed optimally.

Dealing with these challenges requires multidisciplinary expertise. However, they depend on reliable geodata as a basis for their decision-making and for analysing complex spatial situations. While data availability is generally standard in developed nations, countries in the Global South often lack on geodata and on suitable procedures for data acquisition. This information gap hinders evidence-based decision-making and constrains efforts toward sustainable land management.

Nowadays, spatial planners have the competencies and skills to operate modern surveying equipment, such as Global Navigation Satellite Systems (GNSS) or Unmanned Aerial Vehicles (UAVs). Especially UAVs are used to gain up-to-date land information with high spatial, spectral, and temporal resolution. Data acquired by this technology, such as Digital Surface Models, ortho-mosaics, or land cover maps, are applied for planning and monitoring activities.

Not in every country, enough surveyors are available to guarantee a nation-wide, up-to-date coverage. Ethiopia, for example, is currently implementing a land registration system (MEDENDORF et al., 2014), for which it was estimated that 50,000 additional surveyors would be required until 2024 (NAVRATIL and MANSBERGER, 2017). Even though not all of them would need a full university education, the Ethiopian universities were not prepared for this challenge. Even today, only a fraction of the required workforce is available. To mitigate this shortage, specialized training can be provided to experts in similar domains, such as spatial planners. This strategy involves adapting teaching and learning materials originally developed for university surveying programs to equip these professionals with the necessary geospatial competencies.

Beyond the technical operation of surveying equipment, additional competences are required. The availability of spatial data across various sectors in Ethiopia remains a significant challenge, primarily due to the absence of a Spatial Data Infrastructure (SDI) framework. For instance, the geometric structure and positional alignment of spatial datasets often differ across sectors, such as land registration, urban planning, and city administration. These inconsistencies create significant barriers to exchange of data between public bodies and interdisciplinary sectors. Consequently, experts in all sectors need the competence to harmonise these data sets and resolve interoperability issues.

If experts lack the competences, they risk designing plans without considering the spatial characteristics of the (spatial, temporal, radiometric, and spectral) resolution of the data or utilizing inappropriate software platforms. In Ethiopia, such gaps have previously resulted in spatial shifts and geometric inaccuracies creating inconsistencies with national standards and working manuals (e.g., AACA, 2002; ERA, 2013; MoUDAH, 2016). This occurs despite national standards explicitly mandating that land registration and spatial planning must use ground surveying, aerial surveying, and high-resolution satellite images. Addressing these inconsistencies is crucial for improving land governance workflows, minimizing duplication of effort, and ensuring coherent national planning strategies. Skilled workforce is necessary to achieve this goal. Ethiopia currently is still lacking enough experts. To mitigate these problems, investment in education in this field is highly needed.

This paper reports on the experiences of two ongoing capacity-building projects in Ethiopia. Both initiatives focus on the development of learning and teaching materials and the training of the teachers. Furthermore, the projects integrate the concept of Lifelong Learning (LLL) by creating modular course materials which can be reused for LLL activities.

3 PROJECT OVERVIEW

Currently, the authors are involved in two capacity-building projects in Ethiopia: “Implementation of Academic Geomatics Education in Ethiopia for Supporting Sustainable Development (Edu4GEO2)” and “Land Information for Land Management (Li4LaM)”. Edu4GEO2, financed by the Austrian Development Agency (APPEAR program), aims at creating a master curriculum in Geomatics at the Debre Markos University. Li4LaM, funded by the European Union (ERASMUS+ program), aims to improve the teaching environment and teaching methods at four Ethiopian universities: Addis Ababa University, Bahir Dar University, Debre Markos University, and Woldia University. The Austrian partners involved in these projects are Technische Universität Wien and BOKU University Vienna. The University of Agriculture in Krakow and University of Ljubljana are additional partners in the Li4LaM project.

Both initiatives aim to develop materials for live, online, and hybrid teaching, with a focus on surveying and data management. This includes the purchase of UAVs (Unmanned Aerial Vehicles) equipped with RTK/GNSS (Real Time Kinematic/Global Navigation Satellite System), a GNSS Base Station, a Continously Operating Reference Station (CORS), a camera equipment for creating educational videos, and a basic setup for E-Learning and online teaching. Teachers at the Ethiopian universities are trained in the usage of these instruments and equipment to gain the competences and skills to subsequently train their students and national professionals. Both initiatives emphasize capacity development through hands-on field exercises, competency-based teaching approaches, and institutional collaboration. This ensures the long-term integration of modern geospatial tools in academic and professional practice.

A significant challenge in Ethiopia is country’s diverse demographic structure, characterized by the wide variety of ethnicities and languages. This can cause barriers for education. The Li4LaM project tackles these barriers through spreading awareness of potential challenges. The lack of available hardcopy textbooks is

addressed through electronic learning material ensuring a broader, more flexible access to education. In recent years, inter-ethnic conflicts have further complicated the educational landscape, occasionally making traveling dangerous. This volatility culminated in a regional university shutdown during the winter term 2022/23, when for safety reasons, universities had to prevent students to come to the university. During such periods, distance learning techniques are essential, as they allow for educational continuity while students remain in safe locations. Distance learning enriches Ethiopia's current learning environment and fosters a LLL-culture on- and off-campus. The aim is to create tailor-made and flexible education and training systems and solutions to deliver more learner-centred, accessible, and inclusive learning.

A goal of Edu4GEO2 is the implementation of a master curriculum on geomatics at Debre Markos University. This includes the creation of new courses (usually based on courses already existing at other universities) with theoretical and practical modules as well as with test questions. The modules typically contain textbook materials, presentation slides, and practical case studies, which allow students to carry out various professional tasks. Examples are parameter estimation, production of DSM and ortho-mosaics using UAV photogrammetry, spatial data analysis, or gender and land rights. Parts of these courses (or complete courses) can be offered as LLL courses, too.

4 TRAINING CONTENT

Both projects incorporate a train-the-teacher approach. The workshops and training sessions covered a diverse range of topics, tailored to a specific audience. The identification of learning outcomes or modern educational concepts as well as the development of curricula for example, are more relevant for people teaching at universities than for practitioners. Other trainings focused on the practical operation of the hardware acquired through the project. To maintain the project's strategic focus, certain peripheral topics were excluded from the scope.

The depth of instruction varied according to the technical requirements of each subject. For example, machine learning principles were covered only to the extent necessary for utilizing existing online platforms. In contrast, photogrammetric principles received more rigorous treatment, given their critical impact on flight planning and data accuracy.

Not all relevant topics, however, could be taught during the workshops. An important aspect in surveying or geoinformatics curricula is geographical reference frames and spatial data infrastructures (SDI). These topics, extremely relevant for the collection of data, are more time-consuming than the pure training in the use of technology. They require a thorough understanding fundamental theoretical concepts and knowledge of practical implementation. This includes concepts like the Geoid, practical questions like the atmospheric impact of data collection, or implementation issues like dealing with soil movement during the setup of a nation-wide reference frame.

4.1 Use of Surveying Equipment

An important component of modernizing instructional capacity was the acquisition of Unmanned Aerial Vehicles (UAVs) equipped with RGB cameras as well as the purchase of a GNSS (Global Navigation Satellite System) base station to enable operating the drones in a DRTK (differential real time kinematic) GNSS modus.

For administrative reasons, the UAVs first were purchased by the European partners using the project money and afterwards donated and delivered to the Ethiopian partners. This procurement strategy was necessitated by the limited local availability of specialized and up-to-date hardware in Ethiopia as well as by the gained experiences from the previous EduLand2 project ("Implementation of Academic Land Administration Education in Ethiopia for Supporting Sustainable Development") that Ethiopian market prices are significantly higher than those in Europe partly caused that Ethiopian universities often are not getting academic discounts.

For some applications, additional spectral bands in the cameras would be of interest (e.g., the near infrared for vegetation studies). Equipment like UAVs with an infrared or thermal sensor are usually classified as dual-use equipment. This means that equipment can be used for both military and civilian applications. This dual-use equipment would need an export permission by the responsible ministry of the sending country. The DJI Mavic 3 Enterprise with a RGB camera, which is not classified as dual-use equipment, was selected for

the Ethiopian universities as the donation require the export of the hardware from European countries and this selection avoid delays or even the denial of the export.

Efficient use of this hardware for teaching and science requires operational skills. These were provided in two steps:

- Before the delivery of UAVs to Ethiopia: A 3-days workshop in Addis Ababa focused on the process of data acquisition using UAVs. The workshop was held in small groups (5-6 persons) training the whole process from flight and mission planning to carrying out photo flights and the postprocessing of the image to generate digital surface models and orthophoto mosaics. This training adopted a single UAV owned by the Agricultural University in Krakow. It was sufficient to teach the use of the software, explain the principles, let the experts get hands-on experience in flight planning, and allow the trainees to experience the complete workflow. The training was organized on the campus of the Addis Ababa University and with the consent of the nearby ministry.
- After the delivery of UAVs to the Ethiopian universities: A 4-days workshop held at the border of Addis Ababa focused on the use of the provided equipment (see Fig. 1). All four Ethiopian universities used the equipment they received through the project. This allowed the trainers to check the completeness and configuration of the UAVs and how to update the settings and the software. Each Ethiopian university sent 2 staff members to experience the handling of the DJI Mavic UAVs.



Fig. 1: Workshop instructor Piotr Wężyk and one of the Drones in Ethiopia (Photo by Wężyk).

For this 4-days workshop, the following objectives were formulated by the project partners:

- Shared Terminology: Develop a common understanding of standard photogrammetry terms to ensure effective communication among all project members.
- Equipment Readiness: Verify the completeness and operational status of UAV and GNSS hardware delivered to Ethiopian universities, including necessary software updates.
- End-to-End Photogrammetry Projects: Collaborate on the planning (Fig. 2) and execution of UAV flights, 3D model reconstruction, and the generation of high-quality orthophotos.
- GNSS Accuracy: Share technical expertise to achieve high-precision measurements using GNSS equipment.
- Educational Materials: Produce high-quality instructional videos and presentation slides for use across all partner universities.
- Strengthen Institutional Partnerships: Foster deeper collaboration and long-term networking between project members and participating universities.

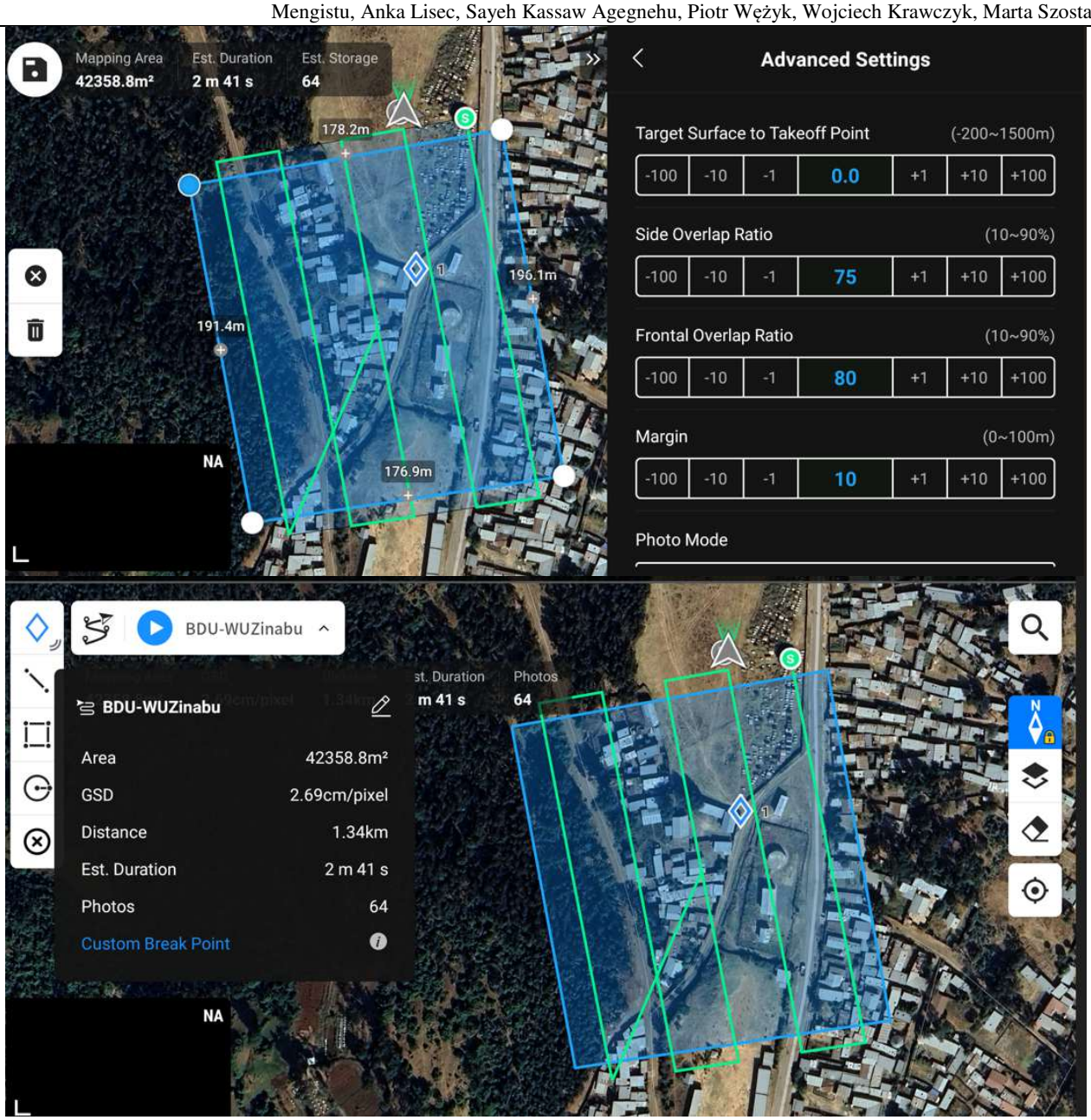


Fig. 2: UAVs Flight Information with DRTK.

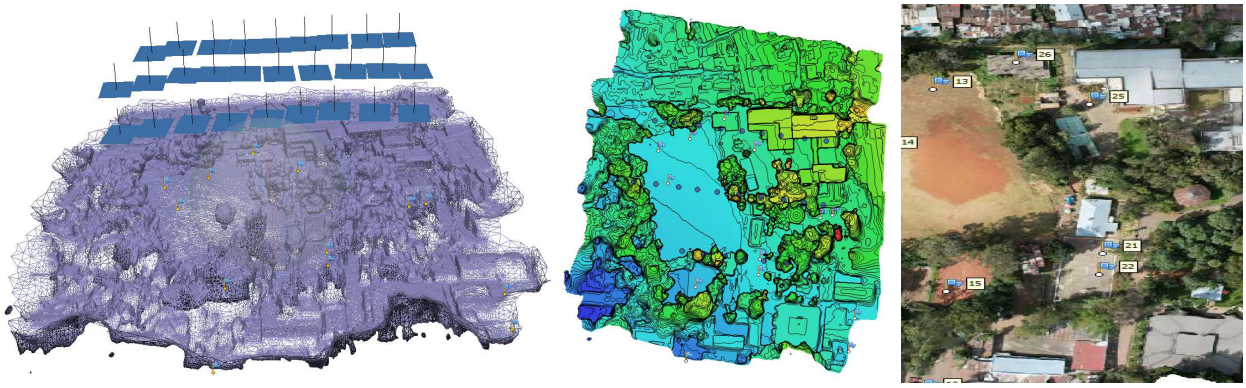


Fig. 3: Example for the results of a flight.

The training started with flight planning, where the path for the UAV is defined. Fig. 2 shows screenshots of this procedure. The trainers explained the effect of the various parameters, discussed advantages and challenges of different settings, and communicated starting values that proved to be appropriate in the past. Tasks necessary before flying also require correct setup of the GNSS base station and the marking of ground

control points. The photo flight itself is an automated process. The last step is the data analysis. It includes merging the different images, generating digital surface models and producing orthophotos followed by subsequent steps, like object classification. Fig. 3 shows one of the created images of the classification in the model. The left image in Fig. 3 shows the terrain model and the positions where images were taken and the image on the right shows the 3D model created from the images. Results like these can be used to analyze thew current situation, identify clusters that need to be protected, detect challenges, and develop solutions.

4.2 Spatial Data Handling

The training on the handling of spatial data was focused on two topics:

- Image Classification using Machine Learning: This task often follows orthoimage production. An expert from BOKU University demonstrated how to use the Google framework for analysis, while an expert from the TU Wien explained how to use local implementations. Both approaches offer unique advantages and disadvantages. In the global South both might be highly relevant.
- Point Pattern Analysis: Observational data often relates to specific sites or areas with high incident frequencies – such as crime hotspots – that require precise identification. Hot-spot analysis enables GIS users to identify these areas and to rasterize the results to merge them with classifications derived from the orthoimages. This approach demonstrated the participants an effective method to combine raster- and vector-data formats.

During the practical sessions, participants also received other relevant information, e.g., how to handle a change of the reference frame or to carry out local transformations. These topics are also relevant for LLL modules with a focus on data integration.

4.3 Improving Teaching Qualities

During a 4-days workshop in Krakow in 2023, aspects of E-Learning were practiced. The workshop aimed to achieve the following objectives:

- Shared Terminology: Develop a common understanding of terms used in learning management systems (LMS) and video production.
- Moodle Course Set-Up: Provide knowledge on setting up a course within the Learning Management System ‘Moodle’.
- Moodle Content Tools: Raise awareness of the content tools available within Moodle.
- Independent Course Creation: Enable project members to independently create Moodle courses and add topics in various formats.
- Open-Source Video Tools: Provide Ethiopian project members with an overview of existing (open source) software tools for producing educational videos.
- Video Production Skills: Train participants in video capturing, screen recording, audio recording and editing, and video editing.
- Workshop Documentation: Enable project members to produce a video documenting the workshop.
- Video Platform Management: Equip Ethiopian university teaching staff attending the workshop with the knowledge to host videos on a video platform (e.g., YouTube Studio).

The focus of the whole workshop was the creation of educational videos and the use of E-Learning tools. Both topics were first theoretically introduced and then practically trained. Only open-source software was used in the workshop to later avoid any problems with software licenses.

During the video production part, social media experts of the University of Agriculture in Krakow provided tips and tricks how videos should be produced (see Fig. 43). In addition, the colleagues from BOKU University, who have experience in the creation of educational videos, demonstrated the software used for video editing. Participants then were tasked with producing their own videos to get some experience for video production using pictures and videos documented with their own smartphones, music, text elements, and screen recordings.

The workshop also provided hands-on experience in the creation of small learning units consisting of different parts like introductory material, literature, educational videos, self-assessment tests, exercises, etc. These units were kept small so they could be easily reused, e.g., for LLL or whenever the curriculum needs to be restructured.



Fig. 4: Presentation at the Social Media Office of the University of Agriculture in Krakow.

To use and provide teaching and learning materials, each Ethiopian university received a server with a Moodle installation that they could integrate into the campus computer network. The decision to use servers placed at the campus and not use a cloud-based solution was influenced by the frequent power outages in Ethiopia which also interrupt the connection to the Internet. The university campuses in Ethiopia are equipped with emergency power units that can support servers, workstations, and the local network. Therefore, the approach with local servers seemed to be more user-friendly. A demonstration and a training how to install and run Moodle activities were carried out during this workshop.

Already during a first workshop in Vienna in 2022, concepts like flipped classroom, support of self-studying for students, team-teaching, and other modern pedagogical concepts were presented. The Krakow workshop was an opportunity to see how material for such concepts can be created.

5 LESSONS LEARNED

The implementation of the two capacity-building projects has yielded several critical insights into international academic collaboration and the technical implementation of professional hard- and software. The following lessons can serve as a basis for future collaboration and projects:

- Cultivating Mutual Respect: The establishment of mutual respect among all project partners is a fundamental pillar for the successful implementation of a project and for achieving the expected results. Most of the participants are currently teaching at their universities, some with decades of experiences. The project does not aim to invalidate this knowledge; the focus was always on widening the toolbox as a teacher because methods working for young students might not necessarily work for LLL courses with domain specialists.
- Addressing Technical Realities: The use of unfamiliar hard- and software sometimes causes challenges not foreseen during project preparation. Hardware acquired in Europe and then shipped to a country of the global South encounters complications regarding warranty support, customer service, and software update cycles. To mitigate these risks, logistical and maintenance frameworks must be fully clarified prior to any procurement.

- Integrated Data Literacy: Training of domain experts to collect data requires training on the use of equipment, but it also needs skills on integrating various data sources. This requires integrated data literacy, such as knowledge on reference system, classification schemes, standards.
- Efficiency of Face-to-Face Training: While digital communication platforms are suitable for delivering theoretical content, the projects underscore that face-to-face training remains effective for practical skill acquisition. In-person the supervision of practical tasks allows the detection and correction of handling errors. This direct mentorship is especially important in training teachers, who must deliver the acquired skills to their students.
- Reuse of Teaching Modules: Training modules can be used for various purposes when designed as parts of a modular system. The materials used to train the trainers on flight planning, for example, can also be used for both, regular students and external experts in the context of LLL. This maximized the benefits of the work invested in the creation of the learning and teaching materials.

6 CONCLUSIONS AND FUTURE WORK

According to RAJABIFARD (2019), geospatial systems are essential for linking land-use decisions to multiple Sustainable Development Goals (SDGs). Land acts as the spatial base where environmental, social, and economic processes interact. Integrated geospatial data helps decision-makers visualize trade-offs between development and conservation to support sustainable land-use planning. Integrated systems enable coordinated monitoring of land degradation and urban growth. Overall, geospatially enabled land management improves sustainable land governance through evidence-based, spatial decision-making.

Early project observations indicate improved instructor competence and a heightened institutional readiness to support Ethiopia's emerging spatial data infrastructure. By strengthening the human capacity necessary for responsible land governance, these efforts contribute directly to the United Nations', specifically SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), SDG 14 (Life below water), and SDG 15 (Life on Land).

The benefits of projects like the ones presented here are manifold. Capacity-building is an established method to address challenges that require long-term sustanabiliy. The target country is enabled to train the people it needs to address the problems. Training material created in such a project are distributed between the universities and help improve their teaching. All involved teachers can provide their students with perspectives from other countries. This helps students to understand the more general implications of the materials they are learning.

The eight universities involved in the project plan to continue the cooperation, not necessarily in this large group. Information on exchange and scholarship programs was already provided. The personal bonds between the project participants, strengthend during the trainings and also the cultural events associated with the workshops and trainings will enable better collaboration and easier communication for joint research and joint poject proposals.

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reviewed paper

Transforming Environmental Planning through Data-driven Structural Models and AI: Chances for Climate-Responsive Urban Landscapes in Riyadh, Saudi Arabia

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1 ABSTRACT

As climate change intensifies extreme heat, increases natural hazards and accelerates ecological decline, cities around the world are facing environmental pressure, creating an urgent need for climate-adaptive and data-driven landscape planning. Recent advances in earth observation and artificial intelligence (AI) now enable ecological and microclimatic processes to be analyzed at high spatial and temporal resolution, opening new pathways for evidence-basedlandscape strategies. However, despite rapid technological progress, it remains unclear how AI and data-driven methodologies can be operationalized within real-world planning to address climate-induced pressures at meaningful spatial scales. Focusing on the metropolitan context of Riyadh, Saudi Arabia, as a rapidly urbanizing city exposed to extreme climatic stress, our latest research shows that AI-enabled and data-driven landscape analytics enhance climate-adaptive planning by translating diffuse environmental signals into actionable design knowledge. Using the emerging frameworks UrbAlytics for remote-sensing-based environmental assessment, nAIture for nature-centered landscape modelling and LIM landscape information modelling®, we show how suchframeworkscouldenhance early detection of microclimatic stress, refine vegetation and land-cover diagnostics, and supportbetter informed, scenario-based design of green-infrastructure interventions. These applications support differentiated risk diagnostics, canopy-performance estimation, and microclimate-responsive spatial strategies. Taken together, these findings show that AI and data-driven models offer immediate opportunities to raise analytical precision, accelerate planning timelines and support more resilient, nature-positive and climate-adaptive urban landscapes when embedded in interdisciplinary expertise and critically interpreted.

Keywords: AI-enabled landscape analytics, Climate-adaptive landscape planning, Nature positiv , Data-driven environmental planning, Urban planning

2 INTRODUCTION

Urbanization and climate change are placing increasing stress on cities worldwide, intensifying the need for adaptive, resilient, and sustainable urban planning approaches. Over the past decade, the combined effects of rapid urban growth, rising temperatures, and environmental degradation have amplified challenges such as extreme heat, urban heat-island effects, and declining ecological performance of urban spaces (Wamsler et al., 2013). These pressures are particularly acute in fast-growing metropolitan regions, where planning decisions must respond to complex climatic dynamics under conditions of uncertainty (IPCC, 2022). As a result, conventional planning instruments increasingly struggle to cope with the speed, scale, and interconnectedness of contemporary climate-related risks (Zong et al., 2023).

In recent years, advances in remote sensing, geospatial analytics, and artificial intelligence (AI) have significantly expanded the analytical capacities available to urban and landscape planners (Weng et al., 2024). High-resolution satellite imagery, microclimatic modelling, and machine-learning techniques now enable the quantification of environmental processes at spatial and temporal resolutions that were previously unattainable (Lyu et al., 2022; Zhao et al., 2025). These developments offer new possibilities for early risk detection, scenario modelling, and evidence-based evaluation of planning interventions. However, despite the growing availability of AI-enabled tools, their integration into planning practice remains uneven and methodologically under-specified. While expectations regarding their transformative potential are high, there is still limited empirical clarity on how such tools can be systematically embedded into real-world planning workflows in a way that improves decision-making, transparency, and environmental performanceparticularly in large, climatically stressed urban contexts (Salhi et al., 2025).

To address this gap, we investigated the application of AI-supported analytical workflows for the assessment and strategic planning of urban green infrastructure using internal case studies developed by the international landscape consultancy LAND. Focusing on Riyadh, Saudi Arabia, we examined how remote sensing, vegetation indices, and data-driven environmental analyses can be combined to support scalable, consistent,

and decision-ready evaluations of urban greenery in an arid metropolitan context. The analysis critically explores both the opportunities and the limitations of these approaches, with particular attention to their methodological robustness, practical applicability, and relevance for climate-adaptive landscape planning.

This paper presents a structured examination of newly developed frameworks for urban green infrastructure analysis and discusses their potential contribution to sustainable and climate-resilient landscape planning. It first outlines the methodological framework, then presents key analytical results, and finally reflects on the implications, limitations, and transferability of data-driven and AI-enabled planning approaches for practice and future research.

3 MATERIALS AND METHODS

The study proposes two methodological approaches and provides an argumentative justification for their applicability to nature-positive and climate-responsive planning in arid cities such as Riyadh. Those frameworks were developed within long-term research projects at LAND, arguing for their validity as methodological approaches advancing nature-positive and climate responsive planning, and justifying their relevance for the planning in arid urban contexts such as Riyadh. In this way, a transparent discussion of methodological choices is covered prior to empirical application, with their implementations briefly presented in the Results section.

Based on a multi-year, systematic combination of applied design practice and scientific inquiry, the LAND Research Lab leadsresearch initiatives responding to increasing demands for quantifiable, scalable, and comparable evidence in landscape and urban planning, particularly under conditions of climate stress and rapid urban transformation. With LIM landscape information modelling® (LIM), the LAND Research Lab has developed a tool based conceptually on the principles of Building Information Modelling (BIM), which has been adapted to landscape systems. Its methodological contribution lies in structuring spatial, ecological, and climatic data within an integrated information model that supports scenario building and long-term monitoring.

Drawing from this tool, analytical frameworks resulting from LAND's research follow a shared design logic: they translate heterogeneous environmental, spatial, and socio-technical datasets into decision-support information that can be integrated into strategic planning processes (LAND, 2024a).

Specifically, two interrelated frameworks form the methodological basis of this study: nAIture, and UrbAlytics. While each framework addresses different analytical scales and questions, they are designed to operate as a coherent methodological ecosystem rather than isolated instruments. conceptually on the principles of BIM and adapts them to landscape systems. Its methodological contribution lies in structuring spatial, ecological, and climatic data within an integrated information model that supports scenario building and long-term monitoring. nAIture focuses on AI-assisted sustainability assessments by linking environmental indicators with machine-learning-supported pattern recognition (LAND, 2024). The tool enables the evaluation of landscape performance across ecological and climatic dimensions, supporting evidence-based prioritization in planning decisions. UrbAlytics addresses urban climate dynamics, with a particular emphasis on heat exposure and mitigation potential. It combines remote sensing, spatial analytics, and statistical modeling to identify spatial patterns of thermal stress and evaluate intervention strategies at multiple urban scales (LAND, 2023). In this paper, these tools are introduced at a conceptual and methodological level only due to confidentiality; their methodologyand analytical outputs are presented in detail in the Results section.

The selection of Riyadh as the contextual anchor for this methodological argument is motivated by three interrelated factors. First, Riyadh is characterized by extreme climatic conditions, where heat stress, water scarcity, and limited vegetation cover pose structural challenges to conventional planning approaches (Suhail et al., 2025). Second, the city's rapid spatial expansion requires scalable and transferable planning methods capable of operating across large territories and multiple governance levels (Aldegheishem, 2023). Third, the availability of high-resolution spatial and environmental data creates a favorable environment for advanced analytical and AI-supported planning tools (Wang et al., 2025). Against this background, the methodological framework proposed in this study argues that data-driven and AI-assisted landscape planning is not merely an optional enhancement but a necessary evolution of planning practice in arid megacities (Xing et al., 2024). The LAND analytical ecosystem is therefore positioned as a means to bridge the gap between

strategic visions, quantitative environmental evidence, and implementable planning actions. The methodology deliberately prioritizes argumentative clarity and conceptual transparency over immediate empirical validation. While this limits the ability to draw site-specific performance conclusions at this stage, it enables a clearer assessment of methodological transferability and planning relevance.

4 RESULTS

Building on LAND's long-standing experience in landscape and urban planning (LAND, 2025a), the results presented in this chapter document the development and application of two data-driven analytical frameworks nAIture and UrbAlytics and their capacity to generate spatially explicit, operational outputs for climate-responsive planning. The section focuses on the structure, analytical components, and resulting indicators produced by these frameworks, without interpretative evaluation highlighting that detailed information can't be shared due to confidentiality and ongoing projects.

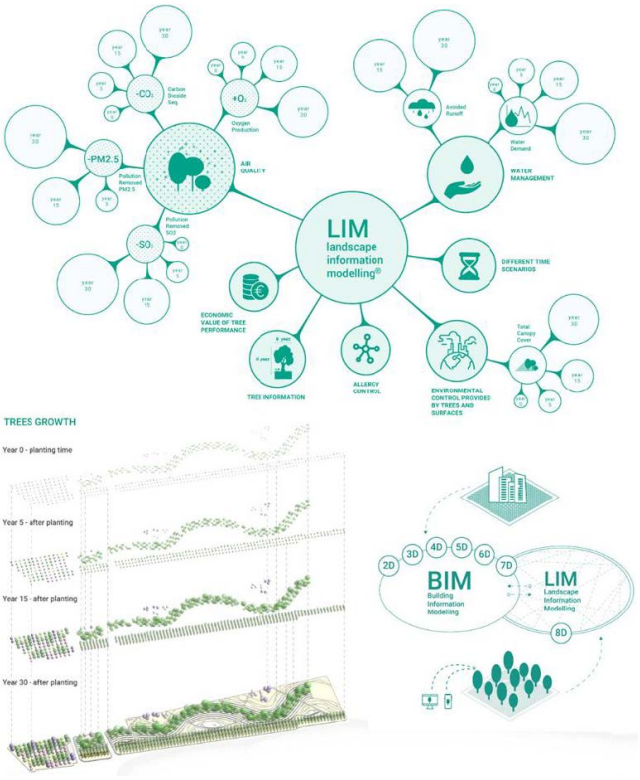


Fig. 1: Overview of LIM parameters and outputs (LAND, 2025)

4.1 NAIture

The nAIture methodology is conceived as an extension of LAND's proprietary Landscape Information Modelling (LIM) framework, advancing it from a primarily evaluative and scenario-based system toward a predictive, AI-assisted planning methodology (LAND, 2024). While LIM provides a structured, BIM-derived data environment for quantifying landscape performance over time (LAND, 2022), nAIture introduces AI as a means to interpret complex environmental datasets, identify patterns, and support anticipatory decision-making in landscape and urban planning. The methodological premise of nAIture is that landscapes are dynamic socio-ecological systems whose performance cannot be sufficiently captured through static assessments alone. Instead, planning requires iterative feedback loops between data acquisition, modelling, simulation, and design intervention. nAIture operationalize this premise by combining multi-scale environmental data with machine learning techniques to enable adaptive and scenario-responsive landscape planning. The methodological workflow of nAIture is based on the integration of heterogeneous spatial and environmental data sources into a unified modelling environment. Core data inputs include: Satellite remote sensing data, providing continuous, large-scale coverage for indicators such as land surface temperature, vegetation indices, and surface permeability. As well as Multispectral and thermal drone imagery, enabling high-resolution, site-specific analysis of vegetation vitality, water stress, and microclimatic variation. In addition In situ environmental sensors, supplying temporally dense data on parameters such as air temperature, humidity, soil moisture, and radiation and contextual planning and

design data derived from LIM, including land-use scenarios, planting strategies, materiality, and temporal growth assumptions (LAND, 2024a). All datasets are spatially harmonized and aligned to allow cross-scale analysis, ensuring consistency between regional remote sensing data and fine-grained local measurements. AI within nAIture is applied in a task-specific and problem-driven manner rather than as a universal solution. Machine learning models are used to process large and heterogeneous datasets to fulfil three closely interrelated analytical functions: First, AI-based classification and regression techniques are employed to extract key environmental indicators, including thermal and water stress, evapotranspiration, air-quality-related ecosystem services, and pollinator attractiveness, by integrating remote sensing data with in-situ sensor measurements. Second, through the analysis of historical and real-time datasets, machine learning algorithms identify spatial and temporal patterns in landscape performance, forming the basis for predictive modelling. This enables planners to anticipate how alternative design or management interventions may influence microclimatic conditions, water performance, and ecosystem services under different climate scenarios. Finally, the derived indicators are reintegrated into the LIM framework, where they support the simulation and comparison of alternative design and management scenarios. In this context, AI functions as a decision-support mechanism that highlights trade-offs and synergies between competing objectives, thereby strengthening evidence-based planning while preserving professional judgement., and threshold effects, thereby strengthening evidence-based decision-making.

Importantly, nAIture follows a human-in-the-loop approach: AI does not replace planning expertise but augments professional judgement by making complex interdependencies visible and comparable. Within the broader planning discourse, nAIture positions itself as a bridge between data-driven environmental analysis and design-led landscape planning (LAND, 2024a).

4.2 UrbAlytics

The UrbAlytics framework was applied to assess urban heat dynamics and the microclimatic performance of Blue and Green Infrastructure at the city scale (Mantente and Castellazzi, 2023). As an experimental sub-project of the H2020-funded project AI4Copernicus aiming to bridge Artificial Intelligence with Earth Observations, the methodology was tested using the metropolitan areas of Milan and Naples as pilot case studies (ibid., 2023).Land Surface Temperature was modeled using multispectral satellite data, enabling the derivation of Surface Urban Heat Island patterns for multiple summer seasons. These outputs were aggregated to capture both intra-annual variability and longer-term thermal trends. The resulting spatial datasets reveal consistent patterns of elevated surface temperatures associated with dense urban fabrics and impervious surface coverage. Based on the LST-derived outputs, a composite Heatwave Potential Risk Index was generated. This index integrates three analytical dimensions: heat intensity, population exposure and spatial vulnerability related to urban morphology. The resulting maps provide a relative representation of heat-related risk across the urban fabric. To quantify vegetation-related cooling effects, tree-cover density and land-cover data were classified into 20 categories of Blue and Green Infrastructure. For each category, a Microclimatic Performance Index was calculated based on biophysical parameters, including shading capacity, evapotranspiration potential and surface reflectance. This allowed for a comparative assessment of different vegetation typologies and their contribution to urban cooling.

An additional analytical layer focused on Park Cool Island effects. Green spaceswere evaluated based on size, spatial configuration and structural characteristics. Their cooling performance was assessed by intersecting park extents with multi-year summer averages of Surface Urban Heat Island values (2018-2022). The analysis identified areas that consistently exhibit lower surface temperatures relative to their surroundings. The result of the UrbAlytics workflow (as seen in figure 2) is the development of a scalable, automated analytical pipeline designed to support climate adaptation planning across different urban contexts. A decision-support module is currently being developed to link spatial heat-risk patterns with a database of Nature-Based Solutions. This module enables the context-specific selection of adaptation measures based on spatial characteristics and environmental performance indicators.

The automated processing chain and the reliance on transferable Earth observation data allow for application beyond the initial case studies, supporting comparative analyses and evidence-based decision-making at the city scale (LAND, 2023).

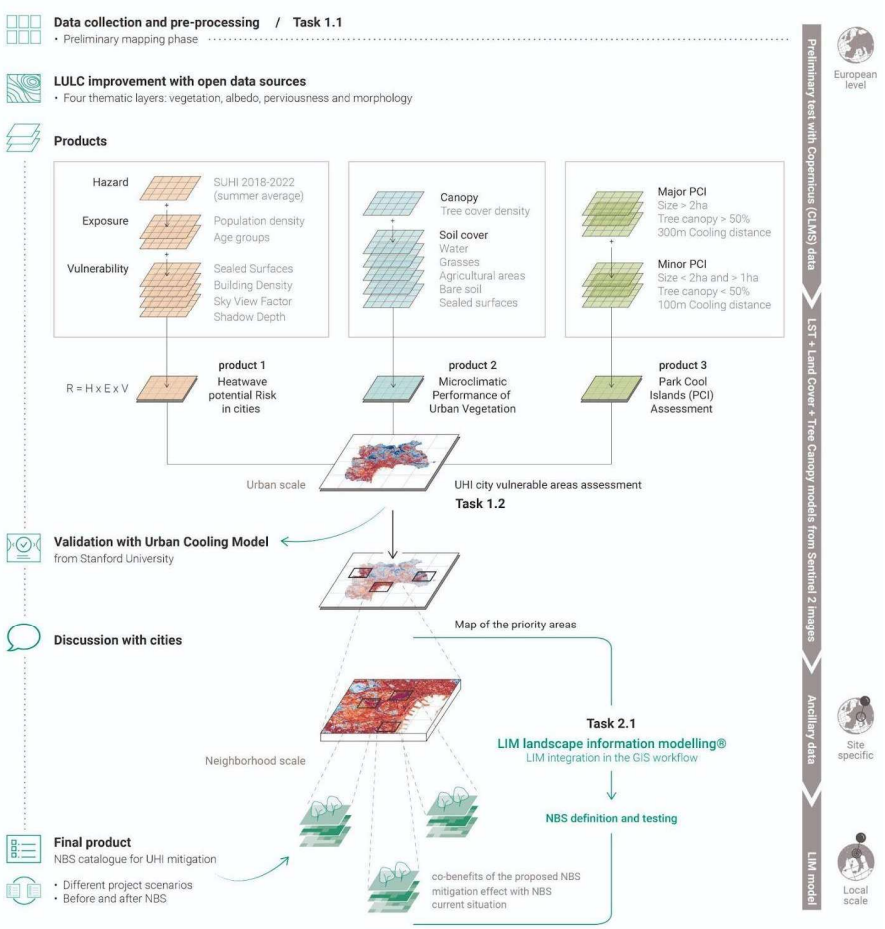


Fig. 2: Al4C Methodology Overview UrbAlytics (Mantente and Castellazzi, 2023)

5 CONTEXTUAL JUSTIFICATION: RIYADH AS A LABORATORY FOR DATA-DRIVEN ENVIRONMENTAL PLANNING

Landscapes shaped by extreme climatic conditions provide a critical testing ground for the advancement of contemporary landscape and urban planning methodologies. In such environments, the limits of conventional design-led approaches become particularly evident, while the need for anticipatory, evidence-based decision-making increases (Kenny, 2020). Arid metropolitan regions, characterized by persistent heat stress, limited water availability, and rapid spatial transformation, therefore offer a compelling context in which to examine the relevance of data-driven and AI-supported planning frameworks (Eshraghi et al., 2024).In this regard, Riyadh constitutes a particularly instructive planning context. As stated above, the city is undergoing accelerated urban growth while simultaneously facing severe climatic pressures that demand early-stage environmental assessment and long-term performance-oriented planning (Alajizah et al., 2024). These conditions challenge established planning routines, which often rely on descriptive analysis and qualitative judgement, and instead require methods capable of integrating large-scale environmental data, modelling spatial dynamics, and comparing alternative scenarios within compressed decision-making timelines (Drescher and Skoyles, 2024).

At a broader scale, Saudi Arabia is currently experiencing a fundamental shift in its planning paradigm, driven by the need to reconcile rapid development with environmental resilience and public well-being. This transition can be interpreted as comparable in ambition and societal relevance to the European Volkspark movement of the early twentieth century, which emerged in response to industrialization and deteriorating urban environmental conditions (Kipar et al., 2025). Within this context, initiatives such as the Green Riyadh program, anchored within the broader framework of Saudi Vision 2030, exemplify a state-led commitment to embedding large-scale green infrastructure, climate adaptation, and public health objectives into contemporary urban development, thereby operationalizing this paradigm shift at the metropolitan scale (RCRC, 2019). In both contexts, strategic investment in public open space reframes landscape infrastructure

as a collective response to systemic pressures, positioning green and blue spaces as essential components of environmental justice, public health, and social cohesion rather than as purely recreational amenities.

Within this transformation, Riyadh functions as a laboratory for exploring how data-driven and AI-supported planning tools can operate not merely as supplementary analytical aids but as structuring elements of the planning process itself. Persistent heat stress, limited water availability and rapid spatial expansion generate environmental dynamics that are highly heterogeneous yet are commonly addressed through planning routines that rely on descriptive analysis, expert judgement and static design assumptions. Under such conditions, qualitative assessments and generalized spatial categories are insufficient to capture the magnitude, distribution and interaction of climatic stressors across the urban fabric.

The environmental processes are characterized by complex relationships between land cover, surface materials, urban morphology, vegetation structure and atmospheric conditions. These interactions operate at spatial and temporal resolutions that exceed the analytical capacity of conventional planning tools. As a result, critical factors such as localized heat exposure, differential cooling effects of green infrastructure typologies, or cumulative impacts of incremental urban growth remain poorly represented in decision-making processes. At the same time, rapid urban transformation places planning authorities under increasing pressure to evaluate alternative development pathways within short timeframes and across large spatial extents. This combination of scale, complexity and time constraint necessitates methods capable of systematically integrating heterogeneous environmental datasets, modelling spatial dynamics and enabling comparative scenario analysis. Data-driven and AI-supported approaches address these requirements by facilitating the automated processing of large-scale Earth observation data, the generation of spatially explicit indicators and the consistent evaluation of planning alternatives. Rather than replacing design-based planning, such methods provide an analytical foundation that allows environmental performance to be quantified, compared and monitored over time.

The advantages of this planning approach become evident when examining recent large-scale developments involving LAND in Riyadh, such as the Concept Masterplan forEXPO 2030(LAND, 2025) and the realization of Al Urubah Park (LAND, 2023b). Both projects are characterized by extensive spatial scope, ambitious environmental targets, and stringent time constraints, creating conditions in which conventional iterative design processes reach their practical limits.In the case of the project site covering more than 400 km² according to internal documentation, the scale and urgency of planning required a consistently digital workflow. Parametric modelling and AI-assisted analyses were embedded across concept development, spatial assessment, and visualization (LAND, 2025).

A comparable logic underpins the planning of Al Urubah Park, a major public open-space project in an arid urban environment. Here, the central challenge lies in providing microclimatic comfort under conditions of extreme heat and water scarcity. To address this, the design process relied on remote sensing, satellite imagery, and AI-based land-cover classification to generate detailed, spatially explicit information on vegetation distribution, canopy density, and surface characteristics (LAND, 2024a). These datasets were combined with performance-oriented models to estimate shading effects, evapotranspiration potential, and thermal behavior, allowing planting concepts, irrigation strategies, and spatial configurations to be informed by quantifiable environmental indicators rather than solely by conventional design assumptions (LAND, 2025).

Taken together, these examples illustrate how AI and data supported analytical frameworks enable earlier, more precise, and more scalable assessment of environmental conditions in demanding planning contexts. They demonstrate that those methods can enhance the capacity of planning processes to respond to climatic stress, provided that their outputs are interpreted within an interdisciplinary framework and combined with ecological expertise and contextual knowledge. Overalla broader shift in contemporary planning practice is required: from predominantly descriptive approaches toward methodologies that integrate environmental data, spatial modelling, and simulation to support anticipatory and evidence-based decision-making. Within this transition, the data-driven frameworks presented in this studyare positioned not as universal solutions, but as adaptable methodological propositions capable of supporting climate-responsive landscape planning in arid metropolitan regions.

6 DISCUSSION

This study examines how data-driven and AI-supported analytical frameworks can be systematically operationalized within climate-adaptive landscape planning, using the metropolitan region of Riyadh as a representative case of an arid city undergoing rapid spatial transformation.The results demonstrate that AI-enabled workflows such as UrbAlytics, nAIture, and LIM landscape information modelling® can substantially enhance the analytical depth, spatial resolution, and scalability of environmental assessments. Rather than functioning as isolated technological add-ons, these tools operate most effectively when embedded within an integrated planning logic that links environmental data, spatial modelling, and design decision-making. A central contribution of this study is the demonstration that climate-sensitive, data-driven planning tools can be developed as transferable methodological frameworks rather than as context-specific prototypes. The results show that AI-supported analytics enable the systematic integration of climatic and ecological sensitivity into planning workflows at multiple spatial scales, using globally available environmental data. While applicable across diverse urban contexts, these tools are particularly effective in arid metropolitan regions, where pronounced environmental heterogeneity and extreme climatic stress require spatially explicit, performance-oriented analysis to support robust planning and design decisions.

The results show that the integration of Earth observation data, vegetation indices, and machine-learning-based classification enables a more differentiated understanding of land cover, canopy performance, and microclimatic stress patterns. This finding aligns with recent literature highlighting the need for quantitative, spatially explicit diagnostics to support climate-responsive planning under conditions of uncertainty and complexity (Weng et al., 2024; Drescher and Skoyles, 2024). In the context of Riyadh, where thermal exposure and cooling potential vary sharply across short distances, such analytical precision is not merely advantageous but essential. This represents a qualitative shift from descriptive assessments toward performance-oriented evaluation, supporting earlier and more informed decision-making in the planning process. Another key insight emerging from this study concerns the scalability of data-driven planning approaches. Riyadh's rapid spatial expansion and the scale of its development initiatives place significant pressure on planning authorities to evaluate alternative scenarios across large territories and within compressed timeframes. The findings indicate that those workflows are particularly well suited to these conditions, as they enable automated processing of large datasets, consistent application of analytical criteria, and comparative evaluation of multiple planning scenarios. Importantly, the study does not suggest that AI replaces design expertise. Instead, the results underscore its role as an enabling infrastructure that allows environmental performance to be quantified, compared, and monitored over time. The discussion further highlights Riyadh's relevance as a laboratory for methodological innovation in climate-adaptive landscape planning. At a broader scale, the findings can be situated within Saudi Arabia's ongoing shift in planning paradigms, exemplified by large-scale initiatives such as the Green Riyadh program under Saudi Vision 2030 (RCRC, 2019). Comparable in ambition to historical European movements that repositioned public open space as a response to systemic environmental pressures, these initiatives frame landscape infrastructure as a central component of public health, environmental resilience, and social well-being (Kipar et al., 2025). Within this transformation, the tools examined in this study illustrate how those methodologies can contribute to operationalizing strategic goals by linking policy ambitions with quantifiable environmental evidence. However, the study also highlights important limitations. AI-supported planning depends critically on data quality, model assumptions, and interpretive expertise. Spectral uncertainty, transferability of models across contexts, and the risk of oversimplifying ecological processes remain significant challenges. Moreover, issues related to data governance, transparency, and accountability become increasingly salient as AI-based systems are embedded in planning practice. Addressing these issues is essential for ensuring the robustness and trustworthiness of AI-assisted planning systems, particularly in the context of smart city infrastructures (Weng et al., 2024). This requires interdisciplinary collaboration and critical oversight, reinforcing the argument that these tools should augment not replace ecological knowledge and design judgement. Taken together, the findings position data-driven and AI-supported landscape planning as a necessary methodological rather than a discretionary technological enhancement. While the study deliberately prioritizes conceptual clarity and methodological positioning over exhaustive empirical validation, it provides a structured framework for integrating AI-supported analytics into real-world planning workflows. Future research should focus on longitudinal evaluation of implemented interventions,

comparative studies across different climatic regions, and deeper investigation into governance mechanisms that ensure ethical and transparent use of data-driven tools and AI in planning.

Overall, this study contributes to the growing body of research that frames climate-adaptive planning as an interdisciplinary, data-informed process. By demonstrating how AI-enabled tools can translate complex environmental data into decision-relevant knowledge, it underscores their potential to support more resilient, nature-positive urban landscapes provided that their application remains critically interpreted, context-sensitive, and embedded within professional planning expertise.

7 CONCLUSION

This paper set out to examine how data-driven and AI-supported analytical frameworks can be systematically operationalized within climate-adaptive landscape planning, using Riyadh as a representative case of an arid metropolis undergoing rapid spatial transformation. It demonstrates that AI and data-driven frameworks such as UrbAlytics, nAIture, and LIM landscape information modelling® are capable of translating heterogeneous environmental data into decision-relevant knowledge that can meaningfully support planning processes under conditions of climatic stress, spatial complexity, and time pressure. Rather than functioning as isolated technological enhancements, these frameworks operate most effectively when embedded within an integrated planning logic that links environmental data acquisition, modelling, simulation, and design intervention through iterative feedback loops.A central contribution of this research lies in advancing the understanding of those frameworks not as autonomous planning solution, but as methodological infrastructures that strengthens evidence-based reasoning in landscape and urban planning. By integrating Earth observation data, machine-learning-supported analytics, and structured information modelling, the proposed approaches enable environmental performance to be assessed, compared, and anticipated across multiple spatial and temporal scales. This represents a shift from predominantly descriptive and static assessments toward performance-oriented and predictive planning practices. In the context of arid megacities, where extreme heat, water scarcity, and ecological vulnerability interact in highly heterogeneous ways, such analytical precision is not merely advantageous but essential for informed decision-making.

The case of Riyadh illustrates how data-driven planning frameworks can address challenges that exceed the analytical capacity of conventional planning instruments. Rapid urban expansion, ambitious environmental targets, and compressed development timelines require methods that are scalable and capable of operating across large territories. The analytical ecosystems examined in this study demonstrate their suitability for these conditions by enabling the automated processing of large-scale datasets and the consistent comparison of alternative planning scenarios. Importantly, these capabilities do not replace design expertise or ecological judgement. Rather, the frameworks function as decision-support systems that enhance transparency, reveal trade-offs, and make complex environmental interdependencies legible to planners and stakeholders.

Beyond the specific case of Riyadh, the methodological implications of this research extend to climate-adaptive planning more broadly. The frameworks presented here are conceived as transferable approaches based on globally available data sources and adaptable modelling logic, making them applicable across diverse urban contexts facing increasing climatic uncertainty. At the same time, their effectiveness depends critically on data quality, model assumptions, and interpretive expertise, highlighting the continued importance of governance, transparency, and interdisciplinary oversight.

Taken together, the findings support a broader reframing of contemporary planning practice. Data-driven and AI-assisted methodologies should not be understood as optional technological add-ons, but as a necessary evolution of planning in response to the scale and complexity of climate-related challenges. Their primary value lies in augmenting human expertise by enabling anticipatory analysis, systematic scenario evaluation, and the alignment of spatial design decisions with long-term climate resilience and nature-positive objectives.

Future research should build on this foundation through longitudinal evaluation of implemented interventions, comparative studies across climatic regions, and deeper integration of social, governance, and equity dimensions into AI-supported planning frameworks. As cities continue to confront accelerating environmental change, the critical and responsible integration of AI into planning workflows will play a decisive role in shaping resilient, livable, and sustainable urban landscapes.

8 DATA AVAILABILITY STATEMENT

The data presented in this study is not available due to ongoing projects and confidentiality limitations.

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Unsichtbare Gruppen – sichtbare Effekte: Eine Untersuchung potenzieller Auswirkungen von Untererfassungen in deutschen Melderegisterdaten und Meldepflichtsbefreiungen auf gängige visuelle Darstellungen von Bevölkerungsgrößen in SDSS

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1 ABSTRACT

Datenbasierte räumliche Entscheidungsunterstützungssysteme (Spatial Decision Support Systems, kurz: SDSS) besitzen ein hohes Potenzial kommunale Planungs- und Entscheidungsprozesse effizienter zu gestalten. Ihr Einsatz ermöglicht eine umfängliche Erfassung, automatisierte Analysen und objektive Bewertungen von Kriterien – allerdings nur, wenn die zugrunde liegenden Daten von hoher Qualität und frei von Verzerrungen sind, und der Algorithmus an allen kritischen Stellen sorgfältig konzipiert wurde (Sugumaran und DeGroote, 2010).

Aggregierte kommunale Melderegisterdaten sind hierbei eine häufig genutzte und zuverlässige Quelle mit überwiegend standardisierten Attributen, die auf verschiedenen räumlichen Granularitäten Informationen über die lokale Bevölkerung bereithalten (Mayer und Memmel, 2026a). Diese Daten werden von den kommunalen Stellen sorgfältig gepflegt und verarbeitet, sind jedoch aus praktischen und systembedingten Gründen nicht völlig frei von Verzerrungen. Eine solche Verzerrung ist der sogenannte Untererfassungs-Bias, der bedeutet, dass nicht alle Einwohnerinnen und Einwohner einer Kommune im Melderegister erfasst sind. Dies betrifft häufig marginalisierte Gruppen wie wohnungslose Menschen oder Personen ohne legalen Aufenthaltsstatus (BMAS, 2022 und Fisher, 1999), aber auch NATO-Angehörige (BfJ, 2020).

Diese Arbeit untersucht am Beispiel der Stadt Kaiserslautern, ob und wie der Untererfassungs-Bias quantifiziert werden kann. Unter Anwendung einer softwarebasierten Exploration werden die potenziellen Auswirkungen weiterer Verarbeitungslogiken oder Konzepte auf die Genauigkeit und Verlässlichkeit von SDSS-Visualisierungen betrachtet. Zudem wird analysiert, wie Datenaggregation auf verschiedenen räumlichen Ebenen diese Effekte verstärken oder abschwächen. Häufig genutzte Darstellungsformen wie Balkendiagramme und Choroplethenkarten werden herangezogen, um diese Dynamiken zu illustrieren.

Keywords: Bias, Spatial Decision Support System, Bevölkerungsdaten, Visualisierungen, Untererfassungen

2 HINTERGRUND

Im Zuge der digitalen Transformation finden auch in Behörden immer mehr datenbasierte SDSS Anwendung. Ziel dieser Systeme ist es, kommunale Akteurinnen und Akteure bei einer effizienten, fundierten sowie möglichst objektiven und transparenten Entscheidungsfindung zu unterstützen. Insbesondere in partizipativen und adaptiven Planungsprozessen erweisen sie sich als hilfreiches Werkzeug: Im Kontext der Raumplanung aufgefasst als heuristischer und wissensgenerierenem Prozess können sie den Austausch zwischen den Beteiligten fördern, Handlungsoptionen systematisch zu prüfen und einen zweiseitigen Lernprozess ermöglichen (Nollert, 2013), auch wenn ihre Ausgaben teilweise mit Unsicherheiten behaftet sind.

2.1 Spatial Decision Support Systems

Räumliche Entscheidungsunterstützungssysteme umfassen technische Systeme, die auf der Verarbeitung georeferenzierter Daten basieren und mithilfe unterschiedlicher Technologien entscheidungsrelevante Ergebnisse generieren. Der resultierende Output reicht von der strukturierten Aufbereitung und Visualisierung heterogener Informationen über Analyse- und Prognosewerkzeuge bis hin zu hochkomplexen, interdependenten Berechnungen und Szenarioanalysen (Sugumaran und DeGroote, 2010).

Diese kommen potenziell in nahezu allen kommunalen Handlungsfeldern zum Einsatz, etwa bei der Verkehrssteuerung, der Standort- und Flächenplanung oder beim Monitoring von Klimaanpassungsmaßnahmen. Abhängig von Anwendungsdomäne und Zielsetzung greifen diese SDSS auf sehr unterschiedliche Datenquellen zurück, die von demographischen Informationen (z.B. Altersverteilung, über Fahrplandaten des ÖPNV bis hin zu Echtzeit-Sensordaten reichen.

Ein weiterer zentraler Aspekt bei der Betrachtung von SDSS sind die eingesetzten Technologien. Diese umfassen unter anderem Verfahren zur Datenaufbereitung und- integration, Visualisierungstechniken, mathematische und statistische Modelle, Optimierungsalgorithmen sowie Methoden des maschinellen Lernens und des DeepLearnings.

2.1.1 Visuelle Darstellungen

Eine häufig genutzte und zugleich intuitiv verständliche Form der Visualisierung raumbezogener Daten stellen Kartendarstellungen dar. Insbesondere Choroplethenkarten finden Anwendung, wenn quantitative Daten auf definierte räumliche Flächeneinheiten aggregiert vorliegen. Choroplethenkarte visualisieren Merkmalsausprägungen, indem begrenzte Gebiete entsprechend der Merkmalsausprägung farblich (oder durch Muster) differenziert dargestellt werden (Dent et al. 2009).

Im vorliegenden Beitrag liegt der Fokus auf dieser Darstellungsform in Kombination mit einem ergänzenden Balkendiagramm (vgl. Abb. 1), das eine vergleichende Einordnung der räumlichen Ausprägungen ermöglicht. Neben der Wahl geeigneter Klassifikationsverfahren kommt der Auswahl der Farbkodierung eine besondere Bedeutung zu, da sie maßgeblich die Wahrnehmbarkeit, Interpretierbarkeit und potenzielle Verzerrung der dargestellten Informationen beeinflusst.

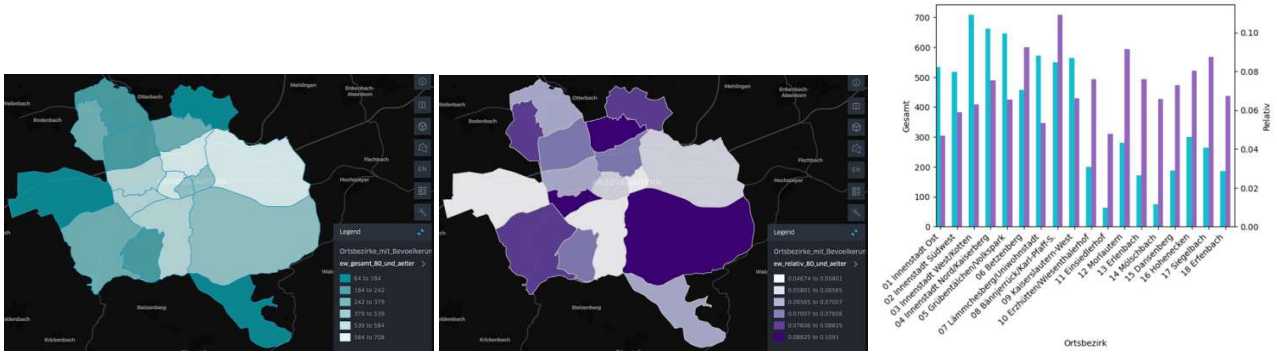


Abb. 1: Gängige Visualisierungen von Bevölkerungszahlen. Hier die über 80-Jährigen in Kaiserslautern auf Ortsbezirksebene im Jahr 2022: Gesamtanzahl (türkis) und relativ zur Gesamtbevölkerung des jeweiligen Ortsbezirks (lila) als Choroplethenkarten und Barchart mit zwei Y-Achsen. (Eigene Darstellung basierend auf von der Stadt Kaiserslautern bereitgestellten Daten.)

Unabhängig von der konkreten Visualisierungsform lässt sich festhalten, dass die Aussagekraft und Qualität der erzeugten Outputs wesentlich von der Verfügbarkeit, Nutzbarkeit und Güte der zugrunde liegenden Daten abhängt (Mayer und Memmel, 2026a).

2.1.2 Datenbeschaffung und -integration

Datenbasierte räumliche Entscheidungsunterstützungssysteme (SDSS) greifen in Abhängigkeit vom Anwendungskontext auf eine Vielzahl unterschiedlicher Datenquellen zurück. In kommunalen Anwendungsszenarien stammen diese Daten sowohl aus internen als auch aus externen Quellen, die sich hinsichtlich Format, Aktualität und räumlicher Granularität erheblich unterscheiden. Ein zentraler Zugangsweg ist die automatisierte Bereitstellung über standardisierte Programmierschnittstellen (Application Programming Interfaces, APIs), die eine regelmäßige oder auch echtzeitnahe Aktualisierung von Daten, etwa aus Sensor- oder Fachsystemen, ermöglichen. Ergänzend erfolgt die Datenbereitstellung häufig projekt- oder anlassbezogen durch kommunale Fachämter oder externe Institutionen. Die Integration dieser heterogenen Datenquellen erfordert insbesondere die Harmonisierung räumlicher und zeitlicher Bezugssysteme, die Vereinheitlichung von Attribut- und Bedeutungsstrukturen sowie die Berücksichtigung von Metadaten und rechtlicher Rahmenbedingungen. (Mayer und Memmel 2026a).

2.1.3 Datenqualität und Transparenz

Die Qualität der Ergebnisse von SDSS hängt maßgeblich von der Qualität der zugrunde liegenden Daten ab. Die Beurteilung der Datenqualität setzt ein hohes Maß an Transparenz hinsichtlich der Datenerhebung, der Vorverarbeitung sowie der angewandten Transformations- und Aggregationsschritte voraus. Informationen über Erhebungsmethoden, Erhebungszeitpunkte, Vorverarbeitungsschritte sowie über potenzielle Fehlerquellen sind notwendig, um die Aussagekraft und Belastbarkeit der Daten einschätzen zu können. Fehlen derartige Angaben oder sind sie nur unzureichend dokumentiert, stellt dies selbst eine Form von

Unsicherheit dar, die das Risiko von Fehlinterpretationen erhöht. Transparenz über Datenherkunft und -verarbeitung ist daher eine zentrale Voraussetzung für die Nachvollziehbarkeit, Vergleichbarkeit und verantwortungsvolle Nutzung datenbasierter Analysen und Entscheidungsunterstützungssysteme (Mayer und Memmel 2026b).

Nicht in allen Fällen ist es Entwicklerinnen und Entwicklern von SDSS möglich, belastbare Aussagen zur Datenqualität zu treffen, insbesondere dann, wenn Informationen zur Datenerhebung und -vorverarbeitung nicht oder nur unzureichend vorliegen. Auf diesen Fall fokussiert sich der vorliegende Beitrag, da auch das Wissen über und mögliche Auswirkungen durch fehlende oder unvollständige Informationen selbst eine relevante Form von Information darstellen. Diese sollten den Nutzenden eines SDSS transparent kommuniziert werden, um einen angemessenen Umgang mit den Outputs zu ermöglichen (Montello et al., 1998). Das Visualisieren von Unsicherheiten setzt jedoch voraus, dass diese selbst messbar oder in irgendeiner anderen Form systeamtisch bewertet werden können (MacEachren et al., 2005). In vorliegenden Fall wird jedoch auf Grundlage einer versucht sehr geringen Informationsbasis auf Attributebene versucht, potenzielle alternative Realisierungen zu erzeugen. Damit soll herausgestellt werden, dass die dargestellte Realität lediglich eine mögliche Ausprägung darstellt, da die Datengrundlage mit Unsicherheiten behaftet ist.

2.2 Bevölkerungsdaten

Bevölkerungsdaten stellen einen zentralen Indikator in vielen SDSS dar und werden auf unterschiedlichen räumlichen Aggregationsebenen genutzt. Häufig erfolgt ihre Verwendung in Kombination mit weiteren demografischen Merkmalen, wie etwa Altersstruktur, Haushaltszusammensetzung oder Nationalität. Diese Daten liefern wesentliche Informationen über die Zusammensetzung der Bevölkerung und ermöglichen es, innerhalb einer Kommune räumliche Muster zu identifizieren sowie Standorte mit spezifischen demografischen Charakteristika miteinander zu vergleichen.

Die Analyse der Altersverteilung bildet beispielsweise eine wichtige Grundlage für Prognosen des Bedarfs an Kindertagesstätten oder schulischer Infrastruktur. Ebenso ist demografisches Wissen über ältere Bevölkerungsgruppen für Anwendungen im Katastrophenschutz von Bedeutung, etwa zur Identifikation potenziell besonders vulnerabler Personengruppen. Darüber hinaus finden Bevölkerungsdaten auch in der Verkehrs- und Mobilitätsplanung Anwendung, beispielsweise zur Abschätzung von Nachfragepotenzialen oder zur Priorisierung infrastruktureller Maßnahmen.

2.2.1 Kleinräumige Bevölkerungsdaten

Bevölkerungsdaten auf gesamtkommunaler Ebene werden in Deutschland im Rahmen der amtlichen Statistik durch die statistischen Landesämter bereitgestellt und sind über entsprechende Veröffentlichungen und Datenportale zugänglich. Diese Daten basieren auf bundes- und landesrechtlich geregelten Erhebungen und dienen insbesondere der Vergleichbarkeit zwischen Kommunen sowie der Abbildung übergeordneter demografischer Entwicklungen.

Sollen Bevölkerungsdaten in kleinräumigerer Auflösung innerhalb einer Kommune genutzt werden – etwa auf Ebene von Ortsbezirken, statistischen Bezirken oder bis hin zur Baublockebene –, ist in der Regel eine direkte Anfrage bei den jeweiligen Kommunen erforderlich. Die Bereitstellung solcher kleinräumigen Daten fällt in den Aufgabenbereich kommunaler Statistikstellen. Diese haben den Auftrag, zur Unterstützung kommunaler Planungsprozesse und politischer Entscheidungsfindung räumlich differenzierte statistische Informationen aufzubereiten und zu analysieren. Um Mehrfacherhebungen zu vermeiden, greifen kommunale Statistikstellen dabei überwiegend auf Daten zurück, die bereits auf Grundlage bundesstatistischer oder landesgesetzlicher Regelungen erhoben wurden (Leischner und Khalil 2026).

2.2.2 Melderegisterdaten

Bei den kommunalen Meldebehörden liegen bereits detaillierte personenbezogene Daten vor, die sensible Informationen wie Geschlecht, Alter, Religionszugehörigkeit und Meldeadresse enthalten. Eine unmittelbare Nutzung dieser Daten in SDSS – selbst in anonymisierter Form – ist aus rechtlichen und ethischen Gründen nicht zulässig. Stattdessen müssen geeignete Verfahren zur datenschutzkonformen Aufbereitung eingesetzt werden, um den Schutz personenbezogener Informationen sicherzustellen und gleichzeitig eine sinnvolle Nutzung innerhalb eines SDSS zu ermöglichen.

Das Melderegister selbst ist jedoch nicht fehlerfrei. Es können Übererfassungen auftreten, etwa durch nicht aktualisierte Melderegistereinträge („Karteileichen“) nach Wegzug aus der Kommune, ebenso wie Untererfassungen, etwa durch nicht gemeldete Personen, die aber dauerhaft dort leben. Darüber hinaus bestehen gesetzliche Besonderheiten, die bestimmte Bevölkerungsgruppen von der Meldepflicht befreien, wie beispielsweise Angehörige der NATO-Streitkräfte oder Bewohnerinnen und Bewohnern von Seniorinnen- und Seniorenheimen. Andere Gruppen, etwa Personen ohne legalen Aufenthaltsstatus oder ohne festen Wohnsitz, melden sich meist nicht. Gleichwohl können sich auch diese Personen freiwillig melden; Wohnungslose mit dem Vermerk „OFW“ (ohne festen Wohnsitz).

Für die Erstellung vergleichbarer statistischer Auswertungen treffen die Statistikstellen bei der Datenaufbereitung bestimmte Annahmen. Personen mit Nebenwohnsitz innerhalb der Kommune, deren Hauptwohnsitz jedoch außerhalb liegt, sowie Personen, die nicht meldepflichtig sind, werden üblicherweise nicht berücksichtigt. Auf dieser Grundlage wird die sogenannte statistische Bevölkerung gebildet (vgl. Abb. 2). Sie dient der besseren Vergleichbarkeit zwischen Kommunen und verhindert Doppelzählungen, indem insbesondere Personen mit Nebenwohnsitzen ausgeschlossen werden (Deutscher Städtetag, 2019).

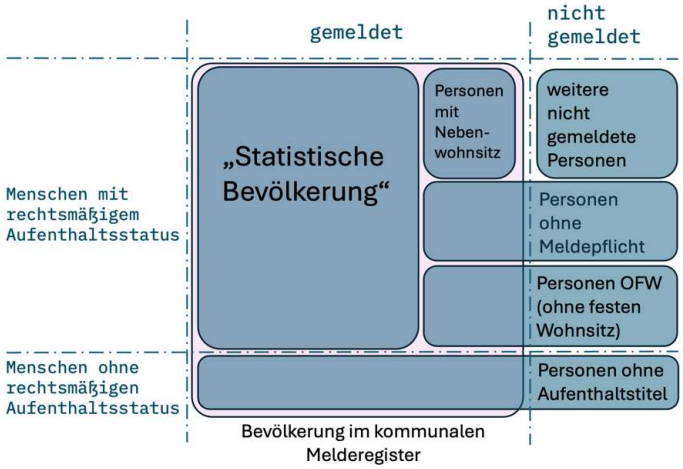


Abb. 2: Die “Statistische Bevölkerung” einer Kommune umfasst standardgemäß nur gemeldete Personen unter bestimmten Voraussetzungen. (Eigene Darstellung nach Deutscher Städtetag, 2019, und Molter, 2024)

2.2.3 Quantifizierung der Untererfassungen

Zur Untersuchung von Über- und Untererfassungen werden in ausgewählten Gemeinden und Gebäuden Stichprobenerhebungen sowohl bei den Meldebehörden als auch direkt bei den Einwohnerinnen und Einwohnern durchgeführt. Die Ergebnisse dieser Stichproben dienen der Hochrechnung registerbedingter Abweichungen und bilden eine wesentliche Grundlage für die statistische Korrektur der Melderegisterbestände. Ergänzend zur Haushaltsstichprobe erfolgt an Anschriften mit Wohnheimen und Gemeinschaftsunterkünften eine Vollerhebung. Zusätzlich werden sogenannte Nullanschriften berücksichtigt, d. h. Anschriften mit Wohnraum, an denen laut Melderegister keine Personen gemeldet sind. Diese werden gezielt in die Stichprobenziehung einbezogen, um vollständige Fehlbestände zu identifizieren und einer systematischen Untererfassung entgegenzuwirken (Statistisches Bundesamt, 2024).

Auch die Methoden des Zensus unterliegen bestimmten Einschränkungen, stellen jedoch die einzige verlässliche Vergleichsquelle dar. Zensusdaten sollten daher nicht als absolute „Wahrheit“ interpretiert werden, sondern als qualitätsgesicherte Referenz, die für die Einordnung, Validierung und Unsicherheitsabschätzung kommunaler Bevölkerungsdaten genutzt wird.

In ganz Deutschland gibt es nach Auskunft des Statistischen Bundesamts 549.103 Untererfassungen. Das entspricht 0,007% der erfassten Bevölkerung (siehe Tab. 2). In dieser Zahl sind wiederum nur Personen enthalten, die einer Meldepflicht unterliegen. Veröffentlichungen zu fehlerhaften Erfassungen erfolgen üblicherweise nur auf kommunaler Ebene. Zur Wahrung des Rückspielverbots werden keine Informationen zu Fehlerfassungen auf kleinräumiger Ebene herausgegeben.

Zusammenfassend lässt sich an diesem Punkt festhalten, dass aufgrund unzureichender Kenntnisse der zugrunde liegenden Erhebungsverfahren sowie der vorgelagerten Vorverarbeitungsschritte Bevölkerungsdaten in SDSS integriert werden können, die für den jeweiligen Anwendungszweck nur

eingeschränkt geeignet sind. Insbesondere bei der Analyse von Krankheitsinzidenzen ist die Berücksichtigung der gesamten relevanten Wohnbevölkerung erforderlich, da andernfalls erhebliche Verzerrungen der Ergebnisse auftreten können. Gleichzeitig sind die hierfür benötigten Informationen nicht in allen Fällen vollständig verfügbar, sodass methodische Ansätze erforderlich sind, die eine transparente und für die Anwenderinnen und Anwender verständlichen Nutzung der vorhandenen Daten ermöglichen.

3 METHODIK

Diese Arbeit untersucht die potenziellen Auswirkungen von Untererfassungen in Melderegistern auf gängige Visualisierungen in SDSS. Da in diesem Fall – wie in Abschnitt 2 dargelegt – kaum Vergleichsgrößen vorliegen, die eine quantitative Überprüfung der Daten erlauben, und lediglich Vermutungen über die räumliche Verteilung der Untererfassungen angestellt werden können, ist eine mathematische Analyse, beispielsweise anhand von Best- und Worst-Case-Szenarien, zwar grundsätzlich möglich, jedoch aufgrund der Vielzahl beteiligter Variablen nur sehr vage. Aus diesem Grund wurde ein explorativer Ansatz gewählt, der mithilfe eines in Python implementierten Tools die potenziellen Auswirkungen von Untererfassungen auf Choroplethenkarten und Balkendiagramme visualisierbar macht.

Die zugrunde liegende Idee besteht darin, dass eine definierte Anzahl von Untererfassungen nach bestimmten Kriterien auf den städtischen Raum verteilt wird. Jede Person, die möglicherweise nicht gemeldet oder in der Statistik erfasst ist, erhält hierbei einen zufällig zugewiesenen Wohnort. Auf diese Weise kann der von der Kommune bereitgestellte Datensatz direkt mit dem alternativ generierten Datensatz visuell verglichen werden. Für die Erstellung der alternativen Verteilungen müssen jedoch verschiedene Annahmen getroffen werden.

3.1 Annahmen und Vorgehensweise

Es bestehen Hinweise darauf, dass Personen, die nicht im Melderegister erfasst sind, nicht gleichmäßig, peripher oder zentral im Stadtraum verteilt leben, sondern, dass sich räumliche Ballungs- oder Clusterzentren bilden. Diese Annahme wird durch Vollerhebungen des Zensus in Wohnheimen sowie durch rechtliche Besonderheiten, wie die fehlende Meldepflicht in Seniorinnen- und Seniorenheimen, gestützt.

Die methodische Vorgehensweise basiert auf der Erzeugung zufälliger Punkte innerhalb der Stadtgrenzen von Kaiserslautern, die die Wohnorte potenziell nicht erfasster Personen repräsentieren. Die Punkte können beliebig im Stadtraum liegen, einschließlich Grünflächen, Straßen, Gewässern oder öffentlichen Gebäuden. Für die Analyse ist jedoch ausschließlich der übergeordnete räumliche Bezirk – entweder der Ortsbezirk oder der statistische Bezirk – relevant, sodass diese Unschärfe vernachlässigt werden kann.

Zur Untersuchung werden zwei räumliche Verteilungen berücksichtigt. Bei der (räumlichen) Gleichverteilung werden die Punkte gleichmäßig über das Stadtgebiet verteilt, wobei größere Flächen aufgrund der Verteilungsmethodik automatisch stärker berücksichtigt werden (siehe Abb. 2). Bei der Cluster-Verteilung wird zunächst eine definierte Anzahl zufälliger Clusterzentren generiert, um die herum die zufälligen Punkte lokal konzentriert und zufällig verteilt werden. Hierbei werden um die x- und y-Koordinaten der Clusterzentren gleichverteilte Zufallswerte im Bereich von –0.01 bis +0.01 um die x- und y-Koordinaten der Clusterzentren erzeugt, anschließend wird überprüft, ob die generierten Punkte innerhalb der Stadtgrenzen liegen. Für jeden erzeugten Punkt wird das jeweilige räumliche Gebiet ermittelt, um auf dieser Grundlage eine angepasste Bevölkerungsstatistik zu erstellen. (Hierbei wird jedes Mal zufällig ein Clusterzentrum gewählt. Clusterzentren, die am Rand liegen, fallen somit weniger ins Gewicht, da zufällig erzeugte Punkte im Bereich um diese häufig außerhalb der Stadtgrenzen liegen.)

Nach der Generierung aller zufälliger Punkte wird bestimmt, in welchen räumlichen Gebieten sie liegen und Visualisierungen (Choroplethenkarte und Barchart) zum direkten Vergleich erzeugt. Für die Darstellungen wird eine feste farbliche Skalierung verwendet, um die Vergleichbarkeit der resultierenden Karten sicherzustellen.

3.2 Analyseumgebung und Implementierung

Zur explorativen Analyse wurde ein Prototyp in Python umgesetzt, der mehrere spezialisierte Bibliotheken nutzt, um unterschiedliche funktionale Anforderungen abzudecken:

- Dash[1] dient als Framework zur Erstellung einer interaktiven Webanwendung und ermöglicht die benutzerfreundliche Darstellung sowie Steuerung der Analyse.
- Plotly[2] wird für die interaktive Visualisierung der Daten eingesetzt und erlaubt dynamische, explorative Grafiken.
- GeoPandas[3] erweitert die Datenanalyse um räumliche Aspekte und unterstützt die Verarbeitung und Analyse von Geodaten.
- Shapely[4] wird für geometrische Operationen wie das Berechnen, Prüfen und Manipulieren von Geometrien verwendet wird.
- Random[5] kommt zur Erzeugung von (Pseudo-)Zufallszahlen zum Einsatz. In diesem Fall die Erzeugung der Lage der Clusterzentren und möglichen Wohnorte der untererfassten Personen.

Gemeinsam bilden diese Bibliotheken die technische Grundlage für eine flexible, interaktive und räumlich orientierte explorative Datenanalyse.

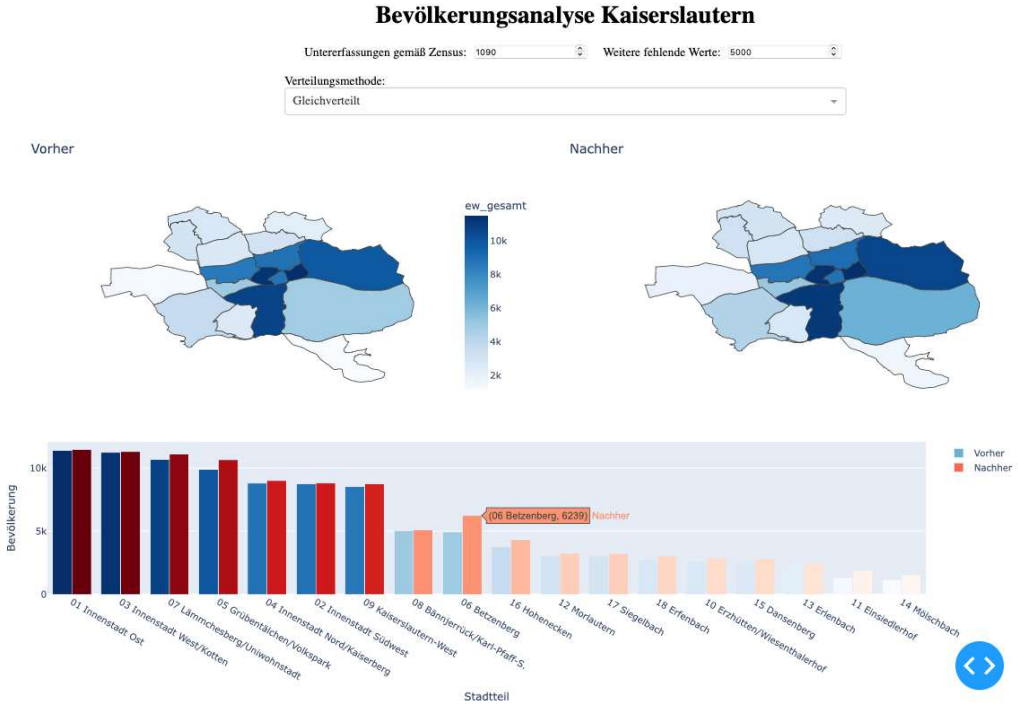


Abb. 3: Oberfläche des Tools. In diesem Fall wurden die zufälligen Punkte räumlich gleichverteilt. Man sieht, dass große Gebiete anteilig mehr Zuwachs bekommen. Die Farbwahrnehmung der Karte ändert sich kaum.

3.3 Parameter

In der Eingabemaske können mehrere Parameter direkt durch die Nutzerinnen und Nutzer festgelegt werden. Dazu zählt die Anzahl der Untererfassungen gemäß Zensus 2022, die standardmäßig mit dem für Kaiserslautern bekannten Wert von 1090 vorbelegt ist. Zusätzlich steht ein weiteres Eingabefeld zur Erfassung zusätzlicher Untererfassungen zur Verfügung, das initial mit einem Beispielwert von 1 000 befüllt ist. Darüber hinaus kann gewählt werden, ob die zufällig generierten Punkte gleichmäßig über das Stadtgebiet verteilt werden sollen, oder konzentriert um zufällig erzeugte Clusterzentren auftreten; voreingestellt ist die Gleichverteilung.

Weitere Parameter werden innerhalb des Codes definiert. Hierzu gehören die räumliche Granularität der Analyse, die entweder auf Ebene der Ortsbezirke oder der statistischen Bezirke erfolgen kann, sowie die Anzahl der Clusterzentren, die in Abhängigkeit von der jeweiligen Art der Untererfassung festgelegt wird.

[1] https://dash.plotly.com
[2] https://plotly.com/python/
[3] https://geopandas.org/
[4] https://shapely.readthedocs.io/
[5] https://docs.python.org/3/library/random.html

3.4 Auswertungen

In der Untersuchung wurden die in Tabelle 1 dargestellten Merkmalskombinationen analysiert und bewertet. Dabei wurden zum einen die Anzahl der räumlichen Einheiten erfasst, die gegenüber dem Ausgangswert eine Veränderung von mehr als 20% aufweisen, und zum anderen das jeweilige Maximum der Abweichungen bestimmt.

Raumbezug	Verteilung	Untererfassungen gemäß Zensus 2022	Weitere fehlende Werte	Anzahl der Cluster-zentren je Art der UE
Ortsbezirke	Clusterzentren	1090	1000	5
Statistische Bezirke			5000	20
			10000	

Tabelle 1: Gewählte Parameterausprägungen für die initiale Untersuchung. Diese werden in allen möglichen Kombinationen betrachtet.

Da die Ergebnisse in hohem Maße zufallsabhängig sind und die Untersuchung einen explorativen Charakter aufweist, wird ergänzend eine vergleichende Beschreibung der visuellen Wahrnehmung der beiden Choroplethenkarten vorgenommen.

4 UMSETZUNG AM BEISPIEL DER STADT KAISERSLAUTERN

Zum Stichtag 15. Mai 2022 lebten in der Stadt Kaiserslautern gemäß Zensus knapp 100.000 Personen. Die Bevölkerungsstruktur der Stadt ist durch einen Faktor geprägt, der für die vorliegende Untersuchung von besonderer Relevanz ist: Die Nähe zur Air Base Ramstein, der größten militärischen Einrichtung der USA im Ausland, führt seit mehreren Jahrzehnten zu einer ausgeprägten Präsenz von Angehörigen der US-Streitkräfte sowie deren Familien im Stadtgebiet und im umliegenden Landkreis. Für Stadt und Landkreis Kaiserslautern wird die Zahl der in der Region ansässigen US-Amerikanerinnen und US-Amerikaner, einschließlich aktiver Soldatinnen und Soldaten, ziviler US-Beschäftigter, ehemaliger Mitglieder der Streitkräfte sowie deren Angehöriger, auf etwa 50.000 Personen geschätzt. Die Zahl der offiziell in Deutschland gemeldeten US-Staatsbürger ist hingegen deutlich geringer, da für NATO-Angehörige keine Meldepflicht besteht. Für den Landkreis Kaiserslautern werden im Jahr 2023 rund 1.185 US-amerikanische Staatsangehörige ausgewiesen, während in der Stadt Kaiserslautern im Jahr 2023 etwa 910 US-Bürgerinnen und US-Bürger registriert waren (Statistisches Landesamt Rheinland-Pfalz 2024). Die US-Community stellt somit einen signifikanten demografischen und strukturellen Faktor dar, der auch die Stadt Kaiserslautern prägt.

Darüber hinaus existieren in der Stadt neun von der Stadtverwaltung gelistete Pflegeheime[6] sowie sieben Gemeinschaftsunterkünfte für Geflüchtete[7],die für die vorliegende Betrachtung ebenfalls von Bedeutung sind. Der Zensus geht für die Stadt von 1.090 Untererfassungen aus, was einer Quote von 0,01 % entspricht und somit über dem Durchschnitt von Rheinland-Pfalz sowie dem Bundesdurchschnitt liegt (siehe Tab. 2).

Raumbezug	Einwohner gesamt	Stationierte US-Streitkräfte	Übererfassungen gesamt	Übererfassungen anteilig (gerundet)	Untererfassungen gesamt	Untererfassungen anteilig (gerundet)
Deutschland	82.719.540	37.547	1.790.259	0,022	**549.103**	**0,007**
Rheinland-Pfalz	4.094.169	18.959	68.153	0,017	**24.977**	**0,006**
Stadt Kaiserslautern	99.689	n.n.	2.198	0,022	**1.090**	**0,01**

Tabelle 2: Über- und Untererfassungen ausgewählter Raumeinheiten gemäß Zensus 2022, Anfrage an Destatis und Deutscher Bundestag 2022

[6] https://www.kaiserslautern.de/sozial_leben_wohnen/soziales_und_gesellschaft/aeltere_mitbuerger/angebote_und_hilfen/Altenpflegeheime/index.html.de

[7] https://www.asz-kl.de/fluechtlingsunterkuenfte/ und https://www.drk-kl.de/angebote/migration-integration-fluechtlingshilfe/

Es wurden sämtliche möglichen Kombinationen der gewählten Merkmalsausprägungen für die Stadt Kaiserslautern untersucht (vgl. Tab. 2). Die hierfür erforderlichen kleinräumigen Bevölkerungsdaten wurden freundlicherweise von der Stadtverwaltung zur Verfügung gestellt.

4.1 Ergebnisse in Kaiserslautern

Tabelle 3 zeigt die Ergebnisse einer explorativen Analyse verschiedener Kombinationen von Merkmalen im Hinblick auf Untererfassungen in Kaiserslautern. Als Ausreißer werden dabei räumliche Einheiten definiert, deren aktualisierter Wert mehr als 20 % über dem ursprünglichen Wert liegt. Dies entspricht Bezirken, in denen die Anzahl der Einwohnerinnen und Einwohner um mehr als 20 % höher ist als in den städtischen Ausgangsdaten.

Die Ergebnisse weisen mehrere erkennbare Muster auf:

- Abhängigkeit von der Anzahl fehlender Werte: Mit zunehmender Anzahl zusätzlicher Untererfassungen steigt sowohl die Zahl der Ausreißer als auch die maximale Veränderung.
- Einfluss der Anzahl der Clusterzentren: Eine größere Anzahl an Clusterzentren verteilt die Untererfassungen stärker über die Bezirke, wodurch die maximalen Veränderungen bei niedrigen zusätzlichen Untererfassungen reduziert werden. Bei hohen zusätzlichen Untererfassungen bleiben Ausreißer jedoch weiterhin signifikant.
- Räumliche Granularität: Auf der Ebene der kleineren statistischen Bezirke zeigen sich deutlich höhere Maximalwerte und mehr Ausreißer. Dies verdeutlicht, dass kleinere räumliche Einheiten besonders sensibel auf Untererfassungen reagieren.

Insgesamt lässt sich festhalten, dass die Anzahl und Ausprägung von Ausreißern sowohl mit der Zahl der zusätzlichen Untererfassungen als auch mit der Anzahl der Clusterzentren zunimmt. Extreme Ausreißer, wie ein Zuwachs von 245 %, könnten bereits bei einer Untererfassung von etwa 1,1 % der Gesamtbevölkerung auftreten. Moderate Ausreißer treten hingegen vor allem dann auf, wenn viele Clusterzentren vorliegen und die Anzahl fehlender Werte gering ist.

Fall	Raumbezug	Verteilung	Untererfassungen gemäß Zensus 2011	Weitere fehlende Werte	Anzahl der Cluster-zentren je Feld	Anzahl der Ausreißer >20%	Maximale Veränderung (zum Ausgangswert)
1	Ortsbezirke	Clusterzentren	1090	1000	5	0	-
2	Ortsbezirke	Clusterzentren	1090	5000	5	3	+98%
3	Ortsbezirke	Clusterzentren	1090	10000	5	5	+77%
4	Ortsbezirke	Clusterzentren	1090	1000	20	0	-
5	Ortsbezirke	Clusterzentren	1090	5000	20	1	+27%
6	Ortsbezirke	Clusterzentren	1090	10000	20	4	+63%
7	Statistische Bezirke	Clusterzentren	1090	1000	5	5	+69%
8	Statistische Bezirke	Clusterzentren	1090	5000	5	10	+151%
9	Statistische Bezirke	Clusterzentren	1090	10000	5	14	+245%
10	Statistische Bezirke	Clusterzentren	1090	1000	20	5	+41%
11	Statistische Bezirke	Clusterzentren	1090	5000	20	12	+122%
12	Statistische Bezirke	Clusterzentren	1090	10000	20	18	+156%

Tabelle 3: Untersuchte Merkmalsausprägungen und zugehörige Ergebnisse. Für die grau hinterlegten Zeilen werden in diesem Beitrag exemplarisch graphische Darstellungen bereitgestellt.

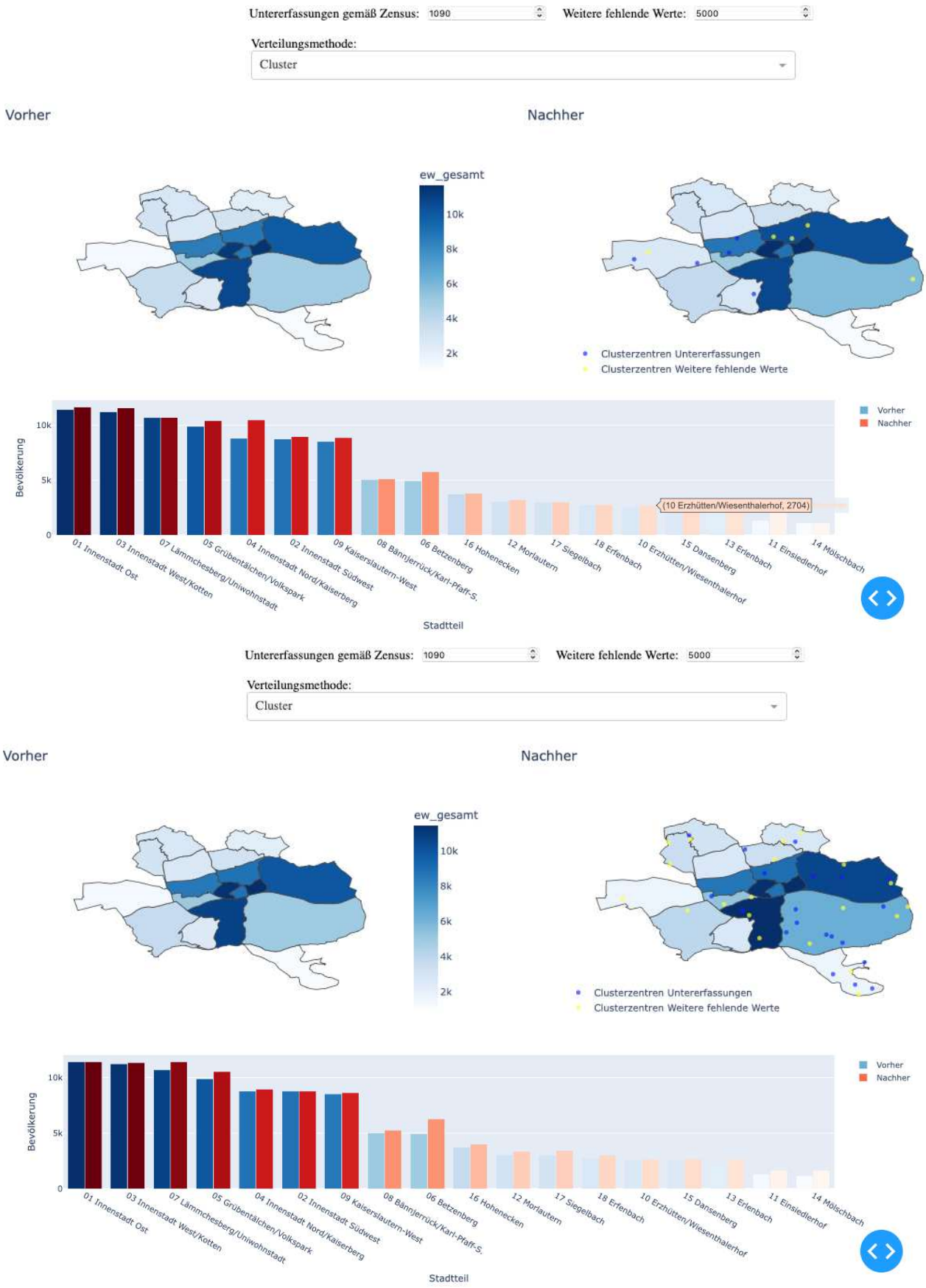


Abb. 3: Vergleich zweier Ergebnisse auf Ortsbezirksebene. Oben sind insgesamt 10 Clusterzentren (Fall 2) und unten 40 (Fall 5).

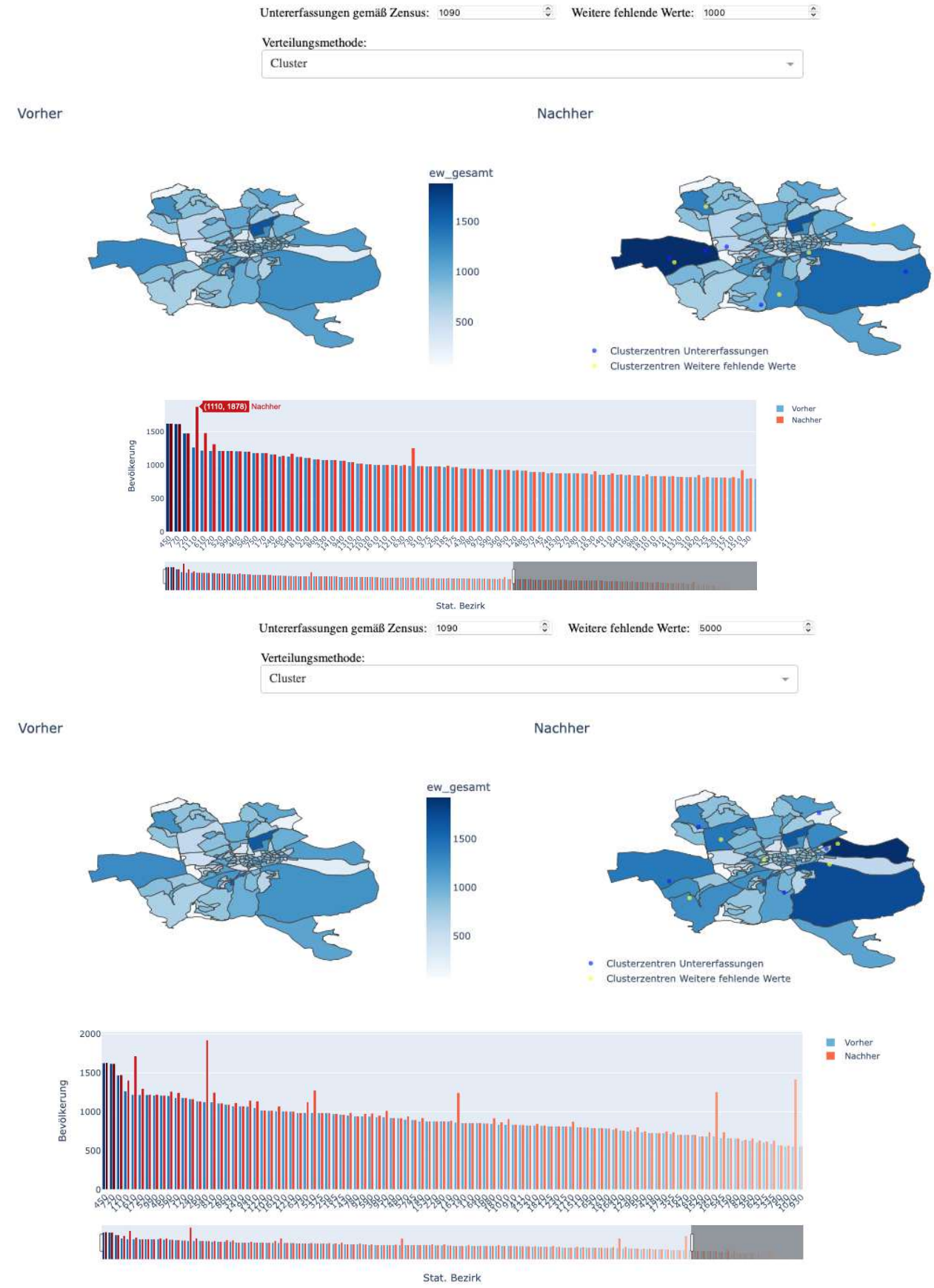


Abb. 4: Vergleich zweier Ergebnisse auf Ebene der statistischen Bezirke. Oben sind 1000 weitere fehlende Werte (Fall 7) und unten sieht man die Ergebnisse für 5000 fehlende Werte (Fall 8).

5 ERGEBNISSE

Die Analyse zeigt erwartungsgemäß, dass die Auswirkungen auf die Choroplethenkarten von der gewählten Verteilungsart, der Anzahl und Lage der Clusterzentren sowie der Größe der betrachteten räumlichen Einheiten abhängen. Bei einer räumlich gleichverteilten Zuweisung von Untererfassungen werden größere Ortsbezirke stärker berücksichtigt, da sie proportional mehr Fläche einnehmen (siehe Abb. 2).

Bei der Cluster-basierten Verteilung zeigt sich eine deutliche Abhängigkeit von der Anzahl der Clusterzentren: Mit zunehmender Anzahl der Clusterzentren nehmen die maximalen Abweichungen in den Bezirken ab. Ortsbezirke, die kein Clusterzentrum enthalten, weisen nur geringe Veränderungen auf, während Bezirke mit Clusterzentren signifikante Unterschiede zeigen (siehe Abb. 3). Zudem ist zu beobachten, dass die Auswirkungen stärker ins Gewicht fallen, je kleiner die betrachtete räumliche Einheit ist (siehe Abb. 4).

Es ist zu beachten, dass die Ergebnisse zufallsbasiert sind; eine erneute Durchführung der Simulation kann daher zu abweichenden Verteilungsmustern führen.

6 KRITIK

Trotz der gewonnenen Erkenntnisse weist der gewählte Ansatz mehrere methodische Einschränkungen auf. Die Ergebnisse sind stark abhängig von den getroffenen Annahmen sowie der zufallsbasierten Generierung der Punkte, wodurch eine hohe Variabilität und eingeschränkte Reproduzierbarkeit besteht. Validierungsdaten für die tatsächliche räumliche Verteilung von Untererfassungen sind nahezu nicht verfügbar, insbesondere für marginalisierte Gruppen oder spezifische Bevölkerungssegmente wie Angehörige der US-Streitkräfte. Darüber hinaus bleibt unklar, in welchem Umfang die betrachteten Gruppen für Planungsprozesse relevant sind und ob die Visualisierungen tatsächlich einen praktischen Mehrwert liefern. Auch die Betrachtung von Übererfassungen oder Korrelationen zu anderen Merkmalen ist aufgrund fehlender Vergleichsdaten nur sehr begrenzt möglich. Insgesamt handelt es sich daher um einen explorativen Ansatz, der eher ein qualitatives Verständnis der potenziellen Auswirkungen von Untererfassungen vermittelt, während eine quantitative Validierung derzeit nicht realisierbar ist.

Aktuelle ergibt sich kein Unterschied durch die beiden Eingabefelder außer die Verschiedenfarbigkeit der erzeugten Punkte, zukünftig ist allerdings eine Kombination aus zwei verschiedenen Verteilungen und eine Integration von Übererfassungen denkbar.

7 FAZIT UND AUSBLICK

Die Untersuchung zeigt, dass Untererfassungen in Meldedaten einen deutlichen Einfluss auf kleinräumige Darstellungen wie Choroplethenkarten und Balkendiagramme haben können. Die Auswirkungen sind insbesondere dann ausgeprägt, wenn die betrachteten räumlichen Einheiten klein sind oder die Untererfassungen in wenigen Clusterzentren konzentriert auftreten. Aufgrund der hohen Unsicherheit in der räumlichen Verteilung der nicht erfassten Personen und der eingeschränkten Verfügbarkeit valider Vergleichsdaten auf kleinräumiger Ebene kann die Analyse nur explorativ erfolgen. Die Ergebnisse liefern dennoch wertvolle Hinweise darauf, wie sich Untererfassungen in unterschiedlichen Szenarien auswirken können und ermöglichen ein besseres Verständnis der potenziellen Verzerrungen in kommunalen Daten.

Auch wenn die Auswirkungen nicht immer sichtbar werden, können selbst ausbleibende Effekte wertvolle Einblicke in die Robustheit von SDSS gegenüber Datenlücken liefern. Diese Untersuchung unterstreicht die Notwendigkeit einer transparenten Kommunikation sowohl von Annahmen, Verarbeitungslogiken und bekannter Besonderheiten von Datengrundlagen, um fundierte Entscheidungen zu ermöglichen und ein kritisches Verständnis datenbasierter Anwendungen zu fördern. Diese Arbeit bildet eine Grundlage für zukünftige Forschung zu Methoden der Unsicherheitskommunikation und zur Gestaltung entsprechender Visualisierungsstrategien in SDSS.

Für die zukünftige Anwendung bietet sich an, die Visualisierungen als ergänzendes Instrument innerhalb von SDSS, in Schulungen zur Datenqualität oder als Grundlage für dynamische Darstellungen von Unsicherheiten zu nutzen. Ein signifikanter Informationsgewinn wäre außerdem zu erwarten, wenn reale Kenntnisse über Clusterzentren oder zusätzliche Daten zu spezifischen Bevölkerungsgruppen in Zusammenarbeit mit Statistikstellen integriert werden könnten. Darüber hinaus könnten Anfragen bei relevanten Stellen, etwa zu Pflegeheimen oder Angehörigen der NATO, dazu beitragen, die unbekannte Zahl

weiterer Untererfassungen grob einzugrenzen. Insgesamt unterstreicht die Analyse den Wert explorativer Ansätze, um potenzielle Verzerrungen zu erkennen, und liefert zugleich Impulse für weiterführende Untersuchungen und methodische Verbesserungen.

8 FÖRDERUNG

Diese Arbeit wird im Rahmen des interdisziplinären Forschungsprojekts „Ageing Smart – Räume intelligent gestalten“, das von der Carl-Zeiss-Stiftung gefördert wird, durchgeführt. Kaiserslautern ist eine von sieben Modellkommunen in diesem Projekt.

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Urban Circularity in Time: Rethinking Quality of Life through Circular Communities

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1 ABSTRACT

This paper proposes an integrated framework that connects circular communities, spatial planning, and time quality assessment (TQA) to support sustainable urban development. Circular communities, comprising material suppliers, producers, service providers, and users, aim to close resource loops and strengthen socio-ecological resilience. Yet, the translation of circular principles into durable, liveable urban environments remains a key challenge.

We introduce the Time–Space–Flow Integration Method, which links the temporal rhythms of daily life with material, energy, and social cycles to guide spatial planning. In this approach, time quality is redefined beyond efficiency or free time to include temporal proximity, synchronization, autonomy, continuity, and regenerative capacities. Circular communities are thus conceptualized as temporal-spatial systems, where short, medium, and long cycles of resources, services, and culture must be harmonized to optimize daily life.

To operationalize this framework, we propose the Circular Community Time–Quality Index (CCTQI), which evaluates urban areas based on daily access to essentials, local closure of resource loops, temporal flexibility of spaces, and intergenerational continuity. Coupled with spatial planning principles, 15–30 minute life radius, multi-layered mixed-use nodes, local metabolism zones, polycentric structures, and temporal flexibility of space, this approach enables the design and assessment of circular communities that are both resource-efficient and experientially rich.

By merging circularity with time quality metrics into Time–Circular Community Spatial Model (TCCSM), the paper argues that a sustainable society is grounded not only in circular systems but in spatial structures that protect and regenerate human time, providing planners with a measurable, actionable framework to shape inclusive, resilient, and high-quality urban life.

Keywords: urban sustainability, quality of living environments, circular community, circular spatial planning, time quality assessment

2 INTRODUCTION

Urban areas are facing unprecedented challenges related to sustainability, resource scarcity, and declining quality of life. Rapid urbanization, coupled with growing consumption, has intensified pressure on ecological systems and urban infrastructures, making traditional planning approaches increasingly inadequate. In response, the circular economy has emerged as a transformative framework for rethinking urban resource management. Circular principles such as reuse, repair, material recovery, and localized production promise to reduce waste, increase efficiency, and enhance socio-ecological resilience. However, translating these principles into functional, liveable urban environments remains a persistent challenge (Geissdoerfer et al., 2025).

Circular communities, understood as integrated systems of material suppliers, producers, service providers, distributors, and users, offer a pathway to operationalize circularity at the urban scale. These communities aim to close resource loops while fostering local innovation, social cohesion, and economic vitality (Marušić and Goličnik Marušić, 2025). Yet, most research has focused on technological solutions or isolated pilot projects, leaving critical gaps in understanding how circular communities influence daily life, temporal experience, and spatial structures. In particular, the interaction between circular resource flows and the lived experience of time in urban settings remains underexplored.

In this paper, circular communities are not conceptualized as self-sufficient or isolated neighbourhood units. Rather, they are understood as networked configurations of circular economy stakeholders operating within and across spatial scales. These configurations rely on collaboration between local actors – producers, service providers, users, and secondary material processors – while remaining embedded in broader urban, regional, and global systems of exchange. The objective is not territorial autonomy, but the spatial

coordination of circular functions so that value-retention processes become accessible, repeatable, and time-efficient within everyday urban life.

This paper addresses this gap by asking: how can time quality assessment inform spatial planning to enable networked circular economy configurations without implying spatial self-sufficiency? We hypothesize that sustainable societies are not solely grounded in circular resource systems but also depend on spatial-temporal structures that protect and regenerate human time. In other words, circular communities function optimally only when the spatial design of cities supports daily life rhythms alongside resource flows.

To address this, we propose an integrated framework that combines the Time–Space–Flow Integration Method, the Time–Circular Community Spatial Model (TCCSM), and a practical assessment tool – the Circular Community Time–Quality Index (CCTQI). Together, these components provide planners and policymakers with a measurable, actionable approach to design, evaluate, and optimize circular communities that are both resource-efficient and experientially rich.

3 THEORETICAL BACKGROUND

3.1 Circular Communities

Circular communities are conceptualized here as networked circular economy configurations composed of producers, service providers, distributors, secondary material processors, developers, and users connected through value-retention processes. These configurations do not imply territorially closed or self-sufficient neighbourhoods. Instead, they represent spatially coordinated stakeholder networks that enable reuse, repair, refurbishment, material recovery, and regenerative practices to operate efficiently within everyday urban contexts while remaining connected to wider regional and global systems.

Despite these benefits, a key challenge remains as most circular community initiatives exist as temporary experiments or isolated interventions, which rarely translate into durable, spatially integrated forms. Without careful planning, circular flows may be physically fragmented or temporally misaligned with daily life rhythms, limiting their potential to improve overall quality of life.

3.2 Time Quality Assessment (TQA)

Time Quality Assessment (TQA) is a framework that evaluates quality of life through the lens of time use, linking urban form to daily routines and lived experiences (Goličnik Marušić and Marušić, 2017). Unlike traditional measures of efficiency or free time, TQA considers time balance, financial balance, and the time quality coefficient (KTQ), capturing both the quantitative and qualitative aspects of daily activities. Applied to urban contexts, TQA enables planners to assess whether residents can comfortably access essential services, participate in community life, and engage in restorative and meaningful activities.

Integrating TQA with circular community planning provides a unique opportunity: It allows assessment of not only whether resources are efficiently cycled but also how these flows affect residents' temporal experience. In other words, TQA bridges the gap between ecological sustainability and human-centered urban design.

3.3 Spatial Planning and Circularity

Traditional urban planning often emphasizes distance, function, or zoning, which can inadvertently disrupt circular flows (Surekha et al., 2025) and misalign with residents' daily rhythms or routines. Time-aware spatial planning, by contrast, considers how spatial arrangements influence the temporal experience of residents. By synchronizing short, medium, and long resource cycles with daily life patterns, planners can ensure that circular practices, such as localized production, repair services, and material recovery, are both operationally effective and experientially accessible.

In this context, a planning model that explicitly integrates time, circular flows, and spatial form is essential. Such a model provides a blueprint for creating circular communities that are not only resource-efficient but also resilient, inclusive, and supportive of human time. This foundation sets the stage for our Time–Space–Flow Integration Method and the Time–Circular Community Spatial Model (TCCSM), which operationalize these principles.

4 CONCEPTUAL FRAMEWORK: TIME–SPACE–FLOW INTEGRATION

Circular communities operate at the intersection of temporal rhythms, resource flows, and spatial structures. The core assumption of the Time–Space–Flow Integration Method is that circular communities function optimally when daily life cycles align with material, energy, and social flows. Misalignment between temporal rhythms and resource cycles can undermine both the efficiency of circular systems and the quality of life of residents. This framework provides a bridge between time quality assessment, spatial planning, and circular community principles, offering a structured approach to design and evaluation.

Central to this approach is a redefinition or upgrade of time quality as introduced by Marušić and Goličnik Marušić (2017). Beyond conventional measures of efficiency or free time, time quality in circular communities (Marušić and Goličnik Marušić, 2025) encompasses five key dimensions (temporal proximity, synchronization, temporal autonomy, continuity, regenerative time). Temporal proximity reflects the time required to access essential services, ensuring that daily needs do not impose excessive burdens. Synchronization refers to the alignment of work, care, mobility, and production cycles, facilitating smooth daily routines. Temporal autonomy captures the ability of residents to choose and control their rhythms of life and most directly correspond to time quality coefficient (KTQ) as defined by Marušić and Goličnik Marušić (e.g. 2014, 2017), while continuity reflects the stability of time arrangements across generations. Finally, regenerative time considers the provision of sufficient time for rest, learning, community engagement, and environmental care. This multidimensional perspective highlights that even well-functioning circular flows cannot compensate for poor temporal-spatial planning.

As grounded in 3.1, in this paper, the term circular community refers to a functional configuration within the circular economy, comprising interconnected actors and value-retention processes rather than a residential or social community. To become operative through spatial planning, such circular economy configurations require a spatial interpretation that makes their functions accessible, repeatable, and efficient in everyday urban life (e.g. Verga and Khan, 2022). Time quality assessment is introduced as a translation tool that links circular economy functions to spatial planning decisions by examining how circular activities consume, save, or redistribute time. From this perspective, circular communities can be interpreted as temporal-spatial systems defined by operational rhythms. Certain circular functions, such as access to services, repair, and mobility, require daily spatial accessibility; others, such as learning, housing adaptation, or local exchange, operate on periodic schedules; while structural circular functions, such as material recovery, infrastructure renewal, and ecological processes, depend on long-term spatial anchoring. These temporal distinctions do not redefine circular communities as social entities but rather identify the spatial requirements necessary for circular economy processes to function efficiently. Spatial planning plays a key role in minimizing temporal and spatial friction between these functions, ensuring that circular economy strategies contribute to reduced time consumption, compact spatial organization, and improved time quality in cities.

Understanding circular communities as circular economy configurations highlights that their successful implementation depends not only on closing material loops, but also on the spatial conditions under which circular functions become accessible and repeatable in everyday life. The Time–Space–Flow Integration framework demonstrates that circular economy processes operate through recurring temporal rhythms and require spatial proximity to minimize friction in daily routines. Time quality assessment provides a means to evaluate these requirements by examining how circular functions affect time use, accessibility, and flexibility.

Building on this insight, the following section translates the temporal and functional logic of circular communities into spatial planning principles. These principles do not prescribe social forms of living, but identify spatial structures that enable circular economy processes to function efficiently while contributing positively to time quality.

5 SPATIAL PLANNING PRINCIPLES FOR CIRCULAR COMMUNITIES

Translating the conceptual framework into actionable strategies requires spatial planning principles that spatially interpret circular economy functions through a time quality lens. These principles do not redefine circular communities as residential entities but rather identify spatial conditions under which circular economy processes can operate efficiently while contributing positively to daily time use.

The first principle is the 15–30 minute life radius, which ensures that essential circular economy-related functions, including food provision, healthcare, education, work, repair, and care services, are accessible within daily time budgets. Unlike traditional distance-based zoning, time-based zoning prioritizes temporal proximity, reducing travel time, coordination effort, and dependence on distant systems, thereby supporting recurring circular activities. Second, multi-layered mixed-use nodes integrate living, production, learning, and care functions within shared urban spaces. This principle supports the co-location of circular economy actors and services, enabling value-retention strategies to function across day–night and weekday–weekend rhythms without spatial segregation. Such spatial overlap reduces friction between circular processes and everyday routines. Third, local metabolism zones spatially anchor resource flows, energy, food, water, and materials, within identifiable urban units. Making these flows visible supports the operational requirements of circular economy systems and enables time-efficient interaction with circular services. Visibility of metabolic processes strengthens engagement while reducing the spatial and temporal distance between users and circular functions. Fourth, temporal flexibility of space allows urban areas to accommodate different circular economy functions at different times. Examples include educational facilities functioning as repair or community hubs outside school hours, parking areas temporarily repurposed for markets or logistics, and workplaces adapted for learning or care activities. Such flexibility increases utilization efficiency and improves time quality without additional land consumption or construction. Finally, polycentric spatial structures distribute circular economy nodes across the urban fabric, creating semi-autonomous yet interconnected centres. This configuration shortens access times to circular services, supports redundancy and resilience in circular flows, and enables repeated local interaction. Reduced spatial and temporal distance between actors involved in circular processes may create conditions that facilitate social interaction and collaboration; however, such outcomes depend on institutional, cultural, and governance factors beyond spatial configuration alone.

6 PLANNING MODEL: TIME–CIRCULAR COMMUNITY SPATIAL MODEL (TCCSM)

The Time–Circular Community Spatial Model (TCCSM) operationalizes the integration of time, circular economy processes, and spatial structure for planning purposes. Its core premise is that circular economy configurations function efficiently when daily time use, spatial form, and resource flows are aligned, reducing temporal and spatial friction in recurring circular activities. The model consists of three interrelated layers, circular flows, spatial structure, and time quality, connected through feedback loops that support adaptive planning and continuous evaluation.

The spatial structure layer translates circular economy functions into planning-relevant spatial arrangements. It is organized around circular nodes differentiated by operational time scale, reflecting the frequency with which circular functions must be accessible. Daily nodes (0–24 hours) accommodate high-frequency functions such as essential services, mobility, repair access, and care. Weekly nodes (approximately 7 days) support periodic functions including local markets, repair and refurbishment services, and learning activities. Seasonal nodes (monthly or longer cycles) host lower-frequency but structurally critical functions such as agriculture, ecological management, material recovery, and cultural activities. These nodes are embedded within reachable time radii to ensure that circular economy processes remain accessible to users and actors without excessive time expenditure.

To support these spatial configurations, the model proposes indicative spatial ratios that guide land-use allocation and building typologies. These ratios are not prescriptive standards but planning benchmarks intended to ensure sufficient spatial capacity for circular economy functions to operate efficiently while maintaining time quality. They are grounded in the need to reduce spatial fragmentation, support recurring circular activities, and enable adaptability over time rather than prescribing fixed design outcomes: mixed-use land (e.g. $\geq 60\%$) enables functional overlap and reduces travel distances; local production and service spaces (e.g. $\geq 15\%$) provide room for repair, reuse, and small-scale manufacturing; public and shared spaces (e.g. $\geq 25\%$) support accessibility, coordination, and visibility of circular activities; and adaptable buildings (e.g. $\geq 40\%$) allow spaces to accommodate changing functions over time.

The time quality layer captures the lived temporal effects of spatialized circular economy processes, focusing on temporal proximity, synchronization of activities, autonomy in daily scheduling, continuity of access, and the availability of regenerative time. The circular flow layer monitors material, energy, water, food, and waste streams to ensure that value-retention loops are physically closed, locally anchored, and visible.

Feedback loops between the three layers enable planners to evaluate how spatial arrangements influence both circular performance and time quality, and to adjust planning strategies as circular economy practices and usage patterns evolve.

7 ASSESSMENT FRAMEWORK: CIRCULAR COMMUNITY TIME–QUALITY INDEX (CCTQI)

The Circular Community Time–Quality Index (CCTQI) operationalizes the Time–Circular Community Spatial Model (TCCSM) by providing a structured set of indicators that evaluate the performance of each model layer. Rather than functioning as a standalone assessment tool, the CCTQI is designed as the monitoring and feedback mechanism of the planning model, enabling planners to assess whether spatial configurations effectively support circular economy processes while maintaining or improving time quality.

7.1 Time Quality Indicators (Time Layer)

Indicators in this category assess how spatialized circular economy functions affect daily time use and lived experience. They reflect the core dimensions of time quality identified in the conceptual framework, including temporal proximity, synchronization, autonomy, continuity, and regenerative time. Key indicators include average daily access time to essential circular services, the share of daily time devoted to mobility, the proportion of spaces supporting multi-time use, and the availability of time for rest, learning, and community participation. Together, these metrics evaluate whether spatial arrangements reduce time pressure and enable coherent daily routines.

7.2 Spatial Structure Indicators (Spatial Layer)

Spatial structure indicators evaluate whether planning principles and spatial configurations align with the operational requirements of circular economy functions. These indicators capture the degree of functional mix, density and distribution of circular nodes, accessibility within defined time radii, and the adaptability of buildings and public spaces. By measuring spatial overlap, polycentric balance, and continuity of public networks, this indicator set assesses whether spatial structures minimize temporal and spatial friction between circular activities.

7.3 Circular Flow Indicators (Flow Layer)

Circular flow indicators measure the physical performance of circular economy processes within the spatial system. They track the degree to which material, energy, water, food, and waste flows are locally closed, reused, or regenerated. These indicators ensure that value-retention strategies are not only planned but materially effective, providing a quantitative basis for evaluating whether circular loops are functioning as intended and whether spatial anchoring supports their visibility and efficiency.

7.4 Composite Evaluation and Feedback Loops

To enable integrated evaluation and comparison across planning scenarios, individual indicator scores are aggregated into a composite Circular Community Performance Score. Weighting reflects the centrality of time quality and spatial structure in enabling circular economy processes, while maintaining the importance of material flow performance. Results from the CCTQI feed back into the TCCSM layers, informing adjustments to spatial design, allocation ratios, and circular infrastructure. This feedback mechanism supports adaptive planning and continuous improvement over time.

8 DISCUSSION

This paper set out to explore how circular economy configurations, conceptualized as circular communities, can be interpreted and operationalized through spatial planning using time quality assessment. The proposed Time-Space-Flow Integration framework, together with the Time–Circular Community Spatial Model (TCCSM) and the Circular Community Time–Quality Index (CCTQI), demonstrates that circular economy strategies are not spatially neutral. Their effectiveness depends on how circular functions are embedded within urban space and how they interact with daily time use.

The key contribution of the framework lies in its ability to translate circular economy logic into spatial planning-relevant thinking. By introducing time quality as an evaluative lens, the paper reveals how circular economy functions consume, save, or redistribute time, and how spatial planning can reduce temporal and

spatial friction in recurring circular activities. This perspective helps explain why circular initiatives often remain experimental or isolated when implemented within spatial structures inherited from linear urban systems.

The planning principles and the TCCSM provide planners with a structured way to design and assess spatial conditions that support circular economy processes. The alignment of operational rhythms, spatial accessibility, and value-retention flows shows that improvements in time quality are not ancillary benefits, but integral outcomes of well-functioning circular systems. At the same time, the CCTQI enables adaptive governance by linking planning decisions to measurable impacts on both circular performance and daily life.

Several limitations should be acknowledged. The proposed indicators and reference values are illustrative and require contextual adaptation and empirical validation. Data availability, especially for time-use and local flow measurements, may constrain application in some contexts. Furthermore, the framework does not prescribe institutional arrangements or governance mechanisms, which will be critical for implementation. These limitations point toward the need for applied case studies and longitudinal analysis. The framework does not assume deterministic relationships between spatial proximity and social cohesion. While spatial configuration can enable interaction, actual social outcomes depend on governance structures, institutional arrangements, and socio-cultural contexts. Future empirical research is required to test the strength and variability of these relationships across different urban settings.

8.1 Distinction from the 15-Minute City Model

The proposed framework differs fundamentally from the 15-minute city model, although both engage with questions of accessibility and proximity. The 15-minute city emphasizes minimizing travel time to essential services in order to enhance urban comfort and reduce mobility-related emissions. Its primary logic is spatial proximity.

By contrast, the Time–Circular Community Spatial Model (TCCSM) is organized around circular economy processes and their operational rhythms. Proximity within a 15–30 minute radius is treated as an enabling condition for certain high-frequency circular functions, not as a normative requirement for neighbourhood self-sufficiency. The model does not assume that all services or production activities must meet local critical mass thresholds within each spatial unit. Instead, it differentiates circular functions according to temporal frequency (daily, weekly, seasonal) and locates them across a polycentric and networked structure.

In this sense, the framework addresses one of the common critiques of proximity-based planning models: that different urban services require different scales of operation and critical mass. The TCCSM explicitly incorporates multi-scalar organization, allowing certain circular processes to operate locally while others function at district, metropolitan, or regional levels. The aim is coordinated circularity, not territorial closure.

9 CONCLUSION

This paper proposes an integrated framework that connects circular economy configurations, spatial planning, and time quality assessment to support sustainable urban development. By interpreting circular communities as functional circular economy systems and translating their operational requirements into spatial planning terms, the study demonstrates that circularity becomes effective only when spatial structures support daily accessibility, proximity, and adaptability.

The Time–Circular Community Spatial Model (TCCSM) and the Circular Community Time–Quality Index (CCTQI) together provide planners with a coherent model for design, assessment, and feedback. The central argument is that sustainable urban development depends not only on closing material loops, but also on protecting and regenerating human time through spatial structures that minimize friction and enable recurring circular activities.

Importantly, the framework does not advocate self-sufficient neighbourhoods or spatial isolation. Instead, it advances a multi-scalar, networked interpretation of circular economy implementation, where local accessibility is combined with regional coordination and differentiated critical mass requirements. By distinguishing between daily, periodic, and structural circular functions, the model accommodates the varying spatial scales necessary for viable urban services and production systems.

Future research should focus on empirical application of the framework in different urban contexts, including urban regeneration and new development, and on refining indicator sets using real-world data. By bridging

circular economy theory and spatial planning practice through time quality assessment, the approach presented here offers a practical pathway toward urban environments that are resource-efficient, time-conscious, and resilient.

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reviewed paper

Urban Drainage Failure in Durban's 2022 Floods and a SUDS Pathway to Improved Resilience

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1 ABSTRACT

Durban's stormwater system is no longer fit for purpose. Durban's 2022 floods exposed a fundamental mismatch between the city's evolving hydrological conditions and its outdated stormwater system. The drainage network, much of it designed for mid twentieth century rainfall and smaller catchments, now functions close to capacity under ordinary conditions and fails rapidly during extreme events. This paper examines the mechanisms behind that failure and identifies the structural and operational constraints that prevent the system from managing contemporary runoff volumes. Using post-event assessments, municipal documentation and targeted stakeholder insights, the analysis shows how undersized pipes, irregular maintenance, blocked channels and disrupted natural drainage pathways created a cascade of hydraulic failures during the 2022 event. These weaknesses allowed localised surcharging to escalate into widespread inundation, particularly in densely populated and low-lying settlements. A focused set of SUDS measures could address these performance gaps by introducing decentralised storage, infiltration and controlled conveyance in congested subcatchments. Rather than advocating generic nature-based solutions, the paper isolates the SUDS functions most suited to Durban's geomorphology, institutional capacity and settlement form. The findings demonstrate that targeted SUDS retrofits, aligned with existing maintenance and operational cycles, would expand system capacity more effectively than further enlargement of conventional infrastructure. The paper outlines a practical pathway for integrating SUDS into routine planning and operations, enabling the city's drainage system to adapt to intensifying rainfall without relying on large-scale capital upgrades.

Keywords: Pluvial Flooding; Stormwater Management; Sustainable Urban Drainage Systems; Urbanisation, Urban Failure

2 INTRODUCTION

2.1 Background

Durban's stormwater system is no longer fit for purpose. At first glance, it is clear that the municipal structures within the province of KwaZulu-Natal are battling to maintain and improve the stormwater management system that continues to fail. During the April 2022 floods, disaster management was unprepared and could not manage the effects of a sudden heavy rainfall period, as seen below, the aftermath is devastating (Hattingh, 2022).

The April 2022 floods represented a critical stress test of this system. Extreme rainfall, concentrated over short durations, rapidly exceeded the hydraulic capacity of pipes, culverts, and open channels across multiple catchments (Muthanna et al., 2018). Widespread surcharge, overtopping, and structural failure occurred, often outside historically mapped floodplains. Damage patterns revealed that failures were not isolated to individual assets but reflected systemic overload, compounded by sediment accumulation, debris blockage, and limited redundancy within the network (Bond & Galvin, 2023). The event exposed the vulnerability of a drainage system designed to move water away quickly, with little capacity to store, delay, or absorb runoff within the urban landscape.

Post-flood assessments highlighted that upgrading conventional infrastructure alone is neither technically nor financially feasible at the scale required to match projected rainfall intensification. Large-scale pipe replacement would involve significant disruption, high capital costs, and long implementation horizons, while still relying on static design assumptions in a context of climatic uncertainty (Martel et al., 2021). This has prompted growing interest in alternative approaches that can enhance system performance without complete infrastructural overhaul (Emmett, 2023).

Within this context, Sustainable Urban Drainage Systems have emerged as a credible resilience pathway. SUDS shift the focus of stormwater management from rapid conveyance to distributed control, aiming to

replicate natural hydrological processes through infiltration, detention, and controlled release (Grab, 2023). Rather than replacing existing drainage infrastructure, SUDS can be retrofitted into the urban fabric to intercept runoff at or near its source, reducing hydraulic loading on downstream systems (O'Donoghue et al., 2022). This approach is particularly relevant for Durban, where spatial constraints and uneven development patterns limit the scope for conventional expansion.

The relevance of SUDS to Durban's 2022 flood experience lies in their capacity to address the specific mechanisms of failure observed during the event. By attenuating peak flows, delaying runoff response, and improving runoff quality, targeted SUDS retrofits can extend the effective capacity of existing drainage assets under extreme rainfall. Importantly, SUDS enable a shift towards catchment-based stormwater management, allowing interventions to be prioritised in areas of greatest hydrological risk rather than applied uniformly across the city (McLeod & Mickovski, 2024).



Image 1: oThongathi post 2022 floods, Captured for Mail and Guardian (2022)

Grab & Nash (2023) expanded their initial thesis by outlining the flood chronology for KwaZulu-Natal, wherein they uncovered interesting insights into the manifestation of urban decay since 1836, leading up to and including the 2022 floods. A common thread of identifying municipal neglect and targeted funding (in more affluent areas) showed the true face of failure as a consequence of urbanisation.

2.2 Introduction

Durban's 2022 floods exposed a fundamental mismatch between the city's evolving hydrological conditions and its outdated stormwater system. Temporally, it is notable to realise that a city built for around 400,000 (four hundred thousand) inhabitants is now home to almost 4,000,000 (four million) people (World Population Review, 2025).

The drainage network, much of it designed for mid twentieth century rainfall and smaller catchments, now functions close to capacity under ordinary conditions and fails rapidly during extreme events (eThekwini Municipality, 2020). Given that many of Durban's existing drainage systems were not designed to handle the increased stormwater volumes resulting from urban expansion and climate change, prioritising the retrofitting of these systems is imperative (Gumbo, 2014). A large-scale initiative should be launched to upgrade conventional drainage infrastructure by incorporating SUDS components that can effectively slow down, capture, and filter stormwater. Special attention should be given to flood-prone areas identified

through flood risk maps and rainfall data. By targeting these high-risk regions for retrofitting, the initiative can maximise the impact on flood mitigation and improve overall urban resilience.

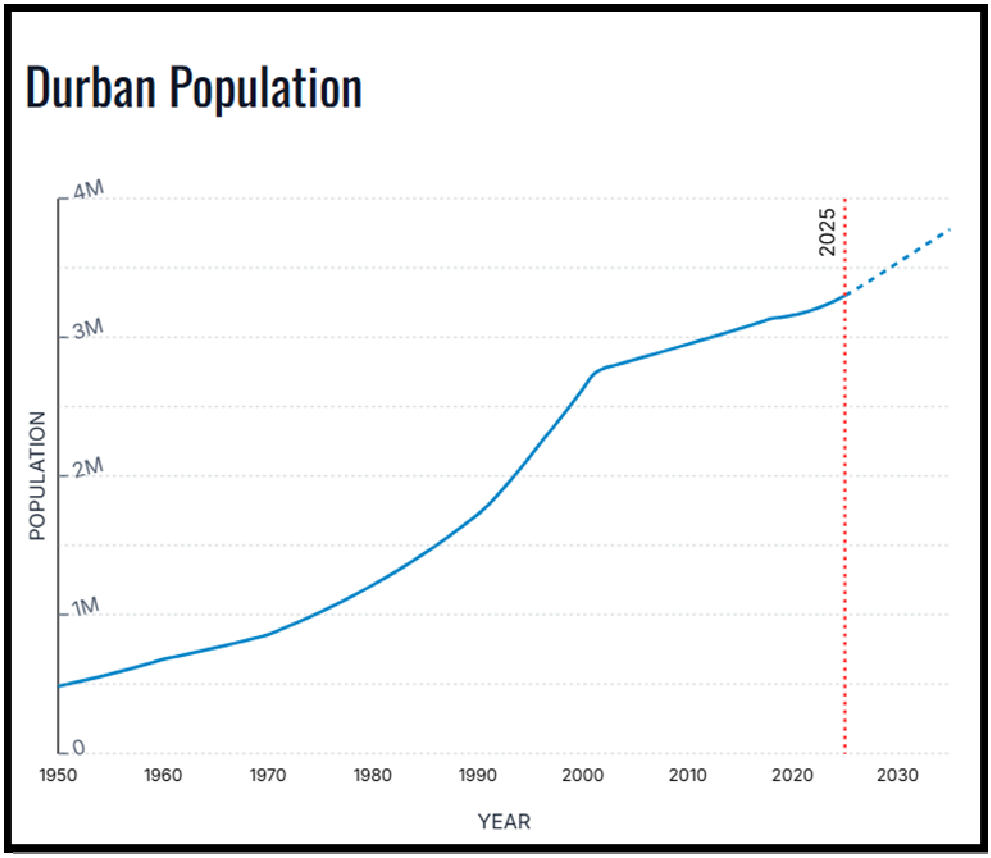


Figure 1: World Population Review: Durban Population 1950 – 2025 (2025)

2.2.1 Problem Statement

Durban's stormwater drainage system is structurally and operationally misaligned with current and projected hydrological conditions. Infrastructure designed for mid twentieth century rainfall regimes and smaller, less impervious catchments now operates at or near capacity during routine storms and fails disproportionately during extreme rainfall events. The 2022 floods revealed that this mismatch is compounded by systemic constraints, including undersized conveyance elements, disrupted natural drainage pathways, inconsistent maintenance and limited flexibility within a highly centralised, pipe-based network. As a result, localised drainage exceedance rapidly propagates into widespread flooding, particularly in dense and low-lying urban areas. Despite growing recognition of Sustainable Urban Drainage Systems, Durban lacks an evidence-based framework that identifies which SUDS functions can realistically address these failures within the city's geomorphological, institutional and operational context. Current planning responses remain biased towards conventional infrastructure upgrades that are capital-intensive and slow to implement. The core problem is therefore the absence of a practical, context-specific approach for retrofitting the existing stormwater system to manage increased runoff volumes and rainfall intensity without relying on large-scale network expansion.

2.2.2 Research Question

- How can targeted SUDS retrofits improve the performance of Durban's existing stormwater system under intensified rainfall conditions, as exposed by the 2022 floods?

3 LITERATURE REVIEW

Rapid urbanisation in many developing cities has led to increased flooding and strain on traditional drainage systems, but SUDS adoption remains slow due to the upfront costs and lack of technical expertise (Carbonell et al., 2023). While some developing countries have initiated pilot projects and recognised the long-term cost savings of SUDS, widespread implementation is still hindered by insufficient infrastructure investment and a

lack of integrated urban planning approaches. Nonetheless, there is growing awareness of the need for sustainable stormwater management, particularly in areas vulnerable to climate change (Archer et al., 2020).

Despite these challenges, developing countries have valuable opportunities to learn from the experiences of developed nations. By prioritising green infrastructure, fostering community engagement, and encouraging collaboration across sectors, they can gradually transition from traditional drainage systems to more sustainable alternatives (Qiao et al., 2018). Pilot projects, coupled with education on the long-term benefits of SUDS, can help build momentum for larger-scale implementation (Li et al., 2024). Strengthening policy frameworks and leveraging data-driven tools for flood risk management can enhance urban resilience in developing regions, helping them better cope with increasing stormwater challenges and the impacts of climate change, as emphasised by the objective of this study.

3.1 The Norm – Traditional Design

Conventional stormwater management in urban areas has long relied on grey infrastructure networks designed to convey runoff away from built environments as quickly as possible. Pipes, culverts, lined channels and detention basins form the backbone of these systems. They were engineered for historical rainfall regimes that assumed relatively stable intensity patterns and predictable peak flows (Raut, 2023). Under contemporary hydrological conditions, shaped by climate variability and increasingly frequent high-intensity storm events, these systems are performing beyond their design thresholds. International studies have documented the diminishing effectiveness of end-of-pipe infrastructure, especially where catchments have been progressively hardened through urbanisation (Nguyen et al., 2024).

In South Africa, the problem is compounded by maintenance backlogs that undermine hydraulic capacity. Blocked drains, silted channels and damaged culverts reduce conveyance efficiency even under moderate rainfall.

Municipal audits across major metros report escalating asset renewal deficits, and the practical reality is that many stormwater networks are operating with components nearing or exceeding their design life (Woods-Ballard et al., 2016). Capacity expansion through pipe upsizing offers diminishing returns in dense urban environments where space is limited, and capital budgets are constrained. These constraints highlight an emerging structural mismatch between traditional grey systems and the hydrological pressures of modern urban climates (Sørensen & Pedersen, 2023).

3.2 The Literature Position

The increasing frequency and intensity of extreme rainfall events under climate change has exposed the structural limitations of conventional urban stormwater systems worldwide. Many cities in the Global South, including Durban, rely on drainage networks designed using historical rainfall data, static design storms, and assumptions of lower imperviousness (Chapa et al., 2020). The April 2022 floods in Durban revealed the consequences of this mismatch, as widespread pipe surcharge, channel overtopping, and infrastructure collapse occurred even outside designated floodplains. Within this context, the literature increasingly positions Sustainable Urban Drainage Systems (SUDS) retrofits as a pragmatic adaptation strategy for improving the performance of existing stormwater systems under intensified rainfall conditions (Paule-Mercado et al., 2022).

A central theme in the literature is that conventional piped drainage systems prioritise rapid conveyance of runoff, transferring flood risk downstream rather than managing it within the catchment. This design philosophy becomes problematic under intensified rainfall, where peak flows exceed pipe capacity and failure cascades through the network (SUDS Team (UK), 2011). SUDS represent a fundamentally different approach, aiming to replicate pre-development hydrological processes by slowing runoff, increasing infiltration, and providing distributed storage. Numerous modelling and empirical studies demonstrate that SUDS interventions can reduce peak discharge, delay time to peak, and lower total runoff volumes entering conventional drainage systems during extreme rainfall events. These effects are particularly pronounced when SUDS are implemented as source controls within highly impervious urban catchments (Hathaway et al., 2024).

The literature on SUDS retrofitting emphasises that meaningful hydrological benefits do not require wholesale system replacement (Kalore et al., 2024). Targeted retrofits, strategically located within critical sub-catchments or upstream of known hydraulic bottlenecks, can significantly improve overall system

performance (Alhama et al., 2024). Studies from dense urban environments show that even partial retrofitting, involving relatively small proportions of a catchment area, can produce disproportionate reductions in flood peaks by attenuating runoff before it reaches overstressed pipes and culverts (Mishra et al., 2024; Yazdanfar & Sharma, 2015). This finding is especially relevant to Durban, where spatial constraints, informal development, and legacy infrastructure limit opportunities for large-scale system redesign.

Specific SUDS components are repeatedly identified as effective retrofit measures. Bioretention systems, infiltration trenches, permeable pavements, detention basins, and green roofs have been shown to perform well under high-intensity rainfall when appropriately designed and maintained (Irvine et al., 2023; Kuller et al., 2017; Zubelzu et al., 2019). Bioretention and detention systems are particularly valuable in retrofit contexts because they provide both storage and controlled release, reducing hydraulic loading on downstream infrastructure. Permeable pavements and infiltration-based measures are effective in reducing directly connected impervious areas, a key driver of rapid runoff generation in urban catchments (Cheshmehzangi et al., 2024). The literature cautions, however, that infiltration-based systems must be carefully assessed in relation to soil conditions, groundwater levels, and slope stability, all of which are critical considerations in Durban's varied topography.

Beyond hydraulic performance, the literature highlights the co-benefits of SUDS retrofits, including water quality improvement, erosion control, urban cooling, and enhanced public space. These co-benefits are not incidental but reinforce system resilience by reducing sedimentation in pipes, limiting channel degradation, and improving post-event recovery. In Durban, where stormwater infrastructure frequently doubles as informal waste conveyance, the pollutant removal capacity of SUDS is particularly relevant. Several studies in South African and comparable contexts demonstrate reductions in nutrient and sediment loads following SUDS implementation, suggesting that retrofits can simultaneously address flooding and environmental degradation (Irvine et al., 2023; Kuller et al., 2017; Parvanehdehkordi et al., 2024).

The governance and institutional dimensions of SUDS retrofitting receive increasing attention in the literature. Technical effectiveness alone does not guarantee improved system performance over time. Successful retrofits depend on integration with municipal planning frameworks, clear maintenance responsibilities, and long-term monitoring. Fragmented governance, limited technical capacity, and budgetary constraints are commonly cited barriers in developing city contexts. The literature argues that targeted SUDS retrofits are most effective when embedded within broader flood resilience strategies, rather than implemented as isolated pilot projects (Kalore et al., 2024). For Durban, this implies aligning SUDS retrofits with asset management systems, spatial development frameworks, and climate adaptation policies.

A further strand of the literature addresses the importance of spatial targeting and catchment-based planning. Hydrological modelling studies consistently show that the location of SUDS interventions matters as much as their type or size (Hathaway et al., 2024; State Government Victoria, 2005). Retrofits placed upstream of critical infrastructure, within rapidly responding sub-catchments, or near known failure points yield greater system-wide benefits than evenly distributed interventions. This insight is directly applicable to Durban, where flood impacts in 2022 were concentrated in specific valleys, transport corridors, and informal settlements situated along constrained drainage routes (Yang et al., 2021).

In synthesis, the literature provides strong evidence that targeted SUDS retrofits can materially improve the performance of existing stormwater systems under intensified rainfall conditions. By attenuating peak flows, reducing runoff volumes, and delaying system response times, SUDS extend the functional capacity of legacy infrastructure without requiring extensive pipe replacement. The Durban floods of 2022 exemplify the risks of relying solely on conventional drainage approaches and underscore the need for adaptive, distributed stormwater management. The literature therefore supports a shift towards strategically planned SUDS retrofits as a central component of urban flood resilience in Durban and similar cities facing accelerating hydrological change.

4 METHODS

This study adopted a qualitative–analytical case study approach to examine the failure of Durban's stormwater system during the April 2022 floods and to evaluate the potential of targeted Sustainable Urban Drainage System (SUDS) retrofits as a pathway to improved resilience. Durban was selected as an

instrumental case because the 2022 flood event represented an extreme but plausible manifestation of projected climate-driven rainfall intensification in coastal African cities, exposing systemic weaknesses in legacy urban drainage infrastructure.

The methodological framework combined documentary analysis, spatial assessment, and synthesis of stakeholder evidence to link observed failure mechanisms with feasible retrofit responses. Rather than attempting to quantify flood magnitudes or replicate hydraulic simulations, the study focused on understanding how and why the existing stormwater system failed, and how alternative drainage approaches could realistically modify system behaviour under similar conditions (Martinko & Gardner, 2019; Saunders et al., 2003).

Data sources comprised three primary components. First, post-event reports, municipal documentation, and published assessments relating to the 2022 floods were reviewed to identify patterns of stormwater infrastructure failure, including pipe surcharge, culvert blockage, channel erosion, and structural collapse (eThekwini Municipality, 2020b; Lopes et al., 2023). These sources provided insight into the spatial distribution of damage and the operational limitations of the drainage network during extreme rainfall. Second, peer-reviewed literature on urban drainage performance, climate change impacts on rainfall, and SUDS retrofitting was analysed to establish a theoretical and empirical basis for evaluating alternative stormwater management strategies. This literature informed the identification of key performance mechanisms through which SUDS influence runoff behaviour, such as peak flow attenuation, storage, infiltration, and controlled release.

Third, stakeholder evidence derived from ward-level inputs was incorporated to contextualise technical findings within on-the-ground experience. Ward councillor questionnaire responses from flood-affected areas in eThekwini Municipality were analysed to capture local observations regarding drainage failure, maintenance challenges, and flood impacts (Moosa, 2025). These responses were not treated as statistically representative but as corroborative qualitative evidence supporting the identification of recurring failure modes and governance constraints.

Analytical synthesis was undertaken through a structured comparison between observed stormwater system failures and the functional attributes of SUDS (Bukhari et al., 2025; Weimer & Vining, 2017). Failure mechanisms identified during the 2022 floods were categorised into hydraulic overload, rapid runoff concentration, loss of conveyance capacity due to blockage, and limited system adaptability. These categories were then systematically mapped against SUDS functions documented in the literature to assess how targeted retrofits could mitigate each failure mode. This mapping exercise formed the basis for deriving the findings and developing the proposed implementation framework.

Spatial considerations were incorporated at a conceptual level by linking flood impacts to catchment characteristics such as imperviousness, slope, and drainage constraints, as reported in post-event assessments. While no new hydrological modelling was conducted, existing studies and municipal analyses were used to support arguments for catchment-based targeting of SUDS retrofits rather than uniform city-wide application.

The outcome of this methodological approach was the development of an evidence-informed framework for targeted SUDS retrofitting tailored to Durban's stormwater context. The framework integrates technical, spatial, and institutional dimensions and is grounded in the specific failure patterns exposed by the 2022 floods. This approach ensures that the study's conclusions are directly linked to observed system behaviour and practical implementation constraints, rather than abstract or idealised drainage models.

This methods design is appropriate for addressing the research question, as it prioritises explanatory insight and applicability to real-world planning and policy decisions over purely predictive modelling.

5 FINDINGS AND CONCLUSION

The analysis indicates that targeted Sustainable Urban Drainage System (SUDS) retrofits can substantially improve the functional performance of Durban's existing stormwater system under intensified rainfall conditions by addressing the key failure mechanisms exposed during the 2022 floods (Grab & Nash, 2023). These improvements are not achieved through wholesale system replacement, but through strategically placed interventions that reduce hydraulic stress on legacy infrastructure.

The first major finding is that peak flow attenuation at source is the most critical performance gain offered by SUDS retrofits. Evidence from post-flood assessments and supporting hydrological studies shows that Durban's stormwater failures were primarily driven by rapid runoff concentration from highly impervious catchments into undersized pipes and culverts (Moosa, 2025). Targeted SUDS retrofits such as bioretention cells, detention basins, and permeable surfaces reduce the volume and rate of runoff entering the drainage network during extreme rainfall. By temporarily storing and slowly releasing stormwater, these measures lower peak discharges and delay the timing of flows, reducing the likelihood of pipe surcharge and surface flooding during high-intensity events (Knight, 2024).

Secondly, the findings show that strategic spatial placement of SUDS retrofits yields disproportionate system-wide benefits. Flood damage during the 2022 event was not evenly distributed across Durban, but concentrated in specific sub-catchments characterised by steep slopes, high imperviousness, and constrained drainage corridors. Modelling and empirical evidence indicate that retrofits placed upstream of known hydraulic bottlenecks, within fast-responding sub-catchments, and adjacent to critical infrastructure significantly reduce downstream flood impacts (Moosa, 2025). This confirms that SUDS effectiveness in Durban depends less on total area treated and more on informed spatial targeting aligned with catchment hydrology.

A third finding relates to the extension of effective capacity of existing infrastructure. Rather than replacing ageing pipes and channels, SUDS retrofits function as distributed pre-treatment systems that reduce the hydraulic demand placed on conventional drainage assets. During the 2022 floods, many failures occurred because infrastructure designed for mid twentieth century rainfall was operating beyond its design envelope (Knight & Grab, 2018). The findings suggest that SUDS retrofits effectively increase the tolerance of these systems to extreme rainfall by lowering inflow volumes and reducing flow velocities, thereby delaying structural failure and limiting erosion, scour, and collapse.

The findings further demonstrate that runoff quality improvement contributes indirectly to system performance and resilience (Parvanehdehkordi et al., 2024; Sewwandi et al., 2024). Post-flood inspections revealed extensive blockage of drains and culverts due to sediment, debris, and waste mobilisation. SUDS elements such as vegetated swales and bioretention systems trap sediments and pollutants upstream, reducing the risk of blockage and loss of hydraulic capacity during storm events (Irvine et al., 2023). This function is particularly important in Durban, where stormwater infrastructure frequently operates as a de facto solid waste conveyance system. Improved water quality management therefore supports hydraulic performance during extreme rainfall, not merely environmental outcomes (SUDS Team (UK), 2011; Zhang et al., 2024).

Another significant finding is that SUDS retrofits are most effective when implemented as part of a catchment-based system rather than isolated interventions. Standalone SUDS installations provide localised benefits but have limited impact on large-scale flood behaviour unless coordinated within a broader drainage strategy (Jacklin et al., 2021; Li et al., 2024b). The evidence indicates that integrated retrofit networks, combining source controls, conveyance attenuation, and downstream detention, offer the greatest reduction in flood risk under intensified rainfall (Moosa, 2025). This systems-based approach aligns with the observed cascade failures during the 2022 floods, where upstream overloads propagated rapidly through the drainage network.

Finally, the findings highlight that institutional and maintenance factors materially influence SUDS performance under extreme conditions. Poor maintenance of conventional stormwater assets exacerbated flood impacts in 2022, and similar risks apply to SUDS retrofits if governance structures are weak (Moosa, 2025). However, the literature and case evidence suggest that SUDS retrofits, when embedded within municipal asset management frameworks, can improve long-term system adaptability and resilience. Their modular nature allows for incremental expansion and adjustment as rainfall patterns continue to intensify, offering a flexible response to climate uncertainty.

The findings demonstrate that targeted SUDS retrofits improve Durban's stormwater system performance by attenuating peak flows, extending infrastructure capacity, reducing blockage risk, and enhancing system adaptability under extreme rainfall. The 2022 floods exposed the limits of conveyance-based drainage alone, and the evidence supports a shift towards spatially targeted, catchment-scale SUDS retrofits as a practical and scalable resilience pathway for Durban's evolving hydrological conditions (Grab & Nash, 2023).

5.1 What does this mean for policy?

The findings have clear implications for stormwater governance, infrastructure planning, and climate adaptation policy in Durban. First, they indicate that flood resilience can no longer be achieved through incremental upgrades of conventional drainage infrastructure alone. Municipal policy must formally recognise SUDS retrofits as essential stormwater assets rather than supplementary or experimental interventions. This requires their integration into stormwater design standards, capital planning frameworks, and infrastructure investment priorities (Barrett & Fudge, 2025).

A key policy implication is the need to shift from asset-based planning to catchment-based stormwater management (Van Niekerk, 2014). The spatially concentrated failures observed during the 2022 floods demonstrate that uniform design standards are inadequate in a context of highly variable topography, land use, and hydrological response. Policy frameworks should therefore mandate catchment-level flood risk assessments to guide the placement of SUDS retrofits upstream of known hydraulic constraints, high-risk communities, and critical infrastructure. This approach enables targeted investment where system performance gains are greatest (Muzioreva et al., 2022; Vasconcelos et al., 2022).

The findings further imply that retrofitting SUDS offers a cost-effective alternative to large-scale pipe replacement, particularly in dense or informally developed areas where conventional upgrades are technically difficult and socially disruptive. Policy should explicitly prioritise SUDS retrofits in capital budgeting processes as a means of extending the functional life of existing infrastructure under intensified rainfall (Department of Agriculture and Rural Development, 2020; Mishra et al., 2024). This is especially relevant in resource-constrained municipal environments, where adaptation measures must deliver maximum benefit per unit of expenditure.

Another important implication concerns maintenance and institutional responsibility. The 2022 floods exposed systemic weaknesses in stormwater asset maintenance, including blockages, sediment accumulation, and structural deterioration (Adebayo et al., 2023; Govender & Cloete, 2023). SUDS retrofits will only improve system performance if they are embedded within clear governance arrangements that define ownership, maintenance schedules, and performance monitoring. Policy must therefore align SUDS implementation with municipal asset management systems and ensure that long-term operational responsibilities are formally assigned and funded (eThekwini Municipality, 2020).

The findings also support a policy emphasis on multi-functional infrastructure. By improving runoff quality, reducing sediment transport, and mitigating erosion, SUDS retrofits deliver co-benefits that reduce downstream maintenance costs and environmental degradation (Govender & Cloete, 2023). Recognising these benefits in policy appraisal frameworks strengthens the case for SUDS investment beyond flood control alone. This is particularly important in Durban, where stormwater systems intersect with ecological assets, informal settlements, and coastal environments.

Finally, the evidence underscores the need for adaptive and incremental implementation pathways. Given ongoing climate uncertainty, policy should enable flexible scaling of SUDS retrofits rather than reliance on fixed design thresholds. The modular nature of SUDS allows for phased expansion as rainfall intensifies and urban development patterns evolve (Moosa, 2025). Embedding this adaptive logic into stormwater policy positions Durban to respond proactively to future flood risk rather than reactively to disaster events.

5.2 The Final Summation

The findings imply that effective stormwater adaptation in Durban requires a policy transition from conveyance-dominated drainage towards integrated, catchment-based SUDS retrofitting. Such a shift aligns infrastructure performance with contemporary hydrological realities and provides a practical, scalable pathway for improving urban flood resilience under intensified rainfall conditions.

The April 2022 floods exposed a structural misalignment between Durban's stormwater system and the city's current hydrological regime. Infrastructure designed for mid twentieth century rainfall intensities and smaller, less impervious catchments proved unable to accommodate contemporary runoff volumes, leading to widespread surcharge, overtopping, and infrastructure failure. The evidence presented in this study confirms that these failures were systemic rather than incidental, reflecting the limitations of a conveyance-dominated drainage paradigm under intensified rainfall conditions.

This study demonstrates that targeted Sustainable Urban Drainage System (SUDS) retrofits provide a viable and effective means of improving the performance of Durban's existing stormwater system without requiring wholesale infrastructure replacement. By attenuating peak flows, delaying runoff response, and reducing inflow volumes to overstressed pipes and culverts, SUDS retrofits extend the functional capacity of legacy drainage assets. Crucially, the findings show that the effectiveness of SUDS is strongly dependent on spatial targeting. Interventions located within fast-responding sub-catchments, upstream of known hydraulic bottlenecks, and adjacent to vulnerable communities yield significantly greater system-wide benefits than dispersed or ad hoc installations.

The study further finds that SUDS retrofits enhance stormwater system resilience through mechanisms beyond hydraulic attenuation alone. Improvements in runoff quality and sediment control reduce the risk of blockage and loss of capacity during extreme events, which were prominent contributors to damage during the 2022 floods. When implemented as connected networks rather than isolated features, SUDS retrofits improve system adaptability, allowing the drainage network to respond more robustly to climate uncertainty and progressive urban densification.

To translate these findings into practice, the study advances a structured implementation framework for eThekwini Municipality. The framework emphasises catchment prioritisation based on observed flood impacts, targeted selection of SUDS typologies aligned with local physical conditions, and formal integration of SUDS into municipal asset management systems. It proposes phased implementation beginning in the most flood-affected sub-catchments, supported by continuous monitoring and adaptive management to accommodate evolving rainfall patterns. Community interface and maintenance governance are identified as integral components, ensuring that SUDS function as durable infrastructure rather than short-term interventions.

The inclusion of this framework underscores that improved stormwater performance is not solely a technical design challenge but an institutional and planning one. Without alignment between hydrological analysis, capital programming, and long-term maintenance responsibilities, the potential



Figure 2: Sustainable Urban Drainage Systems vs Traditional Drainage Systems (Moosa, 2026)

In conclusion, this study argues that Durban's stormwater resilience depends on a deliberate shift from rapid conveyance towards distributed, catchment-based runoff management. Targeted SUDS retrofits, implemented through a structured and institutionally embedded framework, offer a practical, scalable, and adaptive response to the failures exposed by the 2022 floods. This approach provides a defensible pathway

for enhancing urban flood resilience in Durban and offers broader lessons for other rapidly urbanising cities confronting similar hydrological transitions.

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Urban Mining Reloaded: Scanning Building Elements with Gaussian Splatting

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1 ABSTRACT

The construction sector is one of the largest consumers of raw materials. This consumption can be reduced through reuse and recycling of building materials and elements that have reached their end-of-life. However, there is a lack of information on the existing building stock as well as missing information on re-usable building elements suitable to be integrated into architectural design. This paper addresses both areas by presenting methods to estimate the availability of urban materials from city models and by exploring novel approaches for scanning 3d elements using Gaussian splatting. We discuss practical experiments on case studies of buildings in the city of Vienna, Austria. To estimate the material stock, 3d models (LOD 2.1 CityGML) were enriched with GIS data on building periods and typical basement heights from those periods – information which are not included in the surface geometry of the city models. From the evaluation of case studies that were surveyed with detailed representation of geometry and materials and subsequently converted into BIM models, material intensities were determined for specific building types. These data allow rough estimations of the material stock for similar buildings based on gross volume calculations. To provide resources for the re-use of building elements, Gaussian splatting as a digitalization technique was chosen to reduce the deficits of traditional methods like laser scanning and photogrammetry, which often fail when capturing objects consisting of transparent or reflective materials (e.g. glass). We present the integration of 3d objects represented as Gaussian splats into an application for early architectural design (MR.Sketch) and describe the process of converting Gaussian splats into point clouds for the use in BIM environments.

Keywords: urban mining, gaussian splatting, building stock, planning, cities

2 BUILDING LIFE CYCLES

The life story of a building usually encompasses its creation in the past, including planning and construction, its use and maintenance, and finally its eventual decay or demolition. If we also take into account the building materials used in this life cycle, it can be extended to include the origin, type and properties of the materials, their behaviour during the ageing process, and their proper disposal or meaningful recycling. Especially in today's world of resource shortage and conscious care for the environment, these considerations should be at the centre of the planning process. By using Building Information Modelling (BIM) these phases are reflected in a digital model that very often ends when the building gets demolished. This paper discusses the final phase in the existence of a building, namely its demolition or disassembly and its recycling or re-use [RASHID 2015]. The focus is on the re-use of materials and building elements that might not be considered as waste, but as valuable resources and could be integrated into the design phase of a new building. However, the planning for recycling and reuse of materials and building elements requires additional tools and methods, which are rarely present in a traditional BIM workflow. We will address some of these issues and present concepts, methods and technologies that can help to reduce these deficits.

3 URBAN MINING OF MATERIALS

The aim is to investigate how the potential of building materials can be systematically assessed and quantified. The urban mining potential of a city could be calculated using contemporary three-dimensional city models. However, despite constantly increasing accuracy in visual and geometric detail, these models lack information regarding the internal composition of materials. City models are often generated by remote sensing methods, like airborne laser scanning, photogrammetry with drones, sometimes in combination with terrestrial scanning methods attached to vehicles. These strategies allow fast updates of a surface model of an urban environment. The missing parts of the remotely sensed models are the basements and foundations and the interior parts of a building. It would be possible to integrate BIM models from contemporary digital planning resources, but the existing building stock would still miss this information. We will describe a method that allows the estimation of the material stock from an urban surface model of a building. We used

the CityGML model (LOD 2.1) from the city of Vienna to demonstrate the practical application. A first approach of this method was generated by [KLEEMANN 2016], using a 2D polygonal surface, the built footprint of a building and height information stored in GIS layers as part of the Open Government Data (OGD) of Vienna, as well as estimations from experts about basement heights. The resulting calculation of a gross volume of a building for a certain building period and building use (mainly residential buildings) was used to be scaled by material intensities of similar buildings. These reference buildings were surveyed in detail to obtain a relationship between gross volume of the building and its quantitative distribution of building materials. We extended this method to calculate a more accurate gross volume from the CityGML (LOD 2.1) model (supplied by MA41, part of the city administration of Vienna), that contains a more accurate geometric representation of the roof volume. To estimate the gross volume of the basement we sampled various analogue plans of reference buildings (supplied by MA37, city administration of Vienna) to calculate an average basement height for a particular building type and building period. Further details of the entire workflow are described in [HONIC 2023], which describes some of the developed methods from the applied research project BIMstocks [BIMstocks n.d.].

To provide web-based access to the estimation of available material stock an interactive 3d application has been developed with the aid of the CESIUM library [CESIUM n.d.]. (See the web application visualization in [Fig. 1]) Hereby buildings can be selected, a 3d bar chart provides an estimation of the material distribution and the results of the calculation can be exported for further planning purposes.

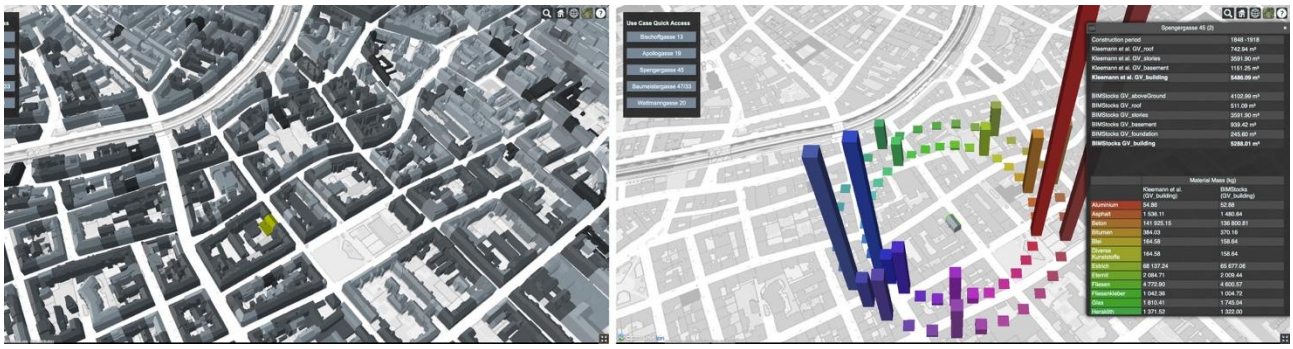


Fig. 1: Interactive web application to calculate the urban mining potential for a building in Vienna.

4 URBAN MINING OF BUILDING ELEMENTS

In the past, building materials or entire parts of buildings that had fallen into ruin or been demolished were reused for secondary purposes. This practice of using spolia can be traced back to antiquity, when decorative or structural architectural elements such as blocks, columns, reliefs, friezes, capitals or portals from destroyed or abandoned monuments were integrated into new buildings with a changed function and in new architectural contexts. Historically, the use of spolia combined economic rationality with iconographic and symbolic significance, as both material and cultural value were preserved and at the same time recontextualised. In the present day, the use of spolia not only corresponds to the guiding principles of sustainable architecture and resource conservation, but also contributes to a greater reflection on cultural heritage and underlines the continuity between historical and contemporary building practices. This raises the question of how building elements can be documented to facilitate their effective integration into future design processes. To extend the availability of reuse of building materials to entire building elements, the applied research project MHUB [MHUB n.d.] addresses several aspects in creating a web-based distribution system for that purpose. Early approaches from industrial partners, such as materialnomaden [MATERIALNOMADEN n.d.] indicate first attempts for a market for the reuse of building elements. Since our work centers on advancing strategies for recycling and reuse,from the existing infrastructure a necessity for a quick, cost effective and visually accurate method to scan building elements seemed desirable. The experience with photogrammetry in previous projects suggested this method, due to its flexible, scalable, cost effective and accurate results. Hereby images are taken from different viewing directions that can be processed into accurate 3d models consisting of highly detailed meshes with detailed color distributions stored in texture maps. However, some experiments showed that not all building elements are suitable to be scanned by photogrammetry. Especially transparent materials (like glass) or reflective surfaces (like metal) proved to be very difficult to digitize with this method. A recent development of a new methodology called

"Gaussian splatting" seemed a promising approach to overcome the deficits of photogrammetry. The following sections of the paper will describe a practical approach to scan building elements with Gaussian splatting and to make the resulting 3d objects usable for design purposes in architecture.

4.1 Scanning with Photogrammetry versus Scanning with Gaussian Splatting



Fig. 2: Scanning a glass brick. Left image, 3d model with photogrammetry; right image, 3d model represented as Gaussian splats.

There are several established techniques to scan objects to create 3d models, such as laser scanning [SCAIONI 2025] and photogrammetry [FENG 2025]. However, Gaussian splatting [KERBL 2023] is an emerging new approach, with properties that elevate it from previous methods, especially in terms of visual fidelity.

As described above, a common basis of photogrammetry and Gaussian splatting is that 3d representations are computed from real, captured images from different viewpoints. While photogrammetry yields explicit geometry and textures, fitting for traditional rendering pipelines, it often fails at objects that are highly specular, translucent/transparent (see [Fig. 2] for the difference in visual fidelity and refer to [RAMIREZ 2025] for a summary of ongoing challenges) or self-emitting (light sources). On the other hand, Gaussian splatting uses implicit, volume-based radiance field data, enabling a high degree of visual fidelity in the aforementioned special cases as well. Gaussian splatting is an emerging technology, with current research aimed at both supporting capture and computations, as well as real-time rendering. Ongoing challenges include the integration of Gaussian splatting in traditional rendering and the isolation of specific parts of the scene (e.g. target objects). We will address these issues in the following sections.

4.2 Scanning Building Elements with Gaussian Splatting

We have evaluated two use cases of creating Gaussian splat representations of building elements: Capturing in-situ in condemned buildings and capturing building elements already removed and processed for re-use. The latter was possible with the help of our project partner materialnomaden [MATERIALNOMADEN n.d.], who specialize in developing processes for the re-use of salvageable construction material. The two use cases afford and require different approaches of creating input data for Gaussian splatting.

Capturing elements in-situ (e.g., doors, windows, tiles, armatures) imposes predominant constraints on the view angles and the lighting conditions. Building elements that are still mounted are obstructed by their surroundings (see [Fig. 3]), thus, depending on the environment, not all features can be captured accurately.

In contrast, building elements that have already been removed and processed can be captured with a high degree of control over the environment. This affords the ease of use of supporting equipment (lights, fiduciary markers and color control/correction tools) and the ability to capture target objects from arbitrary angles. This approach has the advantage of having references for scaling, matching parts of objects from different scanning runs and color-filtering. We will expand on these concepts in the following section.



Fig. 3: Rendering of the results from onsite scanning of building elements in Brush at a residential building in Vienna.



Fig. 4: Offsite scanning of extracted building elements from the stocks of materialnomaden [MATERIALNOMADEN n.d.].

4.3 Editing Gaussian Splats

Isolating a single object from a computed Gaussian splatting scene is a major challenge, since Gaussian splats do not have explicit geometry, but rather a volume of point-based distributions. During capture, the target object and its environment are visually interdependent. Shadows, reflections, refractions, light contributions may often not be attributed to a single object. Thus, editing a Gaussian splat scene for the purpose of object isolation requires a different approach from the geometry-based mesh editing workflow. To compute and edit the Gaussian splat scenes, we have relied upon standard applications, such as PostShot [POSTSHOT n.d.] and SuperSplat [SUPERSPLAT n.d.].

We have experimented with different techniques to separate target objects from the environment. Since many building elements are shaped rectangular, one effective technique is to use bounding boxes. Depending on the scene, we either set the world origin so that our target object is already axis-aligned, or we define the bounding box manually to encapsulate the target object. This way, we can eliminate a large number of undesired splats. In most cases, further depth-based and manual selection/deletion refinements allow for a good approximation of the target object. [Fig. 5]

In a second step, we experimented with color-based filtering. Capturing objects in an environment in which the near proximity of the target object is tightly controlled (e.g., a green screen backdrop), we filter splats according to their color contribution to the scene. Although this approach needs further development, early tests show promise in reducing the need for extensive manual editing.

A key challenge is that a too aggressive editing/reduction can result in unwanted visual artefacts. Object edges may become jagged, transparent objects may develop holes from certain viewpoints. Removing reflections of the original environment may result in an untrue object representation. To combat this, we proceeded in an iterative manner, filtering splats multiple times and evaluating the visual quality of target objects step-by-step. Additionally, we have created multiple versions of the same object with reduced splat

counts, to optimize them for different hardware environments. Although this is a considerable workload, our goal for future development is to use the acquired insights for automating filtering.

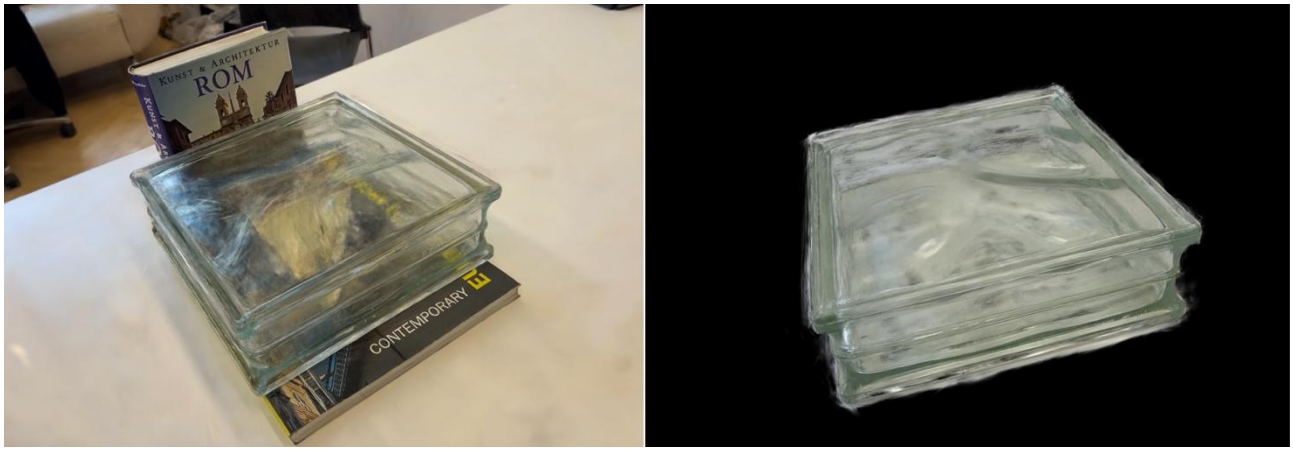


Fig. 5: Left image, original recorded splat distribution; right image, cleaned 3d model, as Gaussian splats.

4.4 Integration of Gaussian Splats into a 3D Sketching Application (MR.Sketch)

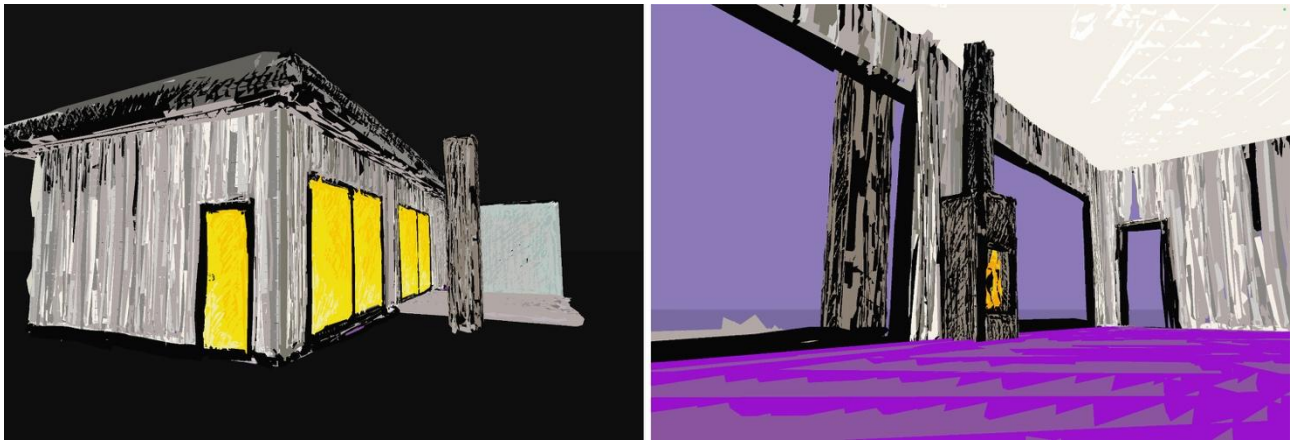


Fig. 6: 3d Sketches of a rooftop house, created with MR.Sketch.

Since our goal is to create a workflow for early architectural design, in which available building elements represented as Gaussian splats can be directly used, we experimented with their integration into 3d architectural sketches. For this task, we used our self-developed, mixed-reality capable 3d sketching application, MR.Sketch [KOVÁCS 2022][KOVÁCS 2023 A][KOVÁCS 2023 B]. This application was conceived to bridge the gap between unhindered, intuitive expression and computer aided design. It allows the creation of architectural sketches directly in 3d with user interactions akin to traditional sketching techniques. Creating architectural sketches directly in 3d enables real-time data exchange between different domain experts (structural engineers, material scientists), who can supply immediate feedback at the earliest stages of design for informed decision-making.

The user input in the application is mainly 3d freehand drawing. The designer can create 3d lines with a strong notion of where they are situated in relation to the virtual space and to the previous parts of the sketch. For this, we employed a projective drawing method, in which lines drawn on a tablet surface are projected onto a proxy geometry (drawing canvas) in 3d space. Refer to [Fig. 6] for exemplary 3d architectural sketches created with MR.Sketch.

However, traditional sketching is not limited to drawing. There are a host of techniques, such as sculpting, collage and montage, kit-bashing, etc. Using Gaussian splat representations of available building elements strongly relates to these techniques, since this approach allows combining existing elements, leading to the discovery of new spatial arrangements. The use of Gaussian splat representation allows for a flexible, yet still high-fidelity utilization of building blocks to map out the design space. Visual fidelity is of high value for this approach, as informed decisions made in the earliest design phase have the potential of a massive impact on project cost and sustainability. Deciding on elements purely by their technical details can lead to

unwanted results, resulting in rollbacks, increasing cost, time and environmental impact. Therefore, our goal with this approach is to convey not just the precise dimensions, but also the visual characteristics of available building elements to support informed decision-making at the earliest possible time in the architectural design process.

4.5 VR Visualisation of Gaussian Splats and Sketched Buildings



Fig. 7: Rooftop house: design proposal with a 3d sketch combined with elements as Gaussian splats, visualization in virtual reality.

One of the benefits of creating sketches directly in 3d is the possibility of visualizing the design concepts from multiple perspectives as well as in multiple scales, with different technical infrastructure. One highly effective approach is virtual reality, since this affords the designer the possibility to experience the structures and spaces in a 1:1, real world scale.

However, visualizing Gaussian splats in virtual reality is challenging, since the original technique of rendering is optimized for a single viewpoint/camera pose. In contrast, virtual reality requires two slightly shifted viewpoints to be rendered with adequate precision and low latency. We have based our experimental visualization application on the Gaussian Splatting Virtual Reality rendering package for Unity [GSVRUNITY n.d.].

Rendering a high number of splats comes with a high computational demand. Furthermore, inconsistencies in depth between the viewpoints, as a result of the sorting of the splat locations at render time can result in visual artefacts. To address the issue of achieving suitable latency, we have made scene-specific adjustments to the density of the computed Gaussian splats. Our goal was to reduce the number of splats, while retaining the visual characteristics of the building elements to a degree that is still suitable for design-oriented decision making. Although this approach currently involves considerable manual fine-tuning, it still can be considered as a proof of concept for the proposed workflow. A frame from our experimental virtual reality visualization application is depicted in [Fig. 7].

Ongoing development efforts focus on the automation of design goal specific reduction of Gaussian splats. As for the sorting issue in virtual reality, our observations yielded the conclusion that although depth related visual artefacts can be a distraction, it does not impede the design process. Our goal is to address this issue as well, but the priority in the given context is low.

4.6 Conversion of Gaussian Splats into Pointclouds for the integration into BIM

Unfortunately, the current CAD and BIM software landscape does not support the use of Gaussian splats in their applications. Maybe this situation might change in the near future, at the current moment strategies to

convert this new form of 3d representations to more widespread 3d formats is a necessary strategy for further planning and design methods. If the generation of splats is dense enough and their volume small enough a conversion to point clouds is a feasible strategy. Of course, this will result in a diminished visual quality of the appearance of the 3d object, but pointclouds are widely supported. We implemented a python script that converts each splat to a point in space, the color of the spherical-harmonics parameter is determined from its omnidirectional diffuse component. The resulting export as ASCII XYZ file can easily be imported in BIM software (e.g., ArchiCad) or 3d Modelling software (e.g., Rhino).

The example below [Fig. 8] shows the use of imported pointclouds, converted from Gaussian splats into ArchiCad. They were imported as Library objects, which allows an instantiated placement into an architectural design.

The building displayed is the sketched version of a Rooftop house, designed by Ingrid Erb with the integration of Gaussian splatting elements, like the glass door and the sink, in their pointcloud representation.

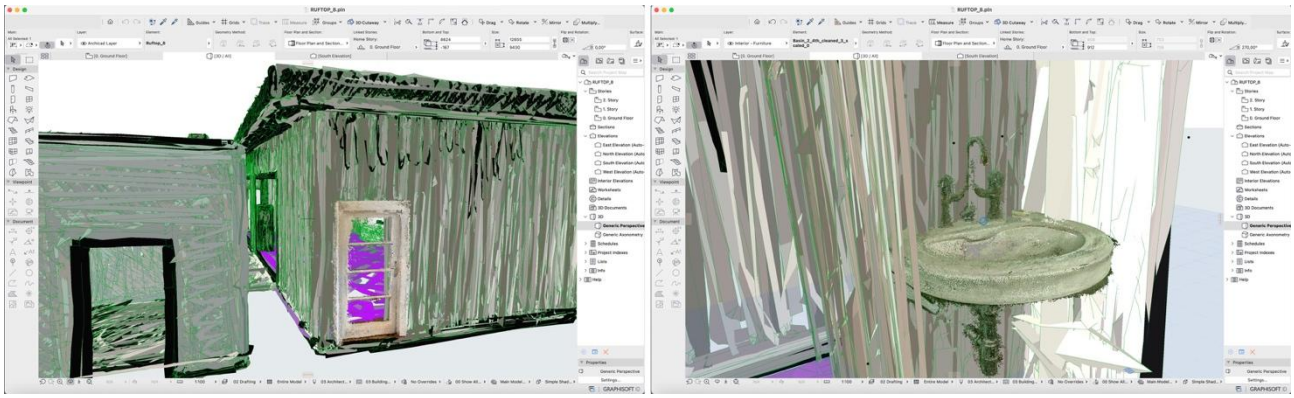


Fig. 8: Integration of building elements, converted from Gaussian splats to point clouds, into BIM software (ArchiCad).

5 CONCLUSION

We introduced several methods that can aid in generating urban mining infrastructures. Urban mining potential of materials could be estimated by evaluating gross volumes of buildings and suitable material indices. To increase the accuracy of material indices more samples of older building stock need to be performed. This might create necessities for destruction free sampling methods and fast and accurate scanning of the interior of buildings, while they are still occupied. For the integration of existing building elements, we introduced the application of Gaussian splatting for scanning building elements with a particular focus on transparent materials. The results of these experiments are very promising, as these high-fidelity visual representations can be used in an iterative design process consisting of early architectural sketching and virtual reality explorations. However, there is currently a lack of support for Gaussian splats in the contemporary BIM and CAD software. To address this issue, we provided a pragmatic approach by converting splats into points. Finally, the integration of building life cycles into urban planning will require more research activities and the improvement of four-dimensional city development strategies.

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[CESIUMn.d.] CesiumJS – 3D geospatial visualization for the web (online) https://cesium.com/platform/cesiumjs/

[MATERIALNOMADENn.d.] materialnomaden GmbH – circular design & architecture (online) https://www.materialnomaden.at

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reviewed paper

Urban Policies and Measures to Asdapt to Excessive Heat: Madrid and London

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1 ABSTRACT

The motivation for this paper is the recent, warrying increase in climate change denial, discouraging decisive action to accelerate both adaptation and mitigation measures, while dramatic climate change manifestations are on the increase. Surprisingly, countries that initially aligned themselves with the Paris Agreement are joining this trend, urging a reduction in the measures proposed to achieve net zero CO2 emissions, alleging a loss of competitiveness in the global market.Thesefacts are provoking reactions byglobal organisations, including COP30, as well as among politicians, academics and the media about how to stem this potential reversal.

Global warming is an all embracing phenomenon affecting all parts of the planet, and although its effects differ between countries and cities, they arose a wide range of responses, some tried and tested, others experimental and leading to innovation, at both governmental and city levels. This paper aims to identify these place-biased policies and practices whilelooking for possible commonalities of more general applicability, using as case study two cities situated in different climatic regions: Madrid, in a transition zone between the semi-arid temperate-cold climate and the mediterranean climate, and London, in a temperate maritime climate.

In both cases, climate change is generating new phenomena for which cities are not adapted. Madrid, with short springs and autumns, harsh winters and hot summers, attributes priority to measure against extreme heat which is increasing year on year. London with more even four seasons, undergoes increasing fluctuating temperatures, heavy rain falls, and high winds and storms from both the Atlantic and the Arctic, but its measures dealt with air pollution due to traffic, its key environmental problem. The focus of the paper is on concrete measuresto find possible common points of more general application, how they are being incorporated at national level in legislation and regulations, and how they are applied and tested in practice, at city level, city-wide, as well as in neighbourhoods and for buildings.

Keywords: climate change, cities, urbanism, urban heat, transformation

2 INTRODUCTION: CLIMATE CRISIS AND CITIES

The adoption of instruments and policies for the adaptation of cities to climate change began at the beginning of the 21st century[1], in response to the warnings issued by the scientific world since the 1970s. Implemented in different ways and with different degrees of effectiveness, their ability to cope with adverse weather conditions has been relative according to the specific circumstances of each country.

Despite these efforts, the increase in greenhouse gases is accelerating the climate crisis and with it the appearance of extreme weather events: droughts, forest fires, floods and, especially, extreme heat. As the World Meteorological Organisation (WMO[2]) records, the increase in the frequency, intensity and duration of heat waves over the past 11 years, 2015 to 2025, were individually the eleven warmest years in the 176-year observational record, with the past three years being the three warmest years on record.

Heat waves are particularly devastating as they affect public health and quality of life. According to a study by Imperial College London and the London School of Hygiene & Tropical Medicine (LSHTM),[3] between June and August 2025, heatwaves that affected Europe caused 16,500 deaths, according to the records of 854 cities (30% of the European population). The study estimates that the increase in average temperatures (2.2°C warmer on average in the areas studied) mostly affects people aged 65 years and older (85%).

[1] European Adaptation Strategy 2013. Covenant of Mayors, 2014-2016
[2] https://wmo.int/news/media-centre/2025-set-be-second-or-third-warmest-year-record-continuing-exceptionally-high-warming-trend
[3] https://wmo.int/news/media-centre/2025-set-be-second-or-third-warmest-year-record-continuing-exceptionally-high-warming-trend

In addition to older adults, heat stress especially affects outdoor workers, an issue highlighted by the World Health Organisation[4] and socioeconomically disadvantaged groups. In addition to personal vulnerability – associated with age, gender and health conditions – socioeconomic vulnerability – associated with energy poverty, resulting from the combination of low income, high energy prices and inefficient housing – prevents households from acquiring air conditioning appliances with the extra energy consumption that this implies. Overall, low levels of thermal comfort have direct consequences on people's well-being and quality of life.

2.1 Effects of global warming on the population

2.1.1 Spain

Spain is increasingly affected by extreme heat. The final report of the Ministry of Health on the 2025 campaign of the National Plan for Preventive Actions against the Effects of Excessive Temperatures on Health,[5] recorded 870 episodes of extreme heat, 73% more than in 2024. Deaths attributable to heat were 3,832, of which 95.98% were people over 65 years of age and more than half (65.29%) were over 85 years of age. In the Community of Madrid, 591 deaths attributable to heat were registered, 84.1% more than in the same period of the previous year.[6]

During the heatwave episodes of 2025, daily electricity demand in the most affected countries, including Spain, soared by up to 14% due to the massive use of air conditioning and other systems to combat heat that increased the price of electricity by up to 15% on the most critical days. This increase caused one in three homes to not be able to reach an adequate temperature to withstand extreme heat, accentuating the phenomenon of energy poverty[7], a situation that affects almost 10% of the population, of which about 20% live in homes with structural problems. The data indicate that 27% of homes do not reach an adequate temperature in winter and 33.6% in summer. Given the magnitude of summer energy poverty, the National Energy Poverty Strategy 2019-2024[8] has been incorporated as a key indicator.

2.1.2 UK

The UK founding legislation to tackle the adverse effects of global warming is the Climate Change Act 2008. Climate change is also included in other statutory instruments.[9] The UK remains committed to the COP Paris Agreement to limit CO2 Emissions to 1.5º Celsius by 2050, albeit under growing opposition.

Putting the UK into the global context in Climate Change and Weather, the UK Met Officeacknowledges the contribution of human activity to warming the planet.[10] It predicts that in future the UK will experience warmer and wetter winters, hotter and drier summers and more frequent and intense weather extremes.[11] Climate change is already causing warming across the UK.[12] Climate models at national, regional and local level have been developed for projections.[13] Heavy rainfall is more likely. Since 1998 the UK had six of the

[4] https://www.who.int/es/news/item/22-08-2025-who-wmo-issue-new-report-and-guidance-to-protect-workers-from-increasing-heat-stress

[5] https://www.sanidad.gob.es/en/gabinete/notasPrensa.do?id=6760

[6] Daily Mortality Monitoring System, Carlos III Health Institute.

[7] Daily Mortality Monitoring System, Carlos III Health Institute: https://ember-energy.org/latest-insights/heat-and-power-impacts-of-the-2025-heatwave-in-europe/

[8] https://www.miteco.gob.es/content/dam/miteco/es/ministerio/planes-estrategias/estrategia-pobreza-energetica/actualizaciondelosindicadoresdelaestrategianacionalcontralapobrezaenergetica-2022_tcm30-549718.pdf

[9] Environmental Protection Act (1990), Flood and Water Management Act (2010), Local Government Act (2000)

[10] https://weather.metoffice.gov.uk/climate-change/effects-of-climate-change (undated)

[11] see table: changes to the UK climate and weather events, in Met Office "Effects of climate change"

[12] All of UK's ten warmest years on record have occurred since 2002. Heatwaves like in summer 2018 are now 30 times more likely to happened. Winter will be between 2 and 4.5 ºC warmer and up to 30% wetter and summer will be between 1 and 6º Celsius warmer and up to 60% drier, prolonged heat with extremes reaching 40 ºC.

[13] UK Climate Projections (UKCP).https://www.metoffice.gov.uk/research/approach/collaboration/ukcp

ten wettest years on record. Heavy rainfall will also increase and lead to flash floods. In 2015 winter storms were at least 40% more likely.[14]

Heatwaves are a risk to health. The summer heatwave of 2003 provoked over 2000 excess death, 680 in 2006and 300 in 2009, mainly of older people.[15] The UK Health Security Agency has set up Adverse Weather and Health Plans(UKHSA) to protect health from weather related harm.[16] It proposes Action areas to improve local planning.

2.1.3 But...

Faced with this backdrop and given changing geopolitical and economic conditions, including rising energy prices affecting the cost of living, there is political pressure in an increasing number of countries against investment in renewables and restrictions on fossil fuels, moving away from the commitment adopted by the COP to net zero CO2 emissions by 2050.

3 MEASURES FOR THE ADAPTATION OF CITIES TO CLIMATIC EVENTS

3.1 European Union

The EU's contribution to the issue began with the approval of the European Adaptation Strategy in 2013, aimed at promoting the establishment of specific measures in member countries, improving decision-making in this area and promoting adaptation in the most vulnerable sectors. The New European Strategy for Adaptation to Climate Change, approved in 2012, advocated the construction of a society resilient to climate change through the promotion of knowledge of climate impacts and adaptation solutions, adaptation planning and climate risk assessments. For its part, the European Green Deal, established in 2019, promotes the ecological transition in order to achieve climate neutrality by 2050, contributing to the goals of the Paris Agreement (COP 2015) to contain global warming to a maximum of +1.5 °C compared to pre-industrial levels. The action of the Covenant of Mayors, 2014-2016, was crucial for the promotion of specific plans and actions at the local level.

In addition, special campaigns have been launched to promote local initiatives, such as "Cities Refresh", adopted in 2019 as part of the European Green Deal to combat heat through nature-based solutions and resilient designs, and the EU Mission: Climate-Neutral and Smart Cities for 2030, launched in 2021 and promoted in 2025 by the European Union's Covenant of Mayors for Climate and Energy, with the aim of acting as innovation laboratories and accelerating the transition to climate neutrality. Among the 100 cities initially selected, there are seven Spanish cities – Barcelona, Madrid, Seville, Valencia, Valladolid, Vitoria-Gasteiz and Zaragoza – and two from the United Kingdom – Bristol and Glasgow.[17]

3.2 Spain

3.2.1 National and regional level.

The increase in heat is the most relevant issue for all levels of government. The winter temperatures – even higher than usual and episodes of extreme heat affects the entire population. Thus the government activatedthe Cold Campaigns to attend to certain social groups.

The national government's action on climate change and extreme temperature issues focuses mainly on inter-administrative coordination, public health and energy regulations in buildings. The Ministry for the Ecological Transition and the Demographic Challenge prepared the National Plan for Adaptation to Climate Change (PNACC) 2021-2030[18] to respond to the effects being experienced in the country – expansion of the semi-arid climate, lengthening of summers, heat waves, increase in the surface temperature of the

[14] https://weather.metoffice.gov.uk/climate-change/climate-change-in-the-uk
[15] UK Health Security Agency, Adverse Weather and Health Plan 2025-2026
[16] ibid.
[17] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en
[18] https://www.miteco.gob.es/content/dam/miteco/es/cambio-climatico/temas/impactos-vulnerabilidad-y-adaptacion/pnacc-2021-2030_tcm30-512163.pdf

Mediterranean and its impact on large cities and the Mediterranean coast – and to set the guiding principles for policies associated with these future climate scenarios.

The aforementioned National Plan of Preventive Actions against the Effects of Excessive Temperatures on Health, 2025, launched by the Ministry of Health, is activated between 16 May and 30 September to prevent its impact on vulnerable groups (the elderly, children, people with chronic illnesses, and outdoor workers). The plan is based on the Meteosalud early warning system, which coordinates health and emergency services in the 182 areas with similar climatic characteristics into which the country is divided. Alerts are activated according to weather forecasts and health risk maps produced daily by the State Meteorological Agency. The Health and Climate Change Observatory, under the same ministry, prepared the Practical Communication Guide. Health and heat, 2025[19], so that institutions, the media and health personnel transmit effective messages to the population for the promotion of self-protection behaviours.

The National Information Coordination Centre on Forest Fires (CCINIF), under the Ministry for the Ecological Transition and the Demographic Challenge, monitors weather risks and coordinates the available state resources to respond to different levels of emergency. The National Emergency Monitoring and Coordination Centre (CENEM), under the Ministry of the Interior, is responsible for monitoring fires and managing the National Alert Network.

Regarding buildings, the Ministry of Housing and Urban Agenda updated the Technical Building Code (CTE) in 2025 to align it with Directive (EU) 2024/1275.[20] In addition to regulating the basic requirements of quality, safety and habitability of buildings, the code introduces the obligation to calculate the Global Warming Potential (GWP) to assess the climate impact of a building throughout its life cycle. Other measures are the reinforcement of energy savings (solar panels, light efficiency), the promotion of sustainable mobility (charging for electric vehicles, bicycle parking) and the updating of indoor environmental quality (thermal insulation, cross ventilation, use of thermal inertia materials). Royal Decree-Law 14/2022, on energy saving measures[21], limits the temperature in public buildings, commercial buildings, department stores, transport stations and airports by establishing a maximum of 19 °C for heating and a minimum of 27 °C for cooling.

At the regional level, the Autonomous Communities have their own protocols to deal with episodes of high temperatures, being able to activate specific mechanisms in certain areas, such as education (modification of schedules), work (prohibition of outdoor activities at times of maximum radiation) or resource management (restrictions on the use of water or reinforcement of devices for extinguishing forest fires)

3.2.2 Local level

The initiatives adopted by Spanish cities for adaptation to climate change are numerous, implemented in different ways and with different degrees of effectiveness. The proposals are varied, including green and blue infrastructure, nature-based solutions, biodiversity corridors, specific rules and regulations for building and special architectural and urban designs. With respect to extreme heat and despite the adverse climatic effects, the adoption of specific municipal plans is markedly unequal, with the cities in the north and east of the country having more instruments compared to those in the south and northwest.

Barcelona is the most advanced example given the implementation of the Superblocks programme in 2016, seeking to transform the city model to give priority to pedestrians, reduce road traffic and increase green areas to mitigate the urban heat island. In addition, the approval of the Climate Plan 2018-2030[22] proposes, among other measures, to incorporate the climate variable into urban planning, improve the thermal comfort of buildings and public spaces, increase green spaces and create a network of climate shelters that has 401 shelters (1 for every 4200 inhabitants), the largest in Spain.

19

https://www.sanidad.gob.es/areas/sanidadAmbiental/riesgosAmbientales/calorExtremo/publicaciones/docs/Guia_Salud_y_Calor_v2.pdf

[20] https://www.codigotecnico.org/

[21] b https://www.boe.es/buscar/act.php?id=BOE-A-2022-12925

[22] https://www.barcelona.cat/barcelona-pel-clima/sites/default/files/plan_clima_juny_ok.pdf

Bilbao is another outstanding example. Its Climate Change Adaptation Plan[23] focuses on high temperatures and heat waves and promotes the creation of a network of 131 climate shelters – 1 shelter for every 2,600 inhabitants, one of the best in Spain. The BIK project was approved in 2025 to adapt the metropolitan area of Bilbao to the impacts of climate change, mainly floods, heat waves and rising sea levels. One of the fundamental pillars of this project is the predictive modelling of climate risks and the implementation of early warning systems.

The creation of networks of climate shelters in open spaces and public facilities is the most widespread urban strategy, although with uneven development. According to the Greenpeace report Red Hot Cities: Climate Shelters and Lack of Protection Against Extreme Heat[24], in July 2025 only 16 of the 52 capital cities had climate shelters with different per capita ratios ranging from very good to acceptable, being insufficient or very insufficient in heat-affected cities, such as Madrid, Valencia, Seville, Cordoba and Alicante.

3.2.3 Madrid

The increase in heat is the most relevant issue for local and regional governments since even winter conditions register higher average temperatures than usual. According to the State Meteorological Agency, the 2023-2024 winter was one of the warmest since 1961, the starting date of the historical series of records. Even when the low winter temperatures activate the Cold Campaigns to provide emergency accommodation, day centres and social care for people in street situations, the episodes of extreme heat are the most alarming as they affect the entire population.

The Air Quality and Climate Change Plan. Plan A[25], was approved in 2017 with the dual objective of guaranteeing the health of the population against the challenge of pollution, and of strengthening the city against the impacts of climate change, reducing its vulnerability to the risks associated with global warming.

In 2025 the City Council launched the Action Plan for Extraordinary Episodes of High Temperatures – CALORMAD[26], derived from the Municipal Emergency Territorial Plan approved in 2023. It is a reactive strategy that is activated based on public health reports and its aim is to reduce morbidity and mortality during extreme heat waves through self-protection recommendations for citizens. In addition to intensifying social reinforcements to respond to the needs of vulnerable people (minors, the elderly, the chronically ill), it offers advice on how to combat the heat at home and abroad, and includes recommendations for activities during hot hours and prevention measures at work, especially work taking place outdoors.

The measures proposed by the Action Plan consist of the opening of at least one centre for the elderly per district between July and August, the adaptation of climate shelters in existing air-conditioned places (cultural spaces, museums and public and private facilities), and the use of municipal swimming pools and certain outdoor spaces. These urban spaces correspond to the existing public fountains and to specially adapted areas in certain parts of the city – water jets (“urban beach” Madrid Río), removable awnings (Plaza del Sol) and nebulizers (children's play area in Plaza de España and pergola in La Gavia park). Other measures are two pilot projects: three low consumption nebulisers in public places (Plaza de Milmarcos, Murcia Street and Porto Avenue) and two refrigerated bus stops (intermodal areas of Pavones and Villaverde Cruce).

4 COMMENTS

Although CALORMAD represents an effective management model to deal with climate crises from the health point of view, the greatest criticism focuses on the lack of a comprehensive long-term urban proposal with more far-reaching initiatives. The interventions adopted are punctual, of limited importance, high cost and low effectiveness. It is worth noting the scarce provision of green areas in peripheral and socially disadvantaged neighbourhoods, the scarcity of public swimming pools and summer sports facilities (30

[23] https://biobilbao.bilbao.eus/wp-content/uploads/2021/05/PLAN-DE-ADAPTACION.pdf

[24] https://es.greenpeace.org/es/sala-de-prensa/informes/informe-ciudades-al-rojo-vivo-refugios-climaticos-y-desproteccion-frente-al-calor-extremo/

[25] https://www.madrid.es/UnidadesDescentralizadas/Sostenibilidad/CalidadAire/Ficheros/PlanAire&CC_Eng.pdf

[26] https://www.madrid.es/UnidadWeb/Contenidos/ContenidoGenerico/PlanesEmergencia/olacalor8.pdf

facilities for 3.5 million inhabitants) and the insufficient number of public climate shelters with free access. According to the Greenpeace report mentioned above, Madrid has 31 shelters (1 per 110,000 inhabitants), a clearly insufficient ratio to meet the demand of its population (3,527,924 inhabitants).

4.1 UK

The Third National Adaptation Programme NAP3 and the Fourth Strategy for Climate Adaptation Reporting,[27] 2023 identifies 5 mechanisms to address risks related to health, communities and the built environment.[28] Its Health and Wellbeing chapter lists intervention to mitigate climate related health risks. New building regulations address overheating in residential buildings.

The Department of Energy Security and Net Zero has incorporated climate adaptation into its net zero retrofit programmes to upgrade existing buildings. NHS Trusts incorporate adaptation strategies into their green plans and are updating resilience standards by 2025.[29]

4.2 London

The global warming situation differs in London from Madrid. Being a more temperate climate with a more puritanical population there was late practice of space heating in the winter and no perceived need for air conditioning in the summer. However, with rising living standards and an increasingly cosmopolitan population central heating became widespread. Relatively cheap energy due in part to indigenous oil and gas discoveries and exploitation in the North Seapeople paid their energy bills and did not feel the need to invest in insulation.

Changes to the UK climate and weather events

	Changes in intensity or frequency so far	Is this linked to climate change?	What is expected in the future?
UK warm spells	Increase	Yes	Increase
UK cold spells	Decrease	Yes	Decrease
UK heavy rain	Increase	Inconclusive	Increase
UK dry spells	No trend detected	Inconclusive	Increase (summer)
UK wind storms	No trend detected	Inconclusive	Increase*

* Some, but not all, evidence supports an increase.

Figure 1: Changes to the UK climate and weather events.

27 https://assets.publishing.service.gov.uk/media/64ba74102059dc00125d27a7/The_Third_National_Adaptation_Programme.pdf

28 The National Planning Policy Framework | MHCLG, Building regulations | MHCLG, Flood and Coastal Erosion Risk Management Strategy, Policy Statement and Roadmap, Environment Agency, Adverse Weather and Health Plan | UKHSA, Publicly Available Specification 2030-2035 | TrustMark

29 https://assets.publishing.service.gov.uk/media/67fe2667694d57c6b1cf8d3c/AWHP_2025_to_2026.pdf

More recently, with rising summer temperatures cooling became more used, initially in work places but also in homes. Rising affluence increased also car ownership often dual in families and larger vehicles. Moreover, more family holidays abroad and foreign business trips all added to CO2 emissions.

At the same time concerns about global warming and the impact on future generations became more widespread and people started to care about attenuating adverse impacts. Promises of taking measures to curb pollution and improve the urban environment by politicians and similar pledges in their manifesto formed part of electioneering.

London was without a London-wide government since the abolition of the Greater London Council in 1986 under Thatcher's premiership. Mounting pressure for a strategic devolved London government led to the creation of the Greater London Authority and for the first time an elected mayor albeit with rather limited powers. From inception of a new London government in 2000 environmental protection was high on the mayors' objectives. Initially labour mayor Ken Livingstone had been known for his 'green' tendencies and had initiated various measures during his two terms of office, including congestion charging andbikes for hire. Later the tory mayor Boris Johnson implemented these policies.The current labour mayor Sadiq Khan continued to take "greening" measures for London in his two terms and his current third one.

These environmental policies form part of the Mayor's London Plan. The last London Plan was approved in 2025 and a new one is under preparation. Sadiq Khan, an ex-transportation minister focused on curbing pollution from cars. He strengthened the measure of the central London congestion charge zone, added another Ultra Low Emission Zone (ULEZ) first in central London, thenin steps for the whole of the Greater London area. This was not implemented without strong objections but the mayor remained firm. He additionally promoted building retrofits, measures to increase solar capacity and enhance green spaces by making 50% of the city green by 2050. He alsowas more stringent than government regulations about better insulation and fossil free heating in the London Building Regulations which are implemented for his current ambitious house building programme.

Accordingly, the latest London Plan includesthe following environmental policies:[30]

- air quality and transportation: London-wide ULEZ; 100% congestion charging in central London; electrifying the London bus fleet; investing in cycle lanes and other infrastructures.
- climate change mitigation: more ambitious net-zero carbon emissions target by 2030 than the central government 2050; "green new deal" to support low carbon jobs; promoting the accelerated green pathway (reducing heat demand in buildings and installing 2.2 million heat pumps by 2030.
- energy efficiency: "warmer homes" – grants for insulation and heating improvements for low income households; 57% more energy efficient new buildings than national standards in the London building regulations.
- green infrastructure and biodiversity: more green roofs, and walls, making 50% of London green by 2050; promoting "National Park City" status, expanding urban forests, improving biodiversity-waste management: recycling 65% of municipal waste by 2030; send no biodegradable wate to landfill by 2026; make London a zero waste city in the longer run.
- solar energy: The Solar Action Plan includes a reverse solar auction programme to encourage the installation of solar panels on homes, aiming to increase capacity to 100MW by 2030.

The mayor is backing up these policies with money with a GBP 9 million "Greener City Fund" and the GBP 34 million "Energy for Londoner" programme.

London's overall emissions have fallen by 21% since 2016 due to implementing these policies. It has to be noted though that no measures are taken of de-sealing London's streets or any measures to turn London into a "Sponge City": and at the same time The Mayor is introducing "grey belt" status in the green belt to be able to build new housing there, thus reducing "green lungs". Also regarding development permits the London Boroughs have the ultimate powers to impose and enforce planning conditions on developers which are the way to extract contributions towards combating global warming.

[30] London Climate Action Plan: Environment Strategy and Pathway to net zero by 2030. Mayor of London, January 2022. To be updated in 2026

Water is also an issue in the changing weather patterns. With more draughts in the summer the reservoirs are low, floods are more frequent with intense rain fall which the drainage is unable to absorb, while rising sea level requires the replacement of the Thames Barrier to prevent flooding upstream. Thames Water the private company which supplies London with drinking water and is responsible for sewage and storm water drainage has increasingly discharged sewage into the rivers and the sea and hasneglected to maintain and repair the water network which loses a fifth of drinking water in leaks. Water demand is estimated to have outstripped supply by 10% by 2025 and will increase to 21& by 2040. The Mayor 2050 plan in the manifesto puts sustainable urban drainage and natural flood management in the forefront of the battle to maximise London's water resources. In reality the mayor has no powers over the private Thames Water company and the regulator has been extremely lenient with the company which passes the fines to the water consumers. It is only when the central government stepped in under pressure of rising complaints that Thames Water has started a programme of replacement of old pipes and equipment, but with the permission to pass a large cost onto the water bills.

Like most London's infrastructure energy supply network is antiquated, deficient and becoming redundant and the electricity substations are reaching full capacity. However, London will never be able to be fully self-sufficient in energy provision, even when using more renewables and it depends on the state and the private companies for its energy security, andonly to some extend for its energy greening objectives.

4.3 Comments

London, like most UK cities and local authorities have long ago had to relinquish municipal control over its basic services, water, energy, transportation (although it gained back quite a lot of the latter), as well as telecommunications and other ICTs which are counted as essential services at present. Recycling can attenuate the service provision problem and campaigns to change people's user habits can also help, but the actual deficit in all these services seems very difficult to overcome and likely impossible without central government support. All this has a direct effect on measures against increasing heat and heavy rain due to climate change.

Measures to curb the warming effects of climate change are multi-fold and interdependent. Ideally they should create positive synergy but in reality they may also contradict each other. This is especially challenging when assessing the impacts on people, their cost of living and the need for them to adjust their behaviour which they may consider against their interests.

5 CONCLUDING REMARKS: CHALLENGES FOR CITIES TO ADAPT TO CLIMATE CONDITIONS

Interventions are an essential tool for urban adaptation to climate change to combat excessive heat, but they require strong legal frameworks, adequate financing, and equitable approaches to avoid social inequalities. The examples of Madrid and London show that cities are able to adopt measures to alleviate extreme weather conditions. Nevertheless, these actions are severely constrained.

Awareness of climate change and the need to take remedial action is widespread and supported, but there remain strong "climate denial" lobbies. Remedial measures require finance and during times of "cost of living crisis" burdening households with extra costs, especially for long term infrastructure measures is creating obstruction, while city budgets are toostrained to carry such investments.

Impacts of global warming on cities are multi-fold, complex and often interdependent and would require comprehensive measures well beyond the means of cities. Both Madrid and London have taken partial measures against global warming, Madrid focusing on combating excess heat and London curbing traffic CO2 emissions. These measures should be fully integrated in local plans.

Each positive measure to curb excess heat or other contributors to global warming can have adverse side effects, and they do not tend to give full attention, such as climate gentrification caused by the displacement of vulnerable populations to less suitable places. Thus provision of climate proposals have to equitable and applied especially in the most disadvantaged neighbourhoods.

Many of these partial measures to curb excess heat and other climate adverse effects in cities are experimental and it is important to set up a robust monitoring system to discover unforeseen side-effects to

be able to take corrective measures. The same evaluation system should also be capable of assessing the effectiveness of the adopted measures.

At present in both Spain and the UK climate change measures are in the hand of central governments, but actions are needed at all levels and more devolution of power has to be instated to the cities as well to local communities. Vertical coordination of measures to alleviate the heat and other effects of climate change is essential to put into place at all levels at the same time. Similarly horizontal coordination between partial action into a more joined-up system has to be set up with channels of user-friendly two-way communications.

The biggest challenge remains financing these enormous efforts still required to realise the COP objective to which both Spain and the UK remain committed and to maintain these levels in the longer term.

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Utilisation of Urban Data in a Municipal Data Platform – A Field Report From the German MPSC Süd-West-Cluster

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1 ABSTRACT

Urban data are a key resource for evidence-based decision-making in municipalities, but are often underutilized due to organizational and technical barriers. This paper reports on the German MPSC Südwest-Cluster, where several municipalities jointly develop an open municipal data platform within a comprehensive Urban Data Management approach. The paper outlines challenges in municipal data handling, describes the project context, platform architecture, and development phases, and presents initial results in the form of data-driven use cases and interactive dashboards. The findings indicate that an open, cooperative platform approach can improve data accessibility and reuse while strengthening municipal data sovereignty and reducing vendor lock-in.

Keywords: Smart City, Data Platform, Urban Data Managament, Data Governance, Digital Twin

2 INTRODUCTION

Urban data constitute a foundational resource for understanding the status quo of urban systems, monitoring structural developments, and supporting evidence-based decision-making (Batty 2013, Mayer & Memmel 2026, Memmel et al. 2017). Municipal administrations typically hold a vast range of datasets originating from diverse departments and legacy systems. However, the potential of these data assets is rarely exploited in practice. The underlying causes are manifold: the existence and location of datasets are often unknown; responsibilities for data ownership and maintenance remain unclear; access procedures are inconsistent or undocumented; and technological fragmentation hinders systematic integration (Priestley et al. 2023). As a result, even data-rich cities struggle to deploy advanced analytical tools or digital services that rely on timely, harmonized, and trustworthy data (Weil et al. 2023).

Addressing these issues requires an integrated approach that simultaneously tackles organizational, strategic, and technical dimensions of municipal data governance. Such an Urban Data Management aims to establish transparency regarding available datasets, define coherent governance structures, clarify stewardship roles, and introduce processes for controlled data usage. Yet, organizational measures alone are insufficient. To operationalize urban data governance at scale, municipalities require adequate technological infrastructures – most notably, a municipal data platform capable of supporting data discovery, ingestion, harmonization, metadata management, quality assurance, and secure provisioning.

The growing relevance of urban data infrastructures must be understood within the broader paradigm of data-driven urbanism and smart city development. International research has emphasised how large-scale data collection, real-time analytics and digital infrastructures are reshaping urban governance and planning practices (Kitchin 2014; Batty et al. 2012). In particular, the increasing availability of fine-grained urban data has led to the emergence of urban analytics as a distinct field integrating spatial analysis, computational modelling and data science in planning contexts (Singleton et al. 2017).

Selecting and implementing a municipal data platform is a non-trivial task. The landscape of commercial solutions is often characterized by high investment and maintenance costs as well as long-term vendor dependencies, which can jeopardize municipal data sovereignty (Hess & Koch 2023). Open-source solutions offer a viable alternative by enabling transparency, adaptability, and reduced lock-in, and by providing a sound basis for inter-municipal cooperation in software development and operation. Recent findings from the MPSC accompanying research further underline that open-source software adoption in municipalities is closely linked to maintaining long-term control over digital infrastructures. The BBSR study identifies proprietary dependencies and limited transparency as recurring risks in municipal IT landscapes and highlights open-source approaches as an effective strategy to mitigate vendor lock-in and preserve institutional autonomy (Berg et al. 2024). At the same time, it emphasizes that technological openness alone

is insufficient: sustainable data sovereignty also requires complementary organizational measures, clearly defined responsibilities, and suitable operating and governance models.

The German MPSC Südwest-Cluster exemplifies how an open-source approach can be realized in practice. Within this collaborative framework, several municipalities jointly fund and coordinate the development and operation of an open-source data platform designed to meet public-sector requirements. The cluster focuses on integrating high-value administrative datasets that are harmonized and made accessible through shared platform components, enabling cross-domain analyses and supporting data-intensive urban management tasks.

The remainder of this paper is structured as follows: Section 3 introduces the concept of Urban Data Management. It first discusses the key challenges associated with municipal data handling (Section 3.1) and subsequently outlines the Urban Data Management (Section 3.2). Section 4 focuses on the MPSC Südwest-Cluster as a practical case study. It describes the funding context and overarching objectives of the collaboration (Section 4.1) and presents the development of the shared data platform, including its system architecture (Section 4.2). Section 5 reports on initial results and lessons learned from the implementation and use of the platform. Finally, Section 6 summarizes the main findings and provides an outlook on future developments and broader implications for Urban Data Management.

3 URBAN DATA MANAGEMENT

3.1 Challenges in Municipal Data Handling

Urban administrations need to rely on data to assess the status quo of the city, to justify and prioritize measures, and to monitor the effects of policies (Memmel et al. 2021). In principle, municipalities already possess a broad portfolio of datasets, ranging from geodata and statistics to administrative registers and sensor streams. In practice, however, the potential of these assets is frequently not realized. Core obstacles are (i) unknown data existence and insufficient transparency about what is available, (ii) missing or inconsistent documentation and metadata (e.g., content, quality, update cycles), (iii) unclear access procedures and responsibilities, and (iv) heterogeneous formats and low machine-readability, which prevent systematic reuse and cross-domain integration (Memmel 2015; Mayer & Memmel 2023).

These deficits are particularly critical for advanced urban applications such as citywide monitoring, simulation, or digital twins, which require consistent data pipelines, quality control, and reliable access over time. Yet, data-based governance tends to fail not primarily due to a lack of data, but due to fragmentation, limited interoperability, and organizational constraints around access and stewardship (Kitchin 2014; Zuiderwijk & Janssen 2014).

3.2 Urban Data Management

We refer to the integrated approach to develop and implement a sustainable strategy and infrastructure for data-driven processes within the administration and in collaboration with the public and external partners as Urban Data Management (UDM).

It explicitly combines organizational measures (roles, processes, competencies) with technical enablement (infrastructure, tools). Key objectives include safeguarding and improving data quality and timeliness, simplifying and accelerating data-related processes, defining standardized exchange procedures (internally and externally), embedding data protection and ethical requirements into operational routines, and providing a central point of contact for data-related questions. Importantly, UDM is not understood as a single project, but as a continuous capability that must evolve alongside changing legal frameworks and emerging technologies (including Artificial Intelligence).

This aligns with public-sector data governance perspectives that emphasize the life-cycle nature of data (creation to deletion), cross-domain coordination, and the need to reconcile value creation with privacy, intellectual property, and accountability (Schieferdecker et al. 2018; OECD 2022).

UDM can be operationalized along two tightly coupled levels: (1) Data strategy level and (2) governance and system level.

3.2.1 Data strategy and governance level

A municipal data strategy serves to clarify fundamental principles and objectives guiding the handling of data within the city administration. It functions as an internal orientation framework, primarily addressing municipal staff and providing clarity, consistency, and legal certainty in day-to-day data-related activities. At the same time, the data strategy articulates the guiding principles of data usage towards the public and external partners transparently, thereby contributing to trustworthiness and accountability in data-driven governance (IFG 2018).

To operationalize these principles, the data strategy defines a coherent set of measures aimed at achieving the stated objectives. These measures typically address multiple dimensions, including organizational action levels, clearly defined roles and responsibilities, standardized processes for data provision and use, and explicit quality criteria for data management. Measures to build the necessary skills within the administration are also an important aspect (Sautter et al. 2023). Further, the strategy establishes criteria for dealing with legal and regulatory issues, particularly regarding data protection, licensing, and ethical considerations. In this sense, the municipal data strategy constitutes a central governance instrument that translates normative goals into actionable guidance and provides a stable foundation for the technical and organizational components of UDM.

3.2.2 System level (technical infrastructure and tooling)

To translate the intent of a strategy capability, respective technical infrastructures and tools need to be provided for tasks such as dataset cataloguing, metadata management, quality mechanisms, role-based access, standardized interfaces, and reproducible integration pipelines. Reference architectures for Open Urban Platforms provide a relevant blueprint for structuring such systems and avoiding isolated "point solutions" (DIN 2017).

Within UDM, an urban data platform is the decisive enabling component because it operationalizes governance requirements in a stable infrastructure: it makes datasets discoverable (catalogue/metadata), accessible (controlled access paths), integrable (pipelines and standards), and usable (APIs and services). Without such a backbone, UDM risks remaining a set of intentions and isolated pilot activities. Conversely, a platform alone is insufficient if not embedded in data strategy and governance; the UDM concept explicitly requires both levels to be aligned.

4 THE MPSC SÜDWEST CLUSTER

The MPSC Südwest-Cluster is an inter-municipal cooperation network comprising five model municipalities from Rhineland-Palatinate (Kaiserslautern, Kusel, Mayen-Koblenz, Bitburg-Prüm, and Linz am Rhein) and St. Wendel (Saarland). The cluster was established to jointly fund and coordinate the development and operation of a shared, open-source municipal data platform. The cluster operates through regular coordination meetings, thematic workshops, and collaborative project work, thereby institutionalizing inter-municipal learning processes.

From an organizational perspective, the Südwest-Cluster can be characterized as a loosely coupled governance network that complements formal municipal responsibilities without replacing them. This structure allows municipalities to retain autonomy while benefiting from shared development efforts, particularly in technically and organizationally complex domains such as UDM.

4.1 Funding Context and Objectives

The Model Projects Smart Cities (MPSC) programme[1] from the German Federal Ministry for Housing, Urban Development and Building (BMWSB) constitutes the central national funding framework for the Südwest Cluster. Launched in 2019, the programme aims to support municipalities in developing integrated, long-term strategies for digital urban development. Rather than promoting isolated technological solutions, MPSC explicitly emphasizes strategic integration, inter-municipal cooperation, and transferability of results.

Across several funding rounds, a total of 73 municipalities, counties, and regions were selected nationwide. Funding periods typically span five to seven years and provide substantial financial resources for both strategic work and implementation-oriented projects. A core objective of the programme is to establish

[1] see https://www.smart-city-dialog.de/en/about-us/model-projects-smart-cities

sustainable digital infrastructures that remain operational beyond the funding phase and can serve as reference models for other municipalities. Within this framework, data-driven urban development and the establishment of municipal data infrastructures have emerged as cross-cutting themes, as data availability and interoperability are considered prerequisites for many smart city applications.

Kaiserslautern was funded within the MPSC programme since 2019, the project team in is made up of representatives from the city administration, the municipal digital agency KL.digital GmbH, and the German Research Center for Artificial Intelligence (DFKI) GmbH.

The central objective of the Südwest Cluster is the joint development and operation of an open municipal data platform. The platform is conceived as a foundational digital infrastructure that enables systematic access to, integration of, and analysis of municipal data across administrative boundaries. In contrast to proprietary, vendor-specific solutions, the cluster explicitly pursues an open-source approach. This decision is motivated by considerations of digital sovereignty, long-term sustainability, and interoperability (DIN 91357 2017). The platform is intended to follow modular architectural principles, allowing municipalities to adopt and extend functionalities according to local needs while relying on a shared technical core.

The municipal data platform operationalizes strategic and organizational objectives through a set of interrelated functional components. These components are not isolated technical elements, but directly reflect the core requirements identified at the governance and strategy level in UDM.

First, the platform provides functionality for secure identity and access management, enabling role-based and purpose-bound data access across administrative units and external partners. This capability is essential for translating data governance principles – such as responsibility, accountability, and compliance with data protection regulations – into enforceable technical mechanisms. By systematically managing identities, roles, and permissions, the platform supports trustworthy data sharing while maintaining legal and organizational control.

Second, the platform enables data integration and process automation across heterogeneous source systems. UDM requires that data from diverse administrative domains, formats, and update cycles can be connected and harmonized in a reproducible manner. Integration and automation functionalities support the configuration of data ingestion, transformation, and routing workflows, thereby reducing manual effort and increasing transparency and repeatability. In this way, the platform implements the UDM objective of simplifying and accelerating data-related processes while improving consistency.

Third, the platform supports analytical access and visualization through dashboard and business intelligence functionalities. These capabilities allow integrated datasets – particularly time-dependent data such as sensor streams or administrative statistics – to be explored, monitored, and interpreted by different user groups. From a UDM viewpoint, dashboards are not merely presentation tools but instruments for organizational learning, monitoring of urban indicators, and evidence-based decision-making.

Fourth, the platform provides functionality for open data provision and data cataloguing. A central catalogue supports data discovery by documenting datasets with standardized metadata, including information on content, quality, provenance, update frequency, and usage constraints. This function directly addresses one of the core challenges identified by UDM: the lack of transparency regarding existing data assets. By enabling structured publication and reuse of data, the platform supports both internal collaboration and external engagement with citizens, research, and the private sector.

Finally, the platform incorporates core data backbone functionalities for managing contextual and historical data. Context management capabilities enable the representation of the current state of urban systems, while time-series persistence supports historical analysis, trend detection, and evaluation of interventions. Geospatial front-end functionalities allow spatially referenced data to be explored and combined with other urban information. Together, these elements form the technical foundation for advanced applications such as simulations or digital twins, which are envisaged in the long-term perspective of UDM.

Taken together, these functional components demonstrate how an urban data platform translates the abstract goals of UDM – such as data quality, accessibility, interoperability, and compliance – into a coherent, reusable, and scalable technical infrastructure. The platform thus acts as the central system layer that enables UDM to move from strategic intent to operational practice.

By consolidating these capabilities within a shared platform, the cluster seeks to reduce redundant development efforts, improve data transparency within administrations, and enable cross-domain and cross-municipal analyses.

4.2 System Development

4.2.1 Project Phases

The joint development of the intermunicipal data platform within the MPSC Südwest-Cluster is structured into three consecutive project phases, each addressing distinct objectives along the path from exploration to long-term operation.

The first phase was the sandbox phase, which ran from January 2024 to June 2025 and has been completed. Its primary objective was to explore the functional and technical possibilities of an urban data platform in a protected experimental environment. During this phase, initial platform components were tested, data integration scenarios were explored, and early visualizations were created. Based on these practical experiments, concrete requirements and development needs were derived in close cooperation with the participating municipalities. The sandbox phase thus served as a foundation for consolidating technical, organizational, and functional requirements and directly informed the subsequent public procurement process for the platform's further development.

The second phase is the development phase, which started in August 2025 and will run until December 2027. This phase is currently ongoing. Its main objective is the establishment and operation of a shared intermunicipal urban data platform, including its continuous technical enhancement and the implementation of both joint and municipality-specific use cases. During this phase, the platform is incrementally expanded, productive data integrations are realized, and concrete administrative and public-facing applications are developed and refined in close coordination with municipal stakeholders.

The third phase is the continuity and productive operation phase, planned to begin after 2027 and currently in preparation. Its goal is the long-term, cooperative operation of the intermunicipal data platform beyond the funding period. This phase focuses on organizational and financial consolidation, the establishment of sustainable governance and operating models, and the continued joint use and evolution of the platform as a permanent digital infrastructure for the participating municipalities.

At the time of writing, the platform is under active development, with initial modules being deployed and tested using real administrative datasets. A staged rollout and pilot operation are planned, allowing participating municipalities to gradually integrate additional data sources and use cases. The Südwest-Cluster thus represents an ongoing field experiment in inter-municipal data platform development, providing empirical insights into both the potentials and challenges of cooperative urban data infrastructures.

4.2.2 Architecture and Components

The technical foundation of the intermunicipal data platform is the Urban Data Space Platform (UDSP) developed by the German GovTech company Hypertegrity AG[2]. The UDSP is an open, modular data platform for the secure integration, processing, and provision of urban data. It is based on modern open-source technologies and is fully compliant with DIN SPEC 91357 (DIN 91357 2017). It uses a cloud-agnostic, containerized infrastructure based on Kubernetes and is architecturally based on the FIWARE framework to ensure interoperability and digital sovereignty. Key components of the platform include an ETL system for standardized data integration (e.g., via NGSI/Node-RED), specialized databases for time series and geodata, API management for controlled data provision, and visualization tools such as Grafana, Apache Superset, and the master portal for evaluating and displaying urban data. An open data portal and open APIs enable data to be efficiently made available to citizens, public authorities, and external service providers, while robust rights management and security features support the reliable operation and scalability of the overall architecture. Fig. 1 provides detailed information about the system architecture.

The UDSP is licensed under the EUPL 1.2 open source licence, and the source code is fully accessible to the public.[3]

[2] see https://www.hypertegrity.de
[3] see https://gitlab.com/urban-dataspace-platform/core-platform

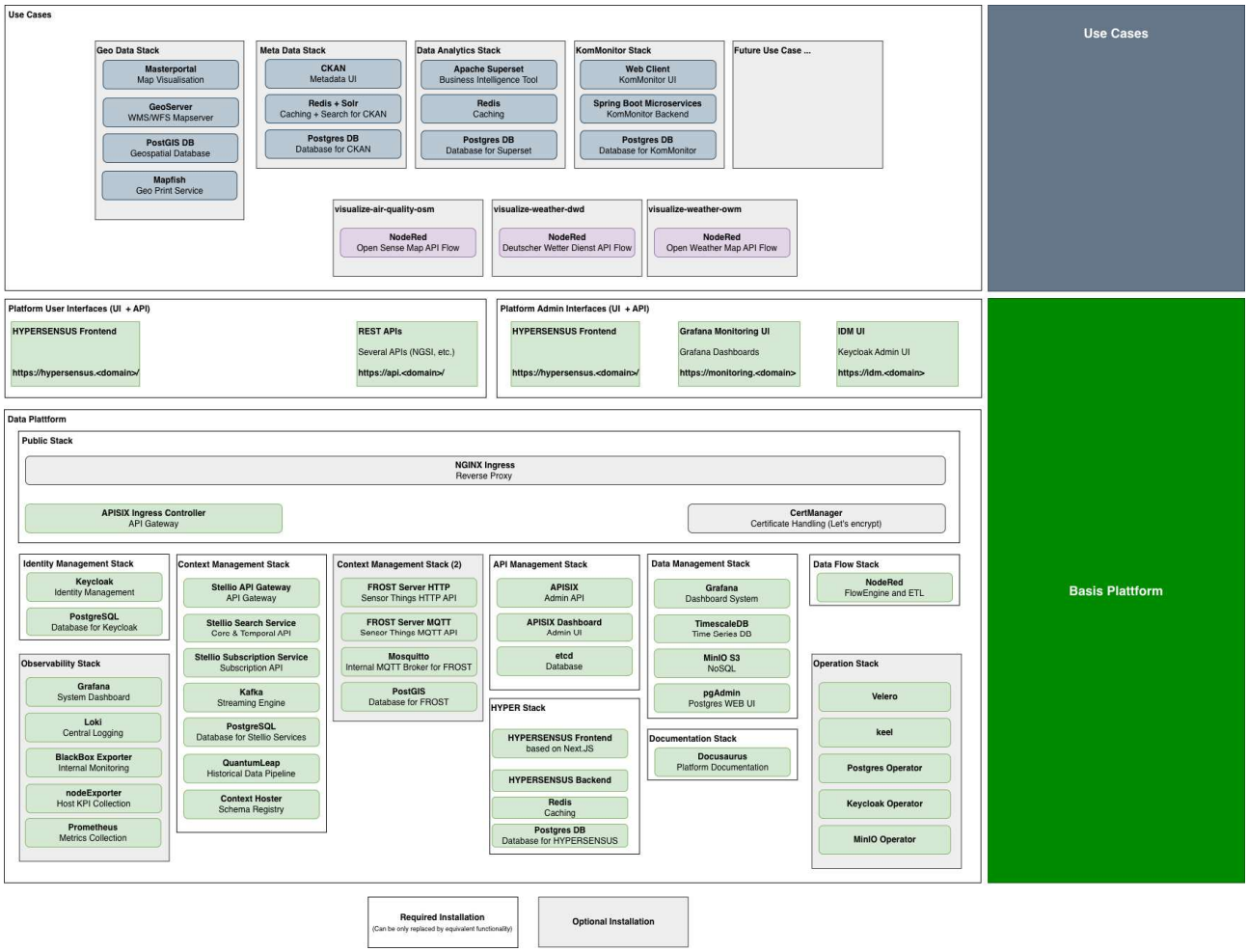


Fig. 1: The UDSP system architecture (Urban Data Space Platform 2026)

5 INITIAL RESULTS

In Kaiserslautern, MPSC project members have worked closely with municipal stakeholders to define concrete data-driven use cases that can support internal administration. For each use case, relevant datasets were identified in workshops with city departments, and interactive dashboards are being developed using the platform's dashboard component (based on Apache Superset). The dashboards integrate the harmonized data (as described in Section 4.2) and allow officials and other stakeholders to explore, compare, and filter the information on demand.

These use cases have been organized into thematic areas covering a wide range of city functions. Table 1 provides an overview of the topics and the data sets currently used in visualizations.

thematic area	**used data sets**
population data	- GDPR-compliant derivatives from registration data (German "Melderegisterdaten")
work & social affairs	- unemployment figures - benefit units (German "Bedarfsgemeinschaften") - commercially provided socio-economic micro-area indicators (MICROM)
mobility	- vehicle registration records (German 'KFZ-Zulassungen') - parking garage occupancy
election results	- results from 2024 city council elections
tourism	- visitor counts - number of brochures sent (with recipient zip codes)

Table 1: An overview of thematic areas and data sets used so far

Dashboards in Apache Superset are composed of individual charts, each representing a specific indicator, distribution, or relationship derived from the underlying datasets. These charts can take different forms, such

as time series, bar charts, tables, or map-based visualizations, depending on the analytical purpose. Multiple charts are combined within a dashboard view, allowing users to explore several aspects of a topic in a single, coherent interface. To improve usability and thematic structuring, dashboards can be organized into tabs, which group related charts and enable a clear separation of analytical perspectives (e.g., temporal trends, spatial patterns, or comparative indicators). Interactive elements such as filters and selections allow users to dynamically adjust the displayed information, for example by time period, spatial unit, or data category. In this way, dashboards support both exploratory analysis and routine monitoring, while remaining adaptable to different user needs and evolving analytical requirements.

Figures 2–4 provide examples of current dashboards that are currently being developed. These initial visualizations demonstrate how the platform helps translate raw municipal data into useful knowledge for decision-makers and the public, consistent with earlier findings on efficiency gains in the cluster.

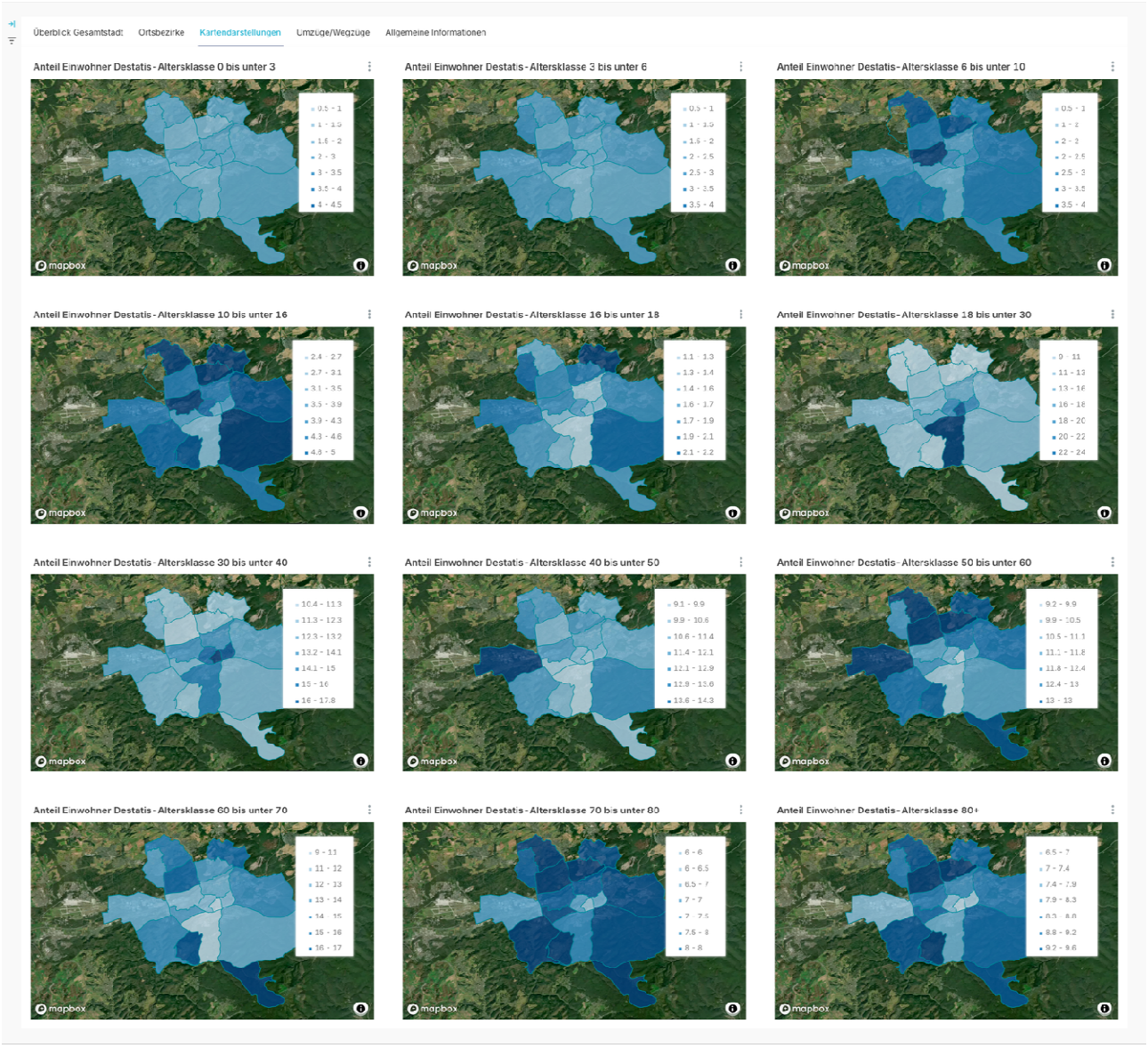


Fig. 2: Dashboard with map-based representations of shares of different age groups from population data in Kaiserslautern.

The first dashboard (Fig. 2) visualizes the spatial distribution of different age groups across the districts of Kaiserslautern. Age-group shares are represented using a choropleth map, where darker shading indicates a higher proportion of the selected age cohort within a given district. From an analytical perspective, this dashboard supports rapid exploratory analysis of demographic patterns and helps municipal actors to identify areas with specific age-related characteristics. Such insights can inform planning and decision-making processes in fields such as housing policy, social infrastructure, education, or mobility planning. Moreover, the map-based representation facilitates communication of demographic trends to non-technical stakeholders by providing an easily interpretable visual overview.

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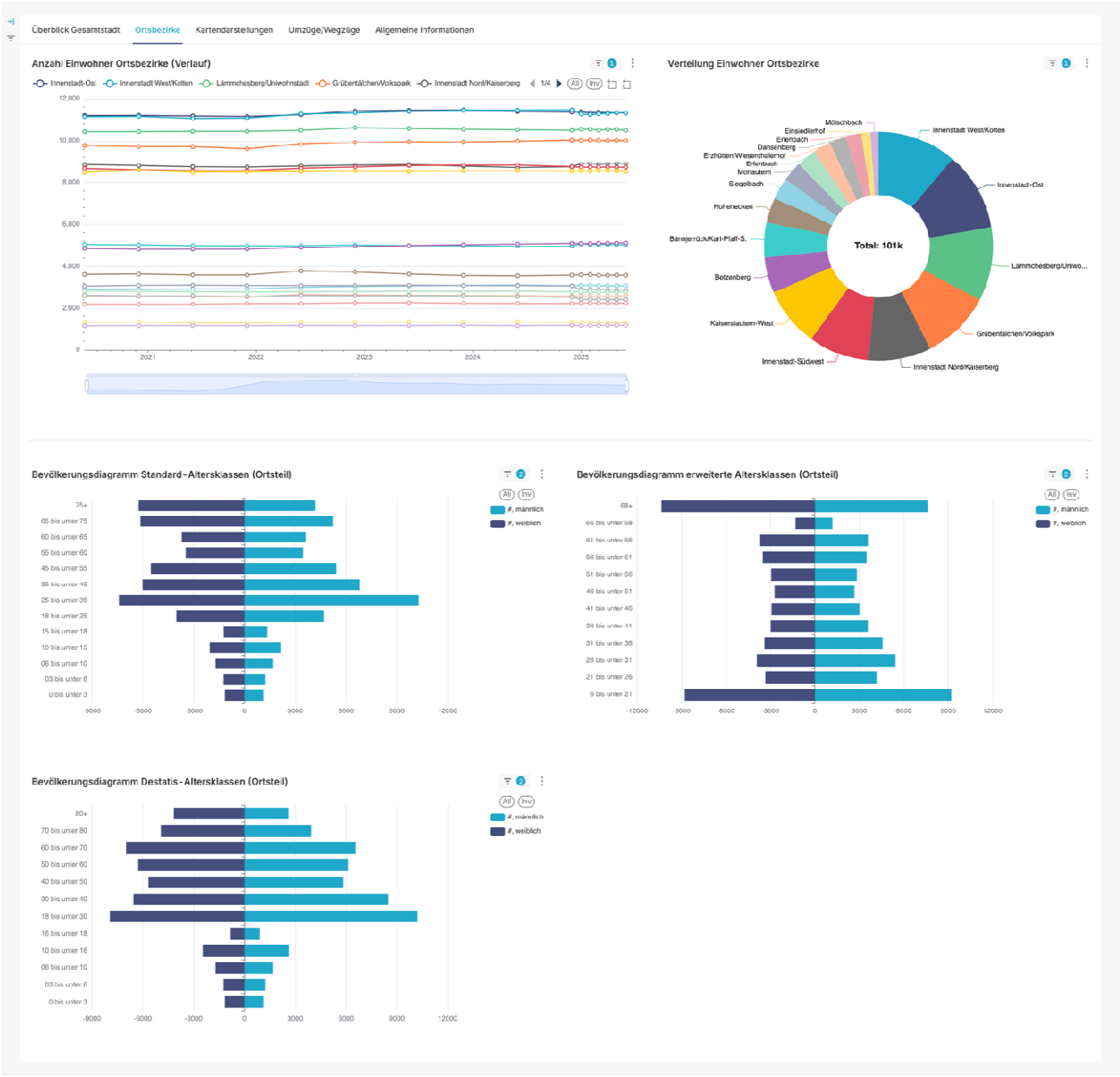


Fig. 3: Dashboard with different information about population data from different city quarters of Kaiserslautern.

The dashboard shown in Fig. 3 presents population data at district level with a focus on temporal development and internal demographic composition. It combines a time series showing the evolution of the total population for individual districts with a comparative view of population distribution across administrative subunits. For the currently selected district, additional charts display the population structure by age, using different age group classifications. This dashboard enables users to analyse both long-term demographic trends and current population structures at a fine-grained spatial level. It supports tasks such as monitoring population growth or decline, comparing demographic developments between districts, and assessing age-specific dynamics. In administrative practice, these insights can be used to support evidence-based planning of public services, such as schools, childcare facilities, or elderly care infrastructure, as well as to inform strategic discussions on urban development and neighbourhood change.

As a last example, Fig. 4 shows a dashboard that allows users to select and compare multiple districts with regard to selected socio-economic dimensions. In particular, it focuses on the distribution of household income classes and educational attainment levels. By enabling side-by-side comparison of districts, the dashboard highlights structural differences and similarities in socio-economic conditions across the city. This comparative perspective supports a more nuanced understanding of social and economic disparities within the urban area. It can be used to identify districts with specific socio-economic profiles, inform targeted policy interventions, and support cross-departmental coordination in areas such as social policy, education,

and urban regeneration. In addition, the dashboard provides a valuable basis for discussing socio-economic developments with political decision-makers and external stakeholders, as it translates complex data into a clear and comparable visual format.



Fig. 4: Dashboard with a comparison of socioeconomic information from different city quarters in Kaiserslautern

The visualizations are continuously refined in an iterative exchange with users, extending and adapting them as new requirements emerge. Early user feedback has been very positive: for example, testing the dashboards revealed the need to establish a common terminology for social statistics across departments. This highlights that technical integration must go hand in hand with semantic alignment.

6 SUMMARY AND OUTLOOK

UDM constitutes a key challenge and opportunity for municipalities aiming to make better use of their growing data assets. While cities already collect large volumes of administrative and statistical data, these resources often remain underutilized due to organizational fragmentation, unclear responsibilities, and heterogeneous technical systems. Addressing these issues requires more than isolated technical solutions: effective UDM must combine governance structures, strategic orientation, and suitable technological infrastructures. On the one hand, clearly defined roles, processes, and shared objectives are essential to enable coordinated data use across departments and municipalities. On the other hand, these governance principles must be operationalized through a capable municipal data platform that supports data integration, controlled access, and analytical use. Without such a technical backbone, strategic data governance remains largely ineffective. Since municipal data platforms represent critical digital infrastructure, data sovereignty and the avoidance of vendor lock-in are of central importance. Dependence on proprietary solutions can restrict flexibility, transparency, and long-term control over data and systems. In contrast, the open and modular approach pursued in the Südwest-Cluster demonstrates significant advantages. By relying on open-source components and shared development, participating municipalities retain control over their data and are able to jointly evolve the platform according to public-sector requirements.

First results from the intermunicipal, cooperative approach applied in the Südwest-Cluster indicate that shared platform development reduces redundant effort, accelerates implementation, and fosters learning across organizational boundaries. At the same time, the collaborative development of dashboards and use cases has revealed additional benefits, such as improved mutual understanding between departments and the need to harmonize terminology and data interpretations.

As a next step, the joint development of additional use cases will be continued and extended, both for internal administrative support and for public-facing open data services. Furthermore, the data platform is to be increasingly integrated into the standard service portfolio of the participating municipalities, moving beyond project-based usage. Finally, particular attention will be given to the development of a sustainable

operating and governance model that enables the long-term, cooperative operation of the platform beyond the end of the funding period. These steps are essential to ensure that UDM evolves from a project initiative into a permanent element of municipal digital infrastructure.

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Verantwortung im Städtebau im Umgang mit Bestand, Leerstand, Ressourcen und räumlichem Erbe

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1 ABSTRACT

Dieses Paper beschreibt, wie die Verantwortung im Städtebau und in der Architektur aus heutiger Sichtverstanden werden soll, insbesondere in Bezug auf bestehende Bausubstanzen, Leerstände, Ressourcenknappheit und räumliches Erbe. Die zentrale empirische Grundlage stammt aus den Tischgesprächen: einem interdisziplinären Diskussionsformat, das sich mit Strategien für Leerstand und öffentlichen Raum im demographischem Wandel auseinandersetzt und Akteurinnen und Akteure aus Forschung, Verwaltung, Planungspraxis, Kultur und Zivilgesellschaft zusammenbringt. Studentinnen, Studenten, Absolventinnen und Absolventen der TU Graz haben in ihren Vorträgen verschiedene Perspektiven zur Thematik präsentiert und somit Impulse für die Diskussion geliefert. Aus diesen Gesprächen ging hervor, dass verantwortliches Entscheiden im Städtebau weniger allein aus formalen Richtlinien entsteht, sondern sich in konkrete Aushandlungsprozessen unter begrenzten Handlungsspielräumen herausbildet: zwischen räumlichem Potenzial und politischen Zwängen, zwischen wirtschaftlichem Druck und sozialen Erwartungen sowie zwischen langfristigen Visionen und kurzfristigen Bedürfnissen. Dabei wurde wiederholt ein Ohnmachtsgefühl kommunaler Akteurinnen und Akteure sichtbar, das häufig defensive, situationsbedingte Handlungsweisen begünstigt und gestaltende Ansätze erschwert. Diese alltäglichen Entscheidungen prägen die Entwicklung und das Erbe von Orten in der Steiermark – insbesondere in Kleinstädten, periurbanen Räumen und ländlichen Regionen, die einem stetigen Strukturwandel unterliegen.

Unterstützende Erkenntnisse stammen aus einem parallelen Seminar der Doctoral School, in dem Vorträge und Diskussionen mit Winfried Nerdinger (Architekturhistoriker) und Ward Verkabel(Professor KU Leuven)zusätzliche theoretische Perspektiven lieferten.

Nerdingers Perspektive fügt dem Inhalt eine historische und moralische Dimension hinzu. Seine Thesen zur Rekonstruktion und zur Politik der gebauten Vergangenheit betonen, dass jeder Eingriff in die bestehende Struktur zwangsläufig auch ein Eingriff in das räumliche Erbe ist. Somit betont er, wie Gesellschaften sich an Teile ihrer Geschichte erinnern, diese interpretieren und manchmal auch auslöschen. Diese Sichtweise verdeutlicht, wie Entscheidungen über Anpassung, Erhaltung oder Abriss eine spezifische historische und gesellschaftliche Verantwortung implizieren, die über Richtlinien wie Bauverordnungen und Denkmalschutz hinausgehen.

Verbakels Begriff des Village Chatter ermöglicht es, räumliche Transformation als einen prozesshaften Dialog zu verstehen. Dieser Dialog entsteht aus lokalen Praktiken, Mustern und gemeinsamem Vokabular und steuert die Erwartungen und Entscheidungen. Diese Perspektive hilft, viele der in den Tischgesprächen aufgeworfenen Fragen, wie der Nachverdichtung über die Typologien bis hin zur sozialen Bedeutung von Schwellen und Gemeinschaftsflächen – als Produkte von Verhandlungen und nicht als vorgeschriebene Entwürfe zu interpretieren.

Zusammen bilden diese drei Komponenten – die gewonnenen Erkenntnisse aus den Tischgesprächen, Verbakels Konzept der Planungskultur und Nerdingers Verständnis des kulturellen Erbes – die Grundlage für ein differenziertes Verständnis verantwortlichen Handelns im Städtebau. Dieses Verständnis verantwortlichen Handelns erscheint nicht als festes, unveränderbares Prinzip, sondern vielmehr als eine prozessorientierte Haltung, die durch Spannungen geprägt ist. Diese Herausforderungen treten insbesondere im Bereich der Erhaltung, Anpassung und ressourcenschonender Weiterentwicklung sowie im Verhältnis von räumlichen Möglichkeiten und sozialen Gegebenheiten. Zudem ist eine Balance zwischen Identitätsschutz und Veränderungen sowie Zusammenwirken von lokalem Wissen und formalen Strukturen erforderlich.

Dieser Beitrag behandelt Themen wie den Umgang mit Leerstand, qualitative Bestandsentwicklung, räumliche Gerechtigkeit und die Verbindung von räumlichem Erbe mit vorausschauender Planung. Er zeigt, dass nachhaltige und verantwortungsvolle Lösungen dort entstehen, wo ein Austausch unterschiedlichster

Wissensformen aufeinander treffen – fachliche Expertise, administrative Erfahrung, soziale Perspektiven und kulturelle Erinnerungen. Der Beitrag schließt mit der These, dass verantwortliches Handeln im Städtebau nicht durch Verordnungen zu erreichen ist, sondern durch ausgehandelte, kollaborative und lokal verankerte Praktiken, die trotz begrenzter Ressourcen Gestaltungsspielräume eröffnen müssen.

Keywords: Städtebau, räumliches Erbe, Verantwortung, Ressource, interdisziplinäre Diskussion

2 EINLEITUNG

Im Kontext von Stadt- und Orts(kern)entwicklung ist der Begriff Verantwortung weit verbreitet, ohne jedoch eindeutig definiert zu sein. Verantwortung erscheint dabei als moralischer Anspruch, als politische Zuschreibung oder als institutionelle Zuständigkeit, ohne klar zu benennen, wie sie tatsächlich wirksam wird. In planerischen Diskursen wird Verantwortung meist mit administrativ definierten Aufgabenbildern, gesetzlichen Kompetenzen oder strategischen Zielsetzungen verknüpft. Demgegenüber zeigt die Praxis räumlicher Entwicklung, dass Verantwortung selten eindeutig verortet ist und sich häufig außerhalb klar geregelter Zuständigkeiten herausbildet. Verantwortlichkeit wird damit nicht primär als formale Zuständigkeit einzelner Akteurinnen und Akteure verstanden, sondern als Ergebnis konkreter Entscheidungs- und Aushandlungsprozesse. Sie entsteht dort, wo Entscheidungen vorbereitet, verzögert, übersetzt oder bewusst nicht getroffen werden – also im Zusammenspiel unterschiedlicher Akteurinnen und Akteure wie Verwaltung, Politik, Eigentümerinnen, Eigentümer und Planung – oft unter Bedingungen begrenzter Ressourcen, widersprüchlichen Interessen und institutionellen Zwängen (Albers, Suwala 2020).

Im Folgenden wird zwischen Verantwortung als normativer Zuschreibung, Verantwortlichkeit als institutionell geregelter Zuständigkeit und verantwortlicher Handlungsfähigkeit als praktischer Ausübung von Entscheidungs- und Moderationskompetenz unterschieden. Der Beitrag konzentriert sich dabei nicht auf moralische Zuschreibungen, sondern auf die Analyse verantwortlicher Entscheidungspraktiken im kommunalen Kontext.

Der Umgang mit dem bestehenden Gebäudebestand, mit Leerstand, begrenzten Ressourcen und räumlichem Erbe zählt in vielen europäischen Regionen zu den zentralen Herausforderungen zeitgenössischer Stadt- und Orts(kern)entwicklung. Insbesondere in kleinen und mittelgroßen Städten sowie in periurbanen und ländlichen Räumen verdichten sich demographische Veränderungen, wirtschaftliche Umbrüche und der wachsende Druck, klima- und ressourcenschonend zu handeln, zu komplexen Transformationsprozessen. Anstelle von Wachstum und Neubau rücken zunehmend Fragen der Anpassung, Wiederverwendung und des selektiven Rückzugs in den Fokus planerischer Praxis, wobei räumliche Entwicklung zunehmend unter Bedingungen von Schrumpfungen, Ressourcenknappheit und strukturellem Wandel gedacht wird.(Oswalt 2004; European Commission 2020).

Während planerische Debatten häufig auf die Fragen der Nutzung, der baulichen Qualität oder der gestalterischen Intervention fokussieren, bleibt die Frage, wie Verantwortung in diesen Prozessen tatsächlich entsteht und wahrgenommen wird, oft unscharf. Verantwortung im Städtebau wird dabei meist implizit mit Steuerung, Planungssicherheit oder der Umsetzung konkreter Projekte verknüpft. Gleichzeitig zeigt sich in der Praxis, dass viele räumliche Entwicklungen weniger an fehlenden Entwürfen oder Konzepten scheitern als an organisatorischen, sozialen und institutionellen Voraussetzungen: an ungeklärten Zuständigkeiten, verfestigten Entscheidungsroutinen, komplexen Eigentumsverhältnissen, widersprüchlichen Interessen oder fehlenden Vermittlungsstrukturen. Verantwortung wird damit nicht nur im Entwurf oder in formalen Planungsinstrumenten verhandelt, sondern bereits in frühen Entscheidungs- und Abstimmungsprozessen, die den Handlungsspielraum räumlicher Entwicklung maßgeblich bestimmen (Forester 1999).

Vor diesem Hintergrund geht dieses Paper der Frage nach, wie Verantwortung im Städtebau im Umgang mit Bestand, Leerstand, Ressourcen und räumlichem Erbe konkret ausgehandelt wird. Im Zentrum steht dabei nicht die Entwicklung von Leitbildern oder Lösungsansätzen, sondern die Analyse von Verantwortung als einer spezifischen Form verantwortlicher Handlungsfähigkeit, die sich in konkreten Entscheidungs- und Aushandlungspraktiken ausdrückt und sich situationsabhängig im Zusammenspiel unterschiedlicher Akteurinnen und Akteure entfaltet. Diese Perspektive steht im Einklang mit aktuellen Debatten zur territorialen Transformation, die räumliche Entwicklung als offenen, mehrstufigen und kontextabhängigen Prozess verstehen (Towards Territorial Transition 2023). Ziel ist es, Formen verantwortlichen Entscheidens

im Alltag sichtbar zu machen, die unter Bedingungen von Unsicherheiten, Machtasymmetrien und begrenzten Ressourcen getroffen werden (Yanow 2000).

Die Untersuchung stützt sich auf die Gesprächsreihe namens Tischgespräche. In diesem dialogischen Format diskutierten Akteurinnen und Akteuren aus Planung, Verwaltung, Wissenschaft und Zivilgesellschaft konkrete Herausforderungen im Umgang mit Leerstand, öffentlichen Raum und demographischem Wandel. Im Mittelpunkt standen dabei nicht abgeschlossene Projekte, sondern laufende Prozesse, Blockaden und Handlungsspielräume kommunaler Praxis. Ergänzt wird diese empirische Perspektive durch theoretische Reflexionen zum Umgang mit räumlichem Erbe und Planungskultur, insbesondere durch die Arbeiten von Winfried Nerdinger und Ward Verbakel. Während Nerdinger die historischen und kulturellen Bedeutungsfragen räumlicher Entscheidungen schärft, eröffnet Ward Verbakels Konzept des Village Chatter Planung als Dialog, der sich aus vielen alltäglichen, nicht formal gesteuerten Beiträgen entwickelt.

Dieser Beitrag eröffnet damit ein Verständnis von Verantwortung, das sich nicht auf einzelne Akteurinnen oder Instrumente reduzieren lässt. Vielmehr wird verantwortliches Handeln als prozesshafte, geteilte Praxis verstanden, die im Zusammenspiel von Organisation, Geschichte und Alltagswissen entsteht (Healey 2007). Die folgenden Kapitel erläutern zunächst die methodische Vorgehensweise, analysieren anschließend die Erkenntnisse aus den Tischgesprächen und ordnen diese abschließend in einen weiteren theoretischen Rahmen ein.

3 METHODIK

Dieses Paper basiert auf einem qualitativ-explorativen Forschungsansatz, bei dem die Erkenntnisse aus unterschiedlichen Gesprächen und Diskussionsrunden gewonnen wurden. Durch diese Methode sollen keine statistischen Beweise und allgemeingültigen Zahlen geliefert werden, sondern es soll ein Verständnis darüber generiert werden, wie verantwortliche Entscheidungen im Städtebau im Umgang mit Bestand, Leerstand, Ressourcen und räumlichem Erbe zustande kommen (Flick 2017). Der Fokus liegt dabei auf Prozessen, Begründungen und impliziten Werten, die in konkreten Diskussionen und Entscheidungen sichtbar werden, und damit auf einem praxis- und kontextbezogenen Erkenntnisinteresse, das sich bewusst von verallgemeinernden Modellen und rein instrumentellen Erklärungen abgrenzt (Flyvbjerg 2001).

3.1 Dialogische Forschungsformate, Datenerhebung und empirische Grundlage

Die zentrale empirische Grundlage dieses Artikels bildet die Symposiumsreihe, Tischgespräch – Strategien für Leerstand und öffentlichen Raum im demographischen Wandel, die zwischen 2024 und 2025 an der Technischen Universität Graz durchgeführt wurde. Die Tischgespräche wurden in Kooperation zwischen dem Institut für Städtebau und dem Institut für Wohnbau entwickelt und als dialogisches Forschungsformat konzipiert. Im Mittelpunkt standen die aktuellen Herausforderungen rund um Leerstand, öffentlicher Raum, Pflege sowie den demographischen Wandel und die Frage, wie diese Themen aus unterschiedlicher fachlicher Perspektive beleuchtet werden können und wie Verantwortung in diesen Feldern konkret wahrgenommen, verteilt, übernommen oder vermieden werden kann.

Die Veranstaltungsreihe bietet eine Plattform für den Austausch von Erfahrungen, Positionen und Lösungsansätzen und bringt Akteurinnen und Akteure aus Wissenschaft, Verwaltung, Planungspraxis, Kultur und Zivilgesellschaft zusammen. Dabei stehen keine abgeschlossenen Projekte im Mittelpunkt, sondern laufende Prozesse, Spannungsfelder und offene Fragen, wodurch Wissen als situativ, verhandelbar und prozesshaft verstanden wird (Nowotny et al. 2003). Beiträge von Studierenden, Absolventinnen, Absolventen Dissertantinnen und Dissertanten dienen als Impulse, um konkrete Fallbeispiele, Beobachtungen, Hypothesen und Entwurfsvorschläge zur Diskussion zu stellen, womit unterschiedliche Wissensformen gezielt aufeinander bezogen werden (Groat & Wang 2013). Die Gespräche sind dabei nicht als klassische Vorträge konzipiert, sondern als moderierte Dialoge, in denen theoretisches Fachwissen und praktische Erfahrungen auf Augenhöhe zusammengeführt werden. Anstatt einer isolierten Betrachtung einzelner Probleme, fördern die Tischgespräche durch ein gezieltes Vernetzen den Austausch zwischen verschiedenen Institutionen bzw. beteiligten Akteurinnen und Akteuren.

Die Datengrundlage des Papers besteht aus Notizen und Transkripten der Tischgespräche. Das Material wurde vollständig gesichtet und nach inhaltlichen Gesichtspunkten ausgewertet. Die Auswertung erfolgte paraphrasierend und zusammenfassend. Dabei wurden die Aussagen einzelner Teilnehmerinnen und Teilnehmer nicht isoliert beleuchtet, sondern als Ausdruck eines gemeinsamen Diskurses verstanden. Ziel

war es, die Vielfalt der Perspektiven sowie wiederkehrende Argumentationslinien und Spannungen innerhalb der Diskussionen abzubilden, ohne individuelle Positionen zu bewerten oder zu rekonstruieren (Mayring & Fenzel 2019).

Der analytische Zugang folgt einer strukturierenden, interpretativen Auswertung des Materials. In einem ersten Schritt wurden zentrale Themenfelder identifiziert, die in den Diskussionen wiederholt auftauchen, etwa der Umgang mit Leerstand, die Rolle von Gemeinden, die Bedeutung informeller Prozesse oder der Konflikt zwischen schnellen Lösungen und langfristigen Zielen. In einem zweiten Schritt wurden diese Themen in Beziehung gesetzt und dahingehend interpretiert, wie Verantwortlichkeiten zwischen verschiedenen Akteurinnen und Akteuren verteilt, ausgehandelt und wahrgenommen werden.

Verantwortung wurde dabei nicht als explizit benannter Begriff untersucht, sondern vielmehr als implizite Kategorie verstanden, die sich in Argumentation, Rollenbilder und Handlungsmustern unterschiedlicher Akteurinnen und Akteure ausdrückt. Dadurch wird Verantwortung als verteilte Praxis sichtbar, die sich im Zusammenspiel von räumlichen, sozialen, politischen und ökonomischen Faktoren herausbildet (Yanow 2000).

Ergänzend zu den Tischgesprächen fließen Erkenntnisse aus dem PhD-Seminar Architectural Research im Rahmen der Doctoral Schoolder Fakultät für Architektur an der TU Graz in die Analyse ein. Dieses Seminar folgte einem dreistufigen Format: Expertinnen und Experten aus unterschiedlichen Disziplinen wurden eingeladen, einen öffentlichen Vortrag an der TU Graz zu halten. Zur Vorbereitung wurden ausgewählte Texte oder Paper der eingeladenen Gäste zur Verfügung gestellt. Abschließend wurden diese Texte sowie die Inhalte der Vorträge in einem geschlossenen Rahmen vertiefend diskutiert und offene Fragen geklärt. Somit wurden Theorie, Forschung und Reflexion systematisch miteinander verbunden (Creswell & Poth 2018).

Die Vorträge und Gespräche mit Winfried Nerdinger und Ward Verbakel lieferten daraus zusätzliche theoretische und historische Perspektiven auf Fragen der Planungskultur, Rekonstruktion und des räumlichen Erbes. Diese dienen im vorliegenden Paper nicht als eigenständige Fallstudien, sondern als konzeptionelle Ergänzung, um die empirischen Beobachtungen aus den Tischgesprächen einzuordnen und zu reflektieren.

Die vollständige Übersicht über die Termine, eingeladene Gäste und thematischen Schwerpunkte der Tischgespräche ist im Appendix dieses Beitrags dokumentiert.

4 ERKENNTNISSE AUS DEN TISCHGESPRÄCHEN

Die drei Tischgespräche veranschaulichen ein Bild, wie die Verantwortlichkeit im Städtebau im Umgang mit Bestand, Leerstand, Ressourcen und räumlichem Erbe verhandelt werden können. Im Zentrum der Diskussionen standen nicht einzelne Projekte oder Entwürfe, sondern die Frage, wie räumliche Entwicklungen unter Bedingungen von Unsicherheiten, strukturellem Wandel und Ressourcenknappheit in Österreich, vor allem in steirischen Gemeinden, organisiert werden kann. Die Handlungsfähigkeit entsteht dort, wo Entscheidungen vorbereitet, ermöglicht oder blockiert werden – häufig lange, bevor formale Planungsinstrumente wie Widmung, Bebauungspläne oder Förderprogramme überhaupt zum Einsatz kommen.

4.1 Ortskernentwicklung als Organisationsproblem

Ein zentrales Ergebnis ist die veränderte Sichtweise auf die Problemdarstellung von Leerstand und Ortskernen. Leerstehende Objekte wurden nicht als Folge von fehlenden Nutzungskonzepten oder mangelnder architektonischer Qualität verstanden, sondern als Ausdruck organisatorischer Hürden. In vielen diskutierten und präsentierten Projekten wären Räume verfügbar, Nutzungsinteressenten vorhanden und soziale Bedürfnisse gegeben, dennoch bleiben viele Gebäude und Räume unter- oder ungenutzt.

Ausschlaggebend sind weniger die baulichen Defizite als ungeklärte Eigentumsverhältnisse, fehlende Vermittlungsinstanzen, Unsicherheiten auf Seiten der privaten Eigentümerinnen und Eigentümer sowie das Fehlen von Akteurinnen und Akteuren , die über längere Zeiträume hinweg Entscheidungsverantwortung tragen und Prozesse kontinuierlich begleiten. Eigentum zeigt sich dabei weniger als eindeutig festgelegte rechtliche Kategorie, sondern als Praxis, deren Bedeutung im Alltag immer wieder neu ausgehandelt wird (Blomley 2016).

Darüber hinaus wird deutlich, dass Architektur und Städtebau in Transformationsprozessen häufig nicht in den Prozess aufgenommen wird, sondern auf bereits getroffene organisatorische, rechtliche und

eigentumsbezogene Entscheidungen reagieren muss. Grundlegende Entscheidungen über Handlungsspielräume und Entwicklungsoptionen werden auf einer vorgelagerten organisatorischen Ebene geschaffen oder bleiben ungeklärt. Diese Ebene wurde explizit als konflikthaft beschrieben, insbesondere dort, wo private und öffentliche Interessen aufeinandertreffen: „Es geht nicht um dieses eine Projekt, sondern um diese Grenzüberschreitung zwischen privatem und öffentlichem Raum – dieser Grenze zwischen dem privaten Raum und der Straße – dort, wo es unterschiedliche Interessen gibt [...] und wo wir versuchen, diese Moderation zu bekommen“ (Lichtblau, TU Graz, 05.12.2025).

Weiters wurde diskutiert, dass organisatorische Blockaden nicht nur strukturell, sondern häufig personell bedingt sind. Ob Ortskernentwicklung vorangetrieben wird oder stagniert, hängt in vielen steirischen Gemeinden maßgeblich von einzelnen handelnden Personen ab – insbesondere von der Haltung der Bürgermeisterinnen und Bürgermeistern oder zentralen Akteurinnen und Akteuren in Verwaltung und Politik. Verantwortliche Entscheidungsbefugnis ist damit häufig personenbezogen organisiert und nur eingeschränkt strukturell abgesichert. Diese personelle Abhängigkeit erschwert nachhaltige Transformationsprozesse, da Entwicklungen stark von individuellen Haltungen, Prioritäten und Handlungsspielräumen abhängen. Veränderungen werden dadurch weniger planbar und können bei politischen Wechseln, personellen Veränderungen oder veränderten Rahmenbedingungen ins Stocken geraten oder neu verhandelt werden.

4.2 Moderation als Schlüsselkompetenz der Planung

Weiters wurde beleuchtet, dass erfolgreiche Veränderungen in der Stadt- und Ortskernentwicklung weniger von technischem Fachwissen abhängen, sondern von der Fähigkeit, zwischen widersprüchlichen Interessengruppen moderieren. Eigentümerinnen und Eigentümer wurden dabei nicht primär als blockierend beschrieben, sondern vielmehr als Akteurinnen und Akteure, die mit Unsicherheiten, Kontrollverlustängsten oder finanziellen Risiken konfrontiert sind. Gleichzeitig gelten Gemeinden zwar als Schlüsselakteure, verfügen jedoch häufig nicht über die notwendigen Strukturen und personellen Ressourcen, um diese Rolle dauerhaft wahrzunehmen. Es wurde wiederholt betont, dass fehlende Moderation nicht zu Konfliktlösung, sondern zu einer Verschiebung von Verantwortung führt. Entscheidungen werden vertagt oder entlang bestehender Routinen getroffen, anstatt aktiv ausgehandelt zu werden. Wie Aglaée Degros formuliert: „Man ist sehr schnell in einer Wunschführung und nicht in einer Moderation von dem, was notwendig ist. [...] Es braucht auch eine Moderation dieser Gespräche“ (Degros, TU Graz, 05.11.2024).

Neu geschärft wurde dabei der Blick auf Macht und Verantwortung innerhalb administrativer Strukturen. Raumordnung, Förderpolitik und Genehmigungsverfahren wurden nicht als neutrale Instrumente beschrieben, sondern als Felder, in denen Verantwortung aktiv ausgeübt – oder bewusst vermieden – wird. Moderation bedeutet in diesem Kontext nicht nur Vermittlung zwischen Interessen, sondern auch den reflektierten Umgang mit institutioneller Macht und Spielräumen. Moderation kann nicht als selbstverständlich vorhandene Kompetenz vorausgesetzt werden, sondern muss als eigenständige Aufgabe erst aufgebaut und erlernt werden. „Es geht gar nicht um die Gestaltung vom Raum, sondern eigentlich darum, die Moderationsfähigkeiten aller Beteiligten zu erarbeiten. [...] Wir stehen da eigentlich alle bei Null“ (Spindler, TU Graz, 04.12.2025).

Planung wird somit zur vermittelnden Praxis zwischen Eigentum, Politik, Verwaltung, konkreten Nutzungsinteressen und langfristigen Entwicklungsperspektiven (Forester 1999). Moderation beschreibt dabei nicht nur einen methodischen Zugang, sondern eine grundlegende Haltung gegenüber Offenheit, Aushandlung und Grenzüberschreitung. Es wurde betont, dass es dabei weniger um einzelne Projekte geht als um die dahinterliegende Idee einer veränderten Haltung: „Die Idee, die dahinter steckt, ist viel wichtiger – nämlich dieses Öffnen der Köpfe und die Öffnung der Grundgrenzen und dieses Moderieren über Grenzen hinaus zwischen Interessen“ (Lichtblau, TU Graz, 05.12.2025).

4.3 Eigentum als Herausforderung der Transformation

Eigentum wird als eine der grundlegenden strukturellen Voraussetzungen benannt, die die räumliche Transformation erschwert. Dabei standen nicht nur Besitzverhältnisse im Fokus, sondern auch emotionale Bindungen, persönlich und familiär geprägte Beziehungen zum Eigentum, Misstrauen gegenüber öffentlichen Akteurinnen und Akteuren sowie lokalpolitischer Argumentationsmuster, die Veränderungsprozesse erschweren oder blockieren. Eigentum erscheint in diesem Verständnis weniger als

eindeutig festgelegte rechtliche Kategorie, sondern als Praxis, deren Bedeutung im Alltag immer wieder neu ausgehandelt werden (Blomley 2016).

Diese Aushandlung zeigt sich besonders deutlich dort, wo kommunale Prioritätensetzungen, bestehende Routinen und finanzielle Rahmenbedingungen aufeinanderprallen. Es wird ein grundlegendes Zielkonflikt kommunaler Entscheidungsprozesse beschrieben: Während der Wunsch nach Erneuerung vorhanden ist, werden finanzielle Ressourcen häufig für die Fortführung bestehender Infrastrukturen gebunden. Projekte, die inhaltlich gut auf aktuelle gesellschaftliche Herausforderungen reagieren würden, bleiben dadurch unerprobt (Degros, TU Graz,05.11.2024).

Der Ankauf von Immobilien durch Gemeinden wurde kritisch hinterfragt. Man sieht darin weniger ein allgemeines Erfolgsrezept als vielmehr einen pragmatischen Ausweg, wenn es keine andere Alternative gibt. Thematisiert wurde dabei insbesondere die Gefahr, dass Risiken und Verantwortung von privaten Eigentümerinnen und Eigentümern auf die öffentliche Hand verlagert werden, ohne dass langfristige Nutzungsperspektiven gesichert sind. Statt klassischer Besitz- und Investitionslogiken traten Zwischenformen in den Vordergrund, die bestehende Strukturen umgehen oder ergänzen. Verantwortliche Praxis zeigt sich dabei in der Erprobung alternativer Modelle wie Pacht, temporäre Nutzung, kooperative Organisationsformen oder einer schrittweisen Aktivierung, auch wenn diese mit zusätzlicher administrativer Komplexität verbunden ist.

4.4 Verantwortung als Prozess und nicht als fertiges Zielbild

Ein weiteres zentrales Learnings die Abkehr von fixierten Nutzungskonzepten. Diese Haltung wird in den Diskussionen explizit formuliert: „Und wir können heute in kleinen Schritten beginnen, anstatt darauf zu warten, dass alle Gesetze perfekt darauf abgestimmt sind“ (Kuhn, TU Graz, 04.12.2025). Erfolgreiche Transformationsprojekte begannen selten mit einem klar definierten Endzustand, sondern entwickelten sich schrittweise und adaptiv. Temporäre Nutzungen und Zwischennutzungen wurden dabei nicht als Übergangslösung verstanden, sondern als eigene Strategie beschrieben, die Lernen, Anpassung und Korrektur ermöglicht.

Diese Offenheit wurde nicht als Planungsmangel, sondern als bewusste Haltung verstanden. Verantwortliches Handeln bedeutet in diesem Kontext, Entwicklungen als lernenden Prozess zu begreifen und Räume nicht zu überdefinieren, sondern Möglichkeitsräume für Aneignung, Veränderung und Mitgestaltung zu schaffen.

4.5 Wiederverwendung, Ressourcen und Klimaverantwortung

In den Gesprächen wurde klar, dass Wiederverwendung bestehender Bausubstanzen zwar häufig mit klimapolitischen Argumenten begründet wird, der Aspekt des Klimaschutzes in kommunalen Entscheidungsprozessen jedoch selten eine eigenständige Rolle spielt. In vielen Diskussionen zur Ortskernentwicklung wurde Klimaverantwortung nicht aktiv mitgedacht, sondern höchstens nachträglich als ergänzendes Argument herangezogen. Gleichzeitig wurde eine deutliche Position formuliert, die diese Leerstelle explizit adressiert: „[...] in einer Art und Weise ist es auch die Aufgabe von uns Architekten zu moralisieren und das Wissen, das wir da im universitären Kontext generieren, auch rauszutragen, [...]. Es ist nun mal so, dass wir mit dem Klimawandel konfrontiert sind, also müssen wir auch über alternative Lebenskonzepte nachdenken. Und deswegen sehe ich das auch als Aufgabe von uns Architekten.“ (Lena Leander Kaschnig, Studentin TU Graz, 31.03.2025)

Vielmehr erscheint der Klimaschutz als eine Art begleitender Faktor, der eng mit den Fragen der Nutzung, Organisation und langfristigen Wirtschaftlichkeit eines Projektes verbunden ist. In steirischen Gemeinden wird Klimaverantwortung nicht über verbindlich festgelegte Vorgaben wirksam, sondern über Abwägungsprozesse im Alltag kommunaler Entscheidungen. Die Wiederverwendung von Bausubstanzen wird dabei nicht als starres Gesetz verstanden, sondern als eine Strategie bei der die ökologischen Vorteile stets gegen soziale Auswirkungen (Nutzungsqualität, Erschwinglichkeit, Quartiersentwicklung) und finanzielle Belastungen (Investitions- und Betriebskosten, Risiken) abgewogen werden müssen. Klimaverantwortung äußert sich daher weniger in eindeutigen Vorschriften als in der Fähigkeit, ökologische, soziale und wirtschaftliche Anforderungen in räumlichen Transformationsprozessen miteinander zu vermitteln (Territorial Urbanism Now! 2024).

4.6 Soziale Infrastruktur abseits zentraler Orte

Auch die räumliche Verortung von Gemeinschaften wurde in den Tischgesprächen diskutiert. Es wurde deutlich, dass sozialer Zusammenhalt in vielen Fällen außerhalb klassischer Ortskerne entsteht. Informelle Treffpunkte, periphere Strukturen und alltägliche Nutzungen am Rand der Siedlung – wie Bushaltestellen, Parkplätze, Gemeinschaftsgärten – übernehmen Funktionen sozialer Verankerung, ohne als solche geplant oder formal anerkannt zu werden. „Die Motivation, in dieser Gemeinde zu bleiben, sich zu engagieren und aktiv zu sein, findet aktuell nicht in zentralen Räumen statt, sondern diese Motivation stammt aus den Peripherien“ (Brinbreier, TU Graz, 04.12.2025).Diese Räume kommen meist ohne architektonische Aufwertung aus; sie leben von alltäglicher Präsenz, wiederkehrenden Ritualen und der unausgesprochenen Übereinkunft über deren Umgangsformen. Bemerkenswert ist dabei weniger die Existenz dieser Orte, sondern vielmehr ihre planerische Ausblendung in Entwicklungsstrategien, Förderprogrammen und Leitbildern. Gerade weil sie nicht repräsentativ gestaltet, nicht eindeutig programmiert und oft rechtlich wenig abgesichert sind, entziehen sie sich gängigen Instrumenten der Ortskernentwicklung.

Die Diskussionen verdeutlichen zudem, dass eine architektonische Aufwertung die sozialen Qualitäten nicht zwangsläufig stärkt, sondern in manchen Fällen sogar gefährdet. Aus dieser Perspektive ergibt sich eine städtebauliche Verantwortung, klassische Leitbilder von Zentralität zu hinterfragen und periphere, informelle sowie nicht-repräsentative Räume als soziale Infrastruktur mitzudenken. Das heißt in diesem Zusammenhang, nicht nur neue zentrale Orte zu schaffen, sondern bestehende soziale Praktiken zu erkennen, zu schützen und in ihrer räumlichen Fragilität ernst zu nehmen.

4.7 Anerkennung von Grenzen

Es wurde deutlich, dass nicht jeder Ort und nicht jeder Leerstand eine Zukunft haben wird. Nicht jede Nutzungsidee findet reale Nutzerinnen und Nutzer, nicht jede Struktur kann dauerhaft aktiviert werden. Verantwortung wurde hier nicht als Anspruch auf Rettung verstanden, sondern als Fähigkeit, Rückzug, Rückbau oder selektive Aufgabe als legitime Strategie anzuerkennen. „Wir haben das Problem, also jetzt in der Steiermark, dass in vielen Ortskernen der Nahversorger stirbt. Das ist ein großes Thema. [...] Wir können nicht Nahversorger retten mit dem Steuergeld, wenn niemand dort einkauft. Das heißt, man muss schon Mut haben zu sagen: das funktioniert nicht“ (Moder, TU Graz, 04.12.2025).

Damit verschiebt sich das Verständnisverantwortlichen Handelns im Städtebau aber auch in der Architektur von einem Wachstums- oder Handlungszwang hin zu einer kontextbezogenen, reflektierten Haltung, die Unsicherheit zulässt und dennoch handlungsfähig bleibt. Für steirische Gemeinden heißt dies, dass ein Perspektivenwechsel notwendig ist: weg vom permanenten Aktivierungsdruck hin zu einer Haltung, die auch Nicht-Entwicklung und Zurückhaltung als verantwortungsvolle Option zulässt. Dies erfordert jedoch politische Rückendeckung und institutionelle Akzeptanz, die derzeit oft fehlen.

4.8 Haltung und Handlungsspielräume

Ein zentrales zusätzliches Learning betrifft die Haltung kommunaler Entscheidungsträgerinnen und Entscheidungsträger. Ortskernentwicklung scheitert, oder gelingt, häufig nicht an fehlenden Instrumenten oder finanziellen Mitteln, sondern an der Frage, ob Gestaltung als aktive Aufgabe verstanden wird oder auf reine Verwaltung reduziert bleibt. Mehrfach wurde ein verbreitetes Ohnmachtsgefühl von Gemeinden ausgesprochen, das zu defensive statt gestaltender Handlungsweisen führt: „Manche sagen, man braucht es gar nicht beginnen, weil das kann nicht funktionieren“ (Moder, TU Graz, 05.11.2025). Proaktive Bürgermeisterinnen und Bürgermeister hingegen nutzen vorhandene Spielräume, auch unter schwierigen Rahmenbedingungen. Diese Haltung lässt sich nicht verordnen, kann jedoch ermöglicht werden – etwa durch das Sichtbarmachen von Handlungsspielräumen, den Austausch erfolgreicher Beispiele und durch unterstützende Formate seitens Land Steiermark und Regionalmanagement. Eine zentrale Aufgabe übergeordneter Ebenen besteht daher darin, dieses Ohnmachtsgefühl gezielt abzubauen und kommunale Handlungsmacht zu stärken.

5 DER UMGANG MIT DEM RÄUMLICHEN ERBE

Einen wichtigen theoretischen Rahmen für die Frage nach der Verantwortung im Umgang mit dem Bestand liefert der Architekturhistoriker Winfried Nerdinger. In seinen Arbeiten über Rekonstruktion und zum Umgang der gebauten Vergangenheit macht Nerdinger deutlich, dass Entscheidungen über Erhalt,

Rekonstruktion oder Abriss keine rein funktionalen oder technischen Fragen beinhalten. Vielmehr stehen sie im engen Zusammenhang mit gesellschaftlichen Deutungen von Geschichte. Wie Nerdinger betont, ist „die Auseinandersetzung mit der Geschichte immer mit Orten verbunden“(Nerdinger, Diskussion TU Graz 2025).

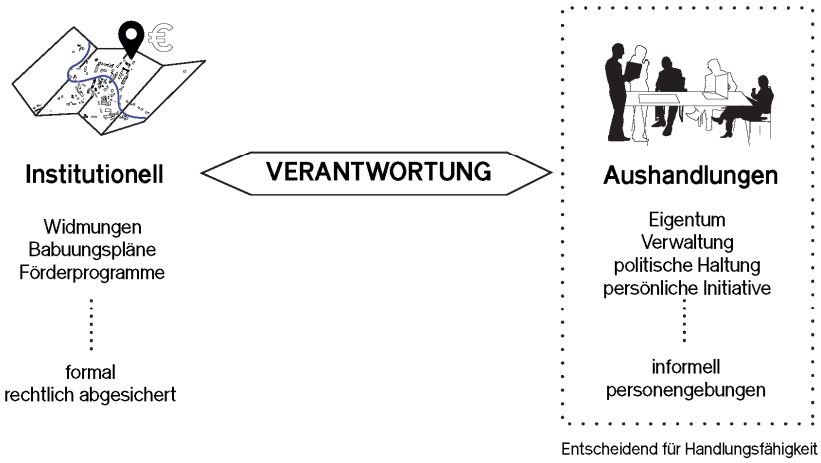


Abb. 1: Verortung von Verantwortung entlang formaler und informeller Entscheidungsprozesse. Quelle: Illustration des Autors.

Zentral ist dabei Nerdingers Kritik, dass Entscheidungen im Umgang mit dem Bestand oft mit vereinfachten und scheinbar sachlichen Argumenten gerechtfertigt werden. Entscheidungen erscheinen häufig als funktional notwendig, wirtschaftlich nicht vermeidbar oder planerisch sinnvoll, während ihre Bedeutung für Erinnerung und Geschichte kaum berücksichtigt wird. Gerade Rekonstruktion, aber auch bewusste Entscheidungen gegen eine Rekonstruktion, zeigen nach Nerdinger, dass Geschichte gesellschaftlich ausgehandelt wird. Dabei wird deutlich, welche Aspekte der Geschichte sichtbar bleiben, welche verdrängt werden und welche Sichtweisen als gültig angesehen werden. Verantwortung bedeutet in diesem Zusammenhang nicht, Geschichte einfach zu „bewahren“ oder „wiederherzustellen“. Vielmehr geht es darum, anzuerkennen, dass jede Form des Umgangs mit dem Bestand eine Abwägung darstellt und immer Auswirkungen auf das historische Verständnis hat.

Ein zentrales Learning aus der Gegenüberstellung von Nerdingers Position und den Tischgesprächen liegt in der Erweiterung des Verantwortungsbegriffes. Verantwortung bedeutet nicht nur, „funktionierende“ Lösungen zu finden, sondern auch eine bewusste Reflektion darüber, welche Bedeutungen durch räumliche Entscheidungen entstehen oder verloren gehen. In den Tischgesprächen wurde Verantwortung häufig als organisatorische, soziale oder mit Steuerung verbundene Aufgabe verstanden. Nerdinger ergänzt diesen Blick um eine historische Perspektive, die deutlich macht, dass auch alltägliche Transformationsentscheidungen Teil eines langfristigen Verständnisses der eigenen Kultur sind. Wie er formuliert, wird „mit Rekonstruktionen […] Geschichte konstruiert, durch Wiederholung […] eine für die jeweilige Gegenwart spezifische Kontinuität geschaffen“. (Nerdinger 2010, S.165) Diese Einsicht gilt nicht nur für Rekonstruktionen im engeren Sinn, sondern für jede Art des Umgangs mit dem baulichen Bestand.

Gleichzeitig stellt Nerdinger die verbreitete Vorstellung infrage, dass Verantwortung ausschließlich im Erhalt von Gebäuden liegt. Er macht deutlich, dass weder Rekonstruktion noch Bewahrung per se verantwortungsvoll sind ¬¬– ebenso wenig ist Abriss automatisch verantwortungslos. Verantwortliches Handeln entsteht vielmehr durch einen bewussten Umgang mit den Spannungen, die der Bestand mit sich bringt: zwischen Erinnerung und Veränderung, zwischen Sichtbarmachen und Aufgeben sowie zwischen historischer Bedeutung und heutiger Nutzung. Diese Haltung passt zu den Tischgesprächen, in denen auch Rückzug, Rückbau und das bewusste Aufgeben einzelner Teile als legitime, wenn auch schwierige, Strategien thematisiert wurden.

Für den Kontext kleiner und mittelgroßer Städte sowie ländlicher Räume bedeutet dies eine wichtige Veränderung im Verständnis von Verantwortung. Während große gesellschaftliche Debatten über den Umgang mit der Geschichte oft an prominenten Bauwerken geführt werden, zeigt sich die Verantwortung im Alltag der Orts(kern)entwicklung häufig in Entscheidungen, die ohne große öffentliche Aufmerksamkeit getroffen werden. So geht es etwa darum, ob ein Leerstand weiter genutzt, umgebaut oder aufgegeben wird und ob seine Geschichte erzählt, neu interpretiert oder stillschweigend vergessen wird. Nerdingers

Perspektive macht deutlich, dass auch solche Entscheidungen Teil des gesellschaftlichen Umgangs mit Geschichte sind – unabhängig davon, ob sie explizit als solche bezeichnet werden.

In Verbindung mit den Tischgesprächen lässt sich Verantwortung im Umgang mit dem Bestand daher als doppelte Aufgabe verstehen. Einerseits geht es um organisatorische, soziale und prozessuale Abstimmungen. Andererseits geht es um einen bewussten Umgang mit den historischen und kulturellen Bedeutungen von Räumen. Verantwortung entsteht dabei nicht nur durch Regeln oder Instrumente des Denkmalschutzes, sondern vor allem dadurch, dass diese beiden Ebenen – der praktische Alltag und die Auseinandersetzung mit der Geschichte – miteinander verbunden werden.

6 VILLAGE CHATTER: PLANUNG ALS DIALOGISCHE PRAXIS

Der Begriff Village Chatter wurde von Ward Verbakel, Architekt und Professor an der KU Leuven, geprägt und beschreibt Planung und Architektur nicht als top-down gesteuerte Entwurfsdisziplin, sondern als Ergebnis eines vielstimmigen, häufig informellen Dialogs innerhalb von Dörfern und Gemeinden. Der Begriff bezeichnet eine Sprache der gebauten Umwelt, die sich aus wiederkehrenden Mustern, lokalen Praktiken, Alltagsentscheidungen und unausgesprochenen Regeln zusammensetzt. Diese Sprache entsteht weniger durch verbindliche Planungsvorgaben als durch stetige Aushandlungen zwischen verschiedenen Akteurinnen und Akteuren, etwa in Genehmigungsverfahren, politischen Diskussionen oder alltäglichen Einzelentscheidungen. Architektur und räumliche Strukturen werden hier nicht als fertige Entwürfe verstanden, sondern als laufende Prozesse, in denen sich Erwartungen und Handlungsspielräume nach und nach festigen.

Im Vortrag und in den anschließenden Diskussionen wurde dieser Ansatz weiter vertieft. Verbakel macht deutlich, dass viele räumliche Konflikte und Qualitätsprobleme nicht durch mangelnder architektonischer Gestaltung entstehen, sondern weil die beteiligten Akteurinnen und Akteure nicht gut miteinander kommunizieren. Gemeinden greifen daher oft auf formale Mittel wie Bebauungspläne oder Leitfäden zurück, da ihnen eine gemeinsame Sprache fehlt, um über Nutzung, Eignung und räumliche Qualität zu verhandeln. Village Chatter kann in diesem Sinne als Versuch verstanden werden, diese sprachliche Lücken zu schließen, und zwar nicht durch neue Regeln, sondern durch die bewusste Benennung und Reflexion bestehender Muster und Praktiken. Verbakel beschreibt den Ansatz dabei ausdrücklich nicht als normative Methode, sondern als ein offenes, lernfähiges Vokabular, das lokale Eigenheiten ernst nimmt und auf Beobachtungen statt Vorgaben basiert. Ziel sei es, “not to prescribe what villages should become, but to learn how they already operate“ (Verbakel, Diskussion TU Graz 2025).

Für den österreichischen und vor allem auch für den steirischen Kontext erweist sich dieser Ansatz als besonders anschlussfähig. Die in den Tischgesprächen diskutierten Herausforderungen im Umgang mit Leerstand, Wiederverwendung und kommunaler Verantwortung zeigen deutliche Parallelen: Auch hier scheitern Transformationsprozesse selten an fehlenden Nutzungsideen oder Entwürfen, sondern an unklaren Zuständigkeiten, fehlender Moderation und mangelnder Abstimmung zwischen Eigentümerinnen, Eigentümern, Verwaltung, Politik und Zivilgesellschaft. Verbakels Perspektive macht sichtbar, dass Verantwortung in solchen Prozessen nicht bei einzelnen Personen liegt, sondern in der Fähigkeit, die vielen unterschiedlichen Abstimmungen zu strukturieren und offen zu halten. Village Chatter wird dabei nicht als autorinnen- und autorengesteuerte Methode verstanden, sondern als ein Prozess, der sich aus fortlaufenden Aushandlungen ergibt und “does not rely on a single author or authority, but emerges from the continuous negotiation of multiple voices, interests and interpretations“(Verbakel, Diskussion TU Graz 2025).

Damit verändert sich das Verständnis von planerischer Verantwortung. Verantwortung wird nicht mehr als feste Vorgabe oder alleinige Bestimmung über die Gestaltung verstanden, sondern als eine Praxis, die aus Beziehungen entsteht und sich im Übersetzten, Vermitteln und Aushandeln entwickelt. Planung wird so zu einer kulturellen Tätigkeit, die nicht in erster Linie fertige Lösungen liefert ¬– sondern sie schafft Rahmen, in denen unterschiedliche Vorstellungen von Nutzung, Qualität und Zukunft aufeinander bezogen werden können.

7 CONCLUSION

In diesem Beitrag wird untersucht, wie verantwortliche Entscheidungen im Städtebau unter gegenwärtiger Bedingungen zustande kommen und wie Akteurinnen und Akteure ihre Handlungsspielräume in Bezug auf Bestand, Leerstand und räumliches Erbe interpretieren. Ausgangspunkt der Analyse waren die

Tischgespräche als dialogisches Forschungsformat, sowie die theoretischen Perspektiven von Winfried Nerdinger und Ward Verbakel. Auf dieser Grundlage zeigt die Analyse, dass Verantwortung im Städtebau nicht als festes Ziel, verbindliches Leitbild oder moralische Pflicht verstanden werden kann. Vielmehr zeigt sich verantwortliches Entscheiden situationsabhängig im Zusammenspiel unterschiedlicher Akteurinnen, Akteure, Handlungsebenen und zeitlicher Perspektiven.

Die zentralen Erkenntnisse aus den Tischgesprächen liegen weniger in der Feststellung, dass Verantwortung vor dem Entwurf entsteht, sondern wo sie tatsächlich verhandelt werden. Verantwortliche Entscheidungsprozesse im Umgang mit Bestand und Leerstand entstehen nicht erst durch bauliche Maßnahmen, sondern bereits in organisatorischen und entscheidungsbezogenen Prozessen: in Eigentumsfragen, institutionellen Abläufen, in Routinen der Verwaltung, in Ängsten vor Risiko und Kontrollverlust sowie in der Abwesenheit klarer Prozesszuständigkeiten. Leerstand wurde in den meisten Fällen dabei weniger als architektonisches oder funktionales Defizit sichtbar, sondern als Ausdruck fehlender Entscheidungs- und Verantwortungsstrukturen. Der entscheidende Beitrag der Tischgespräche besteht darin, verantwortliches Handeln nicht primär als Frage gestalterischer Lösungen oder strategischer Konzepte zu begreifen, sondern als Fähigkeit Prozesse überhaupt erst handlungsfähig zu machen: Akteurinnen und Akteure miteinander in Beziehung zu setzen, Unsicherheiten und Nicht-Entscheidungen bewusst zuzulassen, Rückzug oder gezieltes Aufgeben als legitime Formen verantwortungsvollen Handelns anzuerkennen.

Die Gespräche, vor allem in Bezug auf steirische Gemeinden und regionalen Akteurinnen und Akteuren, machten darüber hinaus deutlich, dass Verantwortung nicht nur fragmentiert organisiert ist, sondern stark von einzelnen handelnden Personen abhängt. Ob Ortskernentwicklung angestoßen, vertieft oder blockiert wird, hängt häufig weniger von Programmen oder Förderungen ab als von der Haltung einzelner Bürgermeisterinnen, Bürgermeister, Amtsleiterinnen, Amtsleiter oder engagierter Fachpersonen. Verantwortliche Handlungsfähigkeit erscheint damit weniger als institutionelle Aufgabe als fragile, personenabhängige Praxis. Diese Abhängigkeit erschwert langfristige Veränderungen und führt dazu, dass Prozesse stagnieren, selbst wenn Problemlagen anerkannt sind. In diesem Zusammenhang wurde auch die Rolle der Förderungen kritisch reflektiert. Die Tischgespräche zeigen, dass Förderinstrumente nur einen begrenzten Lenkungseffekt entfalten. Gemeinden agieren häufig unabhängig von Förderinstrumenten. Maßnahmen werden nicht primär durch Förderverfügbarkeit ausgelöst, sondern entstehen oft trotz dieser Rahmenbedingungen. Damit rückt weniger die Frage nach vorhandenen Mitteln in den Vordergrund, sondern vielmehr, ob Handlungsspielräume überhaupt wahrgenommen, interpretiert und aktiv genutzt werden.

Nerdingers Auseinandersetzung mit Rekonstruktion und dem Umgang mit der gebauten Vergangenheit verdeutlicht, dass räumliche Entscheidungen stets auch gesellschaftliche Interpretationen von Geschichte produzieren. Ob Gebäude erhalten, adaptiert, rekonstruiert, aufgegeben oder abgerissen werden, ist nie eine rein funktionale oder technische Frage, sondern immer mit Fragen von Erinnerung, Sichtbarkeit und dem Fortbestand kultureller Bedeutungen verknüpft. Im Städtebau bedeutet verantwortliches Handeln nicht, Geschichte zu bewahren oder zu reproduzieren, sondern anzuerkennen, dass jede Intervention – ebenso wie jede Nicht-Intervention – Teil des gesellschaftlichen Umgangs mit Geschichte und dem kulturellen Erbe ist. Diese Perspektive vertieft die Tischgespräche dort, wo Entscheidungen über Rückbau, Nicht-Aktivierung oder selektive Aufgabe nicht als Scheitern, sondern als bewusste Form des Umgangs mit dem Bestand verhandelt wurden.

Ward Verbakels Konzept des Village Chatter ergänzt die Perspektive um eine prozesshafte und alltagsnahe Sichtweise. Planung und Architektur werden dabei nicht als von oben gesteuerte Disziplinen verstanden, sondern als Ergebnis vielfältiger, oft informeller Abstimmungsprozesse in lokalen Zusammenhängen. Verantwortliches Handeln bedeutet hier weniger, formale Vorgaben umzusetzen, sondern vielmehr, Dialoge zu ermöglichen und lokales Wissen in räumliche Entscheidungen einzubeziehen. Gerade für kleine und mittelgroße Städte sowie periurbane Räume zeigt sich, dass verantwortungsvolles Handeln nicht auf allgemeinen Modellen beruht, sondern auf anpassungsfähigen und lernenden Prozessen.

Erst in der Verknüpfung dieser drei Perspektiven wird deutlich, was Verantwortung im Städtebau heute bedeutet: sie ist keine Frage besseren Wissens, sondern eine Frage organisatorischer und kultureller Voraussetzungen. Verantwortung zeigt sich nicht in der Vielzahl von Maßnahmen oder Programmen,

sondern in der Fähigkeit, unter Unsicherheit handlungsfähig zu bleiben, Prozesse offen zu halten und Entscheidungen bewusst zu begrenzen.

Dass sich trotz vorhandenen Wissens wenig verändert, ist vor diesem Hintergrund weniger als fehlende Erkenntnis zu verstehen, sondern als Ausdruck der komplexen organisatorischen, finanziellen und administrativen Rahmenbedingungen, unter denen Planung heute stattfindet. Diese Rahmenbedingungen begünstigen Steuerung, Rechtssicherheit und Umsetzbarkeit, während Moderation, Aushandlung und das bewusste Offenlassen von Entscheidungen institutionell kaum anerkannt oder abgesichert sind.

Vor diesem Hintergrund verschiebt sich die Verantwortung im Städtebau von einem allgemeinen Anspruch auf Aktivierung hin zu einer bewussten, kontextbezogenen Haltung. Verantwortliche Entscheidungsfähigkeit bedeutet in diesem Zusammenhang nicht, möglichst viel zu verändern, sondern abzuwägen, wann, wie – und auch ob eingegriffen wird. Besonders im Umgang mit Bestand, Leerstand und knappen Ressourcen zeigt sich verantwortliches Handeln nicht in möglichst vielen Maßnahmen, sondern in der Fähigkeit, zwischen Aktivität und Zurückhaltung zu entscheiden und Stadt- und Ortsentwicklung als offenen Lern- und Aushandlungsprozess zu verstehen.

In Folgeuntersuchungen sollte daher analysiert werden, ob sich die hier vorgestellte dialogische und prozessorientierte Variante der Verantwortungsverhandlung in der kommunalen Planungspraxis langfristig besser bewährt als herkömmliche, stärker instrumentell geprägte Steuerungsmodelle.

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9 APPENDIX

Der folgende Appendix listet die eingeladenen Gäste und Vortragenden der Symposiumsreihe „Tischgespräche – Strategien für Leerstand und öffentlichen Raum im demographischen Wandel" auf, die die empirische Grundlage dieses Beitrags bilden. Die Auflistung dient der Transparenz des Forschungssettings.

Tischgespräch 1.0 – Strategien für Leerstand und öffentlichen Raum im demographischen Wandel

05.11.2024, 11:30Uhr, Technische Universität Graz/Kroneshalle/Krongesgasse 5/1.OG
BEGRÜSSUNG: Andreas Lichtblau Institut für Wohnbau; Aglaée Degros Institut für Städtebau
MODERATION: Michael Heil Institut für Wohnbau
VORTRÄGE VON:
Julian Radl, Masterarbeit 2024 Altersgerecht Wohnen im ländlichen Raum, gesprochen von Michael Heil
Fatma Alegöz Masterstudio2024 Park [re]sidency Rottenmann
Zeynep Bilici
Selina Haingartner
Sandra Zach, Masterarbeit 2020: Alt werden in Würde; alternative Wohnformen im ruralen Raum
Katharina Schlick, Masterarbeit 2017: Nimm Platz Jagerberg: Alternatives und integratives Generationenprojekt
Nina Fank Habe, Dissertation: Autonome Lebensweise im Alter Rigorosum 2025
Sandra Freudenthaler, Masterarbeit 2021: Alter[nativ]raum – ein Leitfaden für altersfreundlichen öffentlichen Raum
GÄSTE: Sabine Vogl, TU Graz/Koordinationsstelle Doktoratsstudien; Ingrid Moder, Abteilung 17/Landes- und Regionalentwicklung; Michael Sebanz, Abteilung 15/FA Energie und Wohnbau; Anna-Christina Kainradl, KFU Graz/CIRAC; Matteo Sattler, KFU/Healthy Streets; Johannes Maier, Volkskundemuseum; Thomas Kain, studio magic; Thomas Kalcher, studio magic.
Tischgespräch 2.0¬– Strategien für Leerstand und öffentlichen Raum im demographischen Wandel
31.03.2025, 16:00 Uhr, Technische Universität Graz/Alte Technik/HS II/KG
BEGRÜSSUNG: Michael Monsberger, Rektorat TU Graz; Andreas Lichtblaum Institut für Wohnbau; Aglaée Degros, Institut für Städtebau
MODERATION: Michael Heil, Institut für Wohnbau; Karina Brünner, Institut für Städtebau
VORTRÄGE VON
Lukas Schneider: Vertiefungsmodul Wachstum ohne Bodenverbrauch? RaumplanungWiSe24/25
Julian Radl, Masterarbeit 2024: Altersgerecht Wohnen im ländlichen Raum
Daniel Laggner-Hofer, Masterarbeit 2025: Raum für die Bevölkerung von Radenthein: Alternative Handlungskonzepte für die Neunutzung von Leerstand in ländlichen Gebieten
Melina Sehn, Vertiefungsmodul Wachstum ohne Bodenverbrauch? RaumplanungWiSe24/25
Theresa Hammerl, Masterarbeit 2024: Altern im Zentrum: eine Alternative zur Einfamilienhaus-Erzählung
GÄSTE
Michael Monsberger, TU Graz/Vizerektor; Sabine Vogl, TU Graz/Koordinationsstelle Doktoratsstudien; Ingrid Moder, Abteilung 17/Landes- und Regionalentwicklung; Stefan Spindler, Abteilung 17/Landes- und Regionalentwicklung; Gerhard Vötsch, Abteilung 17/Landes- und Regionalentwicklung; Robert Jansche, Abteilung 15/FA Energie und Wohnbau; Anna-Christina Kainradl, KFU Graz/CIRAC; Johannes Maier, Volkskundemuseum; Thomas Kain, studio magic; Thomas Kalcher, studio magic; Lore Stangl, metatektur; Josef-Matthias Printschler, metatektur; Peter Reitmayr, reitmayr architekten; Gerhard Mitterberger, Arch DI Mitterberger Gerhard ZT GmbH
Tischgespräch 3.0 – Strategien für Leerstand und öffentlichen Raum im demographischen Wandel
04.12.2025, 17:00Uhr, Technische Universität Graz/Alte Technik/HS II/KG
BEGRÜSSUNG: Andreas Lichtblau, Institut für Wohnbau; Aglaée Degros, Institut für Städtebau
MODERATION: Michael Heil, Institut für Wohnbau; Karina Brünner, Institut für Städtebau
VORTRÄGE VON
Miriam Kuhn, Masterarbeit 2025: Platz für die [Bau]Wende. Zentrum für Zirkuläres Bauen und Handeln. Berlin Kreuzberg
Petra Andricic, Projektübung SoSe25 Housing 2nd: Frohnleiten
Johannes Leiter, Projektübung SoSe25 Housing 2nd: Frohnleiten
Lukas Unger
Christoph Paulegger
Florentine Rom, Masterarbeit 2025: Von Leerstand zu Lebensraum. Nachhaltige und soziale Nachverdichtung im industriellen Bestand
Marius Birnbreier, Masterarbeit 2025: Zwischen Garantie und Autarkie: Selbstverantwortungsräume als Beitrag zur territorialen Gerechtigkeit in peripherisierten Gemeinden
GÄSTE
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Visuelle und KI-gestützte Risikoanalyse von Ausfällen der Straßenverkehrsinfrastruktur zur Vermeidung klimabedingter Schadensereignisse durch eine erhöhte Waldbrandgefahr

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1 ABSTRACT

Der Klimawandel führt bereits heute zu einer deutlichen Zunahme klimabedingter Belastungen der Straßenverkehrsinfrastruktur in urbanen wie ländlichen Räumen. Extreme Wetterereignisse wie Starkregen, Überflutungen, Hitzeperioden oder Schnee- und Eisereignisse beeinträchtigen die Funktionsfähigkeit von Straßennetzen und gefährden die Verkehrssicherheit. Gleichzeitig sind viele bestehende Straßen- und Entwässerungssysteme historisch gewachsen und nur begrenzt an gegenwärtige und vor allem zu erwartende zukünftige Klimaextreme angepasst. Vor diesem Hintergrund adressiert dieser Beitrag den sogenannten Ausfall der Straßenverkehrsinfrastruktur, verstanden als kritische Überlastung des Straßennetzes infolge kumulativer klimatischer Stressoren. Ziel des Projektes ist die Entwicklung und prototypische Anwendung einer KI-gestützten Methodik zur Identifikation und Klassifikation klimatologisch gefährdeter Straßenzüge. Dabei soll ein systematischer, datenbasierter Ansatz entwickelt werden, der Klimaprojektionen, meteorologische Messreihen, topografische Informationen, Geodaten sowie verkehrsinfrastrukturelle Merkmale integriert und so eine räumlich möglichst hoch aufgelöste Risikobewertung erlaubt. Diese Arbeit schließt damit eine Lücke zwischen raumbezogener Klimaforschung, technischer Infrastrukturplanung und digitaler Risikobewertung. Methodisch folgt das Forschungsvorhaben einem mehrstufigen Design, einer theoretischen Fundierung in den Bereichen Klimapolitik, Stadt- und Geländeklimatologie, Infrastrukturvulnerabilität und KI-gestützter Risikoanalyse. Anschließend folgt der Aufbau eines referenzbasierten Datenmodells anhand ausgewählter urbaner und ruraler Modellregionen in denen Klimadaten, topografische Parameter und straßenbezogene Infrastrukturdaten zusammengeführt werden. Daraus resultierend folgt die Entwicklung eines KI-gestützten Analysemodells, das mittels linearer Regressionsmodellierung Risikomuster im Straßennetz identifiziert und in Form eines digitalen Risiko-Zwillings für das Jahr 2050 abbildet. Bei erfolgreicher Implementierung erfolgt die planerische Interpretation der Ergebnisse und die Ableitung von Handlungsstrategien für eine klimaresiliente Verkehrsplanung. Erwartet wird ein Instrumentarium, das Kommunen, Infrastrukturbetreibende und Planungsinstitutionen bei der frühzeitigen Identifikation kritischer Straßenzüge unterstützt. Damit können Entscheidungen zu Priorisierung, Anpassungsmaßnahmen und langfristiger Investitionssteuerung im Sinne klimaresilienter Stadt- und Regionalentwicklung fundiert getroffen werden. Als Validierungsgrundlage für die aufgestellte These wird das Thema der Waldbrandgefahr behandelt, um eine erste Aussage zum laufenden Arbeitsprozess liefern zu können. Der fortschreitende Klimawandel verändert die Häufigkeit, Intensität und saisonale Verteilung von Vegetationsbränden in Europa und damit auch die Risikolage für verkehrliche Infrastrukturen. Für die Straßenverkehrsinfrastruktur entstehen Belastungen sowohl unmittelbar durch thermische Einwirkungen und potenzielle Fahrbahnschäden als auch mittelbar durch Rauch, eingeschränkte Sichtweiten, Sperrungen, Umleitungen sowie durch Folgegefahren nach Bränden, z. B. erhöhte Erosions- und Massenbewegungsneigung infolge einer veränderten Vegetation. In waldreichen Regionen wie Rheinland-Pfalz besitzt die Waldbrandgefährdung daher eine infrastrukturelle Relevanz, die im Rahmen des Dissertationskontexts „Der Klimatologische Verkehrsinfarkt“ als eigenständiger Stressor in ein datenbasiertes, KI-gestütztes Bewertungs- und Klassifikationssystem integriert werden kann. Ziel ist es, eine Brücke zwischen Waldbrand-Indikatoren und einer segmentierten Risikoanalyse entlang des Straßennetzes zu bauen. Diese dient sowohl als Ausgangsbasis für den Ist-Zustand, als auch für ein Zukunftsszenario 2050 unter einem moderaten Erwärmungspfad (ca. +1,9 °C bis Mitte des Jahrhunderts, konsistent zu SSP (SharedSocioeconomicPathways) 2-4.5/RCP (RepresentativeConcentrationPathways) 4.5-nahen Annahmen), um belastbare und erklärbare Aussagen zu ermöglichen. Der vorliegende Beitrag fokussiert die Waldbrandgefahr als Pilotanwendung zur methodischen Validierung des übergeordneten, multirisikoorientierten Ansatzes. Die Auswahl begründet sich durch die Verfügbarkeit etablierter Indikatorik und europaweit harmonisierter Datenprodukte, die eine prototypische Umsetzung im Sinne eines digitalen Risiko-Zwillings ermöglichen können. Klimabedingte Ausfälle der Straßenverkehrsinfrastruktur treten

jedoch auch durch weitere Gefährdungen auf, insbesondere Starkregen, Überflutungen, Hangrutschungen oder Windwurf, deren Integration als Anschlussarbeit konzeptionell vorgesehen ist.

Keywords: Waldbrandgefahr, digitale Risikoanalyse, Planung, Klimaanpassung, Klimawandel

2 METHODIK UND VORGEHENSWEISE

Das methodische Vorgehen dieser wissenschaftlichen Arbeit folgt einem mehrstufigen, interdisziplinär angelegten Forschungsdesign, das theoriegeleitete Grundlagenarbeit, räumlich differenzierte Datensammlung, algorithmische KI-gestützte Entwicklung sowie eine praxisorientierte Interpretation und Ableitung von Handlungsstrategien miteinander verbindet. Ziel ist es, durch die Entwicklung und Anwendung einer KI-gestützten Methodik zur Risikoklassifikation in Rheinland-Pfalz klimatisch gefährdeter Straßenzüge einen Beitrag zur klimaresilienten Verkehrs- und Raumplanung zu leisten. Der Forschungsprozess ist dabei in vier aufeinander aufbauende Hauptphasen (Kapitel 2.1 bis 2.4) gegliedert, wie Abbildung 1 schematisch visualisiert.

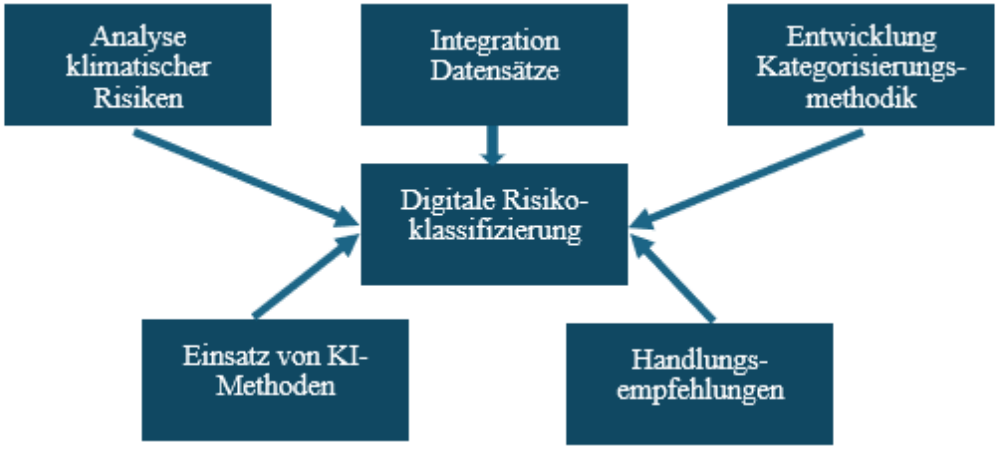


Abbildung 1 Übersicht der Methodik zur Erstellung einer KI-gestützten Risikoklassifizierung von Straßenzügen (eigene Darstellung)

2.1 Theoretische Fundierung und konzeptioneller Rahmen

In der ersten Phase werden die theoretischen Grundlagen erarbeitet, einschließlich Definitionen und Einordnung des Waldbrandkontextes sowie der Waldbrandgefahr. Zugleich wird der wissenschaftliche Konsens zum Klimawandel auf Basis aktueller Erkenntnisse zusammengeführt. Esfolgen Prognosen zur Waldbrandgefährdung in Rheinland-Pfalz mit Blick auf geländeklimatologische Auswirkungen in urbanen und ruralen Räumen sowie Bedeutung, Funktion und Vulnerabilität der verkehrlichen Infrastruktur.

2.2 Datenbasiertes Referenzmodell

In der zweiten Phase erfolgt die empirisch-raumbezogene Operationalisierung durch die Auswahl geeigneter neuralgischer Referenzpunkte (Kreis-, Landes-, Bundesstraßen und Autobahnen). Hierbei werden die innerstädtische und ländliche Topografie berücksichtigt. Es wird eine strukturierte Datenerhebung durchgeführt, die alle für die Waldbrandgefahrenprognose relevanten Dimensionen abdeckt: Klimadaten topografische Daten, politische Grenzen (Rheinland-Pfalz), Infrastrukturdaten zum Zustand der Verkehrsanlagen, Waldkategorisierung, Waldbrandgefahrenindizes für Vergangenheit und Zukunft sowie rudimentär verfügbare Schadenshistorien früherer Waldbrandereignisse. Anschließend erfolgt eine qualitative Vor-Kategorisierung gefährdeter Straßenzüge ohne den Einsatz von KI auf Basis der Kriterienkataloge, die als Referenz für Trainings- und Validierungsdaten dient.

2.3 Entwicklung des KI-gestützten Analysemodells

Im dritten Schritt wird ein erklärbares Regressionsmodell entwickelt, das die Waldbrandgefährdung von Straßenzügen automatisiert bewertet und klassifiziert, indem die in Phase zwei erhobenen Daten prozessiert, harmonisiert und attributbezogen aufbereitet sowie FWI (Feuerwetterindex)-Abbildungsdateien, Topografie-, Vegetations- und Straßennetzdaten integriert werden. Hierzu kommt ein Supervised-Learning-Ansatz (Überwachtes Lernen) mit geobasierter Datenverknüpfung über GIS-Vektordaten zum Einsatz, um hochaufgelöste Gefährdungskartierungen zu erzeugen. Die Modellgüte wird anhand zuvor manuell

klassifizierter neuralgischer Punkte validiert, wobei Trainingsdaten sowohl synthetisch erzeugt als auch aus rudimentär dokumentierten Waldbrandereignissen abgeleitet werden. Die resultierende Risikoprofilierung wird als visuelle Ausgabekomponente gebildet, die straßengenau künftige besonders gefährdete Abschnitte identifizierbar macht.

2.4 Interpretation, Ableitung und Integration in Planungsstrategien

In der abschließenden Phase werden die mit dem KI-System generierten Risikobewertungen analysiert, evaluiert und in den planerischen Kontext eingeordnet. Ziel ist es, sowohl technisch belastbare als auch planerisch umsetzbare Handlungsempfehlungen abzuleiten. Die Arbeit mündet in eine strukturierte Synthese aus Analyseergebnissen, einem digitalen Modell und konzeptionellen Ansätzen, mit dem Ziel, einen konkreten Beitrag zur Verhinderung eines klimatologischen Verkehrsinfarkts zu leisten.

3 THEORETISCHE GRUNDLAGEN VON WALDBRANDGEFAHREN IN EUROPA

3.1 Problemstellung

Im Kontext des fortschreitenden Klimawandels gewinnt die Analyse von Extremwetterereignissen für die Resilienz der kritischen Infrastruktur zunehmend an Bedeutung. Während Starkregen und Hitze bereits intensiv beforscht werden, stellt die Waldbrandgefahr in Mitteleuropa eine wachsende, oft unterschätzte Bedrohung dar. Besonders in waldreichen Bundesländern wie Rheinland-Pfalz (RLP) können Vegetationsbrände direkte physikalische Schäden an Fahrbahnen verursachen oder durch beispielsweise Rauchentwicklung zu gravierenden Verkehrsbeeinträchtigungen bis hin zum klimatologisch bedingten Verkehrsausfällen führen.

3.2 Wissenschaftliche Bedeutung der Waldbrandgefahr international und national

Grundsätzlich wird die meteorologische Komponente der Waldbrandgefährdung in der Praxis über Feuerwetter- bzw. Waldbrandindizes kategorisiert. Diese Indizes verdichten zentralemeteorologische Treiber der Zündwahrscheinlichkeit und Brandausbreitung zu einem skalierbaren Gefährdungsmaß. Hierunter fallen insbesondere Lufttemperatur, relative Luftfeuchte, Windgeschwindigkeit und Niederschlag (vgl. Tabelle 1). International gilt der kanadische „Fire Weather Index“ (FWI) als De-facto-Standard und wird in Europa beispielsweise über das „European Forest Fire Information System“ (EFFIS) des Copernicus Emergency Management Service bereitgestellt. Der FWI ist als System mehrerer Subindizes konzipiert, die unterschiedliche Feuchte- und Brennstoffeigenschaften abbilden und daraus Indikatoren der Ausbreitungsdynamik sowie potenziellen Brandintensität ableiten. Einfließende Attribute sind u. a. Fine Fuel Moisture Code, Duff Moisture Code oder Drought Code. Das Ergebnis ist ein sich kontinuierlich entwickelnder Index, der in operative Gefahrenklassen überführt werden kann und dadurch eine europaweite Vergleichbarkeit zum Thema „Waldbrandgefahren“ ermöglicht.(Umweltbundesamt 2023, S. 3–4; Europäische Kommission und European Environment Agency 2025).

Wetter	Klima	Vegetation	Topografie
Wind	Temperatur	Landnutzungsform	Entfernung zur Wegeinfrastruktur
Exposition des Waldes	Sonneneinstrahlung	Aufbau/Typ Wald	Hangneigung
Niederschlag	Saisonale Bodenfeuchte	Waldzustand/-dichte	Häufigkeit von Störungen
Luftfeuchte	Jahreszeiten	Wasserentnahmestelle	Höhenlage

Tabelle 1 Größen des Gefahrenpotenzials für Straßenverkehrsinfrastruktur eines Waldbrandes (eigene Darstellung; vgl. Landesforsten Rheinland-Pfalz, 2026)

In Deutschland wird die Waldbrandgefährdung traditionell durch den Waldbrand-Gefahrenindex (WBI) des Deutschen Wetterdienstes (DWD) kommuniziert. Der WBI ist historisch an nationale Indextraditionen (M-68-Ansatz) gekoppelt und wurde in den letzten Jahren konzeptionell modernisiert. Hierbei wurden Elemente des FWI-Systems und zugleich nationale Rahmenbedingungen, wie beispielsweise waldtyp- oder bodenbezogene Feuchtestrukturen stärker berücksichtigt. Der WBI wird in fünf Gefahrenstufen ausgewiesen und dient als etablierte Grundlage für forstliche und katastrophenschutzbezogene Lageeinschätzungen.

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Ergänzend wird für offene Vegetationsformen (Gras- und Heideflächen) ein Grasland-Feuerindex (GLFI) verwendet, um brandrelevante Bedingungen außerhalb geschlossener Waldstrukturen adäquat abzubilden. Für eine wissenschaftlich fundierte Infrastruktur-Risikoanalyse ist entscheidend, dass beide Systeme WBI im nationalen und FWI im internationalen, kompatibel gedacht werden. Die Waldbrandlage lässt sich sinnvoll über Ereigniskennzahlen, wie Häufigkeit von Bränden und oder dem Expositionsmaße beschreiben. Da Brandhäufigkeit und Brandfläche regional und von Jahr zu Jahr stark schwanken sowie zudem durch Prävention sowie Waldmanagement beeinflusst werden, sind Jahresaggregate allein für Risikobewertungen nur bedingt aussagekräftig. Für infrastrukturelle Anwendungen ist insbesondere relevant, dass sich Auswirkungen häufig auf wenige, meteorologisch extreme Episoden konzentrieren. Dies bedeutet, dass einzelne intensive Brandlagen Verkehrsbeeinträchtigungen, Sperrungen und Störungsfolgen auslösen. Daher ist es methodisch zweckmäßig, feuermeteorologische Indikatoren wie Hochrisikotage als zentrale Prädiktoren in eine straßenbezogene Risikoanalyse aufzunehmen. Der DWD gibt aktuelle Waldbrandgefahrenkartierungen heraus aber keine langfristigen Risikoanalysen.

3.3 Datensätze zur Integration in GIS am Beispiel Rheinland-Pfalz

3.3.1 Zeitliche Modellierungsdatender Waldbrandgefahr mit Copernicus

Auf europäischer Ebene sind modellierte FWI-Datensätze des Copernicus Climate Data Store zu finden. Hierbei ist für die zeitlich konsistente Modellierung (Vergangenheit–Gegenwart–Zukunft) insbesondere der Copernicus-Datensatz “Firedangerindicatorsfor Europe from 1970 to 2098 derivedfromclimateprojections” einschlägig, da er FWI-basierte Indikatoren als Raster-Zeitreihen bereitstellt und damit sowohl Referenzperioden (ab 1970) als auch Projektionen bis 2098 in einem harmonisierten Datenmodell abbildet. Desweiteren können für das KI-Training auf Basis von Vergangenheitsdaten die Zeitintervalle von 1970 bis 2025 hinzugezogen werden, die ebenso das Worst-Case Szenario mit saisonalen in diesem Fall eigenständigen 4-Jahres Intervallen darstellt. Dabei wird der saisonal ermittelte FWI verwendet, um ein adäquates Abbild einer Bedrohungslage zu generieren. Zusätzlich werden von dem EFFIS bereitgestelte Downloaddaten des Wildfire Risk Viewers von Europa hinzugezogen und mehrere Parameter mit Bezug zur Risikoanalyse als separate Layer in GIS (Geoinformationssystem) eingearbeitet (u.a. High Risk Wildfire, Danger bywheather und Basic Layer, wie Potential burnablelandproportion).(Copernicus 2026b, 2026a)

3.3.2 Straßennetz sowie straßenbezogene Vulnerabilitätslayermit Segment- und Objektattributen

Kernlayer für die spätere Modellierung ist die Segmentierung „RLP_Strassen_20mSegmentierung_OSM“ mit einer bewusst schlanken Attributtabelle (fid, osm_id, fclass, bridge, tunnel). Diese Minimalattribute sind für einen Prototypen vorteilhaft, weil sie die eindeutige Referenzierung über osm_id vorgibt. Zudem können sie eine erste Hierarchisierung über fclass (Straßenklassen) und eine strukturelle Kategorisierung über die Attribute bridge/tunnel ermöglichen. Die Herkunft aus OpenStreetMap ist für wissenschaftliche Reproduzierbarkeit geeignet, erfordert aber eine saubere Aufbereitung der vorliegenden Datensätze.Ergänzend liegen im Projekt straßenfachliche Layer des Landesbetriebes Mobilität Rheinland-Pfalz, mit deutlich reichhaltigeren Tabellen vor, u. a. „Strassennetz_RLP“ (z. B. Segment-/Abschnittslogik, Längen- und Knoteninformationsfelder) und „Netzknoten_RLP“ (Knotenattribute zur Netzlogik). Besonders relevant für die Ermittlung der Vulnerabilität sind die drei ermitteltenZustandslayer „Zustand_Bundesstrassen_2023“, „Zustand_Landstrassen_2022“, „Zustand_Kreisstrassen_2021“, deren Attributtabellen u. a. Klassen- und Segmentierungsfelder sowie Zustands-/Erfassungsvariablen enthalten (z. B. KLASSE, VNK/NNK, Stationierungslogik, Fahrstreifenanzahl). Diese Layer erlauben eine direkte Abbildung infrastruktureller Anfälligkeiten, weil Brandfolgen für den Verkehr (Sperrungen, Einsatzverkehr, Sichtbehinderung) in der Praxis über Netzbedeutung und Zustand vermittelt werden und nicht allein über die existierende Brandgefahr. Als Objekt-Ergänzung liegt zudem „Strassenbauwerke_LBM“ vor (u. a. Bauwerkskennungen, Dimensionen wie Länge/Breite/Fläche), wodurch in der Klassifizierung kritische Einzelobjekte (Brücken/Ingenieurbauwerke) separat priorisierbar werden. Diese Straßen gelten als neuralgische Punkte, da sie eine große Menge an durchschnittlichem täglichem Verkehrsaufkommen (DTV) abdecken.Für eine netzrealistische Vulnerabilitätsbewertung sind zwei Erweiterungen zentral. Erstens die Wirkung eines Abschnittsausfalls auf die Netzfunktion, messbar über Umleitungsaufwand, Redundanz und potenzielle Abkopplung von Teilräumen. Zweitens die Nachfrageseite über Verkehrsbelastungen, etwa das DTV, wodurch die Bedeutung eines Abschnitts für die tägliche Mobilität quantitativ abgebildet werden kann.

Beide Größen sind grundsätzlich über Verkehrsmodelle, Verkehrszählungen oder modellbasierte Belastungskarten integrierbar und können im laufenden Forschungsprozess als zusätzliche Prädiktoren in das Regressionsmodell aufgenommen werden.(QuickOSM 2026; LBM Rheinland-Pfalz 2026)

3.3.3 Vegetations- und Landbedeckungslayerals Brandfläche

Genauere Datensätze lassen sich aus Landbedeckung und Vegetation sowie Zustandsdaten der Vegetation sowie Waldveränderungsdaten gewinnen. Zudem können diese sowohl mit topografischen Parametern (Höhenmodell, Hangneigung, Exposition) als auch mit Straßen- bzw. Infrastrukturdaten (OpenStreetMap, landesweite Open-Data-Geobasisbestände) verschnitten werden. Der Layer „RLP_Landbedeckung_mit_Attributen“ ergänzt diese Vegetationssicht um eine flächige Landbedeckungssystematik (Attributfelder sind u. a. LB_AKT, LN_AKT, SIE_AKT, VEG_AKT, METHOD_AKT, CLC21, Shape_Area), welche die einzelnen Vegetationsflächenarten widerspiegeln (Waldart und Landnutzungskategorisierung). Gerade „VEG_AKT“ und „CLC21“ sind für die Risikologik wertvoll, weil sie eine robuste Maskierung ermöglichen (z. B. Kategorisierung von Siedlung/ Verkehr vs. Vegetationsflächen) und die Expositionsberechnung gegen unbrauchbare Verknüpfungen absichern (z. B. keine Brennstoffzuweisung in versiegelten Bereichen).

3.3.4 Topografie- und Hydrographielayer als Bewertungsgrundlage

Im Projekt sind ein digitales Geländemodell „RLP_DGM_200“ (Raster) sowie kontextgebende Vektorlayerwie Höhenlinien, Flüsse und Seen eingebunden. Auch wenn dieser Layer nicht unmittelbar eine „Waldbrandgefahr“ darstellen, sind sie für eine wissenschaftlich belastbare Segmentbewertung zentral. Die Topografie beeinflusst Mikroklima und Austrocknung (z. B. Südhänge), Windkanalisierung undErreichbarkeit für die Brandbekämpfung (Zugang, Barrieren, Wasserentnahmestellen). Methodisch werden aus dem DGM (Digitales Geländemodell) in GIS oder Python abgeleitete Sekundärvariablen erzeugt (u.a. Hangneigung, Exposition, Höhenlage, etc.). QGIS stellt hierfür reproduzierbare Processing-Algorithmen zur Verfügung. (QGIS 2026; LVermGeo Rheinland-Pfalz 2026)

3.3.5 Administrative Referenzlayerfür das Bundesland Rheinland-Pfalz

Der drei eingebundenen„VG250“-Layer (Land, Kreise, Gemeinden) liefern die administrative Raumlogik und dienen dem Zuschnitt „Rheinland-Pfalz“, der aggregierten Ergebnisdarstellung (z. B. Risikoanalyse je Kreis oder Stadt). Die Datenbeschreibung der „VG250“ hebt genau diese hierarchischen Verwaltungsebenen und Schlüsselattribute als Kerninhalt hervor, sodass sich die oben beschriebenen Flächendaten auf die jeweiligen administrativen Grenzen zuschneiden lassen.(ebenda)

4 INTEGRATION UND VERARBEITUNG IN GIS

Ein belastbarer GIS-Workflow zur segmentbezogenen Bewertung entlang des Straßennetzes umfasst typischerweise folgende Schritte, die sich in GIS und Python reproduzierbar abbilden lassen. Zunächst wird ein konsistenter Untersuchungsraum definiert (hier: Rheinland-Pfalz)und das Straßennetz als Vektorlayer bereitgestellt. Um eine hochaufgelöste Bewertung des Gegenwartsmodells im Sinne infrastruktureller Vulnerabilität zu ermöglichen, kann das Straßennetz in regelmäßige Längensegmente, (in 20 m) unterteilt werden, sodass pro Segment ein eigener Attributsatz entsteht. Parallel werden die relevanten Waldbranddaten in GIS eingebunden, projektionstreu reprofiliert und auf ein einheitliches Referenzsystem gebracht. In Rheinland-Pfalz befinden wir uns typischerweise in „ETRS89/UTM Zone 32N“.Anschließend erfolgt eine attributive Übertragung der genannten Rasterwerte auf die Straßensegmente, welches in Python zugeschnitten entsprechend der Zustandserfassungslayer angepasst wird. Dadurch erhält jedes Segment eine vorläufige Risikobeschreibung, die durch eine Vorgewichtung und Definition der Datensätze je Layer bestimmt wird. Ergänzend werden infrastrukturell und ökologisch relevante Layer erzeugt, die die Brandlast und die potenzielle Exposition beschreiben können.Darunterfallen, wie in Kapitel 3.2 erläutert wurde: Abstand zum Wald bzw. zur brandrelevanten Vegetationsklasse, Waldtypanteile (in %) im Umfeld (Nadel-/Laub-/Mischwald), topografische Parameter (Hangneigung, Höhenlinien, digitales Geländemodell), potenzielle Windkanalisierung in Tälern sowie straßenbezogene Merkmale (Straßenklasse, Verkehrsrelevanz, bauliche Charakteristika, Zustandsbewertung der Straße).

5 KLIMAPROJEKTION FÜR 2050

Die Projektion der Waldbrandgefährdung bis 2050 basiert auf einer Klimaprojektion, welche das Erwärmungsniveau um +1,9 °C bis Mitte des Jahrhunderts darstellt. Hierfür werden häufig SSP2-4.5/RCP4.5-nahe Pfade herangezogen, die eine fortschreitende, jedoch nicht extreme Zunahme thermischer Belastung und eine saisonal differenzierte Veränderung des Niederschlages abbilden. Für die Feuergefährdung sind dabei weniger Jahresmittelwerte entscheidend als die Kombination aus den genannten Größen des Gefahrenpotenzials für Straßenverkehrsinfrastruktur eines Waldbrandes aus Tabelle 1. In der praktischen Umsetzung werden daher aus Klimaprojektionen jene meteorologischen Parameter extrahiert, die für die Indexberechnung erforderlich sind (insbesondere Tageshöchsttemperatur, Niederschlag, Dürreindex, Wind, relative Feuchte bzw. abgeleitete Feuchtegrößen) (vgl. Kapitel 3.2). Liegen für den FWI keine frei verfügbaren, direkten Projektionraster vor, kann die Feuergefährdung für 2050 in einem transparenten Rechenweg aus den Projektionen abgeleitet werden, welches hier über die Copernicus-Daten angewandt wird. Entweder, indem FWI-Indikatoren aus frei verfügbaren Datensätzen direkt genutzt werden oder indem FWI/WBI-nahe Indikatoren mit Python-Bibliotheken berechnet und anschließend wieder als Rasterlayer bereitgestellt werden. Für eine wissenschaftliche Bewertung ist dabei die Unsicherheitsdimension mitzudenken, die ein KI-Algorithmus für die Zukunftsprojektion generieren kann.(IPCC 2026)

6 EINARBEITUNG IN PYTHON

6.1 Erklärung der IPCC-Logik Hazard-Exposure-Vulnerabilityund Vorgehensweise für Python

Für die Einarbeitung der Datenbasis in Python ist es methodisch sinnvoll, die in GIS bereits eingebundenen Layer als kohärentes Risikodatenpaket entlang der IPCC-Logik Hazard–Exposure–Vulnerability zu beschreiben. Die Gefährdung (Hazard) wird über Vergangenheitsdaten, feuermeteorologische Indizes (WBI/FWI) und deren Projektionen abgebildet, die Exposition (Exposure) über Vegetations-/Wald-/Landbedeckungs- und Topografielayer (Brennstoff, Austrocknung, Windkanalisierung) quantifiziert, und die Vulnerabilität (Vulnerability) wird über straßenbezogene Struktur- und Zustandsattribute operationalisiert. (Maarten K. van Aalst, Omar-Dario Cardona 2012, S. 69–72)

6.2 Darstellung in Python-Gegenwartsmodellierung

Für das Gegenwartsmodell wird die in GIS vorliegende Datenbasis in einen vollständig reproduzierbaren Python-Workflow überführt. Ziel ist ein prototypischer, segmentscharfer Risikoindex für das Straßennetz in Rheinland-Pfalz, der als Schulnote von 1 (sehr geringes Risiko) bis 5 (hohes Risiko) ausgegeben und als Attributspalte wieder in GIS visualisiert werden kann. Der Ansatz folgt der etablierten Risikologik, nach der klimabezogene Risiken aus dem Zusammenwirken von Hazard (Gefährdung), Exposure (Exposition/ Brandlastnähe) und Vulnerability (Verwundbarkeit/Kritikalität) entstehen.

Die oben genannten Layer Straßenbasis (aufgeteilt in 20 m Segmente), Feuerwetter-Gefährdung (Hazard) mit den Gegenwartsindikatoren für Europa, Brennstoff-/Vegetationsaufbau des Landbedeckungslayers (Exposure), Topografie (A) aus dem DGM für Hangneigung sowie Höhenlinien (A) und zuletzt der Straßenzustand neuralgischer Punkte werden auf Kreis-, Land- und Bundesstraßen sowie deren Bauwerken (Vulnerability) abgebildet. Als zusätzliches Kriterium werden Wasserflächen hinzugezogen, da sie eine natürliche Risikoreduktion generieren.

Alle Teilindikatoren werden auf 0–1 skaliert (regelbasiert) und anschließend additiv zu einem Gesamt-Score aggregiert, welcher die Schulnotenbewertung wiedergibt. Die Startgewichtung priorisiert Hazard- und Exposure-Elemente, da Feuerwetter (Hazard) und Brandlastnähe (Exposition) primäre Treiber der Vegetationsbrandentwicklung sind. Vulnerability wird geringer gewichtet, weil sie im Gegenwartsmodell vor allem die infrastrukturelle Relevanz und Zustandserfassung des Straßensegments abbildet.

- Hazard H (0–1): H = (High Risk bis Low Risk Layer)
- Exposure E (0–1): Kombination aus
    - Waldnähe: Distanz zum nächsten Nadel- oder Laubwald-Polygon (Referenzdistanz 100 m als praxistaugliche Nähe-Schwelle, die auch in deutschen Waldbrandschutzkontexten als „Waldnähe“ verwendet wird) (stmelf Bayern 2026)

  - Baumdichte: dichter Bewuchs > großflächige Vegetation
  - Landbedeckung: Kategoriegewicht (Wald/ Heide > Gras > Siedlung/Gewässer)
- Vulnerability V (0–1):
  - Straßenkritikalität: Mapping aus fclass (Autobahn höher gewichtet als Anliegerstraße).
  - Zustand: normierte Zustandsnote (Note 1=gut bis 5=schlecht) aus ZEB-Daten
  - Bauwerke: bridge/ tunnel als Kritikalitätsmarker
- Topografie A (0–1): normierte Hangneigung, besonders Südhänge (aus DGM und Höhenlinienlayer abgeleitet)
- Gewässerflächen W (0-1): dargestellt in Flüssen, Seen und Wasserwegen (dargestellt im DGM und Landnutzungslayer)

Gesamt-Score für Gegenwartsmodellierung (eigene Darstellung):

$$Rnow = 0{,}45 \cdot H + 0{,}30 \cdot E + 0{,}15 \cdot V + 0{,}10 \cdot A - 0{,}2 \cdot W$$

Diese Gewichtung ist als begründete Startannahmen zu verstehen (s. IPCC-Risikologik und FWI-Hazardpriorität) und werden für eine Zukunftsprojektion in Kapitel 6.3 über lineare Regression automatisiert „nachkalibriert“. Note=1 bei R<0,2, 2 bei 0,2–<0,4, 3 bei 0,4–<0,6, 4 bei 0,6–<0,8, 5 bei ≥0,8. Diese Schwellen sind bewusst transparent und für Laien nachvollziehbar gestaltet. Alternativ sind Quantile-Berechnungen möglich, wenn eine gleichmäßige Klassenauslastung für schärfere Prognosen gewünscht ist.

6.3 Darstellung des KI-Algorithmus in Python für die Zukunftsprojektion

Der Einsatz von KI wird nicht als Selbstzweck verstanden, sondern als methodisches Instrument zur skalierbaren, konsistenten Gewichtung heterogener Einflussgrößen auf Segmentebene. Während eine regelbasierte Vorbewertung die Strukturierung und Nachvollziehbarkeit des Risikoansatzes ermöglicht, liefert ein erklärbares Regressionsmodell eine datenbasierte Kalibrierung der Parametergewichte und reduziert subjektive Setzungen. Der Mehrwert besteht damit in der transparenten Generalisierung von Einzelfallwissen auf die Fläche sowie in der späteren Erweiterbarkeit auf zusätzliche Gefährdungskategorien und Validierungsdaten.Im nächsten Schritt wird das Gegenwartsmodell nicht ersetzt, sondern als Trainings- und Referenzrahmen genutzt, um ein erklärbares, linearesRegressionsmodell zu erstellen. Die lineare Regression wird gewählt, weil sie auf Standardhardware effizient läuft und ihre Koeffizienten unmittelbar als nachvollziehbare Einflussgewichte interpretierbar bleiben. Für die Zukunftsprojektion wird der Hazard-Input durch den im Projekt vorhandenen Projektionslayer ersetzt (Danger- und Wildfireriskayer), der aus EFFIS-basierten Klimaprojektionen abgeleitet ist und Feuerwetterindikatoren bis zur Gegenwart bereitstellt. Darüber hinaus werden die statistischen Dokumentationen von historischen Waldbränden in Deutschland und Rheinland-Pfalz als vorgewichtete Zeitindikatoren zur Ableitung einer Zukunftsgefahr herangezogen. (BMEL-Statistik 2026; Landesforsten Rheinland-Pfalz 2026)

Praktische Mindestanforderung für den Test des KI-Modells im „Supervised Learning“:

Damit das Regressionsmodell „lernt“, wird eine Zielvariable benötigt. Da keine ausreichenden beobachteten Sperrungs-/Schadensdaten vorliegen, wird in GIS eine Referenzspalterisk_ref (1–5) für eine kleine, bewusst ausgewählte Stichprobe von Segmenten angelegt (20-m-Segment), basierend auf der Gegenwartslogik (Modellierung aus 6.2), lokaler Expertise (historische Statistiken) und Plausibilitätschecks (manuelles Gegenprüfen in Referenzregion) im laufenden Prozess. Das ist methodisch zulässig, solange die Konstruktion transparent dokumentiert wird, d.h.alle Zwischenschritte und Ergebnisse festgehalten werden. Ein erklärbares Kernmodell für die segmentbezogene Risikoklassifizierung ist die Ridge-Regression als lineares Regressionsmodell mit L2-Regularisierung. Dabei wird neben der Residuenquadratsumme ein Negativterm auf die Koeffizientengrößen minimiert, wodurch die Schätzungen bei korrelierten Prädiktoren (typisch bei Umwelt- und Infrastrukturdaten) stabilisiert und Überanpassung reduziert wird. Die Modellvorhersage ist ein kontinuierlicher Risiko-Score, der anschließend über transparente Übergangsergebnisse in das Schulnotensystem 1–5 überführt werden kann. Konzeptionell entspricht dies einer Risikofunktion, die Gefährdung, Exposition und Vulnerabilität systematisch zusammenführt, gemäß der Formel für den Gesamt-Score (vgl. Kapitel 6.2). Die Datenbasis wird hierfür als DataFrame organisiert („Frame“): Jede Zeile repräsentiert ein Straßensegment (optional je Jahr/Saison), jede Spalte einen

modellrelevanten Prädiktor (z. B. Index-/Rasterwerte, Vegetations- und Infrastrukturmerkmale). Die zeitlich korrekte Validierung erfolgt als Rolling-Window-Ansatz: Für ein Zieljahr t wird das Modell mit den Jahren t−10 … t−1 trainiert und anschließend auf t getestet, um die Plausibilität bzw. Güte der Vorhersage außerhalb der Trainingsperiode zu prüfen. Für zeitgeordnete Daten ist diese Trennung zentral, um ein reines „Training auf Zukunftsdaten“ zu vermeiden.Letzendlich dient der KI-Algorithmus vereinfacht als Platzhalter für die gesamte Betrachtung der klimatisch bedingten Extremwetterereignissen und soll in dieser wissenschaftlichen Arbeit den Einsatz von Künstlicher Intelligenz in der Risikoanalyse zum Thema Waldbrandgefahr auf Plausbilität gegenprüfen, da sich die Finalisierung der gesamten Risikoanalyse noch im Arbeitsprozess befindet. (Pandas 2026; scikitlearn 2026)

7 AUFBAU DER PROGRAMMIERUNG ANHAND EINES BEISPIELS DER CODIERUNG:

Der folgende beispielshafte Teilprozess aus Abbildung 2 beschreibt den implementierten Workflow als reproduzierbare Prozesskette aus Datenharmonisierung, Feature-Extraktion und Ergebnisexport. Nach der Festlegung des Untersuchungsraums werden Straßenabschnitte als Segmentgeometrien bereitgestellt und mit Gefährdungs-, Expositions- und Vulnerabilitätsmerkmalen aus Raster- und Vektordaten angereichert. Die Merkmalsermittlung erfolgt über Raster-Sampling sowie räumliche Joins und Zonenstatistiken; anschließend werden die Merkmale skaliert und zu einem Risiko-Score aggregiert. Der Ergebnislayer wird als GeoPackage exportiert und in GIS nach Notenklassen visualisiert. Durch den modularen Aufbau kann der Workflow um zusätzliche Variablen wie DTV oder Netzredundanz erweitert werden, ohne die Grundlogik zu ändern. Eine Veröffentlichung der Codierung ist zum jetzigen Zeitpunkt nicht geplant, da es sich hier um einen vorläufigen Prototyp handelt.

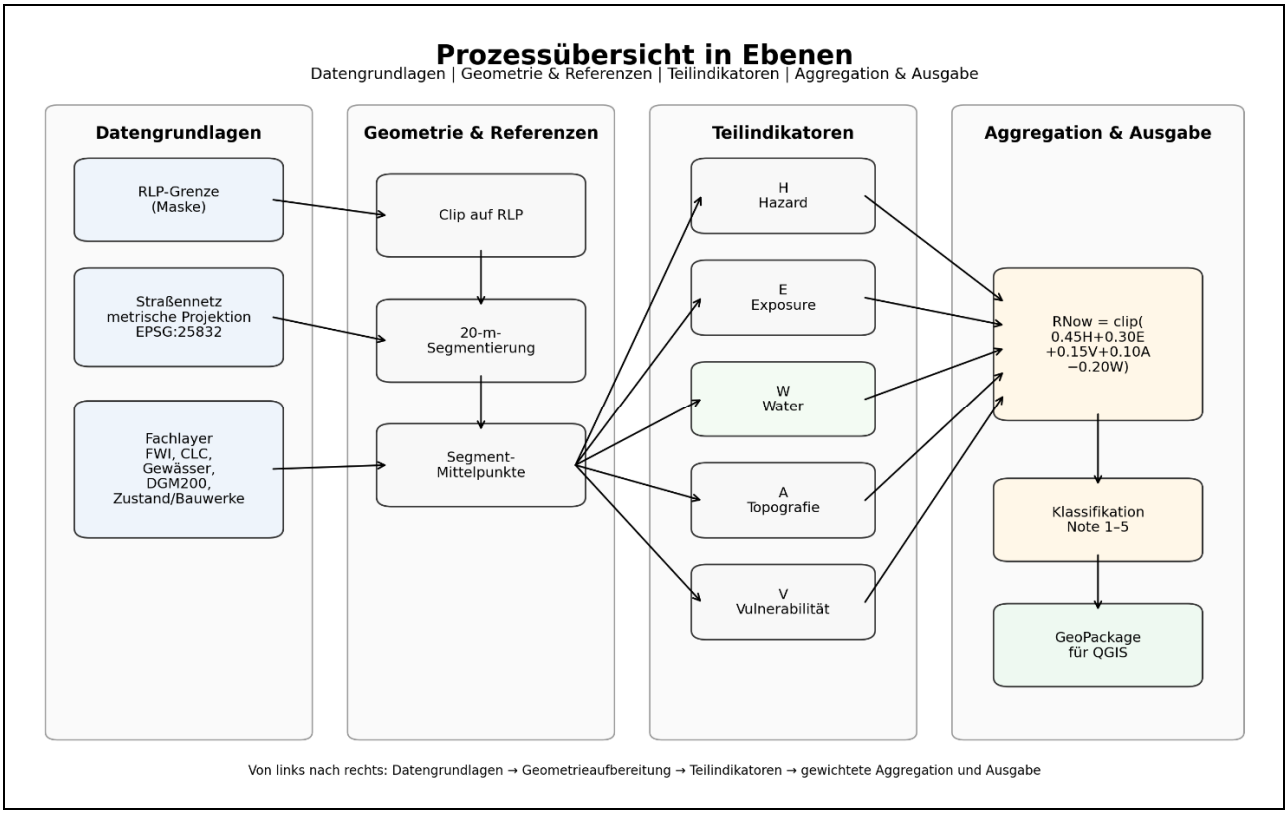


Abbildung 2 Prozessübersicht in Ebenen zur Erklärung der Codierung in Python (eigene Darstellung)

8 DARSTELLUNG DERERGEBNISSE MIT KI-MODELLIERUNG

Der Kartenausschnitt der Bundesstraße 9 (B9) verdeutlichen die im Beitrag verfolgte Logik einer segmentscharfen Waldbrand-Risikoausgabe für Rheinland-Pfalz im Schulnotensystem (Note 1-5) der Gegenwart (vgl. Abbildung 3). Methodisch wird jedes Straßensegment als kleinste Bewertungseinheit genutzt, um eine priorisierbare Risikokarte zu erzeugen, die sich in GIS unmittelbar interpretieren lässt. Die räumlich kohärenten Bewertungen (z. B. Note 1-2 im städtischen Abschnitt Worms–Bobenheim-Roxheim) sind grundsätzlich den lokalen Gegebenheiten erwartbar und im Sinne des Beitrages plausibel, weil die

maßgeblichen Gefahrengrößen der Waldbrandgefährdung, insbesondere Feuerwetter-/Indexwerte (FWI bzw. FWI30 als kurzfristig wirksames Hazard-Signal) und großflächige Expositionsgrößen wie Vegetations- und Landbedeckungsklassen, räumlich nicht auf 20 m „sprunghaft“ wechseln, sondern typischerweise graduell variieren. So werden im unteren Abschnitt die Parameter Südhangexposition und größere Waldfläche im Gegensatz zum städtischen Raum um Worms herum mit seiner Nähe zum Rhein als plausible Ergebniswiedergabe für eine Risikoanalyse gewertet.

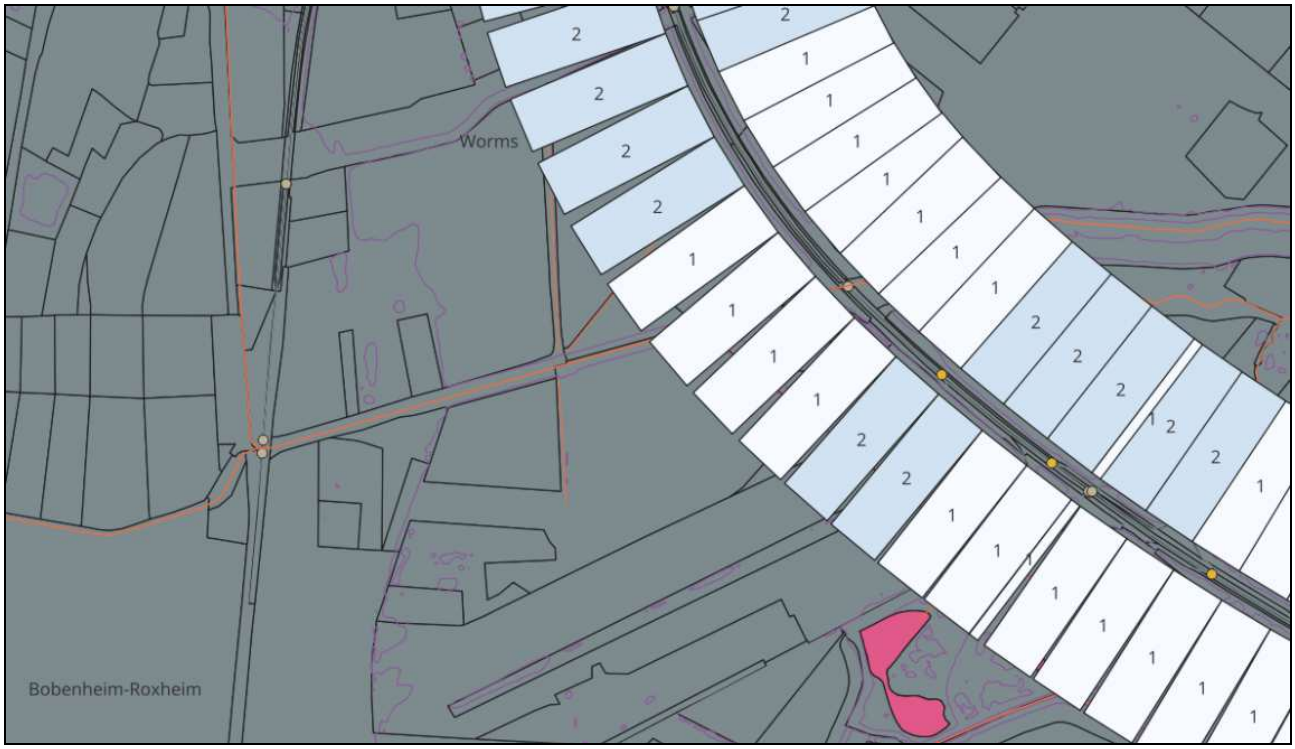


Abbildung 3 Ausschnitt der KI-gestützten Risikoanalyse in GIS für die Gegenwartsmodellierung im städtischen Raum: Worms B9 (eigene Darstellung).

Die Zukunftsprojektion für die B9 visualisiert die modellierte Veränderung der Waldbrandrisikoklassifizierung im Zieljahr 2050 (vgl. Abbildung 4). Im vorliegenden Scoring werden für die Zukunftsprojektion primär die Komponenten Hazard (H) und Exposure (E) angepasst, da insbesondere feuermeteorologische Bedingungen (z. B. Feuerwetterlagen) und vegetationsbezogene Expositionsmerkmale im Zuge des Klimawandels die stärksten systematischen Verschiebungen erwarten lassen.

Für die prototypische Zukunftsabbildung wurden bundesweite Waldbrandstatistiken auf den Untersuchungsraum Rheinland-Pfalz übertragen und im Rahmen eines linearen Regressionsansatzes zur Ableitung einer segmentscharfen Risikobewertung genutzt. Dabei ist methodisch hervorzuheben, dass Waldbrände in ihrer Realisierung häufig lokale Extremereignisse darstellen, deren Auftreten durch stochastische Faktoren und kleinräumige Randbedingungen geprägt ist. Eine realitätsnahe, flächendeckende Projektion auf ein gesamtes Infrastrukturnetz ist daher mit strukturellen Unsicherheiten verbunden. Vor diesem Hintergrund ist die in Abbildung 3 beobachtbare Verschlechterung der Noten gegenüber dem Gegenwartsmodell als Ausdruck einer moderaten Risikoerhöhung zu interpretieren, die vor allem durch einzelne, extremer werdende Trocken- und Hitzeepisoden plausibilisiert werden kann. Gleichzeitig bleibt der Unterschied zum Gegenwartsmodell insgesamt begrenzt. Dies wird als plausibel bewertet, da die Projektion im Prototyp keine abrupten Strukturbrüche des Gesamtsystems annimmt, sondern eine graduelle Verschiebung der dominanten Gefährdungs- und Expositionskomponenten abbildet.

9 DISKUSSION UND FAZIT

Das Vorhaben konnte zeigen, dass sich aus einem begrenzten, in GIS verfügbaren Datenpaket, eine segmentscharfe Risikoanalyse für Straßeninfrastruktur ableiten und als Schulnotensystem von 1 bis 5 kartografisch darstellen lässt. Damit ist grundsätzlich nachweisbar, dass Zustandserfassungsdaten der Straßen gemeinsam mit Gefährdungs- und Expositionsparameternvon einem Extremwetterereignis zu einem konsistenten Risikoabbild zusammengeführt werden können und eine verständliche räumliche Priorisierung

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ermöglicht wird. Für Planungsbehörden ergibt sich daraus vor allem ein Orientierungsnutzen, da räumliche Muster sichtbar werden und eine erste Priorisierung von Prüf- und Maßnahmenbedarfen unterstützt wird. Für die Öffentlichkeit kann ein solcher Ansatz als Hinweisprodukt zur transparenten Risikokommunikation dienen, vergleichbar mit etablierten Gefahrenhinweiskarten (Hochwasser- oder Starkregengefahrenkarten), sofern Grenzen und Unsicherheiten klar benannt werden.



Abbildung 4 Ausschnitt der KI-gestützten Risikoanalyse in GIS für die Zukunftsprojektion: B9 bei Worms (eigene Darstellung)

Die Aussagekraft bleibt in der vorliegenden Form jedoch deutlicheingeschränkt.Viele Definitionen, Skalierungen und Gewichtungen wurden vereinfacht und das KI-Modell wurde nur rudimentär umgesetzt. So sind die Noten primär als plausibilisierte Klassifikation zu verstehen und nicht als belastbare Vorhersage realer Schadensereignisse. Hinzu kommen Risiken durch unvollständige oder fehlerhafte Eingangsdaten, durch Maßstabsunterschiede zwischen feiner Segmentierung und gröberen Gefährdungsrastern sowie durch die grundsätzliche Schwierigkeit, lokal-extreme Waldbrandereignisse realitätsnah auf ein gesamtes Verkehrsinfrastrukturnetz zu übertragen. Segmentbezogene Handlungsempfehlungen konnten zudem nicht abgeleitet werden, da der Prototyp hierfür noch nicht ausreichend kalibriert, validiert und um wirkspezifische Entscheidungskriterien erweitert ist.

Für einen belastbaren, übertragbaren Prototyp sind daher eine systematische Datenharmonisierung, die Einbindung beobachteter Zielgrößen zur Validierung, eine empirische Kalibrierung der Gewichte mit erklärbaren Modellen sowie eine explizite Unsicherheitsanalyse erforderlich. Zudem benötigt es ein Vielfaches an Rechenkapazität, wofür ein dafür ausgelegtes Rechenzentrum zum Einsatz kommen muss. Erst auf dieser Grundlage kann der Ansatz von einer demonstrierten Machbarkeit zu einem verlässlichen Instrument weiterentwickelt werden, das sowohl fachlich robuste Priorisierungen ermöglicht als auch die Grundlage für konkrete, segmentbezogene Maßnahmenentscheidungen liefert.

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Vom Prompt zum Plan mit GenAI: Fotorealistische, synthetische Luftbilder im GIS als neues Werkzeug für Stadt- und Landschaftsplanung

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1 ABSTRACT

Viele Planungsprozesse hängen von visuellen Darstellungen ab, insbesondere in frühen Entwurfs- und Beteiligungsphasen. Doch statt illustrativer Entwürfe und schneller, iterativer Abstimmungen wird der planerische Workflow häufig durch zeit- und ressourcenaufwändige Zeichnungen, Renderings und 3D-Visualisierungen ausgebremst. Diese detaillierten Darstellungsformen sind notwendig, um komplexe räumliche Zusammenhänge nachvollziehbar zu machen. Jedoch fehlt insbesondere für die Variantenentwicklung ein Zwischentyp visueller Darstellung, der sowohl binnen kurzer Zeit erzeugbar ist, als auch ausreichend realitätsnah den Raum abbildet.

Kann generative KI in diese Lücke hineinwirken? In den letzten Jahren haben sich insbesondere Diffusionsmodelle als leistungsfähige Methode der Bildsynthese etabliert. Sie bilden auch die Grundlage moderner multimodaler Modelle wie Google's Gemini oder der Flux-Modelle des deutschen KI-Startups Black Forest Labs. Diese verarbeiten Text- und Bildinformationen gemeinsam, integrieren sogenannte Thinking-Prozesse und verknüpfen semantische mit visuellen Steuerungssignalen, wodurch sie komplexe räumliche Transformationen konsistent erzeugen können. In der Anwendung sind diese Systeme zwar nicht auf die Rekonstruktion realer Messdaten ausgelegt, können jedoch visuell plausible, kontextbezogene Szenen erzeugen.

In der hier vorgestellten Anwendung wurden die genannten Modelle direkt in QGIS eingebunden. Ausgangspunkt ist stets ein realer Geodatensatz (z. B. Luftbild, optional mit Vektordaten annotiert), der durch eine Kombination aus Bild-zu-Bild-Transformation und textbasierten Prompts in natürlicher Sprache modifiziert wird. Die georeferenzierten Outputs ermöglichen es, innerhalb weniger Sekunden fotorealistische Varianten oder Szenarien zu erzeugen, als Vorher-/Nachher-Ansichten gegenüberzustellen oder im größeren räumlichen Kontext zu betrachten, um zu prüfen, ob sich die Planung stimmig in die Eigenart der näheren Umgebung einfügt.

Für die Planungspraxis zeigt sich damit, dass ins GIS integrierte, bildergenerierende KI es erlaubt, prototypische Konzepte schnell und kosteneffizient in hypothetische Varianten zu überführen – etwa indem geplante Strukturen ergänzt, Landschaftselemente verändert oder potenzielle Ereignisse visualisiert werden. Damit entsteht ein neuer Typ synthetischer, fernerkundungsähnlicher Darstellung, der zwischen kartographischer Abstraktion und professioneller, fotorealistischer Visualisierung liegt.

Keywords: Planungsvisualisierung, Variantenentwicklung, Entwurfsprozess, Generative KI, QGIS

2 EINLEITUNG

Das Wort Geografie leitet sich vom Griechischen ge ("Erde") und graphia ("Schreiben") ab, also wörtlich das Schreiben über die Erde. Diese Beschreibungen und länderkundlichen Abhandlungen bestehen sowohl aus Text und Grafik und gehen seit jeher Hand in Hand mit den technischen Entwicklungen. Mittlerweile sind große Teile der Geoinformationen kodiert (Deutscher Städtetag, 2015). Eine Fülle an Informationen über unsere Erde liegt als Vektoren, Rasterdatensätze und Punktwolken vor. Das geographische Arbeiten ist unlängst im digitalen Zeitalter angekommen. Doch die zentrale Aufgabe bleibt unverändert die Kommunikation. Kartographische Darstellungen als Medium informieren den Betrachter über räumliche Organisation von Stadt und Land.

Aufgrund ihrer gemeinsamen Bemessungseinheit – dem Pixel – profitiert speziell die Luft- und Satellitenbildauswertung besonders stark vom Tempo der technischen Entwicklungen in den Computerwissenschaften. Auf großer Fläche wurden dynamische Prozesse wie Urbanisierung schon Anfang der 1980er Jahre kartiert (Singh, 1989). Eine erste Zusammenfassung benachbarter Pixel zu realweltlichen Objekten wurde später durch Blaschke (2010) demonstriert, bevor tiefe neurale Netzwerke mittlerweile zum defacto Standard in der Fernerkundungsanwendung avancierten (Zhu et al., 2017). Hier werden ebenjene Nachbarschaften auf dedizierten Grafikkarten in zahlreichen konvolutionalen Schichten automatisch berücksichtigt und wiederkehrende Muster angelernt. Aktuelle Modellarchitekturen wie Generative

Adversarial Networks (GAN), Diffusionsmodelle und Vision Transformer sind in der Lage, die angelernten Muster im Bild zu reproduzieren (Y. Liu et al., 2024; Sordo et al., 2025; Yarramsetti et al., 2024). Neue Pixel, neue Objekte, werden künstlich generiert.

Die gleichzeitige Veröffentlichung von ChatGPT im November 2022 veränderte die Art und Weise, in welcher heute Künstliche Intelligenz (KI) genutzt wird, disruptiv. Zwar umfasst die Definition von KI eigentlich alle zuvor genannten Algorithmen, vom pixelbasierten Ansatz, über Deep Learning und den Transformermodellen (Alzubaidi et al., 2021; Chamola et al., 2024; Tu et al., 2024), doch wird unter dem KI Begriff heute oft auch ganz konkret die Generative KI (engl. abgekürzt GenAI), das Prompten in natürlicher Sprache und die niederschwelligen Zugänge über Chatboxen, Webbrowser und serverseitige Ausführung verstanden. Für Endnutzer ist schnell zu übersehen, dass das Generieren von Text und Bild auf ebendiesen Servern defacto getrennt behandelt wird. Dabei lassen sich die Bilder generierenden Methoden über programmierbare Schnittstellen (API) auch direkt ansprechen. In dieser technischen Nische erlangten die zuletzt veröffentlichten Modelle von Google (gemini-3-pro-preview, auch bekannt als Nano Banana), ChatGPT (gpt-image-1.5) und Black Forest Labs (FLUX.2) größere Aufmerksamkeit. Neben illustrativen Grafiken produzieren diese nun auch technische Zeichnungen und fotorealistische Darstellungen.

Gegenstand der vorliegenden Arbeit ist es, ebendiese Technologien für Geowissenschaftler, Planer und Verwaltung zu erschließen. Dafür wurde die Nutzeroberfläche und Kommunikation mit dem jeweiligen Modell in ein QGIS Plugin integriert. Gesteuert in natürlicher Sprache und mit tatsächlichen Geodaten kontextualisiert werden georeferenzierte Bilder, bzw. Geodaten generiert. Ziel dieses Artikels ist die Technologie speziell im Planungskontext zu demonstrieren. Die illustrierten Anwendungen reichen von klassischer Bildsegmentierung, über die Darstellung thematischer Karten, bis hin zu fotorealistischen Luftbildern potenzieller Planungsszenarien. Um die Ergebnisse zu validieren, wurden Experteninterviews durchgeführt.

Der Text gliedert sich nachfolgend in einen methodischen Teil, die Ergebnisdarstellung sowie einer kritischen Diskussion, in der sowohl auf die Verwechslungsgefahr als auch auf die grundsätzlichen Probleme generativer KI – Halluzinationen und Ressourcenverbrauch – hingewiesen werden.

3 METHODIK

Vom Prompt zum Plan sind es drei Schritte: Die technische Integration von GenAI ins Geoinformationssystem (GIS), Prompt Engineering, sowie die respektive Inwertsetzung im Planungskontext. Die technische Integration ist in Abbildung 1 dargestellt (linke Seite, orange hinterlegt). Mögliche Anwendungen lassen sich in drei Einsatzmodi gruppieren und sind in Abbildung 1 auf der rechten Seite aufgeführt (mit blauem Hintergrund hinterlegt).

3.1 Technologie

Grundlage ebendieser Arbeit ist die Text-und-Bild-zu-Bild-Synthese (engl. abgekürzt als T&I2I). Dieses Verfahren ermöglicht es Modellen, sowohl linguistische Instruktionen als auch strukturelle Bildvorgaben gleichzeitig zu verarbeiten, um kontrollierte semantische Manipulationen wie Inpainting, Manipulation und Stiltransfer durchzuführen. Im Gegensatz zur einfacheren Text-zu-Bild-Synthese (T2I) ergänzt das Referenzbild die textuelle Instruktion, den eigentlichen Prompt. Diese zusätzlichen Informationen ermöglichen es, Bilder zu generieren, die sich stark am realweltlichen Kontext orientieren. Die Besonderheit der vorliegenden Arbeit besteht darin, tatsächlich Kartenmaterial als Referenzbild einzuführen. Im Folgenden werden dies Luftbilder und Fernerkundungsdaten sein.

Das hierfür entwickelte QGIS Plugin PromptMap[1] übergibt die aktuelle Kartenansicht zusammen mit einem vom Nutzer definierten Prompt an eine API, die die gewünschte semantische Stilisierung erzeugt. Zum aktuellen Zeitpunkt lässt sich zwischen Googles gemini-3-pro-preview und der europäischen FLUX-Modelfamilie von Black Forest Labs wählen. Anschließend wird das generierte Bild heruntergeladen, georeferenziert und im GIS angezeigt. Im Hintergrund werden der Bildbereich, Prompt und Zeitstempel zu Dokumentationszwecken in Form eines attribuierten GeoPackages festgehalten. Die Pipeline ist so gestaltet, dass sie ohne manuelle Zwischenschritte vom Prompt bis zur Darstellung der generierten GIS-Layer durchläuft und damit eine schnelle, reproduzierbare Arbeitsweise ermöglicht.

[1] https://github.com/georoen/qgis-promptmap

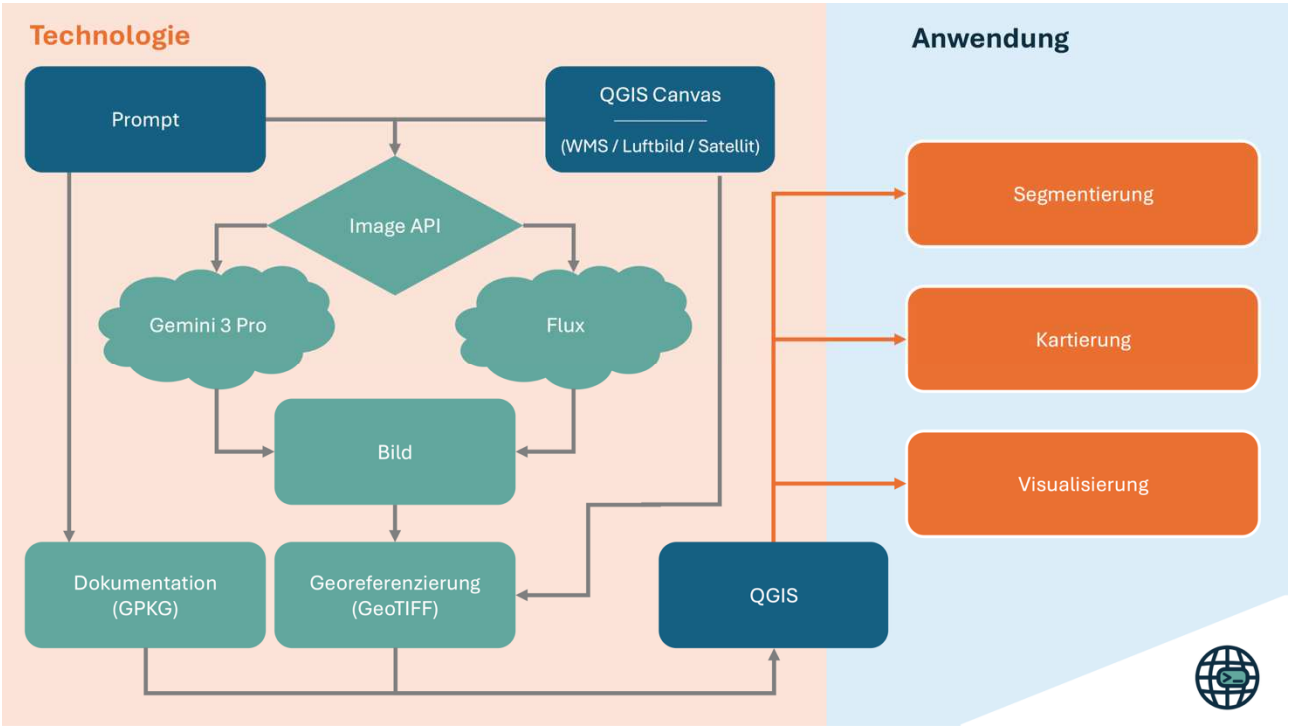


Abb. 1: Schematischer Workflow zur KI-gestützten Bildverarbeitung im GIS-Kontext. Die Anwendung verbindet Prompt-basierte Bildgenerierung über externe Bild-APIs (z. B. Gemini 3 Pro, FLUX.1 Kontext) mit der QGIS-Kartenansicht. Das generierte Bild wird dokumentiert, georeferenziert und als Rasterlayer im GIS dargestellt. QGIS dient als Schnittstelle zur Planung. Beispielhafte Anwendungen sind Segmentierung, Kartierung und Visualisierung.

Aus wissenschaftlicher Sicht ist es wichtig zu betonen, dass GenAI probabilistisch arbeitet. Auch wenn das europäische Modell es Endanwendern erlaubt, durch Festlegung des Seeds Varianzen zu reduzieren, so ist es wichtig zu betonen, dass die Ergebnisse trotz gleicher Eingaben variieren können.

3.2 Anwendungen

Im Folgenden werden exemplarische Anwendungen aus der Stadt-, Landschafts- und Verkehrsplanung vorgestellt. Sie decken unterschiedliche Einsatzmodi generativer KI im GIS ab. Der räumliche Maßstab reicht dabei vom einzelnen Gebäude (ca. 1:500), einem Straßenzug (ca. 1:1.500) bis hin zu landschaftsbezogenen Darstellungen (ca. 1:25.000).

3.2.1 Detektion und Segmentierung

Eine klassische Fernerkundungsanwendung ist die Detektion und Segmentierung von thematisch relevanten Flächen (Blaschke, 2010; Taubenböck et al., 2006; Wurm et al., 2019). Die realweltlich zusammengehörenden Pixel werden in ihrem Kontext verstanden, als Objekte zusammengefasst und einer gemeinsamen Klasse zugeordnet.

Als respektives Anwendungsbeispiel wurden Baustellen gewählt. Aufgrund ihrer visuell heterogenen Erscheinung mit wechselnden Materialien, unscharfen Objektgrenzen und bauphasenabhängiger Varianz ist die Segmentierung von Baustellen sehr anspruchsvoll.

3.2.2 Kartierung

Thematische Karten sind ein zentrales Instrument der räumlichen Analyse. Ähnlich zur Segmentierung werden komplexe Geodaten gezielt reduziert. Im Gegensatz zur Landbedeckungsklassifikation (Weigand et al., 2020) jedoch wird Generalisierung und Symbolisierung von Inhalten bewusst so gewählt, dass räumliche Muster, funktionale Zusammenhänge und Schwerpunkte für Kartenlesende besonders deutlich sind.

Das gewählte Anwendungsbeispiel verwendet einen online veröffentlichten Prompt[2], um wesentliche Strukturen wie Bebauung, Verkehrsflächen und Grünräume maßstabsgetreu hervorzuheben. Dabei offenbart

[2] https://www.linkedin.com/posts/dr-christian-h%C3%BCttich-04542539_generative-ki-ver%C3%A4ndert-gerade-die-spielregeln-activity-7376483274405191680-2U3K

die KI die Eignung generativer Ansätze, eben nicht nur einzelne Objekte zu erkennen, sondern auf scheinbar kreative Art und Weise grafisch ansprechende, präsentationsfähige Kartenprodukte zu erstellen. Im Vergleich zu konventionellen Hintergrundkarten lassen sich diese individuell anpassen und können aktueller sein.

3.2.3 Synthetische Luftbilder

In rot, grün und blau aufgelöste Luftbilder sind aber auch für menschliche Betrachter relevant. Auf den hochaufgelösten Bildern erkennen wir intuitiv auch nicht diskrete Artefakte: begrünte Dächer, lokale Nachbarschaften, Landschaften, etc. Bisweilen werden solche Bilder aus der Vogelperspektive von Drohnen, Flugzeugen oder Fernerkundungssatelliten aufgenommen. Sie zeigen den Status-quo und eignen sich nicht, um zukünftige Szenarien zu visualisieren. Bisweilen gibt es einzelne Ambitionen, etwaige Bilder mithilfe von 3D Rekonstruktionen für KI Trainingszwecke zu synthetisieren (Benjamin et al., 2023; W. Liu et al., 2020), doch verspricht erst der hier vorgestellte Ansatz, den Aufwand derart zu reduzieren, dass dieser Medientyp auch für schnelle, explorative Anwendungen in Frage kommen könnte.

Drei Szenarien wurden ausgewählt, um auf verschiedenen Skalen den KI-Ansatz zu evaluieren. Im ersten Beispiel soll das Flachdach eines verwinkelten Gebäudes um Begrünung und Photovoltaik-Anlagen ergänzt werden. In zwei weiteren Beispielen geht es darum, entweder neue, bauliche Strukturen zu generieren oder zu entfernen.

Zur methodischen Einordnung der synthetischen Luftbilder wurde für die beiden zuletzt genannten Beispiele ergänzend eine anonyme, explorative Befragung unter 35 Expertinnen und Experten aus der Fernerkundung durchgeführt. Den Teilnehmenden wurden jeweils reale Referenzbilder und synthetisch erzeugte Luftbilder nebeneinander präsentiert, mit der Aufgabe, das KI-generierte Bild zu identifizieren. Die Befragung diente einer ersten Einschätzung der visuellen Glaubwürdigkeit synthetischer Luftbilder und wurde durch kurze, qualitative Rückmeldungen zu genutzten Entscheidungsmerkmalen ergänzt.

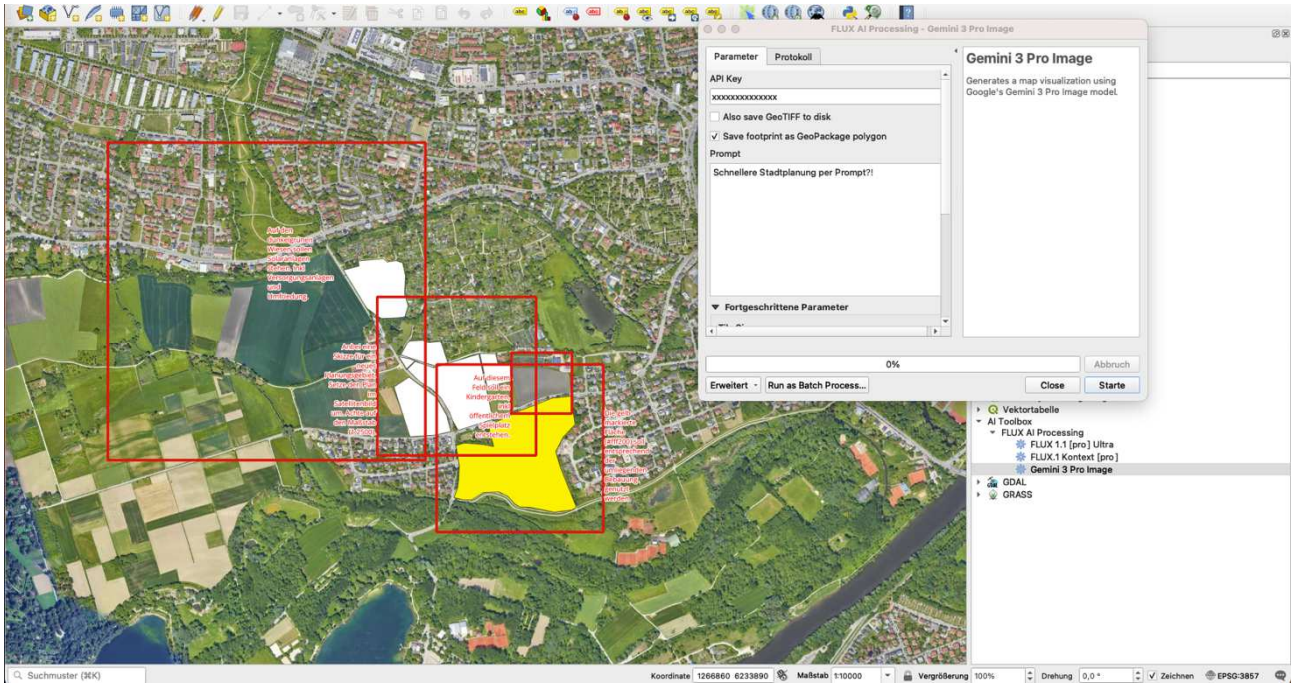


Abb. 2: Zusammenfassende Ansicht des kombinierten Workflows zur KI-gestützten, iterativen Stadtteilerweiterung in QGIS. Ausgehend von einer baulichen Lücke im Süden (gelb) werden in mehreren, räumlich überlappenden Verarbeitungsschritten (rote Boundingbox, inkl. Prompt) neue Nutzungen synthetisiert. Das zugrunde liegende Luftbild dient als Referenz; überlagernde weiße und gelbe grenzen räumliche Eingriffsbereiche ab, um die sukzessive Bildsynthese zu steuern. Rechts ist der geöffnete Dialog des QGIS-Plugins dargestellt, über den Eingabe, Modellwahl und Verarbeitung direkt aus der GIS-Umgebung heraus gesteuert werden.

3.3 Kombinierter Workflow

Abschließend wurde beispielhaft eine iterative Stadtteilerweiterung durchgeführt. In vier Schritten wurde, von einer baulichen Lücke ausgehend, ein Kindergarten, Nahversorgungszentrum und weitere Blockrandbebauungen synthetisiert. Dabei wurden bewusst stets überlappende Beobachtungsfenster gewählt,

um eine nahtlose Integration neuer Parzellen sicherzustellen. Abbildung 2 zeigt eine zusammenfassende Ansicht aus QGIS. Um zusätzlich die Synthese lokal zu steuern, lassen sich Eingriffsbereiche mittels eingezeichneter Polygone abgrenzen.

Eine abschließende Kartierung konvertiert das Komposit aus synthetischen Bilddaten zu einer technischen Zeichnung, wie sie in der aktuellen Planungspraxis üblich ist.

4 ERGEBNISSE

Die Unterteilung der Ergebnisse reflektiert unterschiedliche Anwendungsmodi generativer KI im GIS. Segmentierung und Kartierung dienen der Analyse und Reduktion vorhandener Bildinformationen, wohingegen die Bildsynthese auf die Erzeugung neuer, visuell plausibler Szenarien abzielt. Darauf aufbauend wird im dritten Unterkapitel die Kombination dieser Werkzeuge in einem fiktiven Praxisbeispiel demonstriert, um ihr Zusammenspiel innerhalb eines integrierten GIS-Workflows zu veranschaulichen.



Abb. 3: Visualisierung von Referenzbild (links), Prompt (rechts) und Ergebnis (mittig). a) KI-gestützte Detektion und Segmentierung von Baustellen in hochaufgelösten Satellitenbildern (rot). b) Ableitung einer thematischen Karte aus einem Satellitenbild mit abstrahierter Darstellung von Gebäuden, Verkehrsflächen und Grünräumen.

4.1 Reduktion vorhandener Bildinformationen

4.1.1 Detektion und Segmentierung von Baustellen

Die Ergebnisse in Abbildung 3a zeigen, dass die KI-gestützte Detektion und Segmentierung von Baustellen aus hochaufgelösten Satellitenbildern konsistente und klar abgegrenzte Flächen liefert. Trotz heterogener

Umgebung, variierender Bauformen und unscharfer Übergänge werden die relevanten Bereiche vom übrigen Bildkontext separiert und als zusammenhängende Segmente dargestellt. Optisch sind die von gemini-3-pro-preview generierten Ergebnisse unabhängig von Maßstab und Eingangsdatensatz – Google Satellite oben, digitales Orthophoto (RGB 20cm) der bayerischen Vermessungsverwaltung unten.

Auch wenn im Detail eine kaum sichtbare Variabilität der Farbwerte vorliegt, unterscheiden sich die resultierenden Masken signifikant vom Hintergrund. Mit einer entsprechenden Post-Prozessierung lassen sich die Masken maschinell interpretieren und als Grundlage für weiterführende Analysen nutzen. I.e. in Polygone umgewandelt, lassen sich beispielsweise Flächen und Abstände berechnen und Baufortschritte quantifizieren.

4.1.2 Kartierung urbaner Raum

Abbildung 3b zeigt eine thematische Karte, rechts. Im Vergleich zum Referenzbild, links, zeigt sich eine starke visuelle Reduktion bei gleichzeitigem Erhalt wesentlicher räumlicher Strukturen. Gebäude, Verkehrsflächen und Grünräume werden abstrahiert dargestellt, wobei Maßstab, Proportionen und Lagebeziehungen konsistent zum Ausgangsbild bleiben.

Neben der flächenhaften Darstellung wurden entlang der Straßen auch hellgraue Linien eingezeichnet (PROMPT: […] roads as thin white lines or paths […]). Im Detail repräsentieren diese Linien Kanten zwischen Gehweg und Fahrbahn, jedoch nicht konsistent, und entsprechen genau genommen auch nicht der im Prompt explizit angeforderten Farbe Weiß.

4.2 Synthese fotorealistischer Luftbilder

Abbildung 4 zeigt drei exemplarische Ergebnisse der prompt-basierten Synthese fotorealistischer Luftbilder im GIS-Kontext. Ein reales, georeferenziertes Luft- bzw. Satellitenbild gilt jeweils als Referenz, das mithilfe textueller Instruktionen gezielt semantisch verändert wird.

Im ersten Fall (Abbildung 4a) wird eine komplexe Dachform modernisiert. Die grauen Dachflächen des zentralen Gebäudes wurden dunkelgrün texturiert und gegebenenfalls um blaue Photovoltaik-Anlagen mit hellen Rändern ergänzt. Positiv ist hervorzuheben, dass besonders die nach Süden hin ausgerichteten Paneele unten links im Bild heller sind und somit das Sonnenlicht realistisch zu reflektieren scheinen. Dahingegen fällt kritisch auf, dass der innen liegende Patio nur zur Hälfte angepasst wurde.

Im zweiten Szenario (Abbildung 4b) wird eine bestehende Ackerfläche innerhalb eines Wohngebiets durch eine Einfamilienhausbebauung ersetzt. Die generierte Bebauung orientiert sich hinsichtlich Dachformen, Parzellengrößen und Anordnung sichtbar an der umgebenden Siedlungsstruktur. Auch die Anbindung an das bestehende Straßennetz wird konsistent fortgeführt. Auffällig ist, dass die KI nicht nur neue Objekte ergänzt, sondern implizit auch bestehende Strukturen entfernt oder überformt, sofern dies im Prompt gefordert ist. Dadurch entsteht ein in sich schlüssiges, visuell plausibles Szenario, das sich nahtlos in den räumlichen Kontext einfügt.

Das dritte Beispiel (Abbildung 4c) demonstriert den umgekehrten Fall: Eine großflächige bauliche Struktur (Shoppingcenter) wird entfernt und durch landwirtschaftliche Flurstücke ersetzt. Die synthetischen Ackerflächen orientieren sich dabei an den in der Umgebung dominierenden Feldgrößen, Formen und Nutzungsmustern. Maßstab, Farbgebung und Textur bleiben konsistent mit dem Ausgangsbild, sodass der Eingriff auf den ersten Blick nicht als künstliche Manipulation erkennbar ist.

Zur Einschätzung der visuellen Plausibilität synthetischer Luftbilder wurde für die letzten beiden Beispiele ergänzend eine explorative Befragung durchgeführt. Den Teilnehmenden wurden jeweils ein reales Referenzbild und ein synthetisch erzeugtes Bild nebeneinander präsentiert. Im Szenario aus Abbildung 4b wurde das KI-generierte Bild in 53 % der Fälle korrekt als solches erkannt. Im dritten Szenario (Abbildung 4c) lag die Erkennungsrate bei 57 %. Damit bewegt sich die Erkennungsleistung der synthetischen Bilder insgesamt nahe am Zufallsniveau. Als Hinweise für eine künstliche Generierung wurden im ersten Fall unter anderem eine inkonsistente Ausrichtung der Schatten sowie eine als untypisch wahrgenommene, eher nordamerikanisch anmutende Siedlungsstruktur genannt. Im anderen Beispiel äußerten mehrere Expertinnen und Experten Zweifel aufgrund einer ungleichmäßigen, als künstlich wirkenden Struktur der landwirtschaftlichen Flächen.

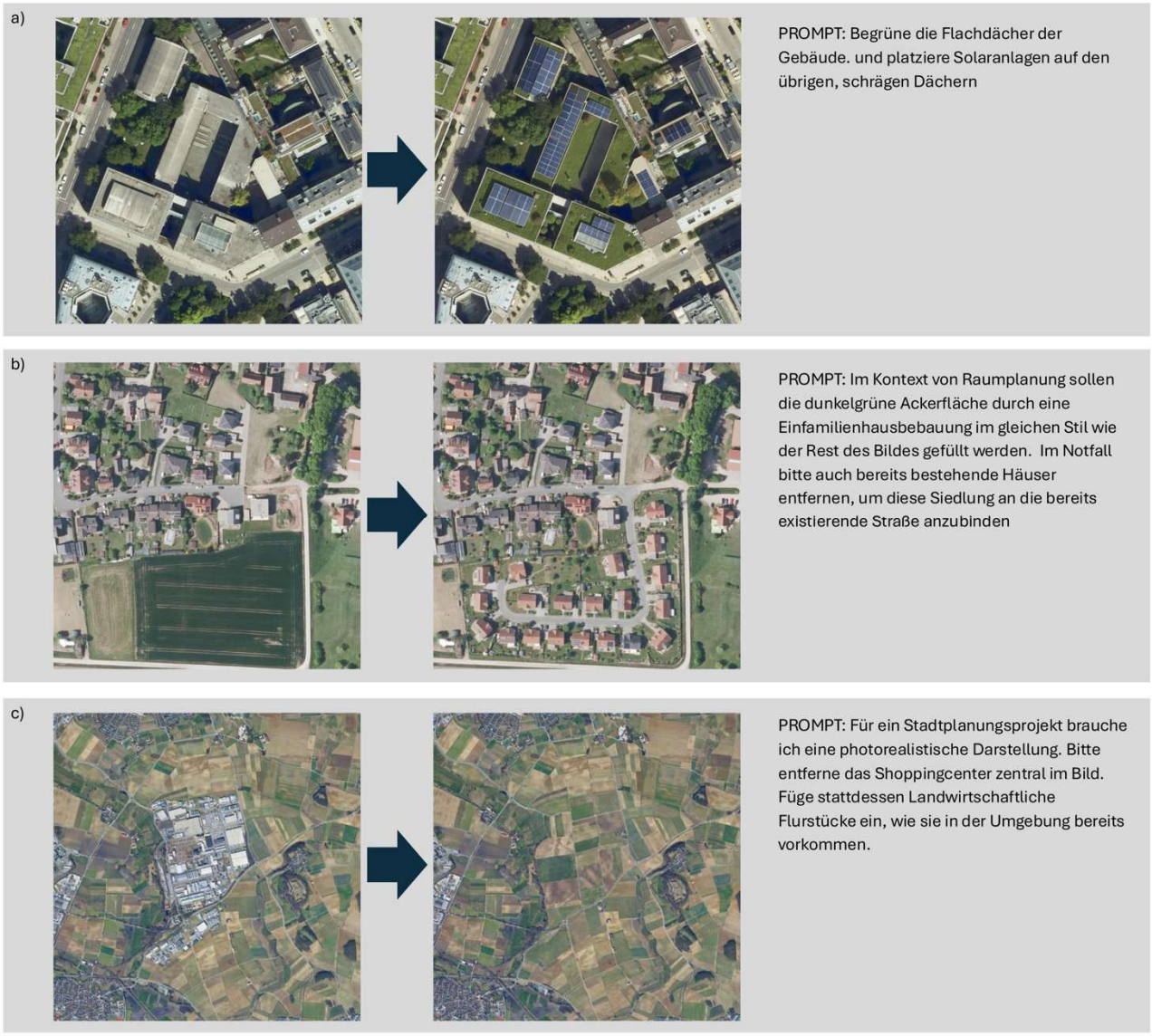


Abb. 4: Visualisierung von Referenzbild (links), Prompt (rechts) und Ergebnis (mittig). a) Modernisierung einer innerstädtischen Dachfläche mit Vegetation und Photovoltaik-Anlagen. b) Ergänzung einer bestehenden Siedlungsstruktur durch Einfamilienhausbebauung auf zuvor landwirtschaftlich genutzter Fläche. c) Stilllegung und Entfernung einer großflächigen baulichen Nutzung und Ersetzung durch landwirtschaftliche Flurstücke.



Abb. 5: Ergebnisse des kombinierten, iterativen Workflows zur KI-gestützten Stadtteilerweiterung im GIS. a) Referenzluftbild als Ausgangszustand. b) Synthetisches Luftbild nach schrittweiser Ergänzung neuer Nutzungen innerhalb überlappender Beobachtungsfenster. c) Aus dem synthetischen Luftbild abgeleitete, abstrahierte kartographische Darstellung mit planungsnaher Symbolik.

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4.3 Kombinierter Workflow

Abbildung 5 zeigt die Ergebnisse eines kombinierten, iterativen Workflows einer fiktiven Stadtteilerweiterung. Ausgangspunkt ist ein noch offenes Feld in einem realen, hochaufgelösten Luftbild, das schrittweise durch synthetische Bildinhalte ergänzt und anschließend kartographisch abstrahiert wurde.

In Abbildung 5b ist das Resultat der schrittweisen Bildsynthese dargestellt. Durch die bewusste Auswahl überlappender Beobachtungsfenster (vgl. Abbildung 2) im Referenzbild konnten konsistente Übergänge zwischen bestehenden und neu generierten Bildbereichen erzielt werden. Das Mosaik aus echten und synthetischen Bildausschnitten erzeugt einen visuell geschlossenen Zustand, der weiterhin der Perspektive und Auflösung eines konventionellen Luftbildes entspricht.

Abbildung 5c zeigt die Überführung des mosaikierten Luftbildes in eine abstrahierte, planungsnahe Darstellung. Gebäude, Verkehrsflächen, Freiräume und technische Anlagen werden dabei grafisch reduziert und eindeutig differenziert. Trotz der Abstraktion bleiben die wesentlichen räumlichen Beziehungen, Parzellierungen und Strukturen des Gebietes erhalten. Das Ergebnis entspricht einer konzeptionellen Planungsskizze, wie sie in frühen Phasen der Stadt- und Landschaftsplanung verwendet wird.

5 DISKUSSION

Kartographie war, ist und bleibt stets eng mit den verfügbaren technischen Mitteln verknüpft. Vom handgezeichneten Plan bis hin zu digitalen Geoinformationssystemen bestimmen Werkzeuge, Datenverfügbarkeit und Rechenleistung, welche Formen räumlicher Darstellung möglich sind. Wie eingangs erwähnt dienen Karten dabei nicht nur der Messung, sondern immer auch der Interpretation, Selektion und Kommunikation räumlicher Zusammenhänge. Der Übergang, von der Kartierung vom Status Quo zur Planung Zukünftiger, bspw. mithilfe von Illustration, technischer Zeichnung, im GIS, CAD, Grafikprogram und 3D Rendering Software, ist fließend. Der hier präsentierte Workflow mäandriert an genau diesem Gradienten. Technische Fortschritte, vom Deep-Learning, über generative T&I2I Bildsynthese und GIS-Integrationen ermöglichen es fortan Anwendern, räumliche Varianten im Planungskontext mittels Prompts visuell zu explorieren.

Aus technischer Sicht ist es zunächst jedoch wichtig zu betonen, dass die meisten in Frage kommenden Modelle sowohl proprietär als auch zu groß für übliche Planungshardware sind, sodass die Nutzung externer Schnittstellen erforderlich ist. Da Referenzbild und Prompt das lokale System verlassen, sind je nach Anbieter und Einsatzzweck datenschutz-, urheber- und vertragsrechtliche Fragen zu klären. Nicht weniger wichtig ist es, gleich zu Beginn, auch auf die ökologischen Kosten durch energie- und rechenintensive Cloud-Infrastrukturen (Hildebrandt, Friederike & Leiner, 2025) aufmerksam zu machen. Während der experimentellen Durchführungen wurden die oft auf Anhieb besten Ergebnisse mit gemini-3-pro-preview generiert. Demgegenüber wurde in Abbildung 4a bewusst flux-2-klein-9b eingesetzt, um den hiesigen Trend zu europäischen, kleineren und damit Ressourcen schonenderen, sowie potenziell auch lokal lauffähigen Modellen zu unterstreichen.

Ebenso wichtig ist ein Bewusstsein für die methodischen Grenzen generativer Modelle. Tendenziell reproduzieren diese Stereotypen. Ein entsprechender Fokus auf US-amerikanische Siedlungsstrukturen schimmert beispielsweise in Abbildung 4b durch. Während wir in der westlichen Welt, bzw. im DACH-Raum im Speziellen, durchaus mit den oben genannten Modellen arbeiten können, ist es wichtig, sich ebendieser Limitation stets bewusst zu sein. Auch hier werden unterrepräsentierte Kontexte nur schwer abbildbar sein. In der Folge ist mit Artefakten und Halluzinationen zu rechnen. An dieser Stelle sind zum einen perspektivische Verzerrungen, als auch vom Referenzbild losgelöste Ergebnisbilder zu berichten. Die Arbeit mit GenAI erfordert also stets eine sorgfältige Kontrolle der generierten Ergebnisse und begrenzt den verlässlichen Einsatz auf lokale, temporäre und klar abgegrenzte Szenarien. Für großflächige, nationale oder globale Anwendungen bleiben hingegen spezialisierte, auf Mess- und Klassifikationsaufgaben ausgerichtete Verfahren weiterhin die geeignetere Wahl. Klassische Fernerkundungsverfahren nutzen außerdem häufig spektral höher aufgelöste Daten. Die hier eingesetzten, für allgemeine Anwendungen spezifizierten Modelle jedoch sind auf dreikanalige Eingangsdaten limitiert. Weiterführende Tests mit Infrarotinformationen und Falschfarbenkompositen sind noch ausstehend.

Ebenjene symbiotische Schnittmenge mit der Fernerkundung wird insbesondere in der Segmentierungsanwendung deutlich. Hier wurden bereits in früheren Arbeiten (Benjamin et al., 2023; W.

Liu et al., 2020) synthetische Bilddaten zum Trainieren klassischerer Modellarchitekturen herangezogen. Doch auch für Stadtplaner und Architekten kann die Segmentierung interessant sein, um bspw. begrünte Flächen schnell zu digitalisieren.

Für die Kartierungsanwendung zeigt sich, dass generative KI weniger als klassisches Klassifikationswerkzeug wirkt, sondern vielmehr als Mittel zur gezielten Generalisierung und Symbolisierung räumlicher Inhalte. Werden bislang oft standardisierte Hintergrundkarten hinzugezogen, knüpft dieses Werkzeug direkt an den kartographischen Gestaltungsprozess an. Für Anwender eröffnet es die Möglichkeit, präsentationsfähige, kontextbezogene Kartenprodukte direkt aus Bilddaten abzuleiten.

Die Erzeugung synthetischer Bilddaten unterstützt sowohl die visuelle Kommunikation als auch analytische Arbeitsprozesse. Die besondere Stärke der vorliegenden QGIS-Integration liegt in ihrer schnellen und flexiblen Erzeugung innerhalb eines iterativen, mit echten Geodaten kontextualisierten Workflows. Wie in Abbildung 5 gezeigt, lassen sich die generierten Luftbilder direkt wieder in den Workflow zurückführen. Vor einer etwaigen Veröffentlichung der Daten, sind diese jedoch deutlich als KI-generiert auszuweisen. Ansonsten könnte die täuschende Ähnlichkeit synthetischer Luftbilder dem Vertrauen in die Raumwissenschaften schaden (Rillig et al., 2024).

Zu guter Letzt ist es wichtig zu betonen, dass KI keine Expertinnen und Experten inhaltlich ersetzen kann. Denn obgleich es technisch möglich wäre, den Kontext um rechtliche Vorgaben zu ergänzen und die Berechnung von Abstandsflächen zu inkludieren, so ist Planung kein rein technischer Prozess, sondern auch ein kreativer Akt mit Auswirkungen auf Lebensqualität und Umwelt (Neumann & Sieverts, 1997). Nutzende dieses Werkzeugs tragen deswegen bei der Formulierung von Prompts eine entsprechende Verantwortung.

6 CONCLUSION

Den griechischen Begriff Geografie wörtlich nehmend, vermag der Workflow „vom Prompt zum Plan" eine bisherige Brücke zwischen analytischer Karte und aufwendiger Visualisierung schlagen.

Mithilfe von GenAI synthetisierte Luftbilder ermöglichen es, räumliche Varianten schnell und kontextbezogen darzustellen, ohne detaillierte Modellierung oder Rendering Prozesse. Damit eignen sie sich insbesondere für frühe, explorative Phasen der Stadt- und Landschaftsplanung. Dies unterstützt sowohl interne Entwurfsprozesse als auch die Kommunikation mit Verwaltung, Politik und Öffentlichkeit.

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🏆 reviewed paper

Von der Nische zur Norm! Mobilitätsprofile als Wissensbasis für die Förderung eines aktiven, nachhaltigen Mobilitätsverhaltens in niederösterreichischen Städten

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1 ABSTRACT

Dieser Beitrag untersucht alltagsbezogene Mobilitätsentscheidungen in drei niederösterreichischen Städten im Kontext der Verbesserung der Nachhaltigkeit und der Lebensqualität. Dabei werden sozialpsychologische Theorien mit einer Q-Methoden-Studie und einer anschließenden Bevölkerungsbefragung kombiniert. Ausgangspunkt ist die Annahme, dass Einstellungen, Normen, Gewohnheiten und situative Kontexte das Verhalten wesentlich prägen und sich in spezifischen Interpretationslogiken der Fortbewegung niederschlagen. Aus der empirischen Analyse ergeben sich fünf Mobilitätsprofile, die emotionale, normative und instrumentelle Motive auf unterschiedliche Weise verbinden: ein gesundheits- und umweltorientiertes Verständnis von Mobilität, eine zweck- und pragmatische Perspektive, eine abwägende und kontextsensible Haltung, ein sicherheits- und kontrollorientiertes Muster sowie ein effizienz- und autonomiebetonter Zugang. Diese Profile zeigen sich in den Städten mit jeweils eigenen Ausprägungen und spiegeln typische Verhaltensmuster wider, etwa die stärkere Bedeutung des Pkw bei bestimmten Wegzwecken und die hohe Relevanz von Gehen und Radfahren auf Zubringerstrecken wie zum Bahnhof. Für die Praxis wird deutlich, dass attraktive Infrastruktur die Grundvoraussetzung für nachhaltige Mobilität bildet, jedoch allein nicht genügt. Darüber hinaus erreichen rein umweltnormative Appelle breitere Bevölkerungsgruppen nicht zuverlässig. Erforderlich ist daher ein umfassender Maßnahmenmix, der zielgruppenspezifische Angebote in Mobilitätsservices, Bewusstseinsbildung, Partizipation und Anreize kombiniert.

Keywords: mobilty, behaviour, sustainability, small cities, policy

2 EINLEITUNG

Die Europäische Union strebt bis 2050 eine Netto-Null-Bilanz bei den Treibhausgasemissionen an, doch die Umstellung auf kohlenstoffarme Mobilität verläuft weiterhin langsam und ist nur teilweise erfolgreich (Sovacool & Griffiths, 2020). Zu den wichtigsten Hindernissen zählen wachsendes Verkehrsaufkommen und tief verwurzelte politisch-wirtschaftliche und soziokulturelle Faktoren wie der Einfluss der Automobilindustrie, die Kultur des Autofahrens und gewohnheitsmäßige Mobilitätsmuster (Prillwitz & Barr, 2011). Obwohl die Einführung von Hybrid-/Elektrofahrzeugen, die Nutzung von E-Bikes und eine verbesserte Fahrrad- und ÖV-Infrastruktur ein nachhaltigeres System unterstützen (Schoenau & Müller, 2017), sind die Emissionsreduktionen bei weitem noch nicht ausreichend (Markvica et al., 2020). Der motorisierte Individualverkehr (MIV) hat trotz praktikabler Alternativen deutlich zugenommen (Schepers et al., 2021), während aktive Fortbewegungsarten wie Gehen und Radfahren außerhalb einiger urbaner Großstädte weitgehend unverändert geblieben sind (Schepers et al., 2021). Die Begrenzung des Autoverkehrs und die Umstellung auf kohlenstoffarme Fortbewegungsmittel sind jedoch gerade für kleinere und mittlere Städte zum Erhalt der Lebensqualität von entscheidender Bedeutung (Nordfjærn et al., 2016) und erfordern ein umfassendes Umdenken im Mobilitätsverhalten (Prillwitz & Barr, 2011; Schoenau & Müller, 2017).

Dieser Artikel veranschaulicht und diskutiert die Ergebnisse aus dem transdisziplinären Forschungsprojekt „NTN – From Niche to Norm“ (Von der Nische zur Norm), das die Alltagsmobilität in drei NÖ Städten – Fischamend, Korneuburg und Stockerau – untersucht hat. Es werden dabei eine Vielzahl sozialpsychologischer Variablen integriert, die das tägliche Mobilitätsverhalten der Menschen beeinflussen und unabhängig von der tatsächlichen Wahl des Verkehrsmittels sind. Die Kernhypothese lautet, dass ähnliche Bedürfnisse und Motivationen zu unterschiedlichen Verkehrsmittelentscheidungen führen können. Mithilfe der Q-Methode und einer Fragebogenerhebung werden Mobilitätsprofile identifiziert, die für die Wahl der Fortbewegung innerhalb einer Stadt entscheidend sind. Folgende Forschungsfragen stehen dabei im Mittelpunkt: (i) Welche soziopsychologischen Variablen beeinflussen die alltägliche Mobilität? (ii) Welche Mobilitätsprofile ergeben sich durch einen Q-Methoden-Ansatz? und iii) Wie sind die

Mobilitätsprofile in der Bevölkerung verteilt? Die Ergebnisse vertiefen das Verständnis für die Bedürfnisse, die hinter Mobilitätsentscheidungen stehen und liefern Informationen für maßgeschneiderte Maßnahmen zur Unterstützung nachhaltiger Verhaltensänderungen.

Der Artikel ist wie folgt aufgebaut: Kapitel 3 diskutiert die Theorie bzw. den konzeptionellen Ansatz. Im Kapitel 4 wird die methodische Herangehensweise d.h die Anwendung der Q-Methode und die Durchführung der Erhebung beschrieben. Kapitel 5 enthält die zentralen Ergebnisse des Forschungsprojekts. Die Arbeit schließt im Kapitel 6 mit einer Zusammenfassung und Diskussion der Erkenntnisse ab.

3 KONZEPTIONELLER HINTERGRUND

Mobilitätsforschungen stützten sich in der Vergangenheit weitgehend auf Annahmen der rationalen Entscheidung und der wirtschaftlichen Optimierung und gingen davon aus, dass Individuen ihre Verkehrsmittelwahl auf der Grundlage messbarer Kriterien treffen (Anable, 2005; Steg et al., 2001). Angesichts der begrenzten Erklärungs- und Vorhersagekraft dieser Modelle wurden zunehmend sozialpsychologische Perspektiven miteinbezogen – vor allem die Theory of Planned Behavior (TPB) (Ajzen, 1991), das Norm Activation Model (NAM) (Schwartz, 1977) und das Comprehensive Action Determination Model (CADM) (Klöckner & Blöbaum, 2010). Diese schaffen es differenzierterzu erfassen, wie Absichten, Normen, Gewohnheiten und situative Kontexte das Mobilitätsverhalten beeinflussen.

In Mobilitätsstudien spielt die TPB eine zentrale Rolle bei der Erklärung, wie instrumentelle und affektive Einstellungen die Präferenzen für bestimmte Verkehrsmittel beeinflussen (Steg et al., 2001; Anable & Gatersleben, 2005). Das NAM wird angewendet, um umweltmotivierte Entscheidungen zu erklären – wie z. B. die Wahl des Fahrrades statt des Autos (Jakovcevic & Steg, 2013). Das CADM betont darüber hinaus, dass die tägliche Mobilität häufig automatisch und gewohnheitsmäßig erfolgt und in konkrete physische (z. B. Infrastruktur) und soziale Kontexte (z. B. Normen) eingebettet ist.

Aus diesen Theorien und der damit einhergehenden Literatur können folgende Bereiche identifiziert werden, die die Wahl der Mobilität beeinflussen: i) Normative Faktoren: Soziale Erwartungen (subjektive Normen), verinnerlichte Werte (persönliche Normen) und der Wunsch, Identität oder Status zu signalisieren (Steg, 2005; Spotswood et al., 2015); ii) Einstellungsfaktoren: instrumentelle Motive (z. B. Zeitersparnis, Komfort, Kosteneffizienz) und symbolisch-affektive Motive (z. B. Autonomie, Gesundheit, Entspannung) (Anable & Gatersleben, 2005; Ramos et al., 2020); iii) Situative Einschränkungen und Kontrolle: wahrgenommene Verhaltenskontrolle und objektive situative Faktoren (z. B. Wetter, Entfernung, Infrastruktur, Sicherheit) (Dill & McNeil, 2013; Hoffmann et al., 2020); iv) Gewohnheiten: Routinemäßige Verhaltensweisen (Busch-Geertsema et al., 2016); v) Umweltbewusstsein und Verantwortung: Bewusstsein für ökologische Folgen und das Ausmaß der wahrgenommenen persönlichen Verantwortung (Mitran et al, 2019).

4 METHODISCHES VORGEHEN

4.1 Die Q-Studie

Um die unterschiedlichen Motivationsfaktoren hinter den alltäglichen Verkehrsentscheidungen zu erfassen und zu konsistenten Perspektiven zu integrieren, wurde die Q-Methode verwendet, die erstmals in den 1930er Jahren vom Psychologen und Physiker William Stephenson vorgestellt und in den folgenden Jahrzehnten in vielen Disziplinen und Forschungsbereichen eingesetzt wurde (Stephenson, 1936; Brown, 1980; Byrne et al., 2017). Als explorative und semi-quantitative Methode ermöglicht die Q-Methode die systematische Erforschung von Subjektivität (Watts & Stenner, 2005) und die Identifizierung unterschiedlicher Standpunkte mittels einer statistischen Berechnung, im Wesentlichen einer invertierten Faktorenanalyse (Stephenson, 1936). Im Ergebnis zeigt eine Q-Studie unterschiedliche Perspektiven von Personengruppen zum untersuchten Thema auf. Die Schlüsselkomponenten einer Q-Methodik-Studie sind:

- Das Q-Set (Q-sample) ist eine Auswahl von Aussagen, die ein möglichst vollständiges Bild der Meinungsvielfalt zum jeweiligen Thema vermitteln (Baker et al., 2017; Watts & Stenner, 2005). In der vorliegenden Studie besteht das Q-Set aus einer Auswahl von Faktoren und zugrunde liegenden Motiven für die Verkehrsmittelwahl.
- Die Teilnehmenden der Q-Studie (P-sample) werden in einem Interviewsetting gebeten, die Aussagen des Q-Sets in Bezug zueinander zu ordnen (entlang der Skala „stimme voll zu – stimme

überhaupt nicht zu“), was zu individuellen Q-Sortierungen führt, die die subjektiven Standpunkte der Personen widerspiegeln (Brown, 1993).

- Im finalen Schritt werden diese Q-Sortierungen dann korreliert und einer Faktorenanalyse unterzogen, um Antwortmuster (Q-pattern analysis) zu erkennen. D. h. es werden Ähnlichkeiten bzw. Unterschiede zwischen den Teilnehmenden errechnet, die zu gemeinsamen Perspektiven – den sogenannten Faktoren – führen.

4.1.1 Die Sammlung von Aussagen

Die Entwicklung eines Sets von Aussagen ist ein zentraler Schritt in der Q-Methode, da es den diskursiven Raum definiert, in dem die Teilnehmenden ihre subjektiven Perspektiven artikulieren können. Die im Q-Set verwendeten Aussagen sollen die gesamte Bandbreite und Vielfalt der Meinungen zu dem betreffenden Thema widerspiegeln (Baker et al., 2017). Um konzeptionelle Breite und analytische Kohärenz zu gewährleisten, wurde in dieser Studie eine deduktive Strategie verwendet, die auf dem Comprehensive Action Determination Model (CADM) basiert. Das CADM synthetisiert die Theory of Planned Behavior (TPB) und das Norm Activation Model (NAM) und integriert somit rationale, normative, gewohnheitsmäßige und situative Komponenten des Verhaltens.

Insgesamt wurden so zunächst 680 Aussagen aus der Literatur deduktiv extrahiert und gemäß CADM klassifiziert. In Folge wurden verwandte Aussagen zusammengeführt, Redundanzen entfernt und weniger relevante Aspekte verworfen. Dieser Konsolidierungsprozess führte zusammen mit der Durchführung zweier Pre-Tests zu einem Q-Set von 45 Aussagen. Alle Aussagen vervollständigten dabei den Satz „Wenn ich in meinem Alltag in meiner Heimatstadt unterwegs bin ...“, was es den Teilnehmenden erleichtern sollte, sich auf alltägliche Fahrten innerhalb der Stadtgrenzen zu konzentrieren. Strecken außerhalb der Stadtgrenzen (z. B. Pendlerstrecken) wurden bewusst zur besseren Eingrenzung und Absicherung der Untersuchungsergebnisse aus der Studie ausgeschlossen.

4.1.2 Die Teilnehmenden

Die Auswahl der Stichprobe sollte die Wahrscheinlichkeit, dass eine Vielzahl unterschiedlicher Standpunkte zum Ausdruck kommt, maximieren (Watts & Stenner, 2005). Dabei ist keine große Zahl an Teilnehmenden erforderlich, da die Q-Methode auch bei einer kleinen Stichprobengröße statistisch signifikante Ergebnisse liefert (Brown, 1993).

In der vorliegenden Studie bezieht sich die Vielfalt der Standpunkte auf die Heterogenität der Verkehrsteilnehmenden hinsichtlich ihrer Wahl des Verkehrsmittels und ihrer zugrunde liegenden Motive. Darüber hinaus wurde mit drei kleinen bis mittleren Städten in Niederösterreich – Fischamend, Korneuburg und Stockerau – kooperiert, aus denen die Stichprobe gezogen wurde. Alle drei liegen in unmittelbarer Nähe der Hauptstadt Wien, weisen ähnliche strukturelle Merkmale in Bezug auf Größe, Entfernungen und Verfügbarkeit von Verkehrsinfrastruktur auf und wurden daher als vergleichbare Untersuchungsgebiete ausgewählt. Einige soziodemografische Variablen (z. B. Geschlechterverteilung, Mindestalter von 18 Jahren) und andere Kriterien (z. B. Führerschein, Besitz einer ÖV-Zeitkarte) wurden vom Projektteam vorab festgelegt, um eine möglichst breite Palette von Verkehrsteilnehmenden für die Stichprobe zu erhalten. Insgesamt wurden 39 Personen für die Q-Studie ausgewählt.

Da die persönlichen Interviews während der Covid-Pandemie 2021 stattfanden, mussten 13 der 39 Q-Interviews online unter Verwendung der Videokonferenzsoftware „Zoom“ und des Online-Tools „Q Method Software“ (Lutfallah & Buchanan, 2019) durchgeführt werden, wobei das Vorgehen immer dem selben Ablauf folgte. Die Teilnehmemden wurden zunächst zu ihren persönlichen Mobilitätspräferenzen und ihrem Mobilitätsverhalten in den jeweiligen Städten befragt. Anschließend wurden sie, wie von Stenner et al. (2008) vorgeschlagen, gebeten, die 45 Aussagen zu lesen und sie in drei Stapel zu sortieren (stimme zu, neutral, stimme nicht zu). Im nächsten Schritt wurden die Teilnehmenden aufgefordert, die Aussagen entsprechend ihrer Zustimmung nach einer erzwungenen Normalverteilung zu sortieren. Abschließend füllten die Teilnehmenden einen soziodemografischen Fragebogen aus, dessen Ergebnisse später zur detaillierteren Beschreibung der gewonnenen Erkenntnisse herangezogen wurden.

4.1.3 Die Faktorenanalyse

Um Ähnlichkeiten und Unterschiede zwischen zwei beliebigen Q-Sorts aufzuzeigen, wurden Korrelationen zwischen allen Q-Sorts unter Verwendung des Pearson-Korrelationskoeffizienten „r“ berechnet.. Da Korrelationen zwischen -1 und +1 liegen, wird eine größere Ähnlichkeit zwischen zwei Q-Varianten durch einen Korrelationskoeffizienten angezeigt, der näher an 1 liegt (Stenner et al., 2008). Unter der Verwendung der Hauptkomponentenanalyse (PCA) zusammen mit der Varimax-Rotation konnten Muster aufgedeckt und eindeutige Faktoren (gemeinsame Ansichten bwz. Profile) zwischen den Q-Varianten identifiziert werden. Die PCA maximiert die Varianz jedes nachfolgenden Faktors (Brown, 1980), während die Varimax-Rotation darauf abzielt, die Varianz durch möglichst wenige Faktoren zu optimieren (Webler et al., 2009). Daraus kristalliersten sich fünf Profile heraus, die statistisch relevant und gut interpretierbar sind und eine pointierte und facettenreiche Sicht auf den Verhaltensaspekt der Mobilität ermöglichen. Diese fünf identifizierten Mobilitätsprofile werden im Ergebnisteil (Kapitel 5) vorgestellt.

4.2 Die Erhebung

Aufbauend auf den Ergebnissen der Q- Studie wurde im Rahmen des Forschungsprojekts eine quantitative Fragebogenerhebung entwickelt und durchgeführt. Die Q-Studie lieferte zwar ein differenziertes Verständnis der subjektiven Perspektiven, die das alltägliche Mobilitätsverhalten prägen, gab jedoch keinen Aufschluss darüber, wie verbreitet diese Profile in der Bevölkerung sind und in welchem Zusammenhang sie mit der tatsächlichen Verkehrsmittelwahl stehen.

Die Erhebung wurde zwischen März und April 2022 in den drei Stadtgemeinden Fischamend, Korneuburg und Stockerau durchgeführt. Die Befragung richtete sich an Einwohnerinnen und Einwohner mit Wohnsitz in der Gemeinde ab 15 Jahren, war freiwillig und anonym. Um eine breite Zugänglichkeit zu gewährleisten, wurde der Fragebogen in zwei Formaten verteilt: (1) als gedruckte Beilage in den Gemeindezeitungen und (2) über einen Online-Link, der als QR-Code in der Gemeindezeitung abgedruckt war. Insgesamt wurden 629 vollständig ausgefüllte Fragebögen gesammelt (Fischamend n=87, Korneuburg n=232, Stockerau n=310). Dies entspricht etwa 2% der Gesamtbevölkerung der drei Stadtgemeinden. Das Durchschnittsalter der Befragten lag bei 49,7 Jahren. 54,5% der Teilnehmenden waren weiblich. Alter und Geschlecht der Teilnehmenden entsprechen damit weitgehend der Grundgesamtheit (= Bevölkerung der drei Stadtgemeinden). Bei den Bildungsabschlüssen sind in der Stichprobe Personen mit Hochschulabschluss und Matura überrepräsentiert. Die Stichprobe erhebt keinen Anspruch auf statistische Repräsentativität im probabilistischen Sinne, jedoch wurde bei der Studie ein vielfältiger und sehr heterogener Ausschnitt der Bevölkerung erreicht.

Der Fragebogen war in fünf thematische Abschnitte gegliedert, die die theoretischen Grundlagen und die sequenzielle Logik der Studie widerspiegelten. Das Umfragedesign zielte darauf ab, die soziodemografischen und verhaltensbezogenen Aspekte der alltäglichen Mobilität, sowie die Zuordnung zu den in der Q-methodologischen Phase identifizierten psychologischen und kontextuellen Faktoren zu erfassen.

5 ERGEBNISSE

5.1 Mobilitätsprofile aus der Q-Studie

Unter einem Mobilitätsprofil wird im Kontext der vorliegenden Studie eine Gruppe von Personen verstanden, deren alltägliches Mobilitätsverhalten von annähernd gleichen Beweggründen beeinflusst wird. Die Q-Sortierung der 45 Aussagen von den 39 Befragten ergab fünf verschiedene Mobilitätsprofile (siehe Abbildung 1), die zusammen 60% der Varianz erklären (vgl. Schauppenlehner-Kloyber et al., 2023). 32 der 39 Q-Sortierungen konnten einem der fünf Faktoren zugeordnet werden. Sieben Q-Sortierungen ließen sich nicht signifikant einem einzigen Faktor zuordnen, d. h. sie erfüllten nicht das Kriterium der Mehrheit der gemeinsamen Varianz bei einem Signifikanzniveau von $p < 0,01$.

5.1.1 Mobilitätsprofil 1: „gesund und bewusst unterwegs“

Für Personen mit dieser Sichtweise erfüllt die Fortbewegung in der eigenen Stadtgemeinde mehr als nur den Zweck, von A nach B zu kommen. Für sie spielen gesundheitliche Aspekte eine vergleichsweise große Rolle, sowie die Möglichkeit, sich in einer schönen Umgebung zu bewegen und dabei Spaß zu haben.

Körperliche Anstrengung wird dazu gerne in Kauf genommen. Außerdem schätzen sie die Möglichkeit, mit anderen Menschen in Kontakt zu kommen. Die Zeitersparnis ist für Personen mit dieser Einstellung im Vergleich zu allen anderen am wenigsten wichtig.

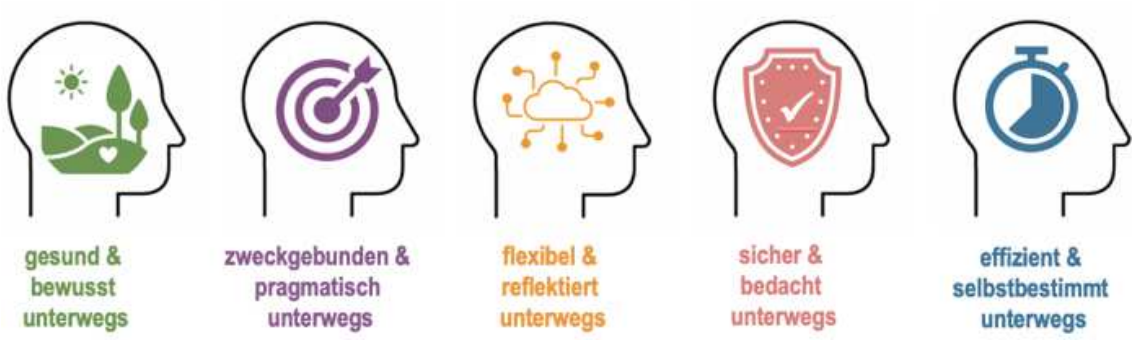


Abbildung 1: Die fünf Mobilitätsprofile aus der Q-Studie

Diese Gruppe ist jene mit dem stärksten Fokus auf umweltbezogene Faktoren. Personen mit dieser Sichtweise spüren eine Verantwortung, den eigenen Einfluss auf Umwelt und Klima zu minimieren, und sie denken an die ökologischen Konsequenzen der eigenen Art der Fortbewegung. Ihnen ist es nicht nur wichtig, dass ihre Art der Fortbewegung ihren Überzeugungen entspricht, sondern sie möchten auch mehr als alle anderen mit dem eigenen Verhalten eine Vorbildfunktion einnehmen. Gleichzeitig orientieren sich Personen dieser Gruppe weder daran, wie Freunde oder Bekannte unterwegs sind, noch denken sie darüber nach, was andere von ihrer Art der Fortbewegung halten. Dem eigenen Verkehrsmittelbesitz stehen sie eher neutral gegenüber, Aussehen und Zustand des Verkehrsmittels sind gänzlich unwichtig. In Abbildung 2 sind die Kernaussagen des Mobilitätsprofils 1 zusammengefasst.

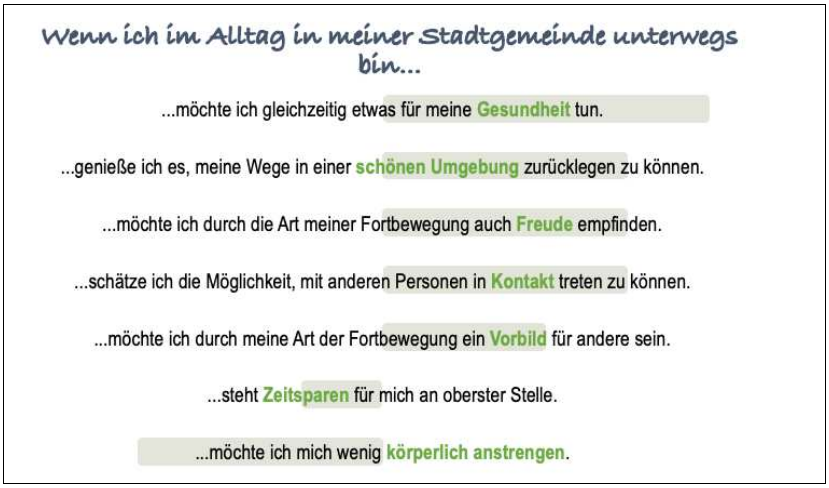


Abbildung 2: Kernaussagen zu Mobilitätsprofil 1 (schattiert von der Mitte nach rechts die Zustimmung/von der Mitte nach links die Ablehnung zur jeweiligen Aussage)

5.1.2 Mobilitätsprofil 2: „zweckgebunden und pragmatisch unterwegs“

Für diese Personen ist die Fortbewegung innerhalb der eigenen Stadtgemeinde in erster Linie zweckgebunden, was einen gewissen Pragmatismus bei der Verkehrsmittelwahl bedeutet. Zentrale Entscheidungskriterien für die Verkehrsmittelwahl sind für diese Personen die Länge und der Zweck der Wege. Bei der Wahl des Verkehrsmittels steht weniger der Wunsch nach eigener Flexibilität im Vordergrund, als vielmehr das Gefühl, dass der Zweck die Art des Verkehrsmittels diktiert. So fühlt sich diese Personengruppe bei der Verkehrsmittelwahl im Vergleich zu den anderen am alternativlosesten und wählt in der Regel häufig das gleiche Verkehrsmittel.

Äußere Umstände, wie z.B. die Verfügbarkeit von Parkplätzen, beeinflussen ihre Entscheidung stärker als andere Personengruppen. Auch der Faktor Bequemlichkeit spielt für Personen mit dieser Einstellung eine vergleichsweise große Rolle, Zeitersparnis ist dagegen kein zentrales Thema. Wichtig ist auch die Unabhängigkeit. Diese Personen wollen spontan und flexibel sein, sich selbst-bestimmt fortbewegen, suchen

unterwegs keinen Kontakt mit anderen Menschen, wollen ein eigenes Verkehrsmittel besitzen und nicht lange überlegen müssen, wie sie von A nach B kommen.

Dieser Gruppe sind umweltbezogene Kriterien bei der Wahl des Verkehrsmittels weniger wichtig: Der Anspruch, die eigene Klimabelastung zu minimieren und die Sorge um die ökologischen Folgen der eigenen Fortbewegung spielen bei der Entscheidung eine untergeordnete Rolle. In Abbildung 3 sind die Kernaussagen des Mobilitätsprofils 2 zusammengefasst.

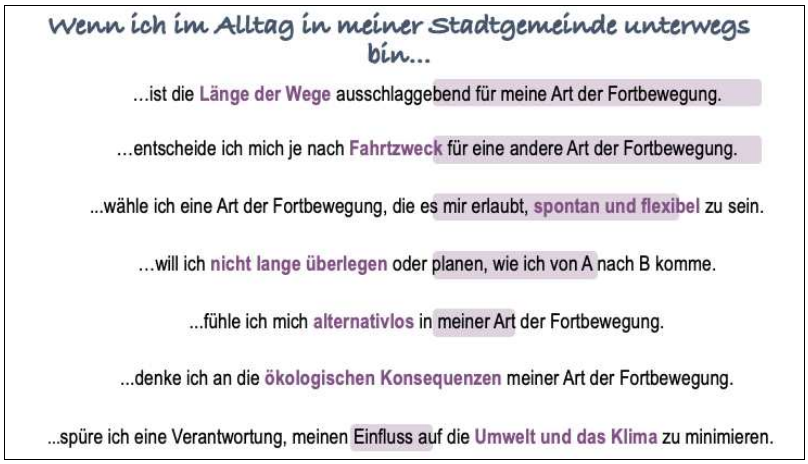


Abbildung 3: Kernaussagen zu Mobilitätsprofil 2 (schattiert von der Mitte nach rechts die Zustim-mung/von der Mitte nach links die Ablehnung zur jeweiligen Aussage)

5.1.3 Mobilitätsprofil 3: „flexibel und reflektiert unterwegs“

Für Personen mit dieser Sichtweise ist die Fortbewegung in der eigenen Stadtgemeinde etwas, das reflektiert und immer wieder neu abgewogen wird. Sie entscheiden sich je nach Fahrtzweck für eine andere Art der Fortbewegung, schätzen dabei die Flexibilität, zwischen verschiedenen Optionen wählen zu können und fühlen sich in ihrer Art der Fortbewegung keineswegs alternativlos. Im Gegensatz zu anderen Personengruppen überlegen sie jedes Mal neu, wie sie sich fortbewegen, sind offen für die Planung, wie sie von A nach B kommen, und wählen letztlich auch nicht immer die gleiche Art der Fortbewegung. Personen mit dieser Sichtweise versuchen, mehrere notwendige Wege miteinander zu kombinieren, fühlen sich verantwortlich für eine möglichst geringe Belastung von Umwelt und Klima und möchten sich mit gutem Gewissen fortbewegen können. Sie versuchen daher, für jeden Weg die aus ihrer Sicht richtige Entscheidung zu treffen.

Von allen Gruppen denken Personen mit dieser Einstellung am meisten an die Verfügbarkeit von Parkmöglichkeiten. Völlig unwichtig ist für sie dagegen, was andere von ihrer Fortbewegungsart halten oder ob sie damit ihren sozialen Status demonstrieren können. Im Vergleich zu den anderen Personengruppen achten sie stärker auf die Ausnutzung der laufenden oder bereits entstandenen Kosten. In Abbildung 4 sind die Kernaussagen des Mobilitätsprofils 3 zusammengefasst.

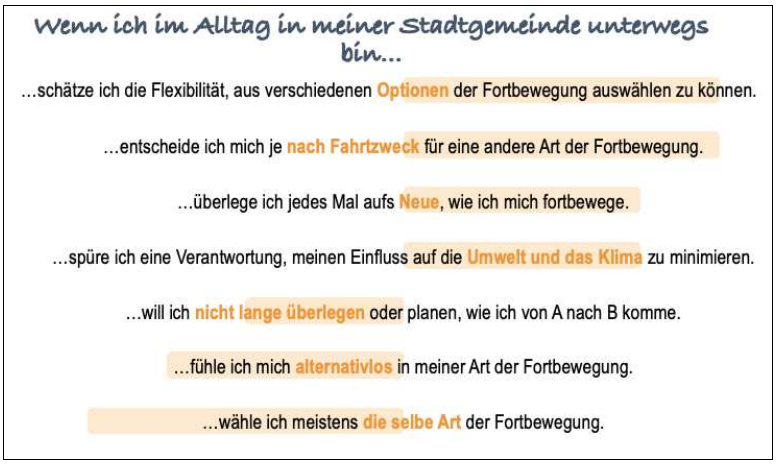


Abbildung 4: Kernaussagen zu Mobilitätsprofil 3 (schattiert von der Mitte nach rechts die Zustimmung/von der Mitte nach links die Ablehnung zur jeweiligen Aussage)

5.1.4 Mobilitätsprofil 4: „sicher und bedacht unterwegs“

Personen mit dieser Sichtweise teilen das Bedürfnis nach Sicherheit und Kontrolle bei der Fortbewegung in der eigenen Stadtgemeinde. Sie wählen die Fortbewegungsart mit dem geringsten Unfallrisiko und vermeiden Situationen, in denen sie sich unsicher fühlen. Dementsprechend bevorzugt diese Personengruppe Wege, die von anderen Verkehrsflächen abgetrennt sind. Sie ist die einzige, die nicht verneint, bei der Verkehrsmittelwahl an die Gefahr von Übergriffen oder Belästigungen zu denken. Im Gegensatz zum hohen Sicherheitsbedürfnis ist es für Personen mit dieser Sichtweise weniger wichtig, bei der Verkehrsmittelwahl flexibel zwischen verschiedenen Optionen wählen zu können oder sich jedes Mal neu für ein Verkehrsmittel entscheiden zu müssen. Vielmehr bevorzugen sie meist die gleiche Art der Fortbewegung. Dabei kommt es dieser Personengruppe weder darauf an, ein eigenes Verkehrsmittel zu besitzen, noch auf das Image des benutzten Verkehrsmittels oder darauf, dass die gewählte Fortbewegungsart zum eigenen Lebensstil passt. Menschen mit dieser Einstellung möchten zwar möglichst bequem von A nach B kommen, nehmen dafür aber auch Zwischenstopps in Kauf. Wohl auch deshalb informieren sie sich im Vorfeld über die zu erwartenden Wetterbedingungen und die Länge der Wege. In Abbildung 5 sind die Kernaussagen des Mobilitätsprofils 4 zusammengefasst.

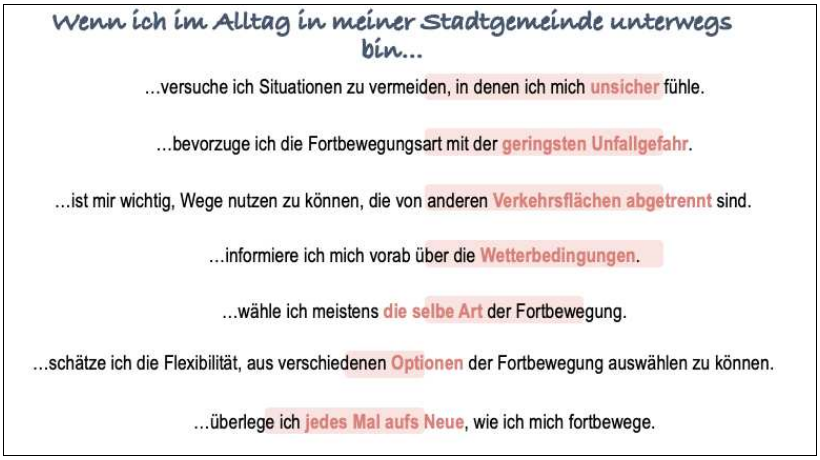


Abbildung 5: Kernaussagen zu Mobilitätsprofil 4 (schattiert von der Mitte nach rechts die Zustimmung/von der Mitte nach links die Ablehnung zur jeweiligen Aussage)

5.1.5 Mobilitätsprofil 5: „effizient und selbstbestimmt unterwegs“

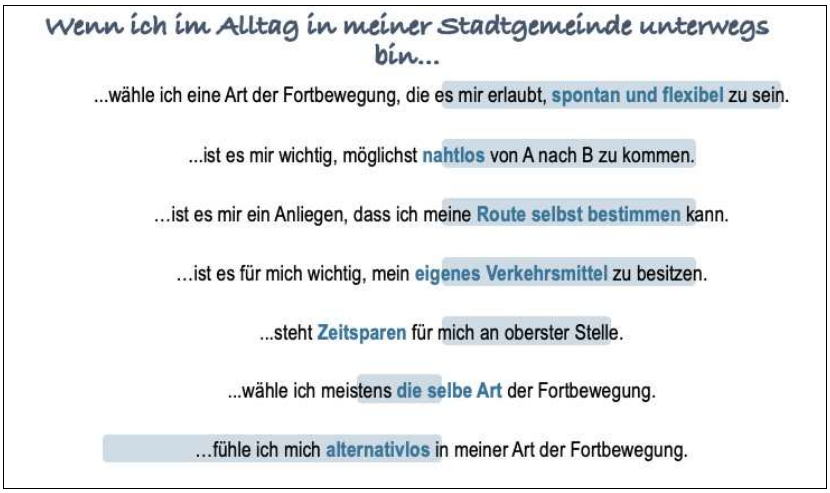


Abbildung 6: Kernaussagen zu Mobilitätsprofil 5 (schattiert von der Mitte nach rechts die Zustimmung/von der Mitte nach links die Ablehnung zur jeweiligen Aussage)

Für Personen mit dieser Sichtweise stehen Effizienz und Unabhängigkeit bei der Fortbewegung in der eigenen Stadtgemeinde im Vordergrund. Zeitersparnis bei der Fortbewegung ist ihnen deutlich wichtiger als den anderen Gruppen, ebenso die verlässliche Planbarkeit. Dazu wählen sie das Verkehrsmittel, das ihnen ein Höchstmaß an Spontanität und Flexibilität bietet, was nicht immer auf dasselbe Verkehrsmittel zutreffen muss. Sie wollen ihre Reiseroute selbst bestimmen und ohne viele Umstiege oder Unterbrechungen ans Ziel kommen. Im Vergleich zu anderen ist ihnen ihre Privatsphäre sehr wichtig, und sie legen keinen Wert darauf,

unterwegs mit anderen Menschen in Kontakt zu kommen. Entsprechend ihrem Bedürfnis nach Zeitersparnis wollen sie unabhängig vom Verkehrsaufkommen vorankommen. Der Besitz eines eigenen Verkehrsmittels ist für diese Gruppe sehr wichtig, wobei sie sich in ihrer Verkehrsmittelwahl keineswegs alternativlos fühlen. Weder die laufenden Kosten noch die Fahrtkosten spielen für sie eine Rolle. Sie legen darauf Wert, dass ihr Verkehrsmittel auch zu ihrem Lebensstil und ihren Überzeugungen passt. Mehr als die anderen Personengruppen überlegen sie sich, was andere über ihre Art der Fortbewegung denken könnten.

Sie wollen mit ihrer Art der Fortbewegung Spaß haben, aber im Gegensatz zu anderen ist es ihnen weniger wichtig, ihre Wege in einer schönen Umgebung zurückzulegen oder gleichzeitig etwas für die Gesundheit zu tun. Weder das Wetter noch die Länge der Wege oder die Verfügbarkeit von Parkplätzen/Parkhäusern beeinflussen sie in ihrer Verkehrsmittelwahl. In Abbildung 6 sind die Kernaussagen des Mobilitätsprofils 5 zusammengefasst.

5.2 Zusammenhänge der Q-Studie und der Fragebogenerhebung

5.2.1 Wie bewegen sich Befragte in den Stadtgemeinden von A nach B?

Abbildung 7 zeigt die drei wichtigsten Fortbewegungsarten – das Auto- und Fahrradfahren sowie das Zufußgehen – im Städtevergleich.

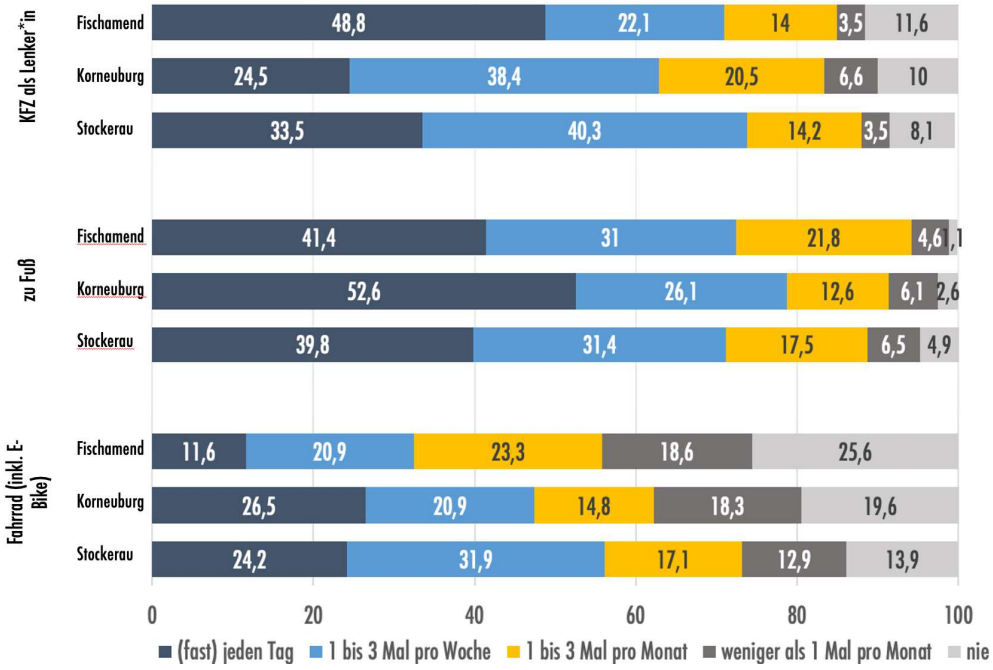


Abbildung 7: Städtevergleich der drei wichtigsten Fortbewegungsarten (n = 629)

Mit 48,8%, die den Pkw „(fast) jeden Tag“ benutzen, liegt Fischamend vor Korneuburg und Stockerau, wo 24,5% bzw. 33,5% „(fast) jeden Tag“ das Auto für Wege innerhalb der Stadtgemeinde verwenden. Das Zufußgehen hat in Fischamend eine ähnlich große Bedeutung wie in Stockerau. 41,4% der Befragten in Fischamend geben an, diese Mobilitätspraktik „(fast) jeden Tag“ auszuüben, in Stockerau sind es 39,8%. Spitzenreiter in dieser Kategorie ist Korneuburg mit 52,6%. Radfahren ist in Korneuburg und Stockerau ähnlich weit verbreitet, in Fischamend ist dies wiederum eine Fortbewegungsart, die nur wenig praktiziert wird. Nur 11,6% der Befragten benutzen das Fahrrad „(fast) jeden Tag“ und 20,9% „1 bis 3 Mal pro Woche“. In Stockerau im Vergleich wird das Fahrrad von den Befragten zu 24,2% „(fast) jeden Tag“ und zu 31,9% „1 bis 3 Mal pro Woche“ benutzt.

Die Teilnehmenden wurden auch befragt, welches Verkehrsmittel sie für welchen Zweck innerhalb der Stadtgemeinde präferieren. In Fischamend wird für Einkäufe des nicht-täglichen Bedarfs zu 62,8% der Pkw verwendet, gefolgt von Begleitwegen (andere Mitmenschen begleiten bzw. transportieren) mit 45,3%, Einkäufen des täglichen Bedarfs mit 44,2% und privaten Erledigungen mit 43,0%. Freizeitwege werden mehrheitlich zu Fuß oder mit dem Fahrrad erledigt. Vergleichbar damit zeigen sich die Zahlen für Einkäufe des nicht-täglichen Bedarfs und Begleitwege in Korneuburg und Stockerau. Ersteres liegt in Korneuburg bei 61,1% und in Stockerau bei 65,8%. Begleitwege werden in Korneuburg zu 41,9% mit dem Pkw absolviert

und in Stockerau zu 51,1%. Private Erledigungen und Einkäufe des täglichen Bedarfs werden in Korneuburg und Stockerau mehrheitlich zu Fuß oder mit dem Fahrrad erledigt. Dennoch ist zirka ein Drittel der Befragten auch hier innerhalb der Stadtgemeinde mit dem Pkw unterwegs. Für Freitzeitwege zeigt sich in beiden Städten ein ähnliches Bild wie in Fischamend. Genaure Details können in den NTN Factsheets Nummer 2a bis 2c nachgelesen weden (Braito et al., 2023a, 2023b, 2023c).

5.2.2 Mobilitätsprofile und ihre Verteilung in den Stadtgemeinden

Ein weiterer Fokus der Fragebogenerhebung lag auf der quantitativen Erhebung der bereits in der Q-Studie identifizierten Mobilitätsprofile. Abbildung 8 präsentiert die Verteilung der fünf Mobilitätsprofile (P1-P5) über die Stadtgemeinden hinweg. Der dunkle/dicke Balken zeigt die Häufigkeit der Mobilitätsprofile in der gesamten Stichprobe, die färbigen Balken zeigen die Ergebnisse der jeweiligen Städte. P4 „sicher und bedacht“ ist mit 23,1% insgesamt am häufigsten vertreten, gefolgt von P2 „zweckgebunden und pragmatisch“ mit 22,4%. An dritter Stelle kommt das Mobilitätsprofil P1 „gesund und bewusst“ (20,2%) und an vierter P3 „flexibel und reflektiert“ (18,8%). Die Einstellung von P5 „effizient und selbstbestimmt“ teilen 15,6% der Befragten.

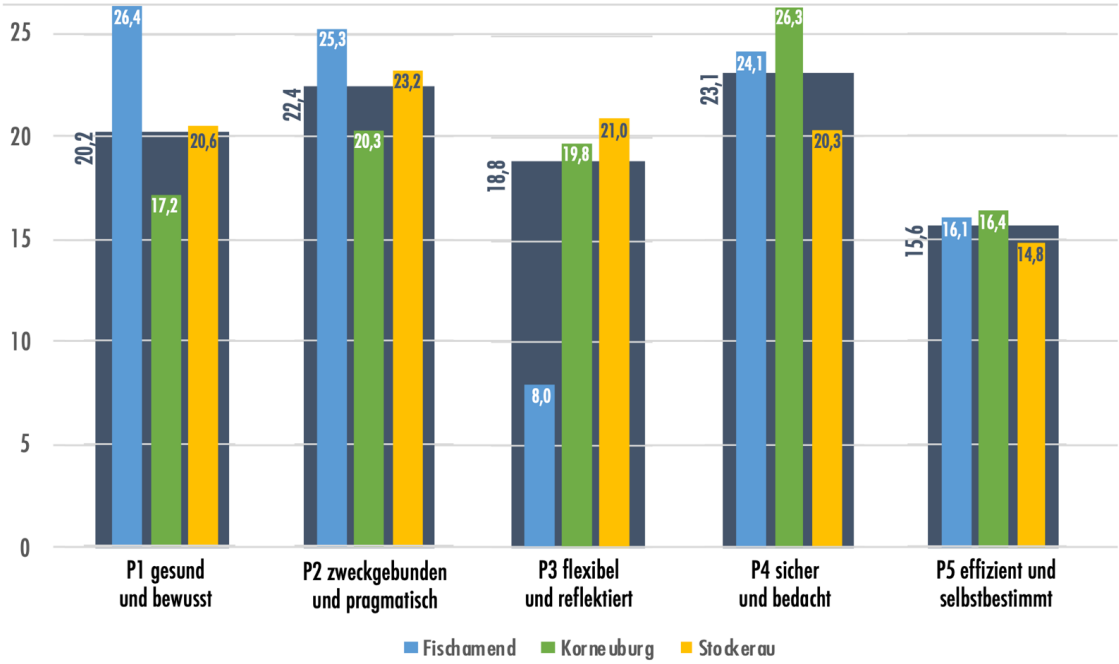


Abbildung 8: Die Verteilung der Mobilitätsprofile über die gesamte Stichprobe (dunkelblauer, dicker Balken, n = 629) und aufgeschlüsselt nach Städten (in %)

Betrachtet man die Verteilung der Profile in den verschiedenen Stadtgemeinden, so fällt vor allem auf, dass in Fischamend mit 26,4% die meisten Befragten das Einstellungsmuster P1 „gesund und bewusst“ teilen, was einem deutlich höheren Anteil entspricht als in den anderen Städten. Gleichzeitig ist in Fischamend P3 „flexibel und reflektiert“ signifikant weniger häufig vertreten. In Korneuburg ist P4 „sicher und bedacht“ mit 26,3% das am häufigsten vertretene Einstellungsmuster, in Stockerau mit 23,2% P2 „zweckgebunden und pragmatisch“.

5.2.3 Zusammenhänge zwischen Mobilitätsverhalten und Profilen am Beispiel Korneuburg

Die Abbildungen 10-12 zeigen, welche Art der Fortbewegung von welchem Mobilitätsprofil für welchen Wegzweck (tägliche Einkäufe, private Erledigungen, Erreichen des Bahnhofs) in Korneuburg bevorzugt wird. Es zeigt sich, dass alle Mobilitätsprofile alle Verkehrsmittel nutzen, aber dass es Unterschiede im Nutzungsgrad gibt. P2 sticht hier besonders heraus. Die täglichen Einkäufe (Abbildung 9) erledigen 59,6% der Personen mit diesem Einstellungsprofil mit dem kw, ebenso private Erledigungen (Abbildung 10) mit 59,6% und immerhin 29,8% der Fahrten zum Bahnhof (Abbildung 11). Andererseits sind Personen, die dieses Einstellungsprofil teilen, durchaus auch mit dem Rad oder zu Fuß innerhalb der Stadtgemeinde unterwegs. Personen, die dem P1 zugeordnet sind, erledigen ihre täglichen Einkäufe und privaten Erledigungen sowie ihre Fahrten zum Bahnhof zu einem hohen Prozentsatz mit umweltfreundlichen

Verkehrsmitteln. Trotzdem sind selbst diese Personen ab und zu noch mit dem Pkw innerhalb von Korneuburg unterwegs.

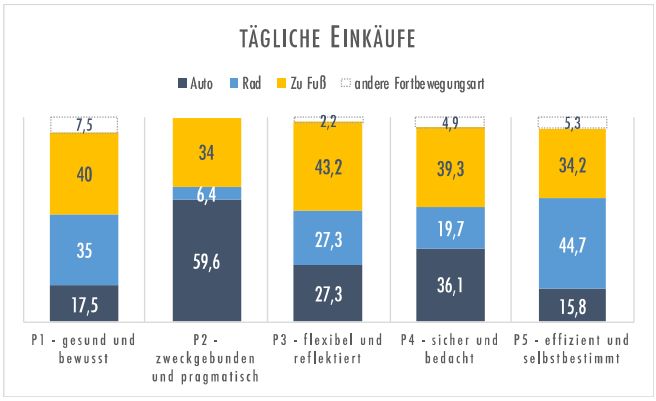


Abbildung 9: Wie erledigen Befragte in Korneuburg ihre täglichen Einkäufe? (prozentueller Anteil der Befragten des jeweiligen Profils, n = 232)

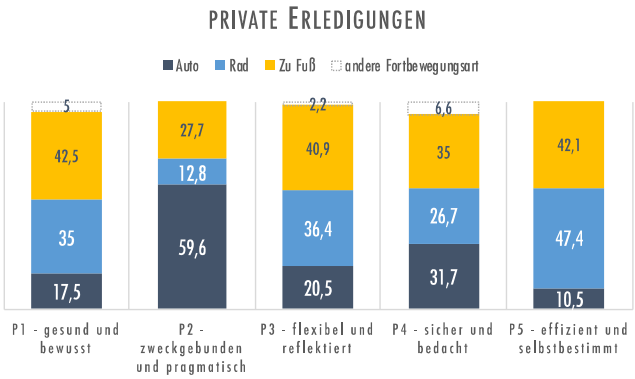


Abbildung 10: Wie erledigen Befragte in Korneuburg privaten Erledigungen? (prozentueller Anteil der Befragten des jeweiligen Profils, n = 232)

Der Weg zum Bahnhof wird in Korneuburg (Abbildung 11) vom Großteil der Befragten in allen Mobilitätsprofilen zu Fuß oder mit dem Fahrrad zurückgelegt. Ist das Ziel der Stadtgemeinde, die Fahrten mit dem Pkw zum Bahnhof noch mehr zu verringern, sind die Gruppen P2 und P4 diejenigen mit dem höchsten Veränderungspotential.

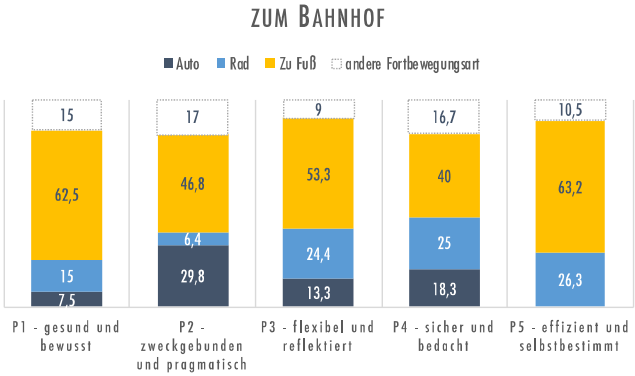


Abbildung 11: Wie kommen Befragte in Korneuburg zum Bahnhof? (prozentueller Anteil der Befragten des jeweiligen Profils, N = 232)

Die detaillierten Ergebnisse aus Fischamend (Braito et al. 2023a) und Stockerau (Braito et al. 2023c) weisen ähnliche Muster auf, wie die hier beschriebenen Zusammenhänge für Korneuburg. In Summe zeigen die Profile entlang der ausgewählten Wegzwecke nach wie vor die Dominanz des motorisierten Individualverkehrs. Gerade diese Wege sollten aber im Sinne einer nachhaltigen Mobilitätswende ersetzt bzw. verlagert werden. Die Verteilungen entlang der Profile weisen zudem darauf hin, dass vielfach Anknüpfungspunkte zur Veränderung gegeben sind. Wichtig ist dabei, dass diese Veränderungen die Bedürfnisse der einzelnen Profile auch berücksichtigen.

6 CONCLUSION

Diese Studie fördert das Verständnis der alltäglichen urbanen Mobilität, indem sie Mobilitätsperspektiven identifiziert und diese mit konkreten Verhaltensmustern und Motivationen verknüpft. Durch die Kombination der Q-Methodik mit einer Fragebogenerhebung konnten fünf empirisch fundierte Mobilitätsprofile entwickelt und validiert werden. Die fünf Profile, die emotionale, normative und instrumentelle Überlegungen miteinander verbinden, offenbaren spezifische Interpretationslogiken, die die Wahl des Verkehrsmittels leiten. In der Mobilität gibt es daher nicht den Radfahrer oder die Autofahrerin sondern Menschen mit unterschiedlichen Wünschen, Erwartungen und Bedürfnissen. Diese Personen lassen sich anhand einer Q-Studie sehr gut in Bedürfnis-Gruppen zusammen fassen und beschreiben.

In der Praxis erfordern die Ergebnisse politische Maßnahmen, die auf die Motivationsvielfalt und die sozio-materiellen Kontexte zugeschnitten sind. Bestehende oder neu entwickelte Maßnahmen zur Förderung nachhaltiger Mobilitätsformen können dahingehend bewertet werden, welche Profile sie insbesondere ansprechen, wobei jene Maßnahmen die größte Wirksamkeit versprechen, die mehrere Profile gleichzeitig ansprechen können, während andere Maßnahmen nur für einzelnen Profile Überzeugungskraft entfalten. Exemplarisch wurden vom Forschungsteam insgesamt 86 Maßnahmen zur Förderung nachhaltiger Mobilitätsformen in den drei beteiligten Stadtgemeinden gesammelt und geprüft, inwiefern diese den Einstellungen und Bedürfnissen der Mobilitätsprofile entsprechen (Scherhaufer et al., 2023). Es zeigte sich, dass Maßnahmen im Bereich Infrastruktur die größte Reichweite haben bzw. gleichzeitig mehrere Profile adressieren. Eine entsprechende attraktive Infrastruktur ist daher die zentrale Grundlage für eine nachhaltige Mobilität innerhalb von Städten oder Gemeinden. Jedoch müssen darüber hinaus auch zielgruppenspezifische Begleitmaßnahmen in den Bereichen Mobilitätsangebote, Bewusstseinsbildung, Partizipation und Handlungsanreize gesetzt werden. Diese Angebote sind oft auch einfacher und kostengünstiger umzusetzen. Die Ergebnisse zeigen aber auch auf, dass das Narrativ eines umweltfreundlichen Verhaltens nicht ausreichend sein wird, um breitere Bevölkerungsgruppen zu nachhaltigeren Mobilitätsentscheidungen zu motivieren. Daher braucht es in Summe einen umfassenden Maßnahmen-Mix, damit alle Perspektiven abgeholt und nachhaltige Mobilitätsmuster zur gesellschaftlichen Norm werden können.

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reviewed paper

Von Klimarisiken zu Planungsentscheidungen. Konzeptionelle Ansätze für geodatenbasierte Klimawandelanpassung, entwickelt im GreenGEO-Projekt

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1 ABSTRACT

Eine wirksame Anpassung an die Folgen des Klimawandels erfordert insbesondere auf Ebene der Raum- und Landschaftsplanung gezielte, umsetzungsorientierte Maßnahmen. Gemeinden verfügen mit Instrumenten wie dem örtlichen Entwicklungskonzept (ÖEK/REK), dem Flächenwidmungs- und dem Bebauungsplan über zentrale Hebel zur Steuerung von Landnutzung und gebauter Umwelt. Die koordinierte Planung und Umsetzung grün-blauer Infrastrukturen (GBI) gilt als wissenschaftlich anerkannte und effektive Strategie zur Minderung klimawandelbedingter Risiken wie sommerlicher Überhitzung, Starkniederschläge, Trockenheit und Biodiversitätsverlust. In der Planungspraxis bestehen jedoch nach wie vor erhebliche Unsicherheiten hinsichtlich Standortwahl, Wirksamkeit, Priorisierung und Quantifizierung der Effekte solcher Maßnahmen, insbesondere in kleineren Gemeinden mit begrenzten personellen und analytischen Ressourcen.Das Projekt GreenGEO, das sich aktuell in der Startphase befindet, adressiert diese Herausforderung gezielt. Aufbauend auf den Ergebnissen des Vorprojekts RaumGrün & Gemeinden verfolgt GreenGEO das Ziel, die bestehende Lücke zwischen der rasch wachsenden Verfügbarkeit klimarelevanter Geodaten und deren konkreter Nutzung in der örtlichen Raum- und Landschaftsplanung zu schließen. Entwickelt werden geodatenbasierte Algorithmen und Entscheidungsgrundlagen, die lokal verortete, objektivierbare und konsensbasierte Planungsvorschläge für effektive GBI liefern. Am Projektende soll der Funktionsnachweis eines webbasierten GIS-Tools erbracht werden, das Raumplanerinnen, Raumplaner, kommunale Entscheidungsträgerinnen und kommunale Entscheidungsträger bei der Auswahl, Bewertung und Umsetzung von standortspezifischen Klimawandelanpassungsmaßnahmen unterstützt.

Derzeit arbeitet das Projektkonsortium intensiv an folgenden Themen:

Im Arbeitspaket „GIS-Inputdaten und Risikozonierung“ (Leitung: AEE INTEC) werden aufbauend auf bestehenden Vorarbeiten verfügbare georeferenzierte Daten zu Klima, Klimawandelrisiken und vorhandener GBI aus unterschiedlichen Quellen recherchiert, bewertet, kombiniert und in einer gemeinsamen GIS-Plattform integriert. Der Fokus liegt auf der Analyse frei verfügbarer GIS-Daten, Satellitenbilder und Luftaufnahmen zur Identifikation klimarelevanter Risikozonen, insbesondere jener Risiken, die durch GBI adressiert werden können. Parallel dazu werden bestehende Datenlücken – etwa bei Straßenbegleitgrün, Verschattungswirkungen von Bäumen oder Versiegelungsgraden – systematisch identifiziert und Methoden zur Datenergänzung (z. B. Fernerkundung, Oberflächenmodelle) bewertet. Zentrales Ziel dieses Arbeitspakets ist die Entwicklung möglichst niederschwelliger, datenbasierter und gemeinsam mit Stakeholderinnen und Stakeholdern harmonisierter Indikatoren zur Ableitung lokaler Klimarisikozonen mit Handlungsbedarf.

Das Arbeitspaket „Effektive grün-blaue Anpassungsmaßnahmen in der Raumplanung“ (Leitung: B-NK) widmet sich der Frage, durch welche Instrumente der örtlichen Raum- und Landschaftsplanung die identifizierten Klimawandelrisiken wirksam adressiert werden können. Auf Basis einer umfassenden Desktop-Recherche und einer strukturierten Datenanalyse werden Risiken, Anpassungspotenziale und relevante planerische Merkmale von GBIsidentifiziert und geclustert. Darauf aufbauend entsteht ein

Maßnahmenkatalog sowie eine Risiko- und Maßnahmenmatrix, die unterschiedliche Anpassungsoptionen vergleichbar macht und Priorisierungsaspekte wie Kosten, Umsetzungsdauer, Wirksamkeit, Zielkonflikte, soziale Effekte sowie Lebenszyklusbetrachtungen berücksichtigt. Die Bewertung und Validierung erfolgt in engem Austausch mit Expertinnen, Experten und Interessenvertretungen.

Im Arbeitspaket „Datenbasierte Planungsalgorithmen für Klimawandelanpassungsmaßnahmen“ (Leitung: Universität Graz) werden auf Basis dieser Ergebnisse Datenmodelle entwickelt, die lokalisierte Risikozonen automatisiert mit geeigneten GBI-Maßnahmen verknüpfen. Ein Decision-Tree-Ansatz verknüpft GIS-Methoden, Datenclustering sowie mathematisch-statistische Verfahren und ermöglicht die robuste Kombination kontinuierlicher und kategorialer Variablen. Iterative Stakeholder-Feedback-Schleifen sichern Benutzungsfreundlichkeit, Praxisrelevanz und die nahtlose Einbindung in kommunale Raumplanungsinstrumente.

GreenGEO macht die wachsende Zahl an Geodaten für eine praxisnahe Klimawandelanpassung nutzbar, fördert den Wissenstransfer zu kommunalen Entscheidungsträgerinnen und Entscheidungsträgern und unterstützt eine systemische Weiterentwicklungösterreichischer Raumplanung hin zum klimaresilienten, nachhaltigen Orts- und Stadtumbau.

Keywords: WebGIS, Klimarisiken, Raumplanung, Bewertung, Planung

2 ENGLISH ABSTRACT

Effective adaptation to the impacts of climate change requires targeted and implementation-oriented measures, particularly at the level of spatial and landscape planning. Municipalities possess key instruments for steering land use and the built environment, such as local development concepts, land-use plans and zoning plans. The coordinated planning and implementation of green-blue infrastructure (GBI) is widely recognised in the scientific literature as an effective strategy for mitigating climate-related risks such as summer heat stress, heavy rainfall, drought and biodiversity loss. In planning practice, however, significant uncertainties remain with regard to site selection, effectiveness, prioritisation and the quantification of impacts of such measures, particularly in smaller municipalities with limited personnel and analytical resources.

The GreenGEO project, which is currently in its initial phase, directly addresses this challenge. Building on the results of the predecessor project “RaumGrün & Gemeinden”, GreenGEO aims to close the existing gap between the rapidly growing availability of climate-relevant geospatial data and their concrete application in local spatial and landscape planning. To this end, geodata-based algorithms and decision-support frameworks are being developed that provide locally grounded, objective and consensus-based planning recommendations for effective green-blue infrastructure. By the end of the project, a functional proof of a web-based GIS tool is to be delivered, supporting spatial planners and municipal decision-makers in the selection, evaluation and implementation of site-specific climate change adaptation measures.

At present, the project consortium is intensively working on the following thematic areas:

Within the work package “GIS Input Data and Risk Zoning” (lead: AEE INTEC), available georeferenced data on climate, climate change risks and existing green-blue infrastructure from various sources are reviewed, assessed, combined and integrated into a shared GIS platform, building on previous preparatory work. The focus lies on the analysis of freely available GIS data, satellite imagery and aerial photographs to identify climate-relevant risk zones, particularly those risks that can be addressed through green-blue infrastructure. In parallel, existing data gaps – such as information on roadside greenery, shading effects of trees or degrees of soil sealing – are systematically identified, and methods for data enhancement (e.g. remote sensing, surface models) are evaluated. The central objective of this work package is the development of low-threshold, data-driven and jointly harmonised indicators for deriving local climate risk zones with a need for action.

The work package “Effective Green-Blue Adaptation Measures in Spatial Planning” (lead: B-NK) addresses the question of how identified climate change risks can be effectively tackled through instruments of local spatial and landscape planning. Based on a comprehensive desktop review and structured data analysis, risks, adaptation potentials and relevant planning characteristics of green-blue infrastructure are identified and clustered. Building on this, a catalogue of measures as well as a risk–measure matrix is developed, enabling the comparison of different adaptation options while considering prioritisation aspects such as costs,

implementation timeframes, effectiveness, potential conflicts of objectives, social effects and life-cycle considerations. The assessment and validation are carried out in close exchange with experts and stakeholder representatives.

In the work package "Data-Based Planning Algorithms for Climate Change Adaptation Measures" (lead: University of Graz), data models are developed on the basis of these results to automatically link localised risk zones with suitable green-blue infrastructure measures. A decision-tree approach combines GIS methods, data clustering and mathematical-statistical techniques, enabling a robust integration of continuous and categorical variables. Iterative stakeholder feedback loops ensure user-friendliness, practical relevance and seamless integration into municipal spatial planning instruments.

GreenGEO makes the growing volume of geospatial data usable for practice-oriented climate change adaptation, promotes knowledge transfer to municipal decision-makers and supports the systemic advancement of Austrian spatial planning towards climate-resilient and sustainable urban and local development.

3 AUSGANGSLAGE

Der Klimawandel stellt eine der zentralen gesellschaftlichen und planerischen Herausforderungen des 21. Jahrhunderts dar. Seine Auswirkungen sind längst nicht mehr nur als langfristige Zukunftsszenarien zu verstehen, sondern prägen bereits heute den Alltag von Städten und Gemeinden. Zunehmende Hitzewellen, veränderte Niederschlagsmuster, häufigere Starkregenereignisse sowie längere Trockenperioden führen zu erheblichen Belastungen für Siedlungsräume, Infrastrukturen und die Gesundheit der Bevölkerung. Besonders betroffen sind dicht bebaute Gebiete, in denen hohe Versiegelungsgrade und der Verlust vegetationsreicher Flächen die negativen Effekte des Klimawandels zusätzlich verstärken(APCC 2025).

Parallel zu diesen klimatischen Veränderungen hat sich in den letzten Jahren die freie Verfügbarkeit klimarisikorelevanter Geodaten deutlich erhöht Satellitendaten, Fernerkundungsprodukte, nationale Klimamodelle sowie thematische Geodatensätze zu Boden, Landnutzung, Vegetation oder hydrologischen Risiken stehen in wachsendem Umfang zur Verfügung (Ching et al. 2018; European Parliament and Council 2007).All diese Daten bieten grundsätzlich ein großes Potenzial, klimatische Risiken differenziert zu analysieren und räumlich zu verorten. In der kommunalen Planungspraxis bleibt dieses vorhandene Potenzial jedoch häufig ungenutzt. Gründe dafür liegen in der fehlenden Aufbereitung der Daten für planerische Fragestellungen, in mangelnder Vergleichbarkeit, in Unsicherheiten bezüglich Aussagekraft und Relevanz einzelner Indikatoren sowie in begrenzten personellen Ressourcen innerhalb der Gemeinden.

Die Rolle von GBI als zentrale Maßnahme der Klimawandelanpassung gewinnt gleichzeitig ebenfalls zunehmend an Bedeutung. Wissenschaftliche Studien belegen ihre vielfältigen positiven Wirkungen, etwa durch die Reduktion von Hitzebelastung, die Verbesserung des lokalen Wasserhaushalts, die Förderung der Biodiversität sowie die Steigerung der Aufenthaltsqualität im öffentlichen Raum(Almaaitah et al. 2021). Trotz dieses Wissens werden entsprechende Maßnahmen in der Raum- und Landschaftsplanung häufig nicht systematisch berücksichtigt oder bleiben auf einzelne Pilotprojekte beschränkt. In vielen Fällen fehlt es an belastbaren Entscheidungsgrundlagen, die es ermöglichen, Maßnahmen räumlich gezielt zu priorisieren und ihre Wirksamkeit nachvollziehbar zu begründen.

Vor diesem Hintergrund setzt das Projekt GreenGEO an. Es reagiert auf die wachsende Diskrepanz zwischen der verfügbaren Datenmenge zu klimarelevanten Fragestellungen und deren tatsächlicher Nutzung in der örtlichen Raum- und Landschaftsplanung. Ziel ist es, diese Daten nicht nur sichtbar zu machen, sondern sie in eine strukturierte, planerisch anschlussfähige Logik zu überführen. Das Projekt versteht sich dabei nicht als rein technisches Entwicklungsprojekt, sondern als integrativer Ansatz, der technische, planerische und governancebezogene Fragestellungen miteinander verbindet. Durch die Entwicklung harmonisierter Indikatoren, datenbasierter Planungsalgorithmen und eines webbasierten GIS-Tools sollen Gemeinden dabei unterstützt werden, Klimarisiken zu erkennen und darauf aufbauend geeignete Klimawandelanpassungsmaßnahmen umzusetzen.

Die Dringlichkeit dieses Ansatzes ergibt sich nicht zuletzt aus den aktuellen klimapolitischen Zielsetzungen auf europäischer und nationaler Ebene, die eine rasche und wirksame Umsetzung von Klimawandelanpassungsmaßnahmen erfordern (BMNT 2017). So beschreibt die EU-Strategie für grüne Infrastruktur ökosystembasierte Ansätze als eines der am weitesten verbreiteten, wirtschaftlich tragfähigen

und wirksamen Instrumente zur Bewältigung der Auswirkungen des Klimawandels und empfiehlt deren Anwendung ausdrücklich als Standard in der Raum- und Landschaftsplanung(EU Kommission 2013). Raum- und Landschaftsplanung nimmt hierbei also eine Schlüsselrolle ein, da sie langfristige Entscheidungen über Landnutzung, Bebauung und Freiraumgestaltung trifft. In der aktualisierten EU-Klimawandelanpassungsstrategie wird der zunehmende Bedarf, „die Fülle der verfügbaren Klimainformationen in maßgeschneiderte, benutzerfreundliche Instrumente zu übersetzen" festgestellt(EU Kommission 2021). GreenGEO greift diesen Handlungsbedarf auf und leistet einen Beitrag zur Weiterentwicklung einer datenbasierten, klimaresilienten Planungspraxis, die sowohl fachlich fundiert als auch für kommunale Entscheidungsträgerinnen und Entscheidungsträger praktikabel ist.

4 VORPROJEKTE

Das Projekt GreenGEO baut inhaltlich und methodisch auf zwei vorgelagerten Forschungsprojekten auf, die sich mit der Rolle der Begrünung und Klimawandelanpassung in der österreichischen Raumplanung bereits tiefgehend befasst haben. Diese Vorprojekte bilden die konzeptionelle, rechtliche und datenbasierte Grundlage für die im Rahmen von GreenGEO vorgesehenen Weiterentwicklungen.

Die Vorstudie „Raum & Grün – Möglichkeiten zur Integration von Begrünung ins Regelwerk der österreichischen Raumordnung“ (FFG Nr. 4121976) wurde im Zeitraum von 2021 bis 2022 durchgeführt. Ziel dieses Projekts war es, zu analysieren, in welcher Form GBIs in das bestehende Regelwerk der österreichischen Raumordnung integriert werden können. Im Fokus standen dabei die rechtlichen und institutionellen Rahmenbedingungen auf Bundes-, Landes- und Gemeindeebene. Durch eine umfassende Dokumentenanalyse zu vorhandenen Strategien, Regelungen und innovativen Fallbeispielen sowie durch den Einbezug von Fachleuten aus Raumplanung, Verwaltung und Forschung wurden bestehende Barrieren identifiziert und Handlungsspielräume aufgezeigt. Das Projekt entwickelte konkrete Empfehlungen, Textbausteine und strategische Ansätze, wie innovative Begrünungsmaßnahmen, insbesondere Bauwerksbegrünungen, verbindlicher in Instrumente wie Raumordnungsgesetze, Bebauungspläne oder privatrechtliche Vereinbarungen verankert werden können. Raum & Grün lieferte so eine rechtlich-planerische Basis, zeigte jedoch auch, dass für die praktische Umsetzung auf Gemeindeebene zusätzliche Werkzeuge und datenbasierte Entscheidungsgrundlagen erforderlich sind(Knoll et al. 2022).

Aufbauend auf diesen Erkenntnissen wurde das Folgeprojekt „RaumGrün & Gemeinden – Pilottest: Begrünung als integraler Bestandteil der örtlichen Raumplanung in Österreich“ (FFG Nr. 4781907) im Zeitraum von 2022 bis 2025 umgesetzt. Das Projekt verlagerte den Fokus von der primär normativen Ebene stärker in die kommunale Planungspraxis. Ziel war es, Begrünung und Klimawandelanpassung als integralen Bestandteil der örtlichen Raumplanung konkret anwendbar zu machen. In Zusammenarbeit mit drei raumtypologisch unterschiedlichen Pilotgemeinden wurden datenbasierte Methoden zur Identifikation lokaler Klimarisiken entwickelt und in einer WebGIS-Applikation zusammengeführt. Diese Plattform ermöglichte den zentralen Zugriff auf Grundkarten, aktuelle Klimadaten, Klimaprojektionen sowie bestehende Risikokarten und stellte damit neue Grundlagen für gemeindespezifische Planungsentscheidungen dar. Zudem wurde ein neuer, niederschwelliger Ansatz für die datenbasierte Identifikation von Hitzerisikozonen in Form des Heat Factor Austria entwickelt. Die Risikoeinschätzung basiert dabei auf dem lokalen Verhältnisvon Hitze- bzw. Kühlbeitragsflächen auf Basis der Landnutzungen. Die WebGIS-Applikation einschließlich der Darstellung des Heat Factor Austria ist in Abbildung 1 dargestellt.

Darüber hinaus wurde im Projekt ein prototypisches Planungsinstrumentarium erarbeitet, das Klimarisikozonen mit konkreten Maßnahmenempfehlungen verknüpfte und diese den Instrumenten der örtlichen Raumplanung zuordnete. Ein zentraler Mehrwert des Projekts lag in der engen Einbindung von politischen und fachlichen Entscheidungsträgerinnen und Entscheidungsträgern aus den Pilotgemeinden sowie von weiteren Stakeholdern auf Landesebene. Dadurch konnten die entwickelten Werkzeuge hinsichtlich Praxistauglichkeit, Verständlichkeit und Umsetzbarkeit überprüft und weiterentwickelt werden (Knoll et al. 2025).

GreenGEO knüpft direkt an diese Vorarbeiten an. Während Raum & Grün den rechtlich-strategischen

Rahmen analysierte und RaumGrün & Gemeinden erste datenbasierte Werkzeuge für die kommunale Praxis bereitstellte, liegt der Schwerpunkt von GreenGEO auf der Vertiefung, Harmonisierung und algorithmischen

Verknüpfung klimarelevanter Geodaten mit planerischen Maßnahmen. Ziel ist es, die im Vorgängerprojekt identifizierten Ansätze weiter zu präzisieren, österreichweit anschlussfähig zu machen und durch transparente, reproduzierbare Entscheidungslogiken zu ergänzen. Damit wird eine Brücke geschlagen zwischen strategischen Zielsetzungen, datenbasierter Analyse und konkreter planerischer Umsetzung.



Abbildung 1: Prototypische WebGIS Applikation aus dem Projekt RaumGrün& Gemeinden mit dem Heat Factor Austria – Veranschaulichung der Risikozonen in einer Pilotgemeinde(Andreas Stöger, AEE INTEC)

5 GEODATENBASIERTE ABLEITUNG LOKALER KLIMARISIKOZONEN

Klimarisiken in Siedlungsräumen müssen im ersten Schritt identifiziert und lokalisiert werden, um eine vorausschauende Raum- und Landschaftsplanung zu ermöglichen. Lokale Klimarisiken treten häufig kleinräumig auf. Eine isolierte Betrachtung der einzelnen Gefahren greift zu kurz, da sich klimatische Belastungen häufig überlagern und auch gegenseitig verstärken können. Vor diesem Hintergrund gewinnt eine integrierte geodatenbasierte Risikozonierung zunehmend an Bedeutung.

Methodisch werden ausgewählte georeferenzierte Satellitendaten und terrestrische Daten miteinander kombiniert, um die erforderlichen Informationen zu generieren und Zonen mit Handlungsbedarf zu identifizieren.Maßgebliche räumliche Einflussgrößen wie Versiegelungsgrad, Flächennutzung, Vegetationsstruktur, Topografie, Bodenbeschaffenheit und hydrologische Rahmenbedingungen werden systematisch zusammengeführt. Der gezielte Einsatz offener Datenquellen ermöglicht eine transparente, reproduzierbare und breit anwendbare Analyse und stellt zugleich die Anschlussfähigkeit an kommunale Planungsprozesse sicher.

Für den österreichischen Kontext stehen zahlreiche offene Datensätze zur Verfügung, die eine differenzierte Abbildung klimarelevanter Gefährdungen erlauben. Dazu zählen unter anderem Überflutungsflächen unterschiedlicher Wiederkehrintervalle, Informationen zu gravitativen und hydrologischen Prozessen, hydrologische Einzugsgebiete, digitale Höhenmodelle sowie Daten zur Landbedeckungund Bodenversiegelung,wie BEV Land Cover. Diese Datensätze weisen eine hohe planerische Relevanz auf, unterscheiden sich jedoch hinsichtlich ihrer räumlichen Auflösung und Aktualität.

Das österreichische Bundesamt für Eich- und Vermessungswesen (BEV) veröffentlichte im Dezember 2024 den ersten flächendeckenden, hochauflösenden BEV Land Cover Datensatz für das gesamte Bundesgebiet. Der Datensatz enthält eine österreichweit homogene Klassifizierung von Informationen zur Bodenbedeckung und ermöglicht eine detaillierte Einteilung in sechs Bodenbedeckungsklassen: Hohe, mittlere und niedrige Vegetation, Gebäude, Bodenflächen und Gewässer.[1]

Ergänzend zu amtlichen Geodaten spielen frei verfügbare Satellitendaten eine zentrale Rolle bei der Analyse klimarelevanter Einflussfaktoren. NASA Landsat liefert seit 1972 ununterbrochene Aufzeichnungen über die

[1] https://www.bev.gv.at/Services/Produkte/Land-Cover/Land-Cover.html

Landbedeckung der Erde. Seine unterstützende Rolle für die Stadtplanung wurde bereits veröffentlicht (Landsat Science 2021). Das europäische Copernicus-Erdbeobachtungsprogramm nutzt reale und Modellierungsdaten für die Naturraumüberwachung, Atmosphären- und Klimamonitoring und Krisenmanagement bei Naturkatastrophen (Demuzere et al. 2022). Die vergleichsweise hohe Aufnahmefrequenz satellitengenerierter Datensätze ermöglicht es, Klimarisiken nicht nur statisch zu erfassen, sondern auch zeitliche Veränderungen und Entwicklungstendenzen abzubilden. Die Kombination multispektraler, thermaler und radargestützter Sensoren ermöglicht eine differenzierte Analyse von Prozessen wie Verdunstung, Wärmeabstrahlung oder Wasserverfügbarkeit, die die Bewertung klimatischer Risiken im Siedlungsraum unterstützen (Coutts et al. 2016).



Abbildung 2: Weiterentwicklung der prototypischen WebGIS-Applikation mit dem bearbeiteten InVEKoS-Datensatz.[2] Dauergrüne und saisonal begrünte landwirtschaftlich genutzte Flächen können nun unterschieden werden, um bessere Aussagen zum lokalen Hitzerisiko treffen zu können.(Andreas Stöger, AEE INTEC, 2025)

Ein wesentlicher Mehrwert der integrierten, georeferenzierten Datennutzung liegtin der Identifikation räumlicher Schwerpunkte, in denen mehrere klimatische Belastungen zusammenwirken. Solche Mehrfachbelastungen treten insbesondere in dicht bebauten Siedlungsräumen auf, in denen hohe Versiegelungsgrade, geringe Vegetationsanteile und eingeschränkte Versickerung bzw. Wasserretention zusammentreffen. In der Planungspraxis müssen derzeit jedoch Informationen aus vielen unterschiedlichen Quellen manuell überlagert und fachlich interpretiert werden, um daraus standortbezogene Handlungsempfehlungen abzuleiten. Eine integrierte, GIS-gestützte Ableitung lokaler Klimarisikozonen stellt daher einen wesentlichen Schritt dar, um die vorhandene Datenbasis gezielt für planerische Entscheidungsprozesse nutzbar zu machen.

Nach der sorgfältigen Harmonisierung der Datenquellen hinsichtlich räumlicher Auflösung und zeitlicher Abdeckungwerden neu entwickelte Algorithmen zu deren Kombination angewendet, umdetaillierte Aussagen zu vorhandener GBIzu treffen und Risikozonen für spezifische Klimarisiken abzuleiten. Diese Informationen sind dann für jede Gemeinde und Adresse in einem Dashboard abrufbar. Sie bilden die Grundlage für Planungsentscheidungen und ermöglichen Vergleiche zwischen frei gewählten Betrachtungsbereichen.

6 EFFEKTIVE GRÜN-BLAUE ANPASSUNGSMASSNAHMEN IN DER RAUM- UNDLANDSCHAFTSPLANUNG

Die wirksame Anpassung an klimawandelbedingte Belastungen im Siedlungsraum erfordert Maßnahmen, die nicht nur ökologisch effektiv, sondern auch planerisch umsetzbar und rechtlich verankerbar sind. Grün-blaue

[2] Integriertes Verwaltungs- und Kontrollsystem zur Umsetzung und Administration der einheitlichen gemeinsamen Agrarpolitik der EU-Länder.

Infrastrukturen haben sich in den letzten Jahren als zentrales Instrument zur Minderung klimatischer Risiken und zur Stärkung ökologischer Funktionen etabliert. Gleichzeitig zeigt sich, dass GBI-Maßnahmen ihren größten Beitrag dann leisten, wenn sie nicht punktuell, sondern im Rahmen eines koordinierten räumlichen Ansatzes umgesetzt werden.

Grün-blaue Anpassungsmaßnahmen umfassen ein breites Spektrum vegetations- und wasserbezogener Interventionen, die gezielt natürliche Prozesse nutzen, um klimatische Belastungen zu mindern und gleichzeitig Biodiversität, Gesundheit und Lebensqualität im Siedlungsraum zu fördern. Dazu zählen unter anderem Entsiegelungsmaßnahmen, Baumpflanzungen, die Qualifizierung öffentlicher Grün- und Freiräume, Dach- und Fassadenbegrünungen, Versickerungs- und Retentionsflächen sowie die ökologische Aufwertung von Gewässerstrukturen. Ihre Wirkung beruht auf gut etablierten Mechanismen wie Verschattung, Verdunstung, Temperaturausgleich, Regenwasserrückhalt und verzögerter Abflussbildung (Tran & Hoang 2025). Für die Raum- und Landschaftsplanung ist jedoch entscheidend, dass diese Maßnahmen standortspezifisch betrachtet werden. Die konkrete Wirksamkeit grün-blauer Anpassungsmaßnahmen entfaltet sich in Abhängigkeit vom räumlichen Kontext, etwa von Bebauungsdichte, Versiegelungsgrad, vorhandener Vegetation, topografischer Lage oder funktionaler Nutzung. Daraus ergibt sich die Notwendigkeit, Maßnahmen standortbezogen einzuordnen und zu priorisieren, um ihre Wirkung gezielt dort zu entfalten, wo sie einen hohen Beitrag zur Minderung der Klimawandelrisiken leisten können(Reinwald et al., 2023).

Die systematische Zusammenstellung grün-blauer Anpassungsmaßnahmen im Projekt ermöglicht deren vergleichende Bewertung und transparente Zuordnung zu spezifischen räumlichen Situationen (van de Ven et al. 2016). Sie basiert auf wissenschaftlicher Evidenz und planerischer Erfahrung und berücksichtigt zentrale Kriterien wie Wirksamkeit, Kosten, Umsetzbarkeit, Zielkonflikte sowie Pflege- und Nutzungsperspektiven als Grundlage für die Priorisierung von Anpassungsoptionen im Siedlungsraum.

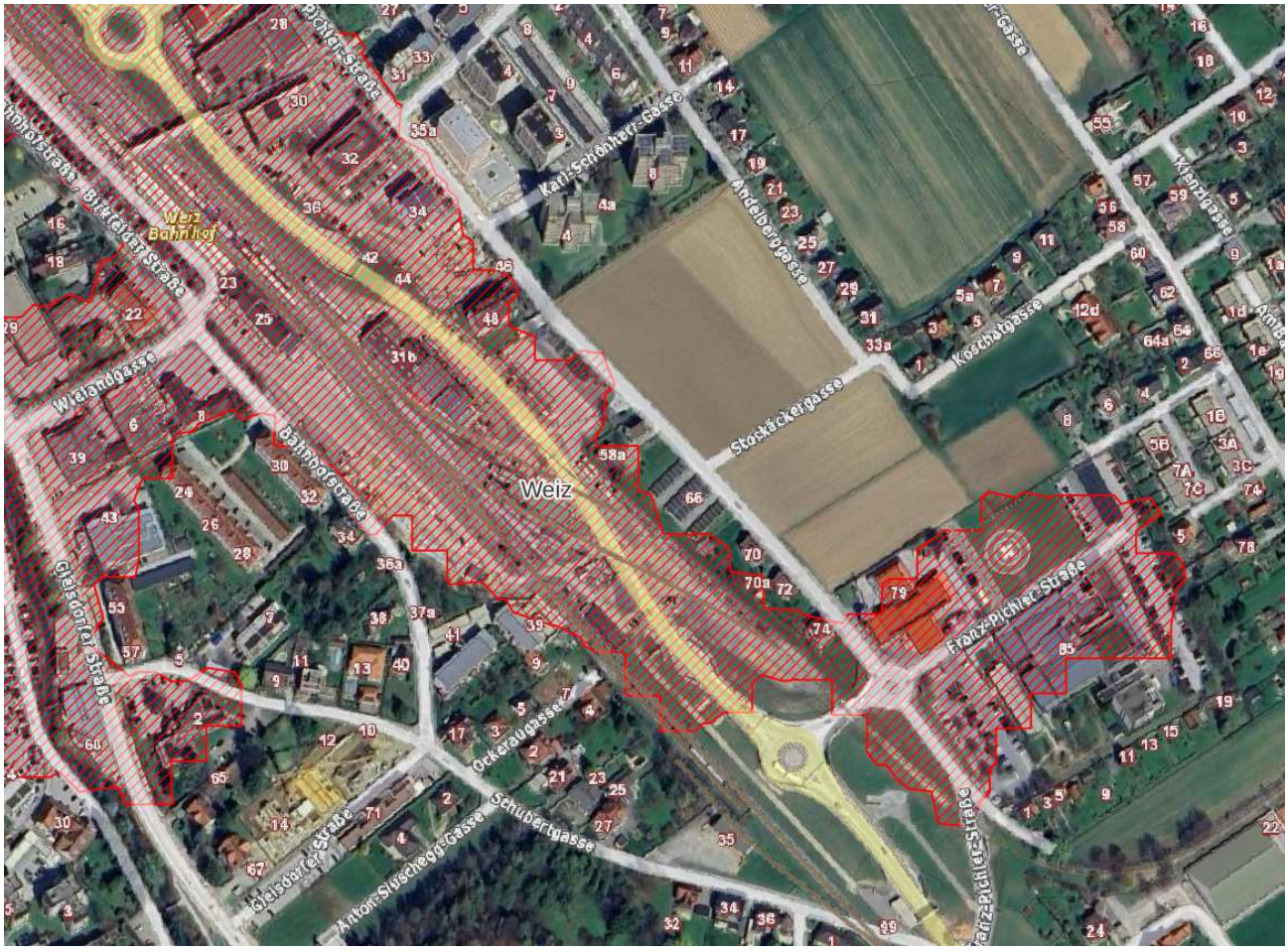


Abbildung 3: Beispielhafte Darstellung einesBereichs einer möglichenTransformationsfläche in Weiz (Markus Karner, RaumRegionMensch, 2026)

Ein Fokus liegt zudem auf der Zuordnung der unterschiedlichen grün-blauen Anpassungsmaßnahmen zu den Instrumenten der örtlichen Raum- und Landschaftsplanung. Diese Zuordnung ermöglicht es, denWeg in die Umsetzung zu strukturieren. Die Maßnahmenmatrix fungiert damit als Schnittstelle zwischen datenbasierter Risikobetrachtung und der operativen Anwendung der Instrumente der örtlichen Raum- und Landschaftsplanung.

Die Zuordnung der Maßnahmen erfolgt dabei zu folgenden Ebenen: Das Örtliche Entwicklungskonzept bzw. das Räumliche Entwicklungskonzept, in dem langfristige Zielsetzungen zur Siedlungsentwicklung, Freiraumstruktur und Klimawandelanpassung festgelegt werden,der Flächenwidmungsplan, der die Möglichkeit bietet, Nutzungen räumlich zu steuern und Flächen für GBIs zu sichern oder klimaangepasste Nutzungsformen festzulegen. Der Bebauungsplan erlaubt eine parzellenscharfe Konkretisierung, etwa durch Vorgaben zu Begrünungsanteilen, Versiegelungsgrenzen oder zur Ausgestaltung von Frei- und Zwischenräumen. Ergänzend eröffnet die Vertragsraumordnung zusätzliche Handlungsspielräume, um GBIs auch auf privatem Grund verbindlich umzusetzen.

fid	Risikozone	Instrument	Widmungsstatus	Eigentumsstatus	Maßnahme
6	HTL, HW, ER	BBPL	BLB, BLU	P, G, OE	Festlegung eines maximalen Versiegelungsgrades
11	HTL, HW, ER	BBPL	BLU	P, G, OE	Festlegung von versiegelungsfreien Freiflächen innerhalb großer Baulandflächen
21	HTL, HW	BBPL	BLB, BLU, VF	P, G, OE	Die Versickerung von Oberflächenwässern ist auf Eigengrund zu gewährleisten.
29	HTL	BBPL	BLU, BLB	P, G, OE	Vorschreibung von Dach- und/oder Fassadenbegrünung
30	HTL	BBPL	BLU, GL	P, G, OE	Festlegung eines Grünflächenanteils (inkl. Vorgaben für gärtnerische Ausgestaltung)
40	HTL, HW, ST, ER	BBPL	BLU, BLB	P, G	Bebauungsfreie Zonen festlegen
51	HTL	BBPL	BLU	P, G, OE	Vorschreibung eines verpflichtenden Bepflanzungskonzepts für Mehrfamilienhäuser (inkl. Monitoring)

Tabelle 1: Maßnahmenliste auf Ebene des Bebauungsplans für den in Abbildung 3 dargestellten Transformationsbereich.

Neben formellen Planungsinstrumenten kommt begleitenden Maßnahmen eine zentrale Rolle in der Umsetzung grün-blauer Anpassungsstrategien zu. Raum- und Landschaftsplanung ist nicht ausschließlich ein technischer Steuerungsprozess, sondern ein sozialer und politischer Aushandlungsprozess, der im alltäglichen Lebensraum der Bevölkerung wirksam wird. Klimawandelanpassung erfordert daher Maßnahmen, die über rechtliche Festlegungen hinausgehen und den Dialog zwischen Verwaltung, Politik und Gesellschaft aktiv unterstützen.

Begleitende Maßnahmen umfassen unter anderem Informations- und Kommunikationsangebote, sichtbare Interventionen im öffentlichen Raum, Beteiligungs- und Dialogformate sowie die Zusammenarbeit mit lokalen Akteurinnen und Akteuren. Sie tragen dazu bei, Klimawandelanpassung im Alltag erfahrbar zu machen, lokales Wissen in Planungsprozesse einzubinden und Akzeptanz für langfristige Veränderungen zu schaffen. Ebenso wichtig ist der Aufbau kommunikativer Strukturen innerhalb der Gemeinden, etwa durch klare Ansprechpersonen, kontinuierliche Informationsformate und niederschwellige Rückmeldemöglich-keiten. In ihrer Gesamtheit stärken solche Maßnahmen die Schnittstelle zwischen Planung und Umsetzung und erhöhen die Wirksamkeit von GBIs im Siedlungsraum.

7 DATENBASIERTEPLANUNGSALGORITHMEN FÜR KLIMAWANDEL-ANPASSUNGS-MASSNAHMEN

Datenbasierte Planungsalgorithmen bilden die verbindende Ebene zwischen räumlich differenzierter Klimarisikoanalyse und der Anwendung von GBIs in der örtlichen Raum- und Landschaftsplanung. Ihr Beitrag liegt darin, heterogene Informationen systematisch zu verknüpfen und in eine strukturierte Entscheidungslogik zu überführen, die planerisch interpretierbar und unmittelbar nutzbar ist. Damit wird es möglich, die Auswahl und Priorisierung von Anpassungsmaßnahmen nicht ausschließlich qualitativ oder subjektiv erfahrungsbasiert vorzunehmen, sondern auf einer konsistenten, reproduzierbaren Entscheidungslogik aufzubauen (Roest et al. 2023). Der Vorteil dieses Ansatzes liegt in seiner Transparenz: Entscheidungswege sind explizit nachvollziehbar und können fachlich überprüft, angepasst und weiterentwickelt werden.

Im Mittelpunkt stehen Datenmodelle, die lokalisierte Klimarisikozonen automatisiert mit geeigneten, nach anzuwendendem Planungsinstrument kategorisierten GBIs in Beziehung setzen. Diese Modelle integrieren unterschiedliche Datentypen, darunter kontinuierliche Variablen wie Versiegelungsgrad, Oberflächentemperatur oder Abflussneigung sowie kategoriale Informationen wie Flächennutzungen, Schutzkategorien oder planungsrechtliche Festlegungen. Durch diese Kombination können komplexe Konstellationen abgebildet werden, die in manuellen Planungsprozessen nur eingeschränkt systematisch erfassbar sind.Durch die Integration gewichteter Bewertungsparameter wie Wirksamkeit, Umsetzbarkeit, Kosten, potenzielle Zielkonflikte oder soziale Effekte können Maßnahmen zudem in Relation zueinander gesetzt werden. Dadurch entsteht eine priorisierte Auswahl von Anpassungsoptionen, die standortspezifische Anforderungen ebenso berücksichtigt wie planerische Rahmenbedingungen. Die algorithmische Struktur ersetzt dabei keine planerischen Entscheidungen, sondern schafft eine konsistente Grundlage für fundierte Abwägungen.

Die Ergebnisse der algorithmischen Verknüpfung sind so ausgestaltet, dass sie direkt an die Instrumente der örtlichen Raum- und Landschaftsplanung anschließen. Maßnahmenempfehlungen werden räumlich verortet und den jeweiligen Planungsebenen zugeordnet, etwa dem Örtlichen Entwicklungskonzept beziehungsweise Räumlichen Entwicklungskonzept, dem Flächenwidmungsplan, dem Bebauungsplan oder der Vertragsraumordnung. Dadurch wird frühzeitig sichtbar, welche planungsrechtlichen Schritte mit ihrer Umsetzung verbunden sind.

Projektziel ist die Entwicklung geodatenbasierter Algorithmen für lokal verortete Planungsvorschläge zu effektiven GBIs als Anpassungsmaßnahmen an den Klimawandel mit Fokus auf der örtlichen Raumplanung. Am Projektende soll der Funktionsnachweis für ein WebGIS-basiertes Visualisierungstool erbracht werden, das eine spezifische, geodaten- und konsensbasierte Entscheidungsunterstützung bei der Umsetzung von GBIs für lokale Raumplanungsbehörden Entscheidungsträgerinnen und Entscheidungsträger bietet. Als Ergebnis des Projekts wird zunächst eine deutlich vertiefte und konsolidierte Datengrundlage zur klimabezogenen Risikozonenberechnung und -ausweisung erwartet, wobei ein besonderer Schwerpunkt auf der systematischen Nutzung und Einbindung von Satellitendaten liegt. Diese werden mit bestehenden, georeferenzierten Informationen zur grünen Infrastruktur verknüpft, um räumlich differenzierte Aussagen zu Klimarisikoprofil, Vulnerabilitäten und Anpassungspotenzialen im Siedlungsraum zu ermöglichen. GreenGEO verfolgt einen möglichst niederschwelligen Zugang zum Ziel, für den ausschließlich frei zugängliche Datenquellen und einfache Berechnungsmethoden ohne Erfordernis für teure Simulationssoftware verwendet werden sollen, die die Realisierung von Anpassungsmaßnahmen in Gemeinden weiter verzögern können.Darauf aufbauend wird eine parameterspezifisch priorisierbare Maßnahmenliste entwickelt, die unterschiedliche Klimarisiken, räumliche und rechtlich-planerische Rahmenbedingungen sowie Wirkungszusammenhänge berücksichtigt. Zur Unterstützung planerischer Entscheidungsprozesse werden Entscheidungsalgorithmen konzipiert, die auf Basis des berechneten Risikoprofils (semi-)automatisierte, standortbezogene Maßnahmenvorschläge generieren. Die Ergebnisse werden in eine erweiterte WebGIS-Umgebung integriert, die eine nutzerfreundliche Visualisierung, Analyse und Auswahl von Anpassungsoptionen erlaubt. Der Vorteil der angestrebten WebGIS-Plattform liegt in der zentralen Datenverwaltung und der dezentralen Verfügbarkeit. Jede:r kann auf die Plattform zugreifen, gleichzeitig erfolgt die Aufbereitung des Datenmaterials zentral, was den Verwaltungsaufwand minimal hält.

Eine intensive Einbindung relevanter Stakeholder begleitet alle Projektphasen und stellt die Praxisrelevanz sowie die Anschlussfähigkeit an bestehende Planungsprozesse sicher. Die Funktionalität und Anwendbarkeit des Gesamtansatzes werden abschließend anhand von Realdatentests in den österreichischen Klimapionierstädten Klagenfurt und Gleisdorf validiert.

8 AUSBLICK UND SCHLUSSFOLGERUNG

Die rapide steigende Anzahl an frei verfügbaren Geodaten ermöglicht es, dass Planungsempfehlungen für Klimawandelanpassungsmaßnahmen in Zukunft auf dieser Datengrundlage automatisiert, nachvollziehbar und transparent erstellt werden können. Die intelligente Verknüpfung unterschiedlich kombinierter Datengrundlagen mit einer priorisierbaren Maßnahmenliste für grün-blaue Anpassungsmaßnahmen erlaubt dabei eine gezielte, standortspezifische Vorauswahl, die auch die rechtliche Ebene der Raumplanungsinstrumente berücksichtigt. Datenbasierte Planungsalgorithmen fungieren damit als strukturierende Schnittstelle zwischen Analyse und Umsetzung. Sie übersetzen komplexe räumliche Informationslagen in klar nachvollziehbare Entscheidungsoptionen und unterstützen die Raum- und Landschaftsplanung dabei, Klimawandelanpassungsmaßnahmen gezielt, priorisiert und instrumentenspezifisch zu integrieren. Ihr Beitrag liegt weniger in der Automatisierung von Entscheidungen als in der systematischen Aufbereitung von Entscheidungsgrundlagen, die eine evidenzbasierte und kontextsensitive Planung ermöglichen.

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reviewed paper

Von MS-COCO zur FGSV: Die Entwicklung und Validierung eines hierarchischen Klassifikationsschemas für die hochspezifische KI-gestützte Verkehrszählung in Deutschland

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1 ABSTRACT

Die effektive und nachhaltige Steuerung urbaner Verkehrssysteme erfordert präzise Daten über eine zunehmend diverse Gruppe von Verkehrsteilnehmenden. Maschinelles Sehen (Computer Vision) bietet hierbei ein enormes Potenzial, um in der Stadt- und Verkehrsplanung die notwendigen hochfrequenten Daten für ein evidenzbasiertes Management bereitzustellen. Doch während viele KI-Lösungen überwiegend im wissenschaftlich-theoretischen Kontextentwickelt und erprobtwerden, bleibt deren praktische Anwendbarkeit häufig ungeprüft.

Anhand zweier Praxisbeispiele aus Süddeutschland beleuchten wir den interdisziplinären Raum zwischen modernen KI-Objektdetektoren einerseits, und den hiesig geltenden Standards zur Verkehrserhebung andererseits. Dies betrifft die Notwendigkeit einer hochgradig spezifizierten Klassifizierung von Verkehrsteilnehmenden gemäß den Richtlinien der Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), Herausforderungen bei der Erfassung durch Wettereinflüsse, sowie strenge Datenschutzanforderungen. Die methodische Grundlage bildeteine manuell erhobene Referenzdatenbank mit über 17.000 annotierten Verkehrsteilnehmendenund vortrainierte YOLOv8-Modelle (You Only Look Once). Mit mehreren experimentellen Konfigurationen wurde untersucht, wie gut die Modelle den spezifischen Anforderungen der Planungspraxis gerecht werden. Im Speziellen wurde ein hierarchisches Klassifikationsschema entwickelt, das von internationalen Standards (MS-COCO, Common Objects in Context) über FGSV-Standards (Forschungsgesellschaft für Straßen- und Verkehrswesen) bis hin zu projektspezifischen Anforderungen reicht.

Die Untersuchung zeigt, dass die Detektionsgenauigkeit (mAP@50) stark von der semantischen Tiefe der Zielvariablen abhängig ist. Während auf der generischen Ebene mit lediglich 7 allgemein gehaltenen Klassen (bspw. Auto, Fahrrad, Person)eine sehr hohe Präzision von 86,3% erzielt wurde, sinkt dieser Wert bei der Anwendung der für die deutsche Planungspraxis notwendigen FGSV-Standards auf 78,0% und bei hochspezifischen Projektanforderungen (19 Klassen – von LastenfahrradfahrendePerson bis zu landwirtschaftlichem Spezialfahrzeug) auf 64,7%. Analog lässt sich auch der Einfluss von Bildqualität auf die Detektionsgenauigkeit quantifizieren. In der besten Konfiguration liegt die durchschnittliche Detektionsgenauigkeit bei 87,8%, wobei größere Objekte wie PKWs, LKWs und Busse mit bis zu 97,8% Genauigkeit detektiert wurden. Kleinere Objekte wie Personen, Motorräder und filigrane Fahrräder wurden jedoch nur in 86,8%, 83,2% und 67,5% Prozent der Fälle korrekt detektiert.

Im Vergleich zur manuellen Auswertung lassen sich mit den getesteten KI-Modellen deutlich größere Datenmengen automatisiert und mit robuster Genauigkeit verarbeiten. Damit werden sowohl großflächigere, als auch langfristigere Verkehrserhebungen möglich. Die erforderliche semantische Tiefe zwingt jedoch zur domänenspezifischen Optimierung. Gleichzeitig steigen mit der Automatisierung die Anforderungen an die Qualität der Datenerfassung allgemein. Valide Planungsgrundlagen hängen also zukünftig noch mehr von der interdisziplinären Schnittstelle von Technologie und Praxis ab.

Keywords: Verkehrszählung, Kamera, MS-COCO, FGSV, Verkehrsplanung

2 EINLEITUNG

Die zuverlässige Erfassung von Verkehrsströmen bildet eine zentrale Grundlage für Verkehrs-, Umwelt- und Stadtplanung (Matthias et al., 2020; Schulthoff et al., 2022). Über klassische, aggregierte Verkehrsvolumina hinaus, besteht dabei zunehmend der Bedarf, die Vielfalt heutiger Verkehrsteilnehmender – darunter Fuß- und Radverkehr, motorisierter Individualverkehr, Lieferverkehre sowie Sonderfahrzeuge – differenziert und in hoher zeitlicher Auflösung abzubilden (Stiller et al., 2026). Vor diesem Hintergrund haben sich in den letzten Jahren Verfahren des maschinellen Sehens als vielversprechender Ansatz etabliert. Mit Künstlicher Intelligenz (KI) ausgestattet, ermöglichen kamerabasierte Systeme eine hochfrequente, flächendeckende und prinzipiell automatisierbare Erfassung von Verkehrsteilnehmenden (Al-qaness et al., 2021). Insbesondere YOLO-basierte Objektdetektoren haben sich aufgrund ihrer Echtzeitfähigkeit in zahlreichen verkehrsnahen Anwendungen bewährt (Redmon et al., 2016; Zhang et al., 2022).

Gleichzeitig weisen mehrere Studien (Galich et al., 2025; Lin et al., 2014; Molchanov et al., 2017; Stiller et al., 2026; Xia et al., 2024) darauf hin, dass generische, vortrainierte Modelle unter realen Einsatzbedingungen häufig an ihre Grenzen stoßen, etwa bei kleinen oder teilverdeckten Objekten, variierenden Licht- und Wetterbedingungen sowie bei der Übertragung internationaler Objektklassen auf nationale, planungsrelevante Kategorisierungen, wie dieder Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV). Hinzu kommen datenschutzrechtliche Anforderungen, die insbesondere in Deutschland eine Reduktion der Bildauflösung oder Anonymisierungsmaßnahmen erforderlich machen und damit die visuelle Detailtiefe weiter einschränken (Stiller et al., 2026).

Um zu evaluieren, wie zuverlässig KI-Systeme unter diesen Rahmenbedingungen für Verkehrszählungen in Deutschland eingesetzt werden können, adressiert diese Studie die identifizierten Einschränkungen in einem systematischen, praxisnahen Untersuchungsdesign. Anhand zweier realer Anwendungsfälle aus Süddeutschland wird schrittweise analysiert, (i) wie leistungsfähig ein generisches, vortrainiertes YOLO Modell „Out-of-the-Box“ ist und welchen Einfluss unterschiedliche Aufnahmebedingungen wie Beleuchtung und Witterung auf die Erkennungsleistung haben; (ii) wie sich eine zunehmende semantische Differenzierung der Verkehrsteilnehmenden, von internationalen Standardklassen (MS COCO) über FGSV-nahe Kategorien bis hin zu hochspezifischen, praxisnahen Klassifikationen, auf die erreichbare Modellgüte auswirkt; sowie (iii) inwieweit ein für die Verkehrszählung optimiertes KI-Modell mit etablierten manuellen Zählungen unter realen Praxisbedingungen vergleichbar ist. Durch diese strukturierte Variation zentraler Einflussfaktoren leistet die Arbeit einen Beitrag zur Einordnung der technischen Möglichkeiten und Grenzen KI-gestützter Verkehrszählung und zeigt auf, unter welchen Bedingungen ein belastbarer Mehrwert für die Planungspraxis entsteht.

Im folgenden Kapitel wird das methodische Setup der Untersuchung beschrieben, einschließlich der zugrunde liegenden Praxisanforderungen, der Referenzdatenbasis sowie des experimentellen Designs. Anschließend werden die Ergebnisse der systematischen Evaluation gezeigtund im Hinblick auf die identifizierten Einflussfaktoren diskutiert, bevor abschließend die zentralen Schlussfolgerungen für den Einsatz KI-gestützter Verkehrszählung in der Planungspraxis gezogen werden.

3 METHODISCHER RAHMEN

Für eine praxisnahe Evaluation basiert die vorliegende Untersuchung auf zwei realen Verkehrsplanungsprojekten aus der Metropolregion München. Beide Projekte zielten auf die Quantifizierung von Verkehrsströmen und speziell der Differenzierung von Verkehrsteilnehmenden im Kontext infrastruktureller Planungs- und Bewertungsprozesse ab.

3.1 Hierarchisches Klassifikationsschema

Unterschiedliche Verkehrsteilnehmende stellen jeweils spezifische Anforderungen an Planung, Bemessung und Bewertung von Verkehrsinfrastruktur, da sie sich hinsichtlich Flächenbedarf, Betriebsverhalten, Sicherheitsanforderungen und Umweltwirkungen systematisch unterscheiden (Schulthoff et al., 2022).

Demgegenüber stehen praktische Einschränkungen der KI-gestützten Kameraauswertung. Zum einen müssen, grundsätzlich, für jede unterschiedene Klasse an Verkehrsteilnehmenden repräsentative Daten für

das Lernverfahren vorliegen. Zum anderen kann eine ungleiche Repräsentation einzelner Verkehrsteilnehmerim Datensatz jedoch zu systematischen statistischen Verzerrungen führen. Mit zunehmender Klassifikationsdifferenzierung steigt damit der Bedarf an umfangreichen und ausgewogenen Referenzdaten pro Klasse. Gleichzeitig nimmt die erreichbare Modellgüte – die Treffsicherheit – typischerweise ab. In diesem Spannungsfeld haben wir ein dreistufiges, hierarchisches Klassifikationsschema entwickelt (Abbildung 1). Der Vergleich der Modellgüte über die drei Ebenen zeigt, wie robust die Modelle gegenüber praxisnaher Klassifikationskomplexität sind.

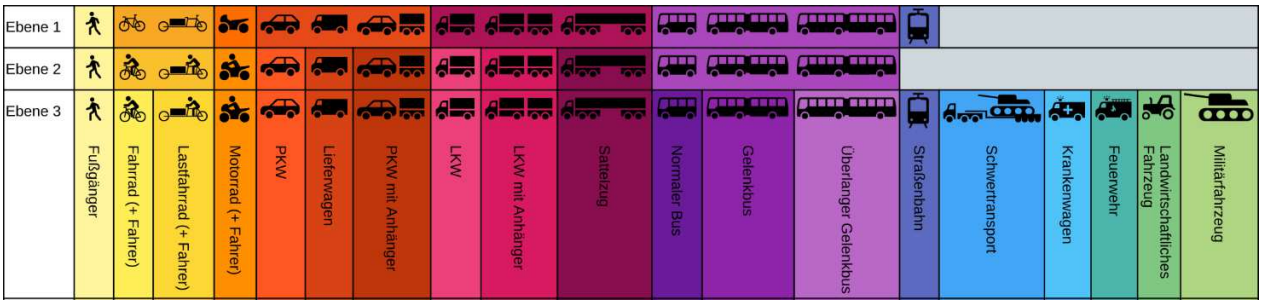


Abb. 1: Hierarchisches Klassifikationsschema. Über drei Ebenen verteilt werden Verkehrsteilnehmende zunehmend spezifischer differenziert. Farbliche Nuancen im Hintergrund unterstreichen die semantischen Unterschiede.

- Ebene 1: Der für internationale Computer-Vision Benchmarks gängige Datensatz MS-COCO (Lin et al., 2014) unterscheidet sieben für diesen Kontext relevante Objektklassen (z.B.person,bicycle,car,truck). Auf eine Übersetzung ins Deutsche wird bewusst verzichtet, um taxonomische Unterschiede nicht zu verlieren. Speziell die Klasse truckinkludiertsowohl schwere LKW, als auchleichtere Lieferwägen und Fahrzeuge mit offener Ladefläche (Pickup-Trucks).
- Ebene 2: Die in Deutschland für nationaleVerkehrsplanung relevanten Empfehlungen für Verkehrserhebungen (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012)schreiben dahingegen eine etwas feinere Differenzierung der Klassen vor. Hier werden motorisierte Fahrzeuge in achtthematische Grundklassen eingeteilt. Diese werden sowohl um Fahrradfahrende (im Folgenden Radler) und Fußgänger ergänzt. Insgesamt entspricht Ebene 2 damit zehn Objektklassen.
- Ebene 3:Diese Ebene erweitert Ebene 2 um zusätzliche, für individuelle Planungsfragestellungen relevante Unterkategorien. Dazu zählen unter anderem LKW mit und ohne Anhänger, Sattelzüge, Gelenk- und Standardbusse, ausgewählte Sonder- und Einsatzfahrzeuge, sowie Lastenradler. Insgesamt entspricht Ebene 3 damit neunzehn Klassen.

3.2 Praxisnahe Datengrundlage

Die Datenerhebung im Gelände erfolgte mittels temporär installierter Kameras an insgesamt 34 Standorten mit 51 einzelnen Erhebungen und einer Gesamtdauer von rund 1.200 Stunden Videomaterial. Die Kameras waren zwar in konstantenHöhen (5 Meter), jedoch in unterschiedlichen Abständen zur Zähllinie montiert, wodurch stark variierende Objektgrößen, perspektivische Verzerrungen und gegenseitige Verdeckungen auftraten. Alle Aufnahmen liegen in einer einheitlichen räumlichen Auflösung von480 × 720 Pixeln vor. Bis auf drei Ausnahmen wurden statt RGB- nur Graustufeninformationen aufgezeichnet.

Zusätzlich decken die Aufnahmen ein breites Spektrum an Umweltbedingungen ab, einschließlich wechselnder Beleuchtungssituationen, Witterungseinflüsse und tageszeitlicher Effekte. Diese Rahmenbedingungen stellen zentrale Herausforderungen für die automatisierte Objekterkennung dar, bilden jedoch zugleich die Realität verkehrsplanerischer Erhebungen ab und sind daher integraler Bestandteil des Untersuchungsdesigns. Für die weitere Analyse wurden die stündlich aufgeteilten Videosequenzen entsprechend in drei Beleuchtungskategorien unterschieden:sonnig (direkte Sonneneinstrahlung mit ausgeprägten Schattenwürfen), bedeckt (diffuse, gleichmäßige Ausleuchtung) unddunkel (Dämmerung und Nachtaufnahmen mit künstlicher Beleuchtung). Diese sind in Abbildung 2 beispielhaft dargestellt.



Abb. 2: Drei beispielhafte Aufnahmen illustrieren die unterschiedlichen Bildkompositionen an Standorten. Außerdem zeigen sie unterschiedliche Beleuchtungssituationen: a) sonnig, b) bedeckt und c) dunkel.

3.3 Annotation Referenzdatenbank

Um die Güte eines automatisierten Ansatzes evaluieren zu können, braucht es annotierte Referenzdaten. In Abwägung von Arbeitsumfang und technischen Anforderungen wurden aus der insgesamt verfügbaren Datengrundlage eine stratifizierte Stichprobe gezogen. Zunächst wurde die Grundgesamtheit an Videodaten auf komplementäre Verkehrssituationen reduziert und jeweils stundenweise Ausschnitte zu unterschiedlichen Aufnahmezeitpunkten und Beleuchtungskategorienpro Standort ausgewählt. Die so strukturierte Referenzdatenbank erlaubt eine differenzierte Analyse der kameragestützten Verkehrszählung unter variierenden Praxisbedingungen.

Um Redundanzen durch signalbedingt wartenden Verkehr und eine hohe Diversität der Trainingsdaten sicherzustellen, wurden aus den Videos in einem festen zeitlichen Intervall Einzelbilder (Frames) extrahiert. Gleichzeitig bestand der Anspruch, auch seltene, aber planerisch relevante Verkehrsteilnehmende ausreichend häufig abzubilden. In ausgewählten Szenen, die insbesondere Spezialfahrzeuge, LKW mit Anhänger oder Lastenradler zeigten, wurde die Abtastrate gezielt erhöht. Insgesamt umfasst die annotierte Referenzdatenbank 3.924 Einzelbilder.

In jedem der ausgewählten Einzelbilder müssen alle erkennbaren Verkehrsteilnehmenden einzeln markiert und einer semantischen Klasse zugeordnet werden. Die räumliche Lokalisierung der Objekte erfolgte mittels rechteckiger Bildausschnitte (Bounding Boxes), die den jeweiligen Verkehrsteilnehmenden eindeutig im Bild verorten. Die Annotation wurde in einem teilautomatischen, mehrstufigen Prozess durchgeführt, bei dem qualifizierte wissenschaftliche Hilfskräfte durch ein vortrainiertes Objekterkennungsmodell der YOLOv8-Familie unterstützt wurden. Die automatisch erzeugten Bounding Boxes wurden anschließend manuell überprüft, bei Bedarf korrigiert und um fehlende Objekte ergänzt. In diesem manuellen Arbeitsschritt erfolgte auch die Zuordnung zu den definierten semantischen Kategorien bis zur feinsten Klassifikationsebene 3.

Ein besonderer methodischer Aspekt ergibt sich außerdem bei Verkehrsteilnehmenden, die – wie bspw. Radler – visuell aus mehreren Objekten bestehen. Diese werden nur in Ebene 1 als separate Entitäten (z. B. person und bicycle) gehandhabt. Um diese semantische Mehrdeutigkeit aufzulösen, wurde das hierarchische Klassifikationsschema um eine logische Fusionsregel ergänzt. Während des Annotationsprozesses werden die Entitäten noch einzeln erfasst. Während der anschließenden Überführung wird geprüft, ob sich die Bounding Boxes von Person und Zweirad räumlich überlagern und die Entitäten für die Ebene 2 und 3 zusammengeführt.

4 EXPERIMENTELLES EVALUATIONSDESIGN

Ziel dieser Studie ist es, die Leistungsfähigkeit einer kameragestützten, vollautomatisierten Verkehrszählung unter dem Einfluss realer Faktoren aufzuzeigen. Die experimentelle Validierung folgt einem kontrollierten Design, bei dem jeweils ein Einflussfaktor variiert und alle übrigen Parameter konstant gehalten werden. Auf diese Weise werden der Einfluss der Aufnahmebedingungen, der semantischen Klassifikation und der Modellarchitektur getrennt untersucht. Die gewonnenen Erkenntnisse werden anschließend zusammengeführt, um eine konsistente Modellkonfiguration für den Vergleich mit der Planungspraxis abzuleiten.

4.1 Variable Aufnahmebedingungen

Optische Systeme sind in der Planungspraxis zwangsläufig mit wechselnden Licht- und Sichtverhältnissen konfrontiert, die sich der direkten Kontrolle entziehen und die visuelle Erkennbarkeit von Verkehrsteilnehmenden erheblich beeinflussen können (Staab et al., 2021; Xia et al., 2024; Zhang et al., 2022).Um in einem ersten Benchmark diesen Einfluss auf kameragestützte Ansätze isoliert zu analysieren, wird ein auf die semantische Ebene 1 vortrainiertesYOLOv8neingesetzt. Modellarchitektur und semantische Klassifikation werden also konstant gehalten, sodass beobachtete Leistungsunterschiede ausschließlich auf die Aufnahmebedingungen zurückzuführen sind. Als Stratum dienen die bereits in der Datengrundlage systematisch erfassten Beleuchtungskategorien (vgl. Abschnitt 3.2).

Zur Bewertung der Modellleistung werden True Positives (korrekt erkannte Objekte), False Positives (fälschlich erkannte Objekte) und False Negatives (nicht erkannte Objekte) betrachtet. Auf dieser Basis beschreibt Precision die Zuverlässigkeit der Detektionen, während Recall die Vollständigkeit der Erkennung quantifiziert. Der F1-Score kombiniert beide Maße als harmonisches Mittel und erlaubt so eine ausgewogene Bewertung der Modellleistung. Die Metrik hat sich insbesondere bei unausgeglichenen Klassenverteilungen als robuste Kenngröße etabliert und wird häufig zur Evaluation von Objekterkennungsmodellen verwendet (Powers, 2011; Sokolova & Lapalme, 2009).

Um die erzielten Werte einordnen zu können, wurde außerdem über alle Beleuchtungsszenarien hinweg ein allgemeines Benchmark berechnet.

4.2 Diversifikation der Klassifikation

Da die verschiedenen Verkehrsteilnehmenden jeweils individuelle Anforderungen an die Planung stellen, ist es gerade in heterogenen, urban geprägten Gebieten wichtig, diese differenziert zu berücksichtigen. Ziel des zweiten Experiments ist es, den Einfluss zunehmender semantischer Differenzierung auf die erreichbare Detektionsleistung zu quantifizieren. Hierbei wird über die drei Varianten des hierarchischen Klassifikationsschemas (Ebene 1–3) iteriert, während die anderen Parameter konstant gehalten werden: Als Datengrundlage werden ausschließlich ausreichend belichteteFrames (sonnig und bedeckt, insgesamt 3.845 Bilder) herangezogen und nach dieser Variable in 50% Trainings-, 30% Validierungs- und 20% Testdaten stratifiziert aufgeteilt. Die Versuche wurden je mit identischen Trainingsparametern über 100 Epochen und einer Batchgröße von 8 trainiert. Weitere Hyperparamter, wie die Lernrate, wurden nicht manuell angepasst und entsprechen damit den Standardeinstellungen der verwendeten YOLOv8-Implementierung. Maßnahmen zum expliziten Ausgleich von Klassenungleichgewichten (z.B. Oversampling oder Klassengewichte) wurden nicht eingesetzt, um die Effekte semantischer Differenzierung unter realitätsnahen Datenverteilungen abzubilden.

Die Modellgüte wird mittels mAP@50 bewertet. Diese mean Average Precision bei einer Intersection of Union von > 0,5 ist ein integriertes Maß dafür, wie gut die Verkehrsteilnehmende sowohl korrekt detektiert und klassifiziert, als auch im Bild lokalisiert werden. Die Auswertung erfolgte als Mittelwert über die jeweils betrachteten Klassen, sodass die Ergebnisse über die drei Ebenen direkt vergleichbar sind.

Ergänzend werden jeweils Konfusionsmatrizen ausgegeben. Sie stellendie manuelle Klassifikation der automatisierten Objektklasse gegenüber. Dadurch lässt sich nachvollziehen, zwischen welchen Verkehrsteilnehmenden systematische Verwechslungen auftreten.

4.3 Vergleich von Architekturen unterschiedlicher Komplexität

Technisch besteht die Möglichkeit, die Leistungsgrenzen der automatisierten Verkehrserkennung durch komplexere Modellarchitekturen zu verschieben. Im Fokus des dritten Experiments steht die Frage, ob der Einsatz größerer Netzwerkarchitekturen in Kombination mit längeren Trainingsphasen eine robustere Klassifikation ermöglicht. Zu diesem Zweck werden zwei Modellvarianten derselben Architektur- und Modellgeneration miteinander verglichen: das kompakte und für Echtzeitanwendungen optimierte Modell YOLO v8n mit rund 3 Millionen trainierbaren Parametern sowie das mit etwa 68 Millionen Parametern deutlich komplexere Modell YOLOv8x. Die Trainingsdauer wird architekturspezifisch gewählt, um eine stabile Konvergenz der Modelle zu gewährleisten. Datengrundlage und semantisches Klassifikationsschema (Ebene 1) werdenüber beide Trainingsläufe hinweg konstant gehalten.

Wie in den vorherigen Experimenten wird die Modellleistung mittels mAP@50 bewertet. Ergänzend werden klassenweise Leistungswerte berechnet, um architekturspezifische Effekte differenzierter analysieren zu können. Das Delta ebendieser Werte zeigt etwaige Leistungssteigerungen an.

4.4 Beispielhafte Anwendung

Zur exemplarischen Prüfung der praktischen Anwendbarkeit und Übertragbarkeit des entwickelten KI-Verfahrens wurde ein Vergleich mit einem etablierten manuellen Erhebungsverfahren durchgeführt. Zum Einsatz kommt das zuvor trainierte YOLOv8x-Modell. Als Referenz dient eine in der Planungspraxis übliche Verkehrszählung, bei der geschulte Mitarbeitende vier fünfzehnminütige Videos manuell auswerteten. Dabei werden alle Fahrzeuge im fließenden Verkehr gezählt.

Da in der vorliegenden Anwendung keine explizite Objektverfolgung eingesetzt wird, basiert die KI-gestützte Auswertung auf der Detektion von Verkehrsteilnehmenden in einzelnen Bildframes. Um Mehrfacherfassungen zu reduzieren und eine zeitlich konsistente Aggregation zu ermöglichen, werden aus den vier Videosequenzen in einem festen Intervall von zehn Sekunden Einzelbilder extrahiert. Die Detektionsergebnisse werden anschließend zeitlich aggregiert und auf dieselben Erhebungsintervalle bezogen wie die manuelle Zählung. Zur vergleichenden Bewertung beider Verfahren wird der zeitliche Verlauf der aggregierten Zählwerte analysiert und statistisch gegenübergestellt, wobei ein Korrelationskoeffizient als Maß für die Übereinstimmung der zeitlichen Dynamik herangezogen wird.

5 ERGEBNISSE

In diesem Kapitel werden die Ergebnisse der experimentellen Evaluation der kameragestützten Verkehrszählung dargestellt. Ausgangspunkt bilden die manuell geprüften Referenzdaten, die die empirische Grundlage für alle nachfolgenden Analysen darstellen. Auf dieser Basis werden zunächst Umfang und Struktur der annotierten Verkehrsteilnehmenden beschrieben, bevor die Ergebnisse der drei Experimente zur Robustheit gegenüber Aufnahmebedingungen, zur semantischen Differenzierung und zur Modellarchitektur vorgestellt werden.

5.1 Hochspezifische Verkehrszählung

Die Referenzdatenbank umfasst insgesamt 17.172 manuell geprüfte Annotationen (s. Tabelle 1). Die Klassenverteilung erinnert stark an reale Verkehrsverhältnisse und ist eben nicht gleichverteilt.Personenkraftwagen stellen mit 70,4 % den größten Anteil der Annotationen, gefolgt von Lieferwagen (10,4 %) sowie Fußgänger (10,2 %). Zusammengenommen entfallen damit rund 91 % aller Annotationen auf diese drei dominanten Klassen.Die verbleibenden Klassen weisen teils sehr geringe Fallzahlen auf. Die aus verkehrsplanerischer Sicht ebenfalls relevantenKrankenwägen, überlange Busse, Schwertransporte und Militärfahrzeuge konnten im verfügbaren Videomaterial nicht erfolgreich identifiziert werden und sind folglich nicht Bestandteil der Referenzdatenbank.

Semantische Klasse	#Annotationen	Semantische Klasse (Fortsetzung)	#Annotationen
PKW	12084	Motorrad	94
Fussgänger	1759	Gelenkbus	84
Lieferwagen	1780	Lastfahrrad	59
LKW	485	PKW mit Anhänger	47
Fahrrad	351	Landwirt. Fahrzeug	11
NormalerBus	196	Strassenbahn	5
LKWmitAnhänger	113	Feuerwehr	1
Sattelzug	103	… Übrige	0

Tab. 1: Verteilung der manuell geprüften Annotationen nach semantischen Klassen in der Referenzdatenbank

Die in der Praxis inhärente Ungleichverteilung an Objektkategorien (engl. class imbalance) ist methodisch besonders relevant, da sie die Modellleistung klassenabhängig beeinflusst und die Interpretation aggregierter Gütemaße erschwert (Japkowicz & Stephen, 2002). Im Kontext des hierentwickelten, hierarchischen Klassifikationsschemas ist dieser Effekt proportional zur semantischen Tiefe der jeweils betrachteten Ebene.

5.2 Benchmark Out-of-the-box-Modell

Um gleich zu Beginn der Studie die Einsatzfähigkeit eines frei verfügbaren, auf Ebene 1 vortrainierten Objekterkennungsmodells einordnen zu können, wurdenvier einfache Benchmarks durchgeführt.Zum einen im Vergleich zwischen allen Annotationen und über alle 3.924 Bilder und zum anderen eine Evaluation, die für die drei Beleuchtungskategorien sonnig, bedeckt und dunkelseparat durchgeführt wurde.

Über alle Beleuchtungsszenarien hinweg wurde ein gewichteter F1-Score von 0,48 erreicht.Dieser Wert ergibt sich aus einer Präzision von 0,79 und einer Sensitivität von 0,35.Das bedeutet, dass ein Großteil der vom Modell detektierten Objekte korrekt klassifiziert wurde, gleichzeitig jedoch nur rund 35 % der tatsächlich vorhandenen Objekte erkannt wurden, während etwa 65 % unentdeckt blieben.Die vergleichsweise hohe Precision weist darauf hin, dass das Modell zurückhaltend detektiert und Fehlklassifikationen weitgehend vermeidet, jedoch auf Kosten einer systematischen Untererfassung. Im Detail wird speziell die Klasse carmit einem F1-score von 0,54 überdurchschnittlich gut erkannt. Für andere Verkehrsteilnehmer, insbesondere person, bus und truck, fällt die Erkennungsleistung deutlich geringer aus (F1-Scores zwischen 0,17 und 0,26). Seltene Klassen wie bicycle, motorcycle und train wurden nahezu nicht erkannt.

Unter guten Lichtverhältnissen (sonnig) erreicht das Modell hingegen einen etwas höheren F1-Score von 0,51. Bei moderaten Beleuchtungsbedingungen (bedeckt) sinkt die Erkennungsleistung wieder auf 0,48. Deutlich stärker fällt der Leistungsabfall bei dunklen Aufnahmebedingungen aus, bei denen lediglich ein F1-Score von 0,30 erzielt wird.

5.3 Zielkonflikt semantischer Differenzierung

In der methodischen Praxis ist es üblich, Modelle auf ihre zukünftigen Anwendungen hin anzupassen. Dabei werden die vortrainierten Netzwerke auf die spezifischen Eingangsdaten und Aufgabenstellungen hin angepasst. Allerdingsverdeutlichen die Ergebnisse einen grundlegenden Zielkonflikt der kameragestützten Verkehrserkennung. Bei konstanter Modellarchitektur (YOLOv8n), identischer Datengrundlage und unveränderten Trainingsparametern sinkt die Modellgüte mit zunehmender semantischer Tiefe deutlich. Wie die Abweichungen entlang der Diagonalen anzeigen, nehmen Verwechslungen zu (Abbildung 3).

Für die generische Klassifikationsebene (Ebene 1 mit sieben Klassen) wird eine hohe Detektionsleistung mit einem mAP@50 von 0,863 erreicht. Die Konfusionsmatrix (Abbildung 3a) weist in diesem Fall eine stark ausgeprägte Diagonale auf, was auf eine robuste und weitgehend fehlerfreie Trennung der siebenVerkehrsteilnehmerkategorien hinweist. Fehlklassifikationen treten nur vereinzelt auf und betreffen überwiegend Randfälle.

Mit der Umstellung auf eine FGSV-nahe Klassifikation (Ebene 2, elf Klassen) reduziert sich die Detektionsleistung auf einen mAP@50 von 0,780. Parallel dazu verändert sich die Struktur der Fehlklassifikationen. Die Konfusionsmatrix (Abbildung 3b) zeigt vermehrt systematische Verwechslungen zwischen semantisch und visuell ähnlichen Klassen, etwa zwischen Fahrzeugen mit und ohne Anhänger oder zwischen unterschiedlichen Nutzfahrzeugtypen. Trotz dieses Leistungsrückgangs bleibt die Mehrzahl der Zuordnungen korrekt, was auf eine grundsätzlich stabile Modellleistung auch bei erhöhter semantischer Komplexität hinweist.

Die ausführlichste Semantik (Ebene 3) führt zu einem weiteren, deutlich ausgeprägten Leistungsabfall. Der mAP@50fällt auf 0,647. Die Konfusionsmatrix (Abbildung 3c) ist im Vergleich nochmals stärker aufgefächert. Im Detail ist erkennbar, dass die Fehlzuordnungen zwischen strukturell ähnlichen Klassen auftreten. Besonders deutlich ist das im Falle des einen Feuerwehrfahrzeuges, welches durch die KI fälschlicherweise als LKW detektiert wurde.

5.4 Auswirkungen der Modellarchitektur

Im Gelände soll eine kameragestützte Verkehrszählung möglichst alle Fahrzeuge erfassen. Vor diesem Hintergrund stellt sich die Frage, ob sich die beschriebenen Genauigkeitsverluste technisch durch den Einsatz leistungsfähigerer Modellarchitekturen abmildern lassen.

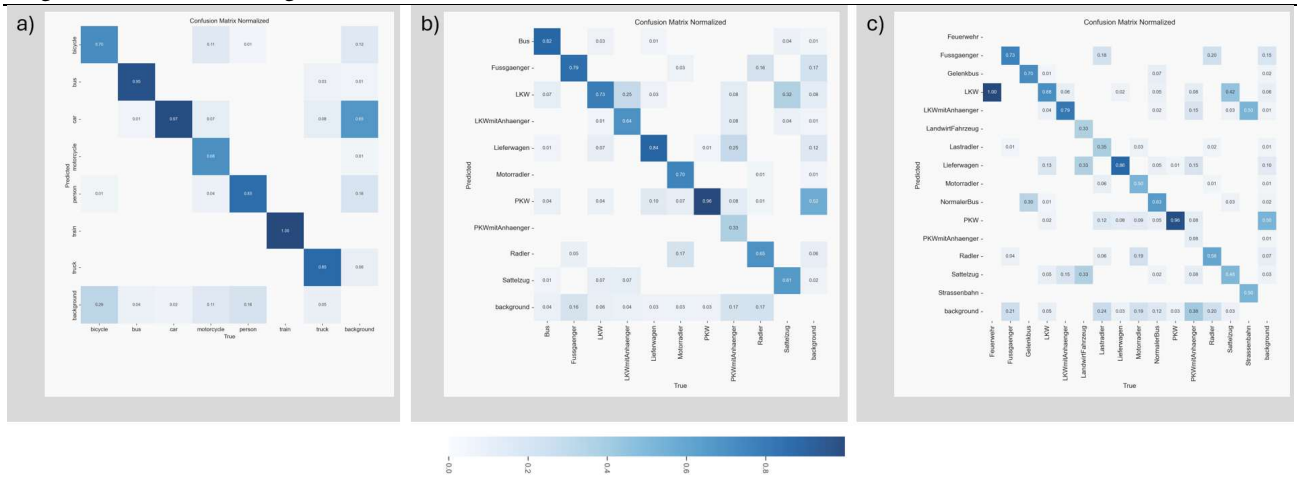


Abb. 3: Normalisierte Konfusionsmatrizen für drei semantische Klassifikationsebenen: a) generische Klassifikation (Ebene 1), b) FGSV-nahe Klassifikation (Ebene 2) und c) projektspezifische Klassifikation (Ebene 3). Die Diagonale zeigt korrekte Zuordnungen, Einträge außerhalb der Diagonale kennzeichnen systematische Fehlklassifikationen zwischen Klassen. Die Farbskala repräsentiert spalten-normalisierte Anteile im Wertebereich von 0 bis 1.

Im Vergleich zwischen YOLOv8n und YOLOv8x zeigt Tabelle 2, dass eine größere Modellarchitektur durchaus zu einer leichten, systematischen Verbesserung der aggregierten Detektionsleistung führt. Der mittlere mAP@50 steigt von 0,863 auf 0,878, was einem Zuwachs von +0,015 entspricht.Eine differenzierte Betrachtung der klassenweisen Ergebnisse zeigt, dass insbesondere kleinere oder strukturell komplexere Objekte wie motorcycle, bicycle und person von der höheren Modellkapazität profitieren, während für größere und visuell klar abgegrenzte Klassen wie bus, car und truck keine konsistenten Verbesserungen zu beobachten sind. In einzelnen Fällen fällt die Detektionsleistung des größeren Modells sogar leicht geringer aus.

Semantische Klasse	***mAP@50***		**Δ**
	YOLO v8n	***YOLO v8x***	
train	0.995	0.995	±0.000
car	0.983	0.978	−0.005
bus	0.943	0.928	−0.015
truck	0.912	0.870	−0.042
person	0.853	0.868	+0.015
motorcycle	0.713	0.832	+0.119
bicycle	0.643	0.675	+0.032
arithmetische Mittel	0.863	0.878	+0.015

Tab. 2: Klassenweise Detektionsleistung für zwei unterschiedlich komplexe Modellarchitekturen bei identischer Datengrundlage und generischer Klassifikation (Ebene 1). Angegeben sind die mittleren Genauigkeiten pro Klasse sowie die Differenz (v8x – v8n).

5.5 Vergleich zur Praxis

Das mit einer Erkennungsgenauigkeit von 87,8 % leistungsstärkste Modell wurde nachfolgend auf vier aufeinanderfolgende Videosequenzen angewendet. Unabhängig von Fahrtrichtung und Fahrzeugtyp ergab die manuelle Zählung insgesamt 200 Fahrzeuge, während die KI-basierte Auswertung 585 Detektionen lieferte. Trotz dieser deutlichen Abweichung auf absoluter Ebene zeigt der Korrelationskoeffizient von r = 0,82 eine hohe Übereinstimmung der relativen Verkehrsdynamik über die Zeit.

Der detaillierte Vergleich der Zeitreihen verdeutlicht, dass die Differenzen primär auf grundlegende konzeptionelle Unterschiede zwischen beiden Verfahren zurückzuführen sind. Ab etwa 5:00 Uhr morgens steigt die Anzahl der erfassten Fahrzeuge in beiden Ansätzen kontinuierlich bis 6:00 Uhr an. Während die Verläufe in den frühen Zeitintervallen noch nahezu parallel verlaufen, reißen die automatisierten Detektionen in der letzten Viertelstunde sprungartig nach oben aus. Dieser Effekt ist darauf zurückzuführen, dass die manuelle Zählung ausschließlich den fließenden Verkehr berücksichtigt, während die KI-basierte Methode auch ruhende sowie an Lichtsignalen wartende Verkehrsteilnehmende in konsekutiven Einzelbildern

mehrfach erfasst. Der beobachtete Unterschied reflektiert somit weniger eine Fehlleistung des Modells als vielmehr unterschiedliche, systemimanente Zähl- und Abgrenzungslogiken.

6 DISKUSSION

Die vorliegende Studie zeigt, dass kamerabasierte KI-Verfahren grundsätzlich in der Lage sind, Verkehrsdynamiken automatisiert und hochfrequent abzubilden. Die Studie zeigt aber auch, dass ihre Leistungsfähigkeit stark von Aufnahmebedingungen, semantischer Zielsetzung und Modellkonfiguration abhängt. Drei komplementäre Experimente verdeutlichen, dass weder generische Modelle noch hochkomplexe Architekturen per se schlüsselfertige Lösungen darstellen. Vielmehr entsteht Modellgüte aus dem Zusammenspiel von Datenqualität, semantischer Angemessenheit und technischer Auslegung. Diese Ergebnisse sind insofern erwartbar, als sie zentrale Annahmen der Computer-Vision-Literatur bestätigen (z.B. Benenson et al., 2014; Brunetti et al., 2018; Redmon et al., 2016), machen den Zielkonflikt jedoch erstmals explizit für verkehrsplanerische Anwendungen sichtbar.

Die Ergebnisse aus der händischen Annotation und des ersten Experiments bestätigen, dass Aufnahmebedingungen wie Kameraausrichtung, Witterung und Tagesgang einen maßgeblichen Einfluss auf die kameragestützte Verkehrszählung haben. Aber auch datenschutzbedingte Rahmenbedingungen limitieren mögliche Einsatzzwecke. Die in unserem Fall maximal reduzierte räumliche Auflösung und eingeschränkte Farbinformation führen zu einem geringen visuellen Signal, das selbst für annotierende Menschen eine eindeutige Klassifikation erschwert. Trotz relativ großer Stichprobe (Tabelle 1) konnte die maximal angestrebte semantische Tiefe (Ebene 3, vgl. Abbildung 1) in der Praxis nicht vollständig abgedeckt werden. Im Falle von militärischen und sonstigen Sonderfahrzeugen ist dies statistisch erwartbar. Im Falle von Krankenwägen jedoch wäre ebenfalls denkbar, dass diese und ihre Aufschriften schlicht nicht identifizierbar sind. Ebenso lässt sich die Länge eines Busses oder eines LKW-Gespanns weniger in der Frontalansicht, als erst im Laufe des Abbiegeprozesses im seitlichen Profil festhalten.

Außerdem stellt die in der Praxis übliche, stark unausgeglichene Klassenverteilung eine in den Computerwissenschaften bekannte Herausforderung für lernbasierte Objekterkennung dar (Lin et al., 2014; Molchanov et al., 2017). Ebendiese Effekte verstärkend offenbaren die Ergebnisse des zweiten Experiments den systematischen Zusammenhang zwischen semantischer Differenzierung und erreichbarer Modellgüte. Während auf generischen Ebenen hohe Detektionsleistungen erzielt werden, geht eine zunehmende semantische Auflösung mit einem kontinuierlichen Leistungsabfall einher. Dieser Befund ist konsistent mit der Literatur zu fein granularer Objekterkennung und tritt insbesondere dann auf, wenn visuelle Unterschiede zwischen Klassen gering sind (Stiller et al., 2026; Xia et al., 2024). Konkret machen die Konfusionsmatrizen (Abbildung 3) deutlich, dass es sich dabei nicht um zufällige Fehlklassifikationen handelt, sondernsich die Verwechslungen auf visuell und funktional benachbarte Klassenkonzentrieren. Vor diesem Hintergrund erscheint es sinnvoll, bestehende Empfehlungen zur Verkehrserhebung künftig nicht nur im Hinblick auf die zunehmende Diversifizierung der Verkehrsteilnehmenden weiterzuentwickeln, sondern auch deren visuelle und sensorische Trennbarkeit explizit zu berücksichtigen.

Die hohe zeitliche Korrelation der Zählverläufe in der beispielhaften Praxisanwendung zeigt, dass relative Verkehrsdynamiken zuverlässig abgebildet werden können. Mithilfe geeigneter Aggregations- und Kalibrierungsverfahren lassen sich KI-basierte Detektionen stochastisch in belastbare Verkehrskennzahlen überführen (Staab et al., 2021). Darüber hinaus erscheint die Integration objektbasierter Tracking-Ansätze als konsequenter nächster technologischer Schritt, um Mehrfachzählungen zu vermeiden und die Vergleichbarkeit mit etablierten Verfahren weiter zu erhöhen. Ein qualitativer Vergleich mit manuellen Verkehrszählungen verdeutlicht jedoch zugleich, dass vollautomatisierte KI-Lösungen nicht eins zu eins mit etablierten Erhebungsmethoden vergleichbar sind. Wenn menschliche Zählungen bewegte Fahrzeuge erfassen, erfolgt eine eindeutige Klassifizierung intuitiv und kontextabhängig.

7 AUSBLICK

Verkehrs-, Umwelt- und Klimaziele erfordern zunehmend hochfrequente, differenzierte und flächendeckende Datengrundlagen, die mit klassischen Erhebungsmethoden nur noch eingeschränkt wirtschaftlich bereitzustellen sind (Schulthoff et al., 2022). Die vorliegende Studie zeigt, dass KI-gestützte, kamerabasierte Verkehrszählungen unter geeigneten Rahmenbedingungen eine valide und skalierbare Ergänzung bestehender Verfahren darstellen können. In drei komplementären Experimenten wurden zentrale

Einflussfaktoren systematisch untersucht, darunter Aufnahmebedingungen, semantische Klassifikationstiefe und Modellarchitektur.

Die Untersuchung zeigt erstens, dass generische Out-of-the-Box Modelle unter günstigen Aufnahmebedingungen eine solide Basisleistung erzielen, jedoch bei ungünstigen Lichtverhältnissen deutlich an Robustheit verlieren. Zweitens, konnte ein klarer Zielkonflikt zwischen semantischer Differenzierung und erreichbarer Detektionsgenauigkeit identifiziert werden. Mit zunehmender semantischer Tiefe steigt zwar die planerische Aussagekraft der Klassifikation, gleichzeitig sinkt jedoch die automatisiert erreichbare Modellgüte. Hierarchische Klassifikationsschemata erweisen sich als geeigneter Ansatz, um diesen Zielkonflikt explizit zu adressieren und Ergebnisse auf unterschiedlichen Aggregationsebenen belastbar zu interpretieren. Drittens, zeigt der Praxisvergleich, dass KI-basierte Detektionen trotz konzeptioneller Unterschiede eine hohe Übereinstimmung der zeitlichen Verkehrsdynamik mit manuellen Zählungen aufweisen und prinzipiell in belastbare Verkehrskennzahlen überführt werden können. Gleichzeitig macht die kritische Diskussion deutlich, dass maschinelles Sehen als eigenständiges Instrument mit spezifischen Stärken verstanden werden muss. Sein Mehrwert liegt weniger in der punktgenauen Reproduktion etablierter Erhebungen als in der kontinuierlichen, automatisierten Erfassung relativer Verkehrsdynamiken über größere räumliche und zeitliche Skalen hinweg.

Die alleinige Steigerung der technologischen Kapazität (Moore, 1965) übertragen auf hiesig stetig wachsende Modellgrößen führt jedenfalls zu messbaren, jedoch immernoch begrenzten Leistungsgewinnen. Zukünftige KI-Generationen werden bestimmte Defizite –so die Erwartungshaltung–kompensieren können, die Notwendigkeit für hochwertigeDaten und realistische semantische Klassifikationsschemata wird allerdings bleiben.

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Warum passen Geographische Informationssysteme gut in den Schulunterricht? – Ein Beitrag zur Verankerung digitaler Geomedien in der Lehrerbildung

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1 ABSTRACT

Die fortschreitende Digitalisierung des Bildungssystems sowie die zunehmende Relevanz raumbezogener Daten in gesellschaftlichen, ökonomischen und politischen Kontexten rücken Geographische Informationssysteme (GIS) immer mehr in den Fokus kompetenzorientierter Lehr-Lern-Prozesse. Obwohl insbesondere das geographische Fachcurriculum, aber ebenso die Curricula natur-und gesellschaftswissenschaftlicher Fächer, zahlreiche inhaltliche und didaktische Anknüpfungspunkte für den Einsatz digitaler Geomedien bereitstellen, findet eine systematische Integration von GIS in der schulischen Praxis bislang nur in begrenztem Umfang statt. Eine zentrale Voraussetzung für eine nachhaltige Verankerung von GIS im Unterricht ist die Professionalisierung angehender Lehrkräfte sowieentlang der gesamten Lehrerbildungskette.

Wird der Einsatz digitaler Geodaten in der Schule aus einer medienpädagogischen Perspektive in den Blick genommen, wird deutlich, dass sich daraus erhebliche Bildungspotenziale ableiten lassen. Die Arbeit mit geobezogenen Informations- und Analysewerkzeugen trägt wesentlich zur Entwicklung jener digitalen, analytischen und reflexiven Kompetenzen bei, die Schülerinnen und Schüler für eine selbstbestimmte, kritische und verantwortungsvolle Teilhabe in einer hochgradig digitalisierten Gesellschaft benötigen (vgl.(Kultusministerkonferenz, 2021)).Damit wird nicht nur ein Zugang zur Förderung fachlicher Kompetenzen eröffnet, sondern zugleich auch ein Beitrag zur allgemeinen Medien- und Datenbildung im Sinne einer zeitgemäßen schulischen Bildung(Pettig & Gryl, 2023a, S. 68)geleistet.

Auf Basis von Erfahrungen aus der universitären Lehrpraxis werden Erfolgsbedingungen und typische Herausforderungen der GIS-Integration in der Lehrerbildung identifiziert: technische und organisatorische Rahmenbedingungen, notwendige Unterstützungsstrukturen sowie der Umgang mit heterogenen Vorerfahrungen. Zusätzlich soll aufgezeigt werden, welche Möglichkeiten zur Beschaffung von Geodaten aktuell bestehen, insbesondere mit Blick auf das wissenschaftliche Arbeiten und die Verfügbarkeit verlässlicher Daten. Abschließend wird herausgearbeitet, dass GIS nicht als zusätzliches „Add-on“, sondern als integraler Bestandteil eines kompetenzorientierten, digital gestützten Fachunterrichts verstanden werden können. Die konsequente Verankerung digitaler Geomedien in der Lehrerbildungskette erweist sich dabei als Schlüssel, um das bestehende Potenzial von GIS für schulisches Lernen langfristig zu erschließen.

Keywords: Geographische Informationssysteme, kompetenzorientierter Unterricht, Higher Education, Lehrerbildung, Geodaten

2 EINLEITUNG

Geographische Informationssysteme (GIS) haben sich in den vergangenen Jahren als zentrale Analyse- und Entscheidungsunterstützungssysteme in einer Vielzahl von Anwendungsfeldern etabliert, darunter insbesondere in der Stadt- und Raumplanung, dem Umweltmanagement sowie im Katastrophen- und Notfallmanagement. Durch ihre Fähigkeit zur integrierten Erfassung, Verarbeitung, Analyse und Visualisierung raumbezogener Daten ermöglichen GIS eine differenzierte Abbildung komplexer räumlicher Zusammenhänge und bilden somit eine fundierte Grundlage für evidenzbasierte Entscheidungsprozesse in Wissenschaft, Verwaltung und Praxis.

Vor dem Hintergrund der fortschreitenden Digitalisierung wird in der Bildungsforschung und -praxis die systematische Integration digitaler Medien – insbesondere digitaler Geomedien wie beispielsweise GIS – zunehmend als didaktische Notwendigkeit angesehen, um Lernende adäquat auf die Anforderungen einer digital geprägten Gesellschaft vorzubereiten ((Pettig& Gryl, 2023b, S. 22) und (Li et al., 2022, S. 2697)).Der Einsatz von GIS und digitalen Geotools im Erdkundeunterricht zielt nicht allein auf den Erwerb technischer Fertigkeiten ab, sondern primär auf die kognitive Anregung der Schüler und Schülerinnen ab, um deren systematisches Analysepotential und die Fähigkeit zu fundierten Entscheidungen zu stärken (Pungel & Steinbach, 2023, S. 67). Durch die Bearbeitung komplexer, raumbezogener Problemvorstellungen

entwickeln die Lernenden ein fachliches Tiefenverständnis sowie überfachliche Medienkompetenzen, die als essenzielle Voraussetzung für ein mündiges Leben in der digitalisierten Gesellschaft des 21. Jahrhunderts gelten(Pungel & Steinbach, 2023, S. 71).

Empirische Studien belegen, dass eine frühzeitige Implementierung von GIS-basierten Lernsettings signifikante positive Effekte auf das räumliche Denken sowie auf das Verständnis komplexer geographischer und raumbezogener Sachverhalte hat. Lernende, die regelmäßig mit GIS arbeiten, weisen ein vertieftes Verständnis räumlicher Interdependenzen auf und zeigen eine gesteigerte Fähigkeit zur Analyse, Interpretation und Bewertung geographischer Daten. Diese Befunde unterstreichen die bildungspolitische und didaktische Relevanz einer curricularen Verankerung von GIS im Schulunterricht zur Vorbereitung auf die Herausforderungen einer dynamischen und sich stetig wandelnden Welt(Kerski, 2003, 134f).

Dervorliegende Beitraganalysiert die Bedeutung von GIS im schulischen Bildungskontext und argumentiert, dass die systematische Integration digitaler Geomedien in der Lehrerbildung nicht nur zur Kompetenzentwicklung der Schülerinnen und Schüler beiträgt, sondern zugleich die Professionalisierung von Lehrkräften in ihrer didaktisch-methodischen Praxis unterstützt. Ziel ist es aufzuzeigen, wie GIS als wertvolles Werkzeug zur Förderung von interdisziplinärem Lernen und zur Entwicklung von Schlüsselkompetenzen genutzt werden kann, um die Bildung im 21. Jahrhundert zu bereichern.

3 DIE ROLLE VON GIS IM BILDUNGSKONTEXT

3.1 Geographische Informationssysteme in unserem Alltag

In Zeiten von Smartphones, Smartwatches und Tablets ist es kaum verwunderlich, dass nahezu alle Menschen mit Geodaten oder Geographischen Informationssystemen in Kontakt sind, auch wenn diese in den meisten Situationen nicht als zentrale Information wahrgenommen werden. Geographische Informationssysteme spielen eine entscheidende Rolle in vielen Aspekten unseres Alltags, indem sie Daten analysieren und visualisieren sowie Entscheidungen unterstützen.

Die folgende Grafik verdeutlicht die verschiedenen Anwendungsbereiche von GIS sowie die spezifischen Rollen, die diese Systeme in unterschiedlichen Kontexten einnehmen. Sie zeigt, dass GIS nicht nur als technisches Werkzeug, sondern auch als integraler Bestandteil von Entscheidungsprozessen, Planung und Kommunikation fungiert.



Abbildung 1: Die multifunktionale Rolle von GIS in verschiedenen Anwendungsbereichen (Eigene Darstellung)

Sowohl die Anwendungsbereiche als auch die verschiedenen Rollen sind in dieser Darstellung nicht gewichtet zu betrachten. Vielmehr soll Abbildung 1zeigen, dass alle dargestellten Bestandteile gleichwertig

sind und gemeinsam zu einem ganzheitlichen System beitragen. Diese integrative Perspektive unterstreicht die Interdependenz der verschiedenen Anwendungsbereiche und Rollen von GIS, die zusammenwirken, um die Effektivität und Relevanz von Geoinformationssystemen in der modernen Gesellschaft zu maximieren.

Gleichzeitig soll Abbildung 1verdeutlichen, dass sich die Anwendungsbereiche nicht nur mit geographischen Schwerpunktthemen verbinden lassen, sondern auch interdisziplinär und fächerübergreifend genutzt werden können. Dabei liegen die jeweiligen Fächer nicht nur im naturwissenschaftlichen, sondern auch im gesellschaftswissenschaftlichen und sprachlichen Bereich. Die genannten Rollen können im Rahmen solcher Unterrichtseinheiten oder auch schulinternen Projekten von den Schülerinnen und Schülern in unterschiedlichen Intensitäten wahrgenommen werden. Hierfür muss allerdings gewährleistet sein, dass die Schülerschaft die entsprechenden Voraussetzungen für eine solche Rolle mitbringen.

3.2 Lehrplananalytische Betrachtung unter dem Schwerpunkt GIS

Betrachtet man den Einsatz digitaler Geodaten im schulischen Kontext aus der Perspektive der Medienbildung, wird deutlich, dass dieser über die Vermittlung fachlicher Inhalte hinausgeht und zugleich die Entwicklung zentraler Medien- und Datenkompetenzen fördert, die als Grundlage für ein selbstständiges, reflektiertes und mündiges Leben in einer zunehmend digitalisierten Gesellschaft anzusehen sind(Pungel & Steinbach, 2023, S. 68). Dies zeigt sich auch mit Blick auf die unterschiedlichen Themenfelder im Unterrichtsfach Erdkunde. Der Lehrplan für die Mainzer Studienstufe in Rheinland-Pfalz ist hinsichtlich der fachlichen Inhalte kompetenzorientiert und methodenoffen formuliert, wodurch sich für den Einsatz digitaler Geomedien gerade auch mit Blick auf den Einsatz von GIS, weitreichende didaktische Anschlussmöglichkeiten ergeben. Auch wenn die Suchergebnisse nach Wörtern wie beispielsweise „GIS“, „Geographische Informationssysteme“ oder auch „Geodaten“ auf den ersten Blick keine Treffer anzeigen, lassen sich beigenauerer Betrachtung der Methoden und Lernfelder die jeweiligen Anknüpfungspunkte ausfindig machen. Allgemein lässt sich an dieser Stelle formulieren, dass der Einsatz von GIS immer dann sinnvoll ist, wenn Mensch-Umwelt-Beziehungen oder auch die nachhaltige Raumentwicklung thematisiert werden sollen, indem die Analyse komplexer Wechselwirkungen zwischen naturräumlichen Gegebenheiten, anthropogenen Eingriffen und Risiken (wie beispielsweise Naturgefahren) zentrale Kompetenzanforderungen darstellen.

Unter Berücksichtigung der in den einzelnen Lernfeldern zu schulenden und weiterzuentwickelnden Methoden zeigt sich, dass vor allem die Lernfelder 3, 7 und 10.1 der gymnasialen Oberstufe einen GIS-methodischen Schwerpunkt aufweisen (vgl. Tabelle 1). Da im Lernfeld 7: „Städtische Siedlungen im Wandel“ neben den verpflichtenden Kompetenzen auch zusätzlich noch vier anregende Kompetenzbeispiele genannt werden, soll dieses näher betrachtet werden:

Die in diesem Lernfeld formulierten Kompetenzanforderungen zielen unter anderem auf die Analyse und Erklärung städtischer Strukturen, sozialräumlicher Disparitäten sowie funktionaler Differenzierungen und Nutzungskonflikte ab und verlangen von den Lernenden, räumliche Prozesse zu untersuchen, zu bewerten und planerische Handlungsoptionen zu reflektieren. Die im Lehrplan geforderte Fähigkeit, raumbezogene Strukturen und Prozesse unter Einbezug unterschiedlicher Standortfaktoren zu analysieren sowie Erreichbarkeiten und Nutzungskonflikte zu beurteilen, korrespondiert in hohem Maße mit zentralen Funktionalitäten von GIS, da sie hier eine systematische Auswertung räumlicher Muster, die Visualisierung komplexer Zusammenhänge sowie die modellhafte Situation planerischer Eingriffe aufweisen. Sie erweisen sich damit als fachtypisches Instrument zur Umsetzung der intendierten Analyse- und Bewertungskompetenzen.

Unter Berücksichtigung der Lehrplaninhalte und der verpflichtenden methodischen Vorgabe wird in Lernfeld 7 der Einsatz digitaler Geomedien im Lehrplan konkretisiert. Der Kompetenzschwerpunkt liegt auf der Analyse städtischer Strukturen unter Nutzung digitaler Karten sowie von Luft- und Satellitenbildern. Damit wird die Fähigkeit der Lernenden gefordert, Raumstrukturen datenbasiert zu erfassen, zu interpretieren und in ihren funktionalen sowie sozialräumlichen Ausprägungen zu erklären. Die explizite Bezugnahme auf digitale kartographische Darstellungsformen weist auf eine methodische Nähe zu GIS-gestützten Arbeitsweisen hin. Da diese eine integrierte Analyse und Visualisierung räumlicher Informationen ermöglichen und über rein statistische Karten hinausgehen. Darüber hinaus regt der Lehrplan im Rahmen des Lernfeldes ausdrücklich die Nutzung und den vergleichenden Einsatz von Geodaten aus diversen Geoportalen an, um beispielsweise Informationen über unterschiedliche Stadtviertel

auszuwerten(Ministerium für Bildung – Rheinland-Pfalz, 2022, S. 51). Diese methodische Vorgabe impliziert die Arbeit mit raumbezogenen Daten unterschiedlicher Herkunft sowie deren kritische Auswahl, Auswertung und Bewertung. In diesem Kontext kann GIS als fachtypisches Instrument verstanden werden, das die im Lehrplan intendierte Analyse-, Methoden- und Urteilskompetenz unterstützt, indem es den systematischen Vergleich räumlicher Strukturen, die Verknüpfung verschiedener Datensätze sowie die reflektierte Auseinandersetzung mit digitalen Raumdarstellungen ermöglicht. Lernfeld 7 stellt damit eines der wenigen Beispiele im Lehrplan dar, in dem der Einsatz digitaler Geomedien nicht nur implizit nahegelegt, sondern in Form konkreter methodischer Zugänge ausdrücklich eingefordert wird.

		M3	M3	M3	M3	M4	M4	M4	M4	M7	M7	M8
Lernfelder Lehrplan MSS		Exkursion	virtuelle Exkursion	Befragung,Interview, Expertengespräch	Kartierung	Informationen aus digitalen & analogen Quellen	Informationen aus Karten-, Luft- & Satelliten-bildern, Fernerkundung	fragengeleitete Raumanalyse	Geoportale	Kartenskizze,Karte, Storymap	Konzepte, Planungen, Strategie-papier	Szenarien, Simulationen, Modelle, Theorien, Indikatoren und Klassifikationen
Pflicht												
1	Globaler Wandel – Der geographische Blick											
2	Klima – ein System im Wandel											
3	Dynamik landschaftsformenden Prozesse											
4	Rohstoffe und Energieversorgung für die Zukunft											
5	Agrarwirtschaft und Ernährungs-sicherung											
6	Produktion und Dienstleistungen in einer globalisierten Welt											
7	Städtische Sied-lungen im Wandel											
8	Disparitäre Entwicklungen											
9	Migration – Herausforderungen eines globalen Prozesses											
Wahlpflicht												
10.1	Tourismus als raumprägender Faktor											
10.2	Mobilität und Verkehr in einer vernetzten Welt											
10.3	Bedeutung und Belastung der Meere											
10.4	Nutzung vulnerabler Räume											

Tabelle 1: Matrix der GIS-Methoden und ihrer Anwendung in den einzelnen Lernfeldern des Erdkunde-Lehrplans (Leistungskurs EK- Rheinland-Pfalz) nach Pflicht (orange) und Anregung (grün); (Eigene Darstellung, nach Ministerium für Bildung – Rheinland-Pfalz, 2022

Die detaillierte Analyse des Lehrplans für den Erdkunde Leistungskurs der Oberstufe verdeutlicht, dass Geographische Informationssysteme im Curriculum weniger als explizit normiertes Unterrichtswerkzeug, sondern vielmehr als implizit angelegtes methodisches Querschnittsinstrument zu verstehen sind. Die Analyse der einzelnen Lernfelder zeigt, dass GIS insbesondere dort eine fachlich konsequente Umsetzung der intendierten Kompetenzanforderungen ermöglicht, wo komplexe räumliche Strukturen, Nutzungskonflikte und raumbezogene Entscheidungsprozesse im Mittelpunkt stehen. GISwird somit nicht zum Selbstzweck, sondern fungiert als Mittel zur vertieften Raumanalyse, zur Förderung datenbasierter Urteilsbildung und zur reflektierten Auseinandersetzung mit digitalen Raumdarstellungen.

Zugleich macht die lehrplanbezogene Betrachtung deutlich, dass die methodenoffene Formulierung der Kompetenzziele den Einsatz von GIS zwar nicht zwingend vorschreibt, ihn jedoch in zentralen Lernfeldern fachlich nahelegt. Daraus ergibt sich für den Erdkundeunterricht das Potential, GIS als integrativen Bestandteil einer zeitgemäßen geographischen Bildung zu etablieren, der die sechs Kompetenzbereiche der Geographie zielorientiert miteinander verknüpft. Vor diesem Hintergrund kommt der Professionalisierung von Lehrkräften im Umgang mit digitalen Geomedien eine Schlüsselrolle zu, um die im Lehrplan angelegten Potentiale didaktisch reflektiert und lernwirksam auszuschöpfen.

4 GIS-WERKZEUGE FÜR DEN UNTERRICHT

In diesem Kapitel wird eine systematische Übersicht über geeignete GIS-Werkzeuge für den Schulunterricht gegeben, die den technologischen Wandel von komplexen Expertensystemen zu niedrigschwelligen, webbasierten Anwendungen mit hoher schulischer Zugänglichkeit in Bezug auf Bedienbarkeit, technische Voraussetzungen und Unterrichtseinbindung dokumentiert. Die ausgewählten Werkzeuge werden hinsichtlich ihrer funktionalen Eignung und ihres didaktischen Mehrwerts kategorisiert, um Lehrkräften eine fundierte Entscheidungsgrundlage für die Integration von GIS in den Unterricht zu bieten.

Bei der Auswahl von Applikationen, Webanwendungen oder anderen Tools, die in den Unterricht eingebettet werden sollen, steht häufig die zentrale Frage im Raum: „Welches Tool ist für meinen spezifischen Einsatz am besten geeignet?“ In Anbetracht der didaktischen und methodischen Zielsetzungen gestaltet sich die Auswahl oft als umfangreich und komplex. Die Vielzahl an Optionen kann dazu führen, dass viele Lehrkräfte das Interesse an der weiteren Auseinandersetzung mit den verfügbaren Werkzeugen verlieren. Vor diesem Hintergrund wäre es von Vorteil, wenn ein oder zwei ausgewählte Tools existieren würden, die eine Vielzahl von Anwendungsbereichen für den Schulunterricht abdecken.

Abbildung 2 veranschaulicht eine systematische Einordnung von GIS-Werkzeugen hinsichtlich ihres funktionalen Komplexitätsgrades sowie ihrer jeweiligen Zielgruppenorientierung.

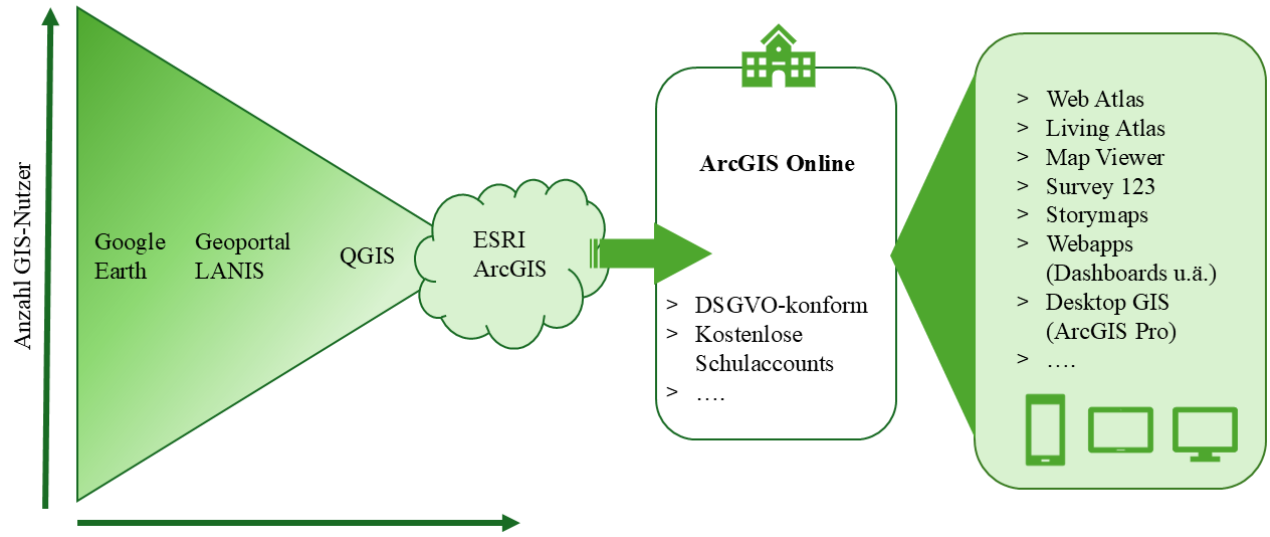


Abbildung 2: Systematisierung von GIS-Werkzeugen nach funktionaler Komplexität und Zielgruppen und deren Anpassung für den Bildungsbereich in Schulen (Eigene Darstellung)

Auf der linken Seite der Darstellung sind niedrigschwellige Viewer und digitale Globen für den Massenmarkt verortet (z. B. Google Earth), die primär der Exploration, Visualisierung und ersten räumlichen Orientierung dienen. Diese Anwendungen zeichnen sich durch eine hohe Benutzerfreundlichkeit und geringe technische Einstiegshürden aus und eignen sich insbesondere für einen ersten Zugang zu raumbezogenen Fragestellungen sowie zur Förderung grundlegender räumlicher Vorstellungen. Digitale Globen oder auch Viewer eignen sich für den Schulunterricht, da sie ein Werkzeug zur Verbesserung der räumlichen Wahrnehmung darstellen und bieten die Möglichkeit, dass Schülerinnen und Schüler eigenständig topographische Profile, wie beispielsweise Geländemodelle in der eigenen Stadt, untersuchen.

Auf einer mittleren Ebene sind Web-GIS-Applikationen positioniert, die einen erweiterten Funktionsumfang zur Analyse und Interpretation raumbezogener Daten zur Verfügung bereitstellen. Hier bieten vor allen

nationale Geoportale wie zum Beispiel das Landschaftsinformationssystem der Naturschutzverwaltung Rheinland-Pfalz (LANIS RLP) Plattformen zur Beschaffung von Geodaten, die bei deutschen Behörden vorliegen (vgl. Kap.5 – Geodatenauskunfts- und Bereitstellungssysteme). Diese Geoportale ermöglichen die Nutzung thematischer Layer, den Vergleich unterschiedlicher Datensätze und eine stärker problemorientierte Auseinandersetzung mit konkreten räumlichen Fragestellungen. Diese Tool-Kategorie stellt eine zentrale Schnittstelle zwischen professioneller GIS-Nutzung und schulischer Anwendbarkeit dar, da sie sowohl fachlich relevante Analyseprozesse unterstützt als auch unter schulischen Rahmenbedingungen mit Blick auf Nutzung verschiedener Endgeräte oder der Internetverfügbarkeit, praktikabel bleibt.

An der Spitze der Hierarchie befinden sichleistungsfähige GIS-Umgebungen wie QGIS oder ESRI ArcGIS eingeordnet, die ein umfassendes Spektrum an Analyse-, Modellierungs- und Visualisierungsfunktionen bereitstellen. Diese Systeme sind primär für professionelle Anwendungsfelder konzipiert und setzen ein hohes Maß an fachlichem Vorwissen sowie technischer Kompetenz voraus. Im schulischen und bildungsbezogenen Kontext der GIS-Nutzung wird dagegen häufig zwischen Open-Source-Lösungen (wie QGIS) und kommerziellen Softwareprodukten des Anbieters ESRI ArcGIS unterschieden. QGIS zeichnet sich als quelloffene Software insbesondere durch seine Kostenfreiheit, hohe Flexibilität und breite Community-Unterstützung aus. Es ermöglicht den Zugriff auf ein umfangreiches Spektrum an Analyse- und Visualisierungsfunktionen und eignet sich aufgrund seiner Offenheit gut für eine transparente Auseinandersetzung mit Geodaten, Datenformaten und Analyseprozessen. Gleichzeitig stellen die vergleichsweise komplexe Benutzeroberfläche und die Vielzahl an Funktionen insbesondere im schulischen Bereich eine didaktische Herausforderung dar, da ohne gezielte Reduktion und Anleitung eine Überforderung der Lernenden und Lehrenden möglich ist.

Die Software-Produkte von ESRI ArcGIS bieten demgegenüber eine integrierte, professionell entwickelte GIS-Umgebung mit hoher Stabilität, umfangreicher Dokumentation und didaktisch aufbereiteten Zusatzangeboten, etwa in Form von webbasierten Anwendungen, Storymaps oder den Field Apps, die auch im offline-Modus bearbeitet werden können. Zusätzlich wird für Schulen in Deutschland, der Schweiz und Österreich eine kostenlose Education-Lizenz angeboten, mit der Möglichkeit eigene Klassenräume zu generieren, Daten vorzubereiten und zu teilen sowie an Schulungen oder Webinaren für Lehrkräfte teilzunehmen. Durch die Verwendung von ArcGIS Online wird den Lehrkräften ein webbasiertes Tool angeboten, welches aus fachdidaktischer Sicht eine didaktische Reduktion im Programmlayout enthält und gleichzeitig die Chance bietet,alle Bausteine einer durchdachten GIS-Anwendung zu nutzen. So können beispielsweise mit Survey123 Daten erhoben, mit dem MapViewer aufbereitet und die Ergebnisse mittels Dashboards oder einer Storymap visualisiert werden (MEVAP-Prinzip). Diese Aspekte erleichtern insbesondere Lehrkräften den Einstieg in die GIS-Welt und eröffnen strukturierte Einsatzmöglichkeiten in unterschiedlichen Schwierigkeitsgraden und Umfängen.Ergänzt wird die Produktpalette durch die administrative Verwaltung auf Seiten der Schule, wodurch die Schule als Controller fungiert und alle personenbezogenen Daten verwaltet. Diese Daten werden auf europäischen Servern gespeichert und nicht an die Rechenzentren in den USA weitergegeben(Schomakers & Kijftenbelt, o.A., o.A.).

Aus didaktischer Perspektive lässt sich festhalten, dass weder QGIS noch ESRI ArcGIS per se „besser“ oder „schlechter“ zu bewerten sind, sondern ihre Eignung maßgeblich vom jeweiligen Einsatzkontext abhängt. Gleichzeitig soll auch aufgezeigt werden, dass der Wunsch nach einem Programm/ Tool, welches eine breitere Produktpalette anbietet, bei ESRI ArcGIS realisierbar ist, was den Lernprozess sowohl für die Schülerinnen und Schüler als auch für die Lehrkräfte erleichtert.

4.1 Erwerben von GIS-Kompetenzen – ein Future Skill?

Die digitale Durchdringung nahezu aller Lebens- und Arbeitsbereiche bewirkt eine epochale Veränderung des Mensch-Umwelt-Verhältnisses, in der räumliche Informationen zu einer grundlegenden Ressource gesellschaftlichen Handelns avancieren. Der souveräne Umgang mit Geoinformationen entwickelt sich in diesem Kontext zu einer digitalen Kulturtechnik, deren Beherrschung weit über fachspezifische Anwendungsfelder hinausreicht(Pettig & Gryl, 2023a, S. 8). Das Erreichen von GIS-Kompetenzen erfordert allerdings eine Verschiebung des Fokus: weg vom isolierten „Lernen über GIS“ hin zu einem integrativen „Lernen mit GIS“ im Sinne eines geographischen Werkzeugs. Die empirischen Befunde unterstreichen somit die Notwendigkeit, GIS systematisch in die Lehrerbildung, schulinterne Curricula und fachdidaktische Konzepte einzubetten, um den Anspruch an GIS als Future Skill nicht nur normativ zu formulieren, sondern

auch praktisch einzulösen(Höhnle et al., 2012, S. 56). Vor diesem Hintergrund lässt sich die Frage, ob GIS als Future Skill zu bewerten ist, nicht allein technisch, sondern primär kompetenz- und gesellschaftsbezogen beantworten.Ein zentrales Argument für die Einordnung von GIS als Future Skill ergibt sich nämlich aus seiner wachsenden Relevanz für den Arbeitsmarkt. GIS-Kenntnisse werden in einer Vielzahl von Berufsfeldern – etwa im Bereich Naturschutz, Stadt- und Raumplanung, im Umweltmanagement oder in datengetriebenen Wirtschaftssektoren – explizit nachgefragt(Sailer et al., 2023, S. 220). Gleichzeitig entstehen neue professionsspezifische Tätigkeitsprofile wie „Geospatial Data Scientist“ oder „Geospatial Software Engineer“, die neben technischem Know-how, vor allem analytische, interpretative und kommunikative Kompetenzen im Umgang mit räumlichen Daten erfordern. Die Fähigkeit, räumliche Problemstellungen datenbasiert zu analysieren und lösungsorientiert aufzubereiten, wird damit zu einer zentralen Qualifikation einer zukunftsfähigen Arbeitnehmerschaft und formuliert zugleich einen klaren Bildungsauftrag an die Schulen und Hochschulen/ Universitäten(Sailer et al., 2023, 220f).

GIS kommt darüber hinaus eine herausragende Bedeutung für die Entscheidungsunterstützung und das Krisenmanagement zu. In praxisrelevanten Anwendungsfeldern wie dem Hochwasserrisikomanagement oder der Katastrophenvorsorge bzw. -bewältigung, bilden GIS eine zentrale Grundlage für Lageerfassung, Prognose und datenbasierte Entscheidungsprozesse(Fabisch et al., 2023, 23f). Der eigentliche Mehrwert dieses Future Skill liegt dabei weniger in der reinen Datenverarbeitung als vielmehr in der Fähigkeit, heterogene Geodaten entlang eines Kontinuums der Erkenntnisgewinnung in belastbares, handlungsrelevantes Wissen zu transformieren. Dies erfordert Kompetenzen zur Verknüpfung verschiedener Datenquellen, zur Bewertung von Unsicherheiten sowie zur adressatengerechten Geokommunikation – Fähigkeiten, die für eine zunehmend datenbasierte Gesellschaft konstruktiv sind (Thomas et al., 2025, S. 182).

Mit Blick auf den Bildungskontext, d.h. der kognitiven Ebene, zielt die GIS-Bildung auf die Entwicklung eines kritischen räumlichen Denkens (criticalspatialthinking), das Lernende befähigt, räumliche Muster zu erkennen, Wechselwirkungen systematisch zu erfassen und die Aussagekraft sowie Grenzen räumlicher Daten reflektiert zu beurteilen(Bearman et al., 2016, S. 394). Der Umgang mit GIS fördert dabei nicht nur die Problemlösekompetenzen, sondern auch das systemische Denken, welches für die Bearbeitung komplexer globaler Herausforderungen wie Klimawandel, Urbanisierung oder Ressourcenknappheit unerlässlich ist(Schulze & Gryl, 2022, S. 155). In diesem Sinne positioniert sich die Geographie durch GIS als zukunftsorientierte Analysewissenschaft mit einem klaren methodischen Alleinstellungsmerkmal.

Ein weiterer zentraler Aspekt der Einordnung von GIS als Future Skill liegt in seiner Bedeutung für Mündigkeit und gesellschaftliche Partizipation. Konzepte wie „Spatial Citizenship Education“ betonen die Notwendigkeit, Lernende nicht nur zu kompetenten Nutzerinnen und Nutzern von Geomedien auszubilden, sondern sie befähigen, räumliche Informationen aktiv als Kommunikations- und Partizipationsinstrumente einzusetzen(Kanwischer & Dorsch, 2023, S. 144).In digitalen Öffentlichkeiten, die zunehmend durch Karten, Dashboards und räumliche Visualisierungen geprägt sind, umfasst dies auch die Fähigkeit, eigene räumliche Repräsentationen zu erstellen, zu verarbeiten und deren Konstruiertheit kritisch zu reflektieren. GIS-Kompetenz schließt somit eine reflexive Kartenkompetenz mit ein, die es erlaubt, Machtstrukturen, narrative und potenzielle Manipulationen in digitalen Raumdarstellungen zu erkennen und zu dekonstruieren ((Pungel& Steinbach, 2023, S. 80) sowie (Gryl, 2016, S. 8)).

Die Vermittlung dieser vielfältigen Kompetenzdimensionen lässt sich methodisch mit dem MEVAP-Modell strukturieren. Dieses Modell bildet den vollständigen Workflow geographischer Erkenntnisgewinnung ab: von der Modellierung über Erfassung, Verarbeitung und Analyse bis hin zur Präsentation. Dieser Prozess fördert in besonderem Maße die Data Literacy und verankert GIS nicht als isolierte technische Anwendung, sondern als integratives Instrument geographischer Analyse- und Urteilskompetenz (Sailer et al., 2023, S. 221).

Zusammenfassend zeigt sich also, dass die Vermittlung von GIS-Kompetenzen im Sinne einer„Spatial Citizenship“für das Schulfach Erdkunde ein zentrales Alleinstellungsmerkmal darstellt, das seine Zukunftsfähigkeit und Unverzichtbarkeit im Kanon schulischer Unterrichtsfächer nachhaltig stärkt. Diese Position lässt sich fachlich dadurch untermauern, dass GIS-Kompetenzen weit über eine spezialisierte technische Fähigkeit hinausgehen und zentrale Anforderungen einer (geo-)digitalisierten Gesellschaft adressieren(Sailer et al., 2023, S. 234). Als Future Skill des 21. Jahrhunderts verbindet sie

arbeitsmarktrelevante Qualifikationen mit der Förderung kritischen räumlichen Denkens, datenbasierter Urteilsfähigkeit sowie demokratischer Teilhabe. Eine curriculare Verankerung von GIS trägt somit nicht nur zur Vorbereitung Lernender auf verantwortungsvolles, reflektiertes Handeln in datengetriebenen Kontexten bei, sondern positioniert das FachGeographie zugleich als zukunftsorientierte Analyse- und Bildungswissenschaft, die einen substanziellen Beitrag zur Allgemeinbildung leistet.

5 GEODATENAUSKUNFTS- UND BEREITSTELLUNGSSYSTEME

Die Verfügbarkeit amtlicher Geodaten hat sich in den letzten 20 Jahren durch technologische Entwicklungen und politische Vorgaben grundlegend verbessert. Die EU-Richtlinie „Infrastructure forSpatial Information in Europe“ (kurz: INSPIRE) bildet die rechtliche Basis, um zehntausende harmonisierte Datensätze aus den Mitgliedstaaten zur allgemeinen Nutzung bereitzustellen (Richtlinie 2007/2/EG des Europäischen Parlaments und des Rates vom 14. März 2007 zur Schaffung einer Geodateninfrastruktur in der Europäischen Gemeinschaft (INSPIRE), 2007, o.A.).

Für Fragestellungen im Bildungskontext ergeben sich zwei Hauptbereiche, die als Geodatenauskunftssystem fungieren können.

(1) Damit Schülerinnen und Schüler lernen mit fachlich korrekten Daten deutscher Behörden zu arbeiten, sind die jeweiligen Geoportale der Bundesländer eine gute Anlaufstelle zur Beschaffung der jeweiligen Geodaten. Die abgedeckten Themenfelder reichen von der öffentlichen Daseinsvorsorge und dem Liegenschaftskataster über digitale Geländemodelle bis hin zu spezifischen Fachdaten der Landesämterfür Statistik in den jeweiligen Bundesländern. In den meisten Fällen sind die Daten der Geoportale in WEB-GIS-Anwendungen der Behörden integriert und können dort in Karten dargestellt werden. Zusätzlich gibt es oft die Funktion, Datensätze in Form von Shapefiles herunterzuladen und mit einem GIS der Wahl zu bearbeiten, zu verändern und zu analysieren. Dies bringt für den schulischen Kontext den entscheidenden Vorteil mit, dass die Daten auf die jeweilige Fragestellung und die Zielgruppe und deren Kompetenzen zugeschnitten werden können.

Der Blick in den Lehrplan (vgl. Kapitel 3.2) zeigt bereits, dass die Arbeit mit Geoportalen lediglich in Lernfeld 7 konkret genannt wird, jedoch sollte klar sein, dass Material, welches in den anderen Lernfeldern verwendet wird, entweder aus den Daten der Geoportale resultiert oder im besten Fall mit den aktuellen Daten aus den Geoportalen von den Lehrkräften aufbereitet und den Schülerinnen und Schülern zur Verfügung gestellt wird.

Der Zugriff auf amtliche Geodaten verdeutlicht den Schülerinnen und Schülern die Relevanz und Bedeutung solcher Datenquellen. Im Gegensatz zu OpenData-Portalen, in denen die Nutzer ihre „Geodaten“ teilen können, jedoch die Metadaten häufig nicht transparent sind, ermöglicht dieser Zugang eine fundierte Analyse und den Vergleich der Datenqualität. Dies fördert das Verständnis für die Unterschiede in der Zuverlässigkeit und Validität von Geodaten und unterstützt die Entwicklung kritischer Bewertungsfähigkeiten im Umgang mit Informationen.

(2) Neben den amtlichen Geodaten gibt es zusätzlich die Möglichkeit über verschiedene Plattformen Geodaten zu beziehen. Hier eignet sich für den schulischen Gebrauch die Schnittstelle von ArcGIS Online sowohl mit den rein behördlichen Daten, aber auch zum Datenaustausch von projekteigenen Daten. Dadurch können Datensätze direkt auf ihre Metadaten geprüft, Layer eingefügt und analysiert werden. Gleichzeitig bietet ArcGIS Online die Möglichkeit auf den ArcGIS Living Atlas of the World zuzugreifen. Hierbei handelt es sich um eine von ESRI ArcGIS initiierte Plattform zum digitalen Austausch von Geodaten, Kartenmaterialien oder auch Datenlayern und geographischen (Attribut-)Informationen (Dagermond).

6 ZUSAMMENFASSUNG UND AUSBLICK

Geographische Informationssysteme sind längst fester Bestandteil des Alltags, auch wenn ihre Nutzung häufig unbewusst erfolgt. Mobile Endgeräte und digitale Anwendungen ermöglichen die kontinuierliche Erhebung, Analyse und Visualisierung raumbezogener Daten, wodurch GIS-Kompetenzen zunehmend auch außerhalb klassischer Fachkontexte an Bedeutung gewinnen. Angesichts neuer Berufsfelder, in denen der reflektierte Umgang mit Geodaten, räumlicher Analyse und kritischer Visualisierung zentral ist, ergibt sich ein klarer Bildungsauftrag, GIS stärker im schulischen Kontext zu verankern. Dies steht im Einklang mit

dem Ziel der Kultusministerkonferenz, Lernende zu mündigen Bürgerinnen und Bürgern zu befähigen, die digitale Informationsräume kompetent und verantwortungsvoll nutzen können.

Mit der Weiterentwicklung des Lehrplans für die Mainzer Studienstufe hat Rheinland-Pfalz hierfür eine wichtige Grundlage geschaffen, indem GIS-bezogene Visualisierungen und die Arbeit mit Geodaten in mehreren Lernfeldern verbindlich berücksichtigt werden. GIS wird damit als methodisches Querschnittsinstrument sichtbar, das fachliche Analyseprozesse unterstützt und zugleich zur Entwicklung von Medien-, Daten- und Urteilskompetenz beiträgt. Eine zielgruppenorientierte GIS-Didaktik fördert dabei nicht nur technische Fertigkeiten, sondern insbesondere kritisches räumliches Denken und die Fähigkeit, komplexe raumbezogene Fragestellungen evidenzbasiert zu bearbeiten. Empirische Befunde unterstreichen die positiven Effekte eines frühen GIS-Einsatzes auf das räumliche Vorstellungsvermögen und das Verständnis geographischer Zusammenhänge und stärken damit die bildungspolitische Legitimation einer curricularen Verankerung.

Die Lehrplananalyse zeigt insgesamt, dass GIS in der gymnasialen Oberstufe als integratives Analysewerkzeug angelegt ist, das insbesondere in raumbezogenen Themenfeldern wie der Stadtentwicklung substanzielle Lernpotenziale eröffnet. Daraus ergibt sich für die Zukunft die Aufgabe, die curricular angelegten Möglichkeiten durch gezielte Lehrerbildung, didaktisch reduzierte Materialien und praxistaugliche Unterrichtskonzepte systematisch auszuschöpfen, um GIS-Kompetenz als Bestandteil einer zeitgemäßen geographischen Bildung nachhaltig zu etablieren.

Trotz dieser positiven Aspekte gibt es jedoch signifikante Barrieren, die einer effektiven Integration von GIS in den Schulunterricht entgegenstehen. Damit Schülerinnen und Schüler in der Oberstufe mit GIS arbeiten können, müssen bereits die grundlegenden Kompetenzen in der Mittelstufe erworben und vertieft werden. Dies bedeutet, dass die Lehrpläne in diesem Bereich ebenfalls modifiziert werden müssen. Im gleichen Zuge müssen in allen drei Phasen der Lehrerbildung Lehrkräfte im Umgang mit GIS geschult werden, weshalb Fort- und Weiterbildungen unabdingbar sind. Hierfür benötigen die Lehrkräfte in zweierlei Hinsicht Zeit:

(1) Werden Weiterbildungsangebote für Lehrkräfte angeboten, müssen sie ausreichend Zeit dafür haben, sich mit den „neuen“ und „unbekannten“ Methoden vertraut zu machen und diese in einem geschützten Kontext auszuprobieren.

(2) Die Lehrpläne aller deutschen Bundesländer zeigen eine Vielzahl an inhaltlichen Vorgaben und methodisch-verpflichtenden Bausteinen. Erfahrungsgemäß ist es für die Lehrkräfte meist sehr schwer alle Forderungen zielgruppenorientiert in den Unterricht zu integrieren. Daher müssen Zeiträume hierfür angepasst werden, damit die Lehrkräfte auch die Möglichkeit haben die Inhalte und Methoden für ihre Zielgruppe aufzubereiten.

Die nachhaltige Verankerung von GIS als Bestandteil zeitgemäßer geographischer Bildung ist untrennbar mit einer Modernisierung der Lehrkräftebildung verbunden. Soll GIS-Kompetenz tatsächlich als Future Skill wirksam werden, bedarf es einer strukturellen Weiterentwicklung geographiedidaktischer Ausbildungsinhalte, die GIS nicht als isoliertes Spezialwerkzeug, sondern als integratives Instrument fachlicher Erkenntnisgewinnung begreift. In diesem Zusammenhang ist es zentral, bestehende Barrieren systematisch in verschiedenen Forschungsfeldern zu identifizieren, um gezielte Strategien zu ihrer Überwindung zu entwickeln. Neben der Professionalisierung der Lehrkräfte im Umgang mit digitalen Geomedien sind die Bereitstellung geeigneter technischer Ressourcen sowie der Aufbau eines unterstützenden schulischen Umfelds wesentliche Voraussetzungen, um GIS dauerhaft als Bestandteil einer modernen Geographiebildung zu etablieren.

Zukünftige Forschungs- und Entwicklungsarbeiten sollten sich daher verstärkt auf praxisorientierte Fortbildungsmodelle konzentrieren, die sowohl technische als auch didaktische Dimensionen des GIS-Einsatzes berücksichtigen. Lehrkräfte benötigen Lerngelegenheiten, in denen sie GIS-gestützte Analyseprozesse selbst erproben, reflektieren und auf unterschiedliche Unterrichtskontexte übertragen können. Parallel dazu erscheint eine kontinuierliche Weiterentwicklung curricularer Vorgaben notwendig, um den dynamischen Anforderungen einer digitalisierten und datenbasierten Gesellschaft gerecht zu werden. Die stärkere Einbindung von GIS in alle Phasen der Lehrkräftebildung ist somit als strategische Aufgabe zu verstehen, die darauf abzielt, Lernende auf komplexe, interdisziplinär geprägte Raumfragen vorzubereiten. GIS eröffnet hier besondere Potenziale für fachübergreifendes Lernen, da die Analyse räumlicher Daten in

ökologischen, ökonomischen und gesellschaftlichen Kontexten verankert werden kann und damit ein vertieftes Verständnis systemischer Zusammenhänge fördert.

Insgesamt wird deutlich, dass GIS nicht nur als technisches Werkzeug, sondern als zentrale Schlüsselkompetenz des 21. Jahrhunderts zu begreifen ist. Die Verbindung arbeitsmarktrelevanter Qualifikationen mit der Förderung kritischen räumlichen Denkens, datenbasierter Urteilskompetenz und gesellschaftlicher Teilhabe unterstreicht die bildungspolitische Relevanz einer systematischen curricularen Verankerung. Eine entsprechend ausgerichtete Lehrkräftebildung stellt dabei den entscheidenden Hebel dar, um die Potenziale von GIS langfristig in eine lernwirksame Unterrichtspraxis zu überführen und die Geographie als zukunftsorientierte Analyse- und Bildungswissenschaft nachhaltig zu stärken.

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What Residents Tell us about Urban Redevelopment Projects in Tokyo: A Comparison of Residents' Feedback and Government Narratives using Google Maps Reviews

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1 ABSTRACT

Digital applications are becoming more and more important for public participation, consultation and surveys, making use of digital twin platforms and interactive Geographic Information Systems (GIS), among others. The most well-known and widely used web-GIS tool with interactive elements is surely Google Maps, which allows users to rate and comment on points of interest (POIs), such as businesses, public services and infrastructure. Akkaya et al. 2024 made use of this extensive collection of user experiences and demonstrated that Google Maps reviews provide valuable feedback on public services and infrastructure, such as public parks. However, regarding living conditions and residential environments, there are no POIs that can be rated or commented on. Condominium complexes and large housing estates, on the other hand, often do have POIs and therefore can be evaluated. Since the 1990s, the Tokyo Metropolitan Government (TMG) has been determinedly promoting the redevelopment of central areas, leading to the construction of a large number of high-rise, mixed-use buildings and condominium complexes. This policy is justified by the revitalization of inner-city areas, increased disaster resilience and the creation of public open spaces, among other things. While the TMG's objectives are set out in various strategies and brochures, the voices of current residents of these developments are notably less prominent. This paper first analyses the feedback and experience of residents of redevelopment projects shared on Google Maps, using qualitative content analysis. It then compares these findings with the narratives on the need for redevelopment of the TMG. Building on this, it demonstrates the extent to which tools such as Google Maps can be used to crowdsource the evaluation of urban development projects and policies.

Keywords: Urban Redevelopment, Public Participation, Crowdsourcing, Narratives, Flexible urban planning system

2 INTRODUCTION

2.1 Digital Planning Tools

New technologies are shaping not only urban form and planning processes, but also how developments, successes and failures are presented. The widespread use of the internet enables local governments to share a wide range of urban development-related materials with the general public, including goals, plans and policies as well as to make project and policy evaluations easily accessible (Tejedo-Romero et al., 2022). Digital tools like smart city applications provide a variety of instruments and opportunities for citizens to participate in urban development processes. On the other hand, other platforms – social media in particular – offer city residents the chance to share their opinions independently of municipal channels and present them to a wide audience, thereby enabling them to join the public discourse on urban development (Ouyang & Bai, 2025). This discourse takes place on various platforms and is characterized by the heterogeneity of communication patterns and channels used by the participants (Radtke & Saßmannshausen, 2025), although the materials on the desirable urban form and its evaluation published by local governments on their websites, in brochures, or on social media posts come from a single source in a coordinated manner. On the other hand, there is "the public". Apart from civil society organizations, citizen assessments of urban form and policies are usually not recorded in writing, or are scattered across many platforms (ibid.). Nevertheless, they contribute to the public discourse and have a significant influence on the development of cities and their neighborhoods (Payne, 2018). Through citizen participation, only a cross-section of citizens' opinions on specific topics at specific times is compiled and made visible.

Digital tools for information, evaluation, and participation are already significant and will continue to grow in importance in the future. Digital twins and web-GIS based tools are among the technologies being used. One well-known example is Project Plateau in Japan, which provides municipalities with digital twins. The

project's website presents use cases, many of which dealing with citizen participation (MLIT, n.d.). Companies such as Maptionnaire offer comprehensive, map-based tools with functions such as map-based surveys for stakeholder consultation and community asset mapping (Mapita Oy, n.d.). These instruments provide an opportunity to collect feedback from citizens and engage them in urban development to varying degrees, though usually only within a specific spatial and temporal context. Conversely, gathering citizens' opinions on urban development processes or evaluating abstract urban policies over a longer period of time receives less attention. However, urban development is an ongoing process, not a spatially or temporally defined event, suggesting potential for new data sources and digital instruments that could complement current approaches to civic participation and evaluation.

In recent years, a number of publications have addressed the use of crowdsourcing to collect citizens' opinions for participation processes and to access and evaluate new data sources (Nummi, 2018), particularly social media platforms (Driss et al., 2019), as well as other platforms that rely on user-generated content. However, these approaches primarily address specific questions defined in terms of space and time. Alizadeh et al. 2019 argue that passive crowdsourcing, in addition to classic active crowdsourcing (i.e., outsourcing a task to a decentralized community or network to answer a specific question (Howe, 2006)), is gaining attention. Passive crowdsourcing utilizes existing content and is particularly suitable for analyzing opinions (Alizadeh et al., 2019) and for compiling fragmented statements scattered across the internet to make them visible.

2.2 Utilizing user-generated data

Social media platforms on which a large number of opinions are expressed, e.g. Twitter, are particularly well-suited for this type of "passive crowdsourcing" (Alizadeh et al., 2019). However, other platforms also collect opinions, such as dedicated review portals (e.g. TripAdvisor). While interactive maps and web-GIS, such as Maptionnaire, have proven effective for active crowdsourcing in citizen participation, there are also web-GIS offerings from private companies that rely on user-generated data and are suitable for passive crowdsourcing.

The best known and most widely used of these platforms worldwide as well as in Japan is Google Maps (Kutikomi, n.d.). Google Maps is a geographic information system that allows users to rate and review places of interest. For almost 20 years, it has offered a platform for expressing opinions (Goldman, 2007).

In addition to the map and navigation tool, the web application offers many other functions, most notably 360° street view images, aerial images, terrain models, and various POIs. Users also have the option of submitting reviews and ratings of 1-5 stars for those POIs. The ratings of businesses, public services, tourist attractions, etc., as well as the navigation function, play an important role in many people's everyday lives and choices (Chen and Chang, 2024).

The data underlying the platform is collected and generated at multiple levels. "Classic GIS data" such as the road network, is supplemented by passively collected data from mobile device tracking, among other sources. Through the affectionate and collective labor of its users writing reviews, Google adds an "extra layer of local information" (Tarr & Leon, 2019) and creates a "digital sense of place" (ibid.). Even though the trustworthiness of these ratings and reviews is increasingly threatened by fake accounts and fake reviews (Gryka, Janicki, 2023), they still represent a large pool of user feedback and opinions and are successfully utilized for research on public facilities, such as libraries (Borrega & Navarra, 2021; Khan & Loan, 2022; Chen & Chang, 2024) and parks (Akkaya et al., 2024). Akkaya et al. 2024 show that POI ratings on Google Maps can be a valuable data source for communities and research in the field of participation in urban planning. In their study, reviews on public parks in Istanbul were evaluated using machine-learning applications, thus making good use of the vast user-generated collection of opinions.

Since neighborhoods or residential environments do not have POIs, no data is generated by users for this purpose and is therefore not available for evaluation. In many cases, however, POIs exist for condominium complexes, which will be examined in this study. An evaluation is rather difficult in most cities due to the low number of POIs. However, the redevelopment policies of Japan's national and Tokyo's prefectural governments, combined with Tokyo's high population, have led to the construction of many condominium complexes, most of which are marked with a POI on Google Maps.

3 URBAN (RE-) DEVELOPMENT IN TOKYO

3.1 Phases of urban (re-) development

Like other cities in post-war Japan, Tokyo experienced enormous population growth (Heinrich & Yamashita, 2017) and, due to the control of the US occupation administration and the lack of guidance from national and local governments, rapid and uncoordinated urban growth (Pernice, 2006). The need for coordinated development and the voices of citizen movements were later taken into account by the City Planning Act, which introduced a development permit system and comprehensive zoning in 1968 (Yorifusa, 2006). The Redevelopment Act of 1969 first introduced the redevelopment of urbanized areas into law with the aim of intensifying land use and, in the current version, renewing urban functions (Art. 1 Urban Redevelopment Act). In 1980, the City Planning Act was updated and the district planning system was introduced, giving citizens influence over zoning and the design of livable neighborhoods (Yorifusa, 2006). During the bubble economy, the central wards of Tokyo experienced significant development in terms of office space, while the population of the 23 central wards declined, with many people opting to live in the suburbs (Machimura, 2021).

After the bubble burst in the early 1990s, land prices fell, and national and local governments increasingly promoted the redevelopment of inner city areas into (super) high-rise buildings by deregulating height regulations and floor-area-ratios (FAR) (Ilunga et al., 2024). For the provision of open or vacant space and the introduction of urban functions, developers are rewarded with generous FAR bonuses (Kubo, 2020). The Urban Renaissance Special Measure law of 2002 (amended 2011) reinforced this trend by largely abolishing planning regulations in the nationally designated Special Urban Renaissance Districts, paving the way for the explosion of super high-rise buildings in Tokyo (Yorifusa, 2006). Due to increased availability (Abe et al., 2018) and the fall in land prices following the bursting of the bubble economy (Machimura, 2021), many people, particularly (female) singles and childless couples, have moved into the condominium complexes springing up in the core city since the 1990s, and especially since the 2000s (Abe et al., 2018). The desire for a detached house in the suburbs is increasingly giving way to the desire for city center living with shorter commutes and the accommodation of smaller household sizes and diversifying lifestyles (Kubo, 2020).

3.2 Objectives of the national and local government regarding redevelopment

In the period following the bursting of the bubble economy and the push towards redevelopment, quality-of-life issues also became a more prominent part of politics and public discourse (Waley, 2007). Though researchers often highlight the stimulation of the economy as a major driver of Tokyo's redevelopment (Abe et al., 2018; Machimura, 2021; Waley, 2007), the national and local governments cite a variety of reasons for urban renaissance and redevelopment.

The current renaissance policy is justified by the need to adapt to the rapid advancement of information technology, internationalization, and the aging population (Art. 1 Urban Renaissance Special Measures Act). These challenges are intended to be overcome by enhancing urban functions, improving urban residential environments and simultaneously promoting disaster prevention with the aim of facilitating the transformation of socio-economic structures and contributing to the sound development of the national economy and the improvement of people's lives" (Art.1 Urban Renaissance Special Measures Act).

As this paper deals with the residential environment of condominium complex residents, the following section focusses on the 'improvement of peoples lives and neighborhoods'.

3.2.1 National Government

The strategy "How should urban regeneration be carried out in response to new trends in the 21st century, such as internationalization, information technology, aging, and population decline?" clearly outlines the objectives pursued by urban redevelopment policy. The central measures for responding to the most pressing trends of the 21st century, such as internationalization, information technology, aging, and population decline, are the encouragement of private urban activity, development and investment, referring to the Urban Renaissance Special Measures Act, and the elimination of urban areas that are densely packed with wooden buildings, that pose fire hazards (TMG, 2003). Private urban activity refers primarily to investments by private developers, but also to the participation and collaboration with local businesses and residents.

In regard to the residential environment, the sustainable city sets the basis for the promotion of walkability, the concentration of, most notably, both residential and commercial as well as various urban functions around stations (TOD Transit Oriented Development) and the creation of green and open space through redevelopment with a distinct "division of roles between the core city and the sub-centers of metropolitan areas to further promote the accumulation of urban functions" (ibid.).

Though "beautiful urban spaces" is not defined by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), it is closely linked to the creation of public space and gathering places by integration of private building activities into the urban development process as well as the integration of the buildings and the open space on privately owned land into the public space. It is to be noted that the success of the redevelopment and revitalization is linked to the well-behavior of the citizens and future residents (ibid.)

As Japan is highly prone to earthquakes (Rikitake, 1991; Ferraes, 2003), the strategy puts great emphasis on disaster resilient buildings, whereas densely populated areas are the primal focus of redevelopment in regards to disaster resilience, due to the risk of fires. Safety and security also covers crime prevention. And though Japan is one of the safest countries in the world (World Bank, 2023), the MLIT not only speaks of strengthening, but of "restoring" public safety in the sense of crime prevention (MLIT, 2003).

3.2.2 Local Government

With the release of the "Tokyo vision 2000", the Tokyo Metropolitan Governments focus shifted from the designation of (business) subcenters in the 1980s to the formation of a circular Megalopolis strategy (Waley, 2007), responding to the outflow of people and the decline of urban functions in the city center and intensified the promotion of high-rise residential buildings in the city center (TMG, 2020). The 'New city planning vision for Tokyo', formulated in 2001 and revised in 2009, specified the desired urban structure and renewal of urban functions through redevelopment and easing land use as well as height and floor are ratios (ibid.).

Following the circular megalopolis structure, the TMG divides the role of the city center and the sub-centers, prioritizing business, commerce and culture in the city center, while focusing on the accumulation of complementary functions in the sub-centers by promoting compact mixed use redevelopment. To create vibrant neighborhoods and attractive residential environments, residential functions should be accumulated around train stations by developing mid- and high-rise residential buildings (TMG, 2009). The transit oriented development approach is meant to shorten the distance between residential areas and jobs, as well as promoting walkability and the use of bicycles (ibid.).

The promotion of urban vitality and vibrancy in city centers and sub-centers primarily involves the redevelopment of extensively used areas by private developers and the relaxation of floor area ratios. The expansion of public transport and the redevelopment of sub-centers are also intended to accommodate the diversification of employment patterns and lifestyles. The urban functions that are supposed to be introduced are only roughly outlined, but childcare, education and culture, and retail are mentioned in particular (ibid.).

The creation of beautiful urban spaces is mainly described for the surroundings of "stately" and representative buildings such as the Marunouchi Station Area and the area around the National Diet Building, as well as the waterfront. For the residential environment and beautiful streetscapes though, the goal is to create unique homes and walkability, while at the same time creating an attractive cityscape by establishing a unified skyline and preventing the subdivision of plots (ibid.).

The increase in green spaces and greenery in recent years is largely attributed directly to redevelopment projects. For this reason, the main focus for the future provision of green spaces lies on private land and the further redevelopment of urbanized areas and the planting of roadside trees as part of redevelopment projects along main roads (ibid.).

3.3 Surveys on Tokyo's high-rise residential buildings

Several surveys have been conducted to determine the relocation motivations of the new residents since the population in the city center began to rise again. Akabayashi et al. 1994 conducted a survey on housing preferences, living conditions and reasons for relocating in 9 high-rise mixed use apartment buildings. The most common reasons for purchasing an apartment were the neighborhood, the cost of living and the commute time. Less prevalent was the desire for a "better living environment (surroundings, management,

safety, etc.) compared to detached houses" (Akabayashi et al, 1994, 62). As reasons for not moving back to a detached home, respondents stated the "safety of apartment complexes", "good management" and the "convenience of apartment complexes". The main reasons for potentially moving back into a single-family home were the proximity to green spaces and nature, and to a lesser degree the worry about noise in the apartment complex as well as the independence of a detached home (ibid.). The survey of Munakata et al. 1998 revealed that the convenience for commuting to work or school was the most prevalent reason for occupying a unit in a high-rise building. Other reasons stated were "'trust in the developer', 'security', 'real estate value', 'desire to own a home', 'safety', 'comfort', 'floor layout', and 'nearby facilities'" (Munakata et al., 1998, 68-69).

4 RESEARCH QUESTION

The urban renaissance policy of the national and prefectural governments led to the construction of an abundance of condominium complexes, which in turn led to feedback from residents through various channels. The question now arises as to whether user-generated content on web-GIS applications, such as Google Maps reviews, can be used to evaluate public discourse on redevelopment and residential environments. If so, which discrepancies arise between the government's redevelopment goals and residents' perceptions of their residential environments?

5 METHODOLOGY

To this end, this paper first summarizes the main objectives and reasons for redevelopment found in national and prefectural plans and policies. The residents reviews on the selected condominium complexes that were implemented as redevelopment projects from Google Maps will be compiled and evaluated using qualitative content analysis. These findings will then be compared with the identified governments objectives. Finally, it is discussed whether the platform considered here is a suitable data source for conducting research, public participation, and policy evaluation of the residential environment.

5.1 Content Analysis

For this study, inductive qualitative content analysis (QCA) according to Mayring 2022 was chosen as the research method. The aim of QCA is to reduce one or more texts to a compilation of key results and, in a second step, to abstract the results into categories and themes (Erlingsson & Brysiewicz, 2017). In inductive QCA, the key results are compiled using open coding, whereby headings and descriptions are noted while reading through the texts (Elo & Kyngäs, 2008). QCA is currently used in a wide range of disciplines, including urban studies (Sheydayi & Dadashpoor, 2023).

5.2 Sampling

The selection of redevelopment projects is based on the table of redevelopment projects in Tokyo Prefecture published by the TMG (TMG, 2024). Projects in neighboring prefectures in the metropolitan area were not considered. The TMG did not specify when the projects were initiated, and also the time spans between the city planning decision and the construction completion notice vary significantly. Since this paper aims to analyze projects that were created in the spirit of deregulation that began in the 1980s, only projects that were completed between 2000 and 2023 and contain n>49 residential units were considered. Since the majority of the aerial images and Street View content from Google Maps was last updated in 2023, no projects completed at a later date were considered. The TMG lists a total of 309 projects, some of which consist of several construction phases or buildings (buildings n=398). In this study, the entire projects were considered, and in the case of complexes with several building components, the reviews were considered collectively. After evaluation based on the above criteria, 122 projects were selected for this study.

The source of the data is the review section of Google Maps. All buildings contained in the subset were identified on Google Maps, and the reviews, ratings, and number of reviews were extracted into a table. This study deals with the residential environment, therefore only the feedback of users who can be associated with the residential function will be analyzed. Only in very rare cases, the author of the reviews indicated their relationship to the building, which made sampling significantly more difficult and necessitated subjective sampling. The use of a multi-layered filter is therefore intended to ensure that the selected reviews actually originate from the residents of the condominium complexes.

After compiling all reviews (n=1455), those that were irrelevant in terms of content and clearly had no connection to the building or the residential environment, e.g. restaurant-reviews, were first sorted out. A major challenge was distinguishing between residents and other authors. Authors with a high number of reviews often posted similar-sounding reviews for other buildings as well. Although this means that only a subpopulation is represented, in the next step all contributions from authors who had written more than 100 reviews were disregarded. In addition to distinguishing between residents and authors with no affiliation to the building, the problem of identifying 'fake reviews' arose. Even if fake reviews cannot be completely eliminated, very positive reviews that made a specific recommendation for renting or buying a condominium, or highlighting the developer were removed. After applying the filter, 108 reviews remained, spread across 49 buildings. To minimize sampling bias, a subset was cross-checked by both authors.

Building		**Environment**	
20	Noise	22	Proximity to Station
15	View	21	Residents (Behavior)
12	Cost	18	Proximity to Supermarkets
8	Cleanliness	16	Security
8	Presence of a Concierge	10	Common areas and facilities
8	Helpfulness of the Manager	10	Location in (Sub-) Center
7	Availability of Amenities	9	Proximity to Shops
7	Security Guards (Behavior)	8	Convenience
6	Quality of Interior Design	7	Comfort
6	Odor Nuisance	7	Proximity to Convenience Stores
4	Reliability of Deliveries	7	Characteristics of Neighborhood
4	Provision of Elevators	6	Quality and Quantity of Parking
4	Entrance/Lobby Design	6	Proximity to Restaurants
4	Garbage Disposal	4	Biking Infrastructure
4	Visible Vacancies	4	Green Spaces
3	Adequate Living Space	3	Proximity to Café
3	Pet-Friendliness	4	Children (Behavior)
3	Quality of Building-Services	3	Disaster Prevention Center
2	Building age	3	Earthquake Resilience
2	Internet Connection Speed	3	Quality of Exterior
2	Building Maintenance	3	Proximity to Medical Facilities
2	Oppressive House Rules	3	(Lack of) Privacy
2	Staff (Behavior)	2	Availability of Playground
1	Quality of Building Materials	2	Quality of Public Space
1	Building Layout	2	Quality of Public Transport
		2	Availability of Taxis
		1	Proximity to Airport
		1	Quantity of Leisure Facilities
138	Total	187	Total

Table 1: Number of Codes.

5.3 Unit of Meaning

The unit of meaning can vary greatly in scope in QCA, but must always allow for the extraction of meaning, while on the other hand, it must be chosen in such detail that only one interpretation is possible (Elo et al., 2014). In any case, the nature of the underlying content should taken into account (ibid.). Based on the available content, which ranges from half-sentences to short paragraphs, the unit of meaning 'word' was

selected. After the first pass in the coding process, it was checked whether the chosen unit of meaning also captured the meaning of the longer paragraphs.

5.4 Categorization and Coding

In preparation for the coding process, the statements in the longer reviews were first summarized. The collected material was reviewed in its entirety and summarized in headings. During the second review of the material, the headings were checked and adjusted if necessary (cf. Mayring, 2022). The adjusted headings (n=325) were transferred to the coding sheets (cf. Cole, 1988). At the end of this process, there were 63 unsorted codes. In the second step, duplicate codes were deleted and the wording of the codes was standardized (cf. Mayring, 2022), leaving 53 codes. The evaluation was to be carried out at different levels of abstraction in order to analyze features of the buildings and the residential environment, as well as overarching goals. Two abstraction steps were therefore carried out, with each code being assigned to only one category and each category to only one main category. In the first stage, the codes were grouped into 13 categories and in the second stage into 6 main categories.

6 RESULTS

A total of 53 codes were assigned. For clarity, the codes were divided into two themes: the broader environment and building features. The environment category accounts for 58% of the headings, while building features account for 42%. Most codes (n=22) relate to “proximity to a station”, followed by “residents (behavior)” with n=21. The two most frequently assigned codes thus relate to the spatial and social environment and not to features of the building. Similarly, “proximity to supermarkets” ranks fourth. With “noise” (n=20), there is only one code in the top 5 that refers to features of the building.

This is also reflected in the abstraction level of the categories. In terms of the residential environment, “proximity of high-rise residential buildings to transport infrastructure” and “accumulation of urban functions” are by far the most important categories. “Safety and security” and “residents (behavior)” follow with almost half as many codes assigned.

When it comes to building features, “noise” is the most frequently assigned code (n=20), followed at some distance by “view” (n=15) and “costs” (n=12). The top three places are thus occupied by “apartment features”, while the following ranks are predominantly occupied by service and staff-related codes. Significantly fewer codes were assigned for structural aspects.

Building		**Environment**	
52	Apartment features	47	Proximity of Residential Buildings to Transport Infrastructure
27	Management	47	Introduction and Accumulation of (Supporting) Urban Functions
25	Staff	25	Safety and Security
25	Building features	25	Residents and their behavior
9	Independence	17	Community and Neighborhood
		15	Convenience and Comfort
		8	Provision of Green and Open Space
		3	Quality of Exterior

Table 2: Number of Codes: Categories.

Building		**Environment**	
77	Built environment	105	TOD
52	Service	67	Social interaction
9	Independence	15	Convenience and Comfort

Table 3: Number of codes: Main Categories.

The apartment features “noise”, “view”, and “cost” carry a lot of weight in this study. Living space, which is another important feature for resident satisfaction (Wuppertal Institut, 2021), was only mentioned three times. The floor plan was not mentioned at all, and the ‘layout of the building’ was only mentioned once.

In addition to specific features, the overall impression of the building and its surroundings was also described. The terms convenience (n=8) and comfort (n=7) were used for this purpose, either individually or in combination. These two terms also stood out as frequent descriptions of other aspects.

7 DISCUSSION

7.1 Residents' feedback on redevelopment

Condominium complexes represent but a single facet of neighborhoods; nevertheless, a considerable number of reviews extend beyond the site of the building and shed light on the residents' perception of their residential environment. Although the opinion of residents and the main government objectives largely coincide, the details of the latter are not reflected in the feedback from residents.

With regard to the accumulation of urban functions and transit-oriented development, which are particularly emphasized by the government, there are many similarities between the government's stated objectives and resident feedback. Apart from apartment-specific features such as noise insulation, the top three factors in the evaluation are proximity to a train station (n=22), walking distance to a supermarket (n=18) or convenience stores (n=7), and building security (n=16). Although the government only give a rough outline of which urban functions are to be accumulated and strengthened, childcare, education, and culture, which indeed are explicitly mentioned, are not found in the reviews, whereas retail, in this case shops (n=9), is clearly represented. Similarly, public gathering places are neither mentioned in the reviews, as is the 'vibrancy' of the neighborhood only of minor importance. This is also evident in the provision of open spaces and greenery on private land as a major reason for redevelopment. Considering the low proportion of open and green spaces in Tokyo (Hwang et al., 2025), one would have expected a much greater emphasis on private or public open spaces (n=2) and greenery (n=4), but this has received little attention in the reviews.

Similarly, against the backdrop of increasing awareness of mega-disaster risks, e.g., earthquakes (Guo & Li, 2016), and although it is used as justification to erase neighborhoods, disaster resiliency is less prominent in the reviews (n=3), presumably due to the technical nature of earthquake-proofing buildings. Increasing awareness is also evitable in regards to security, especially regarding break-ins and encounters on public spaces and common areas (Suzuki et al., 2025). This is also reflected in the results, security (n=16) being one of the main concerns of users, regarding overwhelmingly the existence of security guards and the accessibility to the residents hallways but also the income and social status of the other residents. With n=21, other residents and especially their behavior is a major concern of residents, linking 'lower' rents in older and more peripheral towers with 'uncivilized' behaviors and also security concerns. Interestingly, the 'civility' of the residents is also mentioned in the MLIT's strategy, as it is listed as a prerequisite for the 'creation of beautiful urban spaces' with efforts being made at all levels.

Notably, the study confirms the key findings of Akabayashi et al.'s 1994 survey. The main reasons for purchasing an apartment in a high-rise building, as stated in the survey – environment/location, price, and commuting – are reflected in this study, albeit with a greater emphasis on security and safety (n = 16). In contrast to "worry about noise," the desire for "exposure to nature" is less pronounced in this study. Although the study by Munakata et al. 1998 shows similar correlations, it should be noted that nearby facilities are given comparatively low priority.

7.2 Utilizing Google Maps reviews

The study showed, that although the reviews were submitted for individual buildings, they mainly referred to the surrounding area. Thus, conclusions can be drawn about residential environments and neighborhoods. Passive crowdsourcing promises to access new data sources not tied to specific projects. But despite the benefits of free and easy access, using Google Maps reviews in urban planning (research) comes with a number of methodological challenges.

Passive crowdsourcing leverages existing data sources to conduct broad-based opinion surveys (Alizadeh et al., 2019), although it can only account for the user group of the platform in question. As 86% of Japan's population is considered to be regular internet users (Statista, 2025), and a Google account is the only requirement for participation, the platform potentially allows for broad participation. On the other side, Google users that are not affiliated with the building in any way are not excluded from reviewing, making it challenging to identify residents. Therefore, the sample is highly susceptible to sampling bias and depends

heavily on the researcher's judgment. Participation processes, especially those involving crowdsourcing, are subject to self-selection bias. Reviewing on Google Maps requires intrinsic motivation to actively share one's opinion with both the municipality and the general public, amplifying the bias. Therefore, it can be assumed that significant aspects of everyday life are not shared with the public, resulting in the omission of minor concerns.

Although this study aims to provide an overall view, only a fraction matched the sampling criteria, meaning only few or in many cases no voices are heard per condominium complex. In addition to being insufficiently representative, longer reviews can significantly influence the results of a study as longer reviews are given greater weight. In particular, fake-reviews generated by business owners can strongly influence the results if they are not recognized during sampling. Furthermore, the proportion of owner-occupied and rental apartments is not obvious for all buildings, which makes it difficult to estimate the number of potential users and determine representativeness. In the restaurant industry, the trustworthiness of Google Maps reviews is questionable, as user experiences are heavily influenced by 'stealth marketing' and sabotage from competing restaurants (Frischknecht et al., 2021). This study also noted some overly enthusiastic reviews. Since most reviews consist of only short sentences or keywords, they are difficult to classify as real or fake.

Although Google Maps reviews do not allow for a representative assessment of redevelopment policy, they nevertheless represent part of the public discourse despite issues of small numbers, representativeness, and authenticity. Due to the large number of redevelopment projects, citizens' preferences regarding the residential environment become apparent. Previous studies, such as that of Akabayashi et al. 1994, focused on individual buildings. The results of this study confirm the findings of previous surveys and provide feedback on a large number of projects. The difficulty with abstract issues of urban development is that citizens tend to become more involved as the planning becomes more advanced (Hirschner, 2017). As the study shows, passive crowdsourcing of additional sources of opinion provides snapshots that complement the overall picture of public discourse on urban development.

8 CONCLUSION

Digital tools, including instruments for informing and engaging citizens, are currently receiving a lot of attention. While the development of new tools for citizen participation is emphasized, public discourse receives less attention. However, the evaluation of urban policies and public opinions through passive crowdsourcing suggests great potential. Taking advantage of the large number of redevelopment projects in Tokyo, this paper first highlights the similarities and differences between the government's urban redevelopment goals and residents' feedback on Google Maps regarding their residential environment. The paper then demonstrates that passive crowdsourcing of user-generated content on web-GIS platforms can supplement the evaluation of general discourse on urban development and be integrated into the decision-making processes. The study reveals a high degree of consistency between residents' feedback and the objectives of national and local governments, particularly with regard to the accumulation of urban functions around stations, walkability, and the need for physical safety. Other key goals and reasons for redevelopment by the government, such as the provision of open spaces and greenery, play a lesser role for residents or are not perceived at all.

Despite these findings, the results of this study are only indicative. The target population in the condominium complexes could not be sufficiently isolated. Fake reviews could not be excluded, and the compiled reviews were not representative of the target population. However, user-generated data from private-sector web-GIS applications can complement traditional surveys in the field of residential environment evaluation, as it provides an additional source of citizens' opinions on urban development gathered over an extensive period of time that would otherwise remain unavailable. Using reviews of condominium complexes as a data source to evaluate residential environments and urban redevelopment policies is only the first step in making citizen opinions more visible. Nevertheless, this approach demonstrates the potential of using passive crowdsourcing from web-GIS applications for urban planning and research.

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reviewed paper

ZuZugLeben: Partizipative, soziale und klimaresiliente Vitalisierung einer Arbeitersiedlung der ÖBB – Erfahrung aus der Pilotumsetzung in St. Pölten

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1 ABSTRACT

Im zunehmenden Wettbewerb um qualifizierte Mitarbeiterinnen und Mitarbeiter gewinnt das Angebot an leistbarem Wohnraum immer stärker an Bedeutung. Besonders in Ballungsräumen stellt die Wohnraumsituation für viele Arbeitnehmerinnen und Arbeitnehmer eine große Herausforderung dar und beeinflusst maßgeblich die Entscheidung für oder gegen einen Arbeitgeber. Unternehmen erkennen daher verstärkt, dass attraktiver und bezahlbarer Wohnraum ein entscheidender Standort- und Wettbewerbsvorteil sein kann. Das Angebot an leistbarem Wohnraum entwickelt sich somit für nationale und internationale Unternehmen zunehmend zu einem strategischen Erfolgsfaktor im europäischen Wettbewerb.

Zukunftsorientierte Unternehmen wie die ÖBB haben das Potenzial ihrer Arbeiterwohnareale als wertvolles und zukunftsweisendes Angebot für ihre Mitarbeiterinnen und Mitarbeiter erkannt. Seit einigen Jahren setzt die ÖBB daher im Rahmen eines eigenen Wohnbauprogramms[1] gezielt auf die Entwicklung eines hochwertigen und zugleich leistbaren Wohn- und Lebensumfelds. Ziel ist es, modernen, funktionalen und gut an urbane Räume angebundenen Wohnraum zu schaffen, der die Lebensqualität steigert und gleichzeitig die langfristige Bindung der Mitarbeiterinnen und Mitarbeiter an das Unternehmen stärkt. Dabei werden Arbeiterwohnareale nicht nur als Deckung eines Grundbedürfnisses verstanden, sondern als integraler Bestandteil eines ganzheitlichen Arbeits- und Lebensumfelds. Auf diese Weise positioniert sich die ÖBB als verantwortungsbewusster Arbeitgeberin, die soziale Nachhaltigkeit aktiv fördert und neue Maßstäbe in der betrieblichen Wohnraumentwicklung setzt.

Im Rahmen des von Klima- und Energiefonds geförderten Forschungsprojekts „ZuZugLeben“[2] revitalisiert die ÖBB das historische Wohnquartier „Eisenbahnerhöfe“ in St. Pölten und entwickelt in Österreich erstmals gezielt Wohnkonzepte für Mitarbeiterinnen und Mitarbeiter im Schichtdienst. Ziel ist die nachhaltige Sanierung der über 100 Jahre alten Wohnanalage sowie die Schaffung leistbaren, zeitgemäßen und gesundheitsfördernden Wohnraums. Das Bestandsquartier der Eisenbahnerhöfe ist mit ca. 550 Wohneinheiten dabei das größte seiner Art in Österreich und soll als Demonstrationsprojekt für klimaresilientes, schichtarbeits- und familienfreundliches Wohnen dienen. Wesentlicher Teil des Projektes ist eine partizitative Quartiersentwicklung sowie die Evaluierung des Prozesses und die Verflechtung der Ergebnisse zu einem Prototypen, der als Vorlage für rund 4.000 weitere Wohnungen im Eigentum der ÖBB dienen soll.Der Beitrag zeigt, wie landschaftsarchitektonische Mikroklimasimulationen, grün-blaue Infrastruktur und Tactical Urbanism als Planungsinstrumente eingesetzt werden können, um kurzfristige Interventionen mit langfristiger Transformation zu verbinden.

Keywords: Stadtplanung, St. Pölten, partizipativ, sozial, klimaverträglich

2 EINLEITUNG

Die Transformation historischer ÖBB-Arbeiterinnen- und Arbeiterwohnsiedlungen in St. Pölten zu einem klimaneutralen, sozial integrativen Quartier ist Ziel des interdisziplinären Forschungsprojekts ZuZugLeben (Zug um Zug zum Lebensraum – Partizipative, soziale und klimaresiliente Vitalisierung von Arbeitersiedlungen der ÖBB), gefördert vom Klima- und Energiefonds im Rahmen der Smart Cities

[1] ÖBB-Wohnprogramm, Quelle: https://infrastruktur.oebb.at/de/projekte-fuer-oesterreich/wohnprogramm, abgerufen am 25.01.2026
[2] ZuZugLeben, Quelle: https://www.klimafonds.gv.at/projekt/zuzugleben/, abgerufen am 30.1.2026

Initiative. Neben der energetischen Sanierung steht die partizipative Einbindung der Bestands- und künftigen Bewohnerinnen, Bewohnern, Schichtarbeiterinnen und Schichtarbeitern im Fokus. Temporäre urbane Interventionen – exemplarisch ein Straßenfest in der nebenliegenden Passauer Straße – dienen als Experimentierfeld, um innovative Nutzungskonzepte des Quartiers zu erproben und zukunftsweisende Impulse für eine langfristige Quartiersentwicklung zu geben. Dieser Beitrag beschreibt die angewandten Methoden, präsentiert ausführlich die erzielten Ergebnisse, fasst die zentralen Erkenntnisse zusammen und leitet daraus abschließende Schlussfolgerungen ab. Die landschaftsarchitektonischen Beiträge fungierten als verbindendes Element zwischen Energieplanung, Architektur, Mobilität und Partizipation. Dadurch wurde eine integrierte Betrachtung klimatischer, sozialer und räumlicher Fragestellungen möglich.

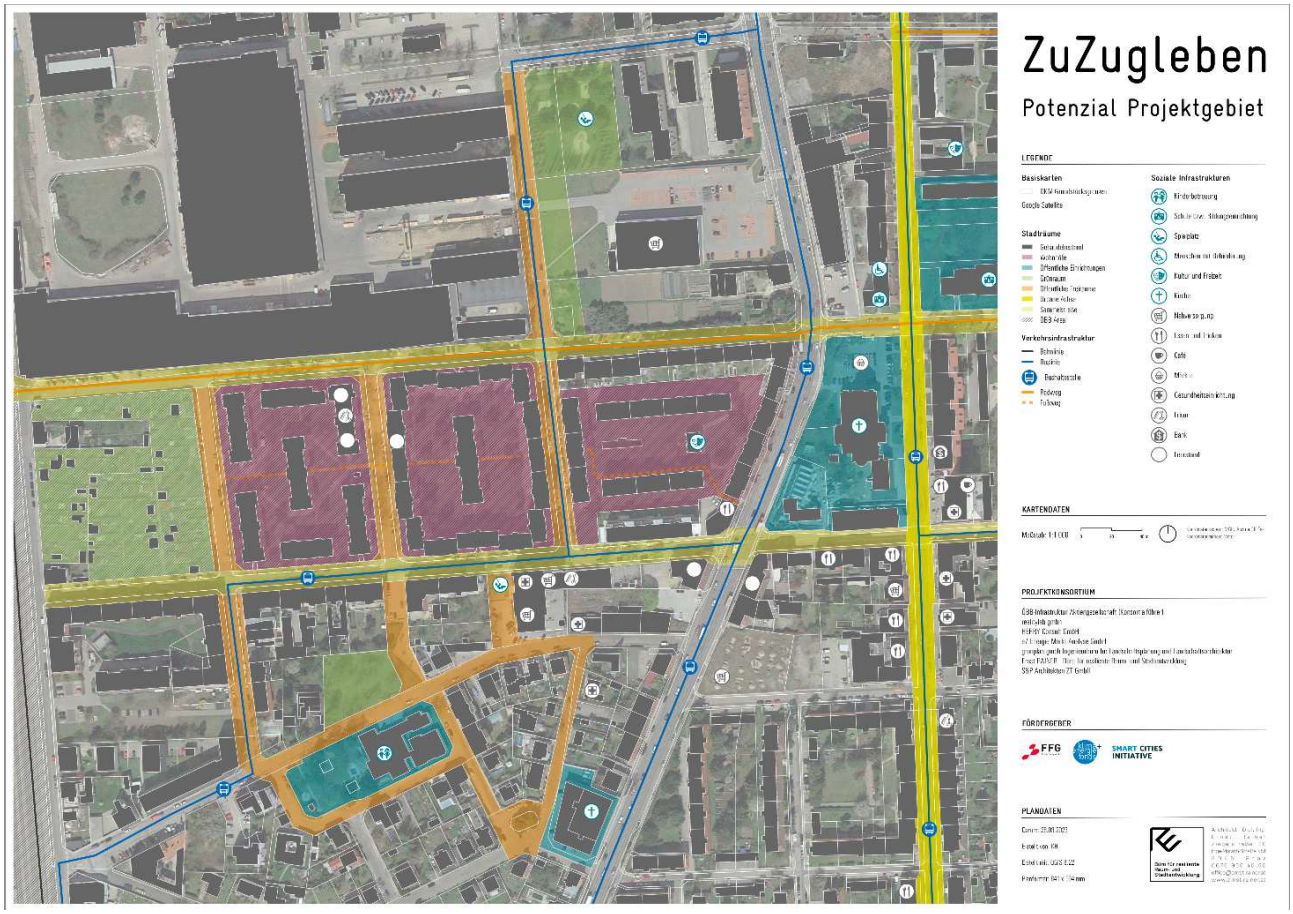


Abb. 1: Projektgebiet ZuZugLeben, Bereich des ÖBB Wohnquartier (rot) und Passauer Straße (lila). Quelle: eigene Darstellung BRRS – Ernst Rainer 2026.

3 METHODEN

Die methodische Vorgehensweise kombiniert bewährte partizipative Verfahren mit detaillierten technischen Erhebungen und urbanistischen Interventionen, um sowohl die sozialen Anforderungen der künftigen Nutzerinnen und Nutzer als auch die klimafreundlichen und mobilitätsspezifischen Rahmenbedingungen zu erfassen.

Grundlage bildete eine umfassende Sozialraumanalyse, die neben der Auswertung vorhandener Dokumente vor allem auf vor-Ort-Begehungen, Kurzinterviews mit Bewohnerinnen, Bewohnern, Stakeholderinnen und Stakeholdern, vertiefende Einzelgespräche, Gruppendiskussionen sowie Fragebogenerhebungen mit Lehrlingen, Schichtarbeiterinnen und Schichtarbeitern setzte. Ergänzt wurde dies durch die Nadelmethode zur Ermittlung von Lieblings- und Unorten in der Wohnanlage und mehrere partizipative Workshops, in denen Wünsche und Befürchtungen direkt mit den Betroffenen diskutiert wurde.

Mikroklimasimulation und landschaftsarchitektonische Entscheidungsmodelle

Parallel wurden technische Bestandsaufnahmen und eine Mikroklimasimulation mit ENVImet/GREENPASS®[3] durchgeführt. Die Simulationen wurden iterativ eingesetzt und bildeten eine Schnittstelle zwischen technischer Planung, Freiraumgestaltung und partizipativen Prozessen. Als solche können sie als Vorstufe bzw. Baustein eines digitalen Quartierszwillings verstanden werden, die es ermöglichen, klimatische Wirkungen von Planungsentscheidungen frühzeitig zu bewerten und interdisziplinär abzustimmen.Dabei zeigte sich, wie vorhandene Vegetationsflächen und Gebäudeschatten zur Abkühlung beitragen und wo gezielte Begrünungsmaßnahmen nach dem Schwammstadt-Prinzip sinnvoll sind. Der Vergleich der beiden Simulationen veranschaulicht, dass die dunkelblauen Bereiche mit geringen Windgeschwindigkeiten in vielen Bereichen mit sommerlicher Überhitzung korrelieren (siehe Abb. 2+3).

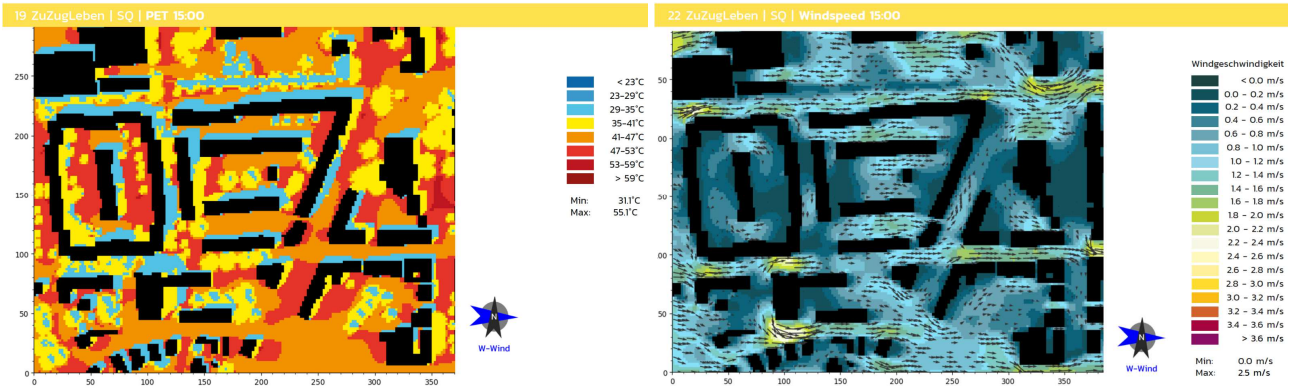


Abb. 2+3: Simulationen der PET Physiologisch äquivalente Temperatur (links) und Windgeschwindigkeit1,5m über Gelände (rechts) des baulichen Bestandes. Quelle: eigene Darstellung gruenplan 2022.

Die landschaftsarchitektonischen Mikroklimasimulationen bildeten dabei nicht nur ein Analyseinstrument, sondern fungierten als entscheidende Planungs- und Entscheidungsgrundlage für die Entwicklung klimaresilienter Freiräume, Verschattungsstrategien und grün-blauer Infrastruktur. ZuZugLeben zeigt somit, wie landschaftsarchitektonische Mikroklimamodelle, grün-blaue Infrastruktur und Tactical Urbanism zu entscheidenden Planungsinstrumenten für klimaresiliente Quartiere werden. Die Ergebnisse veranschaulichen zudem, dass mikroklimatisch wirksame landschaftsarchitektonische Maßnahmen – insbesondere Vegetationsstrukturen, Entsiegelung und Verdunstungsflächen – einen gleichwertigen Beitrag zur thermischen Entlastung leisten wie gebäudetechnische Maßnahmen und daher integraler Bestandteil klimaresilienter Quartiersentwicklung sein müssen.

In einer Erhebungsrunde unter Schichtarbeiterinnen und Schichtarbeitern wurden Themen wie leistbarer Wohnraum, Mobilitätsangebote für die letzte Meile sowie Räume für Co-Working, Fitness, Werkstätten, nachhaltige Energieversorgung und gemeinschaftliches Gärtnern im Quartier abgefragt. Ebenso wurden spezifische Bedürfnisse der Schichtarbeiterinnen und Schichtarbeiter wie Lärmreduzierung und Abdunklung, durchgängig verfügbare Dienstleistungen (Lebensmittelautomaten, Paketstation, Uniformreinigung) ermittelt. Konfliktpotenziale, etwa durch Parkplatzknappheit oder Lärmbelastung, wurden ebenso erfasst wie die Nachfrage nach nachbarschaftlicher Ressourcenteilung. Während des gesamten Projekts wurde die Projektmotivation und der Projektfortschritt in einer veröffentlichten Foto-Dokumentation sowie in Ausstellung von diversen Projektplakaten vor Ort dargestellt.

Auf Basis dieser Erkenntnisse entstanden das Raum- und Nutzungprogrammfür Hof 1, die Grundrisse für die Schichtarbeiterwohnungen mit lebenswertem Wohnumfeld und die Idee eines temporären Straßenfestes als Tactical-Urbanism-Maßnahme. Kern dieser Intervention war die kurzzeitige Umwidmung von Parkplätzen in multifunktionale Aufenthaltsflächen, die mit Parklets, mobilen Spiel- und Bewegungsinseln, temporäre Grüninterventionen sowie Info- und Mitmachstationen ausgestaltet werden. Ein mehrtägiges Programm thematisierte Klima-Spaziergang durch das Quartier, mit seinen mikroklimatischen Stärken und Schwächen, und bot Workshops zu Permakultur, aktiver Mobilität , sowie Kultur- und Sportangeboten an. Ziel war es die Passauer Straße in ein lebendiges Zukunftsbild zu verwandeln, das Impulse für eine dauerhafte Umgestaltung des öffentlichen Straßenraumes zu einem urbanen Lebensraum liefert.Die Intervention wurde bewusst als Evaluierungsformat angelegt (Beobachtung, Feedback, Nutzungsmuster), um Erkenntnisse für die Verstetigung in der Freiraum- und Mobilitätsplanung zu gewinnen.

[3] ENVImet/GREENPASS® https://www.greenpass.io

4 ERGEBNISSE

Dieses Kapitel fasst einen Ausschnitt der Resultate in vier thematischen Schwerpunkten zusammen: die Entwicklung von Schichtarbeiterinnen- und Schichtarbeiterwohnungen mit lebenswertem Wohnumfeld, das nachhaltige Energiekonzept mit klimaresilienter Sanierung sowie die breit angelegte Partizipation von Bewohnerinnen, Bewohnern, ÖBB-Mitarbeiterinnen und ÖBB-Mitarbeitern. Den Abschluss bildete die durchgeführte Aktivierung des öffentlichen Straßenraums durch ein temporäres Straßenfest.

4.1 Schichtarbeiterinnen und Schichtarbeiterwohnungsentwicklung

Die neue Wohnungsstruktur im Trakt Mariazeller Straße 34a-65a basiert auf einer zielgerichteten Bedarfserhebung bei Schichtarbeiterinnen und Schichtarbeitern. Durch die Neuplanung und teilweise Zusammenlegung ursprünglich kleiner 45 m² Einheiten entstanden flexible Wohntypen zwischen 45 und 110 m², die sowohl Single-Haushalten als auch Paaren und Familien gerecht werden. Bei der Ausarbeitung der Grundrisse wurden Ruhe und Wohnbereiche klar zoniert: Südseitige Wohnküchen mit raumhohen Fenstern und großzügigen vorgelagerten Balkonen schaffen helle Gemeinschaftsräume, während die Nordseite einen akustisch und thermisch entkoppelten Schlafbereich bietet, der vor sommerlicher Überhitzung geschützt ist. Vorgelagerte Schrankräume und Sanitäreinheiten fungieren als Schleusen, um die Übertragung von störenden Geräuschen in den Schlafbereich zu minimieren. Ein zentraler Gang verbindet die Räume miteinander und schafft gleichzeitig eine klare Trennung zwischen den Funktionen. Separate Fahrradräume im Kellergeschoß gewährleisten einen reibungslosen Alltag, auch wenn die Bewohnerinnen und Bewohner zu ungewöhnlichen Zeiten aktiv sind. Der wohnungsnahe Freiraum in den Höfen bietet Erholungs-, Freizeit- und Betätigungseinrichtungen für die körperliche Fitness im naturnah gestalteten Grünen, ohne das Quartier verlassen zu müssen.

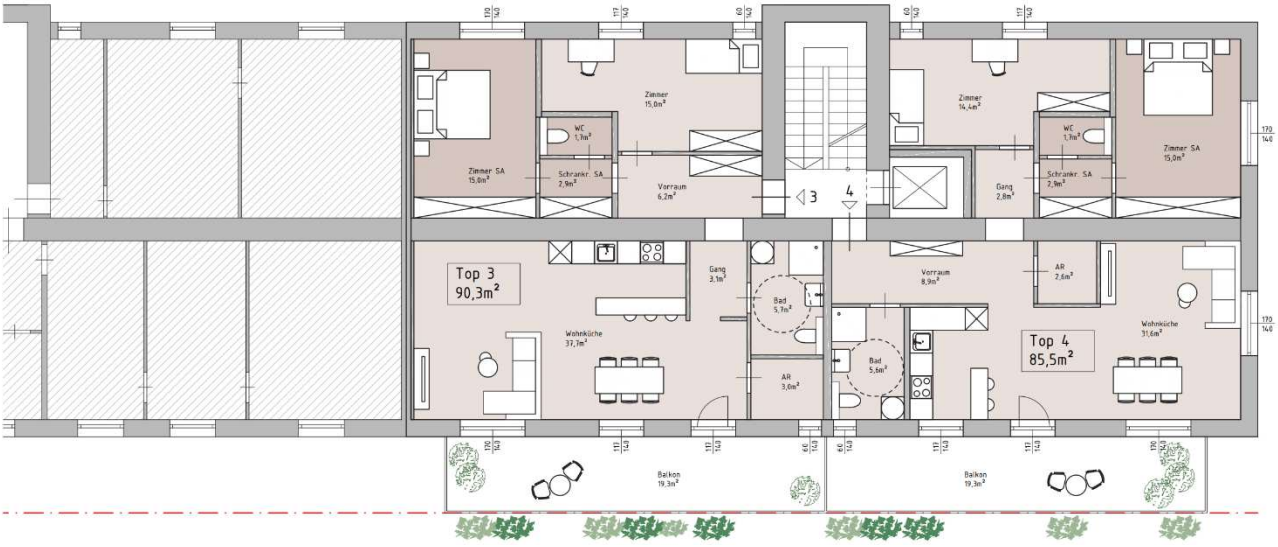


Abb. 4: Beispielhafter Grundriss einer Schichtarbeiterinnen und Schichtarbeiterwohnung. Quelle: Soehne&Partner 2022.

4.2 NachhaltigesEnergiekonzept und klimaresilienteSanierung

Das energetische Gesamtkonzept fokussiert auf die Kombination bewährter Fernwärmeanschlüsse mit modernen Luft-Wasser-Wärmepumpen, die platzsparend im Dachgeschoss installiert werden. Alle Fassaden und obersten Geschossdecken erhalten eine hochwertige Dämmung, und die alten Fenster werden durch zeitgemäße Profile ersetzt. Die Luft-Wasser-Wärmepumpen arbeiten effizient im Teillastbereich, ergänzen das vorhandene Fernwärmenetz und dienen im Sommer zudem zur passiven Raumtemperierung, um Überhitzung vorzubeugen. Eine Niedertemperatur-Fußbodenheizung mit Vorlauftemperaturen um 35 °C sorgt für eine gleichmäßige Wärmeverteilung und senkt die spezifische Heizleistung auf unter 40 W/m².

Ergänzt wird das Konzept durch eine Photovoltaik-Installation auf den Dachflächen, Außenliegender Sonnenschutz in Form von Lamellen und Jalousien reduziert im Sommer die Überhitzung, während die Balkonbegrünungmittels Kletterpflanzen die Verdunstungskühlung fördern und die Aufenthaltsqualität in den Innenhöfen verbessern soll. Die Bestandsbäume werden im Innenhof in das neue Außenraumkonzept integriert, dienen weiterhin als Schattenspender und werden durch Neupflanzungen ergänzt.

4.3 Klimaresiliente Freiraum- und Mikroklima-Strategie (Landschaftsarchitektur)

Die landschaftsarchitektonischen Mikroklimasimulationen (PET und Windfeld) wurden als evidenzbasierte Entscheidungsgrundlage eingesetzt, um thermisch belastete Aufenthaltsbereiche sowie windberuhigte Zonen mit Überhitzungsrisiko zu identifizieren. Auf Basis dieser Ergebnisse wurden klimaresiliente Freiraummaßnahmen abgeleitet, insbesondere zusätzliche Verschattung durch Vegetationsstrukturen, Entsiegelungsmaßnahmen sowie Schwammstadt-Elemente zur Retention und Verdunstung. Damit wird grün-blaue Infrastruktur als funktionale Klimaanpassungsinfrastruktur verstanden und als integraler Bestandteil der Quartierssanierung verankert. Kühl wirksame, beschattete Aufenthalts- und Bewegungsräume reduzieren Hitzestress im Alltag, erhöhen die Nutzbarkeit des Außenraums während sommerlicher Extremereignisse und stärken soziale Interaktion – der Freiraum wirkt somit als zentrale Gesundheits- und Resilienzressource im Quartier.

4.4 Partizipation der Bewohnerinnen, Bewohner, ÖBB-Mitarbeiteinnen und ÖBB-Mitarbeiter

Ein zentraler Baustein von ZuZugLeben ist die Einbindung aller Nutzerinnen und Nutzer über ein mehrstufiges Partizipationsformat, das von innerbetrieblichen Innovationslaboren der ÖBB bis zu offenen Quartier-Workshops reicht. In internen Laboren entwickelten Projektverantwortliche der ÖBB gemeinsam mit Architektinnen, Architekten, Energieplanerinnen und Energieplanern das Konzept der „Hausorganisation 3.0“ (HO 3.0). Diese versteht sich als erweitertes Modell, das über klassische Verwaltung hinausgeht und gemeinschaftliche Infrastruktur, soziale Begleitung sowie nachhaltige Nutzung integriert.

Im bisherigen Prozess zeigten sich vor allem organisatorische und finanzielle Hürden. Problematisch ist die institutionelle Trennung zwischen Eigentum, Sanierung und Verwaltung innerhalb der ÖBB: Während die ÖBB Immobilienmanagement GmbH für Eigentum und Verwaltung zuständig ist, liegt die Sanierungsverantwortung temporär beim Wohnprogramm der ÖBB Infrastruktur AG. Diese Trennung erschwert die Abstimmung innovativer Konzepte wie HO 3.0, zumal die ÖBB Immobilien GmbH als spätere Betreiberin aktuell nicht aktiv eingebunden ist. Zudem blieb die Suche nach einem externen sozialen Träger zur Anmietung von Räumen und Teil-Objektbetreuung erfolglos. Gespräche mit Caritas, Verein Wohnen und Volkshilfe scheiterten, da Objektbetreuung nicht zu deren Kernkompetenzen zählt und eine Finanzierung ohne klare Beauftragung oder über Spenden nicht darstellbar ist.

Finanziell belasten Baukosten und laufende Betriebskosten das Projekt. Gemeinschaftseinrichtungen wie das geplante Zentrum im Pumpenhaus verursachen hohe Investitionskosten, die sich bei der aktuellen Sanierungsphase von nur 64 Wohnungen nicht wirtschaftlich umlegen lassen. Auch die Kosten für soziale Begleitung und Wartung sind bei dieser geringen Bezugsgröße pro Einheit relativ hoch. Hinzu kommen rechtliche Unsicherheiten bei der Umlage sozialer Leistungen.

Zur Lösung wurden zwei Szenarien entwickelt:Im ersten Szenario wird HO 3.0 integraler Bestandteil der Miet- und Betriebskosten. Analog zum Wiener geförderten Wohnbau werden Gemeinschaftsflächen (ca. 2 % der Nutzfläche) als Projektbestandteil über die Gesamtmiete refinanziert. Diese Flächen ermöglichen kompaktere Wohnungen, stärken den Zusammenhalt und senken durch Vandalismusprävention langfristig Kosten. Eine begleitete Besiedelungsphase würde hierbei als Baunebenkosten definiert, was jedoch konzerninterne und rechtliche Anpassungen erfordert.

Das zweite Szenario sieht ein eigenständiges Quartiersmanagement vor. Eine Organisation – etwa ein gemeinnütziger Träger oder eine Bewohnerinnen- und Bewohnergenossenschaft – würde Räume anmieten und soziale Aufgaben übernehmen. Die Finanzierung erfolgte über Beiträge, Gebühren oder Zuschüsse. Vergleichsmodelle aus Wien oder Baden-Württemberg belegen jedoch, dass dies politische Unterstützung und Förderung benötigt. In St. Pölten fehlen diese Strukturen derzeit, was eine kurzfristige Umsetzung erschwert.

Zusammenfassend ist HO 3.0 ein sozial und ökologisch nachhaltiger Ansatz. Die Realisierung scheitert aktuell weniger an Inhalten als an Zuständigkeiten, Finanzierungslogiken und fehlenden politischen Rahmenbedingungen.

Parallel dazu entstanden im “Pumpenhaus”, dem ehemaligen Heizungshaus in Hof 1, niedrigschwellige „Pumpentreff“-Runden, in denen Bewohnerinnen, Bewohner, lokale Akteurinnen und lokale Akteure informell diskutierten, Ideen testeten und Rückmeldungen einholten.

Auf dieser Grundlage wurden im Format Echoraum einige Stadtteilspaziergänge rund um die Eisenbahnerhöfe realisierten, um Bewohnerinnen, Bewohner, Anrainerinnen und Anrainer direkt über die Projektziele zu informieren und erste Nutzungsvisionen für das Wohnumfeld und den öffentlichen Raum zu diskutieren. In der reduzierten Variante „Echoraum Light“ fanden gezielte Zusammenkünfte ohne direkte Beteiligung von Bewohnerinnen und Bewohnern statt: Vertreterinnen und Vertreter der Stadt St. Pölten, der Verkehrsverwaltung und Fahrradverleihunternehmen „Nextbike“ trafen sich vor Ort, um konkrete Projektideen zu präsentieren und gemeinsam Rahmenbedingungen für Mobilitätsangebote sowie temporäre Straßennutzungen zu klären.

Insgesamt fand ein aus dem Projekt heraus initiierter Qualitätsbeirat drei Mal statt, wobei Vertreterinnen und Vertreter aus ÖBB-Infrastruktur AG, Stadt St. Pölten, Klima- und Energiefonds, Salzburger Institut für Raumordnung & Wohnen GmbH (SIR) und dem interdisziplinären Projektteam zusammenkamen. In diesen Sitzungen wurden die Projektideen und der Projektfortschritt besprochen und priorisierte Maßnahmen definiert, von Grünraumstrategien bis hin zu Energie- und Mobilitätskonzepten. Ergänzend gewährleisten Diskussionsrunden die Verwendung von „Best Practice“, sowie die transparente Kommunikation und breite Akzeptanz zentraler Entscheidungen.

4.5 ÖffentlichkeitswirksameAktivitäten

Bereits 2023 präsentierte der Eisenbahner Fotoclub St. Pölten eine eigenständige Foto-Dokumentation, die mehrere Monate lang an der Außenwand des historischen Pumpenhauses hing und historische wie aktuelle Eindrücke der Eisenbahnerhöfe zeigte (siehe Abb. 5). Die großformatigen Fotografien erreichten zahlreiche Bewohnerinnen, Bewohner, Passantinnen und Passanten und stärkten die kollektive Identifikation mit dem Quartier.

Im Juli 2024 entstand eine Kooperation mit der Tangente St. Pölten – Festival für Gegenwartskultur“. Die Kunstperformance X-Erinnerungen“ bespielte das Pumpenhaus über zwei Tage. Eine weiter temporäre Nutzung des Pumpenhauses wurde so erprobt und zog ein vielschichtiges Publikum an (siehe Abb. 7).



Abb. 5+6: Foto-Dokumentation an den Außenwänden des Pumpenhauses (links) und Eröffnung der Ausstellung zum ZuZugLeben Projektstand (rechts). Quelle: Gerhard Hofer e7 2023.



Abb. 7: Performance X-Erinnerungen im Pumpenhaus – Tangente 2024. Quelle: Gernot Tscherteu, realitylab 2024.

Im November 2024 folgte die umfassende Ausstellung der Zwischenergebnisse im Innenhof von Hof 1 (siehe Abb. 6): Große Grafiken visualisieren thermische Sanierungsschritte, Wohnkonzeptvarianten und Partizipationsformate. Diese Plakatserie ergänzt die fotografie-basierte Dokumentation des Projektteams und bietet durch erklärende Texte sowie simple Diagramme einen sachlichen Überblick über den Projektstand.

Als konkreter Pilot für eine langfristige Umgestaltung der Passauer Straße wurde im September 2025 ein mehrtätiges Straßenfest organisiert.Tactical Urbanism wurde bewusst als landschaftsarchitektonisches und städtebauliches Instrument eingesetzt, um klimatische, soziale und räumliche Wirkungen geplanter Maßnahmen unter Realbedingungen zu testen. Die temporären Interventionen lieferten belastbare Erkenntnisse für dauerhafte Freiraum- und Mobilitätskonzepte.

Im Vorfeld wurde dazu eine umfangreiche Parkraumerhebung durchgeführt, um zu gewährleisten, dass trotz temporärer Sperre des Straßenraumes den Anwohnerinnen und Anwohnern ausreichend Parkraum zur Verfügung steht. Bis jetzt genutzte Parkplätze und Straßenraum wurden temporär in multifunktionale Parklets, Spiel- und Bewe-gungszonen, Informations- und Mitmach-Stationen sowie temporäre Grüninterventionen transformiert. Workshops zu urbaner Permakultur, Fahrradservicestationen, Klima-Wanderung und interaktive Zukunftswerkstätten erlaubten es der Quartiersgemeinschaft und ihrer Nachbarschaft, eigene Visionen für eine lebenswerte, autofreie Straße zu gestalten. In Kooperation mit der Stadt St. Pölten und lokalen Akteurinnen und Akteuren entstand ein „Ideenraum“, in dem Bürgerinnen und Bürger Vorschläge entwickeln konnten, die in die städtische Verkehrs- und Freiraumplanung einfließen könnten. Dieses Tactical-Urbanism-Format sollte zeigen, wie öffentliche Straßenräume in einen dauerhaften, attraktiven Begegnungs-, Erlebnis- und Sozialraum des täglichen Lebens überführt werden können, und bot die Grundlage für künftige Verkehrsberuhigungen und Freiräume im urbanen Quartier.

5 ERKENNTNISSE

Landschaftsarchitektonische Mikroklimasimulationen sind zentrale Entscheidungs- und Steuerungsinstrumente für klimaresiliente Quartiersentwicklung und leisten einen gleichwertigen Beitrag zu gebäudetechnischen Maßnahmen. Am Beispiel von ZuZugLeben wird gezeigt, dass Vegetationsstrukturen, Entsiegelung, Verdunstungsflächen und Verschattung – auf Basis digitaler Simulationenrealer Bestandssituationen– integraler Bestandteil zukunftsorientierter Stadt- und Regionalplanung sind.

Tactical Urbanism wird als landschaftsarchitektonisches Planungsinstrument eingesetzt, um langfristige Freiraum-, Mobilitäts- und Klimaanpassungsstrategien unter Realbedingungen zu testen und abzusichern. Temporäre Interventionen im öffentlichen Raum dienen als evidenzbasierte Reallabore, die soziale Akzeptanz, mikroklimatische Wirkung und planerische Annahmen überprüfen und damit den Übergang von kurzfristigen Maßnahmen zu dauerhaften Transformationen ermöglichen.

Die Co-Creation-Workshops, moderierte „Pumpentreffs“ und Echoraum-Spaziergänge haben sich als wirksame Beteiligungsformate erwiesen. Bewohnerinnen, Bewohner, ÖBB-Mitarbeitende und lokale Initiativen lieferten in Gesprächsrunden, Post-it-Feedback und Online-Umfragen zentrale Ideen für die Planung, Begleitung der Bewohner.innen in der Sanierungs- und Bezugphase sowie Impulse für die zukünftige Hausorganisation, Mobilitätsinfrastruktur, Zusammenleben, Kultur, Sport und Freizeit.

Die Rückkoppelung mit den im Quartier lebenden Bewohnerinnen und Bewohner zeigte, dass die Passauer Straße ursprünglich eine zentrale soziale Infrastrukturachse darstellte. In den Erdgeschoßzonen der Gebäude befanden sich zahlreiche Geschäfte wie Nahversorger, verschiedene Dienstleistungsangebote – etwa ein Friseurbetrieb – sowie Gasthöfe (u. a. „Der Eisenbahner“).

Die parallel durchgeführte Stadtraum- und Freiraumanalyse bestätigte zudem, dass die Passauer Straße aufgrund ihrer städtebaulichen Struktur – insbesondere der direkt zugänglichen Erdgeschoßbereiche sowie des klar definierten öffentlichen Straßenraums – über hohe Entwicklungspotenziale verfügt. Der gut erhaltene Baumbestand und die vorhandene Aufenthaltsqualität tragen zusätzlich zur Attraktivität für die Bewohnerinnen und Bewohner bei.

Diese Erkenntnisse führten schließlich zur Auswahl der Passauer Straße als Testraum im Rahmen der Tactical-Urbanism-Strategie.

Der hybride Ansatz aus Fernwärme und Luft-Wasser-Wärmepumpen in Kombination mit Niedertemperaturwärmeabgabeystemen (Fußbodenheizung) temperiert im Sommer auch passiv und verhindert Überhitzung.

Ein zentrales Ergebnis betrifft die Musterwohnungen für Schichtarbeiterinnen und Schichtarbeiter: Akustisch optimierte Schlafbereiche, flexible Raumtrennungen und Schleusenfunktionen als Puffer zum Wohnbereich wurden erprobt und dank direktem Feedback bei Grundrissen, Materialwahl und Belüftung verfeinert.

Die Parkraumerhebung bestätigte, dass im Umfeld genügend öffentliche Stellplätze bestehen, sodass die Innenhöfe autofrei gestaltet bleiben können. Stattdessen fördern eine Radrampe, großzügige Abstellflächen und geplante Sharing-Angebote die nachhaltige Mobilität.

Der Blick auf Quartiersebene zeigte eine hohe Komplexität: Neben ÖBB, Anwohnerinnen und Anwohnern mussten Stadtverwaltung, Verkehrsamt und lokale Gruppen koordiniert werden. Die daraus resultierenden längeren Entscheidungswege und steigenden Kosten führten zu Anpassungen bei Pilotkonzepten und Bauphasen, wodurch die Realisierung mancher Hofflächen in eine spätere Phase verschoben wurden.

Trotzdem ermöglichte die enge Kooperation mit der Stadt St. Pölten den Zugang zu Förderprogrammen und Synergien in Stadtgrün und Mobilität. Diese Partnerschaft trägt maßgeblich zur Aufwertung des gesamten Quartiers bei und schafft die Basis für nachhaltige, integrierte Lösungen.

6 SCHLUSSFOLGERUNG UND ZUSAMMENFASSUNG

Das Projekt ZuZugLeben kann unter Einhaltung von wirtschaftlichen Rahmenbedingungen einen Paradigmenwechsel in der Wohnraumsanierung der ÖBB bewirken: Weg von isolierten Gebäudeverbesserungen hin zu einer integralen Quartiersentwicklung, die Grünraum, Hitze-Resilienz, nachhaltige Mobilität, speziell zugeschnittene Schichtarbeiterinnen und Schichtarbeiterwohnungen und soziale Infrastruktur kombiniert. In einer Branche, in der bisher keine vergleichbaren Innovationsprogramme im Wohnbereich existierten, war dieser ganzheitliche Ansatz für die ÖBB eine erhebliche Herausforderung.

Das Projekt zeigt zudem, dass Landschaftsarchitektur – insbesondere durch Mikroklimasimulation, naturbasierte Lösungen und taktische Interventionen – eine Schlüsselrolle bei der Transformation bestehender Quartiere im Klimawandel einnimmt und als integraler Bestandteil zukünftiger Stadt- und Regionalplanung verstanden werden muss.

Die Realisierungsphase brachte viele Hürden mit sich: Hohen Kosten durch Bauen im Bestand und der vorgeschlagenen Maßnahmen erforderten umfangreiche Umplanungen, neue Bauphasen mussten eingeführt und Prioritäten in der Umsetzung gesetzt werden. Diese Komplexität führte zu Änderungen bei der Fertigstellung von Gemeinschaftsflächen und erforderte eine enge Abstimmung mit internen sowie externen Partnern.

Trotz dieser Widrigkeiten resultierte ein hoher Erkenntnisgewinn auf Seiten des Forschungsteams und der ÖBB: es wurden wertvolle Erfahrungen im Umgang mit partizipativen Formaten ausgetauscht und technische Sanierungsmaßnahmen sowie innovative Energiekonzepte unter Berücksichtigung und Weiterentwicklung naturbasierter Grün-Blauer Infrastrukturen erfolgreich mit nutzerzentrierten Planungsprozessen unter Beachtung der Wirtschaftlichkeit miteinander verzahnt. Die Prototypen für Schichtarbeiterwohnungen lieferten praxisrelevante Einsichten in akustische und räumliche Anforderungen dieser Zielgruppe.

Die enge Kooperation mit der Stadt St. Pölten eröffnete Synergien im Bereich Grünraum und Mobilität und legte den Grundstein für zukünftige Förderprogramme und gemeinsame Quartiersinitiativen. Dieses Vorhaben hat nicht nur das Potenzial, die unmittelbare Wohnqualität in St. Pölten zu steigern, sondern dient der ÖBB als Anregung für künftige Projekte im gesamten Konzern.

In Summe erweitert ZuZugLeben den Blick der ÖBB weit über das einzelne Gebäude hinaus und entwickelt eine integrierte Haltung, die technische Innovation mit sozialem Zusammenhalt und zielgerichtete Entwicklungsstrategien auf Quartiersebene verbindet. Die gewonnenen Erkenntnisse und erprobten Formate sind als wertvoller Methodenkoffer verfügbar und können in kommenden Sanierungs- und Neubauvorhaben effizienter eingesetzt werden.

7 PROJEKTINFORMATIONEN

Projekt ZuZugLeben: Zug um Zug zum Lebensraum – Partizipative, soziale und klimaresiliente Vitalisierung von Arbeitersiedlun gen der ÖBB. Dieses Projekt wird aus Mitteln des Klima- und Energiefonds gefördert und im Rahmen des Programms „Leuchttürme für resiliente Städte 2040“ durchgeführt.

Projektpartner

- ÖBB-Infrastruktur AG
- e7 energy innovation & engineering
- Ernst Rainer – Büro für resiliente Raum- und Stadtentwicklung e.U.
- grünplan gmbh
- Herry Consult GmbH
- realitylab GmbH
- Söhne & Partner Architekten ZT GmbH

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🏆 *reviewed paper*

ZuZugLeben(s)Raum Passauer Straße – Tactical Urbanism als strategischer Baustein der Quartiersanierung

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1 ABSTRACT

Im Forschungsprojekt „ZuZugLeben“, gefördert durch den Klima- und Energiefonds, revitalisiert die ÖBB das historische Wohnquartier „Eisenbahnerhöfe“ in St. Pölten und entwickelt prototypische Ansätze für klimaresiliente und leistbare Quartierssanierung. Ein Schwerpunkt liegt auf der Rückgewinnung und qualitativen Aufwertung öffentlicher Räume als soziale und klimawirksame Infrastruktur im Wohnumfeld.Da Wohnqualität nicht alleine durch den Gebäudebestand bestimmt wird, untersucht das Projekt zusätzlich die funktionale und räumliche Einbettung des Quartiers in sein städtisches Umfeld. In diesem Kontext wurde die Passauer Straße zwischen zwei der drei Höfe als Testareal für eine einwöchige Intervention mittels Tactical Urbanism ausgewählt. Ergänzend zur Gebäudesanierung wurde die Passauer Straße als Testareal für eine temporäre Intervention mittels Tactical Urbanism ausgewählt. Durch die Umwidmung vormals verkehrsdominierter Flächen in Aufenthalts- und Bewegungsraum wurden Akzeptanz, Nutzungsverhalten und klimarelevante Gestaltungselemente (Begrünung, Entsiegelung, Beschattung) unter Realbedingungen erprobt. Die Intervention wurde als Phase-0-Prototyp angelegt, um frühzeitig belastbare Entscheidungsgrundlagen für eine langfristige Umgestaltung zu gewinnen.

Keywords: Tactical Urbanism, Quartiersanierung, Stadtplanung, St. Pölten, Nachhaltigkeit



Abb. 1: Aktive Bespielung der Passauer Straße (Blick Richtung Norden). Quelle: eigene Darstellung BRRS – Ernst Rainer 2025.

2 EINLEITUNG

Die Passauer Straße zwischen Hof 2 und Hof 3 der Eisenbahnerhöfe wurde im Rahmen des Forschungsprojekts ZuZugLeben als Reallabor für eine temporäre Straßenraum-Intervention genutzt. Ziel war es, Tactical Urbanism als strategisches Planungsinstrument in der Phase 0 zu testen: durch kurzfristige, reversible Maßnahmen sollten Akzeptanz, Nutzungsmuster sowie klimarelevante Effekte

(Aufenthaltsqualität, Beschattung, Begrünung) sichtbar und bewertbar gemacht werden. Das Paper beschreibt Untersuchungsraum, Konzeption und Methodik, fasst die Ergebnisse der Intervention zusammen und leitet daraus planerische Schlussfolgerungen für die Verstetigung ab.

3 UNTERSUCHUNGSGEBIET, KONZEPTION UND METHODEN



Abb. 2: Potenzial- und Übersichtskarte des Projektgebietes. Der in Nord-Süd-Ausrichtung verlaufende Abschnitt der Passauer Straße ist in lila Farbe dargestellt. Quelle: eigene Darstellung BRRS – Ernst Rainer 2026.

3.1 Untersuchungsgebiet

Das Wohnquartier der Eisenbahnerhöfe (rot punktiert) befindet sich südwestlich des Stadtzentrums von St. Pölten im Stadtbezirk Sankt Pölten. Abbildung 2 zeigt das Quartier und die Passauer Straße (lila), welches von den Anlagen der ÖBB Hauptwerkstätte im Westen, dem Fabriksgelände der Voit-Werke im Norden und der B20 (Mariazeller Straße) im Osten eingefasst wird. Zwischen Hof 2 und 3 befindet sich die Passauer Straße, welche als Austragungsort für die einwöchige Bespielung bestimmt wurde. In der ursprünglichen Konzeption zum Beginn des 20. Jahrhunderts wurden in den Erdgeschoßzonen von Hof 2 und 3 Nahversorgung, ärztliche Betreuung und Dienstleistungen des täglichen Bedarfs untergebracht, sowie die Passauer Straße dazwischen als Verkehrsweg und sozialer Aufenthaltsort mit Baumallee zur Beschattung angelegt. Aufgrund dieser überaus stimmigen Vorbedingungen wurde die Passauer Straße für diese temporäre Aktivierungs- und Revitalisierungsintervention ausgewählt.

3.2 Konzeption des Straßenfestes

Die Konzeption des Straßenfestes sah von Beginn an den Zugang über Tactical Urbanism vor. Tactical Urbanism ist eine aus dem anglo-amerikanischen Raum kommende Bottom-up Bewegung, welche sich der Selbstermächtigung bei der Partizipation und Gestaltung des öffentlichen und sozialen Raumes bedient (vgl. Lydon & Garcia 2015). Tactical Urbanism wurde als kurzfristig umsetzbares, reversibles Format eingesetzt, um planerische Annahmen unter Realbedingungen zu testen und Rückmeldungen frühzeitig in die Quartiersentwicklung zu integrieren (vgl. Lydon & Garcia 2015). In Workshops und Veranstaltungen im Laufe des Projektes wurden die Anwohnerinnen und Anwohner wiederholt zur Teilnahme an der Gestaltung bzw. dem Einbringen von wichtigen Informationen ermutigt. Diese im Rahmen einer umfassenden Sozialraumanalyse vorgenommenen vor-Ort-Begehungen, Kurzinterviews, vertiefenden Einzelgespräche, Gruppendiskussionen, sowie Fragebogenerhebungen mit potenziellen künftigen wie auch bestehenden Anwohnerinnen und Anwohnern bildeten die Grundlage für die Projektentwicklung des Straßenfestes.

Das Herzstück und somit die eigentliche Aufgabe dieser urbanen Intervention war es, den rechtliche Rahmen, die notwendigen Konzepte, die Kooperationsbereitschaft der Stadt St. Pölten sowie die behördlichen Genehmigungen für die Bevölkerung einzuholen und dafür zu sorgen, dass Menschen den Sozialraum wieder für sich nutzen und aneignen können.

Die Aktivierung der Passauer Straße mittels Straßenfest wurde für einen Zeitraum von einer Kalenderwoche angelegt, fand jedoch in einer gekürzten Form an 4 Tagen statt. Kern des Konzeptes war die Sperre der Passauer Straße für den Straßenverkehr und die Bereitstellung von Aufenthaltsflächen, Sozialraum und Bespielung mittels aktiver Elemente. Die Bespielung wurde nach thematischen Schwerpunkten gegliedert und mit Vorträgen, Workshops und Inhalten des jeweiligen Themas versehen. Dabei wurde darauf geachtet, dass alle relevanten Zielgruppen, Anwohnerinnen und Anwohner des Quartiers, Passantinnen und Passanten

aus der Umgebung und Kinder des Viertels, inhaltlich angesprochen und die Straße wieder zu einem Ort der Begegnung, des Aufenthalts und des Austausches wurde.

Thematisch unterteilten sich die Aktivitäten in 4 Hauptgruppen: Urban Gardening, Klimaresilienz und natürlicher Lebensraum, Aktivitäten für Kinder, Sport und Mobilität sowie Fachvorträge zu Projekten und Bildungsangebote. Als gesonderter Veranstaltungspunkt wurde zum Abschluss der Woche noch ein Straßenfest mit „Langer Tafel“ für die Bewohnerinnen und Bewohner, aber auch Bürgerinnen, Bürger, Besucherinnen und Besucher der Stadt St. Pölten ausgerichtet. Die Intervention umfasste vier Themencluster: (1) Urban Gardening und Biodiversität, (2) Klimaresilienz und naturbasierte Lösungen, (3) Bewegung, Spiel und aktive Mobilität sowie (4) Bildung und Quartiersinformation. Ergänzend wurde ein KlimaWalk als niederschwelliges Bildungs- und Beteiligungsformat durchgeführt. Den Abschluss bildete ein Straßenfest („Lange Tafel“) als sozialer Höhepunkt und sichtbarer Test einer zukünftigen Nutzung als Begegnungsraum.

3.3 Methoden

3.3.1 Urbanistische Methoden

Die Intervention in der Passauer Straße wurde als Tactical-Urbanism-Reallabor zur kurzfristigen, reversiblen Erprobung klimaresilienter Straßenraumgestaltung umgesetzt. Zentrale Elemente waren die temporäre Umwidmung einer hochversiegelten Verkehrsfläche (94,2 % Versiegelungsgrad) in einen fußläufig nutzbaren Aufenthaltsraum sowie die partielle Entsiegelung von fünf Stellplätzen, die als begrünte Rasenflächen umgestaltet wurden. Ergänzend wurden mobile Großbäume, Hochbeete und hitzeresistente Vegetation installiert, um Beschattung, Verdunstungskühlung, Staubbindung und mikroklimatische Regulation zu demonstrieren. Textile Schattenspender und helle, hochreflektive Oberflächen reduzierten zusätzlich die thermische Belastung. Diese grün-blauen Elemente wurden bewusst in ein verkehrliches Experiment eingebettet, das durch Sperrung des Autoverkehrs, Nutzung als Radweg, Begegnungszone und Spielstraße alternative Nutzungsformen des Straßenraums testete. Wesentliches Element der Aktion war die Ausstattung der Straße mit Sitzmöglichkeiten wie Parklets und Straßenmöbel um die Aufenthaltsqualität zu steigern sowie Austausch und Diskurs zur fördern. Abbildung 3 soll einen Überblick über die Gestaltung des Straßenraumes während der Bespielung geben.

Ein weiteres Ziel der Aktivierung des Straßenraumes war eine Entlastung der Innenhöfe. Durch Verlagerung von Aktivitäten wie Sport- und Spielmöglichkeiten soll der Innenhof stärker zur Erholung, insbesondere für die Schichtarbeiterinnen und Schichtarbeiter der ÖBB, und für naturräumliche Nutzung aufbereitet werden. Zudem sollten mittels Ausstellungsflächen Informationen über das Projekt und die Höfe vermittelt und Kunstinstallation lokaler Akteure weitere Identifikation schaffen.

Die Verwendung von Tactical Urbanism diente hierbei als Schnittstelle zwischen strategisch orientierter Planung, Konzeptionierung und Bereitstellung des Sozialraumes sowie der Rückeroberung und Reaktivierung des Straßenraumes durch die Bevölkerung. Dabei galt es diesen Ansatz zu testen und die Rahmenbedingung für künftige Projekte auszuloten. Insgesamt fungierte die Intervention als niedrigschwellige, partizipative Prototypisierung zukünftiger klimaangepasster urbaner Straßenräume, in der ökologische Funktionen, Mobilität und soziale Nutzung räumlich integriert und empirisch überprüfbar gemacht wurden.

3.3.2 Methoden der Erhebung

Die Erhebung basierte auf der Erfassung von Wahrnehmungen und Bewertungen von Anwohnerinnen, Anwohnern, Passantinnen, Passanten und Gästen mittels analoger und digitaler Fragebögen, Kurzinterviews, informellen Gesprächen sowie einem niederschwelligen Abstimmungstool.Thematisch wurden im Fragebogen, neben den obligatorischen personenspezifischen Daten, die Aufenthaltsqualität in der veränderten Passauer Straße, Fragen der Mobilität im Quartier und der größeren Umgebung behandlet. Darüber hinaus Fragen zum Stadtklima mit dessen Auswirkungen und Bedarfen, sozialräumliche Empfindungen im Stadtviertel und der Straße sowie die Wohnqualität und Erreichbarkeit öffentlicher und privater Einrichtungen und Freizeitangebote. Die Bewertung der Fragen erfolgte nach einem Schulnotensystem von 1 (sehr gut) bis 5 (nicht genügend). Mittels eines Abstimmungstools – via Kugeleinwurf – konnten Ja-Nein-Fragen zu den Veränderungen in der bespielten Straße beantwortet werden, zusätzlich waren diese Fragen im Fragebogen enthalten. Dies sollte vorallem ein Familien- und

Kinderfreundlicher Ansatz sein, um auch die Meinung und Empfindung von Kindern einzufangen und ihnen eine Mitsprache zu ermöglichen.



Abb. 3: Lageplan der Bespielung der Passauer Straße. Quelle: eigene Darstellung gruenplan 2025.

Die Auswertung erfolgte deskriptiv; qualitative Aussagen aus Gesprächen und Interviews wurden thematisch gebündelt und in die Interpretation der Ergebnisse integriert.

Abschließendes Element der Erhebungen war der Versuch, nach einem „KlimaWalk“ genannten Spaziergang durch das Quartier, unter Verwendung von hochauflösenden Wärmebildkameras und gemeinsam mit Expertinnen und Experten auf die beim Spaziergang vermittelten und erkannten Themen

einzugehen und daraus Ideen für eine „Zukunftsvision“ des Quartiers zu finden. Dieser Spaziergang zielte dabei besonders auf Schülerinnen und Schüler der höheren Schulen sowie Lehrlinge der Lehrwerkstätte und damit auf künftige Bewohnerinnen und Bewohner in St. Pölten ab.

4 ERGEBNISSE

Dieses Kapitel fasst einen Ausschnitt der Resultate in drei thematischen Schwerpunkten zusammen: die Bespielung der Straße und ihre Effekte, prozessrelevante Ergebnisse, sowie die Auswertung der Umfragen und die „Zukunftsvision“. Eine Anerkennung der Bemühungen des Gesamtprojektes und der Aktivierung des öffentlichen Straßenraumes bildete der Besuch des Vizekanzlers und Ministers für Wohnen, Kunst, Kultur, Medien und Sport (BMWKMS) am Ende der Bespielung. Die Präsentation der Ergebnisse und Erkenntnisse des Prozesses vor der Stadt St. Pölten und dem Konsortium bildet den Abschluss des Projektes.

4.1 Bespielung der Straße und deren Effekte

Die Bespielung und Aktivierung der Passauer Straße darf als Erfolg gewertet werden. Die gesetzten Maßnahmen der Straßenraumgestaltung mittels Parklets und Straßenmöbel einer privaten Firma, landschaftsarchitektonischer Mittel wie der Umwandlung von versiegelten Parkplätzen mittels Rollrasen und zusätzlicher Begrünung in der Straße konnten einen Großteil der Anwohnerinnen, Anwohner und Gäste überzeugen. Die anfängliche Skepsis gegenüber der Transformation von Parkflächen hin zu Aufenthaltsflächen für die Anwohnerinnen und Anwohner des Quartiers und der umliegenden Straßenzüge wich schnell einer Begeisterung und Freude über die Veränderungen. Besonders die aufgestellten Parklets und Straßenmöbel wurden ausgiebig genutzt und führten zu verstärktem Austausch und sozialen Interaktionen zwischen den Bewohnerinnen, Bewohnern, Passantinnen und Passanten des Viertels.

Zu Beginn war die Nutzung zurückhaltend, nahm jedoch im Verlauf der Intervention deutlich zu. Beobachtungen und Gespräche deuten darauf hin, dass die aktive Bespielung, die Sichtbarkeit der Maßnahmen sowie informelle Weitergabe im Umfeld zu steigender Akzeptanz und Nutzung beitrugen. Mehrfach wurde der Wunsch geäußert, einzelne Elemente dauerhaft zu erhalten. Sehr postiv wurden die temporären Begrünungsmaßnahmen aufgenommen. An besonders warmen Tagen war die kühlende Wirkung auf den Parkplätzen mit Rollrasen deutlich spürbar. Sichtbar wurde der kühlende Effekt von Bepflanzung und Begrünung beim KlimaWalk. Durch die Nutzung von Wärmebildkameras konnte dieses Wissen direkt veranschaulicht und der Vorteil von Stadtgrün bzw. die Hitzeinselbildung auf dunklen oder versiegelten Oberflächen dargestellt werden.

Als großen Erfolg darf man die Workshops und Aktivitäten für Schulklassen und Kindergartengruppen nennen. Die Bespielung zielte besonders auf eine Attraktivierung der Straße für Kinder ab und es zeigt sich, dass das Angebot durch Schulen und Kindergärten sehr gerne angenommen wurde. Besondere Freude bereitete dabei die Bemalung und küstlerische Gestaltung der Straße und die sportliche Betätigung im Rahmen der Workshops.

Auffällig war die intensive Nutzung der verkehrsberuhigten Straße durch Kinder und Familien aus dem Quartier. Dadurch ergaben sich neue Kontaktmomente zwischen bislang wenig vernetzten Nachbarschaften. Gleichzeitig wurden bestehende Nutzungskonflikte und unterschiedliche Erwartungen an den Straßenraum sichtbar, was den Bedarf an moderierter Kommunikation und klarer Verstetigungsstrategie unterstreicht.Als positive Elemente können die Filmvorstellung „A Human Ride“ und die Vorträge genannt werden, welche speziell als informative Plattformen gedacht waren, um Themen von Klimawandel, Mobilität, Nachhaltigkeit und Wohnstandort zu behandeln. Dadurch konnten interessante Gespräche und Diskussionen initiert und an die Bevölkerung herangetragen werden.

Als Abschluss der Aktivitäten bot das Straßenfest eine lange Tafel, an der zahlreiche hochrangige Vertreterinnen und Vertreter. Unter den Anwesenden waren auch der Vizekanzler und Minister für Wohnen, Kunst, Kultur, Medien und Sport sowie die Vorständin der ÖBB Infrastruktur AG, die Stadtverwaltung und politische Entscheidungsträger. Alle nutzten die Gelegenheit, sich direkt vor Ort ein umfassendes Bild von der Situation zu machen. Die gesetzten und geplanten Maßnahmen des Gesamtprojekts konnten so unmittelbar an verantwortliche Stellen herangetragen werden.

Eine externe Nutzung der umgestalteten Straße erfolgte am darauf folgenden Samstag , als die „Kidical Mass“ die Passauer Straße als Auftaktort für ihre Demonstration mit zahlreichen Teilnehmerinnen und

Teilnehmern genutzt hat. Hierbei zeigt sich wieder das Potenzial und der Wert von verkehrsberuhigtem Sozialraum für gesellschaftlich relevante Themen und Aktivitäten.



Abb. 4: Teilnehmende Kindergruppen der Workshops, im Hintergrund Parklets und Abstimmungstool. Quelle: © NexGen Creation by Kirill Lialin.

4.2 Prozessrelevante Ergebnisse

Die ursprüngliche Konzeption einer einwöchigen Bespielung konnte nur im Umfang von 4 Tagen umgesetzt werden. Grund für die Abänderungen waren überschneidende Veranstaltungen der Stadt St. Pölten mit zum Teil großem Besucheraufkommen (z.B. „Höfefest“, ORTE Architekturnetzwerk Niederösterreich Stadt-Gespräch zur Stadtentwicklung im Spannungsfeld der Interessen). Zudem waren erhöhte Kosten durch die Beauftragung eines Eventmanagement-Teams zu tragen, wodurch letzendlich die Reduktion des Programmes resultierte.

Die Veranstaltung wurde an sämtliche Haushalte im näheren Umkreis des Quartiers mittels Plakaten ausgeschildert und zusätzlich mehrfach vor dem Event in großem Umfang Flyer an alle Haushalte der Umgebung verteilt. Zudem konnten die Kanäle der Stadt St. Pölten mittels Postwurfswendung an alle Haushalte, Platzierung auf Homepages der Stadt, in sozialen Medien und dem Gemeindeblatt genutzt werden. Darüber hinaus gab es eine erhöhte Webpräsenzen durch die Projektpartner, Workshop-Anbieter, Aussteller und dem ORTE-Magazin für die Veranstaltung betrieben.

Zusätzlich war ein Mobilitätskonzept und ein Umleitungsplan zu erstellen, eine Straßensperrung zu beantragen und eine offizielle Veranstaltung behördlich anzumelden. Dies erforderte einen konkreten Lageplan für die Bespielung, damit sicherheitstechnische Aspekte für eine Rettungsgasse in der Straße eingehalten werden konnten.

Trotz großer Bemühungen von Seiten des Teams konnten leider nur relativ wenige Bewohner des Quartiers mobilisiert werden. Zum Teil lag dies an der geringen Belegung der Wohnungen in Hof 1 und 2 (z.T. Leerstände vor Sanierung der Wohnungen), aber auch daran, dass sich viele nicht vom Konzept überzeugen ließen bzw. es in Ermangelung von Vorgängerveranstaltungen noch keine Erfahrungen hierzu gab. Jedoch hat sich durch Mundpropaganda von Passantinnen, Passanten, Anwohnerinnen und Anwohnern und der Neugierde über die Veränderungen und Aktivitäten im Laufe der Veranstaltung zunehmend Publikum gefunden.

Als abschließendes Ergebniss des Prozesses kann der intensive Austausch des Projektteams, des Eventmanagements, der Akteurinnen und Akteuren der Stadt St. Pölten und der Personen die für die Bespielung der Straße zuständig waren, genannt werden. Durch diese enge Kooperation und Bemühungen konnte die Intervention erfolgreich stattfinden.

4.3 Auswertung der Erhebungen und Gespräche

Im Laufe der Bespielung haben 34 Personen aktiv an den Umfragen teilgenommen und diese analog oder digital ausgefüllt. Das Abstimmungstool wurde gerne genutzt und konnte mit seiner einfachen und

unkomplizierten Abstimmungsform punkten. Jedoch wurden die Ergebnisse der Abstimmung durch unbeaufsichtigte Kinder stark verfälscht, daher gelten 3 von 4 Abstimmungstagen als kompromitiert und können nicht in die Wertung aufgenommen werden. Nachfolgend die wichtigsten Ergebnisse der Abstimmung, der Umfrage und den Kernaussagen der Besucherinnen und Besucher.

- Auf die Frage „Gefällt es Dir, dass in der Passauer Straße (mehr) Sitzgelegenheiten angeboten werden?“ gab es eine überwältigend positive Rückmeldung. Von 42 wertbaren Abgaben stimmten 39 Personen mit „Ja“, 3 mit „Nein“.
- Auf die Frage „Würde es Dir gefallen, wenn es in der Passauer Straße mehr Grünflächen gäbe?“ stimmten 31 Personen mit „Ja“, 7 mit „Nein“.
- Bei der Frage „Würde es Dir gefallen, wenn es weniger Parkplätze und dafür mehr Aufenthaltsflächen gäbe?“ war die Rückmeldung deutlich durchwachsen. Von 37 wertbaren Abgaben stimmten 24 Personen mit „Ja“, 13 mit „Nein“.
- Auf die Frage „Gefällt es Dir, dass in die Passauer Straße zur Spielstraße wurde?“ gab es 43 wertbare Rückmeldung. Dabei stimmten 34 Personen mit „Ja“, 9 mit „Nein“.

Ein auffälliges Ergebnis der Umfrage war, dass über 40% der abgefragten Personen von außerhalb kamen, nur etwa 55% Personen waren aus dem Quartier, der näheren Umgebung oder allgemein aus St. Pölten. Dies ist auf das erhöhte Besucheraufkommen im Zuge der Ansprachen von Politik und Vertreterinnen und Vertretern der ÖBB zurückzuführen.

Gute Noten vergaben die Besucherinnen und Besucher dem Thema Aufenthaltsqualität in der Passauer Straße mit der Frage zur Veränderung in eine Spielstraße (Note 1,76), den aufgestellten Sitzgelegenheiten (Note 1,88), und den räumlichen Veränderungen (Note 2,03) der Straße.

Auf die Frage der häufigsten Fortbewegungsart in ihrem eigenen Wohnviertel gaben 24 Personen an sich zu Fuß, 12 mit dem Rad, 6 mit öffentlichen Verkehrsmittel, 7 mit dem PKW und 3 mit Roller oder E-Scooter fortzubewegen.

Die häufigsten genannten Wünsche der Verbesserung der Mobilitätsaspekte waren dabei der Wunsch nach besseren Radwegen (16 Nennungen), besserem Öffi-Netz (12 N.), mehr Sicherheit im Verkehr (11 N.), weitere Angebote wie Sharing-Angebote (8 N.) und mehr Parkplätze (6 N.).

Diese Ergebnisse korrelieren mit den Befragungen zum Thema Mobilität, wo die Zufriedenheit mit den Fußwegen im Quartier (Note 2,82), den Radwegen (Note 2,97), dem Sicherheitsgefühl als Fußgängerin, Fußgänger, Radfahrerin oder Radfahrer im Straßenverkehr (Note 2,79) und der Angewiesenheit auf den PKW im Alltag (Note 2,97, entspricht der Antwortmöglichkeit „etwas“) abgefragt wurden.

Die Befragung zum Thema Stadtklima ergab, dass die Belastung durch Hitze im Sommer merklich (Note 2,51), der Aufenthalt im Freien bei Hitze als mehrheitlich angenehm (Note 2,27), die Versorgung mit Schattenplätze im Quartier durchschnittlich (Note 2,97), die Ausstattung mit Grünraum im Wohnumfeld eher durschnittlich (Note 2,82), die Versorgung mit Trinkwasserstellen als nicht ausreichend (Note 3,97), der Wunsch nach Begrünung an Häusern und Straßen als eher dringend (Note 2,30) und Häufigkeit des Vermeidens von Hitzeplätzen im Stadtgebiet mit oft (Note 2,18) angegeben wurde.

Häufigste Nennung gemiedener Orte sind große versiegelte Freiflächen und dabei für St. Pölten relevant, der Domplatz, der Rathauspaltz, das Regierungsviertel allgemein und die an das Quartier im Osten unmittelbar angrenzende Mariazeller Straße (B70).

Auf die Fragen zum Sozialraum ihres Wohnquartiers wurde die Lebendigkeit des Viertels mit wenig lebendig (Note 3,39), die Häufigkeit der zufälligen Begegnungen mit eher selten (Note 2,65), die Wichtigkeit von Begegnungsorten mit wichtig (Note 1,90) und Wichtigkeit der Passauer Straße als Begegnungort mit wichtig (Note 2,12) beurteilt.

Bei den abschließenden Fragen zur Wohnqualität wurde die Zufriedenheit mit der eigenen Wohnung mit eher zufrieden (Note 2,24), die Ruhe im Wohnumfeld als eher ruhig (Note 2,33), das Grünflächenangebot als eher durschnittlich (Note 2,79), die Erreichbarkeit und Nähe von Geschäften, Ärzten und Bildung als eher durchschnittlich (Note 2,70), das Sicherheitsgefühl als eher sicher (Note 2,3), die Spiel- und Freizeitmöglichkeiten als durchschnittlich (Note 2,97) und die Anbindung an den öffentlichen Verkehr als eher gut (Note 2,36) bewertet.

Bei den Gesprächen mit Anwohnerinnen, Anwohnern, Besucherinnen und Besuchern stellte sich heraus, dass durch die Installation der Parklets zum ersten Mal seit geraumer Zeit wieder intensivere Kontakte zwischen den Bewohnerinnen und Bewohnern der drei Höfe entstanden sind. Dies zeigte sich durch eine deutliche Nutzung der Sitzgelegenheiten im Bespielungszeitraum und dass die räumliche Intervention sozial wirkt.

Ein wichtiges Gesprächsthema war zudem die Nutzung der Passauer Straße als PKW-Stellfläche, an dem sich die Meinungen deutlich unterschieden. Es kam dabei zu einer Lagerbildung zwischen Pro Parkplatz und Pro Sozialraum. Es wurden die Veränderungen ebenso begrüßt, wie die weggefallenen Parkplätze beklagt.

Die Idee der Belebung wurde von vielen Personen als sehr postiv aufgenommen, Ablehnung entstand vor allem durch die Eingriffe in die Gewohnheiten der Bewohnerinnen und Bewohner. Dabei zeigte sich eine Konfliktlinie zwischen zukunftsorientierter Stadtplanung und Verlustangst bei Parkraum und Gewohntem.

Feedback gab es auch im Bezug auf die Kommunikation, wo zum Einen berichtet wurde, dass über das Fest an vielen Stellen informiert wurde. Zum Anderen haben selbst Bewohnerinnen und Bewohner aus dem Quartier nichts von der Aktivierung gewusst oder die Straßenbespielung aufgrund der farblichen Ähnlichkeit von ÖBB und SPÖ für eine politische Veranstaltung gehalten.

Als Ergebnis des partizipativen KlimaWalks mit rund 25–30 Teilnehmenden, bestehend aus Bewohnerinnen und Bewohnern sowie potenziell zukünftigen Bewohnerinnen und Bewohnern des Quartiers, beschreibt folgender Text die ausgearbeite Vision: „Das Quartier soll als klimaadaptiver, autoarmer und sozial integrativer Wohnstandort konzipiert werden. Durch Entsiegelung, Begrünung und wasserbasierte Infrastrukturen werden mikroklimatische Effekte verbessert und die Aufenthaltsqualität erhöht. Verkehrsberuhigte Straßen sowie vielfältige Spiel-, Bewegungs- und Gemeinschaftsräume fördern Sicherheit, Gesundheit und soziale Interaktion. Kulturelle, gemeinschaftliche und gastronomische Nutzungen stärken lokale Identität, Alltagsbelebung und langfristige Quartiersbindung.“

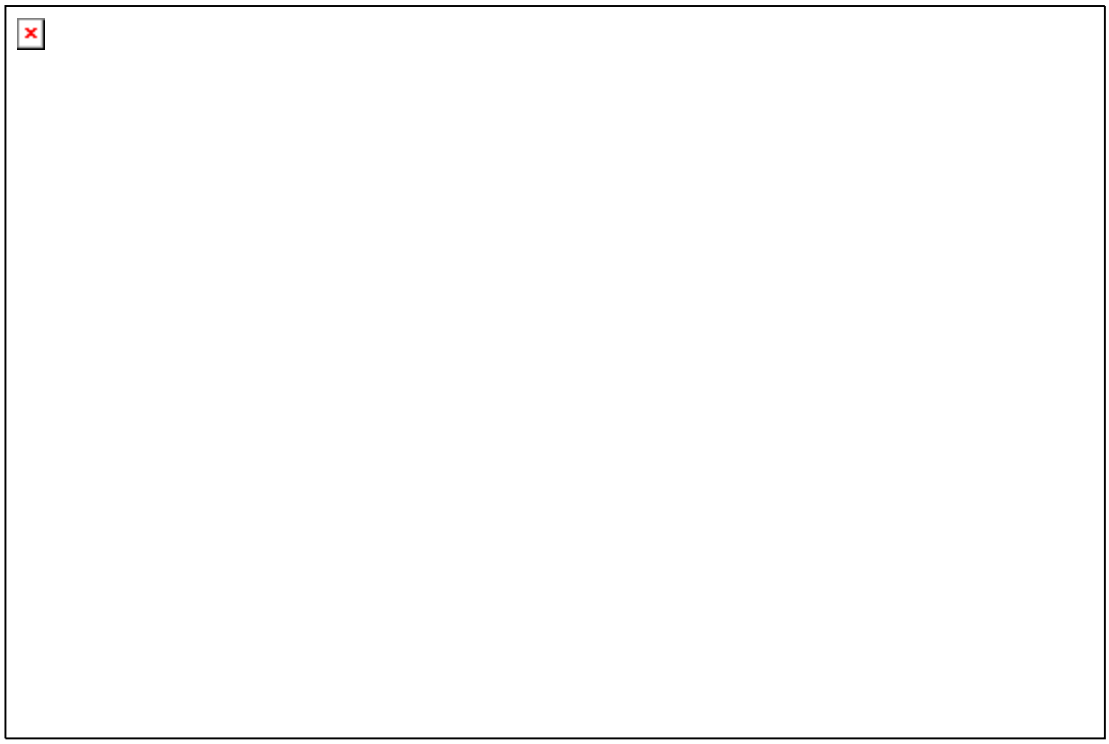


Abb. 5: Ideensammlung des KlimaWalks für die Zukunftsvision. Quelle: © NexGen Creation by Kirill Lialin.

5 ERKENNTNISSE

5.1 Prozessrelevante Erkenntnisse

Die Durchführung temporärer Straßenraum-Interventionen ist mit hohem organisatorischem und finanziellem Aufwand verbunden (Genehmigungen, Sicherheitskonzepte, Umleitungsplanung, Koordination). Im vorliegenden Fall zeigte sich, dass Tactical-Urbanism-Formate zwar als Phase-0-Prototyp wertvolle Erkenntnisse liefern, jedoch nicht per se kostengünstig sind. Ihr Nutzen liegt vor allem in der Reduktion langfristiger Fehlplanungen, in der frühzeitigen Konflikterkennung sowie in der verbesserten

Entscheidungsgrundlage für Verstetigungsmaßnahmen.Aus diesem Grund sind Gemeindeverwaltungen und Stadtteilpolitik gefordert, im Rahmen von nutzerorientierter Planung, die grundlegenen Vorraussetzungen zu schaffen, die es Bürgerinnen und Bürgern erlaubt, sich ihren Lebensraum wieder aneignen zu können. Beispielhaft sind hier die „Grätzloase“ und „Grätzelinitiative 20+2“ in Wien zu nennen. Selbstorganistation von Quartieren setzt die Verfügbarkeit entsprechender Ressourcen voraus.

Wesentlicher Faktor für das Gelingen solcher Interventionen ist die enge Kooperation und Kommunikation der Schlüsselakteure. Gerade im Hinblick auf die konkreten Umsetzungen der geplanten Maßnahmen ist ein Koordinationsteam (Eventmanagment) vor Ort unabdingbar. Dies mag zwar in diesem Fall der Konstellation der Projektpartner von außerhalb St. Pöltens geschuldet sein, kann aber als allgemeine Erkenntnis betrachtet werden.

Es zeigt sich auch, dass die temporäre Bespielung als Phase 0 – Prototyp in der Quartiersentwicklung einen wesentlichen Beitrag zur Senkung von Kosten für die Gestaltung von Sozial- und Lebensraum bieten können. Durch die gezielte Einbindung der Bevölkerung und deren Bedürfnisse, Wünsche und Anliegen bereits in der Planungsphase und dem anschließenden Austesten solcher temporärer Maßnahmen, können Planungsfehler und negative Spätfolgen effektiv vorgebeugt werden. Im konkreten Fall dieser Bespielung kamen diese Effekte nicht zu tragen.

Abschließend ist die Situation vor Ort zu nennen. Über den Erfolg oder das Scheitern solcher Belebungsmaßnahmen entscheidet der Zustand des Quartiers, die Jahreszeit und Witterung, sowie zeitgleich in der Stadt stattfindende Events wesentlich mit. Der deutliche Leerstand der Höfe hat eine intensivere Einbindung der Anwohnerinnen und Anwohner wegen Fehlens selbiger erschwert.

Ziel muss es werden, dass Anreize zur Eigeninitiative der anliegenden Bewohnerschaft gefunden werden, um von einer Finanzierung dieser Aktivitäten durch Dritte, hin zu einer (teil-)selbstständigen Gestaltung und Belebung solcher Orte zu gelangen.

5.2 Interventionistische und räumliche Erkenntnisse

Die Verwendung von Tactical Urbanism als Werkzeug zur Belebung, Rückgewinnung und Gestaltung von Lebensraum konnte sich bewähren. Die im Kontext der lokalen wie nationalen Rahmenbedingungen zur Nutzung öffentlichen Raumes notwendigen Maßnahmen konnten über diesen Ansatz eingeleitet und die Bevölkerung zu kurzzeitigen „Besitzern“ der Straße gemacht werden. Um die tatsächliche Tragfähigkeit solcher taktisch-strategischer Überlegungen unter Beweis zu stellen, bedarf es jedoch längerer Bespielungszeiträume.

Die Bevölkerung ist es nicht gewohnt, eigenständig die Nutzung vormals für andere Zwecke belegter öffentlicher Flächen für sich zu beanspruchen. Daher wäre es notwendig diesen neuen Zugang zur Mitgestaltung fachlich zu begleiten oder diesen öfter und länger zu trainieren.

Anhand des Feedback der Bevölkerung ist festzuhalten, dass eine klimaresiliente Anpassung von städtischem Lebensraum als vordringliche Angelegenheit angesehen wird. Die Ausstattung von öffentlichem Raum mit Trinkwasserstellen, Schattenplätzen, Entsiegelung überhitzender Bereiche und kühlender Begrünung muss ein entscheidender Faktor für künftige Revitalsierungen und Gestaltungen von Wohnquartieren werden.

Weiters gilt die Notwendigkeit der Integration von nachhaltigeren Mobilitätsformen und die Umwandlung von vormals für den Verkehr genutzter Flächen zu mehr Sozialraum als gegeben. Dabei sollte jedoch nicht gänzlich auf die Abhängigkeit der Bevölkerung von PKW vergessen werden. Es bieten sich bei der Gestaltung neuer Quartiere Sammelparkplätze oder -garagen an.

5.3 Soziale Erkenntnisse

Die Bereitstellung von Aufenthalts- und Sozialflächen hat zu einem erhöhten Austausch innerhalb der Nachbarschaft und zu einer Stärkung des Zusammengehörigkeitsgefühls geführt. Soziale Interaktionen sind ein Grundbaustein menschlichen Lebens und einer funktionierenden Gesellschaft. Sie bieten Freizeitmöglichkeiten im gleichen Maß, wie sie als Forum für gesellschaftlichen Austausch und zur Konfliktbewältigung dienen können.

Dieser gesellschaftliche Mehrwert hat sich auch im Bereich der Integration und Inklusion bemerkbar gemacht. Durch das Zusammentreffen verschiedener Kulturen, Sprachen und Religionen entstand die Möglichkeit des gegenseitigen Kennenlernens und des Abbaus von Spannungen.

Als Erkenntnis aus Gesprächen und Befragungen lässt sich ableiten, dass der Wunsch nach einem lebendigen Quartier und die Wichtigkeit von sozial Interaktionen vordringlich ist. Daher gilt es das Wesen der europäischen Wohnstraße als wichtigen gemeinschaftlichen und demokratischen öffentlichen Raum zu erhalten. Denn dieser demokratische und freie Zugang zu öffentlichen Raum ist Grundlage für eine organisierte Nachbarschaft und damit Grundbaustein (selbst)organisierter Quartiere.

6 SCHLUSSFOLGERUNG UND ZUSAMMENFASSUNG

Die temporäre Bespielung der Passauer Straße zeigt exemplarisch das Potenzial öffentlicher Straßenräume als soziale und klimawirksame Infrastruktur in der Quartiersentwicklung. Tactical Urbanism erwies sich als wirkungsvolles Phase-0-Instrument, um Nutzungskonflikte (v. a. Parkraum), Akzeptanz und räumliche Wirkungen unter Realbedingungen sichtbar zu machen.

Die Ergebnisse der Befragungen und Beobachtungen belegen eine hohe Priorität von Aufenthaltsqualität, Sicherheit, Begrünung, Schatten und aktiver Mobilität gegenüber einer rein autozentrierten Flächennutzung. Temporäre Begrünungs- und Beschattungselemente sowie kleinmaßstäbliche Entsiegelungen machten mikroklimatische Effekte unmittelbar erfahrbar und stärkten die Legitimation für grün-blaue Infrastruktur.

Insgesamt bestätigt das Reallabor, dass kurzfristige Interventionen ein geeignetes Instrument sind, um langfristige Transformationsprozesse evidenzbasiert vorzubereiten und partizipativ abzusichern. Die Passauer Straße kann damit als prototypischer Ausgangspunkt für eine dauerhafte Umgestaltung zu einem klimaangepassten, nutzerorientierten Begegnungs- und Bewegungsraum dienen.

7 PROJEKTINFORMATIONEN

Projekt ZuZugLeben: Zug um Zug zum Lebensraum – Partizipative, soziale und klimaresiliente Vitalisierung von Arbeitersiedlun gen der ÖBB. Dieses Projekt wird aus Mitteln des Klima- und Energiefonds gefördert und im Rahmen des Programms „Leuchttürme für resiliente Städte 2040“ durchgeführt.

Projektpartner

- ÖBB-Infrastruktur AG
- e7 energy innovation & engineering
- Ernst Rainer – Büro für resiliente Raum- und Stadtentwicklung e.U.
- grünplan gmbh
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- realitylab GmbH
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9 LITERATURVERZEICHNIS

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Cost Optimisation – the Key to Energy Transition and Climate Protection

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1 ABSTRACT

There is a big difference between having electricity just as the sun shines, 24-electricity, and 24×365 electricity. There is a big difference between replacing 8 kWh thermal energy by 1 kWh electricity at scooters (very small gasoline engines have terrible efficiency) and replacing 1.6 kWh thermal energy by 1 kWh electricity by changing cement production from heating the clinker by burning to heating it by electricity. Some decades ago, it was great for the first photovoltaic owners to run the washing machine when the sun shone. Now the target is to run energy-intensive industry even during a dark doldrum at a competitive price.

Many thought about the energy transition, "We have to do it, whatever it costs". This idea is a sure way to lose.

To meet the necessary cost optimization targets, we cannot hold the energy problem separate from all other problems: another major problem is housing. This ranges from demotivation due to having no chance of owning one's own house up to mass homelessness.

My first approach to combining energy production and housing was in 1991 with the "GEMINI inhabited solar power plant". The transition from the rotating GEMINI inhabited solar power plant to the GEMINI next Generation house with east-west photovoltaics shows what a profitability transition means: in 1992, tracking the sun was cheaper, but from 2010 onwards, a fixed solution became cheaper.

Every component of our civilization must be examined for profitability transitions that have already taken place and those that are yet to come. We cannot design our future based on already outdated conclusions: (1) Large apartment buildings vs. single-family homes, (2) Traditional village layouts vs. the new energy-optimized, (3) Urbanization vs. reruralization, (4) Energy from Biomass vs. Power-to-X, (5) On which latitudes is a high-voltage grid an advantage or a burden?

We designed our GEMINI next Generation house and energy-optimized settlements for maximum cost optimization and for worldwide use. At our research, what could our project do for the energy transition? We encountered many points where profitability transitions had taken place without being noticed. Some are so big that they can be called paradigm shifts.

Keywords: climate protection, energy transition, cost optimization, profitability transition, paradigm shifts, disruption, synergy

2 INTRODUCTION

We got our mobility and transport system not by decreasing the costs of horse breeding. The change from horses to cars is an example of a profitability transition everybody knows. Who could afford a horse for their everyday mobility needs today? It's now an expensive lifestyle item. Big cars now pull horse trailers to events.

Take my lecture as something like a prediction: "Horses will be only for rich people, and rich people will pull their horses in trailers with their cars to distant events." Unimaginable in 1900, but it happened.

This means cost optimization is far more than reducing the costs of every component of an established system. Cost optimization has to study past and predictable profitability transitions and to evaluate just reducing costs in an existing system vs. an entirely new system.

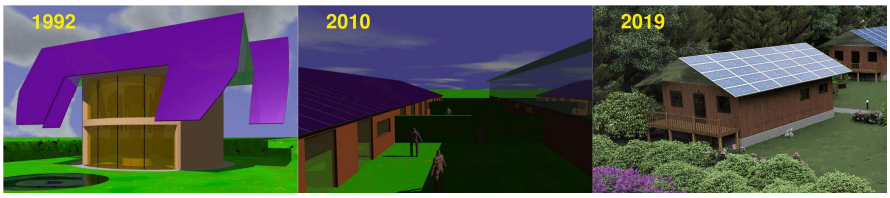
Many imaginations about our future had been created in the past with completely different parameters. Unchecked conclusions from the past endanger our future with unbearable costs.

3 MY PERSONAL EXPERIENCE WITH A PROFITABILITY TRANSITION

I designed the GEMINI next Generation house in February 2019 and tried to figure out in March 2019 why it looks so different from my design in 1992. The design target was in 1992 30 MWh yearly yield in Austria. This can be done with 30 kW peak south-oriented photovoltaic or 23 kW peak horizontally tracking the sun

photovoltaic. Photovoltaics were priced at 7 €/Watt. 30,000 × 7 €/W peak = 210,000 € but 23,000 × 7 €/W peak + 5,000 € for turning the house is only 166,000 €.

In 2019, photovoltaics were already so cheap that 30 MWh/a could be best done by 36 kW peak east-west oriented. Now I tried to figure out in what year the profitability transition took place. It was 2010 and without knowing about the term "profitability transition", I designed exactly in this year low-rise row houses with south-facing photovoltaic panels. The equation had changed to 30,000 × 1 €/W peak = 30,000 € and 23,000 × 1 €/W peak + 7,000 for turning the house is also 30,000 €.



Birds can fly without knowing all the terms of aerodynamics. I reacted with my design change in 2010 to an ongoing "profitability transition" without knowing the term at this time. I realized this concept only 9 years later.

4 ENERGY TRANSITION

The long way from random electricity from sun and wind towards 24×365 electricity. Overseen profitability transitions have to be considered as major accidents.

4.1 Fast load change power plants vs. high efficiency

Here is a current example about increasing costs and CO2 emissions by ignoring a profitability transition.

Some decades ago, nobody imagined that sun and wind energy could deliver more electricity than all the caloric power plants together. Let's look back into this time to understand the historic context:

There are these peaker power plants; they work mainly at midday. They can change the load fast, so no problem replacing them on a sunny day with solar electricity. Medium-load power plants are also no problem. But maybe we will have so much photovoltaic power in the future that we will even have to switch off the base power plants. But these base load power plants have too slow a decrease to be down until midday and too slow an increase to have full power at sunset. So base load power plants are an enemy of the energy transition; they congest the grid! Really, statements like this were still being made by high-ranking Green politicians in Germany even in 2025. The conclusion: All new power plants have to be for fast load change.

Who killed the electric car at the beginning of the 20th century? The lead-acid battery. My Tesla Y with lead-acid batteries would have 20 kWh capacity and 100 km range, 40 kW peak power, and the battery would need to be replaced every 6,000 km. No joke, painful experience at my first electric scooter test, 2006 to 2009.

The same goes for any thoughts towards grid-scale batteries. So the ideal of the fast-changing power plant was born to deal with the changes in photovoltaic and wind energy.

This was the historic context about 3 decades ago. It is shocking that we are still in the first phase of the energy transition. There are 3 phases of using renewable energy from the sun and wind: (1) Random, the sun shines or the wind blows, and we reduce the output of caloric power plants; (2) 24-electricity, stable supply in the range of a day; batteries make a cooperation between sun, wind, and caloric power plants possible; (3) 24×365 electricity, a stable supply for every day of the year, and the fossil fuel for caloric power plants is replaced by power-to-X.

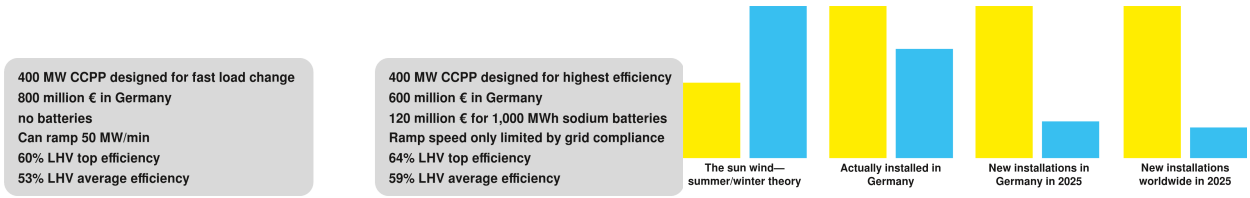
In the first phase, the idea is, whenever the sun shines or the wind blows, we decrease the output of caloric power plants. In the other direction, to increase the output of caloric power plants as soon as it becomes dark or windless. That was the time when the wish for all power plants to be able to make fast load changes originated.

This method has a limit: it is not possible to switch off more power plants than are just running. Because of this limit and because people were unwilling to think ahead, 70 GW was cited as the expansion target for photovoltaics in Germany for many years. They did not even think that renewable energy has to evolve from random to 24-electricity. Why? Lithium batteries were at this time too expensive for this task, and they were

not convinced that this could change. This is despite all the experiences with price decreases in emerging industries.

24-electricity is a cooperation between renewable energy and caloric power plants. There is a weather and demand forecast: the next day we split production on 80% renewable and 20% caloric power plants. When there are 10 caloric power plants, let just 2 of them run with the highest efficiency. All the different yields of photovoltaic and wind power during the day are flattened by batteries. Surprise, the demand for fast load changes at power plants is gone. The batteries make such a slow load change possible that even the slowest-changing base load power plant can follow.

Let's look at the current situation at new power plants to be built in Germany.



Left: 10% less CAPEX 10% less natural gas to burn is already a huge difference for the efficiency-optimized battery version. But thinking in the past, they continue to talk about fast load change power plants. Right: The required ratio according to the 'sun shines more in summer, wind blows more in winter' theory vs. reality.

4.2 From 24-electricity to 24×365 electricity

How to refine 24-electricity to 24×365 electricity? There had been the sun-wind theory for three decades: the sun delivers more in the summer, and wind delivers more in the winter. This would require, on average, in Europe, 2 kW wind systems for every kW photovoltaic. Just right now in Germany, 0.72 kW wind for 1 kW photovoltaic, and the gap widens fast: 0.24 in Germany, 0.2 in the EU and worldwide at new installations in 2024 and 2025.

The next theory was biomass for the winter gap: not enough sun, not enough wind; we would start power plants fueled by biomass. Extremely inefficient land usage. The first border for photovoltaics in Germany was 70 GW: we cannot switch off more caloric power plants than we have running. The next border is at 300 GW photovoltaic and 750 GWh batteries: some sunny summer days, and all Germany is 100% solar-electric all this time.

What to do beyond this next border? Just waste abundant production? Install more batteries? Use it for Power-to-X?

4.3 Simulation of 24×365 systems

We started the simulation in April 2024 to find out if off-grid fast-charging settlements are feasible. We used the EU Photovoltaic Geographical Information System. The start of the design was a 1 ha energy-optimized village with an additional fast-charging area. These are the 1,120 modules with a 25° slope towards the east and west slope on the houses and the 968 modules with an 8° slope east and west covering the central structure. We added a fast-loading area covered with 1,200 photovoltaic modules with a 5° slope facing south at the northern half of Earth and north at the southern half of Earth.

A fast charging station can have very different business. Nearly nothing at the beginning up to beyond the optimal load limit. The simulation tested with 20 kW to 240 kW load in the far north and 80 kW to 400 kW at all other locations in steps of 20 kW. The data was for each hour from 2005 until the end of 2020. For every hour decisions are made, how much should be used for power-to-methanol, and on the other end, do we have to start the generator? The power-to-methanol system is powered during the night by the batteries.

The simulation combined 10 different battery sizes with 10 different power-to-sizes. So a simulation is 16 years × 365.25 days × 24 hours × 10 battery sizes × 10 power-to sizes × 17 different loads = 238,435,200 decisions and calculations. We did the simulation with 50 different places. 35% HHV (Higher Heating Value) efficiency is typical for methanol-powered generators in the 200 kW to 500 kW range. There could be up to 48%, but the additional cost at only some hundred hours of yearly usage makes this high-efficiency option too expensive. The efficiency of a 50 kW to 300 kW power-to-methanol system is assumed to be 50%.

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This simulation is with a flat demand over all the year. With a higher demand in winter, would the 24×365 conversion rate be even lower in Aalborg and Salzburg. On the other side, industry with variable production increases the 24×365 conversion rate.

4.4 Hydrogen – methane – methanol

Why methanol? It is liquid at room temperature. The other options are methane and hydrogen. Both are only an option at huge underground storages and far too expensive for decentralized energy systems. Here we are suddenly in the power-to-hydrogen, methane, and methanol debate. Hydrogen has the highest power-to-efficiency because no DAC – Direct Air Capture of CO2 is required. From a pipe in the bathroom comes 10 L of water per minute containing 1.11 kg hydrogen. Very simple. But You have to suck 4,400 m³ air through a filter to capture as much CO2 as containing the 1 kg carbon. This decreases the efficiency.

But the higher power-to-hydrogen efficiency comes at the price of far more storage costs, because the existing 25 km³ underground gas storage in Germany would contain only a third of the energy when filled with hydrogen. When this 25 km³ (at standard pressure) underground gas storage in Germany is not enough, additional storage would be far cheaper with methanol.

The 25 km³ underground gas storage in Germany is designed for the fossil energy system: delivery is constant all over the year, but in summer there is less demand than delivery, and in winter there is more demand than delivery. The difference is covered by the 25 km³ gas storage.

As the new installation numbers suggest, we are going to a very heavy photovoltaic-oriented energy transition requiring more storage for summer-winter balancing.

4.5 Prices used in the simulation

We used for the simulation 300 €/kW peak photovoltaic total including construction and inverter, 40 €/kWh sodium battery, and 60,000 € for the generator. For power-to-methanol, 10,000 € and 1 € for each Watt. So 50,000 W power-to-methanol is calculated with 60,000 €. These are estimated prices in 2030.

The equipment is different depending on the characteristics of the location. So Aalborg needs far more power to and less battery than Kampala. The chosen equipment for the 6 locations is all a bit above one million €.

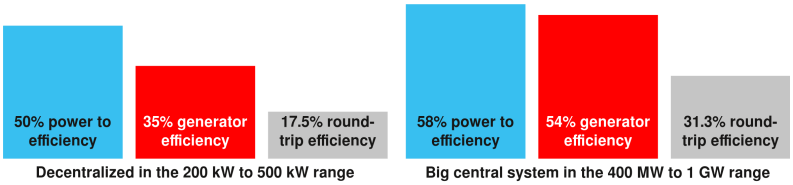
Could the 24×365 electricity problem be solved with batteries alone? We added for comparison 3 battery-only scenarios with the same costs, 3-times and 10-times the costs. This means with 5.5, 30 and 120 kWh battery per kW photovoltaic.

4.6 High voltage grid or no high voltage grid – that is here the question

The high-voltage grid is used to transport electricity over long distances. There are three reasons for this: (1) Geographical features for wind energy systems and hydropower plants, (2) Very efficient central large-scale technology, (3) Minimum and optimal size requirements from energy-intensive industries.

There is more wind in the North Sea than in Bavaria. Austria generates about twice as much electricity from hydropower as Germany, which is much larger. In the past, the centralized large-scale technology counted on the rail connection to bring two freight trains full of coal to the coal-fired power plant every day.

To answer the question, we added to the simulation high-efficiency central systems with 58% at power-to and 54% at generation, grid losses already in the efficiency.



In our assumption, the big central system has 79% more round-trip efficiency. What remains of this huge difference in the complete system?

There is on the diagrams a red line for the yearly average solar yield, a blue line for a central high-efficiency system, and a green line for a decentralized system. This simulates a solar-only system. It is obvious that they should, in Denmark, mix with wind energy to improve the gross yield vs. 24×365 electricity ratio. Since

wind energy is not where most people live, here is the answer: a high-voltage grid to connect all the wind energy with the consumers.

In this simulation, we listed percent improvement against less efficient decentralized systems. This improvement ranges between 5.1% and 26% at the 6 tested locations. Equipment costs × improvement gives the allowed costs for the grid to have equal costs. This is listed as "grid cost allowance" per kW peak photovoltaic. This ranges between 27 € to 151 € maximum grid cost per kW photovoltaic.

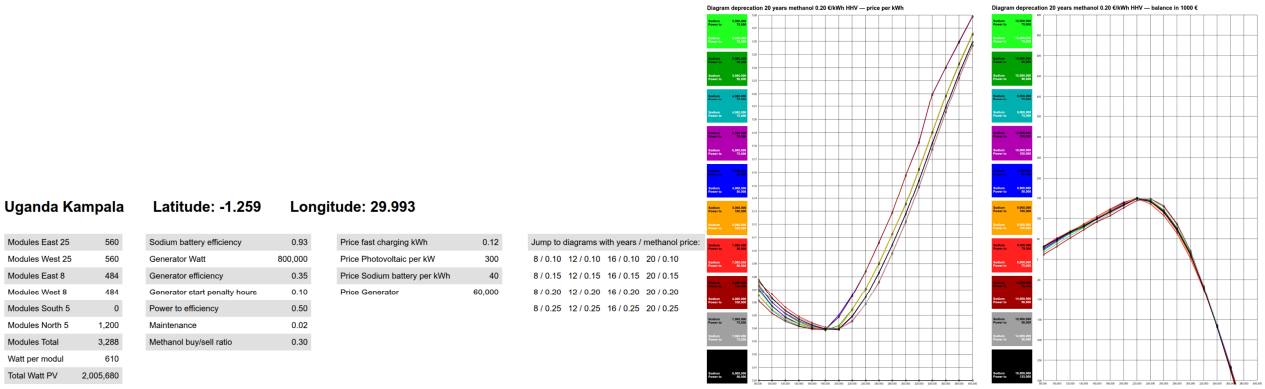
The diagram represents the 365 days of a year on the x-axis and the yield in kWh per kW peak photovoltaic installed on the y-axis. For each day of the year are 16 yellow dots for each yield on this day from 2005 to 2020.

4.7 Simulation download and description

The download contains the 6 locations shown in this paper, each in 3 variants: (1) "battery only" to show the effect of huge amounts of batteries, (2) "central" with assumed efficiencies of big central power to and CCPP systems, (3) "decentral" with assumed efficiencies of 200 to 500 kW systems

The download location is: https://climate.pege.org/2026/solar-yield.7z

Each file starts with a scenario description



Uganda Kampala **Latitude: -1.259** **Longitude: 29.993**

Modules East 25	560
Modules West 25	560
Modules East 8	484
Modules West 8	484
Modules South 5	0
Modules North 5	1,200
Modules Total	3,288
Watt per modul	610
Total Watt PV	2,005,680

Sodium battery efficiency	0.93
Generator Watt	800,000
Generator efficiency	0.35
Generator start penalty hours	0.10
Power to efficiency	0.50
Maintenance	0.02
Methanol buy/sell ratio	0.30

Price fast charging kWh	0.12
Price Photovoltaic per kW	300
Price Sodium battery per kWh	40
Price Generator	60,000

Jump to diagrams with years / methanol price:			
8 / 0.10	12 / 0.10	16 / 0.10	20 / 0.10
8 / 0.15	12 / 0.15	16 / 0.15	20 / 0.15
8 / 0.20	12 / 0.20	16 / 0.20	20 / 0.20
8 / 0.25	12 / 0.25	16 / 0.25	20 / 0.25

Left: Scenario description with Uganda Kampala as an example. Right: Diagram with the 10 best combinations for the lowest kWh production price on the left side and the 10 best combinations with the best balance on the right side

Modules East 25: East-facing modules with a 25° slope.

Generator Watt: Why 800,000 W? The average load is tested up to 400 kW, and the daily load profile has 2 hours with twice the average. To keep the simulation simple and avoid complicated ahead planning, we assumed the maximum possible load as the generator size. 200 kW would be the minimum reasonable size.

Generator start penalty hours: The cold start requires additional fuel.

Maintenance: The maintenance costs each year are 0.02 × CAPEX.

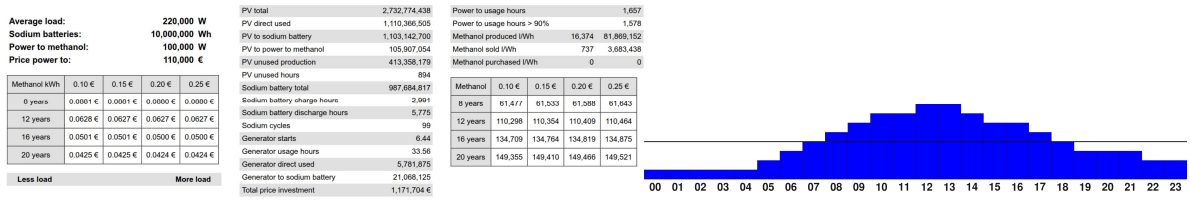
Price fast charging kWh: The off-grid fast charging settlement sells fast charging at this price.

Methanol buy/sell ratio: You cannot sell for the same price as you buy. At 20 cents/kWh HHV, 0.3 means you sell for 20 cents × 0.3 buy/sell ratio makes 6 cents/kWh HHV.

Jump to diagrams with years / methanol price: The price per kWh and the balance are calculated with 8, 12, 16, and 20 years of depreciation and 10, 15, 20, and 25 cents/kWh HHV methanol price.

The lowest production costs do not always bring the best balance. This depends on the sale price. Selling 1 GWh at 4 cents/kWh production costs for 12 cents/kWh brings 80,000 €. But selling 1.2 GWh at 5 cents/kWh production costs brings 84,000 €. This makes the differences between the viewpoint production costs and balance.

At low load, the under-usage of the equipment determines the bad performance in production price and balance. At high load, the fuel usage of the generator determines the bad performance in production price and balance. Purchasing methanol for 20 cents/kWh HHV and converting it with 35% efficiency to electricity means 57 cents in fuel costs per kWh.



Average load:	220,000 W
Sodium batteries:	10,000,000 Wh
Power to methanol:	100,000 W
Price power to:	110,000 €

Methanol kWh	0.10 €	0.15 €	0.20 €	0.25 €
0 years	0.0001 €	0.0001 €	0.0000 €	0.0000 €
12 years	0.0628 €	0.0627 €	0.0627 €	0.0627 €
16 years	0.0501 €	0.0501 €	0.0500 €	0.0500 €
20 years	0.0425 €	0.0425 €	0.0424 €	0.0424 €

Less load — More load

PV total	2,732,774,438
PV direct used	1,110,366,505
PV to sodium battery	1,103,142,700
PV to power to methanol	105,907,054
PV unused production	413,358,179
PV unused hours	894
Sodium battery total	987,684,817
Sodium battery charge hours	2,991
Sodium battery discharge hours	5,775
Sodium cycles	99
Generator starts	6.44
Generator usage hours	33.56
Generator direct used	5,781,875
Generator to sodium battery	21,068,125
Total price investment	1,171,704 €

Power to usage hours		1,657
Power to usage hours > 90%		1,578
Methanol produced l/Wh	16,374	81,869,152
Methanol sold l/Wh	737	3,683,438
Methanol purchased l/Wh	0	0

Methanol	0.10 €	0.15 €	0.20 €	0.25 €
8 years	61,477	61,533	61,988	61,643
12 years	110,298	110,354	110,409	110,464
16 years	134,709	134,764	134,819	134,875
20 years	149,355	149,410	149,466	149,521

Left: For each battery, power-to-methanol and load combination is such a statistic: 1,700 statistics for one location. Right: Daily load profile is a fast charging station

PV unused production: The batteries are fully charged, and power-to-methanol runs at maximum power. Sure, it would be possible to reduce the unused production by much more batteries and a much stronger power-to-methanol system. All the simulations show that reducing unused production to nearly zero increases costs per kWh.

The simulation was created in April 2024 to research the possibility of off-grid fast-charging settlements in Africa. Future versions will have new possibilities to simulate different load profiles.

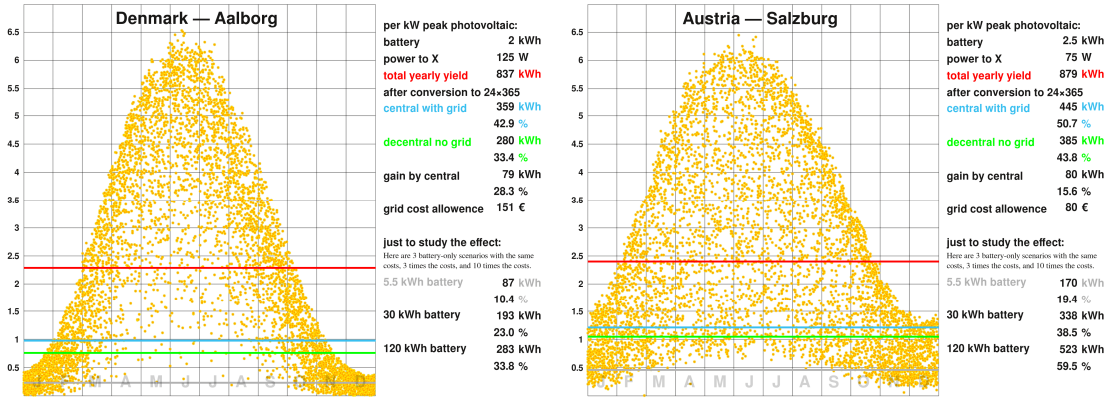
Industry with variable production: It will be possible to set a minimum percent of production rate. So the industry will throttle down in low solar yield situations.

Old town buildings: Old buildings usually have bad thermal insulation. They need much heating in winter and much cooling in summer.

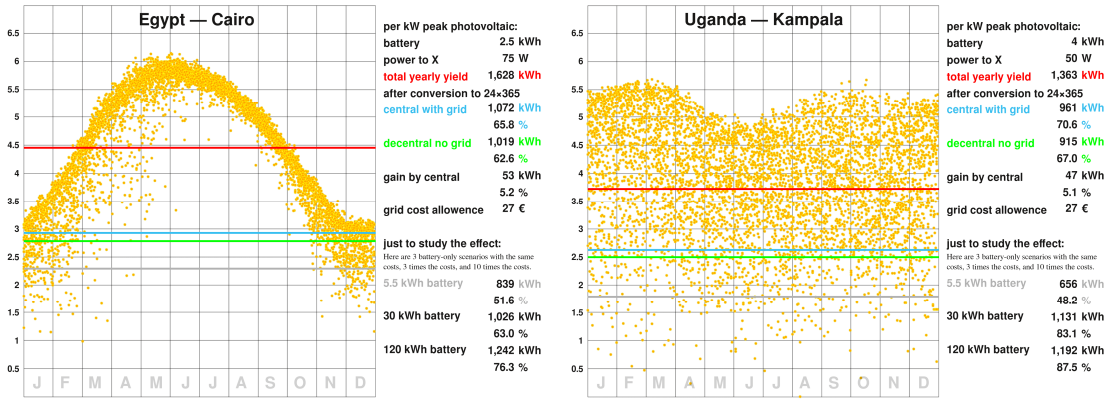
Greenhouse: Growing plants in a greenhouse has several advantages but requires heating or cooling.

4.8 Solar yield and conversion to 24×365 electricity

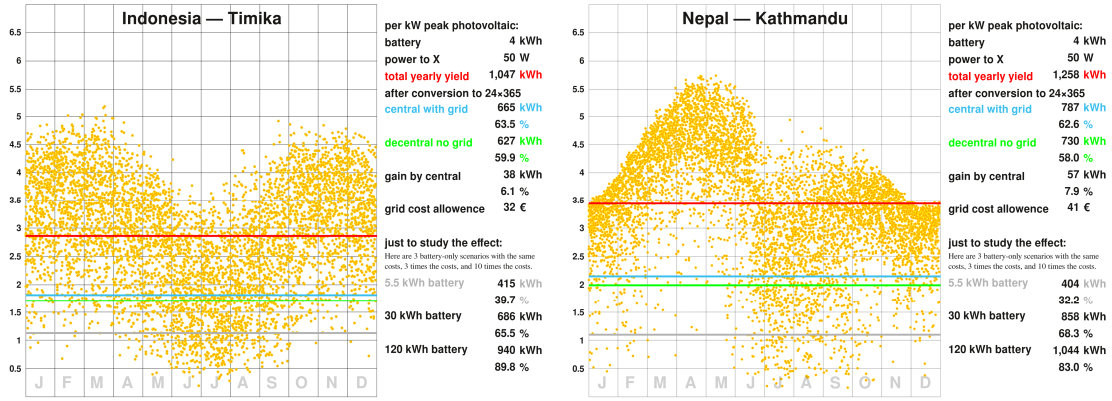
The wide range of solar yield becomes much wider after the conversion of gross yield to 24×365 electricity. 6 examples from our research of 50 locations.



Left: Aalborg, Denmark: At the winter solstice, the sun is only 9.47° above the horizon at midday. So we have here a very drastic difference between the summer solstice and the winter solstice. Right: Salzburg, Austria: At the winter solstice, the sun is 18.76° above the horizon at noon instead of 9.76° in Aalborg. This is sufficient for a 37.5% increase in 24×365 yield.



Left: Cairo, Egypt: Long-term storage requirements are determined almost exclusively by the tilt of the Earth's axis. This results in 165% more 24×365 yield. Not only is there much more gross yield, but also a much more efficient conversion to 24×365. Right: Kampala, Uganda: The weather determines long-term storage requirements. Much less gross yield compared to Cairo, partially compensated by higher 24×365 conversion efficiency.



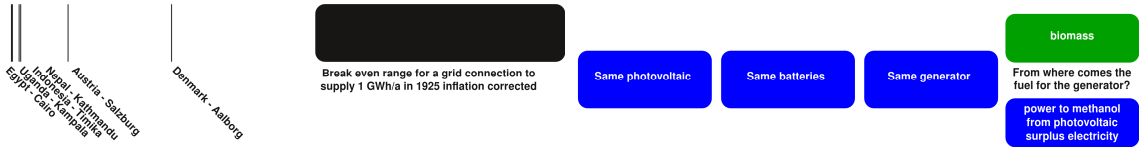
Left: Timika, Indonesia: Timika has a tropical rainforest climate (Af) with heavy to very heavy rainfall year-round. It seems Salzburg is a very sunny city compared to this. It seems from 2005 to 2020 not one sunny day from dusk to dawn. Despite this more or less cloudy weather, there is still 63% more 24×365 yield than in Salzburg. Right: Kathmandu, Nepal: Guess which months are the rainy season. Despite this very pronounced weather phenomenon, 90% more 24×365 yield than in Salzburg.

4.9 Grid development in the past vs. today

Parameters had been entirely different. The grid was to connect to distant coal power plants or hydropower. Was local production an option? Really not! Let's look back one century, to the twenties of the 20th century. Independent from the political system, electrification was a high priority. Here in the West: “electricity to the last mountain farming village” and Lenin wrote, “Communism is Soviet power plus the electrification of the whole country”.

Parameters had been entirely different. The grid was to connect to distant coal power plants or hydropower. Was local production an option? Really not! Diesel engines were at this time no option. Large coal power plants had 18 to 20% efficiency. In the 200 kW range, only 8 to 12%. This means not only nearly double the coal but also higher transportation costs. There is the big coal power plant with its own railroad and a freight train full of coal every few hours. The next point is labor cost. Manual coal/ash handling was dominant in small plants; central benefited from scale and emerging automation.

Assuming a small consumer, industry, or settlement with 1 GWh/a electricity demand, the grid cost allowance had been 1 to 1.8 million € inflation-corrected. No question, grid expansion was a great idea. We just showed the range is 27 € to 151 € per kW photovoltaic. For the assumed 1 GWh/a consumer, this translates to a range of 27 to 534 thousand €. Denmark and Austria are “we already have a great grid” countries. Without these 2 countries in the examples, the range is only 27 to 56 thousand €.



Left: Different time, different places, completely different outcome. When one century and a location more close to the equator changes the high voltage grid from a “must-have” to an “unnecessary, too expensive”. Right: This duel is for the biomass impossible to win. It is unavoidable that fuel generated from power-to-X from surplus solar electricity will expel biomass from the energy market.

4.10 Energy from biomass loses against surplus electricity

The batteries are full; what to do with the surplus electricity? When you have nothing to use surplus electricity for, it is simple waste. Power-to-X becomes, in this situation, simple waste utilization.

Components like large storage of chemical energy and caloric power plants are necessary, regardless of the system. So all the energy from biomass competes against only one component: the Power-to-X system. All the other components are necessary, regardless of the usage of biomass.

5 THE GEMINI PRINCIPLE: DOUBLE USAGE OF LAND

No better solar power plant, no better housing possible on the same ground is the ultimate target of the GEMINI principle.

5.1 Single family homes vs. big houses

Houses built around 1960 in Germany had been a horror in nonexistent insulation. A typical 16-apartment block had been, at this time, between 160 and 220 kWh/a/m² heat demand and 60 to 80 m² per apartment. On the other side had been a single-family house with 250 to 300 kWh/a/m² heat demand and between 100 and 120 m² living space. So a family living in an apartment block had between 9,600 and 17,600 kWh heat demand, while the family in the single-family house had 25,000 kWh to 36,000 kWh heat demand.

In addition to the heat demand problem, owners of single-family houses had been more likely to have a car and to drive more km a year than people living in apartments. All energy had come in 1960 from distant power sources: hydropower plants and coal power plants. Coal power plants supplied by coal mines, and the cars supplied by refineries supplied by distant oil wells. There was only one thing a house could do about energy: consume less energy.

Based on these numbers evolved the idea that apartment blocks are good and single-family houses are bad. The first thermal insulation regulation was introduced in 1977 in Germany. All concentrated only on the heat energy demand: the passive house and the low-energy house. All the efforts had been towards nearly zero heat demand, with nearly no thought beyond.

Range of typical single family homes in Germany	1960		2025	
Size	100 m²	120 m²	140 m²	152 m²
Heat demand per m²	250 kWh	300 kWh	40 kWh	60 kWh
Heat demand total	25,000 kWh	36,000 kWh	5,600 kWh	9,120 kWh
Range of typical 16-apartment block				
Size	60 m²	80 m²	70 m²	85 m²
Heat demand per m²	160 kWh	220 kWh	30 kWh	50 kWh
Heat demand total	9,600 kWh	17,600 kWh	2,100 kWh	4,250 kWh

Both apartments and single-family homes are now bigger but have improved much at lowering the heat demand.

5.2 Contemporary 16 apartment building block

Space and material for a 16-apartment building block in Germany:

Brick/Masonry Construction (Ziegel-Mauerwerksbau) Traditional and common (highest market share in Germany): Load-bearing brick walls, concrete floors/slabs.

- Standard range: 1,200–2,400 m² (0.12–0.24 hectares)
- Bricks/masonry (load-bearing walls, often high-insulation filled bricks like Poroton): 500–700 kg/m² BGF → 1,200–1,680 tons total. (Higher mass due to thicker walls ~30–42 cm for thermal performance.)
- Concrete (mainly floors/ceilings, basement/garage): 250–350 kg/m² BGF → 600–840 tons total. (Less than pure concrete build, as walls carry load.)
- Steel reinforcement: 40–60 kg/m² BGF → 96–144 tons total.
- Only 20 to 40 kW photovoltaic.

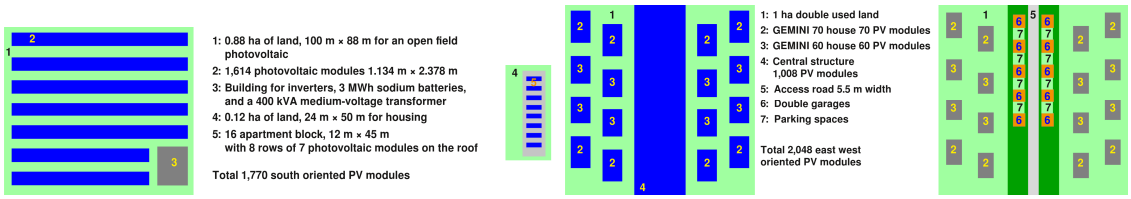
We have to end the time when our energy came mostly from coal mines, oil wells, and gas extraction. So from where should all the energy come from?

I predicted in 1992 that the electricity demand in Germany would increase from 500 TWh to 1,200 TWh because we have to change all the use of thermal energy to electricity; the yield of biomass is magnitudes too low to continue with burning to produce heat or mechanical energy.

Prof. Volker Quaschning wrote in 2016 in “Sektorkopplung durch die Energiewende” (Sector coupling through the energy transition) that the electricity demand will increase from 600 TWh to 1,300 TWh. Some new studies predict more, some less, but let's see what 1,300 TWh means: 1,300 TWh divided by 83.5 million inhabitants is 15,687 kWh per inhabitant. With an average of 2 inhabitants per apartment: 31,138 kWh. With 16 apartments in this block: 498 MWh.

5.3 Conventional usage with housing and open field PV seperated

Let's put the 16 apartment block somewhere on 0.12 ha of land and somewhere else 0.88 ha of open-field photovoltaic systems. 1,670 south-oriented photovoltaic modules with 1.094 MW peak.



Left: Let's put the 16 apartment block somewhere on 0.12 ha of land and somewhere else 0.88 ha of open-field photovoltaic systems. 1,670 south-oriented photovoltaic modules with 1.094 MW peak. Right: Left is seen all the photovoltaic from above; right is seen what is below all the photovoltaic.

5.4 Optimized usage for better housing, more energy, and fewer costs

Now let's compare this with an energy-optimized village like the one presented in my paper for CORP 2025.



Left: The single-family home is dead; long live the new single-family home, which makes a major contribution to energy transition and climate protection. Right: Who would trade living here for the canyon-like streets of a big city?



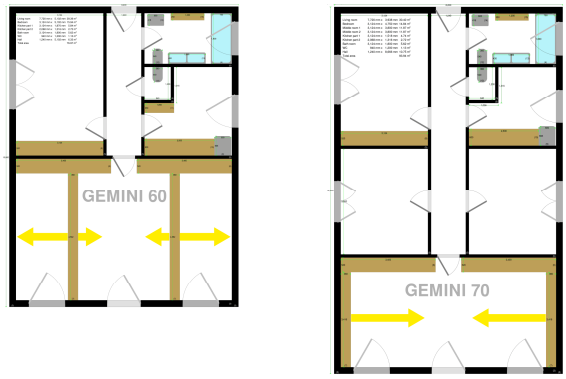
Left: For a complete energy transition, including the electrification of heavy industry, it is necessary for about one-third of the population to live in this way. Right: Anyone who generates so much electricity should also be able to use a small portion of it for luxury items: for example, using a swimming pool in Central Europe from April to October.



Left: The area covered by photovoltaic panels is almost 27 m wide. That's enough for much more than just garages and parking spaces. Right: 40% of the area protected from sun and rain by photovoltaics is communal space for sports, children's playgrounds, and shared activities.

5.5 GEMINI next Generation house type 60 and 70

The number in the house type represents the number of 1,134 mm × 2,378 mm solar modules. We have designed types 50, 60, 70, 72, 80, and 84. However, we think types 60 and 70 will be the most used types. As we made the photos of the settlement, there had been only what are now types 60 and 80. On the site plan is a mix of types 60 and 70.



Slideable wall/furniture elements for a variable usage as one big living room or a small living room and two additional rooms.

We did cost optimization not only at the energy system. Affordability is a key point in every design decision.



Left 1: drawers instead of basement. Left 2: air ventilation system with heat and humidity recovery. Right 1: This machine can produce the frame of a GEMINI 60 house in 3 hours. Right 2: The steel comes from this coil.

We have shrunk the basement. Drawers that are within the thermal envelope of the house. Perfect conditions for long-term storage. Lots of space; perhaps a homeowner in financial difficulty might even consider renting out some of the drawers as storage space.

Biodiversity is only beautiful outside. The ventilation system with heat and humidity recovery not only saves energy but also keeps unwanted intruders away. HEPA filters can also be used.

5.6 Other advantages: floodproof up to 70 cm and “Option Venezia”

Climate change increases flood risk globally. Far more incidents in low-risk and moderate flood-risk areas. The GEMINI next Generation house is floodproof up to 70 cm and will be able to swim for a 20,000 € upgrade called “Option Venezia”. Most homeowners will make the decision based on insurance tariffs: What is cheaper, the down payment for “Option Venezia” or the flood insurance?

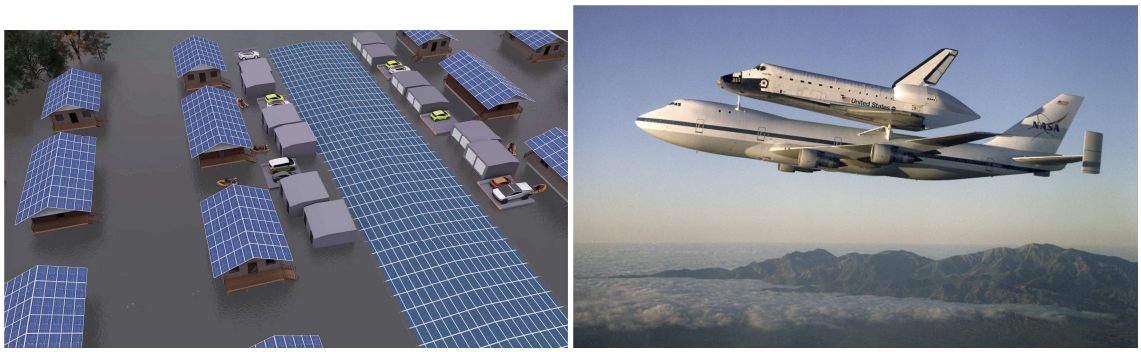
BTW, we thought about a special possibility to make the photovoltaic hailproof. The idea was dismissed after it turned out that this design would be 10 times pricier than the hail insurance. Studying risks is a main job of running an insurance company, so any design avoiding a risk can only be successful when it is cheaper than insurance.

On the other side, fire insurance in California is so expensive that an advanced fire protection system would be far cheaper. When we will be there, we will call it “Option California.”

5.7 Compare conventional vs. energy optimized settlements

Point-for-point compare why the energy-optimized settlement is far cheaper than the conventional approach. Let's start underground with the garage. Makes 32,000 € to 42,000 € per place in middle Europe, but it is common that 2 places have to be for one apartment. Here are the first 64,000 € to 84,000 € for the apartment.

At the energy-optimized settlement, there are garages and parking places below the central photovoltaic structure. Garages below 10,000 € per place, the central photovoltaic is like a huge carport. Let's have one garage place and one parking place. What to do with the difference? Let's have 80 kW photovoltaic and 240 kWh batteries!



Left: The settlement, shown before, at 4.5 m flood. All houses swim. The central structure is fixed, so all garages and parking platforms had been brought outside to swim. Right: A Boeing 747 carrying a space shuttle makes 322 tons of takeoff weight. Or the weight of 5 Abrams M1 main battle tanks. An 100 m² apartment with 2 places in the underground garage can also be up to 322 tons of construction material.

We only finished to compare the underground, and we have already discovered the money for the energy transition. But we are far away from finished.

Only mass helps against impact sound. In a multi-story residential building, such a ceiling is 300 to 350 mm thick throughout. One square meter weighs 500 kg to 600 kg. But that is not one square meter of living space, because in buildings of this type, only 70% of the total area is living space. So that's 700 kg to 850 kg just for the ceiling for one square meter of living space. At the GEMINI house, the floor separating the living area from the drawer system below is less than 5% of this weight.

How do you stop noise over the shortest distance? Sound insulation is a decisive factor for residential satisfaction. Again, this can only be achieved on short distances with mass, a lot of mass. Because the neighbor's stereo system can be louder than the traffic noise outside, the partition walls between apartments are also heavier than the exterior walls. The partition walls between apartments weigh 300 kg to 550 kg per m², while the exterior walls weigh only 180 kg to 350 kg per m² of wall space. We use some optimizations for acoustic insulation between rooms inside the GEMINI house, but in a single-family house, no strong acoustic separation is required. The outside wall is less than 30 kg/m².

This is an enormous material battle to make it reasonably bearable for people to live together in a very small area. Can we continue to afford this type of newly built housing, or must it be considered a luxury for private buyers?

Do we want an energy transition? Do we want climate protection? Then such material battles must be called into question.

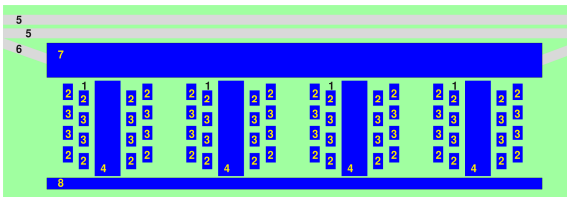
6 OFF-GRID FAST CHARGING SETTLEMENTS

Being able to reach all the areas with no electricity is most important for the change to electric cars and trucks in Africa. As shown before, a high-voltage grid is far too expensive. It makes absolutely no sense to transfer the power of a photovoltaic over some hundred kilometers when a photovoltaic there can do the job also without this grid. There are even more advantages: DC direct by a battery-powered fast chargers are cheaper and more efficient than AC-powered fast chargers.

It can start small, somewhere in a village, with a single GEMINI house with a big PV carport and 100 kW DC charging. This can expand to several houses and a generator to also provide service in very dense cloudy weather conditions. Maybe at a group of 16 houses, a power-to-methanol system will be added.

And the off-grid fast charging settlement grows, and 20 years later it is the size of a usual European highway station.

(1) 1 ha double used land, (2) GEMINI 70 house 70 PV modules × 32 = 2,240, (3) GEMINI 60 house 60 PV modules × 32 = 1,920, (4) Central structure 1,008 PV modules × 4 = 4,032, (5) Highway, (6) Street to the fast chargers, (7) 460 × 15 = 6,900 modules above fast charging and gastronomy, (8) 460 × 5 = 2,300 modules above a connection street behind the village. Total 17,392 modules with 11 MW peak. The inhabitants work in the gastronomy of the fast-charging station and as farmers to utilize the surrounding land.



Typical 24×365 capability for 80 trucks 300 kWh charging and 300 cars 30 kWh charging.

7 ENERGY-INTENSIVE INDUSTRY

I once developed a scale for off-grid solar possibilities depending on photovoltaic size, 3 Wh battery per Watt peak assumed: (1) 5 to 100 W information and light (smartphone, laptop, LED), (2) 200 to 300 W refrigerator (less rotten food), (3) 500 to 1,000 W electric cooking and electric scooter, (4) 3,000 to 6,000 W air conditioner and electric car. But now is to make a big jump upwards on this scale: (5) 80,000 W to 160,000 W house in a workers village designed to contribute to the extreme electricity demand of electric-only running, energy-intensive industry.

These houses are beyond what a simple worker in a poor country could afford, even with selling much electricity to the company. It is for the company to balance house prices, the price of electricity, and the wages to pay.

7.1 Operating mode for energy intensive industry

There is an investment, and it should run all year. This is the standard approach. Would a taxi operator cease operations in winter simply because electricity prices are higher in winter than in summer and consumption is slightly higher? Sure not!

Exactly this question is a main question in energy-intensive industry. There is an investment, there are workers and there are different amounts of available energy and resulting energy prices. Look at the solar yield graph of Cairo, Egypt. Here it is completely predictable; we run the factory with 200 workers in June and with 100 workers in December. Look at Kampala, Uganda. Here it is completely unpredictable for more than some days weather forecast.

At low battery prices, is the conversion from random electricity to 24-electricity always a win. The conversion from 24-electricity to 24×365 electricity comes at a price. This price is shown at the conversion ratio. In our examples, this conversion ratio is between 33.4% and 65.8%. No problem for everyday electricity use, like for car driving or heat pumps.

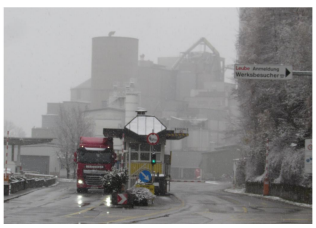
But it is a huge problem when 9,000 kWh are required to produce 1 t of a product where the fossil energy-using competition is at €300/t on the market. 9,000 kWh can propel an electric car more than one time around Earth or produce 1 t of urea fertilizer.

So we show for each energy-intensive industry 3 modes: (1) Constant all the year, (2) Moderate changing of production for cost optimization, (3) Running on 24-electricity, no conversion to 24×365

Remember, 2 centuries ago, steel production emerged only close to coal mines delivering hard coal. It was possible to heat a house with hard coal 1,000 km distant from a coal mine, but not to build a steel factory there.

7.2 Electric-only production of cement





600 kWh per ton for electric only cement production	Aalborg Denmark	Salzburg Austria	Cairo Egypt	Kampala Uganda	Timika Indonesia	Kathmandu Nepal
Usual market price for 1 t	134 €	140 €	66 €	148 €	87 €	89 €
Electricity for the production of 100 € market price	448 kWh	429 kWh	909 kWh	405 kWh	690 kWh	674 kWh
If 70% of the price would be energy, this would be €/kWh	0.156	0.163	0.077	0.173	0.102	0.104
Constant production all the year aound						
Moderate production changes for cost optimization						
Runing only on 24-electricity to be competitive						

Left: hydropower plant Urstein – right; cement factory LEUBE. Table: The energy subsidies in Egypt are running out. Electric-only cement production by photovoltaics is possible in all example locations.

At the hydropower plant Urstein at the Salzach is a sign: 120 GWh/a, we supply to 35,000 households. Only 2.5 km distant is the cement factory LEUBE: 110 GWh electricity and 400 GWh heat for 600,000 t cement

per year. Making a fire to bring the clinker to the required reaction temperature could be replaced by electric-only heating. The 400 GWh heat could be replaced by 250 GWh electricity. So the cement factory would be fully electric with 360 GWh/a fully electric, and the shield at the hydropower plant should be replaced with: 120 GWh/a, we supply 90 workers in the energy-intensive industry.

The non-SI unit “household” translates in middle Europe usually to 3,500 kWh/a electricity; the heating of the household is by burning, and they have only ICE cars. But even when we correct “household” to 8,000 kWh/a, the difference between 15,000 households and 90 workers in the energy-intensive industry is two orders of magnitude.

What moderate production changes in Denmark and Austria? Simple 30 to 45 days berak around the winter solstice.

7.3 Electric-only mineral wool production

There are Heat Degree Days (HDD). You can calculate the heat demand of a house with the energy certificate and the HDD of a location. 100 W/K and 3,900 HDD means 100 W/K x 24 hours x 3,990 HDD = 9,360 kWh/a heat demand. Most extreme permanent inhabited locations in Austria have 5,300 HDD. For example, Obergurgl. Permanent used houses there have good thermal insulation. Vienna has only half of the Obergurgl HDD.

There are also Cool Degree Days (CDD). Manila has as many CDD as Obergurgl, the highest permanently inhabited village in Austria, has HDD. Single glass windows and no insulation. Rich people brag there that they spend for electricity as much as for 4 housemaids, most of the energy for this insanity is imported fossil energy.

So the production of thermal insulation is something very important for hot areas. As we signed an NDA with a construction company in Ghana, my first reaction was to search for electric-only production equipment for mineral wool because insulation material is more expensive in Ghana than in Austria.

2,000 kWh per ton for electric only mineral wool production	Aalborg Denmark	Salzburg Austria	Cairo Egypt	Kampala Uganda	Timika Indonesia	Kathmandu Nepal
Usual market price for 1 t	2,200 €	2,200 €	1,800 €	1,200 €	1,000 €	900 €
Electricity for the production of 100 € market price	91 kWh	91 kWh	111 kWh	167 kWh	200 kWh	222 kWh
If 70% of the price would be energy, this would be €/kWh	0.770	0.770	0.630	0.420	0.350	0.315
Constant production all the year aound						
Moderate production changes for cost optimization						
Runing only on 24-electricity to be competitive						

450 kWh per ton for electric only scrap to steel recycling	Aalborg Denmark	Salzburg Austria	Cairo Egypt	Kampala Uganda	Timika Indonesia	Kathmandu Nepal
Usual value change for 1 t	250 €	250 €	280 €	160 €	50 €	100 €
Electricity for 100 € market price gain from scrap to steel	180 kWh	180 kWh	161 kWh	281 kWh	900 kWh	450 kWh
If 70% of the price would be energy, this would be €/kWh	0.389	0.389	0.436	0.249	0.078	0.156
Constant production all the year aound						
Moderate production changes for cost optimization						
Runing only on 24-electricity to be competitive						

Left: I kept hearing from building biologists about the energy required for production, but now it turns out that this is completely uncritical. Right: Seems there is a price anomaly in Timika.

7.4 Scrap to steel by electric melting

Approximately 29% of global crude steel production is made via electric arc furnace (EAF) melting, which is the primary method for recycling steel scrap (electric melting). So this is an established technology.

7.5 PEM or AEL electrolyzer

PEM electrolyzers have a stable efficiency over a wide range of power input and follow load changes in seconds. You can even connect PEM to photovoltaics directly without any electronics in between. Sounds great, but there are severe disadvantages: shorter usage of the equipment and high prices due to extremely expensive materials like iridium and platinum.

The world production of gold is 3,000 to 3,500 t/a, and platinum is 180 to 200 t/a. We have only 7 to 8 t/a Iridium. Even the complete world production of iridium would be only 11 GW PEM electrolyzers.

Type	PEM			AEL		
Year		2010	2030		2010	2030
Photovoltaic	1 kW	1,500 €	300 €	1.2 kW	1,800 €	360 €
Batteries				3.6 kWh	1,800 €	144 €
Electrolyser	0.8 kW	1,600 €	1,600 €	0.25 kW	200 €	200 €
Total		3,100 €	1,900 €		3,800 €	704 €

Surprise, we have again detected a missed profitability transition.

There had been a time when photovoltaics and batteries had been extremely expensive. No batteries are necessary at a PEM electrolyzer, making the best usage of the expensive photovoltaic. In this scenario, the

high price per kW of PEM electrolyzers did not matter. In this scenario, the scarcity of iridium did not matter. But here again, we have a missed profitability transition. How can this happen so often in the area of the energy transition?

Best explanation is the "It doesn't make economic sense" trauma. In the time before 2009, people working for the energy transition heard again and again, "It doesn't make economic sense". Over several years, this developed into a severe trauma. The reaction was, "We have to do it, whatever it costs". This trauma-induced reaction brought the energy transition in a bad situation.

7.6 Iron ore to steel only by electricity

Iron ore is actually rust mixed with stones. The formula FeO(OH) for rust is a significant simplification: rust is a complex mixture of many different oxides and hydroxides of iron. Some of them have names like Hematite Fe_2O_3 or magnetite Fe_3O_4. If you want iron, you first have to remove the oxygen. This can be done either with carbon or hydrogen. With carbon, you get 2 kg of CO2 emissions per kg of iron, while with hydrogen you have to use about 4 kWh of electricity to produce the necessary hydrogen.

4,000 kWh per ton for electric only steel production from ore	Aalborg Denmark	Salzburg Austria	Cairo Egypt	Kampala Uganda	Timika Indonesia	Kathmandu Nepal
Usual market price for 1 t	650 €	650 €	670 €	550 €	450 €	500 €
Electricity for the production of 100 € market price	615 kWh	615 kWh	597 kWh	727 kWh	889 kWh	800 kWh
If 70% of the price would be energy, this would be €/kWh	0.114	0.114	0.117	0.096	0.079	0.088
Constant production all the year aound						
Moderate production changes for cost optimization						
Runing only on 24-electricity to be competitive						

9,000 kWh per ton for electric fertilizer (urea) production	Aalborg Denmark	Salzburg Austria	Cairo Egypt	Kampala Uganda	Timika Indonesia	Kathmandu Nepal
Usual market price for 1 t	445 €	470 €	300 €	430 €	300 €	150 €
Electricity for the production of 100 € market price	2,022 kWh	1,915 kWh	3,000 kWh	2,093 kWh	3,000 kWh	6,000 kWh
If 70% of the price would be energy, this would be €/kWh	0.035	0.037	0.023	0.033	0.023	0.012
Constant production all the year aound						
Moderate production changes for cost optimization						
Runing only on 24-electricity to be competitive						

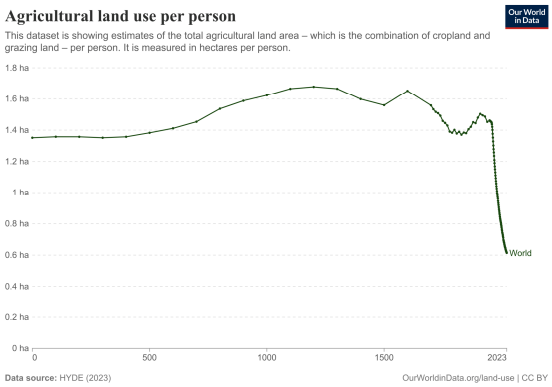
Left: Changing the production of steel by ore: 2 kWh of electricity replaces 1 kg of CO2 emissions. Right: The greatest challenge: cheaper than steel but more than twice the electricity for production.

7.7 Fertilizer production by electricity

At the beginning of the 20th century, Haber was celebrated as the man who made bread from air, thanks to the Haber-Bosch process for producing artificial fertilizer. Earlier sources of fertilizer were guano bird droppings and Chilean nitrate, both of which were limited resources. These limited resources were replaced by a new limited resource: fossil fuels. The best conventional plants emit 1.5 kg of CO2 per kg of urea fertilizer. Since the production of 1 kg of fertilizer costs 9 kWh of electricity, the least favorable ratio for replacing CO2 emissions with clean electricity is 6 kWh to avoid 1 kg of CO2 emissions. Replacing a moped with a 2-stroke engine with an electric scooter meant replacing 4 liters of gasoline/100 km with 10 kg of CO2 emissions with 5 kWh of electricity: only 0.5 kWh of electricity to avoid 1 kg of CO2 emissions. At least one green field in the "Run only 24-electricity" mode, but this is more than enough, because Cairo, Egypt stands for the Sahara, the Arabic peninsula and many more very sunny deserts.

8 AGRICULTURE: HOW MANY SQUARE METERS DOES A HUMAN NEED FOR HIS FOOD?

Mankind started as hunters and gatherers. 12,000 years ago, 500,000 m² to 2,500,000 m² per human. With the agricultural revolution, the land use was reduced by 2 magnitudes.



Scenario: tomato production	Yield per m²	Usage per m²		Usage per kg	
		L water	kWh	L water	kWh
Open Field near Vienna	8	480	1.6	60	0.2
Open Field near Amman	6.8	476	2	70	0.3
Advanced Greenhouse in Vienna with LED light in winter	200	400	900	2	4.5
Advanced Greenhouse in Vienna without artificial light	140	280	650	2	4.6
Advanced Greenhouse in Amman	200	400	1,400	2	7.0

Left: Our World in data: https://ourworldindata.org/grapher/total-agricultural-land-use-per-person. Right: How could the greenhouse in Vienna be improved? Maybe a winter break? How long should the winter break be?

But is this reduction enough? 9 billion × 0.6 ha are 54 million km². A new revolution in reducing required space for food growing could be used first in areas with extreme conditions.

8.1 Food growing: electricity instead of land and water

Jordan has approximately 61 cubic meters of renewable freshwater available per capita per year. This is far below the international threshold of 500 cubic meters per person per year, which defines absolute water scarcity.

To grow food, you need water. This limits Jordan's food production. It is possible to reduce water usage drastically by using much electricity.

Advanced greenhouse: Very low air exchange. The air exchange is controlled by holding the oxygen level below 25%. At the air exchange, humidity recovery is used. CO2 is blown into the greenhouse to achieve the 800 ppm CO2 optimal level for growing tomatoes. The CO2 can be provided by DAC – Direct Air Capture or from cement factories heating the clinker electrically, only providing pure CO2 from the chemical reaction.

Water for cooling is cooled down during the coldest hours of the day to improve the COP of the heat pumps. A GEMINI 60 house has 40 m³ water as low-temperature heat storage, which can be used for this optimization.

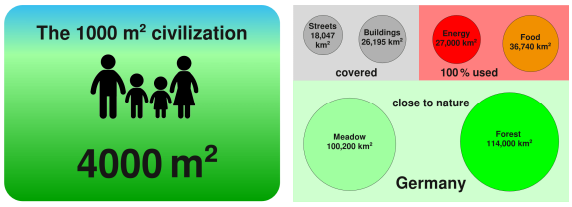
In aeroponic/hydroponic setups, the recirculating solution concentrates salts over time as plants transpire pure water. To prevent toxicity (maintaining EC <2.5–3 dS/m for tomatoes), a fraction must be periodically discharged and replaced with fresh water. For a further reduction of water usage, this water is also recycled as well as economically feasible.

Vacuum glass is decreasing in price, so it will soon be a solution to reduce the heating demand at greenhouses in winter.

LED usage: Amman has enough light all year to grow tomatoes. In Vienna is the decision is to supplement natural light in winter with LED light for optimal plant growth. The outcome in kWh/kg tomatoes is nearly the same, but using much more electricity in winter would further decrease the 24×365 conversion ratio.

8.2 The 1000 square meter civilization

More room for nature, more biodiversity – let's have a space-optimized civilization. Meadows and forests can mostly be considered nature. The main obstacle is not buildings and streets, but agricultural land for food and energy production. Intensive agricultural fields have zero biodiversity and are 100% not nature.



The 1000 square meter civilization would mean 83,500 km² of land usage in Germany and the rest more or less close to nature.

The easiest to resolve in Germany is the area wasting energy from biomass. One hectare of maize for biogas creates only 17 MWh/a, while one hectare of energy-optimized settlement has, even after the 24×365 conversion, about 550 MWh. With the new possibilities, there could be 50,000 km² more meadows and forests while having a very comfortable housing and living standard.

9 CONCLUSION

Thinking new about something important over and over again. All parameters are in a constant state of change. We have to check all the parameters and predict the development for the predictable future. What could be more important than the future of our civilization?

That is far more than just science; it is the foundation of ethics – the science of survival: (1) Knowledge is a prerequisite for ethics; (2) Knowledge is thus able to change the bases of decisions laid by ethics; (3) Ethics force us to verify knowledge.

Let's start to see the future of our civilization in a new, optimistic way!

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Der AACHEN-Kompass: ein innovatives Instrument zur frühzeitigen Verhandlung von Flächennutzungen

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1 ABSTRACT

Der AACHEN-Kompass ist ein neues, innovatives Planungsinstrument der Aachener Stadtentwicklung. Er greift auf den Feststellungsbeschluss des Flächennutzungsplans AACHEN*2030 zurück. Dieser sieht vor, insbesondere aus Gründen des Klima- und Landschaftsschutzes sowie der Klimaresilienz unbebaute Flächen nur noch in sehr begrenztem Maß für die Siedlungs- und Gewerbeentwicklung freizugeben. Die verfügbaren Frei- und Konversionsflächen sind effizient, integriert und nachhaltig zu entwickeln. Vor diesem Hintergrund zielt der AACHEN-Kompass darauf ab, eine Grundlage für die Abwägung künftiger Flächennutzungen zu schaffen. Er soll dazu dienen, Flächen in ihrem Nutzungspotenzial neu zu bewerten und die Innenentwicklung zu stärken.

Neben relevanten Fachbereichen der Stadtverwaltung werden betreffende Grundstückseigentümerinnen und Grundstückseigentümer sowie die Politik frühzeitig in den Prozess eingebunden. Einen wesentlichen Baustein stellt der Informationsaustausch mit betreffenden Grundstückseigentümerinnen und Grundstückseigentümern dar. Gemeinsam mit zwei beauftragten Begleitbüros nimmt die Abteilung Stadtentwicklung die Rolle als Vermittlerin unterschiedlicher Bedarfe und Interessen ein. Diese bilden das Grundgerüst für die Entwicklung von Nutzungsszenarien, welche für den Betrachtungsraum erarbeitet werden. Dabei werden bestehende Strukturen der Umgebung berücksichtigt und Potenziale mit Blick auf die Gesamtstadt herausgestellt.

Aktuell befindet sich das Instrument in der Erprobungsphase. Hierfür sind in einer politischen Gremiensitzung drei Flächen aus einem Portfolio beschlossen worden, die den Kompass-Prozess durchlaufen. Das Ziel besteht darin, jeweils eine Richtungsentscheidung zu initiieren und einen anschließenden städtebaulichen Prozess anzustoßen. Die gesammelten Informationen und Entscheidungen des AACHEN-Kompass stellen eine langfristige Rahmenvorgabe für die künftige Entwicklung der Betrachtungsräume dar.

Keywords: Innenentwicklung, Beteiligung, Flächennutzung, Planungswerkzeug, Richtungsentscheidung

2 EINLEITUNG: WAS IST DER AACHEN-KOMPASS?

Mit dem Feststellungsbeschluss des Flächennutzungsplans AACHEN*2030 hat der Rat der Stadt Aachen im Jahr 2020 beschlossen, insbesondere aus Gründen des Klima- und Landschaftsschutzes sowie der Klimaresilienz unbebaute Flächen nur noch in begrenztem Maß für die Siedlungs- und Gewerbeentwicklung freizugeben. Diese Vorgabe macht es erforderlich, die wenigen verfügbaren Frei- und Konversionsflächen besonders effizient, integriert und nachhaltig zu entwickeln. Um die politischen Gremien bei den dafür notwendigen Richtungsentscheidungen zu unterstützen, wurde der „AACHEN-Kompass“ ins Leben gerufen. Es handelt sich um ein neues Planungsinstrument der Stadt Aachen, welches sich seit 2023 in einer Erprobungsphase befindet und die bereits verfügbaren Planungswerkzeuge ergänzt. Er zielt darauf ab, eine frühzeitige Orientierung für wichtige Entwicklungsräume zu schaffen und diese in den gesamtstädtischen Kontext einzuordnen. Durch den AACHEN-Kompass werden strategische Leitlinien für die Flächenentwicklung definiert, was zu einer Beschleunigung der nachfolgenden Planungsprozesse führen soll (SSR 2025).

Das Verfahren des AACHEN-Kompass umfasst einen mehrmonatigen Prozess, der eine sogenannte „Phase 0“ in der Stadtplanung abbildet. Das konzeptionelle Gerüst basiert auf einer Kombination aus Analysen und Szenarien, die ein Spektrum möglicher Entwicklungen sichtbar machen. Sie werden im Hinblick auf ihre gesamtstädtischen und funktionalen Effekte reflektiert, sodass zentrale Stellschrauben für die Entscheidungsfindung transparent werden. Der AACHEN-Kompass versteht sich als formalisiertes Verfahren und zugleich als strukturierter Gesprächsleitfaden. Im Rahmen der Erprobungsphase werden drei Betrachtungsräume mit dem Ziel untersucht, den Prozess zu optimieren und ein wiederholbares, transparentes Vorgehen zu entwickeln (SSR 2025).

In den Prozess eingebunden sind relevante Fachbereiche der Stadtverwaltung, politische Entscheidungsträgerinnen, politische Entscheidungsträger, externe Akteurinnen, externe Akteure sowie die Eigentümerinnen und Eigentümer der betroffenen Flächen. Unterstützt wird die Stadtverwaltung durch externe Begleitbüros. Die Arbeitsgemeinschaft Reicher Haase Assoziierte (RHA) aus Aachen und KH STUDIO. delli Ponti & Novielli SARL aus Paris entwickelt die raumbezogenen Analysen sowie die Nutzungsszenarien, während das Büro STUDIO | STADT | REGION (SSR) aus München den Prozess begleitet, moderiert und evaluiert. Durch die enge Zusammenarbeit soll ein innovatives Planungsinstrument entstehen, das die Planungskultur der Stadt Aachen nachhaltig weiterentwickeln kann (SSR 2025).

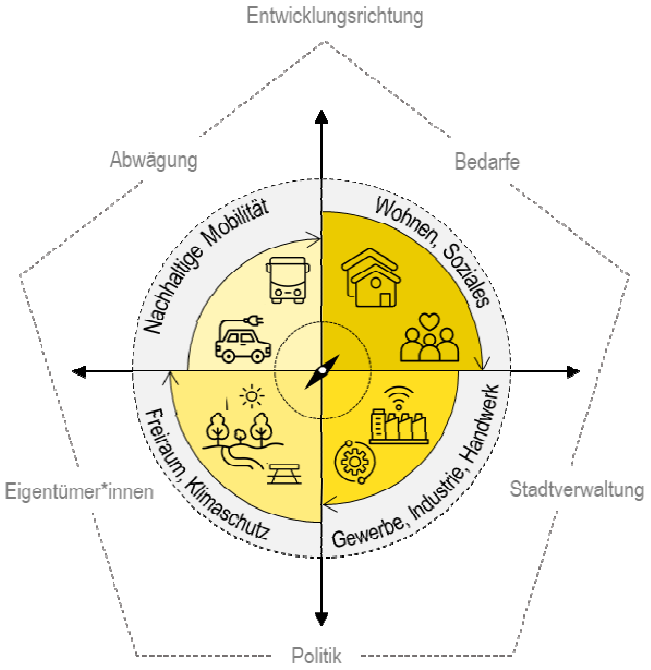


Fig. 1: AACHEN-Kompass.

3 UNTERSUCHTE FLÄCHEN

Im Rahmen des AACHEN-Kompass wird in einer zweistufigen Betrachtung zwischen „Fokusraum“ und „Resonanzraum“ unterschieden. Der Fokusraum bezeichnet die klar abgegrenzte Untersuchungsfläche, auf die sich der Prozess unmittelbar bezieht. Der Resonanzraum erweitert den Blick und umfasst den räumlichen Kontext, in den der Fokusraum eingebettet ist. Dadurch werden Wechselwirkungen mit der Umgebung sowie der Gesamtstadt sichtbar. Auf diese Weise werden mögliche Synergien und Konflikte frühzeitig erkennbar und in die Abwägung einbezogen. Die drei Betrachtungsräume repräsentieren verschiedene städtebauliche Ausgangslagen und verdeutlichen das breite Anwendungsspektrum des Instruments. Es reicht von der Revitalisierung innerstädtischer Konversionsflächen über die Entwicklung neuer Wohnstandorte am Stadtrand bis hin zur Neuordnung komplexer Gemengelagen.

3.1 Aachen-Forst: Sittarder Straße

Der erste untersuchte Fokusraum liegt südwestlich des Aachener Stadtzentrums in unmittelbarer Nähe zur Autobahn und umfasst eine Größe von rund sechs Hektar. Die Fläche wird derzeit industriell genutzt, der Standort des Unternehmens soll jedoch in den kommenden Jahren aufgegeben werden. Im Flächennutzungsplan ist das Areal überwiegend als Wohnbaufläche und zudem als Grünzug dargestellt. Nördlich und südlich überlagern zwei Bebauungspläne die Fläche. Aufgrund der stadtnahen Lage, der Größe und der guten verkehrlichen Anbindung besteht ein hohes Potenzial für die Entwicklung eines gemischten Stadtbausteins. Herausforderungen liegen vor allem in der Integration in das angrenzende Wohnumfeld und in der Abstimmung mit übergeordneten Zielen wie dem Klimaschutz und der Mobilitätswende.



Fig. 2: Betrachtungsraum 1: Sittarder Straße in Aachen Forst.

3.2 Aachen-Richterich: Roermonder Straße/Schloss Schönau Straße

Der zweite Fokusraum befindet sich am nordwestlichen Rand Aachens im Stadtteil Richterich und umfasst rund 14 Hektar. Er ist durch eine gemischte Nutzung geprägt. Im Norden befinden sich großflächige Einzelhandelsbetriebe. Im Zentrum liegt ein großes, weitgehend mindergenutztes Gebäude und im Süden ist eine Mischung aus Wohn- und gewerblichen Nutzungen vorzufinden. Im Flächennutzungsplan ist der Fokusraum als Gewerbefläche dargestellt und wird durch Grünzüge sowie durch eine Gemeinbedarfsfläche ergänzt. Für das Gebiet des Fokusraums liegen mehrere Bebauungspläne sowie Aufstellungsbeschlüsse vor. Altlasten und die Nähe zu ökologisch sensiblen Freiräumen stellen zentrale Herausforderungen dar. Die Fläche bietet ein großes Potenzial für die Entwicklung neuer Wohnquartiere mit ergänzender sozialer Infrastruktur und Nahversorgungseinrichtungen.

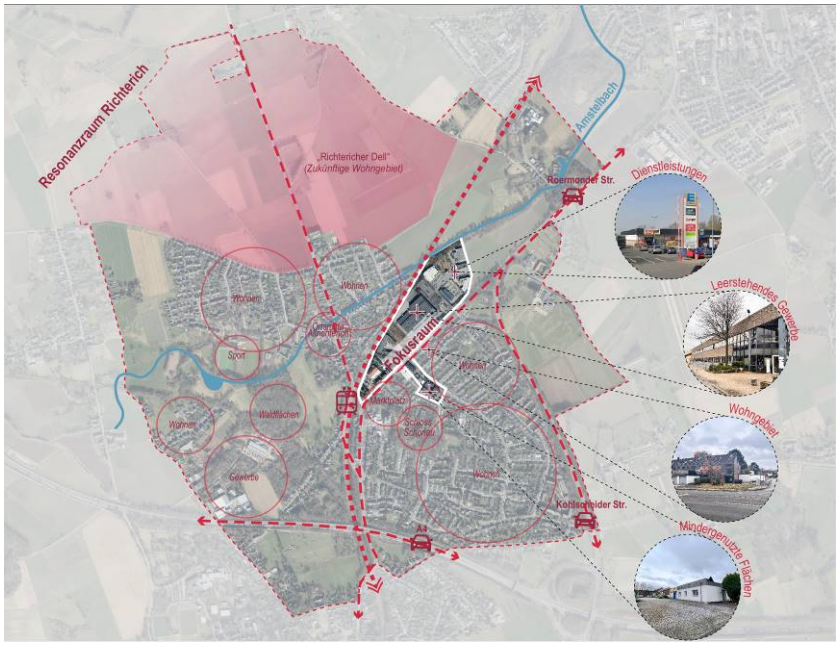


Fig. 3 Betrachtungsraum 2: Roermonder Straße/Schloss Schönau Straße in Aachen Richterich.

3.3 Aachen-Nord: Jülicher Straße/Wurm

Der dritte Fokusraum liegt im Stadtbezirk Aachen-Mitte. Westlich wird er durch eine große Ausfallstraße, der Jülicher Straße, begrenzt. Sie verbindet den Aachener Norden mit der Innenstadt. Östlich angrenzend verläuft ein Bachlauf. Der Fokusraum umfasst eine Fläche von rund 19 Hektar und weist eine heterogene

Gemengelage auf, die von Gewerbebetrieben und vereinzelten Wohnnutzungen geprägt ist. Im Flächennutzungsplan ist die Fläche als gemischte Baufläche dargestellt. Potenziale liegen insbesondere in einer Verknüpfung mit dem angrenzenden Freiraum. Zu den besonderen Herausforderungen zählen die Bewältigung von Nutzungskonflikten zwischen Wohnen und Gewerbe sowie die Anforderungen des Klimaschutzes. Die hohe Anzahl an privaten Grundstückseigentümerinnen und Grundstückseigentümern stellt eine weitere Besonderheit der Fläche dar. Im Fokusraum besteht die Chance, mindergenutzten Flächen eine neue Funktion zuzuweisen.



Fig. 4: Betrachtungsraum 3: Jülicher Straße/Wurm in Aachen Nord

4 PROZESSDESIGN

Das Prozessdesign des AACHEN-Kompass ist in Abbildung 5 veranschaulicht und besteht aus fünf Meilensteinen. Die Durchführung der jeweiligen Formate ist flexibel und kann je nach Gegebenheiten und Aufgabenstellung des jeweiligen Betrachtungsraums variieren.

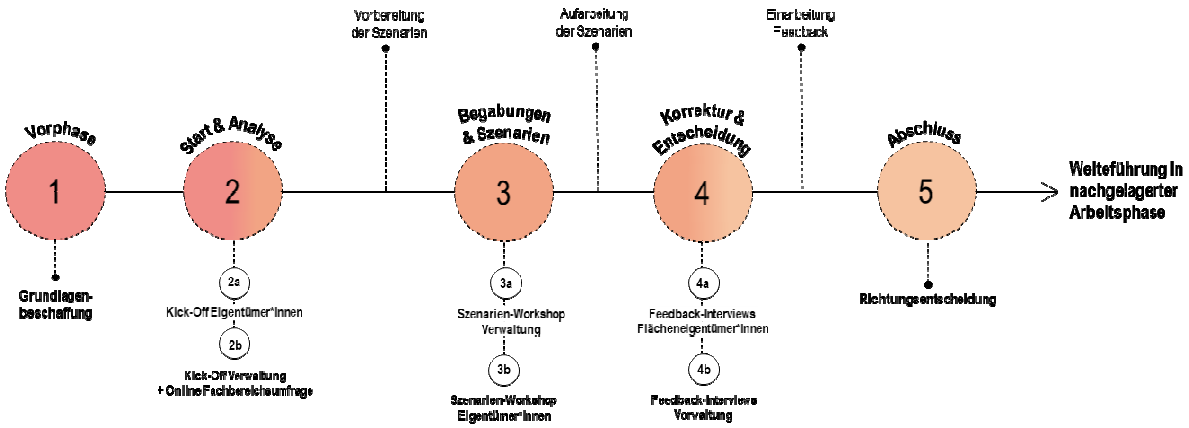


Fig. 5: Meilensteine des AACHEN-Kompass (Stadt Aachen 2025)

Den ersten Meilenstein bildet die Grundlagenbeschaffung im Rahmen der Vorphase. Hierbei werden neben rechtlichen Vorgaben vorhandene Konzepte und Planungen studiert, die für den Fokus- und den Resonanzraum in der Vergangenheit entwickelt wurden. Zudem fließen gesamtstädtische und grenzüberschreitende Studien und Berichte in die Analyse ein, welche bei der Entscheidung über eine zukünftige Entwicklung des Fokusraums beeinflussend wirken können. Als Beispiele hierfür sind Bevölkerungsprognosen, Wohnungsmarktberichte und gewerbliche Mietspiegel zu nennen. Alle Erkenntnisse werden gebündelt und fließen in die Ausarbeitung der Nutzungsszenarien ein.

Den offiziellen Start des AACHEN-Kompass stellt der zweite Meilenstein dar. Er setzt sich aus zwei Kick-Off-Veranstaltungen zusammen, die gesondert mit der Fachverwaltung und den Flächeneigentümerinnen und Flächeneigentümern des Fokusraums durchgeführt werden. Zu Beginn werden den Teilnehmerinnen und Teilnehmern die Informationen aus der Grundlagenbeschaffung vorgestellt. Anschließend erfolgt ein gemeinsamer Austausch in Kleingruppen. Dabei werden Meinungen und Bedarfe zur zukünftigen Entwicklung des Fokusraums abgefragt. Orientierung bieten hierbei die übergeordneten Themenfelder “Flächennutzung”, “Mobilität” und “Freiraum”. Das Ziel der Auftaktveranstaltungen besteht darin, wesentliche Informationen zu erhalten, aus denen sich die zu erarbeitenden Nutzungsszenarien herausbilden. Über den Kick-Off hinaus wird den Teilnehmerinnen und Teilnehmern zusätzlich die Möglichkeit gegeben, ausführliche Informationen und Anliegen schriftlich an das Projektteam zu übersenden (SSR 2025).

Auf Basis der Grundlagenbeschaffung und der eingegangenen Rückmeldungen werden Nutzungsszenarien für den Fokusraum erarbeitet. Eine beigefügte Tabelle legt dar, welche Potenziale das jeweilige Szenario bietet und welche möglichen Restriktionen damit einhergehen. Ergänzend dienen Collagen und Referenzbeispiele als Inspiration und veranschaulichen Möglichkeiten einer städtebaulichen Umsetzung. Gemeinsam bilden das Nutzungsszenario, die Pro-Contra-Auflistung und die Illustrationen einen umfassenden Steckbrief (siehe Abbildung 6), der im Rahmen des dritten Meilensteins in sogenannten “Szenarien-Workshops” vorgestellt wird. Sie bieten der Fachverwaltung und den Flächeneigentümerinnen und Flächeneigentümern die Möglichkeit, Stellung zu nehmen und Anliegen zu äußern.

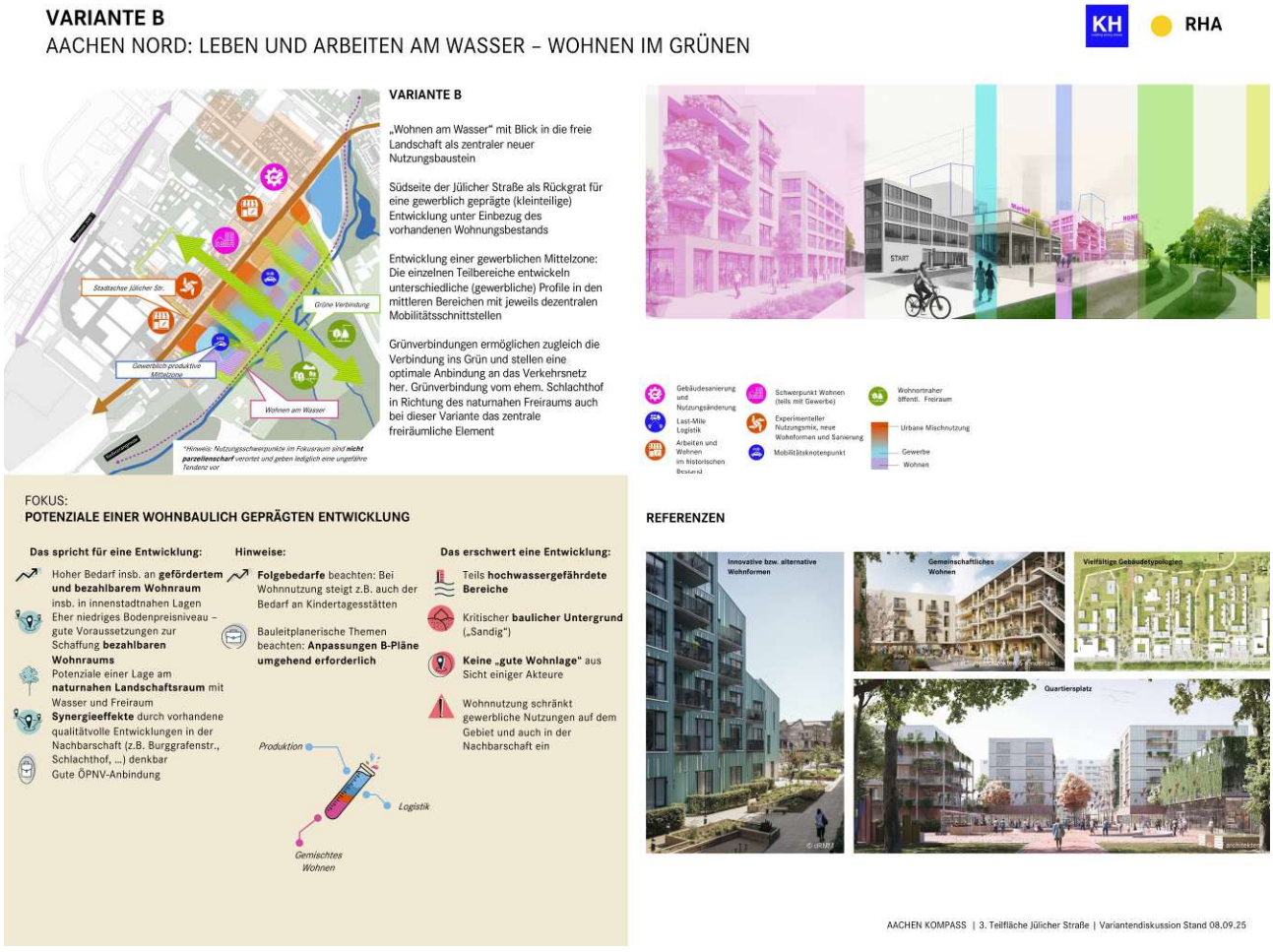


Fig. 6: Szenarien-Steckbrief (REICHER HAASE ASSOZIIERTE, KH STUDIO. delli Ponti & Novielli SARL, STADT AACHEN 2025)

Nachdem alle Anmerkungen und Informationen aus den Workshops in die Szenarien eingearbeitet wurden, findet eine weitere Korrekturschleife statt. Hierbei handelt es sich um den vierten Meilenstein des Prozesses, der die Durchführung von sogenannten “Feedbackinterviews” vorsieht. Den Fachabteilungen, Flächeneigentümerinnen und Flächeneigentümern werden in gesonderten Einzelterminen die überarbeiteten Nutzungsszenarien präsentiert. Sie erhalten erneut die Möglichkeit, inhaltliche und gestalterische Änderungswünsche zu äußern. Das Feedback fließt in die finale Ausgestaltung ein.

Im Rahmen des fünften Meilensteins werden die Szenarien-Steckbriefe der Politk zur finalen Beratung vorgelegt. Die gesammelten Informationen und Belange der beteiligten Akteurinnen und Akteure werden den Entscheidungsträgerinnen und Entscheidungsträgern transparent zugespielt.

5 ZIELE UND POTENZIALE DES AACHEN-KOMPASS

Das Ziel des AACHEN-Kompass besteht darin, Flächen, die ein besonderes Potenzial aufweisen oder mindergenutzt werden, in ihrer zukünftigen Entwicklung zu hinterfragen. Dies geschieht vor dem Hintergrund hoher Bedarfe nach unterschiedlichen Flächennutzungen, die in Konkurrenz zueinander stehen und gegenseitige Konflikte auslösen. Es werden Nutzungsszenarien erarbeitet, die sich in ihrem Nutzungsschwerpunkt und in ihrer räumlichen Struktur unterscheiden. Sie stellen unterschiedliche Entwicklungsmöglichkeiten dar und werden den politischen Akteurinnen und Akteuren zur Beratung vorgelegt. Ziel ist es, dass ein Szenario politisch beschlossen wird, welches den Rahmen für die künftige Planung des Fokusraums setzt. Die Steckbriefe fungieren als Abwägungsgrundlage und sollen die Entscheidung für eine Variante erleichtern. Mithilfe des AACHEN-Kompass wird frühzeitig darüber verhandelt, welchen Nutzungen verstärkt nachgekommen werden soll und welche Belange folglich in den Hintergrund rücken. Es werden grundsätzliche Weichen für die künftige Stadtentwicklung festgelegt. Die explizite Aktivierung der Eigentümerinnen und Eigentümer fördert die Mobilisierung von innerstädtischem Bauland. Eine gemeinsam abgestimmte Richtungsentscheidung ist essenziell und förderlich für den weiteren Prozess. Der gemeinsame Austausch wird seitens der Beteiligten sehr positiv wahrgenommen und bewertet. Je nach Eigentümerinnen- und Eigentümerstruktur stellt die gemeinsame Abstimmung jedoch eine unterschiedlich große Herausforderung dar. Es kann zu divergierenden Entwicklungsinteressen zwischen Eigentümerinnen, Eigentümern, Politik und Fachverwaltung kommen, was einen umfassenden Konsens übe die weitere Planung erschwert.

Im Anschluss an den AACHEN-Kompass werden die gesammelten Informationen und das beschlossene Nutzungsszenario an die zuständigen Fachabteilungen weitergeleitet. Die Aufgabe besteht darin, ein vertiefendes städtebauliches Konzept zu entwerfen, welches die Belange des beschlossenen Nutzungsszenarien berücksichtigt. Wenn möglich, sind für die Realisierung bauleitplanerische Änderungen vorzunehmen. Insgesamt stellt der AACHEN-Kompass somit ein Instrument dar, welches Begabungen von Flächen herausarbeitet, Innenentwicklungen initiiert und eine Abwägung verschiedener Belange forciert.

6 AUSBLICK

Zum gegenwärtigen Zeitpunkt wurde der Prozess des AACHEN-Kompass für zwei von drei Betrachtungsräumen vollständig durchgeführt. Im Anschluss an die Erprobungsphase findet eine Gesamtevaluierung statt, welche sowohl die inhaltlichen Ausarbeitungen als auch die operativen Strukturen des Instruments in den Blick nimmt. Um Neutralität zu gewähren, wird der Abschlussbericht durch das prozessbegleitende Büro SSR verfasst. Ziel ist es, Potenziale und Chancen des AACHEN-Kompass zu betonen und ihn als stetiges Instrument der Aachener Stadtentwicklung zu etablieren. Am Ende soll sich ein erprobter Prozess herauskristallisieren, der binnen eines kurzen Zeitraums durchgeführt werden kann. Nach Abschluss der Erprobungsphase bleibt der Anspruch erhalten, den AACHEN-Kompass kontinuierlich kritisch zu hinterfragen und weiterzuentwickeln. Neue Aufgaben bedeuten neue Herangehensweisen, sodass die Ausführung des Prozesses offen und vielfältig ist. Eine Übertragung auf andere Städte ist möglich und würde eine Bestätigung für das Instrument darstellen. Eine „Phase 0“ bietet das Potenzial, integrativ gemeinsame städtische Entwicklungsziele zu verhandeln und im Sinne der Nachhaltigkeit die räumliche Innentwicklung verstärkt zu avisieren.

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Equity in the 20-Minute Neighbourhood: Residents' Perception in Wester Hailes, Edinburgh

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1 ABSTRACT

Urban inequity continues to intensify globally, despite proximity-based planning models such as the 20-minute neighbourhood being promoted as pathways towards more equitable and inclusive urban environments. However, limited attention has been paid to how justice and equity are defined and experienced by residents, particularly in disadvantaged areas where these policies are implemented. Addressing this gap, this study examines how residents in Wester Hailes, Edinburgh – an underserved neighbourhood and a designated 20-minute neighbourhood site – define a just neighbourhood, their experiences of injustice, and their priorities for advancing equity, and explores how these lived realities challenge the model's equity ambitions.

Using a qualitative case study design, focus group discussions with residents (n = 12) were analysed thematically using NVivo software. Residents defined justice not simply as proximity to services, but in relation to affordable housing, equitable access to quality services and employment, recognition of diverse needs, safe social environments, and meaningful participation in planning. The findings highlight a critical limitation of proximity-based planning: proximity alone cannot deliver justice without addressing broader structural inequalities and ensuring recognitional and procedural justice. By foregrounding residents' perspectives, this study provides important insights for policymakers seeking to implement proximity-based neighbourhood strategies in more just and inclusive ways.

Keywords: Equity, 20-Minute Neighbourhood, Residents' Perception, Wester Hailes, Edinburgh

2 INTRODUCTION

Urban inequality continues to intensify across cities worldwide, driven by rapid urbanisation, climate pressures, and widening socio-economic disparities (UN-Habitat, 2022; Allam et al., 2022). In response, proximity-based planning models such as the X-minute neighbourhood have emerged and been widely promoted as pathways towards more sustainable, liveable, and inclusive urban environments (Büttner et al., 2022). By emphasising local living and ensuring access to essential services within short walking or cycling distances, these models promise to improve accessibility, enhance quality of life, and support more equitable distribution of urban opportunities (Moreno et al., 2021).

Despite these aspirations, proximity-based planning carries profound implications for social justice. Planning decisions regarding the location of services, the allocation of investments, whose needs are recognised, and how planning processes engage local communities actively shape patterns of inclusion and exclusion (Fainstein, 2010).

Existing debates have raised concerns that proximity-based planning may contribute to unintended consequences, including gentrification, displacement, and the reproduction of socio-spatial inequalities, particularly when implemented within market-driven urban contexts (Pozoukidou and Chatziyiannaki, 2021; Calafiore et al., 2022). These risks are especially pronounced in historically underserved neighbourhoods, where new investments may increase land values and attract higher-income residents without adequately addressing existing residents' needs or ensuring their meaningful participation in planning processes.

Despite growing academic and policy interest, the justice implications of proximity-based planning remain insufficiently explored (Mahmoudpour and Shirazi, 2025), particularly from the perspective of residents living in disadvantaged neighbourhoods. Much of the existing literature has focused on spatial accessibility and environmental sustainability, with less attention paid to how justice and equity are affected in X-minute neighbourhoods and experienced, perceived, and defined by residents.

Addressing this gap, this study examines how residents in Wester Hailes, Edinburgh – a socio-economically disadvantaged neighbourhood and a designated site for the implementation of the 20-minute neighbourhood policy – define and conceptualise a just neighbourhood. It further explores the key drivers of injustice and

identifies the changes residents believe are necessary to improve equity and inclusivity. By foregrounding residents' perspectives, this research provides empirical insight into how justice is understood and experienced within the context of proximity-based planning and highlights key considerations for ensuring that proximity-based neighbourhood strategies move beyond spatial proximity to support more just and equitable urban outcomes.

3 METHODOLOGIES

3.1 Wester Hailes as a case study

Wester Hailes is a post-war housing estate developed in the late 1960s in southwest Edinburgh, comprising seven interconnected communities with a population of 11,121 residents. The area experiences some of the highest levels of socio-economic disadvantage in the city. It was selected as a case study because it is one of 19 priority areas for implementing the 20-minute neighbourhood strategy, due to its low deprivation scores and alignment with ongoing regeneration efforts. Despite this policy focus, residents continue to face significant accessibility challenges, including long travel times to essential services such as GP practices and affordable supermarkets. These conditions make Wester Hailes a critical context for examining how proximity-based planning interacts with social justice outcomes.

3.2 Research Design and Participant Recruitment

This study adopted a qualitative case study approach, employing focus group discussions with residents (n = 12) to gain in-depth insights into their perceptions of a just and inclusive neighbourhood, as well as the perceived (in)justice outcomes and implications of 20-minute neighbourhood initiatives in Wester Hailes. Purposive sampling was used to recruit a diverse group of residents. The final sample comprised 12 participants (5 men and 7 women) with varied characteristics in terms of age, ethnicity, ability, and employment status. The data were analysed using thematic content analysis, supported by NVivo 15 software.

4 RESULT AND DISCUSSION

In this section, we explore residents' perspectives on social justice and the just neighbourhood to develop a context-specific conceptualisation of a just neighbourhood in Wester Hailes and consider what these insights reveal about the potential and limitations of the 20-minute neighbourhood approach in delivering just and inclusive outcomes. This includes examining how residents define and understand a just neighbourhood, their experiences and perceptions of injustice, and their priorities for advancing a more just and inclusive Wester Hailes.

4.1 Residents' Definitions of a Just Neighbourhood

This section seeks to identify the key characteristics that emerged as central to residents' understandings of a just neighbourhood. These include access to local services beyond mere proximity, recognition of social diversity and differing needs, and the presence of safe, supportive, and socially cohesive environments. These findings highlight that residents' understandings of justice extend beyond physical proximity to services, encompassing issues of affordability, recognition, safety, and social inclusion.

Access to services, opportunities, and housing: Residents consistently defined a just neighbourhood as one that ensures equitable access to essential services, employment, education, and housing. Accessibility was understood not simply as physical proximity, but as the availability of affordable, high-quality, and inclusive services that respond to diverse needs. Participants emphasised that neighbourhood justice includes access to opportunities and a clean environment, rather than only basic local services. Within this framework, affordable and decent housing was identified as a foundational condition, without which justice cannot be achieved.

Recognition of Social Diversity and Distinct Needs: Residents identified the recognition of social diversity as a defining feature of a just neighbourhood. Justice was conceptualised as an environment in which people from different cultural, ethnic, socioeconomic, and demographic backgrounds are respected, valued, and able to live without discrimination or undue privilege. Importantly, justice was not equated with uniform treatment, but with acknowledging and responding to distinct needs and circumstances. Participants

emphasised the importance of accommodating the specific needs of older people, disabled residents, and minority communities. Consequently, Justice was associated with the capacity of services and the neighbourhood to adapt to varying requirements, prioritising need-responsive provision, rather than reliance on rigid or standardised delivery models.

Safe and cohesive social environments: A third defining characteristic of a just neighbourhood encompasses safety, social cohesion, and a sense of belonging. Residents emphasised that justice is constituted by a friendly atmosphere and the freedom from crime, creating an environment of peaceful coexistence. These factors were viewed as foundational: without them, the effective accessibility of services in the neighbourhood are diminished. Such relational conditions serve as enablers, allowing residents to confidently use public spaces and engage in community life. Consequently, residents articulated a view of justice that is lived through daily interactions, affirming that a just neighbourhood is defined as much by social relations as it is by service provision. Ultimately, a just neighbourhood, was envisioned as one in which people feel safe, connected to others, and genuinely part of the community.

4.2 Residents' Perceived Concerns and Their Justice Implications

This section examines the justice implications embedded in residents' everyday experiences, revealing how place-based challenges are closely connected to wider structural and institutional inequalities. The analysis identifies the following key issues:

Unaffordable Housing: Unaffordable Housing, driven by housing shortage, rising private rents and the deteriorating quality of the housing stock – characterized by outdated facilities and prohibitive maintenance costs – emerged as one of the most frequently and intensely articulated concerns. These pressures were often compounded by high energy costs and the broader cost-of-living crisis, disproportionately affecting low-income households. From residents' perspective, the absence of secure, affordable, and good-quality housing functions as a structural driver of injustice.

Inadequacy of Services and Social Spaces: A second major concern involves the inadequacy of local services (limited availability, low quality, and insufficient capacity) and the scarcity of social infrastructure. Residents pointed to the low quality (particularly in comparison to other neighbourhoods within the city) and limited capacity of existing essential services, such as healthcare and libraries. Beyond functional limitations, these services were criticized for failing to recognize the specific requirements of diverse groups, including non-English speakers, older residents, and families with children. These issues were seen as a significant barrier to meaningful access. Concerns extended to the public space, specifically the lack of quality recreational spaces, such as children's play areas and adequately equipped gathering spots (communal spaces). This deficit restricts opportunities for social interaction, rest, and leisure. Furthermore, access was described as uneven, with essential services physically distant for some parts of the neighbourhood (unevenly distributed across the neighbourhood). This spatial disparity suggests that proximity – a key metric of the x-minute neighbourhood – is a privilege rather than a standard, undermining the foundational principle of equitable access and reinforcing a landscape of unequal opportunity. This confirms that accessibility is compromised by both a lack of culturally responsive provision and uneven physical distribution.

Stigma, Misrecognition, and Social Exclusion: A profound concern raised by residents involves the enduring negative reputation of Wester Hailes, characterized by historical stigma, stereotyping, and underlying racial tensions. Participants described how external perceptions of the area as "deprived" or "problematic" translate into diminished community pride and a reduced sense of belonging among local people. Such perceptions were further reinforced by tangible safety concerns, including antisocial behaviour, crim and youth drug use, causing fear of walking alone in the neighbourhood especially at night. These conditions create a cycle of stigma and create misrecognition and social marginalisation and deepen social and spatial exclusion.

Institutional Neglect and spatial discrimination: A final, overarching concern centres on the perception of Wester Hailes as a disconnected and peripheral geography, disadvantaged relative to the rest of Edinburgh. Residents characterised the area as both physically and socially peripheral, describing a sharp inequality in service provision and environmental maintenance. They noted that their neighbourhood receives significantly less investment, attention, and respect than more affluent areas, intensifying feelings of neglect and marginalisation. This sense of marginalisation is visibly reinforced by the state of the local environment. Participants pointed to persistent issues of inadequate cleanliness, including accumulated litter, dumped waste, and a lack of recycling infrastructure. Furthermore, the presence of vacant and inaccessible buildings

created "undefined spaces" that contribute to a feeling of decay. These physical symptoms of neglect can be interpreted as evidence of spatial discrimination, institutional neglect, and a lack of accountability, which operate as structural drivers of injustice, shaping residents' everyday experiences of inequality and disregard.

4.3 Residents' Priorities towards a Just and Inclusive Wester Hailes

This section explores residents' priorities for advancing a more just and inclusive Wester Hailes. The analysis identified three interrelated categories: equitable and inclusive access to services, social and cultural inclusion, and equitable planning and service provision. These priorities provide important insight into how proximity-based neighbourhood strategies, such as the 20-minute neighbourhood, can better respond to residents' justice needs and aspirations.

Equitable Accessibility: The strongest and most frequently expressed demands fell under equitable accessibility. Residents repeatedly highlighted the need for more, closer, and higher-quality services, especially in health, housing, and transport. This included calls to improve local health services and facilities, increase services supporting daily needs, improve public transport, provide more affordable and quality housing, and ensure walkable access to essential services.

These responses reveal that residents experience injustice primarily as material disadvantage: Wester Hailes is perceived as receiving fewer, poorer, and more distant services than other parts of Edinburgh. The prominence of these codes indicates that a just neighbourhood, for residents, is first and foremost one in which basic urban resources are equitably distributed across space and population groups. This places distributional equity at the centre of residents' understanding of justice.

Furthermore, residents also emphasised inclusive services, particularly the recognition of age-based needs. Requests for greater inclusion of older adults and young people, as well as for more green and recreational spaces for children, show that residents do not simply want more services, but services that are designed for the people who live there. This highlights an important recognitional dimension of social justice. justice was not defined as identical provision for all, but as provision that reflects different life stages, vulnerabilities, and culture. In the context of a 20-minute neighbourhood, this suggests that proximity alone is insufficient: services must also be socially meaningful and appropriate to those who rely on them.

Social and cultural inclusion: Beyond service provision, residents also strongly articulated justice in relation to the social and cultural environment of Wester Hailes. Calls for safer streets, improved security, reduced discrimination, and stronger community pride and belonging demonstrate that justice is also about the right to feel safe, respected, and valued in one's neighbourhood. Similarly, demands for community and cultural activities, festivals, and stronger social integration show that residents want Wester Hailes to be not only functional, but socially and culturally recognised. These themes align closely with recognitional justice, where justice depends on whether people and places are acknowledged as legitimate, worthy, and visible within the wider city.

Equitable planning and service provision management: While less frequently mentioned than service-related improvements, a distinct set of responses addressed planning and procedural justice. These were expressed through three types of desired change: enhanced community engagement and participation, improved waste management and environmental maintenance, and equal service quality in comparison to other neighbourhoods. Together, these codes point to residents' concern with how Wester Hailes is governed, maintained, and treated within the wider urban system, rather than only with the availability of individual services.

Requests for better waste management and environmental cleanliness reflect residents' expectations that their neighbourhood should receive the same standard of care and maintenance as elsewhere in the city, particularly given their perception that lower council tax contributions are used to justify lower levels of service provision.

Similarly, calls for equal service quality indicate a demand for non-discriminatory planning and delivery, where Wester Hailes is not systematically treated as a lower-priority area. This framing reveals that residents interpret environmental neglect not simply as a technical failure, but as a form of institutionalised spatial inequality in how local government allocates attention and resources. The inclusion of enhanced community engagement and participation further shows that residents associate fairness with having a voice in shaping local decisions and improvements, not only with the outcomes themselves.

Together, these codes frame justice in terms of equitable planning and institutional responsiveness: a just neighbourhood is one where services are not only provided, but where the area is properly maintained, fairly treated, and meaningfully involved in decision-making processes.

5 CONCLUSION

This study set out to examine how residents in Wester Hailes define and experience a just neighbourhood, and what their perspectives reveal about the justice implications of proximity-based planning. The findings show that residents' understandings of justice extend far beyond the spatial logic of proximity that underpins the 20-minute neighbourhood model. While access to local services was recognised as important, justice was fundamentally associated with broader structural and relational conditions, including access to affordable and secure housing, equitable and inclusive service provision, recognition of diverse social needs, safe and cohesive environments, and meaningful participation in decision-making processes.

At the same time, residents' everyday experiences revealed persistent and interconnected forms of injustice. Unaffordable and poor-quality housing, inadequate and unevenly distributed services, stigma and social marginalisation, and perceived institutional neglect were identified as central drivers of inequality. These findings highlight that injustice in Wester Hailes is not simply a matter of physical distance to services, but is rooted in structural inequalities, uneven investment, and unequal recognition within the wider urban system.

Residents' priorities for change further reinforce this conclusion. Their calls for improved housing, better and more inclusive services, enhanced safety and social inclusion, and more equitable planning and maintenance demonstrate that achieving justice requires not only improving accessibility, but also ensuring fairness in how neighbourhoods are governed, resourced, and valued. These priorities point to the importance of distributive, recognitional, and procedural dimensions of justice, rather than focusing solely on spatial proximity.

Taken together, these findings highlight important limitations of proximity-based planning when implemented without addressing underlying structural and institutional inequalities. While the 20-minute neighbourhood offers a valuable framework for improving local accessibility, proximity alone cannot guarantee just outcomes. Without affordable housing, equitable investment, socially inclusive services, and meaningful community participation, proximity risks reproducing rather than reducing existing inequalities.

This study contributes to ongoing debates on proximity-based planning by demonstrating the importance of grounding policy implementation in residents' lived experiences. It shows that achieving just neighbourhoods requires moving beyond a narrow focus on spatial accessibility towards a more comprehensive justice-oriented approach that addresses structural disadvantage, recognises diverse needs, and ensures equitable and inclusive planning processes. These insights are particularly relevant for policymakers and planners seeking to implement 20-minute neighbourhood strategies in disadvantaged areas. Embedding justice at the centre of proximity-based planning is essential if such models are to deliver genuinely equitable and inclusive urban outcomes.

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From Market Value to "Climate Value": Quantifying EU ETS-2 Risks in Real Estate Valuations within the Austrian Real Estate Market and its Mitigation through Carbon Neutral Heating and Cooling

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1 ABSTRACT

In 2023, the European Union's second Emissions Trading System (EU ETS-2) was launched and is planned to take effect in 2027 (EUROPEAN PARLIAMENT, 2023).This scheme will cover buildings and road transport sector and represents a fundamental shift in how decarbonization in real estate economics operates. This regulatory framework is the second step, after EU-ETS 1, of the EUs ambition to reduce carbon emissions through a market-based pricing approach. This strategy introduces a market-based carbon pricing mechanism that differs significantly from the existing national fixed-price systems, which is in Austria currently under use (Republic of Austria, 2022), known as "Nationales Emissionszertifikatehandelsgesetz 2022" (NEHG 2022).As the existing legislation in Austria governs currently no cost-sharing between landlords and tenants, all carbon costs have to be carried by the tenant through their energy spending due to NEHG 2022 as of yet and EU ETS-2 in future. This most likelywill impact rental levels, no matter what future legislation exactly will look like, as energyefficiency is already influencing property pricing, as other research indicates (Chegut et al, 2020). Property valuers, investors and lenders potentially face with this transition a future challenge, as established and accepted valuation methods in Austria do not adequately take potentially rising carbon costs currently into account. As a consequence, carbon neutral heat and cooling production from renewables on site currently does not get fully awarded, as property valuerscurrently don't distinguish between carbon intense and less carbon intense heating and cooling.By analyzing a comprehensive set of real estate valuations and the focusingon their current integration of environmental aspects, we will understand how Austrian real estate appraisers currently are considering environmental issues as of today in the real estate valuation process. Further, by employing a sophisticated Discounted Cash Flow (DCF) model, as used in other studies (de Joung et at, 2025), we can project carbon price scenarios what introduces a new metric, the "Climate-Adjusted Market Value" (Carbon Delta AG, 2017) as discussed in the recent past (MSCI, 2024) to quantify the spread between a building's current market price and its value after accounting for future carbon obligations.The findings demonstrate that the mitigation provided by carbon-neutral heating and cooling systems, prevents existing assets from facing a "brown discount, " rendering them economically obsolete – or "stranded" – long before their physical lifespan ends.Consequently, this study give evidence if integrating carbon-neutral technology is no longer merely of an ecological choice but a fundamental financial imperative to secure long-term property income streams and avoid asset stranding in the wake of EU ETS-2.

Keywords: EU ETS-2, Real Estate Valuation, Stranded Assets, Climate-Adjusted Market Value, Carbon neutral heating

2 INTRODUCTION AND BACKGROUND

2.1 European Environment Legislation and Valuation Standards

Climate risksare financial threats caused or exacerbated by climate change. They impact companies and their value chains through physical risks (natural hazards) and transition risks (regulatory, technological, or social shifts), both of which often interact (FMA, 2025a). At the EU level and, consequently, at the national level, climate regulation affects real estate through building rules, carbon pricing, and disclosure requirements, all of which can be captured as transition risks. The recast of the Energy Performance Buildings Directive (EPBD) tightens requirements for new buildings and renovation policy, and it expands data and compliance obligations across the stock (European Commission, 2024). The first European carbon emissions system was introduced in 2005 to meet the Kyoto Protocol targets and is defined by the EU Emissions Trading System (ETS), which applies to emissions frompower generators and energy-intensive industries. The scope of the ETS was enlarged by a second emissions trading system, the EU-ETS2, which was created to cover emissions from buildings, road transport and additional sectors (EUROPEAN PARLIAMENT, 2023). The new system will become operational in earliest in 2027, latest in 2028, which is expected to raise the cost of

fossil heatingas part of the “Fit for 55” progam (European Commission, 2023b).The EU Taxonomy defines when building-related activities qualify as environmentally sustainable and sets technical criteria through delegated acts. (European Union, 2021).The Sustainable Finance Disclosure Regulation (SFDR) requires standardised disclosures on sustainability risks and adverse impacts for financial products with real estate exposure (European Parliament, 2019).The Corporate Sustainability Reporting Directive (CSRD) and the European Sustainability Reporting Standards (ESRS) make climate risks, transition plans and metrics part of mandatory corporate reporting (European Commission, 2024) (European Commission, 2023a) Further, the Corporate Sustainability Due Diligence Directive (CSDDD) adds due diligence duties across supply chains, which matters for development, refurbishment and materials (Directive – EU – 2024/1760, 2024)] Since 2025, EU “simplification” proposals have targeted the scope and timing of the CSRD/CSDDD; final legal texts can shift thresholds and deadlines. (Reuters, 2025). In Austria, building and energy rules are implemented in compliance with EU policy at the national and provincial levels. Building energy requirements are harmonised via OIB Guidelines, especially OIB Guideline 6. (OIB, 2025) The Energy Performance Certificate (EPC) is mandatory for sale and letting under EAVG 2012. (Nationalrat, 2012) Federal energy-efficiency duties are set through the EEffG. (Nationalrat, 2024) Renewables expansion is anchored in the EAG (Nationalrat, 2021) and the EWG (Nationalrat, 2024). Austria’s Nationales Emissionszertifikatehandelsgesetz (Nationalrat, 2022) prices carbon nationally and explicitly links to the planned transfer into EU-ETS2 from 2027, which is central for carbon-intense heating cost trajectories. (Nationalrat, 2022) Climate governance runs through the KSG (Nationalrat, 2017). CSRD transposition has been prepared via a draft Nachhaltigkeitsberichtsgesetz (NaBeG) and remains linked to EU-level omnibus discussions (Bundesministerium für Justiz, 2025). The FMA consolidates supervisory expectations around sustainability disclosure for regulated entities. (FMA, 2025b)

2.2 Comparative Synthesis of Climate Risk Integration in Property Valuation

Traditional Austrian valuation, governed by the Liegenschaftsbewertungsgesetz (LBG) (Nationalrat, 1992) and ÖNORM B 1802-1, primarily treats climate factors as “special value-influencing circumstances” (Section 7 LBG). Physical climate risksare typically addressed through qualitative deductions – a climate risk assessment is not specifically required. However, these norms lack a standardised quantitative framework for internalising transition risks, such as the carbon-pricing impacts of the EU ETS 2. The recognition of EPCsduring the valuation process is highly recommended – if missing, valuers should state "No EPC available, " assess the building's energy efficiency (consulting an expert if necessary), and incorporate these findings into the final market value determination to limit the valuer’s liability (Allerstorfer et al., 2009). The same logic accounts for the recognition of ESG features of buildings when surveilling “sustainable” or “non-sustainable” buildings (Martin M. Roth, 2022)

In contrast to the Austrian valuation frameworks, the RICS Valuation – Global Standards mandate the proactive identification of ESG factors as core value drivers. Valuers must analyse how climate-related sustainability influences marketability and investor behaviour, ensuring these factors directly inform capitalisation rates (yields) and market value. (RICS, 2024).Similarly, requirements were identified in The European Valuation Standards (TEGOVA, 2025), which align valuation practices with the European Green Deal, which addresses the impact of the EU Taxonomy and mandatory renovations on long-term value stability (TEGOVA, 2025) A critical innovation is the “Property Value”, introduced to comply with the Capital Requirements Regulation (European Banking Authority, 2024). This value is based on “prudently conservative valuation criteria”, excluding speculative elements and cyclical price increases to provide a stable basis for mortgage lending.Article 229 clearly states that the property revaluation may exceed historical values if improved energy efficiency or greater resilience, protection, and adaptability to physical climate risk areachieved (European Banking Authority, 2024).The EBA Guidelines further integrate ESG risks into the prudential supervision of financial institutions. Banks must incorporate environmental factors into credit risk appetites and collateral monitoring throughout the entire loan lifecycle (EBA/GL, 2020). This regulatory pressure drives a shift from point-in-time appraisals to continuous risk assessments, especially to identify potential "stranded assets" as the economy transitions to a low-carbon, climate-resilient economy. (EBA/GL, 2020).

2.3 Analytical Synthesis of EU ETS 2 Pricing Scenarios and System Dynamics

The implementation of the second European Union Emissions Trading System (EU ETS 2) in 2028 represents a decisive regulatory shift within the "Fit for 55" framework. Unlike the established EU ETS 1, which primarily targets price-elastic industrial and power sectors, the EU ETS 2 focuses on buildings, road transport, and small industrial installations. These sectors are historically characterisedby high marginal abatement costs, path dependenciesand various structural market failures. The current scientific literature (2023–2025) emphasises that price formation in this market is not merely a function of internal supply and demand but is deeply contingent on the broader European policy landscape and technological replacement cycles.The predictability of price trajectories within the EU ETS 2 is subject to substantial variance due to the diverse modelling frameworks employed across the research community. Rickels et al. (2023) utilise the Computable General Equilibrium (CGE) model "DART" to quantify the efficiency gains of EU-wide trading, particularly in the context of the Effort Sharing Regulation (ESR). Conversely, the PRIMES model, utilised by Günther et al. (Günther et al., 2025), provides a high-resolution simulation of technological substitution – such as the adoption of heat pumps and electric vehicles – in response to marginal cost signals. Market-oriented simulations, such as BloombergNEF's EUCPM 2.0 (Bloomberg NEF, 2025), further refine these projections by incorporating the anticipation and hedging behaviours of fuel distributors, which are expected to drive significant price premiums during the system's initial phase. Finally, other research identifies macroeconomic consequences at the Eurozone level, which links carbon pricing directly to GDP and inflation metrics (Džubur&Pointner, 2024).A fundamental consensus emerging in contemporary research is the conceptualisation of the carbon price as a "residual variable" (Günther et al., 2025). This theory posits that, since the emissions cap is fixed, the equilibrium price is inversely related to the efficacy of non-pricing energy efficiency policies (EPs). For instance, ambitious enforcement of the Energy Performance of Buildings Directive (EPBD) and stringent CO_2 fleet standards for vehicles reduce the residual volume of emissions that must be addressed via the price signal. In a "Weak Policy" scenario, the carbon price must bear the overwhelming burden of abatement, with projections indicating a rise to approximately € 261/tCO_2 by 2030. Conversely, a "Strong Policy" scenario, characterised by high renovation rates and rapid electrification, could stabilise the price at a more manageable € 71/tCO_2.

The institutional architecture of the EU ETS 2 is uniquely intertwined with the Effort Sharing Regulation (ESR). Rickels et al. (2023) note that, until 2030, the trading system primarily serves as a cost-efficient vehicle for Member States to meet their binding national targets. However, the reliance on the Market Stability Reserve (MSR 2.0) as a price-containment tool is viewed with scepticism. While the current legislation aims to trigger allowance releases if prices exceed a threshold of roughly € 45 (in 2020 prices), simulations demonstrate that the limited volume of the reserve – capped at 150 million allowances – is insufficient to neutralise fundamental scarcity. Further, they conclude that maintaining a € 45 cap through 2030 would necessitate the release of 415 million additional allowances, a move that would fundamentally compromise the EU's ecological integrity and 2030 climate targets.

A major challenge identified by Kalkuhl et al. (2023) is the inherent price inelasticity of the heating and transport sectors. Structural barriers, most notably the "split incentives" in the rental market, decouple the carbon price signal from investment decisions; tenants bear the carbon costs while landlords control the capitalfor retrofitting. This inelasticity suggests that prices may need to reach extreme levels to achieve the mandated cap without supportive measures. Consequently, the fiscal dimension of the ETS 2 becomes critical. Researchers unanimously argue for comprehensive revenue recycling mechanisms, such as the Climate Dividend (Klimageld) or the EU Social Climate Fund (SCF), to offset the regressive nature of carbon pricing and maintain public support (Agora, 2023; Džubur&Pointner, 2024). Looking beyond the 2030 horizon, the EU ETS 2 is expected to transition into a high-price paradigm as it approaches the 2050 neutrality target. Following the "Hotelling Rule", the price of finite emission allowances is projected to rise in line with real discount rates as the cap approaches zero. Long-term modelling via PRIMES suggests that sectoral prices will converge toward € 475/tCO2 by 2050 to eliminate the most recalcitrant residual emissions. The evidence suggests that while carbon pricing is a necessary signal, its effectiveness depends entirely on its integration into a comprehensive policy mix. The research underscores that the "cost of neutrality" will be felt either through high carbon prices or through the direct costs of stringent energy efficiency regulations, the latter offering a more predictable and socially manageable transition path.

Source	PolicyContext& Drivers	2030 Price Proj.	Long-Term / 2050 Proj.
Rickels et al. (2023)	ESR Target Compliance	~€ 300	n/a
Günther et al. (2025)	Minimal Regulatory Support	€ 261	~€ 475
BloombergNEF (2025)	Base Case (Incl. Hedging)	€ 122	n/a
EWI (2025)	Multi-Model Consensus	€ 100–€ 200	> € 300 (by 2040)
Günther et al. (2025)	Maximum Efficiency (EPBD)	€ 71	~€ 475
Agora (2023)	PlannedSubsidy/Price Mix	~€ 100	n/a
OeNB (2024)	Price Only (NoSubsidies)	€ 668	>€ 800
EU-COM (2021)	Initial Impact Assessment	~€ 48	n/a

Table 1: Range of ETS-2 Scenario Pricing based on literature research

3 PROBLEM STATEMENT

In Austria, approximately 26% of households use carbon-intensive heating systems, with a similar proportion using biomass heating systems (Statistik Austria, 2025), which are currently regarded as low-carbon technologies. As residential tenants in Austria typically pay rent in addition to other occupational costs, such as energy consumption and service charges, the cost of heating has been a particular concern raised by the Austrian Labour Union in recent times, exerting pressure on rents (ÖGB, 2025). Therefore, the introduction of EU-ETS 2 is expected to put further pressure on rents, as energy costs already seem to doAmaral et al. (2025), and this is currently not taken into accountas climate risk by valuers. As institutional investors and lending banks have to recognise physical and transition climate risks within their risk management and policy frameworks and assess those risks with accepted tools, e.g., the CREEM assessment, private house buyers currently have no assessment method to assess their full climate risk exposure, aside from EPC assessments and natural hazard maps.Unclear private investment decisions may result from this opaque situation.

3.1 Defining the research question and methodology

The quantitative methodology of this study is based on an integrative valuation model that bridges traditional real estate appraisal with forward-looking carbon accounting frameworks. The methodological approach aligns with the recent findings of Jonge et al. (2025), who emphasise the needto embed both Operational Carbon Costs (OCC) and maintenance-related capital expenditures (CapEx) directly into cash flow projections. As investors usually prefer the IRR as an investment metric, the analysis will be enriched by a valuer's view of the Explicit Discounted Cash Flow (DCF) (TEGOVA, 2025), which assesses value change and reflects financial performance through the IRR amid decarbonization.

3.2 Data Acquisition and Portfolio Selection

The primary empirical basis consists of 84 individual real estate valuations systematically extracted from the Austrian Ediktsdatei (the official judicial auction database). These judicial appraisals have high methodological validity, as they are legally required to comply with the strict standards of the Austrian License Valuation Act (LBG). A structured content analysis was conducted to identify key parameters and performance indicators, including heating systems, energy performance indicators (EPCs), and assessments of natural hazard risks, such as using the HORA (Natural Hazard Overview & Risk Assessment) system. To ensure a consistent data baseline, missing energetic parameters were enriched with reference values from the TABULA Building Typology (Austrian Energy Agency, 2010) and the technical benchmarks of OIB Guideline 6 (OIB, 2025).

3.3 EU ETS 2 Simulation and Transition Modelling

The core of the methodology involves simulating the financial impact of the EU ETS 2 on cashflows and, consequently, on IRR and property values. Consistent with current regulatory projections, the model assumes the commencement of market-based carbon pricing liabilities in 2028. From this point forward, the portfolio is subjected to various price scenarios while adhering to a regulatory transition path (Phase-Out) :

- Phase-Out Schedule: The scheduled decarbonization of Austria's economy by 2040 (Jensen &Roniger, 2024), which foresees the full decarbonization of the tested assets before 2040.
- Operational Carbon Costs (OCC) : Following the framework established by Jonge et al. (2025), annual operationalcarbon liabilities (costsunder the EU ETS-2) are modelled until the expected end of the fossil system's regulatory lifecycle in 2040. The EU ETS-2 pricing scenario is aligned with

the scenario simulations of Günter et al (Günther et al., 2025), in a Weak EP, Limited EP and Strong EP as shown in Table 1.

- Technology Substitution:Firstly, for properties currently utilising fossil fuels, a full substitution with air- and ground-source heat pumps is assumed before the respective phase-out date, transforming theminto zero-carbon assets. Secondly, the properties shall receive a full thermal upgrade, pushing them toward a NetZero standard through serial retrofit, following the Energiesprong principles (including geothermal energy generation and façade heating/cooling, as defined by AEE (Weiss, 2025). Electrical Heating shall consume electricity from renewable sources only;district heating from renewable sources and biogenic fuels are treated asneutral within the ETS 2 framework.

3.4 Risk Quantification: Climate Value at Risk (CVaR)

To quantify the financial vulnerability, arising from carbon pricing (EU-ETS 2) and retrofittingneeds tobe calculated. According to MSCI (MSCI ESG Research, 2024) theClimate Value at Risk (CVaR) is a forward-looking financial metric that translates the present value of projected transition costs and physical damages into a percentage-based assessment of an asset's total valuation.Rebonato et al., argue that this metric captures a critical inverse relationship where aggressive carbon abatement policies increase near-term transition expenses but significantly reduce the long-term economic burden of physical climate impacts (Rebonato et al., 2024). In our context, this could involve improved thermal insulation, driven by future regulatory requirements under the "Fit for 55 package" energy efficiency policies. When combined with geothermal heating and cooling, it can help mitigate the effects of weather extremes on occupants, such as heat waves or cold winters. From an investment standpoint, this metric considers the present value of future carbon costs and the discounted Replacement Costs (RC) for climate-neutral heating systems and retrofitting measures at the end of the transition period, relative to the initial market value of an asset as in the CRREM model. Since transition risks are likely to impact cash flows unevenly, income-based valuation methods like DCF are most practical for estimating CVaR. Additionally, beyond CVaR, a second metric was developed: the Climate Value at Opportunity (CVaO), which accounts for rental and market opportunities from retrofitted upgrades, enhancing the asset's ability to generate market rents without discounts. The model employs the following deterministic formulas:

$$CVaR_i = \frac{\sum_{t=T+1}^{T}\left(\frac{R_{i,t}^{carb} - E_{i,t} * P_{ETS2,t}}{(1+r)^t}\right) - \frac{RC_{i,T} + Capex_{i,T}}{(1+r)^t} + \frac{TV_{i,N}^{carb}}{(1+r)^t}}{V_{i,0}}$$

and

$$CVaO_i = \frac{\sum_{t=T+1}^{N}\left(\frac{R_{i,t}^{carb}}{(1+r)^t} - \frac{RC_{i,T} + Capex_{i,T}}{(1+r)^t} + \frac{TV_{i,N}^{decarb}}{(1+r)^t}\right)}{V_{i,0}}$$

$\boldsymbol{E_{i,t} * P_{ETS2,t}}$:Annual operational carbon costs (OCC) derived from the building's emission profile and projected EU ETS 2 prices.
$\boldsymbol{R_{i,t}^{carb}}$: Rent based before decarbonization
$\boldsymbol{RC_{i,T}}$: Discounted Replacement Costs for a climate-neutral heating system (e.g., air-source heat pump) at the phase-out year *T*.
$\boldsymbol{Capex_{i,T}}$:(Median) Capital expenditures for mandatory building envelope retrofitting measures required to reach decarbonization targets.
$\boldsymbol{V_{i,0}}$: The initial (median) indexed market value of the asset as determined by the judicial appraisal.
$\boldsymbol{TV_{i,N}^{carb}}$: Terminal Value based on the carb rent before decarbonization.
$\boldsymbol{TV_{i,N}^{decarb}}$: Terminal Value based on the decarbed rent after decarbonization.

Fig. 1: Formula describing Climate Value at Risk (CVaR) and Climate Value at Opportunity (CVaO).

4 RESEARCH FINDINGS

4.1 Recognition of Climate Risks in the Valuation

Only 33% of all valuations included energy performance certificates toaccount for transition risks; the remaining did not take them into consideration, stating that the property's energy performance is to be expected based on the building's age or comparable buildings. Meanwhile, 61% identified physical climate risks through the HORA assessment (and others) during their evaluations. Further, about 60% of those who commissioned real estate appraisals were banks.

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4.2 Impact of Climate Value at Risk and Climate Value at Opportunity

The research confirms that properties with higher operational carbon intensity are more susceptible to negative price impacts, likely due to transitional climate risks. The simulation of the examined portfolio, based on Günther et al.'s pricing scenarios, suggests that the slow adoption of carbon reduction policies in some European countries – referred to as the "Weak Scenario" – could lead to a greater disparity in "Climate Risk at Value" for carbon-intensive properties, compared to those that are nearly or fully carbon neutral today.

		Gas <2011		Gas >2011		Oil		Distric Heating		Elec		Biomass	
		IRR	Value	IRR	Value	IRR	Value	IRR	Value	IRR	Value	IRR	Value
Strong EP	$CVaR_i$	-0,84%	-7,75%	-0,89%	-8,27%	-1,97%	-17,23%	-0,04%	-0,37%	-0,06%	-0,40%	0,01%	-0,08%
	$CVaO_i$	0,42%	5,08%	3,65%	31,87%	4,84%	41,90%	0,23%	2,99%	1,62%	15,70%	1,81%	17,79%
Limited EP	$CVaR_i$	-1,00%	-9,00%	-0,98%	-9,02%	-2,42%	-20,46%	-0,07%	-0,65%	-0,13%	-0,87%	0,03%	-0,15%
	$CVaO_i$	0,28%	4,00%	3,58%	31,54%	4,68%	41,46%	0,20%	2,72%	1,57%	15,37%	1,82%	17,83%
WeakEP	$CVaR_i$	-1,12%	-9,90%	-1,05%	-9,54%	-2,80%	-22,69%	-0,10%	-0,85%	-0,20%	-1,19%	0,09%	-0,19%
	$CVaO_i$	0,16%	3,19%	3,52%	31,30%	4,50%	41,11%	0,18%	2,53%	1,54%	15,14%	1,82%	17,86%
Average	$CVaR_i$	-0,99%	-8,89%	-0,98%	-8,94%	-2,40%	-20,12%	-0,07%	-0,62%	-0,13%	-0,82%	0,04%	-0,14%
	$CVaO_i$	0,28%	4,09%	3,58%	31,57%	4,67%	41,49%	0,20%	2,75%	1,58%	15,40%	1,82%	17,83%

Table 2: Overview of the portfolio simulation under three ETS-2 scenarios

Transitional risks cause the simulated portfolio's cash flows and IRRs to decrease by 99 to 240 basis points, resulting in a CVaRi between -8, 89% and -20, 12% when compared to cash flow simulations that do not account for potential ETS2 and decarbonization costs. However, decarbonization also offers benefits. Particularly, the thermal refurbishment and upgrade of the heating system through the addition of a cooling system can bring rental levels closer to market rents. This reduces existing discounts on asset and rental prices, which might be viewed as brown or climate-related discounts.Not surprisingly, the CVaR-Upsides were also notable for the carbon-intensive assets, with a potential upside in value of up to 41, 49% identified in the analysed portfolio simulation.

5 CONCLUSION AND OUTLOOK

This study shows that, unlike physical climate risks, perceptions of transitional climate risks remain at a very early stage among real estate appraisers across Austria, and that the obvious benefit of carbon-neutral heating and cooling has not yet been realised. The potential qualitative Climate Value at Risk has yet to be discussed, as advised by organisationssuch as the ECB at the European level and the FMA in Austria, which are raising awareness. This creates uncertainty for investors, banks, and privatehomebuyers when making investment and lending decisions. The results of the quantitative analysis indicate that older properties in weaker real estate markets are more exposed, and that newer ones in stronger markets. Stakeholders should be aware of this fact when buying or lending in certain regions. However, an open dialogue among them is strongly recommended to foster a more holistic approach, especially as climate risks are expected to have stronger impacts on properties than in the past. To achieve a more complete understanding of this emerging topic, the study should be expanded to include a larger sample of valuations, including commercial properties, and future research should track developments toward a more comprehensive valuation approach in the context of climate change and evolving regulations.

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In Fourth Nature Concept, Form Follows Spirit

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1 ABSTRACT

This paper attends the challenges made by REAL CORP 2026 in two ways: bringing up what we are navigating through, between vision and reality – as well as constructing bridges between heritage and the future. Inedit results of an ongoing research that proposes a new framework for architectural and urban design are described, based on the principle of vibrational coherence and the understanding that all matter, light, and life are expressions of oscillating energy fields. Drawing from both contemporary science and ancestral cosmologies, it is a new chapter in the Fourth Nature Concept, in which the built environment is redefined as a living resonant organism, capable of influencing human health, perception, and consciousness through its energetic configuration.

Vibration is the oscillation of energy through matter, measurable in frequencies. Every material and spatial form – from an atom to a city – emits, absorbs, and modulates such frequencies. Architecture, therefore, is never static; it is a continuous field of resonance interacting with the human bioelectromagnetic system. This perspective converges with advances in neuroarchitecture, chronobiology, and bioresonance, which demonstrate that light, sound, color, and material composition directly affect hormonal balance, emotional states, and cognitive performance. Some principles are part of the research, such as: form generates frequency: harmonic proportions create coherent fields. Light modulates vibration: natural light energizes electrons and awakens vitality. Material radiates field: minerals, woods, metals, and pigments emit specific frequencies. Intention guides the field: the creator's thought and emotion leave an energetic signature. Thus, an architectural space can literally resonate with human well-being if it is aligned with natural rhythms and the vibration of life. From these principles will emerge, in the near future, practical applications across typologies, bridging intuition and evidence.

Ultimately, these ideas begin a new chapter on the Fourth Nature Concept: Form Follows Spirit. A new paradigm that reframes architecture as an interface between Earth and cosmos, matter and consciousness, arising from an underlying field of universal coherence. It invites a shift from energy efficiency to energy quality, from building for function to building for resonance. It does not seek to revive esoteric nostalgia but to integrate ancient knowledge (rescued and decoded from old books and manuscripts) with contemporary science. Each wall, surface, and proportion becomes a tuning element, and when light, matter, and geography converge in coherence, architecture transcends construction – it becomes then, an act of planetary healing.

Keywords: Fourt h Nature; Vibrational Architecture; Form Follows Spirit, Spatial Planning, Framework

2 PRELUDE: ON THE PERENNIAL STREAM OF WISDOM

Throughout the ages, those who sought truth have turned not to invention but to remembrance. They did not claim to create wisdom, but to draw from a perennial source – a living spring that flows through time, unchanged in essence though refracted in many tongues. This is the heart of the prisca theologia: the conviction that every genuine philosophy is but a translation of the same eternal current into the idiom of a given age. From all that has been part of this research, this proves to be true: there is always a common denominator, to which studies and renomated authors turn to.

In the Renaissance, prisca theologia, as articulated by Marsilio Ficino (1469), refers to the belief in an ancient, perennial wisdom transmitted through a lineage of sages – from Hermes Trismegistus and Orpheus to Plato – expressing a unified cosmological and spiritual understanding of reality. The relevance of prisca theologia in this paper does not lie in a revival of pre-modern belief systems, but in its epistemological structure: the assumption that nature, cosmos, and human consciousness are intelligible through correspondence, resonance, and unity. From important documents to popular sayings, knowledge tries to survive and make us aware – “in a bedroom where morning sunlight comes in, the doctor does not” was one of my own grandmother's Adelia usual phrases. This arrow goes straight to the heart of a 21st century architect, that is maybe the reason it has stayed there firm, since my childhood.

I see that architecture as it has been practiced for millennia, has always mediated between the tangible and the invisible – bringing to the material world what belongs primarily to the mental world – between the body

of matter and the spirit of place. Yet the contemporary crisis of health, climate and meaning exposes a fundamental fracture: the built world has become energetically incoherent. Modernity, with its focus on efficiency and performance, has often neglected the vibrational dimension of life – the subtle, rhythmic field through which all organisms communicate to each other and with the cosmos. Fourth Nature emerges as a response to this condition. It proposes a reintegration of architecture into the living continuum of energy that sustains life on Earth. In this paradigm, space is not a neutral container but a resonant field, where materials, light, sound, and geometry act as conductors of life`s vibratory order. We can not see it, but we feel it.

This idea comes strongly to the flow of my work as a result of my recent studies at different renomated libraries around the world, such as the Austrian National Library for instance, specifically on its Department of Manuscripts and Rare Books (where the study space itself is a temple of resonance). There I came to know through my eyes and hands the energy of several important scholars that have made this wisdom perennial in meticulously drawn letterings and illustrations. What I have learned there embraces my research targets for a new relationship between mankind and the universe, through a conscient architecture.

To mention some highlights, Marsilio Ficino for example (1433–1499), the great Florentine Platonist, physician, and translator of Plato and Plotinus, wrote De vita libri tres (Three Books on Life). The third book, De vita coelitus comparanda, is the most visionary: it explores how human life can draw vitality from the heavens by harmonizing it with celestial influences. He describes the cosmos as infused with spiritus – a vital breath that flows through all living beings. Marsilio Ficino stood in Florence at the dawn of modernity, rendering Plato and Hermes into the language of his century, translating the subtle into a medicine for the soul. He saw the universe as a living harmony, the human being as microcosm, and life itself as a fragile flame to be nourished by celestial resonances. Interesting is to observe that Ficino stopped translating Plato to work on the incunabula Aureum planeque divinum opusculum Mercurii Trismegisti de potestate ac sapientia Dei (often referred to as the Pomander or Poimandres), in 1463 and first published in 1471, is a collection of Neoplatonic, theological, and philosophical dialogues. It is a key text within the Corpus Hermeticum, attributed to the legendary Egyptian sage Hermes Trismegistus and brings important insights to the ongoing research.

Another significant work of the medieval philosophical tradition, the Calendarium Naturale Magicum Perpetuum that according to McLean (1994) provided a synthesis of the magical symbolism of the Renaissance and medieval periods, has arisen out of the esoteric school of Johannes Trithemius, and made its appearance in 1630. Although it is possible to view it in a merely historical context, it would be quite wrong to see it as something bound to the past, its content is not dead. It can still be pursued today, since it brings a way of synthesis that has become more and more lost to humanity, with the rise and eventual dominance of the analytical mode of thought. More adequate even is to understand “magical” or Hermetic thinking as the ability to see ideas as part of the whole – to see the interconnectedness , the correspondences , between seemingly diverse events, subjects or fields of research. Fourth Nature comes to reconnect us with this hermetic mode of thought, this magical way of looking at the world, because it indeed contains the germ of the future development of our consciousness. During the closing years of the twentieth century, humankind has penetrated even more deeply into the material sphere, in consequence, we now require a spiritual philosophy and esotericism that also encounters the material directly. This is indeed found in Hermeticism, also in the so called alchemy, which works in the different dimensions of substances, colours, geometric forms, smells and sounds to transform the human soul.

These ancient studies are not inventing a doctrine but remembering what had always been known, and giving it form for their own Zeitgeist. In our own delicate moment of planetary transition, the task is the same – in Fourth Nature, the idea is to translate as principles -some of them already figure in biophilia, neuroarchitecture, sacred geometry for instance- and others that are still to be brought to our current lifestyle.

3 WHY FORM FOLLOWS SPIRIT

The Renaissance convergence between prisca theologia, articulated by Marsilio Ficino (1433-1499), and philosophia perennis, developed by Giovanni Pico della Mirandola (1463-1494), establishes an epistemological framework in which reality is understood as an ordered continuum of intelligibility, coherence, and correspondence across multiple levels of existence. While Ficino emphasized the transmission of a primordial wisdom encoded in the harmonies of nature and the cosmos, Pico affirmed the transhistorical validity of this wisdom across diverse cultural and philosophical traditions. This shared

assumption – that form, meaning, and order precede material manifestation – finds a contemporary counterpart in Ervin Laszlo's (2014) concept of Dimension A, defined as a universal informational field that underlies and informs all physical, biological, and cognitive systems.

The Akashic Records – Dimension A – are a dimension of the universe that underlies all things that exist within it. Not only does it underlie all things, but it also connects and preserves the information they generate. It is the womb of the cosmos, the web of the world, and the Universal memory. And this new discovery-or rather, this rediscovery of an ancient and profound understanding-is important for science and for each of us (LAZSLO, 2014, p. 121).

In this sense, Dimension A can be read not as a metaphysical revival, but as a scientifically articulated reformulation of the same structural intuition present in prisca theologia and philosophia perennis: the existence of a unifying field of coherence from which material reality emerges. Within the Fourth Nature framework, spirit is understood precisely as this pre-material, organizing informational domain, to which all of us are connected and architectural form is conceived as its spatial expression.

Thus, Form Follows Spirit in the Fourth Nature Concept describes a continuous lineage of thought – from Renaissance cosmology to contemporary systems theory – in which built form arises from alignment with an underlying field of universal coherence rather than from isolated function, stylistic preference, or purely material causality. We are talking not only of architecture, but of culture as the modified nature by human action: design, technology, art. What is the central point here is the alignment of our consciousness to this cosmic order – the incredible and currently disregarded human mental capacities -capacities that need to be remembered through constant contact with the natural world (fig.1).

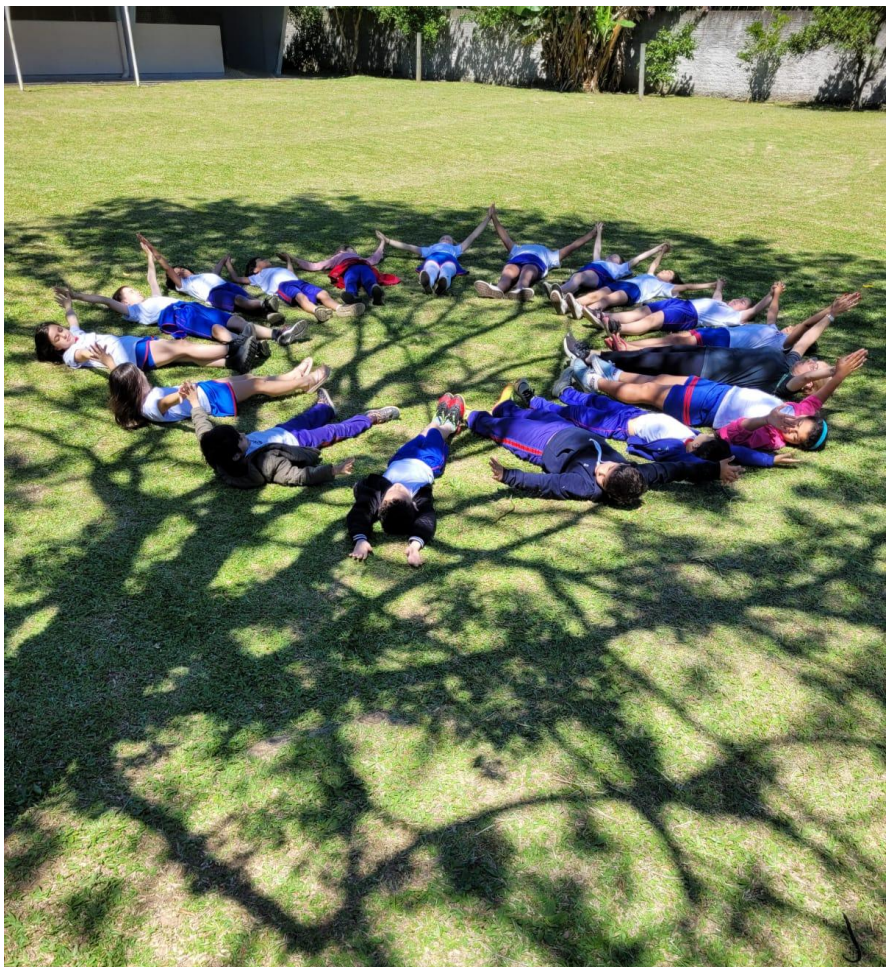


Fig. 1: Art class in a public school in South Brazil. Autor. Silvia Back.

These capacities include the perception that everything is interconnected, through a vibrational informational network: matter, energy, and consciousness are manifestations of informational patterns that vibrate and communicate. This resonates with the idea that architecture and urban space should align with these cosmic information flows, creating environments in tune with the whole. The new science of consciousness as the

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basis of a new world: Laszlo proposes a science that recognizes consciousness as a structuring part of reality-exactly what the Fourth Nature advocates when proposing a vibrational, bioenergetic urbanity attuned to the intelligence of the cosmos. Oneness and co-evolution: we are part of a living and indivisible field, and our health-individual and planetary-depends on the recognition of this unity. The Fourth Nature is coming as a guide for architecture and urbanism to design with awareness of universal interdependence – where what is constructed is brought into form, or is in-formed by a non-formed principle. Spirit is understood here as universal consciousness, an ordering intelligence that precedes material manifestation and informs all levels of reality..

4 VIBRATIONAL COHERENCE

What is vibration? Have you ever wondered what causes the pleasant sound of a breeze whispering through the leaves of a tree, or the touching resonant note of a piano? Or why linen clothing is so comfortable to wear? These phenomena are the result of a common physical occurrence that is part of our daily lives, but to which we may not pay attention: vibration. Vibration is also the third principle described in the Kybalion, a work based on Hermetic philosophy attributed to Hermes Trismegistus, which describes seven fundamental laws that govern the universe and reality. They explain that everything is mental, corresponding on different planes, vibrates, is dual, possesses rhythm, cause and effect, and gender.

Vibration refers to measurable oscillatory movements present in all matter and energy, from molecular and atomic vibration to sound, light, and electromagnetic waves. In living systems, these oscillations are organized into rhythms and frequencies that sustain essential biological functions, such as the sleep-wake cycle, neural activity, and metabolic regulation. The decisive aspect is not the high or low frequency per se, but the degree of vibrational coherence between multiple interacting systems. When vibrations are synchronized and in resonance, information flows with less energy expenditure and greater stability; when there is a mismatch, noise, stress, and dysfunction arise. Thus, speaking of vibration consistently implies defining it as a physical and biological principle of organization, whose quality emerges from the harmony between rhythms, materials, bodies, and environments.

Within Ervin Laszlo's (2014) theoretical framework, Dimension A functions as a universal informational field in which information is not stored statically, but propagated through patterns of resonance, phase alignment, and coherence. For information in such a field to effectively inform physical, biological, and cognitive systems, coherence is not optional but structurally necessary: incoherent or dissonant configurations dissipate informational integrity, while coherent vibrational states enable stable transmission and organization across scales. This principle is consistent with contemporary understandings in environmental physics (Monteith; Unsworth, 2013) where coherent oscillatory behavior underlies self-organization , with chronobiology (Roenneberg, 2017) and neuroarchitecture (Eberhard, 2008), where synchronized rhythms between environmental stimuli and human physiology directly affect cognition, health, and perception. In this sense, vibrational coherence is the operational condition through which Dimension A becomes legible in material form.

Within the Fourth Nature framework, architecture is therefore conceived as a mediating system that can either disrupt or sustain this vibrational coherence. Form Follows Spirit thus denotes a design imperative: spatial form must align with the rhythmic, energetic, and informational conditions that allow Dimension A to manifest as organized, life-supporting environments. And to clarify: fields themselves are not visible but produce observable effects. Fields connect phenomena. Fields are not observable in themselves; only their effects can be observed and measured. They share this quality with all the laws and regularities of Nature. We do not observe the fields themselves; however, the fact that fields are invisible is not a guarantee that we should deny that they are real. It is a guarantee, on the other hand, to maintain that they exist on a plane of reality that is not the same plane of observation. The fields and other forces and laws known to science may exist on another plane that is "hidden" from direct observation. This assumption has important historical antecedents. Many philosophers maintained that the observed world has roots in a real, but unobservable, dimension (FLUDD, 1617) here named generically as spirit.

5 PRINCIPLES BEING DEVELOPED

Based on the several treatises and old books researched, Fourth Nature organizes the principle of vibrational coherence through a quaternary structure that translates universal intelligence into spatial and urban terms.

The idea comes from Poimandres (who does not formulate a quaternary, but a triad): Nous/Logos (spirit) → Nature in generation (process) → Cosmos and bodies (form). This cosmogony allows us to construct the following coherent quaternary scheme: Mens/ Generatio/ Forma/ Civitas – or Principle / Process / Form / World – each corresponding to a specific mode of coherence. The fourth element, Civitas, brings the result of human action into the scene, as the most important target: its mental/physical balance as part of the evolution/healing process together with the planet.

Mens represents the primary layer of coherence. It corresponds to ordering intelligence, understood as the capacity to perceive limits, hierarchy, and proportional relationships before materialization. In architectural and urban terms, Mens defines what deserves to exist, what must remain stable, and what should not be produced. Generatio is the mediating layer through which intelligence unfolds in time. It governs rhythm, sequence, repetition, and assimilation. In urban systems, Generatio determines whether growth becomes coherent evolution or uncontrolled accumulation. Architectural practice frequently bypasses this layer, moving directly from concept to object. Fourth Nature identifies this omission as a primary cause of spatial incoherence. Designing with Generatio means working consciously with temporal cycles, phasing, pauses, and the capacity of environments to absorb change. Forma is the spatial expression of coherence. It manifests through proportion, materiality, orientation, and legibility. Within Fourth Nature, form is not expressive but regulative: it stabilizes resonance by reducing noise and supporting orientation. Harmonic proportions, coherent material palettes, and clear spatial hierarchies contribute to vibrational stability. Conversely, excessive fragmentation and formal competition amplify cognitive stress. Forma thus operates as a regulator of vibrational quality within the built environment. Civitas represents the lived urban condition where coherence or fragmentation becomes observable in behavior, use, and social interaction. It functions as a feedback layer, revealing whether intelligence, process, and form have remained aligned. Indicators of coherent Civitas include informal appropriation, trust in public space, self-regulation, and temporal stability of use. When coherence fails at upstream layers, Civitas compensates through control mechanisms, surveillance, and over-programming.

Together, these four layers allow vibrational coherence to start being translated from abstract principle into operational criteria for architecture and urbanism. The Fourth Nature concept is then seen not as a novelty, but as a continuity-a new vessel for an ancestral wine. Form is not expressive but regulative, proportion, orientation, and material choice directly influence how space is perceived and inhabited. Harmonic relationships support coherent resonance, while excessive fragmentation amplifies noise. Natural light cycles regulate circadian rhythms; material density and texture affect acoustic and thermal behavior; spatial hierarchy supports orientation and cognitive relief. Form thus acts as a regulator of vibrational quality, shaping human experience beyond functional performance.

All this, when connected to ancient constructions and knowledge, has the potential to bring us insights on how to live again according to nature`s forces, using its free energy (BONG,2008), again on the default state of health and abundance.

6 PARTIAL CONCLUSIONS

When sunlight shines through leaves and reaches our eyes bringing us an immense good feeling, it doesn't just deliver brightness-it delivers living patterns. Tradition calls this viriditas (Hildegard von Bingen, 1098), contemporary studies measure it as stress reduction with dappled light (Komorebi), and Rudolf Steiner (1861) /Erwin Laszlo(1932) philosophy interprets it as luminous information that aligns our body with the larger field. In simple terms: it transmits codes of well-being.

Architecture is the layer we build ourselves between us and this well being frequencies inherent to the living world. It shall be therefore understood also as a field of resonance that continuously interacts with human bioelectromagnetic systems. Spatial form, geometry and scale influence acoustic, thermal and electromagnetic patterns; light modulates circadian and neuroendocrine rhythms via retinal and non-visual photoreceptors; and materials condition electrical, thermal and vibrational exchanges through their conductivity, permittivity and acoustic response. The human body, itself an electrochemical and bioelectromagnetic system, responds to these stimuli by adjusting neural activity, hormonal regulation and autonomic balance. From this perspective, architecture does not merely shelter biological functions but actively participates in physiological regulation by shaping coherent or incoherent environmental fields. Architectural quality, therefore, can be framed as the degree to which the built environment supports

resonant alignment between physical space and human bioelectromagnetic organization. In housing, vibrational coherence supports daily rhythms, privacy gradients, and informal social stability. Orientation, materiality, and spatial sequencing influence sleep, recovery, and mental clarity. Public space operates as collective resonance. Legibility, restraint, and temporal accessibility enable coexistence without constant stimulation or over-programming. Urban growth becomes a generative process rather than quantitative expansion. Phasing, pauses, and continuity maintain coherence over time.

In this respect, architectural elements operate as tuning components within a larger environmental system. Walls, surfaces and proportions do not act in isolation; they condition how light, sound, heat and electromagnetic interactions are distributed and perceived, contributing to the overall coherence or disruption of the spatial field. When material choices, geometric order and geographic context are aligned with natural cycles and site-specific conditions, the built environment supports stable exchanges between human physiology and planetary processes. Architecture then transcends the logic of mere construction and functions as a regulatory interface between Earth systems and human life – not by symbolic intention, but through physically grounded coherence that fosters balance, restoration and long-term ecological and physiological health.

Translating vibrational coherence into architectural practice is the next fundamental step for a new relationship between humankind and the forces that govern life on the planet. Let's not build against it anymore, let's be Fourth Nature ally in recovering a qualified existence, allowing our true capacities as mediators between heaven and earth to flourish, and allowing our spirit to inspire us on this task. Fourth Nature does not propose a stylistic agenda. It offers a framework of vibrational coherence capable of bridging heritage knowledge and contemporary science. By aligning intelligence, time, form, and lived reality, architecture and urbanism can move beyond performance toward resonance.

In this sense, form follows spirit – not as belief, but as structural necessity.

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Mapping 15-Minute Walkable Accessibility of Public Services in China's 11 National Urban Agglomerations: A Data-Driven Spatial Coverage Assessment

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1 ABSTRACT

Cities worldwide are increasingly embracing the idea of the "15-minute city" as a pathway to more liveable, equitable and climate-responsive urban environments. This vision emphasizes walkable access to daily services, local resilience, and low-carbon lifestyles – features that have proven valuable in managing urban pressures and supporting recovery during and after the COVID-19 pandemic. In China, rapid urbanization and growing challenges such as air pollution, mobility congestion and widening social disparities have intensified the need for people-oriented, energy-efficient urban development. Responding to this, China's Ministry of Natural Resources issued the Spatial Planning Guidance for Community Life Units (2021), which provides a standardized framework for planning 15-minute walkable living areas and outlines spatial assessment methods for essential public service facilities.

Building upon this framework, this study conducts a comprehensive, data-driven evaluation of 13 categories of urban–rural public services across 170 cities within China's 11 national urban agglomerations. Using high-resolution POI datasets and GIS-based network analysis, we measure and visualize the 15-minute walkable service coverage of each facility type, generating a comparative landscape across cities, across agglomerations, and within each urban agglomeration. The analysis reveals spatial disparities in service provision, diverse facility configuration patterns, and distinctive intra-agglomeration hierarchies. The resulting visual "coverage mode maps" provide an intuitive tool for identifying local deficiencies and strengths, offering actionable insights for planners and policymakers seeking to promote climate-adaptive, resilient and low-carbon urban futures.

Keywords: 15-minute city, Walkable accessibility, Public service facilities, Urban agglomerations, Spatial coverage assessment

2 INTRODUCTION

2.1 From the Global "15-Minute City" to China's City-Region Strategy

The "15-minute city" has emerged as an influential planning paradigm aimed at improving liveability, social equity, and low-carbon urban lifestyles by ensuring that essential daily services are accessible within a short walk or cycle. Since its formulation by Moreno, the concept has evolved from an urban design vision into a governance-oriented framework that evaluates everyday accessibility through time-based thresholds.

The COVID-19 pandemic further reinforced the relevance of proximity-based planning. Mobility restrictions and pressure on healthcare systems revealed the importance of neighbourhood-level service availability and walkable environments, accelerating global debates on resilience, climate adaptation, and post-pandemic urban recovery.

In China, proximity planning has been institutionalised through the concept of the "community life circle," formally embedded in national spatial planning guidance issued in 2021. Rather than adopting the 15-minute city as a policy import, China reframed it as a standardised planning unit to support people-centred urbanisation and the equalisation of basic public services under the 14th Five-Year Plan.

Importantly, contemporary Chinese urbanisation is increasingly organised at the scale of urban agglomerations. These city-regions function as strategic carriers of population, economic activity, infrastructure investment, and governance coordination. China's 11 national urban agglomerations together account for nearly one billion residents and dominate national economic output, yet they differ markedly in development level, settlement structure, and spatial inequality. This diversity makes the city-region scale particularly relevant for examining how proximity-based accessibility is structured across China's urban system.

2.2 City-Regions, Inequality, and the Limits of Proximity Planning

Existing studies on public service accessibility in China consistently highlight persistent spatial inequality – between urban cores and peripheries, between large metropolitan centres and smaller cities, and especially between urban and rural areas. Even within economically advanced regions, fragmented governance and uneven facility distribution can produce substantial differences in everyday accessibility.

Urban agglomerations provide a critical lens for analysing these inequalities. Unlike single cities, city-regions encompass multiple jurisdictions, settlement hierarchies, and development trajectories. They are simultaneously sites of agglomeration economies and arenas of redistribution, where regional coordination can either mitigate or amplify spatial disparities.

Super city-regions such as the Yangtze River Delta and the Guangdong–Hong Kong–Macao Greater Bay Area benefit from dense settlement patterns and strong fiscal capacity, enabling more comprehensive service networks. In contrast, inland and peripheral agglomerations face dispersed settlements, complex terrain, and constrained public resources, increasing the difficulty of achieving walkable access. These structural differences suggest that a uniform application of the 15-minute standard may be neither realistic nor equitable across all regions.

2.3 Research Objectives and Scope

This study adopts a deliberately empirical and diagnostic research scope. Rather than developing causal models or policy evaluations, it focuses on systematically measuring and comparing 15-minute walkable accessibility to public service facilities across China's major urban agglomerations.

Specifically, the study quantifies the spatial coverage of 15-minute walkable access to 14 categories of urban–rural public service facilities across 174 cities in China's 11 national urban agglomerations, based on 2022 POI data and pedestrian network analysis. Urban agglomerations are treated as the primary analytical units in order to reveal regional patterns that remain obscured in single-city analyses.

The study further distinguishes between urban and rural accessibility outcomes, reflecting China's long-standing urban–rural dual structure. By presenting coverage outcomes as comparative indicators rather than causal explanations, the paper provides a nationwide baseline portrait of proximity conditions, highlighting where accessibility advantages and deficits are structurally concentrated across China's urban system.

3 STUDY AREA, DATA, AND METHODOLOGY

3.1 Study Area

The analysis covers China's 11 national-level urban agglomerations, encompassing 174 prefecture-level cities. These city-regions represent the core spatial framework of contemporary Chinese urbanisation and regional development. They include globally competitive coastal clusters, interior growth poles, and emerging or peripheral regions, together accounting for the vast majority of China's urban population and economic activity.

Urban agglomerations are adopted as the analytical scale for three reasons. First, they reflect China's dominant spatial organisation of development and governance. Second, they encompass diverse settlement types, enabling systematic comparison of urban–rural accessibility. Third, many national policy agendas related to public service provision, resilience, and low-carbon development are explicitly framed at the city-region level.

3.2 Data Sources and Processing

The analysis is based on a national POI dataset of public service facilities for 2022, collected from mainstream Chinese digital mapping platforms. Following national spatial planning guidance, 14 categories of essential public service facilities were identified, covering education, healthcare, food services, culture, sports, elderly care, and other daily welfare-oriented functions.

Data cleaning involved removing duplicates, correcting invalid coordinates, and standardising facility classification to ensure nationwide comparability. While POI data may underrepresent informal services – particularly in rural areas – it remains one of the most effective data sources for large-scale accessibility analysis due to its spatial precision and national coverage.

Pedestrian road network data were constructed for all cities by processing detailed road vectors to represent walkable infrastructure. Motorways and access-restricted roads were excluded, while local streets and pedestrian pathways were retained. Network cleaning addressed connectivity errors to ensure consistent modelling conditions across regions.

3.3 Measuring 15-Minute Walkable Service Coverage

The study evaluates proximity-based accessibility using a network-based 15-minute walkability approach consistent with China's "community life circle" framework. For each facility POI, a 15-minute pedestrian service area is generated based on a standard walking-speed assumption (1.5 m/s), corresponding to approximately 1,350 m of network distance. Where national guidelines specify facility-specific service radii, those thresholds are applied.

Accessibility is operationalised as an area-based indicator: the share of built-up land that falls within a 15-minute walkable catchment of a given facility type. Coverage is calculated separately for urban and rural built-up areas within each city and then aggregated to the urban agglomeration level using population-weighted averaging. This approach emphasises the distributional significance of accessibility outcomes for residents and enables consistent comparison across regions.

4 RESULTS

The results reveal pronounced differences in 15-minute walkable public service coverage across China's 11 urban agglomerations. Aggregated outcomes display a clear tiered pattern, with coastal and economically advanced regions generally outperforming inland and peripheral agglomerations.

Urban areas consistently exhibit higher coverage than rural areas, but the magnitude of the urban–rural gap varies substantially. In some city-regions, strong urban accessibility is accompanied by relatively robust rural performance, while in others, high urban coverage contrasts sharply with limited rural access, producing significant internal inequality.

The Guangdong–Hong Kong–Macao Greater Bay Area emerges as a clear outlier, exhibiting exceptionally high coverage across most facility categories and the smallest urban–rural gap. Dense urban form, compact settlements, and mature service networks contribute to near-comprehensive walkable access, particularly in Hong Kong and Macao.

By contrast, the Capital Economic Circle demonstrates more modest average performance. While core metropolitan areas show strong urban coverage, extensive peripheral and rural areas with weaker accessibility reduce the overall regional outcome, highlighting pronounced internal heterogeneity.

Mid-tier agglomerations – including the Yangtze River Delta, Chengdu–Chongqing, and the Middle Reaches of the Yangtze River – display intermediate performance, typically combining strong urban accessibility with uneven rural outcomes. At the lower end of the spectrum, western and northern agglomerations exhibit consistently lower coverage, particularly in rural areas, reflecting dispersed settlements and constrained service networks.

Across facility categories, education and basic healthcare generally achieve higher coverage than cultural, sports, and elderly-care services. However, substantial regional variation persists, underscoring the multi-dimensional nature of proximity-based accessibility.

5 DISCUSSION

The city-region comparison highlights a key finding: rural accessibility is the binding constraint shaping China's 15-minute performance. While metropolitan cores often achieve relatively high walkable coverage, persistent rural deficits significantly lower regional averages, particularly in Tier 2 and Tier 3 agglomerations.

High-performing regions such as the Greater Bay Area demonstrate that proximity planning can function as a region-wide public good when dense settlement patterns, strong fiscal capacity, and integrated governance align. In contrast, large and fragmented city-regions reveal that political or economic centrality does not automatically translate into equitable everyday accessibility.

Facility-type contrasts further suggest that market-driven services achieve proximity faster than welfare-oriented services. Healthcare and education accessibility reflect not only facility supply, but also institutional organisation, spatial morphology, and network permeability. In this sense, the 15-minute metric operates as a diagnostic tool that captures how urbanisation, governance, and spatial form jointly shape everyday accessibility.

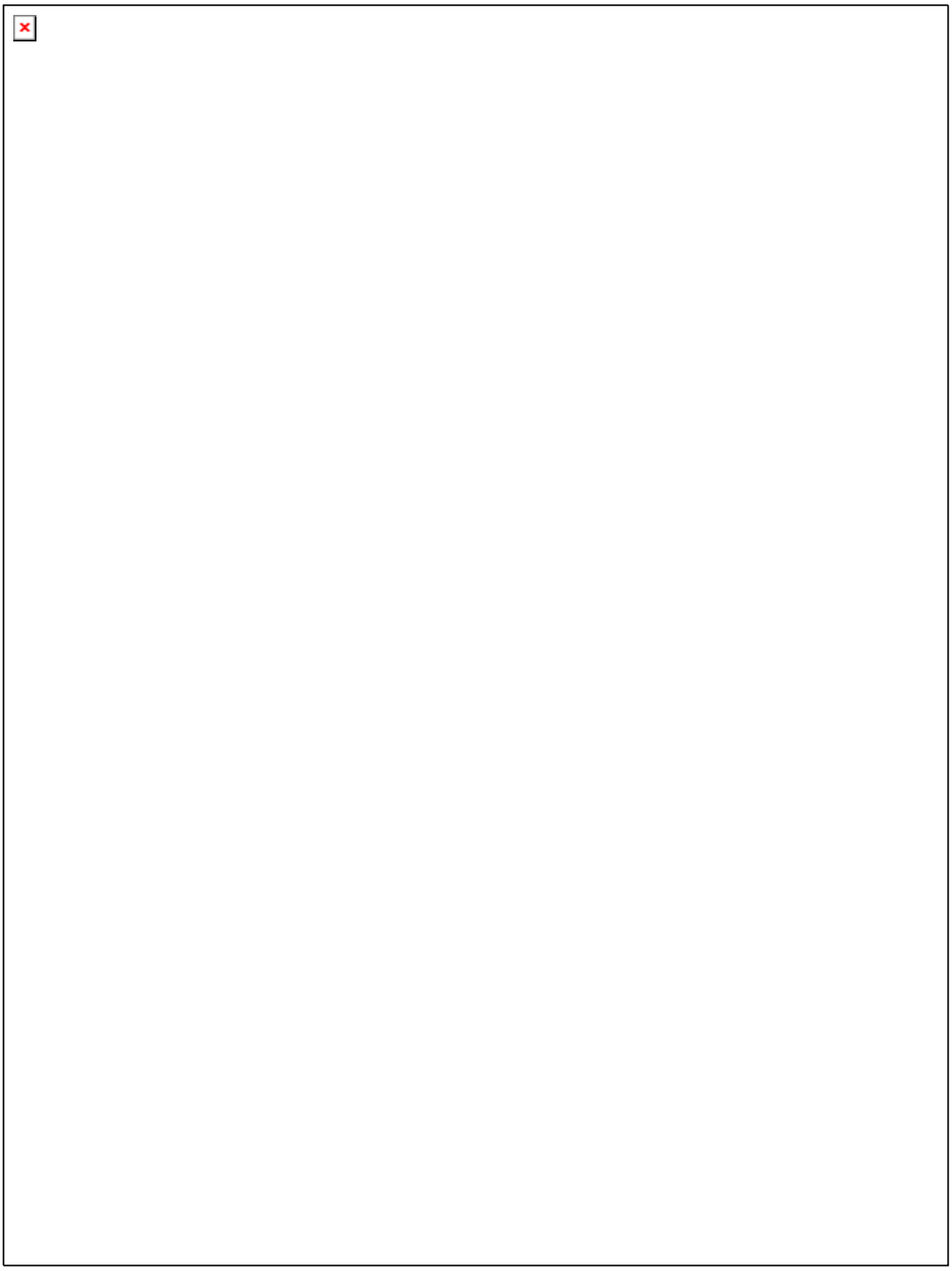


Fig. 1: D3.js-Based Radial Visualization of 15-Minute Walkable Public Service Accessibility across China's 11 Urban Agglomerations. Note: Each radial chart presents the cumulative 15-minute walkable coverage of public service facilities for cities within a given urban agglomeration. The innermost ring represents urban (built-up area) facility coverage, the middle ring represents rural facility coverage, and the outermost ring represents the integrated urban–rural facility coverage, calculated by weighting urban and rural results by their respective population shares. Together, the three concentric rings illustrate both internal urban–rural disparities and the overall proximity performance of each city within the urban agglomeration.

6 CONCLUSION

This study provides a nationwide, city-region-level assessment of 15-minute walkable access to public services across China's 11 national urban agglomerations. Three conclusions stand out.

First, proximity-based accessibility exhibits clear regional tiering, but the decisive factor is rural performance rather than metropolitan capacity. Second, different facility types follow distinct distribution logics, revealing structural constraints beyond simple under-supply. Third, under post-pandemic fiscal constraints, proximity planning must prioritise equity-efficient interventions – such as improving pedestrian connectivity and coordinating service provision at the city-region scale.

Overall, the "15-minute city" is viable in China only if reframed from an urban design slogan into a spatial justice principle aimed at urban–rural integration and time-based equity across diverse territorial conditions.

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Neuromarketing-Based Gamification for User Experience and Cognitive Load Management in Physical Therapy

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1 ABSTRACT

Gamification techniques are widely used in physiotherapy and rehabilitation processes to maintain patient motivation and ensure the continuity of treatment. Current studies in this field (Huber et al., 2021; Krepkovich et al., 2022; Arbuckle et al., 2025) show that game-based applications not only increase user satisfaction but also improve patient participation and the overall usability of applications. However, the balancing of cognitive load in gamification strategies and the neurophysiological foundations of this process are not yet clear. Inappropriate levels of cognitive engagement can negatively affect the learning process and application success (Müller et al., 2025; Ayoob et al., 2020).

This study presents the NEURO-GAMER PT approach, which approaches gamification applications within the physiotherapy discipline from a neuromarketing perspective and integrates multisensory feedback with neurophysiological data, to the academic literature. This research is based on a randomized controlled experimental design to deeply examine changes in user experience and cognitive load in gamified rehabilitation processes.

Keywords: Neuromarketing, Gamification, User Experience, Cognitive Load Management, Physical Therapy

2 NEUROMARKETING-BASED GAMEFICATION FOR USER EXPERIENCE AND COGNITIVE LOAD MANAGEMENT IN PHYSICAL THERAPY

2.1 Introduction

The use of virtual reality (VR) and gamification elements in physical therapy and rehabilitation processes yields superior results in terms of patient motivation and adherence to treatment compared to traditional treatment methods. Studies focusing on stroke, Parkinson's disease, and musculoskeletal disorders show that gamified rehabilitation approaches improve balance control, motor skills, and functional independence in daily life for patients (Syed et al., 2019; Cameirão et al., 2010; Arbuckle et al., 2025).

While users' general attitudes towards gamified physiotherapy systems are mostly satisfaction-oriented (Huber et al., 2021), the underlying cognitive load dynamics of this experience have generally been limited to survey-based measurements.

These findings suggest that gamification strategies in physiotherapy should be considered not only as a motivator but also as a strategic improvement motivation tool that manages cognitive load and attention mechanisms. Evidence from the neuromarketing literature reveals that individuals' decision-making, reward perception, and attention processes are largely shaped by unconscious (latent) mechanisms. This indicates that user experience cannot be fully explained by self-report (subjective) questionnaires alone; it needs to be supported by sensitive neurophysiological tools such as EEG (Ahmed et al., 2025). However, neuromarketing-focused approaches allow for the unraveling of the incomprehensible dynamics behind superficial responses by examining the decisive role of emotional and cognitive arousal on user behavior (Robaina-Calderín, 2021; Ouzir, 2023; Yadete & Kant, 2023).

This study, stemming from this need, aims to experimentally investigate the effects of multisensory feedback on user experience and cognitive load in gamified physiotherapy applications.

2.2 Methods

The study group consisted of individuals aged 18 and over who experienced mobility limitations due to trauma, surgery, or chronic illnesses and required rehabilitation.

A total of 40 volunteers were randomly assigned to experimental and control groups, and all participants were selected to complete at least 6 weeks of rehabilitation after treatment.

To ensure methodological reliability, cognitive ability will be assessed using the Mini Mental State Assessment (MMSE > 20); medical contraindications that could compromise the safety of haptic feedback VR systems, such as epilepsy and the presence of implants, will be excluded from the study. To minimize bias in the assessment process, a single-blind sampling strategy will be applied, preventing researchers from accessing group distributions

2.2.1 Critical Game Design Elements to be Examined from a Neuromarketing Perpective

In this study, neuromarketing dynamics will be observed and measured through unconscious processes such as attention management, cognitive load balance, reward expectation, sensory feedback, flow state, and emotional arousal, thus influencing user experience and treatment adherence.

2.2.2 Overall Assesment and Research Expectations

This study provides a significant analytical framework for evaluating the generalizability of observations to different rehabilitation scenarios, including individuals experiencing functional loss due to stroke, trauma, surgery, or illness. Accordingly, the research aims to establish a theoretical and methodological reference point on the applicability of neuromarketing-based game design in the field of health and rehabilitation.

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New Alliances and Microdevelopment Approaches for Affordable Housing in Southern Africa

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1 ABSTRACT

This article aims to explain how new alliances between private initiatives and actors and the relevant administrative authorities and politicians are changing the way affordable housing is created in southern Africa, particularly in the Republic of South Africa and in Namibia. The goal is to supplement or replace the state-controlled housing supply systems in South Africa and Namibia with a more development-oriented approach, which is currently being promoted "from the bottom up" by many new actors and real estate companies. In both countries, there is still a significant shortage of affordable housing, especially for the lowest income groups. These target groups are generally not well served by the top-down housing programs of recent decades. This article attempts to clarify the significance of these new "bottom-up" approaches in a sustainable housing policy and how their "dormant potential" can be leveraged.

Keywords: Affordable Housing, Microdevelopment, South Africa, Namibia, Informal Settlement

2 NEW ALLIANCES AND MICRODEVELOPMENT APPROACHES

2.1 The initial situation

First, it must be noted that over the past three decades, a strong wave of urbanization in the major cities of South Africa and Namibia has led to a dynamic increase in the demand for housing. Depending on the source, the backlog, i.e., the shortfall, in South Africa is estimated at 2.4–2.6 million households that do not have adequate, permanent (urban) housing (DEP. STATISTICS REPUBLIC SOUTH AFRICA, 2024; MC.GAHEY, 2024). In its 2021 human settlements strategy, the city of Cape Town, for example, assumed that around 50,000 additional apartments would be needed there alone each year. In reality, however, only around 20,000 new homes are being built (TUROK, 2025). Depending on the source, the backlog in Namibia is estimated at up to 300,000 homes in total, which is also many times the annual production (approx. 2,000 residential units per annum) (PETERSEN, 2024). The shortage on the housing market is therefore continuing to worsen. Cape Town is representative of the housing markets in many cities in both countries.

Over the past three decades, official housing policy in both South Africa and Namibia has tended to focus on "building out of the problem" (TUROK, 2025, p. 2) through top-down approaches and the large-scale construction of detached housing units for poor households. The problems and limitations of these approaches are well documented in the literature and in studies (KLUG et al., 2013; PIETERSE, 2019). This model of housing provision was predominantly based on the "ownership model" with a continued commitment to state-subsidized housing, which was often built on the outskirts of cities.

The top-down approaches of the public sector have neither produced the necessary production figures nor, with their financing programs and a kind of overregulation (administrative regulations, inappropriate standards), supported the efforts of small private developers and homeowners to participate in housing production, but rather hindered them.

2.2 What's new?

Meanwhile, both residents and the private sector are increasingly responding with new approaches to the construction and financing of affordable (rental) housing, e.g., in the townships of larger cities. Many of these approaches have their origins in the organically grown housing solutions that have been a feature of local accommodation since the townships were established. From the outset, these settlements offered inadequate housing to meet the needs of black city dwellers. Residents responded to this as so-called DIY developers by expanding their homes and, where possible, building housing in private gardens.

Beyond large-scale top-down approaches in the conventional housing market, homeowners and small-scale developers could become important players investing in higher-quality brick-and-mortar rental apartments. A number of players have emerged who help residents and owners of small areas to develop them appropriately and finance this development.

This enables a decentralized approach that can be tailored to the capabilities of each individual, thereby unlocking the "dormant potential" of the housing supply. Some authors already refer to this sector as the "largest provider of housing" in large cities (MC.GAHEY, 2024, p. 193). Moreover, it offers considerable advantages for urban densification, income generation, and the development of a stronger local economy.

However, this microdeveloper and small-scale housing segment is less formalized in Namibia than in South Africa. Instead, Namibia has several alternative models, mostly community- or government-driven, that pursue similar goals: more affordable housing, lower barriers to entry, and participatory processes. In South Africa, the formalization of this segment is more advanced. In the meantime, the attitude of the official authorities towards these new approaches and partners has also changed.

For example, the City of Cape Town's current Review 2025/2026 of the five-year plan "Integrated Human Settlements" (2022/2023-2026/2027) states: "The private sector can play a critical role in the provision of affordable housing (...). Considering the reality that demand will increasingly outweigh supply of housing, combined with the pressure that human settlement grant funding is under, it is critical that the City begins considering innovative approaches to incentivise or collaborate with the private sector to enable affordable housing" (CITY of CAPE TOWN, 2025, p. 100).

This is leading to new alliances between various initiatives and actors from the private sector, especially the non-profit segment, and the relevant administrative bodies and political decision-makers, who have now recognized the potential of the new microdevelopers for the development of low-cost rental accommodations.

2.3 Institutions and players of microdevelopment

In order to better assess these new players in microdevelopment and the thrust of their activities in both countries, this section provides a brief introduction to some of these players and institutions, without claiming to be exhaustive. This segment is a constantly growing cosmos of initiatives and players that promise to form the basis of a new dynamic for expanding the housing stock in both countries. Sections 2.3.5 and 2.3.6 deliberately include the two most important funds, known as non-profit financial institutions in South Africa and Namibia, which were established in the mid-1990s and on which microdevelopment projects in the housing sector can rely.

2.3.1 South African Shack/Slum Dwellers International Alliance (SASDI)

SASDI is the South African branch of the Shack/Slum Dwellers International network and represents an alliance of movements, NGOs, and community-based actors working to combat poverty and promote bottom-up development processes. As an alliance, it includes other institutions and actors such as the Informal Settlement Network (ISN), the FEDUP savings groups and community organization, and the Community Organization Resource Centre (CORC), which, as a registered non-profit organization (NPO), provides professional support and mediation services for organized resident networks, in particular for ISN and FEDUP. CORC's main tasks are to support communities in developing their structures, strategic planning, and organization.[1] CORC organizes peer learning and the exchange of experiences between various community and settlement projects (CORC, 2015).

While the Informal Settlement Network (ISN) mobilizes and negotiates for better infrastructure and housing upgrades, SASDI sets the framework for collaboration, policy influence, and joint programs. CORC provides planning, data tools, dialogue platforms, and negotiation support close to the settlement groups. This three-part alliance of ISN, SASDI, and CORC thus strengthens the planning capabilities and bargaining power of poverty-affected communities, enabling them to realize self-designed improvements, partial infrastructure development, and long-term housing options.

The alliance therefore does not primarily operate as a construction company in the traditional sense, but rather as a social movement and support infrastructure. The result is not just "a house," but an inclusive urban development process that improves housing, safety, and social conditions in the long term – often complementing government housing subsidies.

[1] https://www.devex.com/organizations/community-organisation-resource-centre-corc-63894

To date, the Alliance has built approximately 15,000 houses, of which around 13,000 were built as part of the People's Housing Process (PHP).[2] A further 6,500 households have benefited from improvements to their homes or infrastructure through upgrading. In addition, land tenure security (legal or de facto secure housing in informal settlements) has been achieved for approximately 20,000 households.

2.3.2 Shack Dwellers Federation in Namibia (SDFN) & Namibia Housing Action Group (NHAG)

The Shack Dwellers Federation of Namibia (SDFN) is a community-based organization in Namibia that works to improve the housing and living conditions of low-income people, especially those living in informal settlements, shacks, or without secure shelter. It receives administrative and technical support from the Namibia Housing Action Group (NHAG), for example in informal settlement upgrading processes, infrastructure installations, and house construction, for example through consulting or project planning.

The SDFN is a nationwide network of savings and housing groups, which today consists of over 1,000 savings groups with more than 30,000 members in all 14 regions of Namibia. Members form savings groups in which they regularly deposit small amounts of money. Each group manages its own funds and has its own bank account. These savings form the basis for further steps such as land purchases, services, and construction projects.

Since its inception 20 years ago, the SDFN has built over 7,000 homes for low-income families (ENDJALA, 2025). In 2023, the number of completed houses amounted to approximately 350, which corresponds to an approximate average value over all 20 years (PLENTZ, 2024). In 2025, a further 3,310 residential units were announced for the coming years (ENDJALA, 2025).

2.3.3 Development Action Group (DAG), South Africa

The Development Action Group (DAG), established in 1986, is a leading South African non-governmental, not for profit organisation focused on urban development and housing issues. It worked to create equal, inclusive, and sustainable neighbourhoods and cities through development processes that foster human rights, equity, and dignity.

DAG's impact in the urban sector over the years can be attributed to the organisation's role in unlocking the development of approximately 8,000 new low-cost housing opportunities; facilitating improved security of tenure for 27,000 people; providing direct assistance in securing community services to over 100,000 households in over 85 projects; securing and unlocking R275 million (app. 14,5 Mio. EUR) for housing projects. The Contractor and Developer Academy (CDA) was established under the umbrella of the DAG to support the construction of affordable small rental apartments in townships. The CDA provides advisory services, targeted training, and direct support to emerging contractors and developers to provide affordable, better-managed housing. In addition to this, the CDA aims to raise awareness around the crucial role played by emerging developers and contractors in the delivery of affordable housing, and thus is involved in numerous lobbying and advocacy activities.

2.3.4 Urban Think Tank Empower (UTTE), South Africa

Urban Think Tank Empower (UTTE) is also a Non-Profit Company (NPC), dedicated to developing and implementing a new public housing model with the potential to improve South Africa's difficult public housing conditions (DU PLESSIS, 2024). Urban-Think Tank's association bringing together an alliance of local and international partners. These partners include local community members, government officials, built environment practitioners, impact investors, NGOs and international donors, pioneering innovative approaches to driving impactful change by combining collective expertise and resources.

Empower Khayelitsha was the first full community development built as a live prototype to demonstrate the alternative affordable housing solutions. They create a triangle of terraced housing that it says provides a model for how to build in the country's informal settlements. Completed on a site called BT-Soweto in Site C of Khayelitsha, just outside of Cape Town, the development is the company's first using their Empower Upgrade model and includes a public open space, community centre and playground as well as 72 homes for 428 residents. UTTE aimed to create a financially and ecologically sustainable community-focused model for developing these areas while addressing some of the deficiencies of the post-apartheid building

[2] https://towardsthehumancity.org/initiative-76-south-african-sdi-alliance-slum-upgrading-cape-town

programme, which has focused on relocating residents to new low-cost mass housing (AOUF, 2025). Since starting work on BT-Soweto 10 years ago, the team now have 14 other developments in the works, most of them instigated by the communities themselves. UTTE relies on complete buy-in from residents, which includes a 10 per cent monetary contribution to the cost of the housing, financed through microloans. The rest of the funding comes from a mix of government subsidies and charitable giving.

2.3.5 uTshani Fund, South Africa

The uTshani Fund is a non-profit financial institution in South Africa that was founded in 1994/1995. It is closely linked to the South African Homeless People's Federation (SAHPF) and the Federation of the Urban and Rural Poor (FEDUP) (DEPARTMENT for HUMAN SETTLEMENTS, 2014, pp. 39). It was created to pool financial resources and pass them on to savings and credit groups among the poorer population so that they can build socially acceptable and affordable homes or improve their living situation. The uTshani Fund uses a financing model that specifically targets community savings and credit structures (mostly through nsuku zonke groups). Instead of granting traditional mortgage loans, the fund provides pre-financing or low-interest loans, essentially as “bridge financing”, which enable savings groups to build their own homes while receiving government housing subsidies at the same time (UTSHANI FUND, 2010).

The fund can administer and distribute government housing subsidies, which is particularly important because many households without their own creditworthiness would otherwise be unable to access these funds. The loans are granted at relatively low interest rates and with longer terms (e.g., 15–24 years, often much cheaper than standard market loans) (OMENYA, 2007, pp. 111). The fund thus enables communities with very low incomes to build or improve their own homes – with sustainable financing instead of purely government-funded construction methods. Poor households often have no collateral and no access to traditional bank loans. The uTshani Fund creates an accessible financing option that is specifically designed for low incomes. It is therefore an important financing and empowerment tool for affordable housing outside the traditional banking and government systems.

According to an evaluation, between the mid-1990s and 2000, 3,906 houses were built exclusively with uTshani Fund loans (i.e., before the government subsidy was paid out), and an additional 1,250 houses were supported by a combination of uTshani bridge financing and government subsidies. This means that by July 2000, at least 5,150 households had benefited directly from uTshani financing during the construction process. For various reasons, there is no concrete and exact record of the projects supported in the years that followed. However, there are reports that a total of approximately 8,000 houses have been built to date through the Federation's structures, which include the uTshani Fund (BAUMANN, BOLNICK, MITLIN 2012). Other studies even mention more than 11,000 houses that are said to have been built in the broader network context (GUMBO, ONATU, 2015, pp. 27).

2.3.6 Twahangana Fund, Namibia

The Twahangana Fund is a community managed revolving fund that provides microloans to the members of the savings groups of the Shack Dwellers Federation in Namibia (SDFN), for the purpose of land acquisition, servicing of land and the construction of housing. The Fund serves as a tool for the very poor inhabitants of Namibia to access financial assistance, which is not given to them by official banking institutions. Since 1995, the Twahangana Fund channeled over 231 million NAD (app. 13 million EUR) to the different groups of the SDFN for the construction of over 6,000 houses, reaching 24,000 people. The money received through the Fund is repaid by the members of the savings groups and these repayments contribute to the Fund (CAHF, 2021). Since 2000, the Namibian Government has assisted groups from the SDFN through the Twahangana Fund to obtain housing through donations from the Ministry of Urban and Rural Development (MURD). Previously, the groups also benefited from a national housing program, ‘Build Together’. For the past years, the SDFN has shown its community-led capacities to manage donor money and governmental subsidies thanks to years of experience and solid management systems. This encouraged the development of partnerships with the private sector. Transparency seems to be one of the big principles of the Fund. The und is managed by the communities themselves, together with NHAG and SDFN.

3 EVALUATION OF NEW MICRODEVELOPMENT APPROACHES AND CONSEQUENCES FOR THE POLICY MIX

Both countries already have a very large housing shortage, amounting to 2.4 to 2.6 million housing units in South Africa and 200,000 to 300,000 housing units in Namibia, which is many times higher than the countries' current annual housing production. In South Africa, the annual completion figures for recent years range between 60,000 and 90,000 housing units (public and private), while in Namibia they are around 1,700 to 2,000 housing units (public and private). It is clear that much greater efforts are needed in both countries to catch up with the above-mentioned backlog and the future increase in demand for housing.

Looking at the segment of microdevelopers and small houses for low-income earners, which is the focus of this article, a comparison of project numbers and demand quickly shows that, in quantitative terms, this segment can only be part of the solution to the housing problem in both countries.

Qualitatively, however, these microdevelopment activities are one of the most effective approaches to affordable housing in the low-income segment, as they successfully target a group that would otherwise be virtually unreachable with traditional approaches.

SDFN's offering in Namibia, for example, reaches very low-income households that do not have access to bank loans and are not served by either the private market or traditional government programs. In this segment, SDFN is one of the largest functioning providers overall. Many government programs fail in this area due to solvency and implementation problems.

SDFN houses often cost between N$120,000 and N$180,000 per unit, which is significantly less than government- or privately-subsidized social housing. A high proportion of personal contributions and local construction methods significantly reduce costs and improve affordability. Per dollar invested, SDFN is therefore above average in terms of efficiency, even if it scales more slowly.

In addition, repayment rates for SDFN's savings and loan models are comparatively high, as community pressure and personal contributions help reduce defaults. The houses almost always remain in the original ownership of the target group. This is politically significant, as many previous programs have often failed due to defaults and resales.

Similar experiences have been made in South Africa with the offerings of the SASDI Alliance (FEDUP, CORC), the uTshani Fund, and the DAG. Here, too, the costs per housing unit are significantly lower than for government social housing. Social housing achieves higher construction quality and formal security, but at significantly higher costs.

Microdevelopment and community-based approaches are therefore an essential component of a functioning housing policy. However, this is not only about new construction activities, but also about the important housing policy component of existing stock development. For example, around two-thirds of South Africa's backlog is located in informal settlements. Therefore, it must also be about in-situ upgrading of informal settlements, the upgrading of backyard housing, and the overall redensification of existing neighborhoods. These are also important tasks in terms of sustainable urban development.

Although the construction of new social housing is indispensable in terms of quality, it is too slow and too expensive in terms of quantity to solve the urban housing problem in southern Africa on its own. Microdevelopment is not a substitute, but it is the most efficient instrument for relieving the market quickly and cost-effectively.

This is where the scaling argument comes into play. Microdevelopment scales horizontally (many small actors). Social housing scales vertically, but slowly and with limited capacity. Neither segment can reduce the backlog on its own.

Microdevelopment and community approaches offer the advantage of leverage. They act as an innovation platform for participatory modernization and incremental housing construction, gradually changing project architecture and practice as well as the attitude of public authorities. There is therefore a high qualitative leverage effect.

Scaling up microdevelopment approaches can only be successful if sufficient developed and suitable land is made available. Its availability remains a key obstacle. It is also a matter of making planning law (zoning, density, parking) more flexible, which public authorities should ensure. Other important levers include the

adequate provision of microfinance and support for technical standards, such as type plans or building catalogs. Public authorities should also strengthen tenant protection and security, especially in informal settlements (WEBER, MENDELSOHN, 2017).

However, scaling up and long-term success also require training and education for those involved, as well as the establishment of governance structures that enable institutional stability and efficient management. This is particularly relevant in South Africa, where community organizations are sometimes politicized and conflicts arise with local elites or parties. Here, the danger of instrumentalization or repression should be countered by providing these initiatives with political protection and recognition for their work.

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Regional Innovation Systems and Transformative Innovation Policy: An Embedded Approach

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1 ABSTRACT

Transformative Innovation Policy (TIP) is a strategic framework that addresses major societal challenges by promoting (distruptive) innovation, participatory processes and cross-sector collaboration. Due to its multi-scalar perspective, TIP is gradually being adopted in regional policy contexts, where place-based needs and local capacities play a pivotal role. However, effective regional approaches require integration into strategies at a higher governance level, which address infrastructure, legislation, and regulation and provide shared learning environments. Building on a recently completed project initiated by the Austrian Conference on Spatial Planning (ÖROK), this paper proposes a practitioner-oriented approach in which regions and their innovation ecosystems are embedded within a multi-level governance framework (TrIP – Transformative regionally embedded Innovation Policy). The model links: (i) shared visions and cross-sectoral strategies; (ii) innovation spaces and co-creative processes; (iii) learning, scaling up and diffusion across regions; and (iv) the adaptation of regulations, norms and institutions, including exnovation. This approach is illustrated through two case studies: an energy transition initiative in a rural area and a logistics innovation in an urban area.

Keywords: Regional Innovation System, Transformative Innovation Policy, Multi-Level-Governance, Spatial Planning, Participatory Processes

2 RATIONALE

In the past, innovation and innovation-oriented regional policy focused primarily on an economic agenda, with economic growth and competitiveness as overarching goals. Today, there is a broad consensus that, while this type of innovation policy has had a positive effect on growth, it has failed to address societal challenges. The scientific community is therefore promoting "transformative policy" as a new political paradigm, which has been adopted by many countries and is increasingly being advocated by the OECD and the European Commission. This is referred to as "transformative innovation policy" (Schot & Steinmüller, 2018) or "mission-oriented innovation policy" (Mazzucato, 2013), and "challenge-driven innovation policy" (Coenen, Hansen & Rekers, 2015). Despite differences in detail, these variations follow the same rational of transforming socio-technical systems. According to Trippl et al. (2023), new approaches are needed to support the transition to ecologically sustainable and socially inclusive economic practices. Traditional policy approaches such as cluster promotion or smart specialisation are therefore insufficient to initiate innovation-based territorial transformations.

2.1 Building blocks and intervention points for a transformative policy

A transformative innovation policy comprises the following elements:

- A strategic policy framework that aligns existing strategies with societal challenges ("directionality").
- Participatory and open processes that enable joint learning involving different stakeholder groups.
- A cross-sector portfolio of measures that integrates public and private investment.
- A comprehensive understanding of innovation that encompasses changes in regulations, norms and institutions, as well as technological advances.
- A central challenge for transformative innovation policy is overcoming the lock-ins and path dependencies of unsustainable systems, such as fossil-based energy production and consumption. Such system innovations cannot be developed and tested in isolation. It is therefore important to create spaces where new ideas can be developed and tested (innovation spaces), for example through living labs, enabling new approaches to be tested in systemic contexts and real-world situations.

- In addition, exnovation is also required. This can include reducing support for unsustainable technologies (e.g. fossil energy) and implementing regulatory changes to cushion the negative social effects of the transition ("just transition").

The following graphic summarises this approach and its points of intervention.

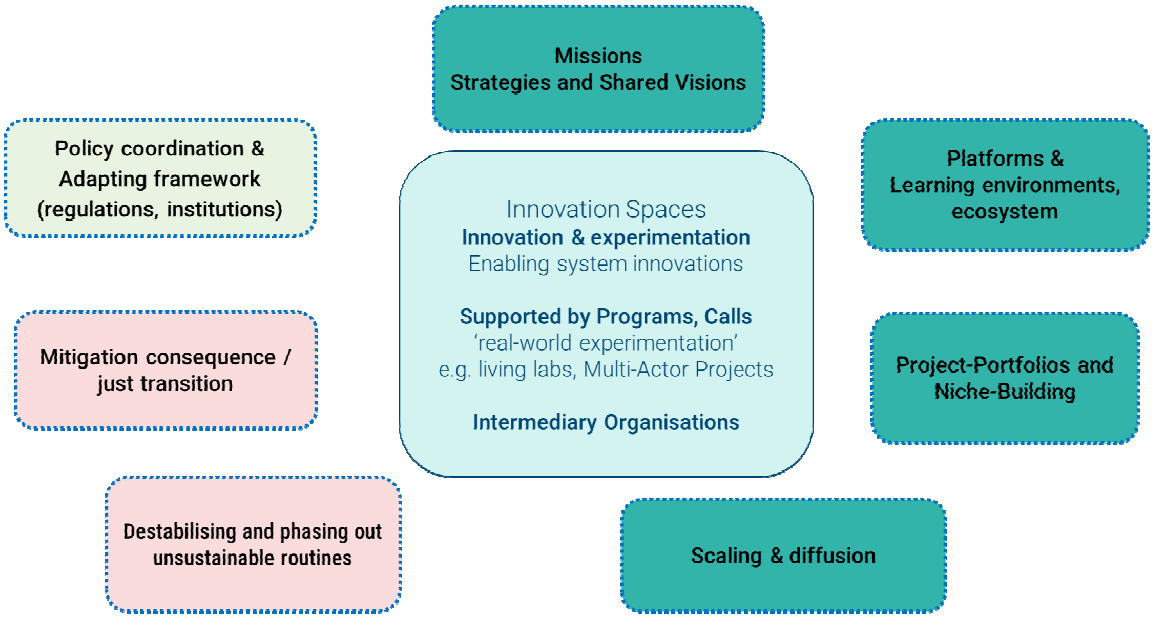


Fig. 1: Intervention Points of a Transformative Innovation Policy Source: own illustration.

3 EMBEDDED PLACE-BASED – REGIONAL INNOVATION SYSTEMS IN TRANSFORMATION PROCESSES

3.1 The Spatial Dimension and the Role of Regions

Despite its growing prominence, the initial contributions to transformative innovation policy have been criticised for paying insufficient attention to space and place, in particular overlooking the impact of geographical contexts, regional capabilities and spatial inequalities on transformation processes (Coenen et al., 2015). Traditional regional innovation policies, including Smart Specialisation Strategies, have largely focused on science- and technology-driven innovation, often failing to incorporate broader forms of social innovation and the voice of society. In response to these criticisms, an increasing amount of literature is calling for new governance models that facilitate transformation through multi-actor and multi-scalar approaches (Pontikakis et al., 2022; Serger et al., 2023). Accordingly, local and regional levels offer advantages as they represent complex systems within geographical areas and have appropriate planning instruments at the municipal level (Wanzenböck & Frenken, 2020).

However, the regional level must be embedded within higher policy levels, such as national or supranational. These levels can support transformation by defining overarching goals, supporting interregional learning (e.g. via intermediaries and platforms) and implementing complementary measures in areas such as regulation, tax policy, infrastructure and basic research. A central task of the higher levels is therefore to provide coordination structures that facilitate exchange and joint learning between regions. Thus, support from higher levels is needed to ensure the diffusion of local innovations and to coordinate the interests of different regions and sectors.

From this "embedded place-based" perspective, regional initiatives are not autonomous "containers"; they interact with and are shaped by higher-level strategies, funding architectures and regulatory environments. As RIS are open systems, they can draw on external knowledge and programmes while providing a context in which system change becomes tangible and negotiable.

3.1.1 The evolution of Regional Innovation Systems

A Regional Innovation System (RIS) denotes the set of organisations and people that cooperate in a network-like way within a geographically identifiable area to generate innovation – invention, experimentation and establishment of new practices – plus the communicative processes that keep this collective endeavour

aligned. RIS as a concept ist not new and developed from the classical triple helix of education/research/business to improve conditions for firm innovation and regional competitiveness via an interactive ecosystem view that explicitly integrates demand and users, recognising that technology-push alone does not ensure adoption. Transformation-oriented RIS or challenge-oriented RIS (Trippl et al. 2023) in contrast are primarily focusing on the solution of societal–economic challenges and persue visions of sustainable regional development. So as main differences to the former concepts broader partnerships of actors and affected groups co-create solutions, multi-level interaction beyond regional borders is treated as essential, and innovation includes not only new products and business models but also social innovation and cultural change. RIS therefore function as place-based interfaces between technological development, political strategies and the "everyday world", enabling transdisciplinary collaboration, learning and mobilisation close to citizens and local practice.

3.1.2 Four types of transformation oriented RIS

Building on this transformative understanding of regional innovation systems (RIS) four models can be drawn (in reality usually found as hybrids). (1) Bottom-up grassroots: a small group of committed individuals/organisations tackles a societal problem, develops a novel solution, and diffuses it through spatial proximity, shared problem situations and personal networks; like-minded groups in other regions adopt and adapt the solution, triggering wider spread. (2) Transforming existing RIS: established, economically oriented clusters/networks (often policy-funded) expand their scope due to external triggers (e.g., regulation, market opportunities) and add sustainability/transition goals; they broaden the cluster by integrating users and complementary service actors, enabling more radical innovations and improving societal acceptance and diffusion. (3) Strategy-oriented regional coalition: within a clearly delimited inter-municipal territory, a transformative strategy is co-developed; key impulses come from core actors and regional management/intermediaries (e.g., LEADER), often acting as "social entrepreneurs" (LEADER-forum 2020) who organise initiatives around region-specific resources or challenges; networking across regions generates spill-overs and replication. (4) Bottom-linked/ Top-linked: impulse and steering originate outside the region (state/federal/EU), providing cross-sector policy framing and programme funding for regional experimentation, coordinating thematic focus, and harvesting lessons for subsequent strategic decisions.

Still these advantages of the regional level are a potential, meaning, that they not necessarily are accessible or fully developed. Additionally regional transformation pointed out with the four models provide restricted impact since levers of change are often held on other decision-making levels and systems. So, a wider perspective beyond the mere regional is needed.

3.1.3 Towards transformative regionaly embedded innovation policy (TrIP)

RIS unveil their strenghts in a set of distinct processes, often startet with diagnosing a thematic challenge by reflecting on existing practices of need provision and by identifying systemic lock-ins and interdependencies. The bounded regional context supports making system relations visible. A cross-context („multi-actor") coalition then forms (e.g., administration, business, education, technology and civil society), explicitly involving end-users to improve usability and uptake, and engaging actors defending the status quo to anticipate resistance and to develop sloutions to make them "co-winners of change". A shared image of an alternative future functions as the "glue" for collaboration. The coalition mobilises resources by combining endogenous capacities (commitment, local knowledge, networks) with inputs from outside the region (knowledge stocks, funding, programme access). This enables experimentation with sustainable (system) solutions – products, processes, services and social innovations – which are tested and applied in a regional setting. As noted, these processes alone are not sufficient for broader societal change. They need to be embedded in favourable conditions that we refer to as "transformative regionally embedded innovation policy" (TrIP).

TrIP is defined as the ensemble of actions that make RIS processes more likely, orchestrate and strengthen them, align them to shared trajectories, and enable scaling and roll-out. Key functions include articulating cross-sectoral goals and visions ("red threads") that help to orient decentralised developments and – if also coated with political legitimacy – provides important "backing" for regional actors to foster the the importance of change. Since attempts for transformative change goes hand in hand with uncertainty and experimenting with alternative practices, TrIP is also to provides "enabling spaces" for experimentation, e.g. with suitable legal framework in funding schemes. and providing time and capacity for adjustment. Without

targeted measures to unlock path dependencies and support unlearning, new solutions may merely coexist with the old or fade out. Finally, learning is linked to adaptive framework-making, including second-order learning loops that translate experiences into supportive structures and revised rules.

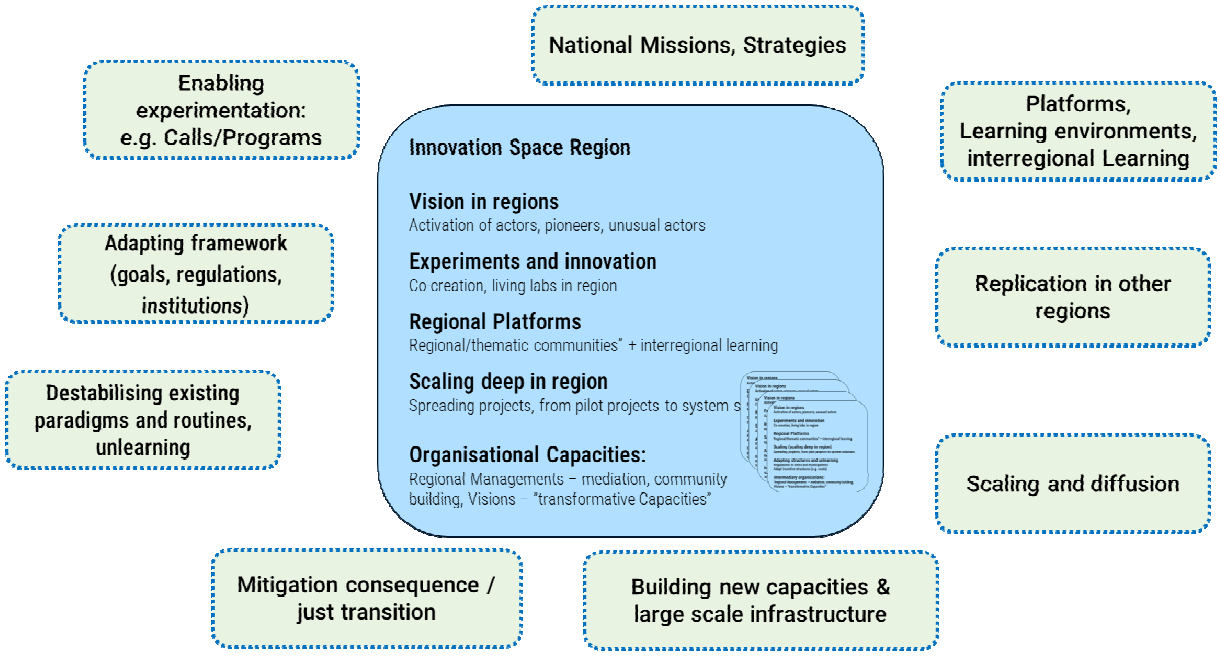


Fig. 2: Regions and Transformation embedded. Source: own illustration

3.1.4 Holzwelt Murau – RIS fostering energy transition

The Holzwelt Murau case demonstrates how an "embedded place-based" regional innovation system (RIS) can contribute to transformative change. The region's development cannot be considered a geographically and systemically isolated success story, but as an evolving constellation of actors, intermediaries, strategies and experiments that remains coupled to supra-regional goals, support schemes and knowledge relations.

A long-term trajectory emerged in the 1990s when regional actors recognised that wood could be leveraged for economic renewal and sustainability. Early projects focused on sustainable forest use, timber construction and biomass. In 2002, a broad participatory strategy process ("Energievision Murau") formulated a shared future image with a then visionary target: regional energy autonomy by 2030. This strategic framing created directionality, enabled coordinated project portfolios and helped stabilise commitment across sectors.

Capacity building can be considered as the decisive mechanism. From 2012, Holzwelt Murau established a Climate and Energy Model Region (KEM) and later a Climate Adaptation Model Region (KLAR!), strengthening professional coordination and interfaces to national instruments. The case underlines the role of intermediaries, dense networks and clear regional governance. Co-creation formats connected pioneers, firms, multipliers and municipalities, while broad communication, energy counselling and participation formats (e.g., energy camps) made benefits visible and addressed resistance.

A pivotal step towards system integration was the establishment of a regional "Reallabor". It enables experimentation with energy load-distribution models, produces demonstrators and supports cross-sector integration. Partnerships – including with Energie Steiermark – are providing an enabling environment for start-ups. Participating at the Horizon Europe project REFORMERS (Replication Valley) further institutionalised experimentation, learning and transfer. Reported outcomes indicate substantial material change: Murau produces roughly three times more electricity than it consumes; around three out of four buildings are heated CO_2-neutrally; and about 45 biomass plants are complemented by CHP-based heating plants, small power plants and wind installations. A regional energy cooperative ("Murauer GreenPower") provides an ownership channel for citizens. Surplus electricity is intended to support e-mobility expansion and the positioning of Murau as a testbed.

Multi-level embedding is explicit through reference points such as the National Energy and Climate Plan, Styrian regional development legislation, EU instruments (LEADER, Horizon), and federal resources via the Climate and Energy Fund and the FFG. The case also points to exnovation dynamics – e.g., local installers

deciding early not to install oil fuelled heating system – and to remaining governance gaps, notably the need for stronger regulatory feedback loops and intensified coordination with Land, federal and municipal levels.

3.1.5 Sustainable Logistics 2030+ Lower Austria-Vienna

The City of Vienna, the Province of Lower Austria, and the Chambers of Commerce of Vienna and Lower Austria has initiated the joint cooperation initiative "Sustainable Logistics 2030+ Lower Austria–Vienna". This initiative is part of a broader policy of mobility transition (Mobilitätswende) at national level, and aligns logistics policy with climate, transport and urban development objectives.

The action plan was developed through a comprehensive process in which more the one hundred actions were grouped into 35 measures and eight thematic clusters, supplemented by pilot projects. The focus is on social innovations and adapting framework conditions within the public sector rather than technological innovations.

Learning and experimentation are strongly emphasised through the pilot projects, for which mainly the federal government's support programmes are being utilised. This initiative incorporates systematic feedback loops to ensure that insights and lessons learned from pilot projects are continuously fed back into planning departments and other relevant public authorities, supporting institutional learning and adaptive policymaking.

An interim evaluation (Gruber/Mollay 2024) revealed positive effects on creating an ecosystem and testing and implementing pilot projects and the interaction with public administration. However, it also revealed the limitations of transformative activities based mainly on voluntary activities of the logistic companies.

3.1.6 Lessons learned for the policy approach

In summary, the critical factors and lessons learned from the cases are as follows:

- Activating people: The focus was on co-creation, citizen participation, and joint learning.
- Setting visions: Clear goals, such as achieving energy self-sufficiency, provided orientation and motivation.
- Networked working: Technology, society and the economy were systematically linked.
- Accepting resistance: Critics were actively involved, for example through consultations and concrete opportunities for participation.
- Open dialogue: Exchanging ideas with other regions and programmes strengthened capacity for innovation.
- Long-term approach: Success is based on continuous capacity building over decades.
- Multi-stakeholder and multi-level approach: Transformation can only succeed through the interaction of a wide variety of stakeholders at all levels.
- Transformation intermediaries act as a "facilitating structure". They connect local needs with supra-regional resources, thereby enabling spaces for experimentation, knowledge-building, and system change.

The case of the sustainable logistic initiative also reveals that achieving widespread impact requires either regulatory changes (e.g. a ban on trucks with combustion engines in the city) and/or economic benefits for the partners involved.

4 CONCLUSION

This paper has demonstrated that transformative innovation policy (TIP) requires stronger and more explicit regional integration to realise its potential. Regions are not merely arenas for implementing national or supranational strategies; they are also key sites for experimentation and learning. Therefore, strengthening regional capacities for transformative innovation – including intermediary competencies, participatory governance, and reflexive policymaking – is a central policy challenge.

However, regional experimentation alone is insufficient. Scaling up must be an integral part of transformative policy schemes, connecting local pilot projects with strategic coordination, regulatory adaptation and learning across governance levels.

Transformative change gains momentum when regulatory frameworks and market conditions create joint incentives for stakeholders to invest, innovate, and adapt. Without such embedding, experimental initiatives risk remaining isolated or merely symbolic, rather than contributing to systemic change.

The agility and innovative power of the public sector is decisive. Politics and public administration should evolve from setting frameworks to taking on a proactive role ("entrepreneurial state", Mazzucato (2013)), acting as regulators, moderators, and coordinators.

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Small and Medium Size Cities: Smart, Sustainable, Resilient, Innovative with Best Quality of Life

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1 ABSTRACT

Small and medium-sized cities (SMSCs) are increasingly being recognised as significnt places for managing contemporary urbanisation challenges whilst simultaneously advancing smart, sustainable, resilient and innovative urban development pathways. The researcher investigates whether SMSCs can act as laboratories for transferable urban solutions capable of informing both metropolitan and rural development contexts. Using Alberton, located within the City of Ekurhuleni Metropolitan Municipality in Gauteng Province, South Africa, as a case study, the researcher examines how governance capacity, spatial structure, digitalisation, infrastructure investment and community-based innovation influence quality of life outcomes. A qualitative case study approach is employed, combining policy analysis, spatial planning review and comparative international practice. The findings show that Alberton exhibits magnificent potential to function as an innovation arena due to its scale, institutional proximity to residents, manageable spatial complexity and integration within a metropolitan system. However, institutional fragmentation, infrastructure backlogs and limited local innovation financing pushback the city's transformative capacity. The study concludes that SMSCs such as Alberton represent strategically important platforms for advancing smart and resilient urban solutions that can be scaled upward to metropolitan regions and adapted for smaller towns and rural settlements.

Keywords: urbanisation, cities, small, medium, size

2 INTRODUCTION

Global urbanisation is increasingly characterised by differentiated growth patterns, with a substantial proportion of population expansion occurring outside large metropolitan cores (UN-Habitat, 2022). Small and medium-sized cities (SMSCs) are becoming essential to national urban systems and regional development trajectories, even though megacities still dominate policy discourse (OECD, 2023). Many people believe that SMSCs are more flexible, socially cohesive, and agile than big city governments. This allows them to experiment with new governance models, sustainability initiatives, and smart technology (Batty et al., 2023).

Located in the Ekurhuleni Metropolitan Municipality in South Africa's Gauteng Province, Alberton serves as a typical case.It is historically considered as a residential and industrial town with diverse socio-economic profiles, connectivity to larger cities and ongoing infrastructure and sustainability challenges. Alberton is a town with a population of around 121,000, based on the 2011 census, and is likely larger today due to population growth.

3 BACKGROUND

Recent urban policy literature has shifted towards polycentric development and place-based innovation strategies, recognising that urban sustainability cannot be achieved through large cities alone (Harrison et al., 2023).SMSCs are a key phenomenon on the progresss of sustainable urbanization. With relatively lower development costs, less traffic, and better service accessibility, SMSCs serve as important intermediaries that connect rural economies with metropolitan systems (Rodríguez-Pose and Griffiths, 2022).The strategies for smart cities have also changed from being technology-centered to being governance- and citizen-oriented frameworks that emphasize environmental sustainability, data-enabled decision-making, and innovative service delivery (Yigitcanlar et al., 2023). For SMSCs, these strategies are often more feasible due to smaller administrative scale and closer institutional proximity to communities (Meijer and Bolívar, 2023).

South Africa offers a special setting for SMSCs to serve as platforms for change because of the country's ongoing spatial inequality, infrastructure deficiencies, and institutional capacity limitations (Turok and Visagie, 2023). South Africa, which has the most unequal society in the world (World Bank, 2022), is still dealing with the effects of apartheid, which prevented the black population from advancing and developing. In order to address these injustices in a sustainable way, a concerted effort is being made. SMSCs have the

power to promote equitable and inclusive sustainable development for all citizens. Notably, Alberton offers a bright chance to fulfill this promise.

3.1 Rationale of the Study

Few empirical studies have been conducted on the practical application of SMSCs in the Global South as innovation hubs that can produce scalable urban solutions (Pieterse et al., 2023). Most studies on smart and resilient cities tend to focus on large metropolitan areas. By analyzing Alberton's ability to carry out integrated smart, sustainable, and resilient development interventions that enhance quality of life and offer transferable policy lessons, this study fills this gap.

3.2 Scope of the Study

The study leverages both spatial and conceptual scopes to deepen the analysis.

3.2.1 Spatial scope

The research focuses on Alberton and its functional integration within the broader Ekurhuleni metropolitan region.

3.2.2 Conceptual scope

The study focuses on four interlinked dimensions:

- smart governance and digital innovation,
- environmental sustainability,
- urban resilience,
- quality of life and social inclusion.

3.2.3 Temporal scope

The analysis focuses on policy and planning frameworks between 2022 and 2026.

4 CONCEPTUAL AND THEORETICAL FRAMEWORK

4.1 Small and Medium-Sized Cities

SMSCs are typically characterised by moderate population size, limited institutional layering, and closer governance-citizen relationships (OECD, 2023). These characteristics create favourable conditions for policy experimentation, collaborative governance and rapid institutional learning (Rodríguez-Pose and Wilkie, 2023).

4.2 Smart and Innovative Cities

Contemporary smart city theory emphasises human-centred digitalisation, institutional innovation and data-driven governance rather than technological determinism (Yigitcanlar et al., 2023). For SMSCs, innovation is frequently organisational and social rather than purely technological (Meijer and Bolívar, 2023).

4.3 Sustainable Urban Development

Sustainable urban development integrates environmental protection, economic vitality and social equity (UN-Habitat, 2022). In SMSCs, sustainability pathways are often closely linked to compact urban form, local economic diversification and integrated infrastructure provision (Sharifi and Allam, 2023).

4.4 Urban Resilience

Urban resilience theory emphasises adaptive governance, institutional learning and infrastructure robustness (Meerow and Stults, 2023). Smaller cities may display higher adaptive capacity due to reduced institutional fragmentation and more coherent stakeholder networks.

4.5 Spatial Justice and Quality of Life

Quality of life is shaped by spatial access to services, mobility, public space and economic opportunities (Marans and Stimson, 2022). Spatial justice theory highlights how planning systems either reproduce or mitigate socio-spatial inequalities (Turok and Visagie, 2023).

5 POLICY AND INSTITUTIONAL FRAMEWORK

At national level, South Africa's urban development agenda is framed by integrated planning, climate resilience and infrastructure-led development (DFFE, 2022; National Treasury, 2023). The District Development Model further seeks to enhance intergovernmental coordination and local innovation (COGTA, 2023).

At metropolitan level, Ekurhuleni's growth and development strategies prioritise:

- digital transformation of municipal services,
- economic diversification,
- infrastructure resilience,
- spatial integration (City of Ekurhuleni, 2023).

However, explicit recognition of SMSCs as innovation platforms remains underdeveloped in current policy.

4. RESEARCH METHODOLOGY

A qualitative case study approach was adopted. Data sources included:

- municipal and national policy documents,
- spatial development frameworks,
- secondary academic literature.

Thematic analysis was used to examine how Alberton's governance, spatial structure and infrastructure systems support or constrain innovation, sustainability and resilience (Braun and Clarke, 2022).

6 INTERNATIONAL AND COMPARATIVE PRACTICES

International experience demonstrates that SMSCs can function as effective innovation arenas when supported by strong multilevel governance and local experimentation mechanisms. Nowaczyk et al. (2022) argue that small- and medium-sized smart cities have unique innovation potentials and provide multiple documented case examples of smart governance, mobility, environment, and economy applications tailored to SMC contexts,highlighting that innovation isn't exclusive to large metropolises.In Europe, small cities have pioneered open data platforms, participatory budgeting and low-carbon mobility pilots that were later adopted by metropolitan governments (OECD, 2023). Small and medium-sized cities (SMSCs) worldwide have emerged as innovative arenas addressing socio-economic challenges through locally embedded and mission-oriented strategies, as illustrated by Japanese cities such as Kitakyushu, Hamamatsu and Aizuwakamatsu, which demonstrate place-based smart-city missions centred on energy transitions, digital experimentation and strong citizen and stakeholder collaboration (Kitagawa, 2025). In the United States, Vallejo has implemented participatory budgeting as a governance innovation to improve transparency, civic engagement and trust in local public finance, and is frequently cited in the academic literature on participatory and deliberative local governance in North America (Spada and Ryan, 2017). Similarly, Porto Alegre represents one of the most established and influential global models of participatory budgeting, widely recognised for deepening democratic participation and reshaping municipal decision-making processes (Wampler and Avritzer, 2004). In Brazil, Presidente Prudente introduced a municipal innovation law aimed at supporting start-ups, strengthening university–industry collaboration and enabling applied research at the local level, reflecting the localisation of Brazil's broader innovation policy framework (Di Giorgio, 2009). In Switzerland, Aarau has piloted data-driven and participatory policymaking approaches designed to enhance the legitimacy and effectiveness of public decisions by combining digital tools with citizen engagement (Wellings et al., 2023). Iloilo City has adopted smart urban systems, including free public Wi-Fi and technology-supported flood-risk management, as part of a broader sustainability and community-oriented urban development strategy aligned with national and international smart-city frameworks (World Bank, 2024). Asian SMSCs have demonstrated how digital infrastructure and public-

private partnerships can accelerate service delivery innovation (Yigitcanlar et al., 2023). Across contexts, the most successful SMSCs display:

- institutional autonomy,
- stable innovation funding,
- integrated spatial and digital planning,
- community-driven innovation ecosystems (Sharifi and Allam, 2023).

The table below showcases SMSCs practical examples of implementation of mechanisms to propel sustainability.

Initiaves	**City Examples and reference types**
Institutional autonomy	Cities with innovation laws (*Presidente Prudente*); Japanese MOIP cases (Kitakyushu, Hamamatsu, Aizuwakamatsu)
Stable Innovation funding	*Presidente Prudente* Innovation Fund; participatory budgeting frameworks
Integrated spatial and digital planning	Adopted in Aarau, Iloilo City digital services and public infrastructure
Community-driven ecosystems	Vallejo & Porto Alegre participatory budgeting; Japanese citizen platforms; Iloilo e-mobility and environmental management

Table 1: Examples of SMSCs initaitives for effective innovations. Source: author, 2026.

7 THE ALBERTON CASE STUDY

7.1 Urban and Institutional Context

Alberton operates within a metropolitan governance structure while retaining a distinct urban identity and locally specific development priorities, a configuration that is widely recognised in the literature on metropolitan governance and secondary-city positioning as enabling both policy coordination and place-based responsiveness (OECD, 2023; UN-Habitat, 2022). Its urban form, characterised by compact residential neighbourhoods, local commercial nodes and relatively strong functional connectivity to regional employment centres, reflects patterns typically associated with small and medium-sized cities embedded in large metropolitan regions (OECD, 2023).

7.2 Smart and Innovative Practices

The digitalisation of municipal services, the introduction of online development application systems and the emergence of local data platforms indicate incremental progress towards smart governance, consistent with the international shift towards digitally enabled local public administration in small and medium-sized cities (World Bank, 2023; UN-Habitat, 2022). However, the limited presence of local innovation laboratories and relatively weak collaboration with universities and start-ups constrain the depth of Alberton's innovation ecosystem, reflecting well-documented institutional and organisational barriers faced by smaller municipalities in developing sustained urban innovation capacity (OECD, 2023; Caragliu and Del Bo, 2023).

7.3 Sustainability and Environmental Management

Environmental sustainability initiatives in Alberton currently focus primarily on waste management, energy-efficiency retrofitting of public assets and limited public transport improvements, which align with the early-stage sustainability pathways commonly observed in small and medium-sized cities (UN-Habitat, 2022; World Bank, 2023). Nevertheless, comprehensive low-carbon and climate-neutral urban strategies remain underdeveloped at the sub-city scale, a challenge that is widely attributed to constrained technical capacity, fragmented governance and limited access to climate finance in secondary and peripheral urban areas (OECD, 2023; UN-Habitat, 2023).

7.4 Urban Resilience

Infrastructure resilience remains a critical challenge in Alberton, particularly in relation to electricity reliability, stormwater management and road maintenance, reflecting broader infrastructural vulnerabilities in rapidly urbanising metropolitan regions in the Global South (World Bank, 2022; UN-Habitat, 2023). Although institutional capacity for integrating climate risk into spatial planning is emerging, this integration is not yet systematically embedded across planning and infrastructure investment processes, a limitation widely identified in urban resilience and climate adaptation research for small and medium-sized municipalities (OECD, 2023; Meerow and Newell, 2023).

7.5 Quality of Life and Social Inclusion

Alberton benefits from comparatively good access to basic services and public amenities, which is consistent with evidence that metropolitan-adjacent small cities often outperform more remote settlements in service provision (UN-Habitat, 2022). However, persistent spatial inequalities between established suburbs and lower-income peripheral areas continue to shape uneven access to public space, mobility and urban opportunities, reflecting entrenched patterns of socio-spatial fragmentation in South African and other highly unequal urban systems (Turok and Visagie, 2023; UN-Habitat, 2022). Limited public space upgrading and uneven public transport coverage further constrain inclusive quality-of-life improvements, particularly for low-income households and youth (OECD, 2023).

7.6 Alberton as an Innovation Arena

The analysis indicates that Alberton's scale, administrative accessibility and manageable spatial complexity create favourable conditions for piloting digital service innovations, community-based infrastructure monitoring, small-scale renewable energy solutions and local mobility experiments, which correspond closely with the types of low-risk, place-based urban innovation initiatives recommended for small and medium-sized cities in the international policy and academic literature (OECD, 2023; Caragliu and Del Bo, 2023; UN-Habitat, 2022). These characteristics position Alberton as a viable and transferable innovation platform capable of generating solutions relevant to larger metropolitan systems as well as to smaller towns and rural service centres, thereby reinforcing the strategic role of small and medium-sized cities as experimentation arenas within multi-level urban governance systems (OECD, 2023; World Bank, 2023).

8 FINDINGS AND RECOMMENDATIONS

8.1 Key Findings

The study finds that Alberton demonstrates strong potential to function as a smart, sustainable and resilient innovation arena due to:

- reduced institutional complexity,
- proximity between decision-makers and communities,
- embeddedness within a metropolitan infrastructure system.

However, this potential is constrained by:

- limited innovation financing,
- insufficient cross-sector partnerships,
- weak spatial integration of resilience and smart city strategies.

8.2 Policy and Planning Recommendations

(1) Institutional innovation platforms

Establish a local urban innovation hub linking municipal departments, universities and private sector partners.There is a tremendous need for Alberton to construct local urban innovation centers which link with critical institutions such as banks and universities to equip its populace.By involving small businesses, community organizations, and urban planners in the co-development of place-based solutions, SMSCs such as Alberton can foster local innovation ecosystems. Support for small businesses and local economic initiatives promote social inclusion and create a variety of job opportunities, which is in line with the larger SDG 11 objectives for sustainable urbanization.

(2) Integrated smart and resilience planning

Embed digital infrastructure and climate resilience measures explicitly within local spatial development frameworks.The Ekurhuleni Metropolitan Municipality should cordinate and oversee the integration of smart and resilience planning as per the Spluma framework.There is need for active participation in spatial development that collaborates with digital infrastructure and climate resilience measures.

(3) Targeted pilot projects

Use Alberton as a demonstration site for renewable micro-grids, data-enabled service delivery and inclusive public space regeneration.The town planners of Alberton should engage with the governement and private sector to assist in the provision of renewable energy infrastruture as the nation faces loadshedding.

(4) Knowledge transfer mechanisms

Establish formal intermunicipal learning platforms to help successful projects scale up and out to both urban and rural settings. The formalization of intermunicipal learning platforms empowers SMSC administrators by providing them with all the knowledge they need to manage a town or city sustainably. This also helps with accountability.

8.3 Contribution of the Study

This study shows that SMSCs can serve as strategic and useful spaces for urban innovation in the Global South. Within national urban systems, Alberton provides examples of how intermediate-scale cities can serve as a link between experimentation and the diffusion of large-scale policies. Alberton is an excellent illustration of how SMSCs can promote wise and sustainable development that benefits its residents if they are given the required resources. Town planners and other urban place stakeholders should use Alberton as a model for how to use resources to establish SMSCs that act as hubs within a nation's larger urbanization framework. This study can be used to support the sustainable development of SMSCs by town planners and other researchers, especially in the Global South.

8.4 Conclusion

To conclude, I am reminded of Wildavsky's observation regarding implementation.If planning is everything, maybe it is nothing (Wildavsky, 1973). If the SMSC concepts are fully implemented, sustainability will undoubtedly be achieved, and equitable living conditions will flourish not only in the Global South but worldwide. There is a greater need for action and implementation rather than excessive planning.

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Solution Paths – Paving the Way to Mobility as a Service by Analysing the Attitudes, Acceptance, and Barriers to the Use of On-Demand Mobility Services in East Styria, Austria

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1 ABSTRACT

Background & Aim: Although public transport and active mobility are increasingly common in urban areas, private cars remain the dominant mode of transport in most rural areas. Although many regions offer public transportation, including some micro-transit or sharing services, their potential is not yet being fully exploited. The project "Lösungswege" (Solution Paths) recognizes the potential of rural areas and small towns as a major lever for driving sustainable transformation in the mobility sector and eliminating inequalities caused by poor mobility. It aims to understand the mobility needs of people in the region and identifies the obstacles that prevent them from using existing public services. The wishes and visions of the local population are taken into account in order to build a digital platform that ist tailored to the users' needs and offers Mobility-as-a-Service in Eastern Styria.

Methods: Within the project two group workshops in differet municipalitites were conducted with 35 participants in total. Methods such as self-reflection, perspective shifts and design-thinking were used to analyze personal mobility needs and the needs of certain groups such as older people with mobility restrictions. Based on that participants (further) developed existing and new mobility solutions. A complementary quantiative survey among 557 participants analyzed the mobility habits, needs, acceptance of and barriers for the use of micro transit and sharing services in East Styria.

Results: The workshops revealed, that most people would like to see cars become less important. Nevertheless, it is clear that the existing public mobility services need to become more flexible and reliable, as they are currently often perceived as impractical and difficult to integrate into everyday routines. Participants' ideas to promote the use of existing offers included, for example, expanding the validity of annual public transport tickets for the use of micro-transit and sharing, introducing autonomous vehicles in the area, or charging shared electric vehicles with solar power. The survey results confirmed that private cars are perceived considerably more flexible and comfortable by the citizens than public transport. Many participants cite pricing, limited availability nearby as well as complicated reservation and booking processes as dominant barriers. Nevertheless almost half of the participants can imagine using micro-transit and sharing services more frequently in the future. As motivation factors free test rides or closer facilities were mentioned.

Conclusions: The collected data provides valuable insights about mobility needs and requirements that a platform for booking various mobility services must meet. Thus it forms the basis for the successful introduction of MaaS in Eastern Styria, which suits the needs of all (potential) users, including vulnerable groups.

Keywords: shared mobility, on-demand, mobility-as-a-service, sustainable mobility, micro-transit

2 BACKGROUND

2.1 Mobility in rural areas in Austria

Due to advancing climate change, Austria has set itself ambitious goals as part of the "Green Deal," with the long-term aim of achieving a climate-resilient and climate-neutral society (Bundesministerium für Land- und Forstwirtschaft, Klima- und Umweltschutz, Regionen und Wasserwirtschaft, 2026). The transportation sector is a important lever for this. While the level of motorization in Austria's urban centers increased only slightly or even declined between 2005 and 2018, the level of motorization in peripheral areas of Austria increased significantly. Similarly, a significantly higher number of annual kilometers traveled by car is evident in rural regions of Austria than in urban centers, which highlights the potential of rural regions in terms of mobility transition and reduction of emissions (VCÖ, 2019). According to Poltimäe et al. (2022) this car depencence in rural areas is mainly due to longer distances and poor public transport coverage.

2.2 Mobility poverty and equitable mobility

The observed car dependence in rural areas can lead to transportation poverty, especially when people have limited or no access to a private car due to financial constraints, physical limitations (e.g. impairments), or age for instance (Mattioli, 2016; Rangel Guevara, 2024). This can lead to unequal opportunities and social exclusion. According to Ringhofer et al. (2025) sharing and micro transit could counteract that, but the acceptance and usage has to be given.

2.3 Mobility services in the project region East Styria

The project region is located northeast of Graz, the capital of Styria and Austria's second largest city. In smaller cities like Weiz, Hartberg, Gleisdorf and Fürstenfeld the public transport coverage is partly classified as very good. However, many villages in between have basic access or even no access to public transport at all (Land Steiermark, 2026). Therefore, there are various micro-transit and sharing services available in the region, which are intended to supplement the existing, but in some cases insufficient, public transport system. SAM for instance is a shared taxi, which has several predetermined stops in the project region, East Styria. During the operating hours it runs on-demand and can be booked via telephone hotline and the SAM Webapp (Tourismusverband Oststeiermark, 2026). Additionally, there is WASTI, which is also a shared taxi, operating according to the same principle, but only in the area of Weiz. Weiz furthermore offers E-Carsharing and (E-) Bikesharing (Stadtgemeinde Weiz, 2026).

2.4 Aim of the study

However, the question arises as to whether and how regularly these services are used, how well they are accepted in the region, and what barriers prevent the use of public transport, micro-transit and sharing services. In addition, it should be examined how the booking processes are currently perceived and what wishes there are in the region with regard to ease of use, low effort, and accessibility for all when booking mobility services. Future visions for mobility in the region from the perspective of citizens should also be taken into account.

3 METHODS

3.1 Workshops

Two workshops with citizens from East Styria were conducted. The aim was to generate a heterogeneous group of citizens aged 12 to 85, users and non-users of regional mobility services and people with as well as without disabilities. Therefore, convenience sampling was used at first. Building on that, social organizations, schools and other local facilities were contacted to complement the group especially with younger people, that were underrepresented in the sample so far (Nagele, 2026).

One of the workshops was held in Weiz, which took three hours and the second one was held in Hartberg and took around two and a half hours. In total 35 citizens participated in the workshops. 15 identified as female and 20 as male. 74.29% of the sample have a driver's license. 2 participants indicated to have an impairment that limits their mobility (Nagele, 2026).

The procedure of the workshops was as follows:

(1) Activating interventions to get to know each other

(2) Presentation of the results of the previously completed mobility diaries from the participants to reflect on own mobility patters.

(3) Definition of central mobility terms to ensure a common and uniform understanding.

(4) Brainstorming to different questions and documentation of the ideas on a bulletin board (e.g. where would on-demand mobility services be meaningfully applicable? What would foster or hinder the use of those services?)

(5) Perspective shift exercise in small groups: Putting onesef temporarily in the perspective of an older person with mobility impairments, a young person, a comfortable and an economical person. The task was developing the requirements or needs of those groups regarding mobility services and obstacles that they face.

(6) Collection of measures to meet the needs of all citizens with regard to different focus points like adaptability, rural barriers, costs or booking (e.g. how could existing services be improved so that they are used more frequently? Are existing services suitable for vulnerable groups? Which barriers for the use of micro-transit need to be overcome in rural areas?)

(7) Formulation of requests to companies and politicians as well as long-term and short-term visions. (e.g. how could shared mobility in the region look in the near future? Which framework conditions are necessary?)

The audio of the workshops was recorded and the documented results on flipcharts and bulletin boards were collected for later digitalization. With the help of MAXQDA and the reflexive thematic analysis according to Braun and Clarke (2024) the qualitative data was structured, categorized and analyzed (Nagele, 2026).

3.2 Quantiative Survey

The quantitative questionnaire is based in part on standardized questions about socioeconomic status and vulnerability from the Austrian ministry for innovation, mobility and infrastrucure (BMIMI, 2011) and Schasché's (2024) UTAUT model for user acceptance.

The questions cover the general mobility behavior, satisfaction with and attitude towards public transport, micro-transit and sharing as well as the barriers for using such services. It also addresses the question of what needs to change in order for the services to be used more, and how residents would like to book these services.

The survey was spread online (e.g. Social Media), but there was also the possibility to fill it in on paper. To this end, senior citizens' facilities and farmers' markets for instance were specifically visited in order to enable older residents of the region to participate.

There was a total of 925 responses. After adjusting for surveys that were terminated prematurely and adjusting for individuals who neither lived nor worked in the project region, 557 completed questionnaires remained and were included in the analysis.

The data analysis was conducted using SPSS.

4 RESULTS

4.1 Workshops

4.1.1 Mobility behavior, mobility decisions, and satisfaction with different modes of transportation

Almost 50% of the participants use the private car for commuting (e.g. to work, school, shopping or appointments). 20% use active transport (e.g. walking, (E-)cycling) and also 20% use a combination of active public and private transport. Only 11% stated that they mainly commute by public transport.

Investigating the attitudes toward various modes of transportation revealed that participants see many advantages to private cars (e.g., time, effort, flexibility, safety, reliability, weather dependence). Only in terms of environmental friendliness did private cars score poorly. Active mobility is also perceived as advantageous, except for the factors of safety, weather dependency, and transporting objects.

Combined mobility was generally viewed rather critically. This form of mobility is rated significantly lower than the others, especially in terms of reliability and time required.

Participants mainly chose the private car due to convenience, flexibility, habit, transportation of luggage and reliability. Active mobility on the other hand is mainly chosen due to habit, environmental friendliness and convenience.

4.1.2 Mobility needs, obstacles and chances and the attitudes toward alternatives to private cars

The participants describe very individual mobility needs, that are shaped by their daily routines and life situations. The workshops highlited the desire for better conntections: “Connections must be better coordinated, otherwise waiting times are unrealistic”. As barriers they also name the lack of reliability and punctuality as well as the limited operating hours. Especially for elderly they point out the booking of mobility services via app or website as obstacle. For younger people mobility services that provide a safe ride to festivities, music and sports clubs would be relevant.

For younger people, who want to be independent from their parents, shared student taxis could also be a suitable alternative to parent taxis for the last mile. Participants also see a chance to arrive relaxed at work through the use of public transport and point out the potential of expanding existing Bike-Sharing services to more regions in East Styria.

The use of transportation services like public transport and micro transit is strongly connected with social norms, emotions and cultural attributions, as the workshops showed. Although those mobility services are perceived practical for rides to the doctor, for students and for seniors, they are also often considered uncool or annoying and stressful due to delays and waiting times. On the one hand participants see the potential that those mobility services can improve life quality and reduce loneliness, but not for themselves, but primarily for people with disabilities (“bus travel is only for people with impairments”). Social norms or values such as environmental awareness can nevertheless be a driving force and a motivation to forego buying another car and using alternatives instead.

4.1.3 Technical and digital accessibility

During the workshop, participants emphasized that there is a need for a uniform, lucid and user-friendly app that makes it easy to book all mobility services. Nevertheless, there is also a need for offline-booking options. Limited network coverage and user-friendliness for senior citizens, for example, require the option of booking by telephone and the availability of various payment options.

4.1.4 Governance, politics and cooperations

Participants pointed out that politics and companies need to be more involved and act in concert. Push and pull factors against cars, such as fewer parking spaces at companies, financial incentives for active and public mobility, or better public transport connections to large employers in the region, are considered sensible measures, for example.

4.1.5 Marketing and future visions

It became clear that SM offerings in Eastern Styria can only be successful if they are communicated in a more visible, attractive, and understandable way. Implementation ideas include campaigns such as car fasting and information events that alleviate fears about sharing one's own car. Future visions for the region reach from a comprehensive sharing network and sharing within neighborhoods to the integration of all mobility services into the “Klimaticket” (annual national/regional public transport ticket) to the introduction of electric autonomous vehicles. Generally, participants would like to see private cars become less important in the future.

4.2 Quantitative Survey

4.2.1 Demographic characteristics

The survey included 557 participants living or working in the region. 91.56% conducted the survey online and around 9% on paper. The participants were aged 14 to 93 years (mean: 42 years). 50.45% identify as female, 48.11 as male and 1.44% in total identify as diverse or did not specify. Most people live in rural areas (61.22%) and 38.78% live in smaller cities like Weiz, Hartberg, Fürstenfeld, Gleisdorf or even in Graz

(but work in East Styria). 7.25% of the participants indicated to have an impairment (hearing. Seeing, walking or others) that influences their mobility. In terms of mobility, they are mainly dependent on other people, public transport or micro-transit.

4.2.2 Mobility behavior and dependence

For all considered routes (commuting to work, shopping, passenger transport and leisure time) the car is the most used means of transport. More than 54% mainly commute to work by car for example, whereas only 26.39% mainly use public transport and 15.74% use micro mobility (walking, (E-)Bike, (E-)Scooter). Other options like taxis, motorcycles, micro-transit and sharing are rarely used (less than 5% in total) (n = 451). Most of them commute 11-30min to work (n = 453). Participants living in rural areas have a longer commute than participants living in more urban areas.

Over 80% have a driver's license (n = 552) and 76% indicated that they have a private car. Around 6% partly have access to a private car. 32.49% of the participants drive more than 15,000km per year (n = 477). This share is higher among male (41.77%) participants than among female (22.32%) and higher among people living in rural areas (37.24%) than in cities (n = 25.13%).

4.2.3 Awareness and use of micro-transit and sharing

When asked about the frequency of use of various mobility services, over 30% stated that they were unaware of Wasti, WeizBike, CarsharingWeiz and other micro-transit and bike-/carsharing services. However, only 8% did not know SAM (n = 543). From the aroung 92%, who know SAM, about 76% indicated that they never use it. Generally, only 26.82% of the sample use micro-transit (n = 548) and 16.95% use sharing services n = 547). 38.75% use at least one micro-transit or sharing service (n = 542). Older participants (above 65 years), participants living in urban areas and participants with disabilities rather use micro-transit or sharing than younger participants, from rural areas and without disabilities.

But 46.34% indicate that they could imagine using micro-transit (more frequently). This willingness is lower in the younges age group (14-18 years) than among participants older than 18 years and lower among male than among female participants. Especially participants who are already using micro-transit are considerably more willing to use it more frequently.

4.2.4 Mobility needs, barriers and motivations

60% state that they feel that their mobility needs are at least rather taken into account. 40% (rather) disagree. People living in urban areas and with disabilities rather agree with that than people in rural areas and without disabilities. Users of different mobility services (bus, train, SAM, Wasti, other micro-transit services, Weiz Bike, other bikesharing services, Carsharing Weiz and other carsharing services) were asked how satisfied they are with the service. The satisfaction was the highest for Carsharing Weiz (n = 52) and WeizBike (n = 58) and lowest for other micro-transit (n = 45) and bike sharing services (n = 26), SAM (n = 185) and the bus (n = 421). The satistfaction is higher in urban areas and female participants tend to be more satisfied with most services than male participants. People with at least one disability are more satisfied with bus, train, SAM, Wasti and other micro-transit options, but not with sharing services.

Reasons for their dissatistfaction are for example prices, time effort, limited operation hours, reliability and poor connections.

The main obstacles for the use of micro-transit are costs, the complicated purchase or booking process and the avaibalibity of information (n = 153). For sharing the main barriers include limited availability nearby, the rental costs, complicated reservation, payment and booking processes as well as th availability of information (n = 96).

37.02% stated that they would use micro transit or sharing more often if there would be free test rides. Also information events, sharing locations and micro-trannsit stops nearby are considered as reasonable motivation factors. However, 20.99% indicate, that they would not use micro-transit or sharing despite everything (n = 543).

4.2.5 Booking of mobility services

The survey revealed, that most people would like to book via smartphone app or webapp, but more than 30% count booking via phone-call and more than 7% booking at the municipality to their preferred options (n = 545). Especially older participants (65 and above) and people with impairments prefer those two options.

5 DISCUSSION

The findings of the workshops and survey clearly demonstrate the continued dominance of the private car in Eastern Styria, which is primarily explained by its superior everyday practicality rather than by negative attitudes toward alternative mobility options. Convenience, flexibility, reliability, habit, and the ability to transport goods consistently favor car use.

Despite low actual usage, both the workshops and the survey reveal a considerable openness toward micro-transit and sharing services. A large share of participants would be open to try the services if there were for exanple free test rides or if the services were nearby. This indicates that resistance to sustainable mobility does not stem from general skepticism, but from concrete performance deficits such as poor connections, limited operating hours, high costs, and insufficient distribution.

Social norms and values shape mobility choices in ambivalent ways. While public transport and micro-transit are socially recognized as useful and environmentally beneficial, they are often perceived as unattractive or inconvenient for personal use.

Strong spatial and sociodemographic inequalities persist. Rural residents face higher car dependence and lower satisfaction with public mobility services due to structural constraints, while older adults and people with disabilities rely more on public and micro-transit services but encounter significant digital access barriers. These groups prefer booking personally or via telephone instead of using apps.

The results of this study, as well as the study by Klementschitz et al. (2024), conclude that the use and booking of on-demand transport should be geared towards the needs of customers and be as low-threshold and simple as possible. This means that complete connections with different modes of transport must be bookable via one platform and that there must be barrier-free and non-digital booking options in order to promote the use of the services.

6 CONCLUSIONS

Overall, the results suggest that sustainable mobility in rural regions fails not because of a lack of acceptance, but because alternative services do not yet match the everyday performance of the private car.

However, the results provide valuable insights into the needs of the population and thus offer the opportunity to address barriers in a targeted manner. The participatory workshop approach proved particularly valuable, as it generated solution ideas developed by the population itself rather than imposed top-down, which can enhance acceptance. Overall, the findings indicate that existing mobility services need to be better coordinated and expanded in order to reduce waiting times and improve everyday practicality. In addition, accessible non-digital booking options are essential. Beyond service provision, effective marketing that highlights the benefits of these services for all citizens, as well as close cooperation between political actors and companies, play a decisive role in counteracting car dependency. Based primarily on the workshop results, it can be concluded that many residents would welcome a reduced importance of private cars in the region.

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Teilen ohne Barrieren: Anforderungen und Handlungsspielräume für barrierefreies Carsharing und Mitfahren

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1 ABSTRACT

Die barrierefreie Gestaltung von Mobilitätsangeboten ist eine zentrale Voraussetzung für eine inklusive und sozial gerechte Mobilitätswende. Obwohl Carsharing und Mitfahrangebote in Österreich zunehmend als Bausteine multimodaler Verkehrssysteme etabliert werden, fehlen bislang konkrete Leitlinien zur barrierefreien Ausgestaltung dieser Angebote. Dadurch bleiben wesentliche Anforderungen an physische Zugänglichkeit von Fahrzeugen und Haltepunkten, barrierefreie digitale Buchungs- und Informationssysteme sowie die soziale Nutzbarkeit für diverse Nutzerinnen- und Nutzergruppen weitgehend unzureichend berücksichtigt. Das Paper entwickelt auf Grundlage einer kriterienbasierten Analyse zentrale Anforderungen an barrierefreies Carsharing und Mitfahren. Auf dieser Basis werden zentrale Bedarfe und Ansatzpunkte für die Planung und Umsetzung barrierefreier Sharing-Dienste herausgearbeitet. Damit unterstützt das Paper, Barrierefreiheit als Qualitätskriterium multimodaler Mobilität zu berücksichtigen, und bestehende konzeptionelle sowie regulatorische Lücken gezielt zu adressieren.

Keywords: Inklusive Mobilität, Barrierefreie Verkehrssysteme, Sharing Dienste , Multimodale Mobilitätsstrategien, Mobilitätsgerechtigkeit

2 THEORETISCHER UND KONZEPTIONELLER RAHMEN

Geteilte Mobilitätsangebote wie Carsharing und Mitfahrdienste werden in der verkehrswissenschaftlichen und planerischen Debatte zunehmend als Ergänzung bestehender Verkehrssysteme diskutiert. Ihre Einbindung in nachhaltige Mobilitätsstrategien erfolgt dabei häufig vor dem Hintergrund ihrer digitalen Organisation und ihrer potenziellen Rolle in multimodalen Nutzungskontexten. Empirische Studien weisen jedoch darauf hin, dass die tatsächliche Nutzung dieser Angebote stark selektiv ist und bestehende Mobilitätsungleichheiten potenziell reproduziert oder verstärkt werden können (Dill et al., 2021; Lucas, 2012).

Im Unterschied zum klassischen öffentlichen Verkehr sind Carsharing- und Mitfahrangebote weitgehend digital organisiert und basieren auf appgestützten Buchungs-, Kommunikations- und Bezahlprozessen (Lopes, 2023). Gleichzeitig unterscheiden sie sich deutlich in ihrer institutionellen Ausgestaltung. Während Carsharing-Angebote in der Regel professionell organisiert sind und auf standardisierten Fahrzeugflotten sowie zentral gesteuerten Plattformen beruhen, basieren Mitfahrangebote überwiegend auf privat organisierten Fahrten und direkter Interaktion zwischen Einzelpersonen. Diese unterschiedlichen Systemlogiken beeinflussen maßgeblich, in welchem Umfang Anforderungen an Zugänglichkeit verbindlich umgesetzt und verlässlich abgesichert werden können.

Vor diesem Hintergrund zeigen empirische Befunde, dass zentrale Nutzungshürden geteilter Mobilitätsangebote insbesondere in digitalen Zugangshürden, eingeschränkter physischer Zugänglichkeit von Fahrzeugen und Treffpunkten sowie mangelnder Transparenz der Angebotsinformationen liegen (Dill et al., 2021; Lucas, 2012). Forschung zur digitalen Barrierefreiheit verdeutlicht zudem, dass visuell dominierte Interfaces, fehlende Screenreader-Kompatibilität oder ausschließlich auditive Kommunikationsformen systematische Nutzungshürden erzeugen, insbesondere für Personen mit mobilitätsbezogenen oder sensorischen Anforderungen (Park & Chowdhury, 2022; Lazar et al., 2017). Diese Barrieren sind dabei nicht als individuelle Defizite zu verstehen, sondern als Ergebnis nicht angepasster technischer, organisatorischer und sozialer Systeme (Goralzik et al., 2022; Lucas, 2012).

Aus dieser Perspektive wird Barrierefreiheit im vorliegenden Beitrag als analytisches Konzept verstanden, das funktionale Zugänglichkeit entlang der gesamten Nutzungskette geteilter Mobilitätsangebote adressiert. Sie umfasst den Zugang zu Informationen und Buchungssystemen, die Nutzbarkeit von Fahrzeugen und Treffpunkten sowie die soziale und kommunikative Ausgestaltung der Nutzungssituation und bildet die konzeptionelle Grundlage der nachfolgenden kriterienbasierten Analyse von Carsharing- und Mitfahrangeboten.

3 METHODISCHES VORGEHEN

Die Analyse basiert auf einer literaturbasierten, kriteriengeleiteten Auswertung wissenschaftlicher Studien zu Barrierefreiheit, inklusiver Mobilität und geteilten Mobilitätsformen. Ziel ist die systematische Identifikation funktionaler Anforderungen entlang der Nutzungsphasen von Carsharing- und Mitfahrangeboten. Hierzu werden einschlägige Arbeiten entlang definierter Kriterien analysiert, die digitale, physische und soziale Nutzungssituationen abbilden. Der Fokus liegt auf mobilitätsbezogenen sowie sensorischen Anforderungen im Bereich Sehen und Hören. In einem abschließenden Syntheseschritt werden die identifizierten Anforderungen querschnittlich zusammengeführt und als Mindestanforderungen barrierefreier geteilter Mobilität systematisiert.

3.1 Analyseperspektiven

Die Auswahl der betrachteten Anforderungen orientiert sich an ihrer empirisch belegten Relevanz innerhalb der europäischen Bevölkerung sowie ihrer strukturellen Bedeutung für die Nutzung von Carsharing- und Mitfahrangeboten. Aktuelle europäische Erhebungen zeigen, dass funktionale Einschränkungen einen relevanten Teil der erwachsenen Bevölkerung betreffen und sich insbesondere auf die Alltagsmobilität auswirken (Eurostat, 2025; European Commission, 2025). Besonders häufig betreffen diese die körperliche Mobilität sowie sensorische Voraussetzungen im Bereich Sehen und Hören (Eurostat, 2022). Vor diesem Hintergrund konzentriert sich die Analyse auf mobilitätsbezogene sowie sensorische Voraussetzungen, die im Kontext von Carsharing und Mitfahren besonders wirksam werden. Die Analyseperspektiven dienen dabei nicht der Abgrenzung von Nutzerinnen- und Nutzergruppen, sondern der analytischen Strukturierung von Nutzungshürden, die aus nicht angepassten technischen, digitalen und organisatorischen Rahmenbedingungen resultieren.

3.2 Analysekriterien

Die Ableitung der Analysekriterien orientiert sich an empirischen und konzeptionellen Arbeiten zur inklusiven Mobilität, die Barrieren als Ergebnis von Zugangshürden entlang der Nutzungskette beschreiben. Studien zeigen übereinstimmend, dass Nutzungshürden weniger durch das Fehlen von Angeboten entstehen als durch eingeschränkte Zugänglichkeit, geringe Verständlichkeit digitaler Schnittstellen sowie organisatorische und soziale Unsicherheiten im Nutzungskontext (Lucas, 2012; Velho et al., 2016; Stanley et al., 2010). Entsprechend wird Barrierefreiheit entlang zentraler Nutzungsdimensionen analysiert. Berücksichtigt werden insbesondere:

- der Zugang zu Informationen sowie zu digitalen Buchungs- und Kommunikationssystemen,
- die physische Erreichbarkeit und Nutzbarkeit von Fahrzeugen sowie Halte- und Treffpunkten,
- die organisatorische und soziale Ausgestaltung der Nutzungssituation (Bolz et al., 2022).

Diese Dimensionen sind für Carsharing- und Mitfahrangebote besonders relevant, da beide Angebotsformen weitgehend digital organisiert sind und ein hohes Maß an Selbstständigkeit voraussetzen. Gleichzeitig unterscheiden sie sich deutlich in ihrer institutionellen Ausgestaltung, was sich unmittelbar auf die Umsetzbarkeit und Verlässlichkeit barrierefreier Lösungen auswirkt (Shaheen et al., 2019) und im Rahmen der Analyse systematisch berücksichtigt wird.

4 ANALYSE: BARRIEREFREIE ANFORDERUNGEN AN CARSHARING- UND MITFAHRANGBEOTEN

Aufbauend auf dem theoretischen und methodischen Rahmen werden im Folgenden zentrale Anforderungen an barrierefreie Carsharing- und Mitfahrangebote analysiert. Die Analyse folgt den im vorherigen Kapitel definierten Kriterien

4.1 Anforderungen für Personen mit Mobilitätseinschränkungen

Mobilitätsbezogene Anforderungen erzeugen Barrieren insbesondere im physischen Zugang zu Fahrzeugen, Standorten und konkreten Nutzungssituationen. Im Rahmen der kriterienbasierten Analyse lassen sich diese Anforderungen drei Bereichen zuordnen: der Nutzung von Fahrzeugen, der Erreichbarkeit von Stell- und Treffpunkten sowie der organisatorischen Ausgestaltung unterstützender Nutzungsprozesse.

Ein zentrales Kriterium betrifft die Verfügbarkeit und systematische Einbindung barrierefrei nutzbarer Fahrzeuge. Empirische Studien zeigen übereinstimmend, dass diese ihre Wirkung nur dann entfalten, wenn sie integraler Bestandteil des Angebots sind und ohne zusätzliche organisatorische oder informationelle Hürden buchbar gemacht werden (Delaere et al., 2024; Goralzik et al., 2022; König et al., 2021). Für Carsharing-Angebote bestehen hierfür vergleichsweise große Handlungsspielräume, da Fahrzeugflotten, Buchungssysteme und Informationsangebote zentral organisiert sind und barrierefrei nutzbare Fahrzeuge als regulärer Bestandteil des Angebots integriert werden können.

Praxisbeispiele wie das Carsharing-System tim in Graz, bei dem ein rollstuhlgerechter Transporter regulär Teil der Flotte ist (tim Holding Graz, 2024), oder Stadtmobil Rhein-Neckar mit integrierten rollstuhlgerechten Fahrzeugen (Stadtmobil Rhein-Neckar, 2024) verdeutlichen, dass Barrierefreiheit insbesondere dann wirksam umgesetzt wird, wenn sie frühzeitig als strukturelles Angebotsmerkmal berücksichtigt wird.

Bei Mitfahrangeboten ist eine vergleichbare Angebotssteuerung strukturell nur eingeschränkt möglich, da Fahrzeuge überwiegend von Privatpersonen bereitgestellt werden. Entsprechend verlagert sich der Fokus von der physischen Fahrzeugausstattung auf Transparenz und Verlässlichkeit. Klare Angaben zur Fahrzeugausstattung, realistische Einschätzungen von Einstiegssituationen sowie eine eindeutige Kommunikation vor Fahrtantritt werden zu zentralen Kriterien, um Fehlbuchungen und Nutzungsausschlüsse zu vermeiden (Mitropoulos et al., 2021; Chan & Shaheen, 2012).

Ein weiterer zentraler Anforderungsbereich betrifft die Erreichbarkeit von Stellflächen, Haltepunkten und Trefforten. Für Carsharing-Angebote sind barrierefrei gestaltete Standorte mit stufenlosem Zugang, ausreichenden Bewegungsflächen und einer gut integrierten Umgebung entscheidend für die tatsächliche Nutzbarkeit (Elorduy & Gento, 2025). Mobilitätsstationen fungieren hierbei als kritische Schnittstellen, da sie Übergänge zwischen Verkehrsmitteln organisieren und maßgeblich über Inklusion oder Ausschluss entscheiden (Martinez et al., 2024). Bei Mitfahrangeboten kommt der Gestaltung von Treffpunkten eine besondere Bedeutung zu, da diese häufig situativ gewählt werden und zusätzliche Orientierungs- und Zugangshürden erzeugen. Fehlende Standards stellen hier ein wesentliches Ausschlussmoment dar (Mitropoulos et al., 2021).

Ergänzend gewinnen unterstützende Nutzungsprozesse an Bedeutung. Flexible Zeitlogiken, unterstützendes Verhalten von Fahrerinnen und Fahrern sowie tür-zu-tür-orientierte Angebote erhöhen die Nutzbarkeit geteilter Mobilitätsangebote für Personen mit Mobilitätseinschränkungen signifikant. Während Carsharing-Anbieter solche Prozesse institutionell absichern können, bleibt ihre Verlässlichkeit bei Mitfahrangeboten stärker von individueller Bereitschaft abhängig (Stanley et al., 2019; Velho et al., 2016).

4.2 Anforderungen für Personen mit Sehbeeinträchtigungen

Für Personen mit Sehbeeinträchtigungen entstehen Barrieren vor allem im Zugang zu Informationen, in der Orientierung sowie in der Interaktion mit digitalen Systemen. Die relevanten Anforderungen lassen sich drei Bereichen zuordnen: der barrierefreien Gestaltung digitaler Schnittstellen, der multisensorischen Informationsbereitstellung sowie der Unterstützung bei der Orientierung im Nutzungskontext.

Ein grundlegendes Kriterium ist die barrierefreie Ausgestaltung digitaler Plattformen, da Buchung, Information und Kommunikation bei Carsharing- und Mitfahrangeboten nahezu vollständig digital erfolgen. Studien zur digitalen Zugänglichkeit zeigen, dass fehlende Screenreader-Kompatibilität, visuell dominierte Benutzeroberflächen oder unzureichend strukturierte Inhalte zu systematischen Nutzungsausschlüssen führen, insbesondere für blinde und seheingeschränkte Personen (Park & Chowdhury, 2022; Lazar et al., 2015).

Für Carsharing-Anbieter bestehen vergleichsweise große Handlungsspielräume, da Apps sowie Buchungs- und Informationssysteme zentral entwickelt werden können. Eine an internationalen Standards digitaler Barrierefreiheit orientierte Gestaltung, wie sie etwa durch die Web Content Accessibility Guidelines konkretisiert wird, zielt darauf ab, digitale Nutzungsschritte unabhängig von sensorischen, motorischen oder kognitiven Einschränkungen zugänglich zu machen (World Wide Web Consortium, 2023). Mit dem European Accessibility Act werden solche Anforderungen zunehmend verbindlich (European Commission, 2025). Bei Mitfahrangeboten hängt ihre Wirksamkeit hingegen stärker von der anschließenden Interaktion zwischen Fahrerinnen, Fahrern und Mitfahrenden ab (Velho et al., 2016).

Ein weiterer Anforderungsbereich betrifft die multisensorische Informations- und Feedbackbereitstellung. Informationen dürfen nicht ausschließlich visuell vermittelt werden, sondern müssen durch auditive oder taktile Elemente ergänzt werden, etwa im Buchungsprozess oder bei der Auffindbarkeit von Fahrzeugen und Treffpunkten. Empirische Forschung zeigt, dass akustische Signale, sprachbasierte Navigationshinweise oder taktile Markierungen die selbstständige Nutzung deutlich erleichtern (Brock & Jouffrais, 2015), sofern sie systematisch in die Nutzungsphasen integriert werden (Mwaka et al., 2023).

Schließlich betrifft ein dritter Anforderungsbereich die Unterstützung bei der Orientierung vor Ort. Feste Stationierungsorte, eindeutige Fahrzeugkennzeichnungen und digitale Ortungssysteme erhöhen die Orientierungssicherheit bei Carsharing-Angeboten (Paul & Zöller, 2019; Müller, 2018). Demgegenüber erzeugen flexible Treffpunkte bei Mitfahrangeboten zusätzliche Unsicherheiten, weshalb klare Kommunikationsregeln und redundante Informationsstrukturen besonders relevant sind (Paul & Zöller, 2019).

4.3 Anforderungen für Personen mit Hörbeeinträchtigungen

Für Personen mit Hörbeeinträchtigungen entstehen Barrieren insbesondere in der kommunikativen Ausgestaltung von Carsharing- und Mitfahrangeboten. Die relevanten Anforderungen betreffen die visuelle und textbasierte Informationsbereitstellung, die barrierefreie Gestaltung von Kommunikations- und Supportstrukturen sowie die soziale und organisatorische Ausgestaltung der Nutzungssituation (Goralzik, 2022; Lucas, 2012).

Ein zentrales Kriterium ist die vollständige visuelle und textbasierte Bereitstellung aller nutzungsrelevanten Informationen. Akustisch vermittelte Hinweise, etwa zur Fahrzeugankunft oder zu kurzfristigen Änderungen, müssen durch gleichwertige visuelle Alternativen ergänzt werden. Empirische Untersuchungen zeigen, dass textbasierte Benachrichtigungen, Chatfunktionen und visuelle Statusanzeigen kommunikative Barrieren deutlich reduzieren (UITP & European Network on Independent Living, 2023; Goralzik, 2022). Während Carsharing-Angebote solche Funktionen institutionell absichern können, hängt ihre Wirksamkeit bei Mitfahrangeboten stärker von der Bereitschaft einzelner Fahrerinnen und Fahrer ab.

Ergänzend stellen visuelle Orientierungshilfen ein relevantes Kriterium dar, insbesondere an Abholorten ohne feste Infrastruktur. Deutlich sichtbare Fahrzeugkennzeichnungen und visuelle Identifikationshilfen reduzieren die Abhängigkeit von akustischer Kommunikation und erhöhen die Nutzungssicherheit (Vogelauer & Fürst, 2013).

Ein weiterer Anforderungsbereich betrifft barrierefreie Support- und Notfallstrukturen. Eingeschränkte Kommunikationsmöglichkeiten können das subjektive Sicherheitsgefühl erheblich beeinträchtigen und die Nutzungsbereitschaft reduzieren (Lucas, 2012). Barrierefreie Supportkanäle, die unabhängig von Telefonie nutzbar sind, stellen daher eine grundlegende Voraussetzung für gleichberechtigte Nutzung dar (European Commission, 2022).

Schließlich kommt der Schulung und Sensibilisierung von Fahrerinnen, Fahrern und Servicepersonal eine zentrale Rolle zu. Internationale Leitlinien betonen die Bedeutung klarer Verhaltensregeln und Sensibilisierungsmaßnahmen, um diskriminierende Situationen zu vermeiden und die soziale Nutzbarkeit geteilter Mobilitätsangebote für Personen mit Hörbeeinträchtigungen zu verbessern (European Commission, 2022).

5 SYNTHESE DER ANALYSEERGEBNISSE

Aufbauend auf der kriterienbasierten Analyse werden die identifizierten Anforderungen vergleichend verdichtet und als querschnittliche Mindestanforderungen systematisiert. Tabelle 1 gibt hierzu eine zusammenfassende Übersicht, ordnet die Anforderungen übergeordneten System- und Handlungsfeldern zu und zeigt die unterschiedlichen strukturellen Umsetzungsmöglichkeiten von Carsharing- und Mitfahrangeboten auf.

Die Ergebnisse zeigen, dass sich die Anforderungen in Abhängigkeit von körperlicher Mobilität sowie sensorischen Voraussetzungen im Bereich Sehen und Hören zwar in ihrer konkreten Ausprägung unterscheiden, jedoch wiederholt auf dieselben Phasen der Nutzung von geteilter Mobilität verweisen.

Analysekriterium	Mindestanforderung	Perspektiven	Umsetzung
Digitale Zugangs- und Buchungssysteme	Barrierefreie Apps und Websites nach WCAG 2.1 / EN 301 549	Sehen, Hören, Mobilität	Carsharing: zentral steuerbar; Mitfahren: abhängig von barrierefreier Kommunikation nach Buchung
Informationsbereitstellung	Redundante Informationsformate entlang der Nutzungskette	Sehen, Hören	Carsharing: standardisierbar; Mitfahren: häufig uneinheitlich
Kommunikation	Textbasierte Kommunikation als Alternative zu Telefonie	Hören, Sehen	Carsharing: institutionell absicherbar; Mitfahren: abhängig von individueller Bereitschaft
Fahrzeugzugang und Nutzung	Keine zusätzlichen physischen Barrieren	Mobilität, Sehen	Carsharing: größerer Gestaltungsspielraum; Mitfahren: stark begrenzt
Stell- und Treffpunkte	Barrierefrei erreichbare Stellflächen und Treffpunkte	Mobilität, Sehen	Carsharing: plan- und standardisierbar; Mitfahren: situativ
Transparenz der Angebotsinformationen	Klare Angaben zu Fahrzeugtyp, Ausstattung und Nutzung	Mobilität, Sehen	Carsharing: standardisierbar; Mitfahren: besonders relevant
Assistenz und Unterstützung	Niedrigschwellige Assistenz- und Supportangebote	Mobilität, Sehen, Hören	Carsharing: organisatorisch absicherbar; Mitfahren: überwiegend freiwillig
Organisation und Verantwortung	Klare Zuständigkeiten und Antidiskriminierungsrichtlinien	alle	Carsharing: formalisierbar; Mitfahren: fragmentiert
Sensibilisierung und Schulung	Schulung von Fahrerinnen, Fahrern und Supportpersonal	Mobilität, Sehen, Hören	Carsharing: realistisch umsetzbar; Mitfahren: begrenzt steuerbar
Notfall- und Beschwerdestrukturen	Barrierefreie Notfall- und Feedbackkanäle	Sehen, Hören	Carsharing: institutionell verankerbar; Mitfahren: häufig fehlend

Tabelle 1: Querschnittliche Mindestanforderungen barrierefreier Carsharing- und Mitfahrangebote; Quelle: Eigene Darstellung auf Grundlage der kriterienbasierten Analyse (s. Kap. 4).

Über alle betrachteten Perspektiven hinweg erweisen sich insbesondere der digitale Zugang zu Informationen und Buchungssystemen, die Auffindbarkeit und Erreichbarkeit von Fahrzeugen und Treffpunkten, die Gestaltung der Kommunikation zwischen Nutzerinnen, Nutzern, Anbieterinnen und Anbietern beziehungsweise Fahrerinnen und Fahrern sowie unterstützende organisatorische Rahmenbedingungen als zentral. Diese Elemente wirken als Querschnittsfaktoren, da ihre Ausgestaltung die Nutzbarkeit geteilter Mobilitätsangebote unabhängig von der Art funktionaler Einschränkungen maßgeblich beeinflusst. Wiederkehrend zeigt sich, dass Nutzungshürden weniger aus individuellen Einschränkungen resultieren als aus nicht angepassten technischen, digitalen und organisatorischen Rahmenbedingungen.

Die vergleichende Betrachtung verdeutlicht zugleich systematische Unterschiede in den strukturellen Umsetzungsmöglichkeiten zwischen Carsharing- und Mitfahrangeboten. Carsharing-Angebote sind institutionell organisiert und verfügen über zentral gesteuerte digitale Plattformen, standardisierte Fahrzeugflotten und formalisierte Betriebsprozesse. Dadurch bestehen vergleichsweise große Handlungsspielräume, Barrierefreiheit als strukturelles Angebotsmerkmal zu verankern, etwa durch barrierefreie App-Gestaltung, verbindliche Informationsstandards oder organisatorisch abgesicherte Unterstützungsangebote.

Mitfahrangebote basieren demgegenüber überwiegend auf privat organisierten Fahrten und direkter Interaktion zwischen Einzelpersonen. Barrierefreiheit ist hier weniger durch formale Standards abgesichert und stärker von individueller Kooperationsbereitschaft, informeller Kommunikation und situativen Lösungen abhängig, was die Verlässlichkeit barrierefreier Nutzungsmöglichkeiten mit erhöhten Unsicherheiten verbindet.

Trotz dieser Unterschiede lassen sich Anforderungen identifizieren, die unabhängig von der jeweils betrachteten funktionalen Perspektive als grundlegend einzustufen sind. Diese werden in Tabelle 1 als Mindestanforderungen verstanden, da ihre Nichterfüllung systemübergreifend zu strukturellen Nutzungshürden entlang der gesamten Nutzungskette führt. Dazu zählen insbesondere barrierefreie digitale

Zugangs- und Informationssysteme, redundante Kommunikationsformate, transparente Angaben zu Angebotsbedingungen sowie klar geregelte Zuständigkeiten für Unterstützung und Beschwerde. Implizite Annahmen über Nutzerinnen- und Nutzerkompetenzen, etwa visuelle Orientierung, auditive Kommunikation oder zeitlich flexible Interaktion, erweisen sich dabei als zentrale Ursachen für Mobilitätsausschlüsse.

6 SCHLUSSFOLGERUNGEN

Aufbauend auf den verdichteten Ergebnissen der kriterienbasierten Analyse zeigt sich, dass Barrierefreiheit in Carsharing- und Mitfahrangeboten nicht als nachträgliche Ergänzung einzelner Zielgruppenanforderungen verstanden werden kann. Vielmehr erweist sie sich als querschnittliche Systemqualität, deren Wirksamkeit sich entlang zentraler Elemente der Nutzung entscheidet.

Die Analyse verdeutlicht, dass unterschiedliche funktionale Voraussetzungen zwar zu spezifischen Anforderungen führen, diese jedoch auf weitgehend identische strukturelle Schnittstellen innerhalb der Nutzungskette verweisen. Daraus folgt, dass Barrierefreiheit nicht entlang einzelner Nutzerinnen- und Nutzergruppen, sondern entlang zentraler Systemelemente adressiert werden muss. Insbesondere digitale Zugangs- und Buchungssysteme, die Auffindbarkeit und Erreichbarkeit von Fahrzeugen und Treffpunkten sowie verlässliche Kommunikations- und Unterstützungsstrukturen erweisen sich dabei als zentrale Hebel für eine inklusive Nutzung geteilter Mobilitätsangebote.

Gleichzeitig zeigen sich systematische Unterschiede zwischen Carsharing- und Mitfahrangeboten. Während Carsharing-Angebote aufgrund ihrer institutionellen Organisation über größere Handlungsspielräume verfügen, Barrierefreiheit verbindlich in Plattformdesign, Flottenmanagement und Serviceprozesse zu integrieren, ist sie bei überwiegend privat organisierten Mitfahrangeboten weniger standardisierbar und stärker von Transparenz, Kommunikation und situativer Unterstützungsbereitschaft abhängig.

Die im Beitrag abgeleiteten querschnittlichen Mindestanforderungen lassen sich vor diesem Hintergrund als maßgebliche Faktoren zur strukturellen Verankerung von Barrierefreiheit in geteilten Mobilitätsangeboten verstehen. Die Ergebnisse zeigen, dass barrierefreie digitale Zugangs- und Informationssysteme als verbindliche Mindestanforderung zu verstehen sind, unabhängig von der jeweiligen Angebotsform. Darüber hinaus verdeutlicht die Analyse die Notwendigkeit klarer Vorgaben zu Transparenz, Kommunikation und Zuständigkeiten, um Nutzungssicherheit insbesondere in weniger formalisierten Mitfahrangeboten zu gewährleisten.

Schließlich legen die Befunde nahe, dass Förder- und Regulierungsinstrumente Barrierefreiheit nicht punktuell, sondern systematisch entlang der gesamten Nutzungsphasen adressieren müssen, um strukturelle Nutzungshürden wirksam zu reduzieren. Weiterführende Forschung sollte die identifizierten Mindestanforderungen empirisch validieren und untersuchen, wie unterschiedliche Governance-Ansätze zu ihrer verbindlichen Umsetzung ausgestaltet werden können, insbesondere im Spannungsfeld zwischen institutionell organisierten und privat geprägten Mobilitätsangeboten.

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The Affordability Crisis of Carbon-Intensive Heating: Assessing the Impact of EU ETS-2 on Households in Austria

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1 ABSTRACT

In 2023, the European Union's second Emissions Trading System (EU ETS-2) was launched and is planned to take effect in 2027 (European Union, 2023). This scheme will cover buildings and the road transport sector and represents a critical turning point for housing affordability in Austria. This regulatory shift introduces a market-based carbon pricing mechanism that will cover the building sector, fundamentally altering the cost structure of heating. Under current Austrian legislation (Republic of Austria, 2022), there is no regulation for cost-sharing between landlords and tenants, unlike in neighbouring jurisdictions of Germany. This stands in sharp contrast to the regulatory framework in Germany, where the Kohlendioxidkostenaufteilungsgesetz (BGBl. I S. 2154) has established a tiered liability model. While this German statute forces landlords to assume up to 95% of carbon costs in energy-inefficient buildings to incentivise retrofitting, the Austrian system currently transfers the full financial weight of rising carbon prices directly to tenants. Consequently, the full financial weight of rising carbon prices will be transferred directly to tenants, exacerbating the financial burden on households already struggling with energy costs, unless they are protected by the Social Climate Fund (European Union, 2023).

As energy cost were in the recent past significant rising and contributing significantly to Austria's inflation, the regulatory gap exacerbates the financial burden on households already struggling with energy costs, creating a "double penalty" for low-income tenants, which already reside in buildings with the highest carbon intensity and energy consumption as described in the statistic Austria's report on energy poverty (Statistik Austria, 2024). Since the year of strong inflation in Austria, the cost of living is moving stronger in the concern of the Austrian: 50% of respondents are concerned about how to finance the cost of living in future, and 66% stated that affordable housing plays an important role in their voting decision (FORESIGHT, 2024). These figures emphasise the social significance of affordable housing and illustrate the consequences if housing costs strain households further due to ETS-2, while wages may struggle to keep pace. The aim of this paper is to understand how a potential change in policy from the current Austrian "the tenant pays anyhow for it" to a cost-splitting approach, as in Germany, would affect the critical affordability requirements for renters set by many landlords.

Methodologically, the study combines a comparative legal analysis with a dynamic financial simulation. First, the Austrian legislative framework (NEHG) is contrasted with the German Kohlendioxidkosten-aufteilungsgesetz to define the structural "Liability Gap" between the two jurisdictions. Second, the research performs a longitudinal stress test on a representative sample of Austrian residential listings, stratified by energy efficiency and heating source. By assuming a "lock-in" scenario where a tenant rents an apartment in 2025, the model projects the total cost of occupancy through 2035 under rising EU ETS-2 carbon prices. The core metric analysed is the "Break-Even Wage Growth" – the annual income increase required for a household to maintain housing costs below the critical 40% affordability threshold. The analysis compares this required growth rate against Austria's historical wage inflation, identifying the specific "affordability gap" created by the decoupling of carbon costs from income trends in the area of decarbonising the Austrian housing stock.

Keywords: EU ETS-2, Affordable Housing, Decarbonisation, zero carbon heating, zero carbon cooling

2 INTRODUCTION

The baseline for energy reduction within the European Union is set by the European Green Deal's objective to achieve climate neutrality by 2050. As a result of this target, the "Fit for 55" legislative package was released as the critical policy framework to align EU statutes with the first milestone target of reducing net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. Therefore, energy efficiency is elevated to a "first principle", as set in the Energy Efficiency Directive (European Parliament, 2023), which mandates significant reductions in final energy consumption across all EU member states. This systemic shift is driven by the dual necessity of the urgent need to decarbonise the European economy to mitigate impacts

from climate-related risks, and, on the other hand, the strategic imperative to enhance energy security by reducing reliance on volatile, carbon-intensive energy in international commodity markets (European Commission & Draghi, 2024).A central pillar of the "Fit for 55" strategy is the expansion of the existing carbon pricing system (ETS) to the residential and transport sectors through the establishment of the EU ETS-2 (Directive (EU) 2023/959). By internalising the environmental externalities of fossil heating fuels, the EU creates a market-based incentive for deep renovations and the adoption of carbon-neutral heating technologies. However, as the building sector accounts for approximately 40% of the EU's energy consumption and 36% of its energy-related greenhouse gas emissions, this transition poses a significant challenge to strained housing affordability, as the cost of carbon-intensive heating is expected to rise (Perdana & Vielle, 2026). To address the resulting socio-economic disparities, the package includes also the so called "Social Climate Fund" (SCF), which has the intention to mitigate financial challenges of vulnerable European households, which are expected to be strongly exposed during this transition phase towards the EU's carbon neutrality pathway (European Parliament, 2023) with at least EUR 86.7 billion over the 2026-2032 period. In the context of the Austrian real estate market, these directives necessitate a fundamental reassessment of asset viability, as mandatory efficiency improvements through retrofitting and heating system changes, along with the rising costs of carbon on the other hand, may establish a new economic reality where carbon and energy performance become critical factors in a property's long-term financial and social sustainability.

3 REGULATORY FRAMEWORK

The fundamental change ahead for the Austrian residential market is a shift in heating costs that current national legislation does not address. The European Union's "Fit for 55" package introduces a market-driven carbon pricing system via the EU ETS-2 to incentivise the decarbonisation of the real estate sector. But as of yet, it is not completely clear how sustainable the current cost-sharing framework of the ETS2 scheme in Austria will be, as it shifts the financial decarbonisation liability of rented real estate from the landlord to the tenant. But tenants usually can't control the decarbonisation of the real estate they rent, nor do they receive retrofitting subsidies from European and national funds, funded by EU ETS-2 earnings. These funds shall provide in the EU approximately "EUR 23.7 billion, of which app. EUR 19 billion are earmarked for renovations" (Implementation of ETS2 and the Social Climate Fund, 2025).

Unlike the German regulatory model (CO2KostAufG) (Bundesamt für Justiz, 2022), which implements a tiered liability system, forcing landlords to assume a significant portion of carbon costs in energy-inefficient buildings, Austrian law (Nationalrat, 2022) currently allows for the pass-through of these expenditures to the tenant through their energy bills. As of today, Austrian tenants shall fully be held accountable for the financial impact of their energy and carbon consumption, based on a "Polluter-Pays Principle" (Verursacherprinzip) – therefore, since the implementation of the NEHG, carbon taxes can be found on Austrian energy bills to be paid by tenants and subject to 20% VAT. In comparison, the German CO2KostAufG, since 2023, represents a targeted regulatory intervention designed to resolve the classic "split incentive" problem within the real estate market. Unlike traditional carbon taxes that function merely as consumption surcharges in Austria, the CO2KostAufG introduces a dynamic, ten-level, staged model that allocates carbon costs between landlords and tenants based on a building's specific energy performance. This model calculates the building's carbon intensity in kilograms of CO_2 per square meter of rental space per year. In properties with the highest energy efficiency, defined as emitting less than 12 kilograms of CO_2 per square meter, the tenant continues to bear the full financial weight of the carbon price, as the building's infrastructure is already assumed to be optimised.

However, as the building's efficiency decreases and its carbon footprint grows, the landlord is required to carry an increasing share of the costs. In the least efficient buildings, which emit more than 52 kilograms of CO_2 per square meter, the landlord must carry 95% of the carbon costs, leaving only 5% to the tenant. This framework effectively internalises the climate risk into the landlord's operational expenses, transforming the carbon price into a direct financial incentive for building retrofits and heating system upgrades, as recommended in the recast of the Directive (EU) 2023/1791 (European Parliament, 2023), which refers to the idea of "split incentives". This split incentive addresses "the lack of fair and reasonable distribution of financial obligations and rewards relating to energy efficiency investments among the actors concerned, for

example, the owners and tenants or the different owners of building units, or owners and tenants or different owners of multi-apartment or multi-purpose buildings", as stated under article 2 of the directive.

This economic divergence in Austria is not just a technical issue but also acts as a significant socio-political catalyst. Recent data highlights public concern over rising housing costs; the Volkshilfe Sozialbarometer (Foresight, 2024) shows that 50% of respondents see the overall cost of living as their main worry, and 66% consider affordable housing a key factor in their voting decisions. These figures highlight the political instability connected to the ongoing energy transition, as pressure on affordable housing in Austria continues to rise. Notably, heating problems are increasingly impacting lower-income households and are associated with discussions on income inequality. Additionally, heat waves and rising temperatures increase demand for cooling, particularly in urban areas. Alexandra Wegscheider-Pichler et al.'s findings on existing energy poverty, combined with rising urban thermal stress, suggest that the "tenant-pays-all" policy approach may soon hit a socio-economic limit.

Maintaining a policy that disconnects rising operational costs from landlord investment incentives risks the financial stability of lower- and middle-income households and could undermine the democratic legitimacy of the climate transition for many voters. Furthermore, pressure on Vienna's housing market – driven by a growing population and fewer building permits – will increase difficulties for median- and lower-income households, as rents for new apartments have risen in recent years, especially in Vienna's private rental sector (CBRE Austria, 2025).

4 METHODOLOGY

The rollout of the EU ETS 2 in 2028 marks a significant regulatory change within the "Fit-for-55" initiative. Unlike EU ETS 1, which mainly targets industrial and power sectors sensitive to price fluctuations, EU ETS 2 shifts focus to buildings, road transport, and small industrial facilities. These sectors are known for high marginal abatement costs, path dependencies, and structural market failures. Recent scientific studies (2023–2025) emphasise that market prices are influenced not only by supply and demand but also by the overall European policy environment and technological replacement cycles. The predictability of price trajectories in the EU ETS 2 varies significantly because researchers use different modelling frameworks. Rickels et al. utilise the Computable General Equilibrium model DART to quantify the efficiency gains of EU-wide trading, particularly in the context of the Effort Sharing Regulation (ESR). Conversely, the PRIMES model, utilised by Günther et al. (Günther et al., 2025), provides a high-resolution simulation of technological substitution – such as the adoption of heat pumps and electric vehicles – in response to marginal cost signals. Market-oriented simulations like Bloembergen's EUCPM 2.0 Bloomberg NEF (2025)enhance these projections by accounting for the expectations and hedging actions of fuel distributors, which are expected to lead to significant price premiums during the system's initial stage.

A fundamental consensus emerging in contemporary research is the conceptualisation of the carbon price as a "residual variable" (Günther et al., 2025a). This theory suggests that since the emissions cap remains constant, the equilibrium price is inversely related to the effectiveness of non-priced energy efficiency policies (EPs). For example, strong enforcement of the Energy Performance of Buildings Directive (EPBD) and tight CO2 fleet standards for vehicles decreases the amount of emissions that need to be reduced through price signals. In a "Weak Policy" scenario, the carbon price must bear the brunt of abatement efforts, reaching about € 261/tCO_2 by 2030. In contrast, a "Strong Policy" scenario, with high renovation rates and rapid electrification, could keep the price lower at around € 71/tCO_2.

Wien Energie, the city-owned energy provider (Compass Lexecon, 2026), warns that households relying on fossil gas for heating could face two financial shocks. These stem from fluctuations in energy prices and the ongoing push toward decarbonisation, including a transition from natural gas to biogas. Their research indicates that direct carbon costs might increase from about € 13/MWh in 2026 to over € 50/MWh by 2040. Simultaneously, decreased network usage is expected to quadruple grid fees to above € 130/MWh, raising concerns about the affordability of gas heating. However, this situation could change, as affordability thresholds for residential properties generally limit housing costs to no more than 30% of income.

The well-known "30% Rule" was introduced in 1937 in the US, stemming from the United States National Housing Act of 1937. It states that households should spend no more than 30% of their income on housing costs, which include rent, energy, and operational expenses charges. This guideline continues to be a

benchmark for housing affordability in the US today (Schwartz & Wilson, 2008). Compared to these US standards, European statistics pertain to a certain level. 30% (GSC, 2025)to 40% (Eurostat, 2025).According to Deutsche Bank Research Institute, Vienna's average affordability rate is at 37%. Meanwhile, the OECD reports that rental housing costs for Austrian households nationwide are about 19, 4%, which is slightly below the European average (20, 5%).Furthermore, housing cost overburden rates in Austria have decreased in the private sector from 10, 6% in 2019 to 10, 1% in 2024, and in the subsidised sector from 7, 7% to 5, 8%. (OECD, 2025).The above-mentioned Deutsche Bank Research Institute report highlights that Vienna's utility costs are among the highest globally, ranking 6th in 2025. The report notes that cities like Warsaw, Vienna, and Prague have been significantly affected by Russian gas imports in recent years. In 2020, Vienna's utility expenses were similar to those in London or Hong Kong, implying that energy prices are not the only factor influencing costs. Statistik Austria also reports that Viennese renters pay 5% more than the national average, making it the second-highest in Austria. As a result, it is expected that renters, especially in the private and communal sectors, which dominate Vienna's rental market, generally view their rental costs negatively. (Statistik Austria, 2025).

In this paper's simulation, a random sample of 386 apartment rental ads from the real estate portal "derstandard.at" in Vienna was analysed. These ads were examined for rent, EPC data, and heating type, and their data consistency was checked. Seventeen per cent lacked references to the heating system's energy performance certificate and were discarded. The remaining ads were grouped by heating type (ETS-2 relevant or not). This dataset was used in simulations to assess potential exposure under different carbon pricing scenarios aligned with those of Günther et al.'s ETS-2 scenarios.

These scenarios, driven by strong EU policy implementation, include a "strong" decarbonisation pathway, a "limited", and a "weak" pathway, with ETS-2 prices projected between € 63-279/ton CO_2 in 2028, € 180-418/ton CO_2 in 2035, € 324-522/ton CO_2 in 2040, and approaching € 564/ton CO_2 by 2050. The scenarios set ETS-2 prices per square metre per year, based on each asset's CO_2 intensity per square metre, forming the first price layer. The second layer is defined by the current annual rent per square metre, including service charges and VAT, which increases by 2% annually, aligning with the ECB's target inflation rate. Merging these layers yields a future rent series until 2040, indicating tenants' future rental burden if they sign a lease in January 2026. A 20% VAT was added to the ETS-2 costs, as required by law, to maintain price consistency with annual tenancy.

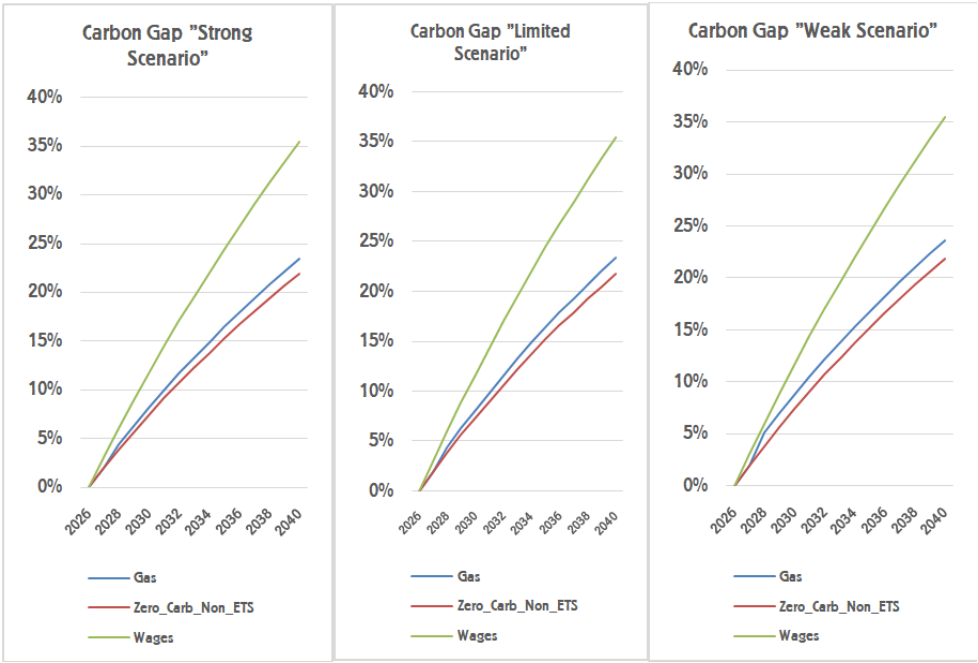


Fig 1: development of ETS-2 scenarios,

5 RESULTS

This research primarily investigates whether ETS-2 poses a threat to rental affordability for potential tenants in Austria, as scenarios for energy costs were excluded. The simulation results and data sets suggest no

immediate danger. In every scenario modelled, assumptions about historical wage growth outperform the projected costs of carbon pricing. This trend holds across all scenarios, regardless of how aggressively carbon prices increase. Even under a scenario with weak policy enforcement and a significant rise in carbon costs – such as an annual ETS-2 increase of 3.91% for gas-heated apartments – the ETS-2 costs would only constitute about 26.67% of the gross rent (excluding energy bills) by 2040.

Since affordability appears unaffected by ETS-2 pricing scenarios, it would be valuable to explore the quantification of the "carbon gap". According to Rebonato et al. (2024), climate value on risk is defined by comparing a scenario without ETS-2 pricing to the "Weak Scenario." This comparison involves evaluating rental costs with and without carbon costs to determine the carbon gap. The table below shows the total rental costs per square meter accumulated over the periods from 2026 to 2040 and from 2026 to 2050, including 20% VAT.

		Strong Scenario		Limited Scenario		Weak Scenario	
		2040	2050	2040	2050	2040	2050
Gas_No ETS	[€ /sqm]	4.213	7.638	4.213	7.638	4.213	7.638
Gas_ETS	[€ /sqm]	4.503	8.211	4.532	8.249	4.532	8.249
Carbon Gap	[€ /sqm]	290	573	319	612	319	612
		6, 44%	6, 98%	7, 05%	7, 41%	7, 05%	7, 41%

Table 1: Comparison of the Carbon Gap across different scenarios.

In this most extreme scenario, the carbon gap increases by 7, 41% of rental expenses. Since this level does not appear to threaten affordability across the sample set, which has an average annual rent per square meter of € 246, 37 for gas-heated, € 262, 48 for district-heated, and € 300, 84 for geothermal-heated apartments, the next question is at what price points the ETS-2 curves would intersect the affordability curves. Backward calculations show that if the ETS-2 price is approximately € 600 per ton of CO_2 in 2028 and around € 3200 per ton in 2040, the affordability curves would be crossed.

6 DISCUSSION AND POLICY IMPLICATIONS

The findings of this paper raise several questions. Firstly, there seems to be a link between rental levels and the discussed ETS-2 pricing risk: in a strong housing rental market with high rents, such as Vienna, affordability ratios remain stable. This is supported by Austria's wages generally increasing faster than both index-linked rents and ETS-2 pricing scenarios. Based on the sample used, this may not apply to regions with lower rents, where the rent-to-ETS-2 price ratio differs from the sample used in this paper. The same may apply to stressed office and commercial property markets, which currently experience low tenant demand due to oversupply or Austria's weak economy, or a tenant market prevails. Second, the mechanism for ETS-2 cost-sharing between landlords and tenants warrants further discussion. In the sample, properties with ETS-2 risk tend to have lower rents compared to those with low or zero carbon heating, suggesting a possible carbon discount. This is relevant because it could indicate whether a cost-splitting model like Germany's is necessary in Austria to support affordability in markets with strong demand and weak supply as Vienna, or whether a specific real estate market can balance itself. An important aspect of monitoring is whether the additional ETS-2 costs might exceed reasonable rents in a specific submarket, paid by tenants of comparable properties with low or zero carbon heating, meaning that both property types (carbon and carbon-neutral) have the same occupational cost levels.

Regardless of whether ETS-2 prices surge or remain stable, it is clear that only carbon-neutral or zero-carbon heating and cooling systems offer strong protection against transition climate risks, providing tenants with a certain cost certainty in their rental decisions.

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The GERICS Process Model Approach to Integrate Future Climate Change Information into Adaptation Strategies

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1 ABSTRACT

Effective preparation for climate change impacts necessitates the proactive integration of scientifically robust climate information into decision-making processes across both the private and public sector. Companies are increasingly confronted with regulatory requirements for non-financial reporting, including scenario-based risk assessments aligned with the EU Taxonomy Regulation. Simultaneously, public institutions – such as counties and municipalities in Germany – are mandated to develop climate adaptation strategies under the Federal Climate Adaptation Act (KAnG), which must be based on the results of climate projections for the near and far future. In response to these evolving demands, the Climate Service Center Germany (GERICS) has developed the GERICS Process Model for Companies, a prototypical climate service product designed to enable decision makers to embed projected future climate conditions into adaptation management. This prototypical model was co-developed through an inter- and transdisciplinary process, emphasizing practical applicability and stakeholder engagement via structured interviews and participatory workshops. The model consists of eight interconnected phases: i. stocktaking, ii. classification, iii. identification, iv. supplying information, v. capability, vi. derivation and implementation of measures, vii. evaluation, and viii. process solidification. It serves as a bridge between scientific climate data and operational decision-making, promoting cross-organizational thinking and supporting both mitigation and adaptation strategies. Based upon successful collaborations with private sector actors, the next step of the prototypical development involves adapting and scaling the model for application within public sector organizations at the municipal and county level. This expansion aims to align with the requirements of the KAnG and to support the development of robust, evidence-based climate adaptation strategies for communities as well as companies connected to these areas.

Keywords: climate change adaptation, climate change information , climate services, co-creation , transdisciplinarity

2 INTRODUCTION

Preparing for extreme weather events and other climate change impacts requires the forward-looking integration of scientifically robust climate information into strategic decision-making processes across both the private and public sector. Companies are increasingly subject to regulatory demands for non-financial reporting, risk assessments and the demonstration of substantial contributions to environmental objectives in accordance with the EU Taxonomy Regulation (European Commission, 2021; Technical Expert Group on Sustainable Finance (TEG), 2020a; TEG, 2020b). One key component is the use of climate change scenarios to consider plausible future climate conditions, which include a range of possible outcomes based on different human activities, particularly greenhouse gas emissions.

Public sector organizations are likewise facing new regulatory frameworks. In Germany, for example, the Federal Climate Adaptation Act (Bundes-Klimaanpassungsgesetz, KAnG) mandates federal, state, and local authorities – including municipalities and counties – to develop and present precautionary climate adaptation strategies. These strategies must be based on state-of-the-art scientific climate risk analyses and incorporate medium- and long-term climate information (BMUV, 2023).

In response to these evolving requirements, the Climate Service Center Germany (GERICS), in collaboration with various companies, developed and tested a prototypical climate service product – the GERICS Process Model for Companies (Gehrke et al., 2025; Gehrke et al., 2024). Its primary objective is to create a practical and user-oriented framework to enable decision makers to systematically integrate future climate information into adaptation management processes. The development process was guided by the principles of transdisciplinarity and co-creation, which serve as fundamental concepts for integrative research (Schuck-Zöller et al., 2024). One goal of this approach was to ensure that scientific insights were translated into

actionable knowledge in a comprehensible and accessible manner. To this end, interviews and workshops were used as effective formats for stakeholder engagement, particularly for participants without a scientific background.

Based upon this, the GERICS Process Model aims to enable decision-makers to assess and evaluate climate-related direct and indirect impacts of climate change for their own strategic planning processes. This should be achieved by using future-oriented climate data in conjunction with company-specific and local information, combined with a holistic view of the respective system in which the company is embedded.

Building on positive feedback and good experiences gained from the collaboration with companies, further prototypical product development will now be continued for public sector stakeholders at the municipal and county level. The goal is to develop a GERICS Process Model for counties and municipalities.

Against this background, this paper briefly introduces the current prototypical product status of the GERICS Process Model and reflects on its practical application, incorporating specific feedback on individual phases as well as questions and challenges raised from corporate decision-makers (chapter 3). Furthermore, it outlines the key requirements of the German Federal Climate Adaptation Act (KAnG) for municipalities and counties to be taken into account to meet the needs of public sector actors (chapter 4). The final chapter presents a brief conclusion and outlook (chapter 5).

3 THE GERICS PROCESS MODEL AND FIRST LESSONS LEARNED FROM THE PRACTICAL USE BY COMPANIES

3.1 The model phases

This chapter briefly introduces the eight-phases of the GERICS Process Model for companies, developed to provide a structured procedure for assessing climate vulnerabilities and identifying the most relevant direct and indirect impacts of climate change – mainly based on promoting transdisciplinary collaboration between internal and external stakeholders.

The eight phases of the GERICS Process Model are as follows (Gehrke et al., 2025; Gehrke et al., 2024):

(1) Stocktaking: Companies start by identifying climate-related events and their potential impacts across operational sites, supply chains, and markets. This includes for example both direct and indirect effects, informed by historical data, stakeholder input, and external sources such as hazard maps and urban climate analyses.

(2) Classification: Identified past, current and plausible future impacts are evaluated by experts in the company in terms of relevance and severity using weighted decision matrices. This prioritization process aligns with strategic objectives and regulatory requirements, particularly those outlined in the EU Taxonomy.

(3) Identification: Key climate variables – such as the number of heat days, drought periods, or heavy rainfall events – are selected based on regional climate projections. The selection of these parameters is tailored to the company's specific context and aligned with regulatory guidelines.

(4) Supplying information: Climate information about relevant climate variables is compiled and adjusted to meet company-specific needs. Products such as the GERICS Climate Outlooks (Pfeifer et al., 2021) provide results of regionalized climate projections that support long-term planning and decision-making.

(5) Capability: Companies are enabled to interpret and apply climate information effectively through targeted training and customized formats. Best practices and case studies facilitate the translation of data into strategic actions.

(6) Derivation and implementation of measures: Suitable adaptation measures are developed and prioritized to enhance organizational resilience. These measures span short-, medium-, and long-term horizons and include "no-regret" options that align with EU Taxonomy criteria.

(7) Evaluation: The success of implemented adaptation measures is assessed through iterative monitoring and evaluation. Key challenges include the attribution of outcomes and the definition of meaningful indicators. The evaluation process also considers stakeholder engagement and the integration of updated climate data.

(8) Process solidification: The aproach is embedded into organizational structures to ensure continuous learning and adaptive capacity building. Resilience is conceptualized as an ongoing process, enabling companies to respond flexibly to evolving climate risks.

In general, the process model is designed to remain adaptable to practical applications by different user groups in different sectors. As a framework it accommodates varying levels of data availability and observational evidence and incorporates feedback loops between phases to support continuous improvement.

3.2 Lessons learned from the current practical use

The prototypical application of the GERICS Process Model for the use by companies has demonstrated that the first four phases – focusing on stocktaking, classification, identification and supplying information – have been the most actively used. In contrast, the transition toward internal integration, facilitation, and evaluation of climate risk management, beginning with phase 5, has only recently been carried out or remains in the planning stages.

In its current form, the approach complies with emerging climate-related regulations and fosters innovation through a structured and systemic framework as well as forward-looking planning. For decision-makers within companies, the phases of the model have proven particularly valuable in organizing internal processes. Moreover, the model offers an easily understandable starting point for engaging with detailed climate change information and anticipated impacts, facilitating internal dialogue and strategic planning.

However, additional explanatory support has been necessary in several areas. For instance, the detailed steps and their sequence within the process require further clarification for decisionmakers. Terminology such as "system elements" or the various climate parameters and their relevance to specific climate hazards were not immediately understood by company representatives confronted with it for the first time, so that the integration of specific external guidance is key at this point. The most substantial feedback and needs for support were related to the understanding and proper use of the climate parameters provided.

A scientific sound basis for these parameters are the GERICS Climate Outlooks (Pfeifer et al., 2021), which offer insights into possible future climatic changes at regional scales. These outlooks summarize common key climate indicators – such as temperature, number of heat days, dry days, wind speed, and heavy rainfall days – in a concise format. The projections illustrate trends of these parameters throughout the 21st century, providing valuable information on how climate conditions may evolve in specific regions of Germany. It is essential to consider both current and projected developments in climate parameters and align them with the specific requirements of each company.

At this stage of the process, companies often identified significant challenges in integrating the climate information into their risk management frameworks. A key issue was how to handle the wide range of potential future climate developments. Risk management practices typically require a focus on one or two scenarios – such as RCP 2.6, 4.5, or 8.5 – and within those, on specific statistical values like the median or a particular percentile. Furthermore, the bandwidth or results within each scenario makes the available information often challenging to be used in practise. Additionally, for certain business-specific questions, the required climate change information is not yet available. This includes data on specific definitions of extreme rainfall events, temperature thresholds, and maximum expected values for temperature or precipitation. Where feasible, these support needs are addressed through the ongoing development of the GERICS Climate Outlooks as well as other climate services. However, some requirements – such as the provision of maximum expected temperature or precipitation values and the combination of two specific indicators of particular interest to a company for new insights – necessitate fundamentally new research efforts. Furthermore, it has to be taken into account, that the climate projections only consider 30-year averages, which makes it difficult to determine robust value intervals for shorter periods.

Moreover, practical experiences show that decision-makers frequently are challenged in delineating their system boundaries and levels of influence relevant to their organization or business model. This difficulty arises partly because the system under consideration – focused on adaptation to climate change impacts – differs often substantially from meanwhile well-established approaches to climate mitigation or other relevant reporting requirements. Consequently, prior experience and knowledge in this domain are typically lacking. Decision-makers also often struggle to establish a causal link between an observed or anticipated vulnerability and the underlying climate-related driver, as illustrated by a tree falling onto a railway track,

which may result from various causes – such as uprooting due to storm or the lowered stability of the soil after a heavy rainfall event. Without a precise identification of this cause, however, it is not possible to determine the appropriate and relevant climate parameter(s).

In summary, several key success factors for the use of the GERICS Process Model have already been identified in collaboration with companies. A basic requirement of this specific approach depends on close, trust-based cooperation between internal and external stakeholders from the outset. Its effectiveness also relies on one or more facilitator(s) in the company who has the resources, position, mandate and capabilities to internally engage all other relevant experts within the company, leverage their expertise and imply knowledge to evaluate and prioritize areas for action as well as to develop appropriate adaptation measures.

The use of the process model also provides significant added value by fostering transformative adaptation solutions to address climate change impacts. This includes promoting new forms of collaboration, encouraging cross-organizational thinking and action, reimagining adaptation needs from a systemic perspective, and involving other relevant stakeholders in addressing climate risks. These efforts can be embedded within a framework of transdisciplinary co-production, ensuring that the resulting solutions are comprehensive, inclusive, and innovative.

Following this retrospective perspective on the experiences of using the GERICS Process Model with companies, the next chapter will take the above findings into account and furthermore focus on the level of counties and cities. The necessity for this is explained below.

4 KEY REQUIREMENTS OF THE GERMAN FEDERAL CLIMATE ADAPTATION ACT (KANG) FOR CITIES AND COUNTIES

To ensure that the current regulatory framework conditions and requirements are taken into account in the further development of the existing GERICS Process Model for use by counties and municipalities, key requirements of the Federal Climate Adaptation Act (KAnG) will additionally be introduced.

With this new federal adaptation act, entered into force in July 2024, counties and municipalities in Germany are now subject to new legal obligations (Schink, 2024; BMUV, 2023). For the first time, this legislation establishes a legal framework for climate change adaptation in Germany, representing a governance-based approach to precautionary climate policy. According to §1, the act aims to prevent or – where prevention is not possible – minimize the negative impacts of climate change. It seeks to enhance the resilience of ecological systems and society to future climate impacts, maintain equitable living conditions, and prevent climate-induced increases in social inequality.

Regarding key conceptual foundations, the following three definitions from §2 are particularly noteworthy:

- Climate adaptation: The alignment with current or anticipated impacts of climate change.
- Climate risk analysis: The identification and assessment of present and future risks associated with the impacts of climate change, whereby the necessary scope and level of detail of the analysis shall be appropriately determined by the legal entity responsible for its preparation, based on its situation and needs.
- Public task carriers: All entities performing public tasks, regardless of whether they are organized under public or private law.

A key legal provision is the requirement that public task carriers give due consideration in their planning and decision-making on a cross-disciplinary and integrated basis to the objective of climate adaptation (§8). This includes both current and anticipated future climate impacts.

Specific obligations for counties and municipalities are outlined in two paragraphes. According to §11, the federal ministry responsible for climate adaptation must receive biennial reports from the federal states detailing which municipalities and counties currently already have climate adaptation concepts developed and which do not. These reports must also specify the regional and local climate data used for adaptation planning. §12 further addresses counties and municipalities indirectly via the federal states. The states are responsible for designating public entities to develop climate adaptation concepts for municipalities and counties where such plans do not yet exist. The catalog of measures should include preventive measures for extreme heat, drought, and heavy rainfall, as well as actions that promote individual preparedness among citizens. Moreover, §12 stipulates that climate risk analyses for municipalities and counties should be based

on vulnerability assessments or comparable decision-making tools providing "hotspot-analysis" that identify priority risks and urgent needs for action. Thus, municipalities may draw on additional sources of information, like adaptation-related representations and determinations within land-use planning, flood protection strategies and heavy rainfall maps. Moreover, adaptation planning by other territorial authorities must be considered – both vertically (e.g., municipal associations) and horizontally (e.g., adaptation strategies of neighboring municipalities). The climate adaptation concept is intended to serve as a sort of catalog of measures tailored to local conditions. It is also acceptable for adaptation concepts to rely on comparable planning foundations, provided that relevant plans and concepts from neighboring municipalities are explicitly considered.

In summary, the KAnG addresses an existing gap by requiring all administrative levels within the federal territory to develop plans and concepts for climate adaptation. This ensures a systematic approach to climate impact issues, albeit in the form of a framework law. However, it must also be noted that the KAnG confronts all administrative levels with complex planning decisions. For counties it imposes several core requirements, particularly due to their role as supra-local administrative bodies and associations of municipalities (Völker et al., 2024). These include, depending on state-level regulations: i) developing climate adaptation concepts, ii) conducting climate risk analyses, iii) coordinating and supporting inter-municipal efforts, iv) documenting and tracking progress in adaptation activities, and v) contributing to the federal states' reporting obligations. The city level may also face significant challenges in developing climate adaptation strategies. Yet, this is precisely where adaptation measures are most critical, as cities are responsible for land-use planning and thus for regulating land utilization, performing public health protection tasks, and, ultimately, planning, implementing and maintaining key critical infrastructure.

Hence another, appropriately adapted GERICS Process Model will go beyond support to address new regulatory requirements and the integration of climate information into strategic planning processes. It also will take into account that adaptation of urban areas and their surroundings is more than creating hot spot maps or developing adaptation strategies. It requires the consideration of many more factors and drivers, including their interactions as well as many interests from key players such as administration (from local to regional), politics, and companies, which makes comunication key for successful adaptation.

5 CONCLUSION AND OUTLOOK

The practical application of the GERICS Process Model approach shows that it sucessfully supports regulatory compliance and structured internal processes for companies, offering a clear entry point for climate-related dialogue and planning. As a framework it also fosters systemic and innovative adaptation strategies through transdisciplinary co-production, promoting cross-organizational thinking and transformative solutions, whereby effective implementation depends on close collaboration with external experts and internal engagement across different departments. However, it was shown, that most companies still require additional guidance on process steps, terminology, and the use of climate parameters. Challenges include integrating localized climate data, managing scenario uncertainty, and addressing gaps in extreme event definitions.

Based on the current experiences, the GERICS Process Model will now be transferred and further developed not only as a methodological guideline but also as a strategic framework to meet the needs of cities and counties. It aims to support the systematic embedding of climate adaptation within administrative structures, budgetary frameworks, and political decision-making procedures. Thereby a close connection and communication with the company perspective in the region will be established to support an integrated approach, bringing together municipalities, counties and companies. The overarching goal is to support and enable decision-makers to systematically identify and assess climate risks and to derive appropriate adaptation measures – with particular emphasis on the implementation of climate risk analyses.

The further development of the GERICS Process Model for municipalities and counties offers great potential for implementing the requirements of the German Federal Climate Adaptation Act (KAnG). It is now planned to identify pilot municipalities and counties to co-develop and test the model exemplary. As part of this transdisciplinary work, especially a close collaboration between science and practice on equal footing in the context of prototypical product development, remains a key success factor for engaging with representatives from counties and municipalities.

Beyond damage prevention and adaptation, this approach aims to contribute to the broader transformation toward a sustainable, climate-neutral, and climate-resilient society. Furthermore, it offers added value by fostering the development of transformative adaptation options within a transdisciplinary co-production framework. This includes the creation and use of new forms of collaboration, the exploration of emerging fields of action, cross-organizational thinking and decision-making, the systemic understanding of interconnected structures and their adaptation needs as well as the integration of additional relevant stakeholders to address climate impacts.

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Überholverhalten von Kraftfahrzeugen gegenüber Radfahrenden im urbanen Mischverkehr: Empirische Untersuchung des Interaktionsverhaltens in Bogotá, Kolumbien

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1 ABSTRACT

Die faire Verteilung des Straßenraums für die verschiedenen Verkehrsteilnehmenden stellt insbesondere in Städten mit hoher Motorisierungsrate und begrenzten Flächenpotenzialen für aktive Mobilität eine zentrale Herausforderung der urbanen Verkehrsplanung dar. Dies trifft auch auf Bogotá, Kolumbien, zu, wo seit der COVID-19-Pandemie durch die Implementierung neuer Radverkehrsinfrastruktur eine Umverteilung des Straßenraums erfolgt. Da in vielen Straßenräumen kein ausreichender Raum für die Realisierung baulich getrennter Radverkehrsanlagen besteht wurden auf mehreren bedeutenden Verkehrsachsen Fahrspuren mit Priorität für den Radverkehr eingerichtet, die aber auch durch den Kfz-Verkehr befahren werden dürfen. Für diese „Vía ciclo-adaptada“ bilden die Überholabstände zwischen Kfz und Radfahrenden ein wichtiger Indikator zur Beurteilung der objektiven und subjektiven Verkehrssicherheit der Radfahrenden.

Die vorliegende Studie analysiert das Überholverhalten auf einer der wichtigsten Hauptverkehrsstraßen Bogotás mit einem Vorrangabschnitts für Radfahrende. Der methodische Ansatz der Studie stützte sich auf Erfahrungen mit Messungen des Überholabstandes Kfz-Rad in verschiedenen deutschen Kommunen. Maßgebliche Hinweise lieferte dabei das Projekt „Gü-Rad“, das im Jahr 2022 im Bundesland Baden-Württemberg durchgeführt wurde. Aufbauend auf den Ergebnissen dieser Methodik wurde eine umfassende Datenerhebung in Bogotá konzipiert. Hierzu wurden über einen Zeitraum von 18 Monaten an drei Erhebungszeitpunkten die Überholabstände erhoben. Die Ergebnisse weisen auf systematische Unterschiede im Überholverhalten in Abhängigkeit von der Längsneigung der Fahrbahn, der Verkehrsdichte und dem Fahrzeugtyp hin. Die Ergebnisse leisten einen Beitrag zum Verständnis der Interaktionen zwischen Fahrzeugen und Radfahrenden unter räumlich beschränkten Bedingungen in Bogotá. Zudem sind diese Hinweise bei der Planung von Radverkehrsinfrastruktur unter Einhaltung ausreichender Überholabstände zwischen Kfz und Fahrrad zu berücksichtigen.

Keywords: Überholverhalten, Radfahrende, Mischverkehr, Kfz-Rad, Interaktionsverhalten

2 HINTERGRUND: PROJEKT „GÜ-RAD“ IN DEUTSCHLAND

Überholvorgänge zwischen Karftfahrzeugen und Radfahrenden stellen einen zentralen Einflussfaktor sowohl für die subjektive Wahrnehmung als auch für die objektive Verkehrssicherheit dar. Insbesondere bei der Führung des Radverkehrs im Mischverkehr auf der Fahrbahn kommt dem seitlichen Überholabstand eine wichtige Bedeutung zu, da er das individuelle Risikoexpositionsniveau, das Stressempfinden sowie die Attraktivität des Radverkehrs als alltägliche Mobilitätsform wesentlich prägt (Dozza, 2014; Useche, 2019). Bei der Führung des Radverkehrs auf Hauptverkehrsstraßen im Mischverkehr auf der Fahrbahn ist in Karlsruhe, Deutschland das Überholen durch ein Fahrzeug mit 36 % der wichtigste Stressauslöser für Radfahrende (Merk et al. 2022; Merk et al. 2021). Hauenstein et al. 2023 zeigen, dass in Deutschland der gefühlten sichere Überholabstand der Radfahrenden bei ca. 1,60m liegt. In Deutschland spielt bei den Überholvorgängen Kfz-Rad die objektive Verkehrssicherheit im Vergleich zur subjektiven Sicherheit eine untergeordnete Rolle. So machen Überholunfälle Kfz-Rad weniger als 1% aller Unfälle mit Radfahrerbeteiligung in der Stadt Freiburg aus (Heizmann 2024).

Vor diesem Hintergrund widmete sich das F+E-Vorhaben „gÜ-Rad Überholabstand zwischen Kfz und Rad“, gefördert durch das Bundesministerium für Verkehr und digitale Infrastruktur im Rahmen des nationalen Radverkehrsplan, der systematischen Untersuchung seitlicher Überholabstände zwischen Radfahrenden und vorbeifahrenden Kraftfahrzeugen in zehn Modellkommunen in Deutschland. Ziel war es, Überholsituationen zwischen Kraftfahrzeugen und Radfahrenden im innerstädtischen Straßennetz systematisch zu identifizieren, quantitativ zu bewerten und die Wirkung von verkehrlichen Maßnahmen auf die Überholabstände zu erfassen (Eckart et al. 2024). Die nachfolgende Darstellung konzentriert sich auf die Erhebungsmethodik des Vorhabens, welche nach Bogotá übertragen wurde. Die gemessenen Überholabstände sowie die

verkehrlichen Einflussfaktoren sind aufgrund der sehr unterschiedlichen Radverkehrsinfrastruktur in Deutschland und Kolumbien nicht vergleichbar und werden daher nicht dargestellt.

Zu Beginn des Projekts wurden Straßenabschnitte identifiziert, die aus Sicht der kommunalen Planungspraxis als besonders problematisch im Hinblick auf enge Überholvorgänge wahrgenommen wurden. Auf den ausgewählten Strecken wurden die Überholabstände Kfz-Rad im Realverkehr erhoben. Die Datenerhebung erfolgte mithilfe des OpenBikeSensors (OBS), eines bürgerwissenschaftlich entwickelten Messsystems zur Erfassung seitlicher Abstände zwischen Radfahrenden und überholenden Kraftfahrzeugen (Schleinitz et. al, 2022). Der OpenBikeSensor misst während der Fahrt mittels Ultraschallsensoren kontinuierlich den Abstand zu Objekten links und rechts des Fahrrads. Überholvorgänge werden durch die Radfahrenden per Knopfdruck markiert. Die gemessenen Distanzen werden rechnerisch um die Lenkerbreite korrigiert, sodass der verbleibende seitliche Abstand zwischen Fahrrad und vorbeifahrendem Objekt bestimmt wird. Ergänzend werden GPS-Daten aufgezeichnet, die eine räumliche Zuordnung der gemessen Überholabstände ermöglicht. Die Ergebnisse werden auf einem Portal als Karten dargestellt.

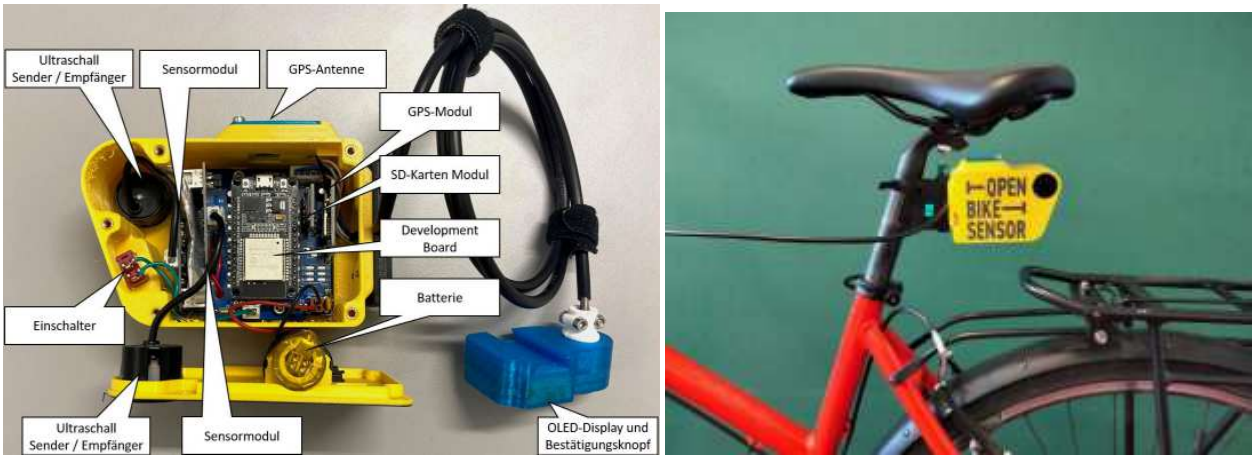


Abb. 1: Innenansicht OpenBikeSensor mit bezeichneten Komponenten und Befestigung OBS.

In den 10 Kommunen nahmen geschulte Radfahrende an der Messung teil, die die entsprechenden Straßenabschnitte über mehrere Wochen hinweg wiederholt befuhren. Jeder Überholvorgang eines Kraftfahrzeugs gegenüber einem Radfahrenden wurde als Ereignis erfasst und mit dem Abstandswert sowie der räumlichen Position gespeichert (Abbildung 2). In einem ersten Schritt wurden die erfassten Überholvorgänge auf Ebene der einzelnen Straßen aggregiert und statistisch ausgewertet. Diese Gesamtbetrachtung umfasste unter anderem die Berechnung von Lage- und Streuungsmaßen wie Mittelwert und Median sowie die Analyse der Verteilung der Überholabstände, um grundlegende Aussagen zur Überholsituation auf den jeweiligen Straßen treffen zu können.

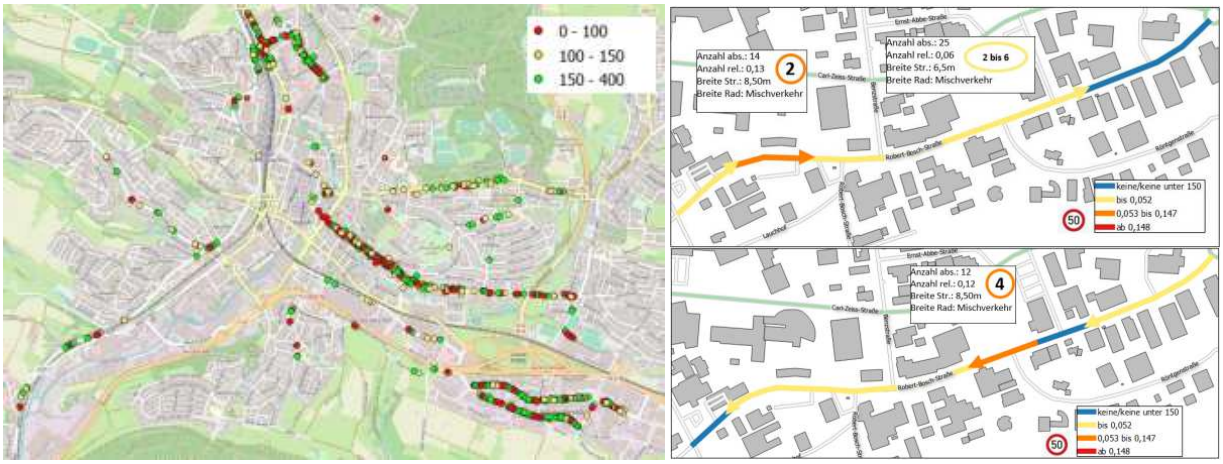


Abb. 2: Beispiel der Übersicht von Überholvorgänge (links) Aalen und Eingrupierung der Abschnitte (rechts) Robert-Bosch-Straße Aalen

Für eine differenziertere Analyse wurden die untersuchten Straßen anschließend in Abschnitte von jeweils 100 Metern Länge unterteilt. Diese räumliche Segmentierung diente dazu, lokale Unterschiede innerhalb

eines Straßenzuges sichtbar zu machen und insbesondere räumliche Häufungen enger Überholvorgänge zu identifizieren (Abbildung 2). Ausgewertet werden die absolute Anzahl der registrierten Überholvorgänge, der Anteil der Überholvorgänge unterhalb definierter Abstandsschwellen – insbesondere unterhalb des innerorts geltenden Mindestüberholabstands von 1,50 Metern – sowie Mittelwert und Median der gemessenen Überholabstände. Ergänzend wurden Streuungsmaße herangezogen, um die Variabilität der Abstände innerhalb eines Abschnitts zu beschreiben. Um Verzerrungen durch unterschiedlich häufig befahrene Abschnitte zu vermeiden, wurde die Bedeutung einzelner Segmente zusätzlich in Relation zur Anzahl der durchgeführten Befahrungen bewertet. Dadurch kann berücksichtigt werden, dass eine hohe Anzahl an Überholvorgängen nicht ausschließlich auf problematische Verkehrsverhältnisse, sondern auch auf eine hohe Nutzungshäufigkeit durch Radfahrende zurückzuführen sein kann.

3 ANALYSE DES ÜBERHOLVERHALTENS KFZ-RAD IN BOGOTÁ KOLUMBIEN

Das im deutschen Projekt gÜ-Rad entwickelten Verfahre zur Erfassung und Bewertung ermöglicht die Überholvorgängen Kfz-Rad zu erheben. Die Methodik wurde nach Bogotá übertragen.

Bogotá in Kolumbien verfügt mit mehr als 677 km über eines der größten Radwegenetze Lateinamerikas (SDM, 2024), sieht sich aufgrund der historischen Priorisierung des motorisierten Verkehrs jedoch mit anhaltenden Platzbeschränkungen auf wichtigen Verkehrsadern konfrontiert. Im Jahr 2021 setzte die örtliche Verkehrsbehörde eine kostengünstige Maßnahme in einem der Hauptkorridore im Nordosten der Stadt um: Auf einem 2,1 Kilometer langen Abschnitt ohne eigenständige Radverkehrsinfrastruktur wurden die rechte Fahrspur mit Piktogramme markiert, die eine Vorrangstellung der Radfahrenden anzeigen „Vía ciclo-adaptada“. Die Fahrspur darf jedoch weiterhin auf durch den Kfz-Verkehr befahren werden, wodurch die Kapazität der zweispurigen Straße für Kraftfahrzeuge unverändert bleibt. (SDM, 2020).



Abb. 3: Querschnittsansicht der untersuchten Strecke in Nord-Süd-Richtung

Die untersuchte Hauptstraße ist für die Erschließung des Nordostens der Stadt von hoher Bedeutung. Auf der Relation werden pro Tag mehr als zwei Millionen Wege über alle Verkehrsmittel hingweg erhoben (SDM, 2023). Wie in Abbildung 03 zu sehen, verfügt die Straße pro Richtung über einen Gehweg, zwei Fahrspuren für den Mischverkehr und eine exklusive Fahrspur für das BRT-System „TransMilenio”. Somit müssen Radfahrende entweder die Mischverkehrsfahrbahn oder den Gehweg nutzen. Bei Überholvorgängen Kfz-Rad sollen Fahrzeugführende einen Mindestabstand von 1,5 m einhalten (Congreso de la República de Colombia, 2016). Die Überholvorgänge Kfz-Rad werden für diesen Straßenabschnitt erhoben.

3.1 Methodik Erhebung Überholabstände Kfz-Rad

Das Erhebungsdesign der deutschen Studie wird nach Kolumbien übertragen. Folgende Parameter wurden berücksichtigt:

- Erfassung der seitlichen Überholabstände Kfz-Rad mithilfe von OpenBikeSensoren. Zusätzlich erfolgt eine Videoaufnahmen der Befahrung. Dies ermöglicht eine Videoanalysen zur Identifizierung des überholenden Fahrzeugtyps und seiner Position entlang des Straßenabschnitts.

- Die Datenerhebung erfolgte durch Befahrungen über einen Zeitraum von 18 Monaten (für die Jahre 2024, 2025 und 2026). Dadurch können mögliche Verhaltensänderungen in Abhängigkeit vom Verkehrsaufkommen und von der konsequenten Einhaltung der Vorschriften ermittelt werden.
- Die Untersuchungsstrecke von 1,3 km wurde nach infrastrukturellen Rahmenbedingungen in homogene Teilstücke unterteilt.

3.2 Darstellung und Diskussion der Ergebnisse

Die Erhebung, die sich auf drei Tage verteilte, wurde über einen Zeitraum von 18 Monaten durchgeführt mit Erhebungstag 1 im Juni 2024, Erhebungstag 2 im April 2025 (zehn Monate später), und Erhebungstag 3 im Januar 2026 (acht Monate später).



Abb. 5: Ausgestattetetes Fahrrad (links), Piktogramm in schlechtem Zustand (Mitte) und hohes Verkehrsaufkommen (rechts).

Die Überholvorgänge Kfz-Rad werden je Fahrtrichtung in Karten dargestellt (Abbildung 6). Als Überholvorgang wurde die Interaktionen definiert, in dem ein Kraftfahrzeug einen Radfahrer in derselben Fahrtrichtung überholte. Bei der Erhebung im Jahr 2026 gab es auf Teilabschnitten Stau, wodurch die Radfahrenden in den Seitenraum ausweichen mussten und es keine Überholvorgänge gab. Für die Klassifizierung der Überholabstände wurden die Bereiche <100 cm, 100 cm bis 150 cm und >150 cm verwendet. Zusätzlich wurden für jede Richtung Heatmaps entsprechend der Überholpunktdichte erstellt, und diese mit den Unfällen mit Radverkehrsbeteiligung im Längsverkehr überlagert.

Die erfassten Überholvorgänge wurden nach den Analysevariablen aggregiert und statistisch ausgewertet. Diese Analyse umfasste unter anderem die Berechnung von Lage- und Streuungsmaßen wie Mittelwert und Median sowie die Analyse der Verteilung der Überholabstände, um grundlegende Aussagen zur Überholsituation auf den jeweiligen Unteruchungsabschnitten treffen zu können (Tabelle 1).

Variabel	n	Media	Median	Std.	P25	P75	Überholvorgänge Kfz-rad < 150 cm
Gesamte Daten	1406	122.67	105	71.63	67	173	69%
Bergab <3%	141	127.5	106	74.2	75	165	7%
Bergauf >3%	824	116.17	99	66.15	66	154.25	43%
Flach (Von -3% bis 3%)	437	132.41	112	78.52	67	198	19%
2024	483	108.3	83	71.09	57	147.5	26%
2025	557	107.19	97	63.47	61	137	32%
2026	366	165	165	66.98	111	216	11%

Tabelle 1: Statistische Daten je Analysevariable

Die Überholabstände Kfz-Rad sind von der Längsneigung der Fahrbahn abhängig. Die Abschnitte die flach sind, weisen die höchsten Mittelwerte (≈132,4) und die größte Streuung bei den Überholabständen auf. Auch bei Bergab-Abschnitten sind die Überholabstände groß (≈127,5), jedoch mit geringerer Varianz. Bergauf kommt es zu deutlich niedrigeren Überholabständen (≈116,2). Diese Muster deuten darauf hin, dass die Überholabstände in Abschnitten mit flacher oder abfallender Längsneigung tendenziell höher ausfallen. Dies könnte auf die höhere Fahrtgeschwindigkeit der Radfahrenden und den damit einhergehenden niedrigeren Geschwindigkeitsunterschied zu den Kfz zurückzuführen sein.

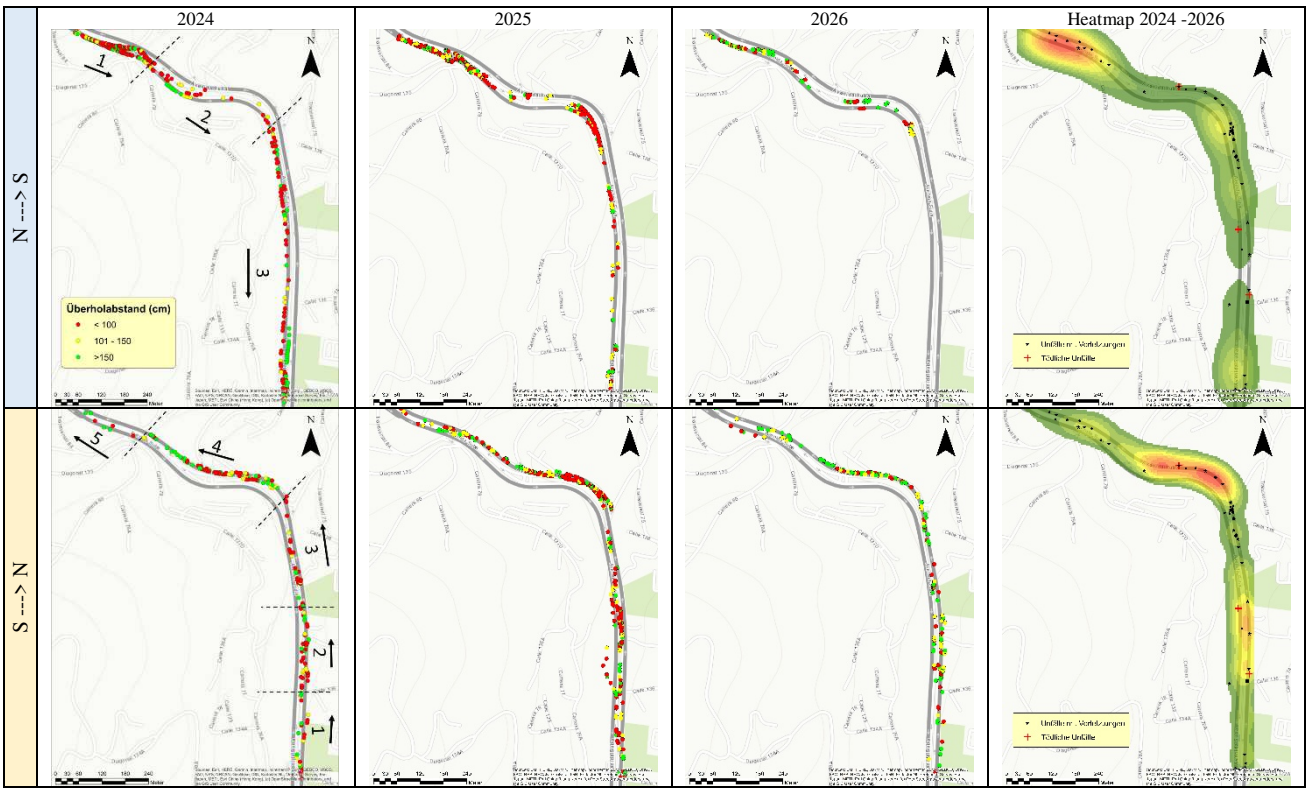


Abb. 6: Überholvorgänge je nach Fahrtrichtung und Erhebungsjahr + Darstellung der Unfallorte von 2007 bis 2024 auf Heatmap. Richtung N-S: 1-Bergauf, 2-Bergab, 3-Flach. Richtung S-N: 1-Flach, 2-Bergauf, 3- Flach, 4-Bergauf, 5-Bergab

Im Jahr 2024 weisen die Überholabstände die niedrigsten Mittel- und Medianwerte in der Zeitreihe auf. Im Jahr 2025 steigen die Überholabstände moderat an, und gleichzeitig nimmt die Variabilität zu.Im Jahr 2026 steigen die Überholabstände bei den Mittel- und Medianwerte deutlich an, begleitet von einer großen Streuung. Im Zeitraum von 2025 bis 2026 ist die Kfz-Verkehrsmenge auf dem untersuchten Abschnitt aufgrund der Eröffnung einer altnativen Verbindung deutlich zurückgegangen. Der Anstieg der Überholabstände Kfz-Rad lässt sich damit durch die zurückgehende Kfz-Verkehrsmenge erklären. Die Entwicklung im Zeitverlauf kann zudem als leichter Hinweis darauf interpretieren, dass die Verkehrsteilnehmenden im Laufe der Zeit bewusster und rücksichtsvoller gegenüber Radfahrenden agieren.

Zusätzlich zur Analyse des Überholverhaltens wurden die aufgezeichneten Videos ausgewertet. Ermittelt wurden der Fahrzeugtyp (Pkw, Motorräder, Busse, Lkw und Radfahrer), und die Spurposition. Wie in der Abbildung 07 erkennbar, entspricht die relative Position in Bezug auf das OBS-Gerät der seitlichen Position beim Überholen innerhalb der analysierten Fahrspuren. Die beobachtete Verteilung zeigt, dass 76 % der Lkw und 63 % der Pkw die linke Spur benutzen, um vorbeizufahren. Busse hingegen verteilen sich hingegen ähnlich häufig auf den inneren Bereich der linken Spur (eher rechts) und die gesamte rechte Spur. Motorräder tendieren dazu, sich sowohl auf der linken Spur (35 %) als auch im inneren Bereich (eher links) der rechten Spur vorbeizufahren.

Der Vergleich zwischen den Jahren 2025 und 2026 zeigt, dass der Nutzungsanteil der linken Spur von 43 % auf 55 % steigt, während der Nutzungsanteil der rechten Spur von 17 % auf 6 % sinkt. Die Werte der übrigen Positionen verteilen sich gleichmäßig. Diese veränderte Fahrspurwahl ist voraussichtlich auf die abnehmende Kfz-Verkehrsmenge zurückzuführen. Sobald die Verkehrsqualität (LOS) eine freie Fahrspurwahl durch die Kfz zulässt, wird mit der Wahl der linken Fahrspur ein höherer Abstand zum Kfz-Verkehr hergestellt. Dies kann als rücksichtsvolles Verhalten der Kfz-Fahrenden gegenüber den Radfahrenden interpretiert werden.

Die räumliche Verteilung der Überholpunkte wurden mit den Radverkehrsunfällen im Längsverkehr überlagert. Im Ergebnis zeigt sich, dass die Lage der Unfälle mit zwei der drei Überholhotspots übereinstimmen. Anders als in Deutschland, wo Radverkehrsunfälle im Längsverkehr und speziell Überholunfälle sehr selten sind, zeigt sich in Bogotá ein Zusammenhang zwischen den Überholvorgängen und den Radverkehrsunfällen.

	LF	LF-R	M	RF-L	RF	Anzahl
Bus	37%	11%	12%	21%	19%	57
Lkw	76%	3%	3%	7%	10%	29
Motorrad	35%	11%	16%	26%	12%	636
Pkw	63%	3%	9%	17%	9%	599
Radfahrende	0%	0%	0%	14%	86%	21

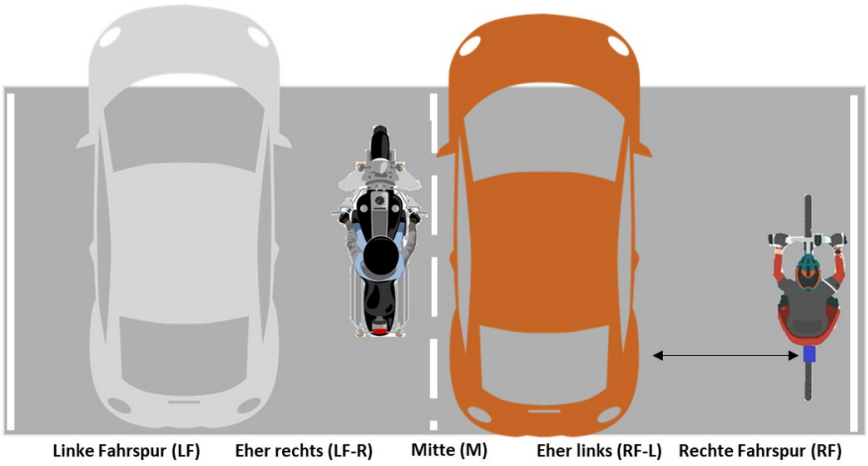


Abb. 7: Verteilung der vorbeifahrenden Fahrzeuge während der Erhebung

4 SCHLUSSFOLGERUNGEN

Die Untersuchung der seitlichen Überholabstände Kfz-Rad über einen Zeitraum von 18 Monaten in Bogotá zeigt deutliche Veränderungen im Interaktionsverhalten zwischen Kraftfahrzeugen und Radfahrenden. Die Ergebnisse verdeutlichen, dass sowohl die Längsneigung der Fahrbahn als auch die Verkehrsmenge und damit einhergend der LOS einen systematischen Einfluss auf die Überholabstände ausüben. Insbesondere auf flachen und bergab verlaufenden Abschnitten werden größere Überholabstände eingehalten, was auf höhere Geschwindigkeiten der Radfahrenden zurückzuführen sein könnte. Zudem steigen die Überholabstände mit abnehmender Kfz-Verkehrsmenge und verbesserten LOS. Die Videoanalyse bestätigt diese Tendenzen und zeigt, dass insbesondere größere Fahrzeuge bei geringeren Verkehrsmengen häufiger Spurwechsel nutzen, um ausreichende Abstände zu gewährleisten. Die räumlichen Muster der Überholvorgänge weisen auf potenzielle Konfliktzonen hin, die mit der Häufungen von Radverkehrsunfällen im Längsverkehr korrespondieren. Die Ergebnisse leisten einen Beitrag zum Verständnis der Interaktionen zwischen Kfz-Verkehr und Radverkehr in Bogotá. Zudem liefert die Untersuchung Hinweise, welche Rahmenbedingunge in Bogotá bei der Planung von Radverkehrsinfrastruktur für die Einhaltung ausreichender Überholabstände zwischen Kfz und Fahrrad zu berücksichtigen sind.

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Wiener Forschungsfragen: Wissen für eine klimagerechte Stadt

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1 ABSTRACT

Städte und Regionen stehen angesichts des Klimawandels, wachsender Bevölkerung, Fragen der sozialen Gerechtigkeit und rasantem technologischem Fortschritt vor tiefgreifenden Veränderungen. Städtische (Nachhaltigkeits-)Politik, Stadtentwicklungs- und Transformationsprozesse leben von einem adaptiven Zusammenspiel vielfältiger Akteurinnen, Akteure, Interessen und Wissensbestände. Um wirksame (planerische und strategische) Entscheidungen für die Transformation treffen zu können, braucht es verlässliche, praxisnahe wissenschaftliche Grundlagen. Genau hier setzt das Projekt Wiener Forschungsfragen an.

Ziel des Projekts war es, jene Wissens- und Forschungsbedarfe zu identifizieren und sichtbar zu machen, die für die Erreichung der Wiener Klimazieleentscheidend sind. In einem strukturierten Dialogprozess wurden Bedarfe der städtischen Verwaltung, stadtnaher Unternehmen und der unterschiedlichen Wissenschaftsdisziplinen zusammengeführt. Über 200 Expertinnen und Experten aus Magistratsdienststellen, Infrastruktur- und Versorgungsunternehmen, Hochschulen und Forschungseinrichtungen wirkten in 16 thematisch fokussierten Workshops mit. Das Ergebnis ist ein priorisierter Forschungsfragenkatalog, der die aktuell dringendsten Wissensbedarfe aufzeigt und gleichzeitig als Orientierung für zukünftige Forschungskooperationen dient.

Der Praxisbericht demonstriert, wie Städte evidenzbasierte Planung stärken und wissenschaftliche Ressourcen gezielt aktivieren können, um die Herausforderungen des Klimawandels, der Transformation urbaner Infrastruktur und der sozialen Nachhaltigkeit zu bewältigen. Die Wiener Forschungsfragen sind nicht nur für Wien relevant, sondern bieten ein übertragbares Modell für andere Städte und Regionen. Sie eröffnen neue Wege, wie Wissenschaft, Verwaltung und Praxis gemeinsam die Zukunft gestalten können.

Keywords: Stadtplanung, Wien, Klima, Wissen, Forschung

2 EINLEITUNG UND KONTEXT

2.1 Strategische Zielsetzungen der Wiener Klimapolitik und die Rolle der Wissenschaft bei der Erreichung dieser Ziele

Die zusehends deutlicher spürbaren Auswirkungen des Klimawandels stellen Städte weltweit vor immer größere Herausforderungen – so auch Wien. Mit der Smart Klima City Strategie hat sich die Stadt Wien ambitionierte Ziele für eine nachhaltige Entwicklung gesetzt, die gleichzeitig die hohe Lebensqualität für alle in Wien lebenden Menschen auch in der Zukunft sicherstellen sollen. Der Wiener Klimafahrplan definiert die maßgeblichen Hebel und Maßnahmen zur Erreichung der Wiener Klimaziele. Für die Entwicklung der erforderlichen Lösungswege und der Abschätzung des erforderlichen Ambitionsniveaus und der Wirkung der geplanten Maßnahmen in den Bereichen Klimaschutz, Klimaanpassung und Kreislaufwirtschaft sind Wissenschaft und Forschung essenzielle Partner. Um wirksame (planerische und strategische) Entscheidungen für die Transformation treffen zu können, braucht es verlässliche, praxisnahe wissenschaftliche Grundlagen. Nichtzuletzt schaffen Wissenschaft und Forschung auch jene Evidenz, die es der Politik und Verwaltung erlaubt, fundierte und zielgerichtete Maßnahmen zu ergreifen und diese gegenüber der Gesellschaft begründet zu vertreten. Die Kommunikation wissenschaftlicher Forschungsergebnisse und evidenzbasiertes Agieren sind wesentlich, um die Akzeptanz der Bevölkerung für

staatliches Handeln zu gewinnen und das Bewusstsein für die Wirkung eigener Handlungsmuster und Initiativen zu schärfen.

2.2 Forschung entlang realer Anforderungen und Fragestellungen der Stadt

Vor diesen Hintergründen wurden im Rahmen des Projekts der Wiener Forschungsfragen aktuell vorhandene Wissens- und Forschungsbedarfe identifiziert, deren Beantwortung/Bearbeitung die Entwicklung zielgerichteter Maßnahmen für die Erreichung der Wiener Klimaziele unterstützt.

Die inhaltliche Struktur des Forschungsfragenkatalogs ist angelehnt an die wesentlichen Schwerpunkte der Smart Klima City Strategie und des Wiener Klimafahrplans. Die Forschungsfragen gliedern sich in neun Themencluster: Energieversorgung, Bau und Gebäude, Kreislaufwirtschaft, Mobilität, Naturräume und Stadtökologie, Klimafitte Grün- und Freiräume, Klimagerechtigkeit, Awareness und Teilhabe, Märkte und Finanzierung. Alle Themencluster umfassen dabei eine Vielfalt an Subthemen und Querschnittsmaterien, wie die klimaresiliente Stadtgestaltung, die Transformation des öffentlichen Raums, naturbasierte Lösungen und grün-blaue Infrastruktur, Fragen der Governance und sozialer Gerechtigkeit und viele mehr.

Die wichtigen Themen Klimagerechtigkeit, Bewusstseinsbildung und Beteiligung spannen sich wie ein Bogen über die 3 Ks (Klimaschutz, Klimaanpassung und Kreislaufwirtschaft). Die Klimakrise betrifft alle Menschen, aber keineswegs alle gleich. Klimapolitik ist daher immer auch Sozialpolitik.

Wien – genauso wie alle anderen Städte – wird neue Ansätze entwickeln, erproben und umsetzen müssen, um die gesetzten Ziele erreichen zu können. Das umfasst einerseits technische Neuerungen, zunehmend treten aber auch soziale Innovationen und neue, wissenschaftliche Prozesse in den Vordergrund. Diese sind stärker von den Bedürfnissen der Bürgerinnen und Bürger inspiriert, breiter getragen und unterstützen dabei, neue Lösungswege zu testen.

3 DIE WIENER FORSCHUNGSFRAGEN

3.1 Entstehungsprozess

Der Forschungsfragenkatalog basiert auf einem intensiven Dialog zwischen den Einrichtungen der Stadt Wien – von Dienststellen des Magistrats über die Wiener Stadtwerke bis hin zu den verschiedenen Unternehmungen und Unternehmen der Stadt – und Vertreterinnen und Vertretern der Wiener Hochschulen. In einem strukturierten Dialogprozess wurden Bedarfe der städtischen Verwaltung, stadtnaher Unternehmen und der unterschiedlichen Wissenschaftsdisziplinen systematisch zusammengeführt. Insgesamt wirkten über 200 Expertinnen und Experten aus Magistratsdienststellen, Infrastruktur- und Versorgungsunternehmen, Hochschulen und Forschungseinrichtungen in 16 thematisch fokussierten Workshops mit.

Diese Prozessphase zeichnete sich durch einen iterativen Wechsel von Dialog- und inhaltlichen Konsolidierungsphasen aus, in denen der Forschungsfragenkatalog kontinuierlich weiterentwickelt und geschärft wurde. Der Prozess war dabei bewusst so gestaltet, dass ein systematischer Abgleich zwischen dem konkreten Forschungsbedarf seitens der Stadt Wien und den inhaltlichen Forschungskompetenzen der beteiligten wissenschaftlichen Partner ermöglicht wurde. Auf diese Weise konnten die Fragestellungen von Beginn an aus wissenschaftlicher Perspektive nachgeschärft und methodisch präzisiert werden, ohne den unmittelbaren Praxisbezug zu verlieren. Die resultierenden Forschungsfragen bilden somit einerseits den konkreten, praxisrelevanten Bedarf der städtischen Einrichtungen ab und sind andererseits fachlich so formuliert, dass sie als tragfähige Ausgangsbasis für wissenschaftliche Forschungs- und Kooperationsprojekte dienen können.

Inhalt des Forschungskatalogs bilden damitjene Fragestellungen, die – in aggregierter Form – aus Sicht der städtischen Einrichtungen von vorrangiger Bedeutung sind, um die zur Erreichung der Wiener Klimaziele notwendigen Instrumente, Programme und Maßnahmen entwickeln und umsetzen zu können.Damit ist keinesfalls impliziert, dass es sich bei den aufgeworfenen Fragen um die einzig relevanten handelt. Es wurde vielmehr bewusst eine Auswahl getroffen, die jene Fragen in den Mittelpunkt rückt, bei denen auf Seiten der städtischen Akteurinnen und Akteure ein unmittelbarer Bedarf nach spezifischen Forschungsergebnissen besteht.Das Ergebnis ist ein priorisierter Forschungsfragenkatalog, der die aktuell dringendsten Wissensbedarfe aufzeigt und gleichzeitig als Orientierung für zukünftige Forschungskooperationen dient.

Besonders hervorzuheben ist, dass der Katalog als „lebendes Dokument“ konzipiert ist. Die Dynamik des Klimawandels, technologischer Entwicklungen und die zunehmende Bedeutung sozialer Innovationen führen dazu, dass stetig neue Fragen entstehen. Außerdem werfen wissenschaftliche Erkenntnisse auch gleichzeitig immer wieder neue Fragen von hoher Relevanz auf. Der vorliegende Katalog ist daher als Momentaufnahme und erster Impuls zu verstehen und bedarf einer regelmäßigen Evaluierung und Aktualisierung.

Abbildung 1 zeigt diesen Prozess der Erstellung, Umsetzung und zukünftig durchzuführenden Evaluierung des Forschungskatalogs.

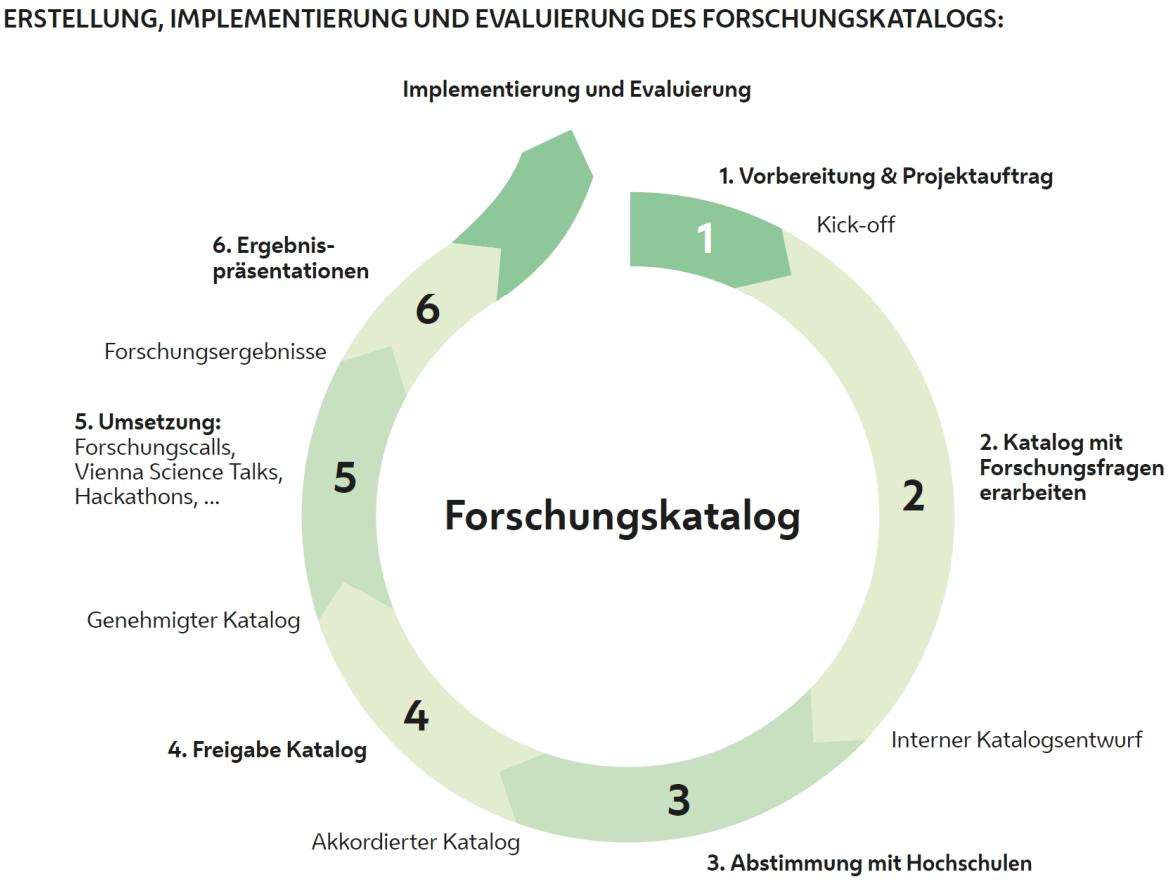


Abb. 1: Prozess zur Erstellung, Umsetzung und Evaluierung des Forschungskatalogs zum Thema Klimaschutz, Klimaanpassung, Kreislaufwirtschaft

3.2 Adressatinnen und Adressaten des Forschungskatalogs

Der vorliegende Forschungsfragenkatalog bildet einen wesentlichen Baustein, um die bestehende Kooperation zwischen der Stadt Wien und der vielfältigen Wissenschafts- und Forschungslandschaft am Standort Wien weiter zu stärken.

Für die Hochschulen soll er Orientierungspunkte bieten, um Forschungsschwerpunkte an der spezifischen Nachfrage städtischer Einrichtungen ausrichten zu können. Forschungsprojekte können praxisnäher gestaltet werden, wenn sie im Dialog mit den künftigen Anwenderinnen und Anwendern entwickelt werden, wenn sie auf reale Daten zugreifen können, die von der Stadt bereitgestellt werden, oder wenn konkrete Anwendungsfälle als „test bed“ für Analysen, Laborsituationen oder Pilotierungen zur Verfügung stehen.

Für die Einrichtungen der Stadt Wien besteht die Möglichkeit, konkrete Antworten auf Fragestellungen aus der täglichen Praxis zu erhalten und damit eine evidenzbasierte Grundlage für die Entwicklung treffsicherer Programme und Maßnahmen zu schaffen.

Um die Zusammenarbeit zwischen den Hochschulen und der Stadt Wien zu vereinfachen, sind zu den einzelnen Einträgen und Forschungsfragen jeweils Themenpatinnen und Themenpaten angegeben. Die Themenpatinnen und Themenpaten sind Organisationseinheiten beziehungsweise Mitarbeitende in der Stadt Wien und ihren Unternehmungen und Unternehmen. Sie nehmen eine aktive Rolle ein, indem sie für Rückfragen und für den weiteren Austausch mit Forschenden zur Verfügung stehen.

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Für die Forschung, insbesondere zu urbanen Herausforderungen, sind Ressourcen essenziell. Diese umfassen nicht nur finanzielle Forschungsförderungen, sondern auch die Einbettung der Forschung, ihrer Methoden und Ergebnisse in Reallabore, den Zugang zu qualitativ hochwertigen Daten und zu einschlägigen Expertinnen und Experten aus der Praxis sowie die Interaktion mit lokalen Stakeholderinnen, Stakeholdern, Bürgerinnen und Bürgern beispielsweise in Citizen-Science-Projekten.

Der Forschungskatalog ist als Printprodukt und Onlineversion in deutscher und englischer Sprache veröffentlicht.

4 FAZIT

Die Entwicklung der Wiener Forschungsfragen zeigt, wie die Abstimmung zwischen Wissenschaft und städtischer Verwaltung bei der Entwicklung der erforderlichen Lösungswege und der Abschätzung der Wirkungen geplanter Maßnahmen unterstützen kann: durch Strukturierung von Forschungsbedarfen, Schaffung klarer Schnittstellen zwischen Verwaltung und Wissenschaft, Benennung von Ansprechpersonen und in Folge bei der Umsetzung durch potentielle Identifikation von Reallaboren und Testumgebungen sowie durch partizipative Formate, die Wissen und Bedürfnisse unterschiedlicher Akteurinnen imd Akteuren verbinden. Gleichzeitig unterstützt der Forschungskatalog die strategische Ausrichtung von Forschungsförderungen und bildet eine Grundlage für neue Projektkonsortien.

Der Forschungsfragenkatalog ist kein statisches Wissensarchiv, sondern bildet den Ausgangspunkt für kontinuierliche Weiterentwicklung, Priorisierung und kooperative Wissensproduktion.

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Yes, we CAN! Data-Driven Decision Making with the Climate Action Navigator

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1 ABSTRACT

Cities urgently need to reduce greenhouse gas (GHG) emissions to comply with climate targets. To support evidence-based planning, we present the Climate Action Navigator (CAN) (HeiGIT 2026), a co-created, data-driven dashboard designed to analyse urban environments by means of a broad set of spatial assessment tools. While CAN is neither the first nor only dashboard that builds on open data and open source software for monitoring urban climate action, its commitment to transparency, adaptability, usefulness, and usability makes it uniquely suited for NGOs, (small) municipalities, and citizen initiatives. CAN's assessment tools are co-created with municipal partners, researchers and local stakeholders, and integrate heterogeneous datasets to offer a holistic and accessible dashboard to assist in decision-making. This is supported by the high spatial resolution of CAN's tools, which reach down to the neighbourhood and even the street level. With intuitive, interactive maps, the tools empower decision-makers to identify and compare intervention areas, thereby supporting targeted, actionable insights.

The dashboard focuses on two core thematic areas: active mobility and GHG emissions. For mobility, CAN offers assessments related to walkability (hiWalk), bikeability (hiBike), and multimodal accessibility (transportability) globally. For emissions, it provides high-resolution estimates of emissions related to heating, traffic, and land cover change, as well as CO_2-budgets for selected cities. Because of data limitations, these tools are currently constrained to Germany. In addition, CAN utilizes deep learning models to detect rooftop solar panels from remote sensing imagery, again currently restricted to Germany.

With its intuitive interface, CAN enables stakeholders to more effectively urge for climate action measures, prioritise interventions, and evaluate policy plans. This contribution presents CAN's co-created assessment tools, with a focus on the tools related to GHG emissions, and illustrates how the dashboard is designed to assist data-driven policy-making and accelerate climate action at the urban scale.

Keywords: Big Data, Active Mobility, Heating Emissions, Traffic Emissions, Dashboard

2 INTRODUCTION: THE FUTURE OF CLIMATE ACTION IS URBAN

Urban areas are key drivers of CO_2 emissions, being responsible for around 70 % of global CO_2 emissions and primary energy consumption. More than half of the global population lives in urban areas, and this is expected to increase to 70 % by 2050 (IPCC 2022). Not surprisingly, urban areas are also highly exposed to climate change, especially informal settlements and slums (Hussainzad & Gou 2024). At the same time, urban areas can be seen as "the future of climate action" (Rossbach & Filho 2025), because they offer multiple leverage points for societal transformation. As centres of innovation, cities and urban areas are "where solutions can move fastest – if supported with the right tools and resources" (Rossbach & Filho 2025). This requires evidence-based decision-making, which is facilitated by data-driven tools.

However, most data-driven tools developed so far to support climate action suffer from a series of limitations that hamper their usefulness to guide decision-making, or are rather resource-intensive. Most tools, e.g. CityMetrics (World Resources Institute 2026) or the Climate Risk Dashboard (IIASA 2026), only provide data aggregated to administrative areas, are limited to a single topic (e.g., heat stress), are only available for a

few cities, or focus on reporting rather than urban planning. ClimateView, for example, helps municipalities track, manage, and advance their climate action efforts (ClimateView 2025). It thereby encourages municipalities to set science-based targets, to monitor progress, and to report on steps taken. However, especially for cities with limited financial and maintenance resources, ClimateView might be too resource-intensive. And whilst ClimateView integrates various data sources for a comprehensive view of climate impact, it does not utilize geospatial data for urban-specific insights. Another example are tools displaying localized greenhouse gas (GHG) emissions such as ClimateTRACE (Climate TRACE 2026), which do not resolve emissions from all important sectors (e.g., housing and road traffic) at sub-city scale. A dashboard integrating tools for different climate action topics with data at high spatial resolution and global coverage does not yet exist.

CAN wants to fill this gap with its commitment to openness, adaptability, usefulness, and usability. It is explicitly developed for NGOs, municipalities, and citizen initiatives. Additionally, its utilisation of open geospatial data can provide highly relevant and actionable insights for urban areas, helping them to prioritise and implement climate actions effectively. And since CAN's assessment tools are co-created with municipal partners, researchers, and local stakeholders, this community involvement helps to leverage local knowledge and engagement, which is a valuable, yet often overlooked resource. Furthermore, the co-creation approach ensures that the dashboard is both useful and usable for those making decisions. Supported by the spatial resolution of the assessment tools that reaches down to the neighbourhood and even the street level, intuitive, interactive maps allow decision-makers to identify and compare intervention areas for targeted climate action. However, as most of the assessment tools are based on OpenStreetMap (OSM) data, the availability and quality of data is an issue in some areas of interest, and will be continuously improved using methods such as data fusion and Deep Learning.

In the following sections, the paper firstly describes CAN's key principles of openness, transparency, global coverage, usefulness, usability, and CAN as a "living product", arguing that these principles define "right tools" for climate action as demanded by Rossbach & Filho (2025). Secondly, we present CAN's current and future array of assessment tools (i.e., hiWalk and hiBike, Heating Emissions and CO_2 Budget, LULC Change, and Land Consumption), also reflecting on their respective limitations. Based on this, the next section discusses how CAN supports data-driven decision making, to then conclude that, yes, we can act now.

3 THE CLIMATE ACTION NAVIGATOR

3.1 Key Principles

Openness. To generate the greatest impact possible and maximize usefulness, the CAN's tools are based on open data, the code is open source, and the dashboard is accessible and free for anyone to use. Despite being free of charge, CAN requires initial user registration for safety reasons and to enable users to access and view their past computation results when returning to the dashboard. Registered users are also able to download data generated with CAN to use in further analyses.

Transparency. The methodology of each tool is documented clearly and limitations and uncertainties are communicated and emphasised. Being open source, expert users can also audit the code to understand exactly how indicators are generated.

Global coverage. Since solutions for climate action are needed everywhere, CAN's assessment tools strive for global coverage, with an emphasis on urban areas. As data availability varies greatly from region to region across the planet, some of the tools are currently only available for Germany. The quality of the global indicators' databases also varies regionally, which can occasionally limit their usefulness. To mitigate this, we leverage globally available datasets such as remote sensing data or OpenStreetMap (OSM) and, if possible, integrate other heterogeneous datasets to increase coverage. To fill remaining data gaps, new methods using e.g. deep learning (DL) are in development.

Usefulness and usability. Assessment tools are created in close collaboration with partners such as NGOs and citizen initiatives, ensuring that the tools will provide added value for them. Usefulness is further supported by the high spatial resolution of the tools down to street level, the visualisation of intuitive and interactive maps, and the option to further analyse results with GIS. These features enable targeted and actionable insights at the micro-scale that assist stakeholders in making decisions.

CAN is a "living product". We, HeiGIT's Climate action team, can and will adapt its interface, data outputs, and both number and functionality of assessment tools based on partner requests and user feedback. It is an adaptive project that evolves in response to technical innovations as well as partner demands and needs.

3.2 Assessment Tools

Currently, the dashboard offers assessment tools in mainly two thematic areas: active mobility (with global coverage) and GHG emissions (currently only for Germany). For active mobility, it includes a walkability tool (hiWalk) and a bikeability tool (hiBike). For GHG emissions, CAN features both a heating emissions and a CO_2 budget estimation tool. Furthermore, there is a tool on CO_2 emission estimation from LULC change as well as one for land consumption. Tools on further thematic areas, e.g. transitability and rooftop solar, will be added over time.

Active mobility. The hiWalk and hiBike assessment tools provide indicators for the safety, comfort, and practicality of walkable and bikeable infrastructure in user-selectable areas of interest at urban scale. Both tools are based on OSM and remote sensing data and provide micro-scale, street-level indicators: A categorisation of walkable or bikeable paths depending on whether the path must be shared with other users (e.g., motorised traffic) (Fig. 1), and indicators on path smoothness and surface types. hiBike includes an additional indicator for dooring risk showing infrastructure that brings cyclists into the danger zone of opening doors from parallel parked vehicles.

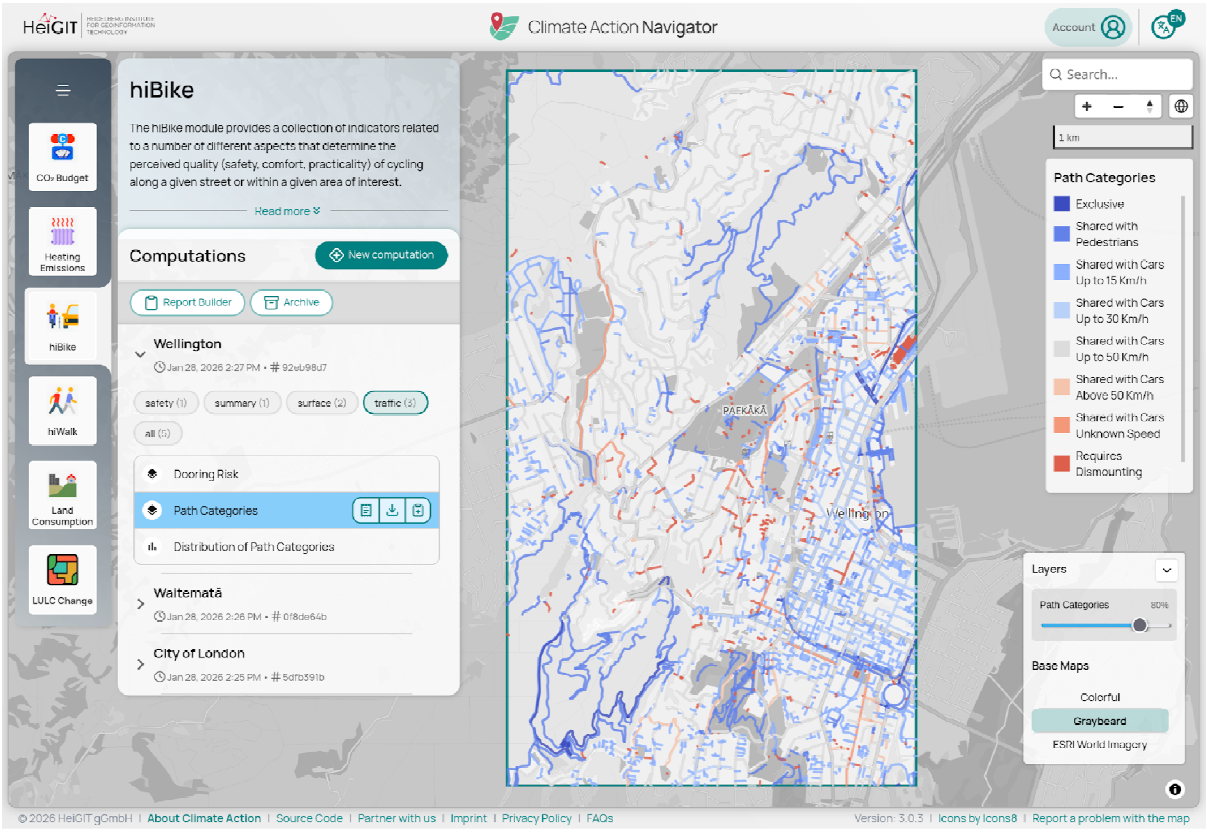


Fig. 1: hiBike Path Categories in a rectangle around downtown Wellington, Aotearoa (New Zealand).

Both tools feature an optional greenness indicator and a detour factor indicator. The former highlights green paths that feature more vegetation; the latter points out those areas where pedestrians or cyclists need to take large detours to reach their destination. While hiWalk and hiBike have global coverage in principle, their reliability varies from region to region due to differences in the quality of underlying OSM data. Another example of data scarcity is the usage street-side parallel parking, as mapped in OSM, as a proxy for dooring risk. We are developing deep learning methods to address these data gaps.

GHG emissions. The heating emissions tool (Kong et al. 2026, subm.) estimates scope 1 emissions from residential heating based on data from the German census of 2022 (Statistisches Bundesamt 2024) using a bottom-up approach. The tool provides maps showing absolute and per capita CO_2 emissions at 100 m spatial resolution (Fig. 2), as well as the drivers of those emissions, i.e., building construction year and the

corresponding energy consumption rates and building energy carrier, and the associated magnitude of emissions related to heating. The CO_2 budget assessment tool uses global carbon budget data (IPCC 2021) and emission data from German cities to calculate the remaining CO_2 budget that the selected city can still emit while adhering to shared commitments to limit global warming to 1.5 °C or at least well below 2.0 °C, according to the Paris Agreement (UNFCC 2016). The LULC Change tool uses carbon stock values from bookkeeping models (e.g., Hansis et al. 2015) to estimate the carbon flows caused by changes in land use and land cover. It uses a deep learning model to derive LULC changes from satellite data in a given time period.

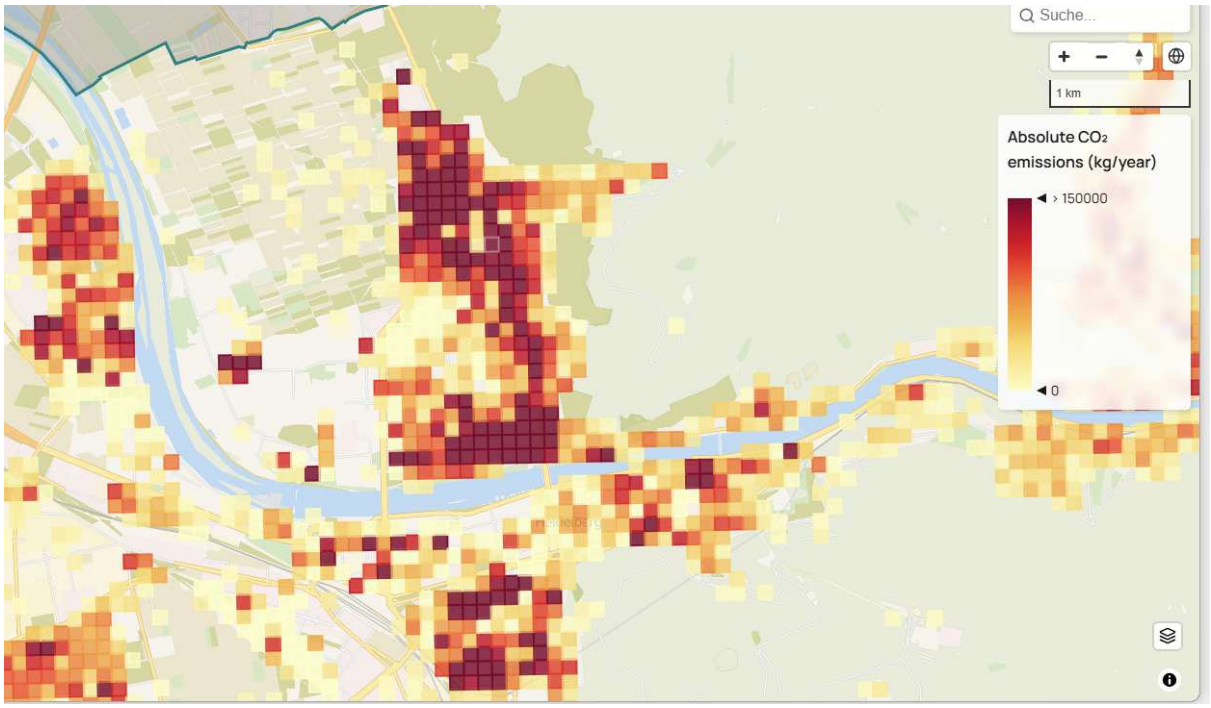


Fig. 2: Absolute CO_2 emissions from residential heating in Heidelberg.

Land consumption is assessed based on OSM data. The tool indicates how much land cover has been converted from natural land into built up infrastructure for various land uses in a given area. A tree map displays the percentage of consumed land (broken down into buildings, roads, and parking lots) as well as percentages of agricultural and unconsumed natural land.

Assessment tools under development. Ongoing work on a transitability assessment tool aims at providing indicators for the availability and quality of public transport, such as the number of services that can be reached within a reasonable distance from a given location, as well as stop coverage and frequency, based on publicly available schedules and OSM data. A prototype of a traffic emissions tool estimates street-level annual emissions from road traffic. It extrapolates traffic counts across the road network using road type data from OSM and population data from the Global Human Settlement Layer (Schiavina et al. 2023). It then applies emission factors from the COPERT emission calculator tool (Ntziachristos & Samaras 2024) based on speed limits as well as vehicle and fuel mix to estimate road traffic emissions. The tool will provide maps showing estimated traffic volume as well as CO_2, CO, and NO_x emissions for each road segment. A yet unpublished rooftop solar tool analyses aerial imagery to detect rooftop solar panels and display their amount, locations, and spatial distribution in an area of interest. Another assessment tool in early stages of development uses deep learning to monitor subtle land cover changes based on remote sensing data and AlphaEarthembeddings (Brown et al. 2025), to combat land degradation processes with an initial focus on steppe environments in Mongolia.

4 EMPOWERING STAKEHOLDERS: DATA-DRIVEN DECISION MAKING WITH THE CLIMATE ACTION NAVIGATOR

CAN's assessment tools are designed to empower stakeholders through a data-driven approach, enabling them to make informed decisions for effective climate action. These tools are created in a partner-driven fashion, in close collaboration with stakeholders such as NGOs or municipal administrations. To this end,

HeiGIT's climate action team employs a partner workshop process that allows us to apply design-thinking techniques (Rösch et al. 2023) with the respective partners as equals. This collaborative approach ensures that the indicators are directly applicable in practice and tailored to the specific demands and needs of the partners.

One example of this empowerment is HeiGIT's collaboration with the citizens' initiative Klimanetz located in Heidelberg, Germany, to develop the CO_2 budget tool. It displays local GHG emission trends and encourages discussions with the general public, activists, and policy makers based on facts and scientific insights. Furthermore, the tool enables comparisons between Heidelberg's emissions with those of four other German cities, providing valuable context for local climate action efforts. While the tool was initially developed for Heidelberg only, we have included more cities since and plan to expand it further.

During the co-creation process of the tool, a series of idea incubation workshops was held together with Klimanetz, using virtual collaborative workspaces. Within the workshop series, at first initial requirements for the tool were defined, such as the tool's objective and success measures. Next, different user stories were developed to understand the requirements of various user groups, e.g., activists and decision makers. In a third step, the planned tool features were prioritised, so that we were able to develop a demo version. The final workshop was held to review the tool to ensure that the tool is actually usable and useful for Klimanetz and other potential users.

Furthermore, partnerships with scientists have emerged and ensure that CAN's indicators mirror scientific advancements. One notable collaboration is with the environmental physicists at Heidelberg University, where we are developing a CO_2 emissions inventory of the Rhine-Neckar region in southwest Germany. They are using CAN's emission data as input for a model to simulate CO_2 concentrations in the urban atmosphere at high spatial resolution, and to optimize the placement of CO_2 sensors in a monitoring network (Vardag & Maiwald 2024). follows a looser approach with regular meetings, providing valuable input for the development of the emission estimation methodology and tailoring the emission inventory to meet scientific requirements. The heating emissions tool, as well as the traffic emissions tool currently under development, are direct outcomes of this cooperation. Through these tools, CAN effectively translates the latest scientific insights into practical tools, thereby linking scientific knowledge with climate action. This empowers stakeholders by providing them with reliable and actionable data to inform their decision-making process.

Attempting to establish partnerships around the world plays an important role for CAN's continuous development and improvement. However, a bias towards European partners is obvious, such as the WWF Austria, Walkspace.at, Radlobby Austria, or Someware in France, which limits the applicability of our tools outside of Europe. Yet, we are collaborating with the Lagos Urban Development Initiative (LUDI) in Nigeria to develop walkability indicators that address issues in Western African cities. Additionally, we are in the process of establishing further collaborations with stakeholders from countries of the Majority World to expand the reach and the impact of CAN.

5 CONCLUSION: YES, WE CAN ACT NOW

In conclusion, CAN serves as an adaptable tool for stakeholders engaged in climate action. With its principles of openness, transparency, global coverage, and co-creation, it provides essential data to support informed decision-making for climate action. The dashboard currently offers assessment tools in the realms of active mobility and GHG emissions, with plans to expand into additional thematic areas in the near future, e.g. transitability and land degradation.

One of the main strengths of CAN is its development through a collaborative and transdisciplinary co-creation process involving experienced partners from relevant fields. This approach ensures that CAN's tools are tailored to meet the specific demands and purposes of its users. However, this strength may be reduced in those areas where open data, e.g., OSM data, is limited. As a living product it allows for continuous adaptation of its interface, data outputs, and assessment tools in response to feedback or changing framework conditions.

The time to act on climate change is now. Delaying effective climate action will only exacerbate the challenges we face and limit our options for mitigation and adaptation. We invite NGOs, citizen initiatives, and other stakeholders to collaborate with us, leverage CAN's tools, and implement effective climate action tools tailored to their specific needs and contexts. While the challenges of climate change are significant, we

are committed to working towards the best possible future. CAN aids urban climate action, inspiring stakeholders to take immediate and effective measures, and making it one of the “right tools” for urban climate action. Yes, we can act now.

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