reviewed paper

From Urban Design to Energy Simulation – a Data Conversion Process Bridging the Gap Between Two Domains

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1 ABSTRACT

Rapid urbanisation and the ever-growing world population have put a heavy toll on world climatic conditions especially in the way existing and new urban developments emit carbon. As per an estimation[1], 28% of all energy related carbon emission worldwide accounts for energy used to heat, cool and light the buildings. In this context along with new approaches in urban designs, it requires continuous new technological developments, smart tools, and processes that can audit these urban designs particularly based on its energy efficiency. This calls for the development of a common process which supports urban designers, sustainable technology experts, and geospatial technology experts alike in producing results which help a) to reach sustainable city targets and b) to create climate change mitigation and adaptation strategies. A major technical challenge in developing such a process is the heterogeneity of tools, methods and data formats that architects, urban designers, sustainability experts, and geospatial pundits traditionally work with. This paper tries to counter this challenge and derive an exemplary data exchange process between commonly used urban design tools Rhinoceros3D, AutoCAD, Esri CityEngine and the Open Geospatial Consortium (OGC) standardised open data model of CityGML version 2.0 aiming to assess new urban designs regarding cities' energy demands using 3D City Models.

Keywords: Data Interoperability, Geometric Modelling, Urban Design, Energy Simulation, CityGML

2 INTRODUCTION

Urban design, on the one hand, as a process of shaping and characterising new neighbourhoods are becoming more complicated due to the rapid expansion of cities. On the other hand, urban design is getting more scrutinised than ever before, particularly regarding carbon emission reduction, as well as climate-responsive building designs. Conventional urban design methods focused more on designing and characterising the physical arrangement of urban elements in the neighbourhood but lacked performance assessments such as building stock energy audits for the proposed urban design. However, with the rapid evolution of computer science and geospatial technologies, modern urban design methods involve continuous use of 3D city modelling for better understanding, planning, and visualisations of the urban design (Chundeli, 2017). In present times, applications of 3D city models have gone far beyond visualisation (Biljecki et al., 2015). One such domain, where these virtual 3D city models find themselves increasingly used is in City Energy Modelling (CEM). CEM relies on a bottom-up approach to know the total energy demand of cities and districts by analysing its building stock's energy demand. One way to analyse building stock energy demand is by using individual building geometries and their characteristics. To store and share such semantically rich 3D city models, City Information Models (CIM) has been developed. One such standardized open data model to store and share 3D semantic city models is CityGML.[2] With the continuous development and implementation of CityGML, as of today, buildings of more than 100 megacities (under open data initiatives from different governments) are freely available for public use on different Level of Details (LoD):[3] LoD1 represents buildings in block models while LoD2 includes additional roof geometries. LoD3 in addition to LoD2 also includes building openings e.g. doors and windows. LoD4, in addition to LoD3 also includes building interiors (Biljecki, 2013) (LOD4 data are normally not distributed as open data due to privacy issues). CEM software, such as SimStadt[4], make use of these CityGML models to calculate building stock

[1] Global Status Report 2017 published by International Energy Ageny, United Nations.
[2] https://www.opengeospatial.org/standards/citygml
[3] https://3d.bk.tudelft.nl/opendata/opencities/
[4] An urban energy simulation platform developed at University of Applied Sciences – HfT Stuttgart.

energy demands. Additionally, SimStadt also helps in simulating energy demands based on different refurbishment scenarios (Nouvel et al., 2014).

The application of SimStadt, an energy demand simulation for existing buildings has been successfully demonstrated by Nouvel et al. (2015), but it remains interesting to see how new urban designs can be converted into CityGML based open data model e.g. for use in SimStadt. A challenge in such a study is to produce error-free CityGML building geometries which can be used for analysis and simulations tasks within the tools which were initially used to sketch new urban designs (Biljecki et al., 2016). To address this challenge, the three case study regions, namely Gowanus (Brooklyn – New York, USA), Nordwestbahnhof (Vienna, Austria) and Wienerplatz (Stuttgart, Germany) were probed. The case studies regions of New York and Vienna were modelled using Rhinoceros3D. In the case of Vienna, the project also utilised the Rhinoceros3D'S parametric plugin of Grasshopper before converting it to CityGML LoD1. For the CityGML conversion, the Feature Manipulation Engine (FME) has been used to create the buildings' and building parts' geometry. The case study region of Stuttgart was modelled in LoD2 using Esri's CityEngine before converting it to CityGML, also using FME. The resulting CityGML geometries were then simulated with SimStadt to compute their heating demand. Additionally, in the Stuttgart case, the photovoltaic potential of roof surfaces was also calculated using the converted LoD2 models.

The aim of this paper is, to describe the data conversion process leading to above-mentioned datasets and shall serve as a guideline to generate simulation ready semantic CityGML building models. Such a well-defined data exchange process, between commonly used 3D modelling urban design software and energy simulators, supports initiating a workflow especially between urban designers and sustainability experts to produce enhanced outcomes of both the domains.

The work presented by the authors in this paper is carried out during an ongoing project "Integrated analysis and modelling for the management of sustainable urban food water energy ReSOURCEs (IN-SOURCE)".[5]

3 TOOLS, TECHNIQUES AND DATA FORMATS USED FOR 3D CITY MODELLING

3D city models are georeferenced, digital semantic models representing real-world physical elements such as buildings, vegetations, street furniture, terrain surfaces and landscapes in three dimensions. Past decades have witnessed the evolution of many different tools, techniques and data formats that are used for developing, managing and visualising 3D city models. A typical city model can be constructed automatically or semi-automatically from various acquisition methods such as aerial images and maps (Buyukdemircioglu et al., 2018), stereo satellite images (Kocaman et al., 2006), synthetic aperture radar (SAR) (Sharafzadeh et al., 2018) and LiDAR point clouds (Buyuksalih et al., 2019). Along with these photogrammetric and remote sensing tools and techniques, processes for constructing 3D city models using vector datasets from computer-aided design (CAD) and geographic information systems (GIS) have also been in practice for a long time. Last but not least, using shape grammar for 3D city models (Dobraja, 2015), implementing urban planning with procedural modelling using Rhinoceros3D (Fink, 2018), utilising OpenStreetMap to generate 3D models (Over et al., 2010) and, modelling 3D buildings using CAD-based software such as Autodesk InfraWorks or SketchUp (Wang et al., 2012) have all been widely used techniques to create a digital twin of cities.

Elements of 3D city models are encoded in data formats. Each tool used to generate the 3D city models will produce outputs in its own readable data format. Exemplary data formats, used by architects, urban designers, geoinformatics experts, and municipalities worldwide, range from CAD software such as AutoCAD (.dwg) or (.dxf) over 3D multipatch shapefiles from Esri ArcGIS and CityEngine (.shp) to COLLADA (.dae) and the native data format of Rhinoceros3D (.3dm). Moreover, during the last decade, the XML based open data model of CityGML has gained a lot of user attraction because of its capability to not only store georeferenced 3D city models but also the ability to store semantics and topological information of these 3D city models (Kolbe, 2009). OGC approved CityGML encoding standards[6] form the basis on how real-world physical elements must be stored and represented as virtual 3D city models in CityGML. Storage and representation of these 3D city models should follow a certain set of rules and regulation defined as conformance requirements in the encoding standards. These conformance requirements are particularly

[5] https://www.hft-stuttgart.de/Forschung/Projekte/Projekt208.html/en
[6] https://portal.opengeospatial.org/files/?artifact_id=47842

important when 3D city models in CityGML are to be used beyond visualisation such as in analysis and simulation (Coors et al., 2020). The 3D City Database (a.k.a 3DCityDB), an open-source 3D geo-database is used to store, represent and manage CityGML datasets in a relational database which is providing the additional capability to perform complex analytical tasks beyond visualisation. Additionally, to store 3D objects and their semantics which are not a part of core CityGML schema, CityGML application domain extensions (ADE) can be developed. As of 2018, 44 CityGML ADEs supporting various applications have already been developed and used (Biljecki et al, 2018). However, it is worth mentioning that new geometrical objects and related properties, introduced as a part of any CityGML ADE, by default inherit characteristics of the CityGML encoding standard and do not relate with data interoperability between CityGML and any other data formats. In a simple term, CityGML ADEs are placed on top of CityGML to enrich its core schema to accommodate application-specific new objects and their features.

As there are so many different tools and data formats available and used by various domain experts, one of the current issues and challenges in 3D city modelling is the definition and development of a data exchange interface to produce joint outputs when combining different domains (Billen et al., 2014). This is, in particular, true for architects and urban designers, who, along with their building stock designs, are also interested in the assessment of these building stocks based on their energy demands. Typically, architects and urban designers use tools like Rhinoceros3D (with its parametric plugin Grasshopper), AutoCAD and Esri CityEngine for proposing new urban designs, while geospatial and urban energy simulation experts use CityGML as an input for their CEM software such as SimStadt. Neither Rhinoceros3D nor AutoCAD or Esri CityEngine can produce CityGML datasets out of the box. In a related paper, Jesus et al. (2018) demonstrated a data conversion process from Rhinoceros3D to CityGML. As an input, a shapefile was first imported into Rhinoceros3D with its Heron plugin and then extruded to produce a 3D geometry. This 3D geometry was later exported to COLLADA file using Rhinoceros3D built-in file export functionality before converting it into CityGML LoD1 using FME. However, since the focus of this work was on visualisation, conformance requirements for CityGML buildings were not considered during the conversion process. Such a translation process justifies visualisation output but is not recommended for analysis and simulation exercises such as calculating energy demands of buildings using 3D city models. Furthermore, the building footprint shapefile, when extruded, produced a uniformly extruded block model, which, in reality, is not always a relevant geometry for all building types as most buildings have building parts, too, which can have different building geometries and attributes than the main building. In particular for architects and urban designers who are not always GIS users, unanswered questions still remain, like (i) how to translate building geometries to CityGML buildings which are originally modelled in a non-georeferenced local coordinate system using Rhinoceros3D without importing georeferenced shapefiles of building footprints? (ii) How to translate Rhinoceros3D buildings having building parts and related attributes to CityGML adhering to the conformance requirements of the encoding standard for CityGML?

In another study, Billen et al. (2014) mention that Esri CityEngine shows LoD1 modelling for CityGML well, but there is still a problem in using it to model buildings with roofs and building openings for translating it to valid CityGML LoD2 and LoD3 geometries respectively. This issue was once again highlighted by Janečka (2019) in their Esri shapefile to CityGML conversion. Output CityGML dataset only contained property of gml:building having multisurface geometry to justify their results for visualisation purpose. However, as per CityGML conformance requirement 10.3.9.4, required semantic information of ground, wall and roof surfaces for LoD2 buildings were missing. Considering both the studies ones again the same question stands, how to translate 3D geometries particularly of LoD2 from CityEngine to CityGML with semantics which is following the CityGML conformance requirements?

4 GEOMETRY VALIDATION IN CITYGML FOR ANALYSIS AND SIMULATION

The quality of results produced by any analytical or simulation software directly relies on the quality of the input data. The same is true for 3D city models and CityGML. With an increasing number of users using CityGML models for various analysis and simulation (Biljecki et al., 2015) use cases, such as solar radiation analysis, visibility analysis, noise propagation in traffic planning, wind flow analysis, flood damage analysis, data quality and consistency approaches of CityGML datasets are now being thoroughly investigated. OGC itself launched the CityGML Quality Interoperability Experiment to study and investigate aspects of schema conformance, geometry and, semantics validation and validation of conformance requirements for CityGML

ISBN 978-3-9504173-8-8 (CD), 978-3-9504173-9-5 (print)
Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI, Clemens BEYER, Judith RYSER, Christa REICHER, Canan ÇELIK

datasets (OGC, 2016).[7] As an outcome of the experiment, different software packages were developed, and several recommendations were given to improve the quality and consistency of CityGML models. In his article, Biljecki et al. (2016) have synthesised most regularly occurring geometric and semantic errors in CityGML datasets. Based on his findings and other similar investigations (Coors et al., 2020), several tools such as val3dity (Ledoux, 2018), FME geometry validator and CityDoctor[8] are in continuous development. Furthermore, based on the validation report, FME geometry validator and CityDoctor can also automatically heal building geometries of CityGML to a certain extent. (Alam et al., 2013).

Since this paper is also dealing with an energy demand simulation test case, in particular, validation of building solid geometries and face orientation of building surfaces is critical as those directly affect the building volume calculation and therefore energy demand calculations. In their article, Coors et al. (2020) proved this by comparing the building volume of a correct building solid geometry with an error-prone building solid geometry. Hence, to compute a correct building volume, it becomes very important that building solid geometries in CityGML are created correctly following the conformance requirement 10.3.9.4 of the CityGML encoding standard. As an example, based on this CityGML conformance requirement, Padsala and Coors (2018)[9] explained how to insert building solid geometry in CityGML building and building part datasets using FME.

Considering the above-mentioned validation parameters and adhering to the CityGML encoding standard, this paper tries to overcome some data interoperability limitations mentioned in chapter 2 and explains how to translate valid CityGML geometries from Rhinoceros3D and Esri CityEngine that can be used for analysis and simulation such as of energy demand calculation using SimStadt.

5 DATA CONVERSION FROM URBAN DESIGN TO ENERGY SIMULATION

5.1 Case Study 1: Gowanus (Brooklyn, New York, USA)

The case study region of Gowanus (previously known as South Brooklyn) represents a neighbourhood in the New York City (NYC) borough of Brooklyn. Formerly, a dominant industrial zone, it is now under rezoning led by NYC's planning department, the American Institute of Architects New York Chapter (AIANY), New York Institute of Technology (NYIT) and community stakeholders.

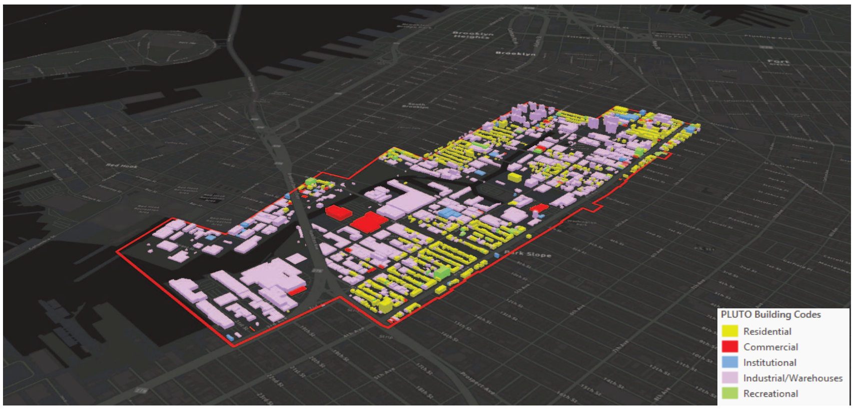


Fig. 1: Gowanus existing land use 3D map

Based on population projections and following NYC landuse mapping guidelines, a full build-out redeveloped 3D scenario was modelled in LoD1 using Rhinoceros 3D. i.e all the building footprints were applied with the highest and best use of available zoning laws. The redeveloped 3D scenario was modelled in a non-georeferenced local coordinate system.

[7] http://mail.opengeospatial.org/lists/lt.php?id=fR4CDVYeAlJfHwhTCwA
[8] https://www.citydoctor.eu/index.php/citydoctor_main.html?language=en
[9] https://gitlab.com/volkercoors/CiD4Sim/-/wikis/usefulTools/FME-Workbenches

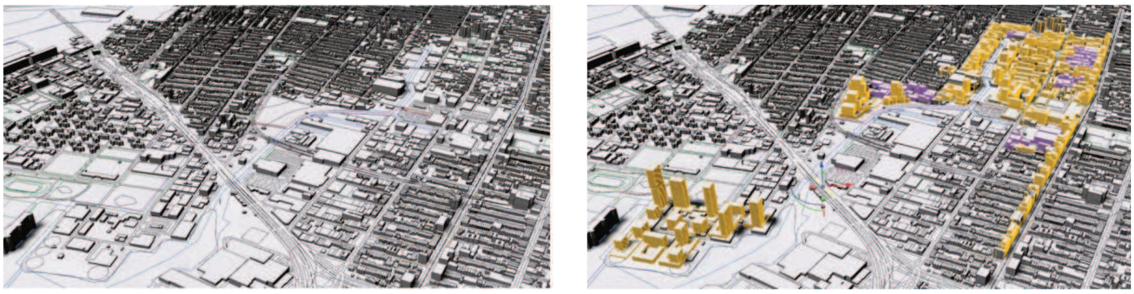
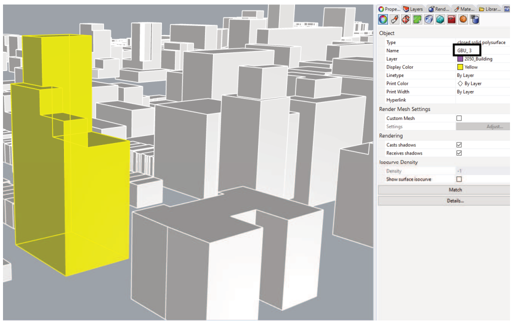


Fig. 2: Left figure shows existing building stocks, the right figure shows new building stocks modelled in Rhinoceros3D

Each building geometry was given a unique ID to be later used during the conversion to CityGML. In a separate spreadsheet, related building attributes of the year of construction and building functions were maintained, for each building ID, which represents the minimum set of attributes to calculate an energy demand using SimStadt. In this particular use case, overlapping, intersecting or adjacent building parts, belonging to the same building but having different building heights, were modelled as single building geometries, instead of an individual building part of the building. Since Rhinoceros3D cannot export semantics for geometries, a comment column with the value "Building" was specified against each building ID in the above-mentioned spreadsheet.



	B	C	D	E
1	ID	Year	Land Use	Comment
2	GBU_0	1970	E1	Building
3	GBU_1	1930	E1	Building
4	GBU_2	1917	C1	Building
5	GBU_3	2050	RC	Building
6	GBU_4	2010	RM	Building
7	GBU_5	2035	RC	Building
8	GBU_6	2045	RC	Building
9	GBU_7	2045	RI	Building
10	GBU_8	2035	RW	Building
11	GBU_9	2045	05	Building
12	GBU_10	2050	F5	Building
13	GBU_11	2050	F4	Building

Fig. 3: Left figure shows building geometry with ID in Rhinoceros3D, the right figure shows its related information

For this use case, the end to end workflow from urban design to the energy simulation can be represented as below (Fig. 4). The FME workbench used for Rhinoceros3D to CityGML conversion will be discussed in chapter 6 section 6.1.

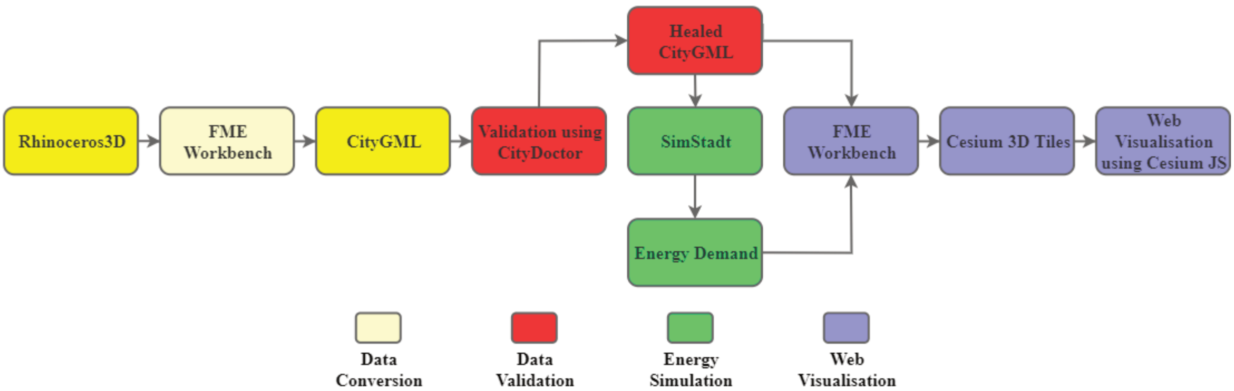


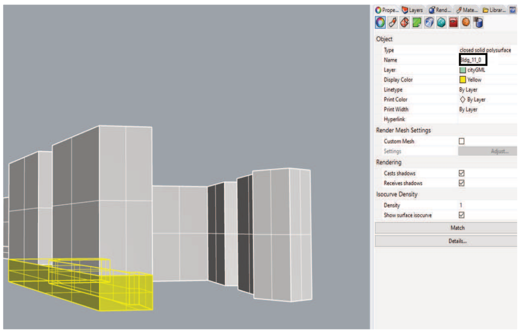
Fig. 4: Workflow Diagram

5.2 Case Study 2: Nordwestbahnhof (Vienna, Austria)

The Nordwestbahnhof case study focuses on the application of the parametric urban design strategy on a central site in Vienna. The use of parametric modelling techniques allows generating a broad set of urban design variants that meet the criteria of sustainable development targets. The goal is, to create and simulate different designs to achieve a decision basis and to draw a possible outline for further steps. As a first step, the described urban development model of the Nordwestbahnhof was modelled in LoD1 using Rhinoceros3D and its parametric plugin of Grasshoper3D based on a georeferenced building footprint shapefile.

Fig. 5: A 3D Map of Nordwestbahnhof

This use case differs from the previous use case of Gowanus in the way the building models are designed. As, in the case of Gowanus, overlapping, intersecting or adjacent building parts, belonging to the same building but having different building heights were modelled as single building geometries, for Nordwestbahnhof, algorithms were applied in Grasshopper to correctly classify the volumes into single buildings and buildings coupled with their building parts. Each building geometry was given a unique ID to be later used during the conversion to CityGML. In a separate spreadsheet, for each building ID related building attributes of the year of construction and building functions were maintained. Furthermore, to preserve the hierarchical structure of CityGML (i.e building consists of building parts) for each unique ID, a parent ID was introduced. “Building” and “BuildingPart” were used as semantic parameters within the comment column to identify buildings with or without building parts.



Bldg_Parent_ID	Bldg_ID	Comment	block	use	m2	floors	height[m]
Bldg_0	Bldg_0_0	BuildingPart	11b	office	14656	9	27
Bldg_0	Bldg_0_1	BuildingPart	11b	commercial	1628	1	4
Bldg_0	Bldg_0_2	BuildingPart	11b	residential	11815	20	60
Bldg_0	Bldg_0_3	BuildingPart	11b	residential	3568	12	36
UUID_1	Bldg_1	Building	3s	school	6347	2	8
UUID_2	Bldg_2	Building	6	school	5987	2	8
UUID_3	Bldg_3	Building	6	school	3278	2	8
UUID_4	Bldg_4	Building	6	school	3470	2	8
UUID_5	Bldg_5	Building	13	school	3497	2	8
UUID_6	Bldg_6	Building	13	school	3622	2	8
UUID_7	Bldg_7	Building	13	school	3631	2	8
UUID_8	Bldg_8	Building	13	school	3557	2	8
UUID_9	Bldg_9	Building	2	office	15524	13	39
UUID_10	Bldg_10	Building	2	office	8806	13	39
Bldg_11	Bldg_11_0	BuildingPart	2	commercial	4725	2	9
Bldg_11	Bldg_11_1	BuildingPart	2	office	16217	13	39
Bldg_11	Bldg_11_2	BuildingPart	2	office	10598	13	39
UUID_12	Bldg_12	Building	8	office	804	1	3

Fig. 6: Left figure shows building geometry with ID in Rhinoceros3D, the right figure shows its related information

For this use case, the end to end workflow remained the same as in the use case of Gowanus (See chapter 5, section 5.1, Fig.4). However, the FME workbench used to convert Rhinoceros3D to CityGML was updated to write both gml:Building and gml:BuildingPart, this is further discussed in chapter 6, section 6.2.

5.3 Case Study 3: Wienerplatz (Stuttgart, Germany)

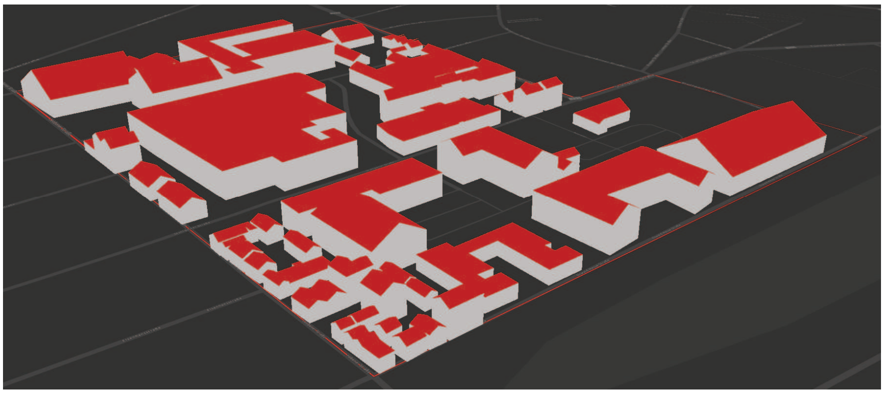


Fig. 7: A 3D Map of Wienerplatz

The case study region of Wienerplatz was modelled using Esri’s CityEngine. Initially, building footprints from AutoCAD were converted to a georeferenced 2D shapefile before importing it into CityEngine. Unlike the above two use cases, instead of a spreadsheet, attributes related to each building footprint such as building height, roof type, year of construction and building function were stored in a shapefile. Inside CityEngine, a certain rule-based algorithm known as computer generated architecture (CGA) shape grammar[10] was applied on the shapefile dataset, which generated LoD2 building models based on its geometry and attributes.

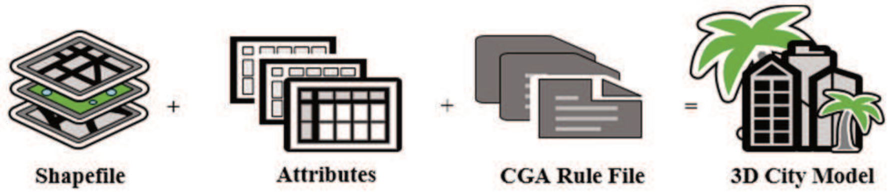


Fig. 8: 3D city modelling workflow in Esri CityEngine

An end to end workflow for the use case of Wienerplatz can be represented as below (Fig. 9). The FME workbench used for CityEngine to CityGML conversion is discussed in chapter 6 section 6.3.

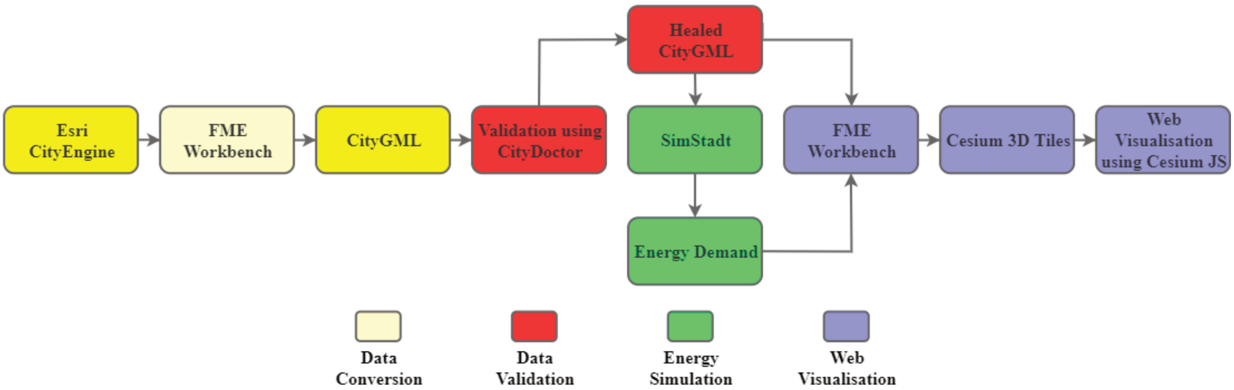


Fig. 9: Workflow Diagram

6 RESULT AND DISCUSSION

6.1 Case Study 1: Gowanus (Brooklyn, New York, USA)

The workflow represented for the use case of Gowanus resulted in the following output

Fig.10: Left figure shows 3D models in Rhinoceros3D, the right figure shows its heating demand visualised on cesium globe

The FME workbench, used to generate the CityGML LoD1 building dataset from Rhinoceros3D data, can be represented as shown below (Fig. 11). Since FME doesn't support the native data format of Rhinoceros3D (.3dm), 3D building models from Rhinoceros3D were exported to COLLADA using inbuilt COLLADA exporter as a first step and were then imported into FME alongside its relevant attribute spreadsheet.

[10] https://doc.arcgis.com/en/cityengine/2019.0/cga/cityengine-cga-introduction.htm

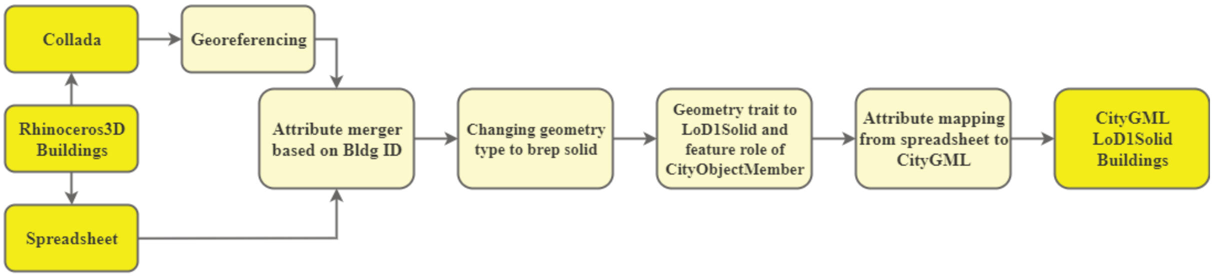


Fig. 11: FME Workbench Diagram

Since the redeveloped 3D scenario of the use case of Gowanus was modelled in a local coordinate system of Rhinoceros3D, georeferencing was done in FME using "3DAffiner" transform. An openly available CityGML dataset of NYC was used as a reference. Alternatively, if no such georeferenced datasets are available for reference, the "EarthAnchorPoint" command in Rhinoceros3D can also be used to georeference the data in the WGS84 spatial reference system. The data can then be projected to the required projected coordinate system using FME. In the case of the Gowanus data, misoriented surface normals of the 3D models were encountered which lead to wrong orientation in Rhinoceros3D and in return, to an incorrect translation into CityGML during the conversion process. In the end, CityDoctor was used to validate the resulting CityGML geometry and to heal wong surface normals. Alternatively, the geometry validator of FME could also be used to perform validation and repair tasks. The healed CityGML dataset was then used for the simulation within SimStadt to compute the heating energy demand of the buildings. Afterwards, the results were again combined with CityGML to visualise them on the web framework CesiumJS[11] by using 3D Tiles.

6.2 Case Study 2: Nordwestbahnhof (Vienna, Austria)

Workflow represented for the use case of Nordwestbahnhof resulted in the following output

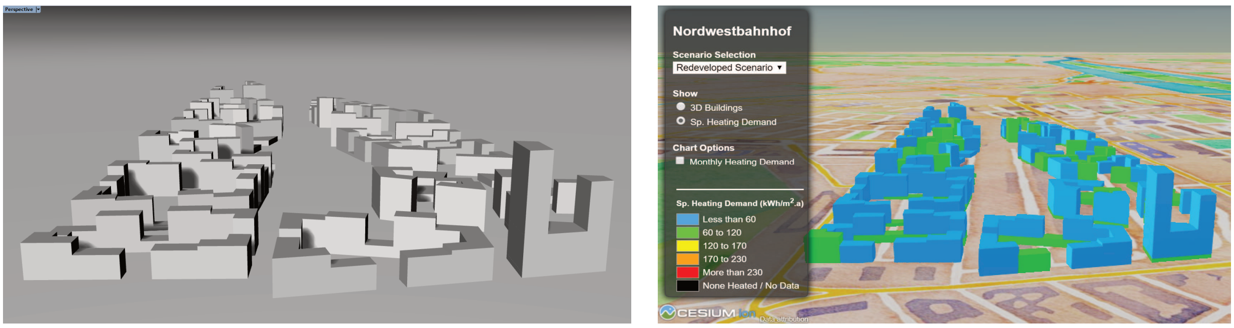


Fig.12: Left figure shows 3D models in Rhinoceros3D, the right figure shows its heating demand visualised on cesium globe

The FME workbench used to generate CityGML LoD1 building with its building part dataset from Rhinoceros3D can be represented as below (Fig. 13).

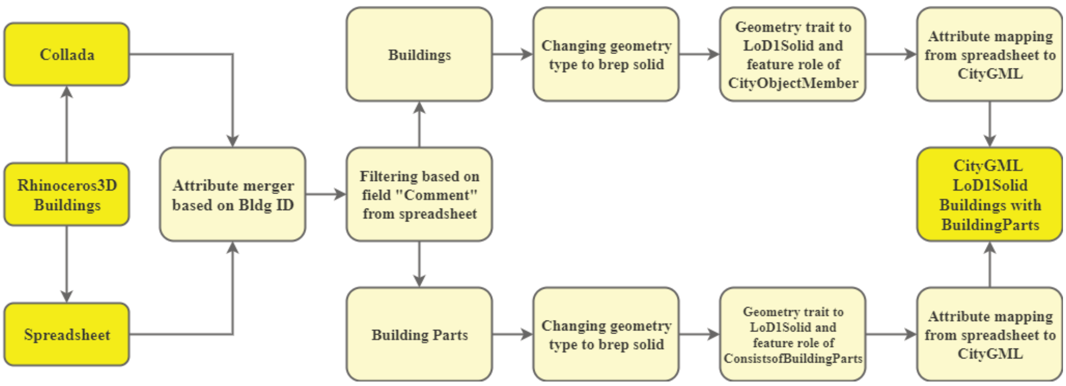


Fig. 13: FME Workbench Diagram

[11] CesiumJS is an open source javascript library used to develop interactive 3D geospatial applications for web.

For the case of Nordwestbahnhof, 3D building geometries in Rhinoceros3D were modelled on top of an imported georeferenced building footprint shapefile. Hence, “3DAffiner”, as used in the use case of Gowanus, was not needed. Furthermore, separate geometries with relevant semantics for building parts and integrating them with its related attributes’, proved to be an added benefit, particularly during the energy calculations in SimStadt. In this way, heating energy demand for individual building parts within the same building, taking into account different building uses and geometrical appearance, could be calculated.

6.3 Case Study 3: Wienerplatz (Stuttgart, Germany)

Workflow represented for the use case of Wienerplatz resulted in the following output

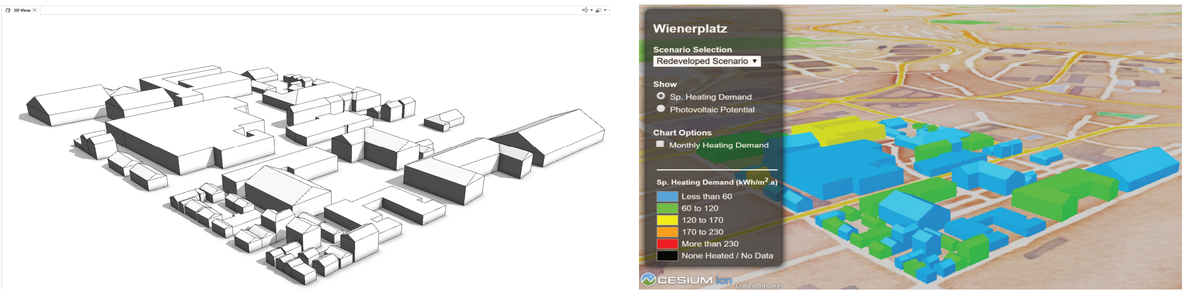


Fig. 14: Left figure shows CityEngine 3D model, the right figure shows its heating demand visualised on cesium globe

The FME workbench used to generate CityGML LoD2 building from Esri CityEngine can be represented as shown below (Fig. 15). As an input to FME, 3D building models from CityEngine were first exported as a 3D multipatch shapefile using its inbuilt shapefile exporter and then imported into FME for further conversion to CityGML.

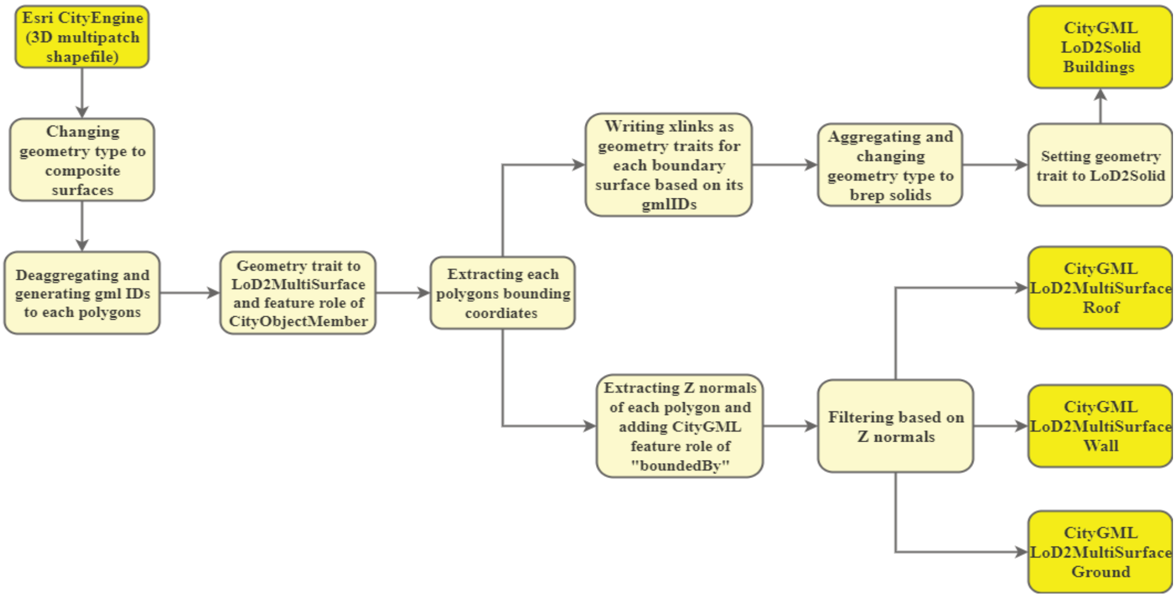


Fig. 15: FME Workbench Diagram

Since LoD2 CityGML building datasets were produced for Wienerplatz, a photovoltaic potential analysis of roof surfaces for individual buildings was also made possible within SimStadt.

As an alternative to the workflow described for Wienerplatz, Esri’s data interoperability extension for ArcGIS Pro was also tested. However, the produced CityGML building geometry was defined as a generic city object having a LoD4 multi-surface geometry which was not following the encoding standards of CityGML for LoD2 building datasets. As a result, even though the produced CityGML dataset could have been used for visualisation purposes, it could not be used for heat demand and photovoltaic potential analysis within SimStadt.

A reverse workflow from CityGML to 3D multipatch shapefiles, with integrated heating demand and photovoltaic potential results from SimStadt, is explained by Padsala and Coors (2015) in their article.

Fig. 16: SimStadt's photovoltaic potential analysis of roof surfaces visualised on cesium globe

7 CONCLUSION

Since 3D city models encoded in the open data format of CityGML are increasingly used for analysis and simulation, it becomes critical that the geometries and semantics are modelled correctly following the encoding standards set by the OGC. Thus, this article sought to identify and explain some of the difficulties and obstacles encountered when implementing data interoperability between commonly used 3D city modelling tools like Rhinoceros3D, Esri CityEngine and CityGML using three use cases as examples. The differences among the use cases lay in the way building geometries were modelled in Rhinoceros 3D for the use case of USA (LoD1 buildings) and Austria (LoD1 buildings with their building parts), while for the use case of Germany, 3D building models were created using Esri's CityEngine. These 3D building models, once converted to CityGML, were then used as an input to the urban energy simulator SimStadt. They were based on the geometry, semantics and other attributes such as building function and year of construction. Buildings were analysed and heating demands, along with photovoltaic potentials of roof surfaces (only in the case study of Germany), were calculated and visualised on the web using CesiumJS. Thus, the method presented in this paper successfully demonstrates one approach were different tools, techniques and data formats used by urban designers, sustainability experts and geospatial pundits can be integrated to deliver joined outcomes that fulfil the targets of a sustainable city and the climate change mitigation and adaptation goals. This forms a starting point in developing an intelligent digital environment that supports informative decisions and facilitates the exchange of information between stakeholders. This investigation also opens further research in data exchange methods for LoD3, LoD4, and BIM-CityGML scenarios which can be further used for analysis and simulations.

8 ACKNOWLEDGEMENTS

We would like to give our acknowledgements to the JPI Urban Europe, the Belmont Forum, the Federal Ministry of Education and Research – BMBF Germany and the Federal Ministry Republic of Austria Transport, Innovation and Technology for their financial support to the project IN-SOURCE. We would also like to thank our IN-SOURCE project partners from the west, New York Institute of Technology (NYIT) and the Central University of New York (CUNY) for their continued help and support. We would also like to extend our sincere thanks to the project "SimStadt" for giving us the necessary data required for the case study of Wienerplatz.

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ISBN 978-3-9504173-8-8 (CD), 978-3-9504173-9-5 (print)
Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI, Clemens BEYER, Judith RYSER, Christa REICHER, Canan ÇELIK