Nature-Based Solutions through Blue-Green Infrastructure as Measure of Adaptation, Resilience and Liveability to Climate Change: Case Study City Lab Saltillo, Mexico

Catalina Diaz, Eduardo Santillán-Gutiérrez, Gabriela De Valle, Carmina Villarreal

(M.Sc. Catalina Diaz, Universitaet Stuttgart, Nobelstrasse 12, 70569 Stuttgart, Germany, catalina.diaz@iat.uni-stuttgart.de)
(Dr. Eduardo Santillán-Gutiérrez, Tecnológico de Monterrey, Centro del Agua, Av. Eugenio Garza Sada Sur No. 2501, Monterrey, Nuevo León, México, eduardo.santillan.gtz@tec.mx)
(M.Sc. Gabriela De Valle, Municipal Planning Institute Saltillo, Blvd. Colosio 290-3 Col. Valle Real, Saltillo, Coahuila, gdevalle@gmail.com)
(B.Ec. Carmina Villarreal, Municipal Planning Institute Saltillo, Blvd. Colosio 290-3 Col. Valle Real, Saltillo, Coahuila, cvillarreal@implansaltillo.com)

1 ABSTRACT

The impacts of the current urbanization and climate change challenges are well documented, as well as, the role of cities and the urgent action that needs to take place at the local level, especially in small and middle-sized cities. As extreme climatic events unfold, there is a need to identify the potential and the strategies that can help municipalities steer urban planning on a more sustainable and resilient track to reach the global climate goals within the next decade. Now more than ever, Nature-based solutions (NbS) such as Blue-green infrastructure(BGI) are proving to be a feasible alternative for cities to adapt their urban environment in response to climate change, while simultaneously obtaining economic, environmental, and social co-benefits.

Anticipating climate challenges in cities makes it vital to change today's traditional urban planning into initiatives that consider greener solutions like BGI. However, some implementation barriers such as the lack of stakeholders' involvement to navigate and co-create a more resilient and adaptive city environment, make difficult the transition.

As part of the Morgenstadt Global Smart Cities Initiative (MGI), financed by the German Government through the International Climate Initiative (IKI), the city of Saltillo located in the Northeast region of Mexico is paving the path towards sustainable urban planning through the City Lab project. In the first phase, the City Lab consisted of an integrated urban analysis, stakeholder engagement, and the co-creation of a roadmap of solutions by experts and local actors to tackle the city's urban challenges. The City Lab process allowed anchoring the identified measures in the planning documents of Saltillo, ensuring the implementation of the roadmap in the long term. Simultaneously, it opened up spaces for co-creation and community engagement valuable to understand the city´s local environment and identify its potential. In the second phase of the City Lab, the implementation of a pilot project based on BGI addressed the most pressing problems of the city such as pluvial floods, water scarcity, and depletion of aquifers. In this regard, the stakeholders were actively involved in analyzing, planning, formulating, developing, implementing, testing, evaluating, and maintaining the pilot project to cope with climate impacts and contribute to sustainable urban development in the short, medium and long term. In this paper, special attention will be given to the process of pilot project implementation, showing the efforts that the City Lab Saltillo is undertaking to implement BGI techniques such as rain gardens, infiltration basins, permeable pavement, and vegetation in a public and urban space as an adaptation measure in response to climate change. This effort is reshaping the city's discourse, shifting the role of urban planning, and highlighting climate action as a shared responsibility among the public, private, academic, and civil society.

Keywords: Urban planning and co-creation, Blue-green infrastructure, Nature-based solutions, Climate change adaptation, Governance of Nature-based solutions

2 INTRODUCTION

In the current race against climate change impacts, urban interventions for mitigation and adaptation gain relevance when dealing with middle-size cities, covering approximately 45% of urban areas in emerging economies like Mexico, and expected to bear the brunt of climate impacts in the coming decades (UN-HABITAT, 2022). On the other hand, the need to update the planning processes and urban interventions calls for immediate action and for pilot concepts that are easily implemented, tested and replicated in case of success. Implementing nature-based solutions (NbS) as actions that aim to protect, sustainably manage, and restore natural and modified ecosystems addressing current societal challenges (IUCN, 2020),is a feasible alternative to address current climate challenges in middle-size cities from emerging economies. NbS is also an umbrella term for a variety of nature-based approaches such as Low-Impact Development (LIDs), Best

Management Practices (BMPs), Green infrastructure or Ecosystem-based Adaptation (EbA) among others (IISD, et al., 2022). For the pilot project in Saltillo, the implementation of NbS has been done through Blue-green infrastructure (BGI). The latter offers the greatest benefits for the provision and control of water quantity and quality as well as biodiversity. Being flood control one of the key services of BGI, it allows substantial hydrological functions easing the interception and allowing the retention of rainwater and stormwater, and at the same time offers benefits along the recreational, cultural, and well-being dimensions (Bacchin, K., et al 2016; Kopp et al, 2021).The implementation of the pilot project in Saltillo is expected to increase and improve green permeable areas in the city, the reduction of floods and their impacts, and promote citizen engagement and participation in urban planning processes.

2.1 Saltillo climatic conditions

The Mexican city of Saltillo has a population of almost one million inhabitants (INEGI,2020). The city located in the desert of Coahuila is a highly vulnerable area exposed to variability in hot temperatures between spring and summer (Fig 1). Nevertheless, during the short rainy season, heavy rainfall and storms are frequent due to mainly intense atmospheric phenomena (Mok et al., 2021). Despite Saltillo´s average annual precipitation of 484 mm, the climatic conditions and extreme weather cause floods and droughts (IMPLAN, 2021). However, these extreme events are not the only ones; the city suffers heat waves during the spring and summer, and cold temperatures in winter.

Fig. 1: Localization city of Saltillo, Mexico.

In addition to the above, the city of Saltillo has had rapid urbanization, growing extensively as a sprawling city. Its urbanization patterns characterized by the concentration of the population in the centre of the city with few green spaces and sealed permeable surfaces, exacerbate the increasing temperature, the urban heat islands (UHIs), and flooding in urban spaces due to the lack of pluvial drainage in most parts of the city and insufficient capacity in areas where it exists. It is expected that the effects and impacts of climate change in Saltillo and the region will be worse than today, and with the combination of rapid and unplanned urbanization, extreme events will be more frequent with many monetary and non-monetary consequences for the population (Mok et al., 2021).

2.2 Pilot project background: Saltillo's city profile and roadmap

Through the first phase of the City Lab, it was possible to identify opportunities to improve the performance of Saltillo in selected sectors and to develop custom-made, sustainable and integrated solutions to improve the urban infrastructure processes or services. This research phase was supported by interviews with local actors and resulted in a city profile as a diagnostic of the city with identified potentials and a roadmap with project ideas that were co-created between the City Lab team and the local actors. In the water sector, the urban assessment highlighted challenges such as flooding, lack of rainwater drainage, and water shortage as pressing in Saltillo. To address these challenges, a recommendation was made to integrate Blue-green infrastructure into the urban space, enhancing the city's green permeable areas and recharging already overexploited aquifers by creating a sponge city effect (Ordonez J.A., et al., 2021).Such a recommendation was taken forward in the pilot project implementation.

3 METHODS AND TOOLS

The pilot project was developed by an international and interdisciplinary team composed of research institutions such as the University of Stuttgart IAT and the Fraunhofer Society and a local team formed by the Municipal Planning Institute (IMPLAN) and the Tecnológico de Monterrey. The international institutions performed the project coordination, and the local team provided the local know-how, conducted the stakeholder management and outreach, and coordinated the research and the pilot project implementation on-site. To achieve the implementation of the BGI techniques such as rain gardens, infiltration basins, permeable pavement and vegetation in a public and urban space as an adaptation measure to climate change five steps were developed (see Fig. 2).

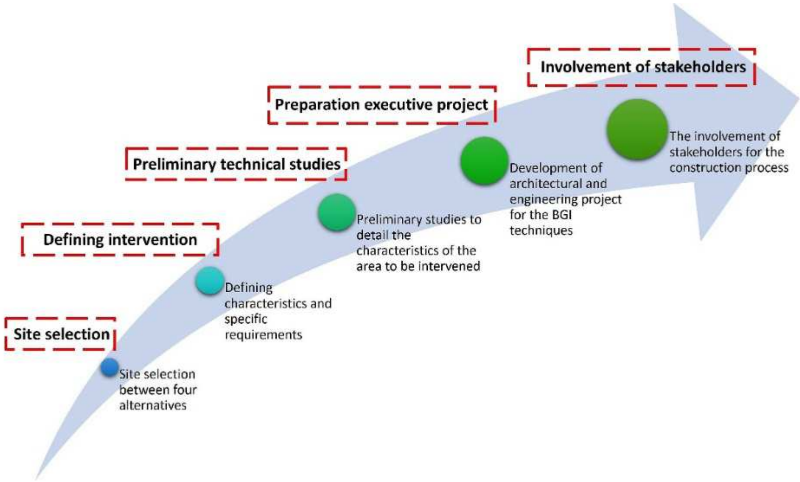

Fig. 2: Diagram process of the implementation pilot project.

For step one, site selection, the team performed a mapping exercise with a Geographical Information System (GIS)to identify public spaces that flooded after rain events and where citizens were affected by them. Then, the sites were evaluated using similar criteria and presented to the Mayor of the city, the Directorate of Public Works, and the Directorate of Urban Development to find the most suitable place to intervene. The following criteria were considered during the evaluation:

- Facilities and networks: No public networks were affected during the construction work.
- Flood risk and frequency: Frequency of flooding events per year.
- Social impact: Number of citizen complaints due to flooding.
- Land use: Public or private space.
- Population density: Benefited citizens.
- Aesthetic urban development: The potential of improvement of the green public space.
- Contribution to the achievement of the City Lab Project objectives: Demonstrative adaptation measure.

To define the intervention, a participatory process was carried out aiming to involve the neighbours in the co-creation of the pilot project. During this exercise, the neighbours were asked about the current use of the public space, their experiences during the flooding events, and their expectations from an urban intervention to improve the area. In the third step, preliminary technical studies were conducted to understand the characteristics of the area to be intervened. Technical studies such as a topographic survey, soil mechanics, hydrological study and vegetal inventory were executed. With this information, the next step consisted of the elaboration of an executive project, appointed through public bidding. The company selected for the implementation was responsible for making architectural and engineering designs for the public square. In this step, the City Lab local team and the selected company carried out a SWOT analysis of environmental and socio-cultural characteristics to be considered in the design process for the integration of BGI techniques. The design proposal, acknowledging the physical characteristics of the selected site, involved the topography, urban trees, landscape, and hydrographic and hydrology conditions of the site. Regarding socio-cultural aspects, the design proposal focused on multiple users and rights holders' involvement. To anchor the project in the local environment, the fifth step consisted of the involvement of stakeholders that could support the project's implementation and maintenance after the end of the City Lab project in Saltillo.

4 RESULTS

The implementation of the pilot project in Saltillo has been a joint effort that started with the MGI Initiative, and the City Lab project and was followed by city assessments, participatory workshops and the roadmap of project ideas. The integration of the Planning Institute of Saltillo (IMPLAN) in an international cooperation project like MGI drew the attention of local stakeholders and authorities, and the results of the research and the potential of the pilot project idea opened the door to in-kind cooperation from third parties. Regarding the best site for the implementation of the pilot project, mapping with GIS tools to identify the areas with pluvial flood risks showed four potential sites (Fig. 3).

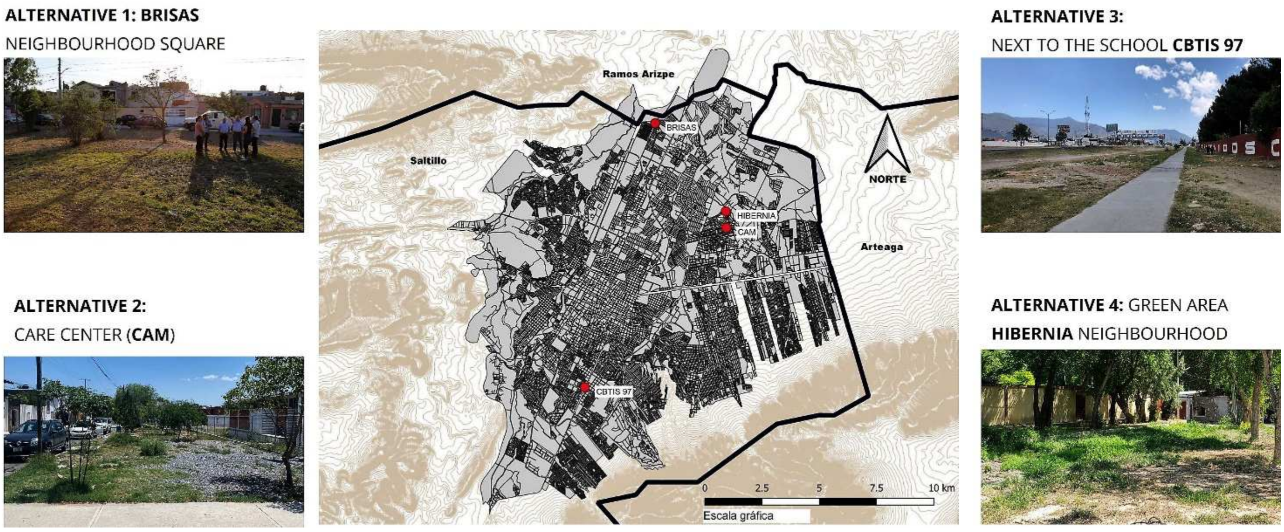

Fig. 3: Pilot sites identified with GIS.

After mapping, the four sites were evaluated using similar criteria (see Table 1). Obtaining the best conditions to introduce BGI techniques was a square in the neighbourhood Brisas where there were no public networks affected, a high risk of flooding, and thus complaints from neighbours. Furthermore, the land use would allow an intervention and it could contribute to the overall MGI project objectives. The square has a total surface area of 0.35 hectares, with a total of 106 people living in 30 private homes. The population density of the area directly benefited by the pilot project is 30,388ha per km², and the housing density is 84 homes per hectare (IMPLAN, 2023). Being this square the site with the highest density of the shortlisted four, these figures highlight the overall low density in the city, one of the main characteristics of Saltillo´s urban fabric.

SELECTION CRITERIA	Alternative 1 BRISAS SQUARE	Alternative 2 CARE CENTER	Alternative 3 CBTIS SCHOOL	Alternative 4 LA HIBERNIA
Technical conditions (no public networks affected)	Good	Good	Good	Good
Flood Risk according to GIS and Saltillo´s Risk Atlas	High	Medium	Medium	High
Social Impact: Numberof Citizen complaints due to flooding	High	High	High - Medium	Low
Land Use	Public Green Area	Public Green Area	Public Green Area	Private Residential
Population Density	High	Medium	High	Low
Urban Image Improvement	High	High	Medium	Low
Visibility	High	Medium	High	Low
Contribution to the achievement of the MGI Project objectives	High	Medium	Medium	Low

Table 1: Selection criteria pilot area

With the pilot site selected, a needs assessment with the neighbours of the pilot area was also undertaken. The local team contacted the Secretary for Social Development of Saltillo to gain an understanding of the procedures for citizens' involvement in planning processes. The first approach was done with the support of the Secretary and only to the local neighbours' council who manifested interest in the pilot intervention. After this encounter a workshop was organized for all neighbours to map the needs, the problematic areas after the rain events, and the current uses of the public space where the pilot is taking place. The latter was a crucial step to ensure the acceptance of the intervention and to recognise and incorporate the current dynamics and activities that take place in the pilot area (Fig. 4).

Fig. 4: Participatory processes to identify specific requirements for the neighbours.

To complete the site assessment, the City Lab team conducted technical studies with support from the Secretary of Infrastructure and Public Works of Saltillo. A topographic survey and a soil mechanics study were performed to identify the characteristics of the terrain and to assess the feasibility of the construction of a rain garden and an infiltration basin to tackle the pluvial floods in the selected area. Figure5 summarizes the topographic and hydrologic conditions of the area.

Fig. 5: Topographic and hydrologic conditions of the pilot area (Elaboration: PEW Studio)

The results of the topography survey indicate the runoff accumulates in this area without outlets or storm drains. Only one grate connected to the sanitary sewer with a reduced capacity was identified, which cannot be enlarged because it would cause an overflow through the sanitary pipes into the houses in the area. As a result, runoff accumulates in the area, causing flooding on the avenue, sidewalks and even, in heavy rains, flooding into the houses. This amount of water accumulation remains for days in the area until it is gradually drained through the sanitary sewer and evaporates or is absorbed in the green area.

The estimation from the hydrological study shows that the maximum runoff volume that reaches the property in a two-year return period was 20,135 m3,in 5 years 42,000 m3, and in 10 years 61,740m3. In all cases, the runoff volume estimated is high. This is due to the urban basin with an area of 2.27 km2being95% impermeable. The simulation was carried out considering extreme storm situations with a duration of 24 hours, using the HEC-HMS software developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC). Given these scenarios, it was decided to consider a large capacity for the design and size of the rain garden and infiltration basin techniques to reduce flooding events related to a year return period. Besides the technical studies forementioned, to develop the executive project, which included the landscape and engineering design for the public square, two characteristics were considered for the SWOT analysis (see Fig. 6).

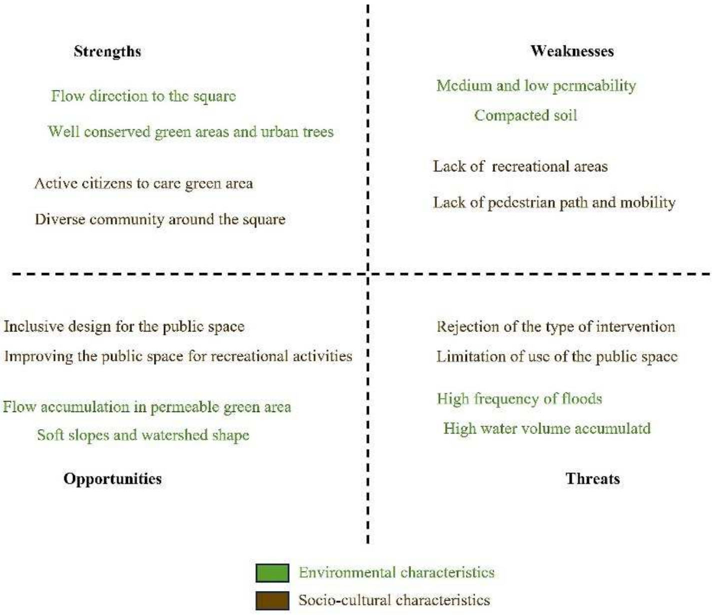

Fig. 6: SWOT analysis for environmental and socio-cultural characteristics.

The analysis highlighted strengths, weaknesses, opportunities, and threats for each characteristic analyzed. The design proposal involved four BGI techniques to cope with the high water volume accumulated after rain events, the lack of pedestrian and path mobility, the limited quality public space, and the medium and low permeability, among other factors. Figure 7 shows the design of the public square integrating a rain garden, an infiltration basin, permeable pavement, and vegetation. The infiltration basin was located in the centre of the square where the run off accumulates after heavy rain. The calculation of its capacity considered the volumes identified in the technical studies. The rain garden was located along the street to mitigate the risk of flooded houses and reduce citizens' complaints. The existing vegetation was maintained and more was added to create comfortable spaces for the neighbours to stay, and permeable pavement was implemented in areas where the neighbours were already doing some activities. The considerations for the last two measures aimed to create inclusive public spaces with improved conditions for recreational activities for the local community.

Fig. 7: Render of the pilot project.

During the implementation phase, a high level of involvement of local stakeholders was achieved. Not only the local community was involved and interested but also the Mayor of the city, various municipal directorates, as well as private sector representatives actively participated. The available budget of the MGI project for the pilot project in Saltillo was only allowing a percentage of the overall project design. Thanks to the outstanding project dissemination during the first phase of the CityLab, and the acknowledged relevance of the project by the local stakeholders, the municipality contributed with technical studies and the landscaping of the square. Private companies contributed to the excavations for the infiltration basin and the rain garden, and the local community contributed knowledge and valuable insights from the pilot area. Stakeholder outreach and management as well as the overall planning was performed by the City Lab team. The company appointed for the design, performed as well the construction and works management to deliver the BGI techniques.

5 DISCUSSION

In times of rapid urbanization, increasing population, resource depletion, degradation of ecosystems, growing pressures on urban land and water resources, and a climate crisis, Nature-based Solutions (NbS) such as Blue-green infrastructure (BGI) provide multiple opportunities for both society and nature to increase their climate resilience (Rizzi and Utkarsh, 2020). These solutions bring diverse natural and semi-natural features and processes into urban and rural landscapes, through locally adapted, resource-efficient, and systemic interventions to provide different ecosystem services that can be useful as adaptation and mitigation measures for climate change (EC, 2020).

Like many cities, Saltillo’s future needs to be anticipated, changing from today's urban spaces into blue-green spaces, and implementing BGI as an adaptation measure for the climate crisis. However, the implementation of NbS is not yet well disseminated in certain areas and in some cities of emerging economies is still a mechanism to be explored. This was evident in Saltillo, where this type of infrastructure was not implemented before, and there is a shortage of contractors in the region with expertise on this particular topic.

While international cooperation projects such as the MGI Initiative and the City Lab in Saltillo opened the door for funds, stakeholder engagement, research and co-creation of solutions for sustainable urban development, they are only the first step in a socio-urban transformation that needs to be promoted by the city including all public, private, academia, and civil society sectors. This is a key finding that points to the role of the governance of NbS as the enabler of these types of interventions.

From the global perspective, although BGI plays a key role in sustainable urban development, their design and planning stress the need for multidisciplinary and integrated approaches that are aligned with frameworks of global relevance such as the SDGs(Kopp et al, 2021) and to the strategic planning documents in the city such as Climate Action Plans. On the other hand, despite the efforts of global agreements and instruments to make climate action more inclusive and transparent, in most countries, it continues to be considered primarily a government task. Being NbS a people-centric approach for climate adaptation that involves decision-making over public goods, the involvement of different stakeholders with different interests is key to ensuring climate justice(GIZ, 2019).

In both phases of the City Lab project in Saltillo, the relevance of intersectoral participation to anchor the project results in the city's environment was evident and thus highlighted the role of the public, private, civil society and academic sectors in the urban transformation of the city. This is a key finding to understand and go beyond the limitations imposed by short-term projects, such as the City Lab, which come with time and financial limitations. The governance of NbS approaches such as BGI needs to be considered to overcome barriers to urban transformation. From the policy perspective, established visions, plans and strategies are necessary and need to be supported with laws that define institutions for the adaptation processes and that establish implementation mechanisms. Policies and laws need to be accompanied by processes that promote public participation and communication, monitoring and evaluation and conflict resolution (Iza A., 2019).

From the social perspective, BGI has the potential to empower communities when involved in the project phases, including their perspective and knowledge in the analysis, design, implementation and monitoring of the intervention (Kopp et al., 2021). The recognition of the current activities performed by the neighbours in the pilot area was crucial to engaging the local community and rights holders in the process. Thanks to the scope and size of the intervention of the pilot project in Saltillo it was easier to reach out to stakeholders with a clear message of what was intended and their replicability potential and benefits for the city.

With the selection of the four BGI measures in this pilot project their replication could be executed even in smaller areas that require less time, costs and effort in its interventions. From the experience of the implementation of the pilot project in Saltillo, the installation of permeable pavements and greening were the least time-consuming measures while the implementation of the infiltration basin and the rain garden required more work, machinery, and earth movements. The latter, of course, is because of the magnitude of the flooding in the area.

In terms of maintenance of BGI, it is important to highlight that each BGI technique is unique in terms of size, shape, components and service delivered, thus requiring specific maintenance actions (Langeveld et al., 2022).According to Vollaers et al. (2021), all BGI´s components could have specific failures that can occur within them, especially on the interfaces, and in some cases the responsibilities to solve them go from one actor to the next, impacting the cost. The experience in the case of Saltillo's pilot project showed that the decisions made by the implementing bodies played a role in how costly or easy would it be to maintain the techniques implemented. Low-cost maintenance should always be considered first since the long-term costs can be much higher than the costs associated with the planning, design, and construction phases. In this sense, it is relevant to involve the citizens and the staff taking care of the area and provide spaces for understanding the maintenance requirements. It is worth mentioning that some guidelines for maintenance activities exist, such as those proposed by Seattle Public Utilities (2019). This guideline recommends the maintenance actions needed before visual inspection. Finally, it is worth highlighting that if the maintenance of BGI is done correctly and promptly, it would dictate whether the long-term benefits intended are achieved.

Through the pilot project implementation, it was also evident that modular approaches with implementation phases make it easier to execute infrastructure projects, especially when time and financial resources are limited. In Saltillo, the modularity of the pilot project concept allowed the management of the financial resources available to give priority to the BGI techniques that would tackle the flooding in the pilot area.

With the implementation of the pilot project in Saltillo and the spaces for citizen participation that were opened, the municipality can work hand in hand with the local neighbours for the maintenance and monitoring of the pilot area. This was possible thanks to the timely involvement of the municipality and the local neighbours and the identification and protection of the current practices and activities of the neighbours in the pilot area. The monitoring of the project provides key input to the municipality to upscale or apply pilot projects like this in other districts of Saltillo.

6 CONCLUSION

The implementation of NbS such as BGI is proving to be a suitable approach to cope with the impacts of climate change in middle-size cities where the most urgent action is required. There are many derived benefits from the ecological, social, and economic perspectives that come along with this type of intervention. However, the success of BGI depends to a large extent on the governance structures that are conceived for their design, implementation, and maintenance. Actors from all sectors need to be acknowledged and integrated according to their interest level and vulnerability towards climate change impacts. It is crucial to align the scope of the interventions with local and global agendas, but it is also relevant to intervene with a sufficient understanding of the areas of work, the community and the local environment. This opens the door for cooperation, and tailor-made solutions to adapt to the identified climatic risks and offers a solid base to introduce monitoring and evaluation processes that are key to building a solid base in the replication of such measures. While international cooperation and financing mechanisms are essential to kick-start rapid sustainable urban transformation at the local level, they are not sufficient to transform cities in their entirety. Thus, the need to anchor this type of scheme with strategic planning documents and to the local environment of stakeholders is the key to sustainable urban transformation, adaptation, resilience, and liveability in the face of climate change.

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