SUSTAINABILITY STRATEGIES IN THE APPLICATION OF THE BLUE INFRASTRUCTURE AND ITS VISIBILITY IN URBAN AND REGIONAL PLANNING

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ABSTRACT

The concept of Green Infrastructure (GI) includes different strategies or approaches related to sustainability, such as green spaces, Sponge Cities Program (SCP), Nature-Based Solutions (NBS), and water management, such as Best Management Practices (BMPs) and Low Impact Development (LID). Included in this concept is the *Trame Bleue* (TB), or Blue Infrastructure (BI), which is implicit or even absent in the scientific production related to GI. This research investigates the integration of the *Trame Bleue* in the relationship between Green Infrastructure (GI) and urban and regional planning (URP) as an important strategy for sustainability and resilience. Through the analysis of scientific articles published between 2018 and 2024, we sought to observe the visibility of the Blue Infrastructure in sustainable URP strategies using GI in various applications, as well as in *Écoquartiers*, or Eco neighborhoods. The publications show varying levels of exposure and emphasis on this plot, as well as barriers to its implementation. This study aims to demonstrate that the role of the BI goes beyond water resources management, flood control, and mitigation solutions and that, to increase urban sustainability and resilience, its interconnection with other planning elements must be considered from the beginning of projects and interventions. For this, a brief framework for the implementation of GI in URP is proposed based on the authors of the researched sample. To achieve sustainable URP, a holistic approach is necessary, considering strategic planning, technological innovation, ecosystem services, and above all, socio-environmental equity.

Keywords: Blue Green Infrastructure. Green Infrastructure. Land use. Sustainable development. *Trame verte et bleue*. Urban and Regional Planning. Water management.

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INTRODUCTION

Despite the growing recognition of green infrastructure (GI) as an instrument to strengthen urban resilience, its implementation still faces financial, institutional, social and technological challenges, making it difficult to consolidate in Urban and Regional Planning (URP) policies (Elderbrock et al., 2020; Matsler et al., 2021; Reu Junqueira et al., 2023; Wilfong et al., 2023). This difficulty becomes even more evident in the face of the intensification of climate disasters and the advance of urbanization, which impose increasing pressure on ecosystems and city infrastructure. GI presents itself as a solution capable of mitigating environmental impacts, strengthening ecological connectivity and contributing to urban sustainability (Ahern, 2013; Mell, 2010, 2015; Pauleit et al., 2017). However, one of the main obstacles to its effective adoption is the gap between academic production and its practical application, making it difficult to disseminate knowledge and translate the concept to managers and decision-makers (Sinnett et al., 2018).

In the pioneering concept of GI by Benedict and McMahon (2006), "an interconnected network of protected land and water that supports native species, maintains natural ecological processes, sustains air and water resources, and contributes to the health and quality of life for communities and people" (in Pellegrino & Ahern, 2023), blue infrastructure and the importance of its ecosystem services in supporting these processes are included. The connectivity present in this concept, a principle dear to ecological landscape planning, reinforces the interdependence between natural and human systems (Fletcher et al., 2014; Mell, 2010; Ndubisi, 2002). Furthermore, it is important to have a consensus on the concept and its terms so that there is an efficient connection between planners, communities, policymakers, stakeholders and other agents in both the planning and implementation of GI (Fletcher et al., 2014; Matsler et al., 2021; Mell, 2010).

Divergences in the nomenclature, definitions and objectives of GI, depending on the area or geographic location, can hinder its application, planning, maintenance and its benefits (Matsler et al., 2021; Mell, 2010). At the same time, while the term "Green Infrastructure" is often used broadly and generically, encompassing its multi-potentiality, blue infrastructure (BI) is hidden, ignored or treated separately. The opposite occurs in France, where the term Trame verte et Bleue (TVB) refers to a concept and guidelines extracted from the Grenelle I Law of 2009 (Centre de Ressources Trame Verte et Bleue, n.d.), increasing the visibility of blue infrastructure and ensuring equality with green infrastructure in urban and regional planning procedures. The term Blue Green Infrastructure (BGI)[4] has recently been used to

[4] The recently widespread concept of BGI was initially based on Benedict and McMahon (2006), which was later expanded globally and consolidated as Green Infrastructure (GI) (Mell & Scott, 2023).

refer to TVB as well. This leads us to the question: how is the *Trame bleue* (TB) considered in studies that address the process of creating or regenerating urban and regional landscapes?

This question could initially be answered with sponge cities and *écoquartiers*. These are exemplary approaches within urban planning, promoting the integration of blue infrastructure as a fundamental strategy for sustainability. The concept of sponge cities emerges as a response to the need to reconfigure the urban environment to better manage water, planning beyond flood mitigation. The Sponge City Program (SCP) proposes the incorporation of water as a structuring element of urban space, providing efficient drainage, promoting the recharge of aquifers, improving water quality and expanding green spaces, with positive impacts on climate regulation and reducing carbon emissions (Nguyen et al., 2019). The application of the GI, especially its *Trame bleue*, is the central axis of this model, allowing cities to increase their water and ecological resilience in a way that is integrated with the urban fabric.

At the same time, French *écoquartiers* are seen as a potentially sustainable urban experiment, by structuring neighborhoods that reconcile environmental, social, and economic demands. These projects function as laboratories for the development of sustainable urban solutions, adopting environmental certifications, participatory processes, and multi-scalar governance strategies (Bonard & Matthey, 2010; Chastenet et al., 2016). The importance of decentralized water management in these neighborhoods is reinforced, emphasizing the integration of TB and associating it with urban design and community involvement. Thus, both sponge cities and *écoquartiers* demonstrate that the *Trame bleue* can be a structuring axis of urban planning, favoring climate adaptation and quality of life in cities.

This study aims to understand how the *Trame bleue* is addressed and incorporated in the relationship between URP and GI, identifying challenges and possibilities for the inclusion of the *Trame bleue* (TB) in spatial planning and urban regeneration. The methodology adopted is based on a literature review that analyzed publications between 2018 and 2024 and focused on the intersection between “water management” or “water resources” and urban and regional planning. This analysis allowed us to map how TB, integrated with the concept of GI, has been discussed in academic literature. The choice of this method is justified by the need to outline an updated overview of knowledge on the topic, identify emerging trends, and highlight critical gaps for future research and policy formulation. The option for a literature review, instead of a rigid systematic approach, allowed us to select studies directly connected to the relationship between TB and URP, according to the filters used in the databases themselves.

The results reveal that, despite the increase in the frequency and severity of climate disasters and the growth of academic production in the area, TB still receives little attention in urban planning. Its presence is more evident in studies on water management and flood control, but it rarely appears as a structuring element of urban and regional planning. This omission compromises the ability of cities to face the challenges of climate change and reduces the potential of GI as a tool for socio-environmental equity (Pauleit et al., 2017). The literature on water management remains focused on the design of infrastructure and technical systems, often disregarding the organic nature of processes and the need for an integrated approach. It is necessary to analyze spatial and functional continuity in the URP in terms of the physical connectivity of landscapes, but it is also necessary to verify the fluidity in the relationship between actors involved and in the development of projects. In this sense, the idea of a continuum, as proposed by Spirn (1995), connects to the connectivity approach explored by Benedict and McMahon (2006) and Ndubisi (2002), expanding the understanding of TB within the urban fabric.

The relevance of this study lies in its contribution to highlighting the role of TB in research that addresses the relationship between GI and URP, filling a gap in the literature. By integrating different perspectives and offering a critical analysis, the aim is to not only inform, but also stimulate academic and practical debates, driving more comprehensive and effective policies that recognize TB as a central element in building resilient cities.

THE METHODOLOGICAL APPROACH

To achieve the objective of this study, a literature review approach was adopted, which is essential for an in-depth understanding of the topic and for the critical integration of the most relevant results found in the literature. The research was conducted based on articles in the areas of green infrastructure and urban planning on the Web of Science (WOS) and Scopus databases.

The initial search was carried out using the term “Green Infrastructure” covering both the topics and the titles, abstracts and keywords of the articles published from 1995 to 2024. With the time frame of the period from 2018 to 2024, the selection was restricted to peer-reviewed articles. In total, 4,712 articles were identified in WOS and 4,353 articles in Scopus.

To refine the results, specific filters were applied. In WOS, the search was limited to the categories of Environmental Studies, Urban Studies, Ecology, Water Resources, Regional Urban Planning, Biodiversity Conservation, Development Studies and Environmental Engineering, resulting in 725 articles. From this sample, 116 articles focusing on Water Resources and 64 articles related to Regional Urban Planning were selected. To ensure the quality of the sample, duplicates were eliminated and the final selection of 22 articles was made based on the relevance of their titles, abstracts and keywords, with emphasis on the confluence of green infrastructure with water resources and regional planning. In Scopus, the search was also targeted at the Environmental Sciences area and filtered at the subcategories of Urban Planning, Urban Development, Urban Design and City Planning, resulting in a sample of 219 articles. Subsequent analysis based on titles, abstracts and keywords led to the selection of 32 articles that explored the intersection between green infrastructure, urban planning and water resources.

In a second analysis cycle in Scopus, the search was restricted to the Water Management category, which generated 150 articles. With a specific focus on Urban Planning, 82 articles were selected based on related keywords, such as urban areas, land use, sustainable development, urbanization and city. After careful screening, 23 articles were selected, and, finally, 50 publications of significant relevance were selected for further analysis.

This search was also expanded by including books, theses and manuals that address the intersection between green infrastructure and urban planning. These materials were identified through additional databases and academic networks, such as ResearchGate, Academia and Google Scholar. This strategy of continuous inclusion ensured that the literature review was comprehensive, up-to-date and reflected both previous and more recent contributions to the topic. A table with references and article titles is attached, providing a brief overview of the selected articles.

THE *TRAME BLEUE* IN THE RELATIONSHIP BETWEEN GREEN INFRASTRUCTURE AND URBAN AND REGIONAL PLANNING

The authors see the incorporation of GI into urban planning as a tool for urban regeneration in the pursuit of sustainability and social benefits. GI is seen as a strategy capable of increasing the resilience of cities in the face of climate change and rapid urbanization, including the use of GI in water management.

Stormwater management is linked to GI practices seen as resilience approaches, such as in food production in urban areas (Nasr & Potteiger, 2023). Suggestions, such as converting roads into green spaces (Lee & Kim, 2023) and lawn areas into planting areas (Elderbrock et al., 2020), are seen by the authors as solutions to increase stormwater infiltration, biodiversity, connectivity and landscape aesthetics. Renaturation of water systems is also suggested in a way that mimics natural drainage and restores aquatic ecosystems (Gougeon et al., 2023; Matsler et al., 2021), as well as the use of natural infrastructure itself, or use of BGI, to combat flooding (Hamel et al., 2021) and to promote equity and environmental justice (Hoover et al., 2021).

GI SERVICES MULTIFUNCTIONALITY

As previously stated, the authors reinforce this perspective of multifunctionality by suggesting that GI be used to provide a variety of services, such as: flood control, air quality improvement and recreational opportunities, in addition to integrating historically underrepresented and vulnerable communities and involving them in its design (Hasala et al., 2020). The incorporation of GI (both its green areas that contribute to drainage and its blue infrastructure) in the URP has the potential to stimulate social justice by dissolving historical inequalities and systemic racism in urban planning (Hoover et al., 2021), favoring equity, protecting communities from flooding and the lack of stormwater management (Conway et al., 2022). Authors recommend that these communities be revitalized with public funding, incorporating small-scale GI, such as green roofs (Song et al., 2024), or through other Nature-based Solutions (NBS) (Liu & Wu, 2022) in degraded and vulnerable areas (Hasala et al., 2020), providing human well-being and restoring people's connection with nature (Sinnett et al., 2018). Several authors (Kooy et al., 2020; Kvamsås, 2021; Rojas et al., 2022; Wilfong et al., 2023) advocate the use of NBS, an approach that is part of GI (Fletcher et al., 2014), regardless of scale, in addition to the observation of Ecosystem Services (ES), or ecological services, in the integration of GI and URP.

According to the research in this sample of articles, for these initiatives to be successful, regulation and the development of clear standards for their implementation are necessary. Cities such as Malmö, Sweden (Schubert et al., 2017), with green roofs and green spaces or constructed wetlands, as in Krueger National Park, South Africa (Staddon et al., 2018), demonstrate that regulations requiring the inclusion of GI in new developments can ensure that it is integrated into urban development plans sustainably. However, policymakers must be included in the research process, accessing its results, so that they can be translated into policies efficiently.

The authors identified some gaps that also need to be addressed, such as the lack of longitudinal research on the outcomes of the relationship between health and GI, in addition to the lack of emphasis on design in the planning of these infrastructures (Sinnett et al., 2018). Added to these gaps and concerns about water resource management and flood mitigation, studies propose the use of the multifunctionality of GI in urban policy initiatives, starting with land use planning. Some authors in this sample suggest incorporating GI into urban and regional planning, with direct or indirect reference to land use policy. To ensure greater success in its implementation, GI should be included from the beginning of urban development projects or from the analysis of scenarios in the case of urban regeneration, considering the distinct requirements of each location (Liu & Wu, 2022).

THE INCLUSION OF GI IN URBAN PLANNING AND IN LAND USE

The potential for including GI in land use policies is rarely discussed in the academic literature. Many articles emphasize the importance of incorporating GI into planning, but they do not always include land use in this dynamic. In addition to mentioning land use in the construction and forecasting of scenarios (Liu & Wu, 2022), only one article in our sample, Axelsson et al. (2020), deals more incisively with the issue of land use, directing urban form in conjunction with green and blue infrastructure. This article also examines the use of natural and semi-natural GI systems to obtain greater control over the consequences of urban development and to combat pluvial flooding and heat islands.

The integration of GI into land use policy reinforces the need to use it as a tool for protecting ecosystems and for paradigm shifts. Stormwater management, for example, could be improved through mitigation efforts, such as the creation of legislation that prevents the increase of impervious surfaces, in addition to controlling urban densification management and reducing environmental concerns (Muller & Mitova, 2023). The valorization of regions such as wetlands and floodplains, areas that contribute to the hydrological cycle (Hamlin & Nielsen-Pincus, 2020), would be favored by such policies, facilitating the conservation of what is often seen as a barrier to urban expansion (Rojas et al., 2022).

THE INSERTION OF GI IN LAND USE LEGISLATION TO PROMOTE ECOLOGICAL CONNECTIVITY AND SOCIO-ENVIRONMENTAL JUSTICE: ACTORS, SCALE AND LOCAL CHARACTERISTICS

Ecological connectivity is essential for the effectiveness of GI in urban development, as it promotes ecosystem resilience and improves environmental quality. The establishment of ecological corridors connects parts of natural ecosystems and urban green areas, ensuring the continuity of ecological processes. These corridors promote the movement of species and the exchange of genes between populations, increasing urban biodiversity and helping to preserve natural ecosystems in urbanized areas (Heim LaFrombois et al., 2022). Floodplain restoration also enriches connectivity through interconnection with rivers and other water bodies while fostering important ecosystem services, such as flood mitigation and water availability (Hamlin & Nielsen-Pincus, 2020). Considering these themes, connectivity and land use, the authors believe that incorporating GI into urban planning promotes environmental resilience by favoring species mobility and the maintenance of essential ecological processes (Heim LaFrombois et al., 2022).

Establishing ecological corridors and restoring floodplains enhances biodiversity and ecosystem services. However, to make this feasible and successful, these must be incorporated into land use regulations (Hamlin & Nielsen-Pincus, 2020; Hoover et al., 2021; Johns, 2019; Liu & Wu 2022), with a focus on local characteristics and community needs (Kooy et al., 2020; Kvamsås, 2021; Wilfong et al., 2022). Connectivity also needs to be defined in terms of cohesive Urban Green Infrastructure (UGI) networks, in which multiple elements, such as green roofs, bioswales and rain gardens, are interconnected and work together. Using Geographic Information Systems (GIS) and established theories of landscape connectivity, it is possible to identify areas prone to fragmentation and prioritize actions that reconnect these green elements (Zheng & Barker, 2021). While the adoption of these strategies by local populations is often linked to the recreational value and accessibility of new green areas, planners often direct them towards achieving gains in biodiversity and wildlife (Morris & Tippett, 2023). Working in an integrated manner, ecological resilience is increased, allowing ecosystem functions to be maintained even in complex urban contexts.

By reconciling GI with urban land use legislation, productive and integrative networks are developed that connect multiple land uses and BGI initiatives, thus increasing the positive impact of GI. In this way, the results go beyond sustainability, with connectivity and gains in ecosystem services; they create a resilient urban environment capable of coping with social and ecological stresses. For example, the addition of community gardens and urban gardens in this context maximizes social benefits while improving community inclusion in the planning process (Nasr & Potteiger, 2023).

Implementing GI in urban planning, combined with land use policies, requires a holistic approach. According to Hamlin and Nielsen-Pincus (2020), there are 3 dimensions of GI: technological, social and ecological, and among the policy interventions that can encourage its use, the authors mention changing rules such as accounting regulations, including the non-monetary values of nature in these. Regarding these values, it is observed that perceptions about wetlands have changed; what was previously seen as places for expansion of the real estate market has become an asset with environmental value, with the potential to reduce dependence on gray infrastructure. This beneficial change protects wetlands from indiscriminate development, favoring their environmental functions in stormwater management and response to natural hazards (Johns, 2019; Rojas et al., 2022). Hoover et al. (2021) add that GI should be incorporated into land use policies as an important component of urban planning to ensure that green spaces and NBSs are integrated into the development process rather than being considered as an afterthought. Water resource management by cities can be carried out more satisfactorily, reducing the effects of impervious surfaces, through the development of land use rules, aided by modeling practices to assess urban surface changes (Muller & Mitova, 2023).

For GI to be implemented effectively, both local factors and the historical legacies of urban areas must be considered. The authors emphasize that GI planning should be tailored to local climatic circumstances and physical characteristics, such as urban surface types and flood sensitivity, using hydrological modeling and local community knowledge (Kooy et al., 2020; McFarland et al., 2019), echoing Ian McHarg's method[5]. This integrated approach allows for better land use decisions based on the environmental and social characteristics of each location, ensuring that GI meets individual community needs. However, in some developing countries, partnerships between institutions and GI initiatives can be influenced by historical practices of institutionalized racism, as has been the case in American cities, demonstrating that the impacts of GI can vary significantly depending on how and where it is implemented and may, in certain contexts, perpetuate socio-spatial inequalities (Heck, 2021; Hoover et al., 2021).

Urban governance and municipal regulations play an important role in prioritizing and managing GI. Creating municipal regulations based on design guidelines can create a regulatory environment that promotes the equitable and efficient implementation of GI (Staddon et al., 2018; Walker, 2021). Dividing urban areas into functional zones, such as flood risk control zones, can reap the maximum benefits of GI. Once again, the importance of considering the characteristics of each location is reinforced here. In terms of governance and policy formation, the sample demonstrates two distinct approaches in the United States, where local political ethos drives land use policies and prioritizes sustainable projects in Portland and Phoenix. While Portland adopts a progressive and integrated strategy, Phoenix focuses on economic development with minimal government interference, encouraging efficiency over sustainability (Fink, 2018). Still on governance, the authors point out that social involvement maximizes social and environmental benefits. Participatory initiatives, which involve the public in the design, implementation, and monitoring, play an important role in the acceptability of new green spaces (Fink, 2018; Nasr & Potteiger, 2023; Song et al., 2024).

In contrast to the production of works related to public participation, ecological interconnection and land use receive minimal attention in the sample of articles studied.

[5] In its ecological vision, the "McHarg Method" or "University of Pennsylvania Method" saw the city as an ecosystem formed by the sum of historical, biological, physical and social processes (McHarg, 2000; Ndubisi, 2002).

INSTITUTIONAL COLLABORATION, GOVERNANCE, POPULAR PARTICIPATION AND SOCIAL JUSTICE IN THE IMPLEMENTATION OF THE GI

The GI multidisciplinary and multi-scalar nature, combined with holistic approaches, improves its implementation. Technical and social barriers are overcome through collaboration between planners, researchers and professionals from different areas (ecology, engineering and urban planning) to develop more effective urban solutions, mitigate problems such as flooding, restore ecosystems and improve the quality of urban life (Hamel et al., 2021; Hamlin & Nielsen-Pincus, 2020; Matsler et al., 2021; Probst et al., 2022; Zuniga-Teran et al., 2019). Collaborative programs such as BiodiverCity[6] demonstrate the good impact of inter-institutional cooperation in promoting biodiversity and the extension of urban green areas (Schubert et al., 2017).

The development of integrated solutions that combine green and blue infrastructure to foster urban resilience is facilitated by collaborative work between municipal agencies responsible for urban planning, water and the environment (Kvamsås, 2021). Efficient communication between professionals involved, such as engineers and planners, ensures the technical validity of suggestions (Giner et al., 2019) and, considering the needs and preferences of the community, the acceptance and involvement of these initiatives increases. Popular participation in decision-making results in practices that are adaptable to local demands, strengthens the legitimacy of initiatives (Heim LaFrombois et al., 2022; Kvamsås, 2021), and increases confidence in the effectiveness of the measures adopted with the "learning by doing" approach (Morris & Tippett, 2023). This promotes a sense of belonging and shared responsibility, in addition to encouraging the collaborative creation and maintenance of green spaces (Song et al., 2024).

Active community participation in design and implementation (Elderbrock et al., 2020) can ensure success and equitable distribution of GI interventions. Even in temporary or transitional neighborhoods, it is important to give residents a greater voice by driving grassroots initiatives (Zheng & Barker, 2021). Public awareness and education about the importance of GI are needed to reduce pollution and the effects of climate change. New technologies help communicate impacts and visualize them in the local landscape, even those previously invisible, such as pollution, contributing to community understanding of techniques and possible solutions (Dean et al., 2022). Supporting grassroots activities, training the population, and increasing knowledge about the benefits of GI are essential factors in encouraging local acceptance of BGI, boosting citizen engagement, and supporting

[6] The project aimed to promote biodiversity and increase sustainability in urban areas through the identification of new approaches, collaboration with institutions and companies and incorporation of ES into urban design (Schubert et al., 2017).

decentralized decision-making. After decades of centralized management, a rethink of how members of society view their responsibilities and duties to manage stormwater is needed (Wilfong et al., 2023). Although the meaning of BGI varies among stakeholders, its goals in promoting sustainability can serve as a point of convergence (Willems et al., 2020).

Portland is an example of a participatory strategy that uses collaborative decision-making to develop innovative and inclusive climate strategies (Fink, 2018). Phoenix, on the other hand, has adopted an opposite, centralized approach that is more typical of top-down governance, which focuses on efficiency and corporate interests, making its climate initiatives technocratic and reactive, more concerned with immediate economic needs than with long-term sustainability. As these two examples demonstrate, cultural and political differences can impact governance (Fink, 2018).

To ensure that GI is fully incorporated into urban planning, it is essential to articulate both top-down and bottom-up strategies; innovation in governance models is essential, thus facilitating the city's adaptation to climate change (Staddon et al., 2018). Furthermore, the adoption of GI should be complemented by laws that prevent gentrification, often associated with urban revitalization. To ensure that the benefits of GI are distributed fairly and do not worsen current or historical inequalities (Hoover et al., 2021), proposals for regulations on real estate speculation, rent control, and support for cooperative housing are also needed (Walker, 2021).

In St. Louis (USA), for example, the legacy of racial segregation and discriminatory planning practices have resulted in significant inequalities in infrastructure provision and investment (Heck, 2021). This can be addressed through public consultations and workshops, ensuring that these minority and historically marginalized communities are served, encouraging more equitable and inclusive urban development (Hoover et al., 2021). Participatory processes allow the public to express their views and identify priority areas for GI interventions, addressing specific environmental issues and promoting solutions that reflect local concerns (Elderbrock et al., 2020). Low-income communities can also be integrated through incentive programs, such as subsidies and tax exemptions, ensuring equitable distribution of benefits linked to GI.

The diversity of hydrosocial relationships[7] (Wilfong et al., 2023), including diverse perspectives on decentralizing stormwater management, is essential for GI solutions to function as catalysts for social justice and urban equity rather than just meeting immediate demands (Wilfong et al., 2022). To include GI in a larger context of sustainability, urban

[7] Hydrocitizenship relations: decentralization of rainwater management and promotion of water citizenship, or the increase in citizen responsibility, achieved by understanding the roles involved and the function of public authorities, as well as one's own position as a citizen when accepting their obligations (Wilfong et al., 2023).

planning strategies that prioritize environmental quality and social justice are needed (Zheng & Barker, 2021). To this end, the costs of installing and maintaining residents must be reduced, removing financial barriers that exclude disadvantaged populations, promoting social cohesion and improving quality of life (Kooy et al., 2020; Matsler et al., 2023; Walker, 2021).

Implementing GI to address contemporary environmental and social challenges requires strong inter-agency collaboration, combined with the simplification of administrative processes to direct investments in an inclusive manner, increase program accessibility, prevent gentrification and promote integrated management of green areas and urban waters (Matsler et al., 2023; Walker, 2021; Wilfong et al., 2022). Even in the private sector, measures need to be designed to encourage landowners to make their land more accessible to establish green spaces (Song et al., 2024), thus strengthening community connections. It is considered that both GI and TB meet the cultural and aesthetic demands of people living in the urban environment, helping to establish pleasant public areas and enhance historical and landscape heritage (Gašparović et al., 2022).

Interdisciplinary and collaborative engagement between diverse stakeholders, including local communities, NGOs, government agencies, and the private sector, develops a shared understanding of the benefits of GI (McFarland et al., 2019; Willems et al., 2020). Research by Johns (2019) demonstrates how understanding GI and its roles in urban planning facilitates progress in its implementation. In her research, respondents were people involved in GI policy, and they reached the consensus that municipalities need to do more about GI in stormwater management.

The effectiveness of GI depends on public engagement and its ability to foster a cultural shift that recognizes its relevance in urban planning. This is possible through grassroots measures, such as education and awareness-raising activities, that empower citizens and encourage the voluntary adoption of sustainable behaviors (Fink, 2018; Morris & Tippett, 2023). Coordination between the public and private sectors, NGOs and local communities promotes knowledge sharing and resource optimization, while the participation of academic institutions contributes to the exchange of information and the identification of best practices to be implemented (Heim LaFrombois et al., 2022; Johns, 2019) in a social learning environment fostered by continuous stakeholder engagement (Hamel et al., 2021).

Even in monitoring, the participatory approach to GI oversight proves essential to align the perceptions of the various stakeholders involved and ensure the equitable distribution of resources, seeking solutions beyond precipitation problems (Axelsson et al., 2020) or natural resource management measures (Morris & Tippett, 2023). As previously stated, legitimate community participation should be addressed throughout the process, from planning to ongoing operations, with tactics adjusted to reflect results and develop new requirements (Matsler et al., 2023).

THE IMPORTANCE OF SCALE AND LOCAL FACTORS

The authors also highlight the role of GI in urban planning in solving accessibility problems (Morris & Tippett, 2023) and other problems caused by rapid urbanization (Zheng & Barker, 2021). They emphasize the need to work at small scales (Wilfong et al., 2022), or at the neighborhood scale (Zheng & Barker, 2021) to better understand local characteristics and, according to Wilfong et al. (2022), to more efficiently mimic natural processes such as infiltration and evapotranspiration. The researchers emphasize that GI should be used to manage stormwater and improve water quality, especially in areas vulnerable to flooding (Gašparović et al., 2022) or in regions with extreme weather events (Gougeon et al., 2023).

Some researchers emphasize the need to focus on the specificities of geography and local peculiarities. Following the example of meltwater in snow-affected countries, bioretention cells are proposed as a strategy to improve it, reducing contaminants from precipitation and improving urban environmental quality (Gougeon et al., 2023; Kooy et al., 2020; Morris & Tippett, 2023; Nguyen et al., 2019; Walker, 2021). In addition to water quality, the authors emphasize the relevance of water quantity, highlighting the need to combine GI policies with current gray infrastructure schemes, as in coastal cities (Johns 2019; Rojas et al., 2022).

Success in the sustainability and maintenance of the application of GI in the UP depends not only on local characteristics (Carter et al., 2017; Dean et al., 2022; Zheng & Barker, 2021), but also on the demands of the communities included in the planning, particularly in the Global South that faces severe challenges (Zuniga-Teran et al., 2019). To this end, it is necessary to develop new statutes that encourage the adoption of GI regulations, such as reallocating financial resources to prioritize investments aimed at the sustainability and resilience of cities (Axelsson et al., 2020; Cousins & Hill, 2021; Walker, 2021). It is also important to encourage education and knowledge about GI to gain community support and ensure that projects meet their requirements (Dean et al., 2022), avoiding green gentrification (Walker, 2021), while improving their acceptance, resulting in a new relationship of citizen responsibility (Wilfong et al., 2023).

TOOLS, APPROACHES AND BARRIERS IN THE APPLICATION OF GI

TOOLS TO SUPPORT GI DESIGN

In the sample studied, research and tools have been developed to improve the implementation of GI. For example, the research by Wang et al. (2023) on the optimization of green infrastructure, gray infrastructure and blue infrastructure based on spatial functional zones. In this, it is suggested that this approach offers a more reliable and adaptable solution for urban stormwater management, while these functional zones serve as a reference for the design and layout of GI in urban areas. This approach could be accompanied by tools developed by other authors, such as the Green Infrastructure Cost-Effectiveness Rating Index (GICRI)[8] (Reu Junqueira et al., 2023), a tool that can help decision makers prioritize GI investments, informing where and how to implement these solutions more effectively, or a spatial configuration tool that can help managers prioritize GI investments, a multi-objective optimization tool[9], informing where and how to implement assertive solutions, developed by Chen et al. (2024).

Focusing on TB, this last tool examines the hydrological relationships between various types of green infrastructure, including green roofs and permeable pavements. The aim is to determine the optimal configuration of green infrastructure in a target area, considering water efficiency and life-cycle costs, emphasizing the importance of considering the specificities of the location where GI systems will be implemented, as well as suggesting the use of NBSs in urban water management (Chen et al., 2024).

TECHNIQUES INDICATED BY THE AUTHORS FOR APPLYING GI IN WATER MANAGEMENT

The sample also includes works that approach the topic in a more technical way and are focused on engineering than on urban planning, highlighting the importance of evaluating the interactions between the various structures and systems used in water management. However, when designing landscapes with GI, they follow the same reasoning as authors more focused on urban and regional planning. These take into account other factors, such as location, hydrological characteristics and type of land use, to improve the effectiveness of GI implementation (Chen et al., 2024; McFarland et al., 2019), integrating green, blue and

[8] Green Infrastructure Cost-Effectiveness Rating Index (GICRI): Helps prioritize investments in RI, taking into account climate scenarios and associated uncertainties, and seeking assertiveness in implementation based on analyses that consider projected variations in climate circumstances, such as rainfall frequency and intensity. In their essay, the authors address the importance of innovative and proactive approaches to flood risk management, in which blue infrastructure can play a significant role (Reu Junqueira et al., 2023).

[9] The tool combines the Storm Water Management Model (SWMM) and the Strength Pareto Evolutionary Algorithm (Chen et al., 2024).

gray infrastructures, maximizing rainwater absorption and reducing surface runoff (Chen et al., 2024) and mitigating thermal pollution that degrades aquatic ecosystems (Simpson & Winston, 2022).

This part of the sample focuses on GI approaches, where their use is through vegetated swales and other stormwater control practices, recommended reducing the volume and flow of runoff in suburban and neighborhood-scale watersheds, while providing ecosystem services (Woznicki et al., 2018). However, studies show that Decentralized Stormwater Control Measures (SCMs) are more effective than traditional infrastructure (curb and gutter systems) in precipitation events of less than 20 mm, which are more frequent but may not be sufficient when not integrated with other infrastructure in larger events (Woznicki et al., 2018). Studies also suggest that SCMs may not provide sufficient treatment to protect cold-water ecosystems from urban development, requiring a limitation of impervious areas and the use of LIDs, among other strategies (Simpson & Winston, 2022).

Three terms with a greater focus on water resources are found in the sample: Blue Green Systems (BGS), Integrated Green-Gray-Blue System (IGGB) and Sponge Cities Program (SCP). In the application of BGS, green and blue elements (vegetation and water) are combined to maximize ecosystem services and improve connectivity between natural spaces, mitigating urban heat and providing multiple environmental benefits (Probst et al., 2022). The IGGB for stormwater management proposes a model to evaluate the interaction of green-gray-blue infrastructures and determine the spatial arrangement that maximizes rainwater absorption, minimizing surface runoff, increasing drainage capacity and improving natural water circulation in urban areas (Chen et al., 2024). The SCP Program was launched by the Chinese government, associating traditional water management techniques with the LID concept (Chikhi et al., 2023).

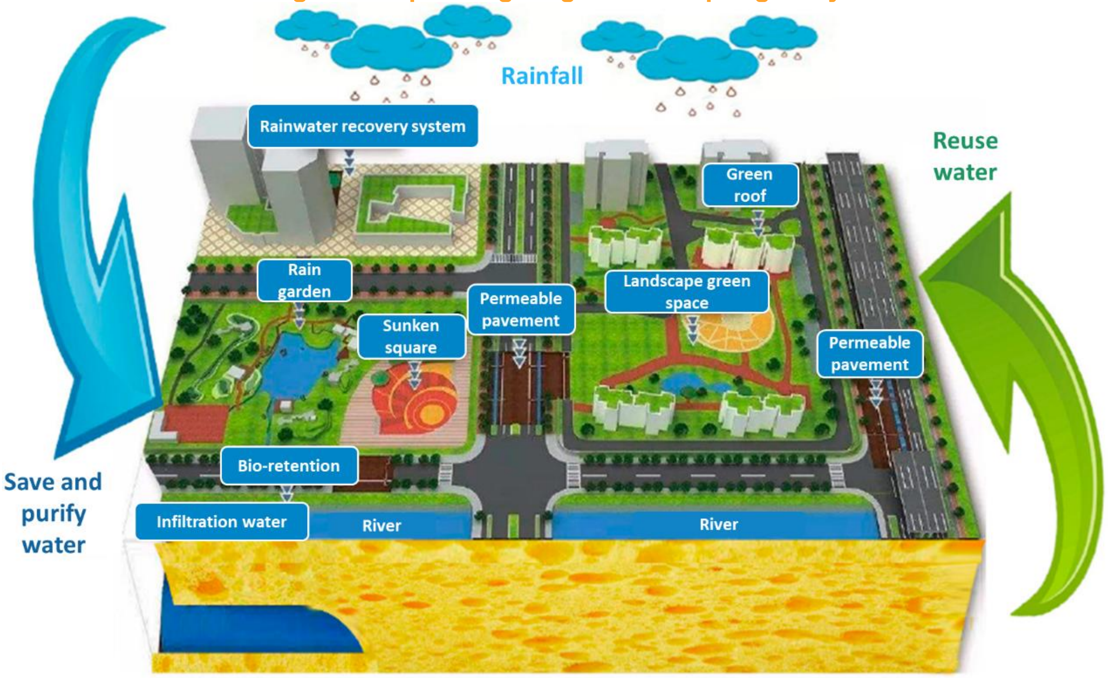
SPONGE CITIES AND LIFE CYCLE COST ANALYSIS OF GI

The construction of sponge cities, or the Sponge Cities Program (SCP), developed in China in 2013, is an urban model that proposes integrated urban water management, inspired by the capacity of natural ecosystems to absorb, store and filter rainwater (Ahmed et al., 2024; Chan et al., 2018; Chikhi et al., 2023; Wang, 2024b), a measure to combat flooding, water scarcity and environmental degradation.

Based on principles of Green Infrastructure (GI) and Low Impact Development (LID), sponge cities prioritize nature-based solutions (Chan et al., 2018), such as floodable parks, green roofs, permeable pavements, rain gardens and artificial wetlands (Ahmed et al., 2024; Chan et al., 2018; Wang, 2024a). These structures reduce runoff and mitigate flooding, in addition to improving water quality, recharging aquifers, and promoting urban biodiversity (Nguyen et al., 2019; Wang, 2024a).

Figure 1 illustrates how a sponge city works, highlighting how rainwater is collected, filtered, and reused. Infrastructure such as green roofs, rain gardens, and permeable pavements contribute to reducing runoff, minimizing flooding, and mitigating the heat island effect, promoting sustainable management of urban water resources (Chen & Chen, 2020).

Figure 1: Operating diagram of a Sponge City



Source: Adapted from Chen and Chen, 2020

The economic viability and effectiveness of solutions such as this can be validated using tools such as the Storm Water Management Model (SWMM)[10], used in hydrological modeling for flood prevention (Mei et al., 2018). Furthermore, life-cycle cost analysis of this approach, as with other GI approaches, can ensure the financial sustainability of investments, considering the costs of implementation, operation, and long-term benefits (Kvitsjøen et al., 2021). Collaboration between social sectors (Kvitsjøen et al., 2021) and local regulations in accordance with hydrological, climatic, and soil characteristics (Nguyen et al., 2019) make GI initiatives successful and sustainable in cities. Strategic planning of an Integrated Stormwater Management System (ISMS) incorporating GI and LID technologies would optimize its benefits and reduce flood risks. Since the intensive use of GI systems in non-extreme events

[10] The Stormwater Management Model (SWMM) was developed by the United States Environmental Protection Agency (EPA) to reduce runoff through infiltration and retention, as well as to reduce discharges that harm water bodies. It can evaluate stormwater management measures for gray infrastructure, such as pipes and storm drains, and is an effective tool for developing cost-effective hybrid green/gray stormwater control systems (U.S. EPA, 2014).

can minimize flood depth and runoff velocity (Kvitsjøen et al., 2021), providing more efficient water management.

THE EXPERIENCE OF FRENCH *ÉCOQUARTIERS*

ÉcoQuartiers, or eco-neighborhoods, is an urban planning model that emerged in France, and are considered laboratories for the city of the future. They seek to integrate urban and rural elements, balancing environmental, social and economic needs (Bonard & Matthey, 2010; Chastenet et al., 2016). Clichy-Batignolles in Paris, for example, was developed on a former industrial and railway site. The project received the *ÉcoQuartier* certification by incorporating social housing, commercial spaces and an extensive public park, as well as sustainable technologies such as solar and geothermal energy, rainwater harvesting systems and green roofs (Bazard, 2016; Flurin, 2017).

The innovations applied to contribute to the mitigation of heat islands and promote sustainable mobility, with an emphasis on public transport and shared roads for active mobility (Bazard, 2016). However, as noted by Bonard and Matthey (2010), projects like these can generate negative externalities, such as increased traffic in the surrounding areas and real estate pressure, which can lead to gentrification. Measuring their post-implementation impact, especially on social inclusion and economic viability, remains a challenge (Chastenet et al., 2016).

The *ÉcoQuartier* certification in the evaluation of eco-neighborhoods uses environmental, social and economic indicators, such as greenhouse gas emissions, social diversity and water management (Chastenet et al., 2016). These often occupy underutilized intra-urban land, such as industrial or port areas, limiting their ability to combat disorderly urban expansion. To avoid the cities sprawl, it is necessary to adopt complementary strategies, such as the densification of existing areas and the requalification of underused spaces (Bonard & Matthey, 2010).

Governance also plays an important role in the functioning of this urban planning model, and according to Boquet et al. (2020), an integrated approach is required, involving citizen participation and collaboration between the public and private sectors. Another major difference in this model is the assessment tools, guideline manuals and incentives for the collaborative economy, which strengthen participatory management and the construction of more cohesive and supportive communities (Boquet et al., 2020).

CHALLENGES IN IMPLEMENTING GI IN URBAN AND REGIONAL PLANNING

According to the authors, there are financial, institutional, social and technical barriers (Table 1) that hinder the implementation of GI and the adoption of sustainable practices in the management of water resources in urban environments.

Table 1 – Barriers to implementing GI in PUR

Barriers	Authors and Descriptions
Financial	Lack of adoption of stormwater fees and financing to comply with regulations and renew aging water, sewer, and stormwater infrastructure (Cousins & Hill, 2021);
	Acceptance of stormwater management fees (Johns 2019);
	Inequalities in investment in water infrastructure (Kooy et al., 2020);
	Financial barriers, such as proof of property ownership that excludes underserved communities (Dean et al., 2022; Matsler et al., 2023), also constitute a social barrier;
	Lack of information on the monetization and cost-benefits of RI for real estate developers, engineers, and local authorities (Sinnett et al., 2018).
	Lack of information on monetization and cost-benefit of GI for real estate developers, engineers and local authorities (Sinnett et al., 2018);
Institucional	History of disproportionate investment in gray infrastructure (Johns, 2019);
	Lack of community participation and disconnection from local identity can hinder the acceptance and implementation of GI (Hamlin & Nielsen-Pincus, 2020);
	Environmental injustices and disparities in access to water services based on race and geographic location (Heck, 2021), an institutional and social barrier;
	Political decision-making processes that do not prioritize environmental considerations or the long-term benefits of GI (Reu Junqueira et al., 2023);
	Centralized and top-down governance models (Wilfong et al., 2023).
Social	Barriers to participation, such as costs and limited space, requiring inclusive strategies (Conway et al., 2022);
	Failure to consider stakeholders' perceptions when identifying strategies that overcome challenges and maximize benefits in implementing GI (Elderbrock et al., 2020);
	In co-benefit analysis, runoff reduction is often considered at the expense of other benefits, such as water quality, recreation, and public health (Reu Junqueira et al., 2023);
	Gentrification generated by real estate appreciation due to aesthetic improvements and other GI gains (Walker, 2021).
Technical	Regulatory and legislative barriers, bureaucratic structuring, which can hinder the implementation of innovative stormwater management strategies. Complex regulations due to city growth and climate uncertainties, requiring adaptations (Axelsson et al., 2020);
	Challenges in integrating with existing infrastructure (Cousins & Hill, 2021);
	Dependence of perceptions of local climate characteristics, aesthetics, personal needs and values on the suitability of water-sensitive technologies, influencing their acceptance and necessary variations (Dean et al., 2022);
	Lack of awareness about the importance of green spaces in public health makes it difficult for managers to convince them to integrate GI into urban planning (Giner et al., 2019);
	Lack of public awareness promotion by planners and policy makers about the role of GI in quality of life and mitigating inequalities (Hoover et al., 2021);
	Inequalities in water infrastructure and political complexity that influence the effectiveness of natural solutions (Kooy et al., 2020);
	Uncertainty about the hydrological performance of GI, generating resistance and limiting its widespread adoption (Kvamsås, 2021);

Barriers	Authors and Descriptions
	Variations in terminology and concepts across geographic regions alter their understanding and implementation, as well as local characteristics and cultural contexts; generating different research focuses, methodologies, and efficiency metrics that may not be universally applicable (Matsler et al., 2021);
	Climate and socioeconomic uncertainties that make it difficult for policymakers to plan stormwater management systems (Mei et al., 2018);
	Discrepant perceptions between professionals and the community impact sustainability due to a lack of confidence in technical solutions suggested (Morris & Tippett, 2023);
	Lack of understanding of heat sources and heat sinks in cities and local climate zones; lack of creation of high spatial and temporal resolution urban heat maps (Probst et al., 2022);
	Lack of information on the technical and economic feasibility of IR alternatives, especially in modernization areas. Gaps in the analysis of construction and maintenance costs of different types of GI and their effectiveness in precipitation management (Reu Junqueira et al., 2023);
	Low adoption of GI due to local implementation obstacles (Willems et al., 2020).

Source: Prepared by the authors, 2025

The need for coordination between different administrative levels of governance, the development of new policy instruments specific to the integration of green infrastructure into gray infrastructure, and the reallocation of traditionally allocated investments, as well as the removal of institutional barriers, remain major challenges in the transition from gray to green. Collaboration between NGOs, the public sector and the business sector can drive a cultural shift by increasing capacity and understanding of the benefits of GI, engaging communities and stakeholders, and increasing the acceptability of proposed solutions (Johns, 2019).

STRATEGIES FRAMEWORK FOR INSERTING TVB INTO URP

Based on the articles researched, a brief framework is proposed for implementing the *Trame verte et bleue* in urban and regional planning (Table 2).

Table 2 – Framework for implementing the TVB in urban and regional planning

Items	Strategies
Strategic Planning and Integration in Urban and Regional Planning	Incorporate GI from the beginning of urban and regional planning projects (Axelsson et al., 2020; Carter et al., 2017; Liu & Wu, 2022); Use of inventories to protect and enhance green spaces, preventing uncontrolled urbanization (Feltynowski & Kronenberg, 2020; Nasr & Potteiger, 2023; Schubert et al., 2017); Value wetlands and their relationship with the hydrological cycle (Hamlin & Nielsen-Pincus, 2020; Rojas et al., 2022; Willems et al., 2020); Create municipal laws that encourage GI, including sustainable urban development codes (Giner et al., 2019; Johns, 2019; Muller & Mitova, 2023).
Water Management, Sponge Cities and Nature-Based Solutions (NBS)	Integrate GI with gray infrastructure to optimize stormwater management (Chen et al., 2024; Kvitsjøen et al., 2021; Staddon et al., 2018); Apply principles of the "Sponge City" methodology to improve infiltration and water quality (Mei et al., 2018; Nguyen et al., 2019; Zheng & Barker, 2021); Renaturation of water systems to restore aquatic ecosystems and improve natural drainage (Gougeon et al., 2023; Matsler et al., 2021; Staddon et al., 2018; Wang et al., 2023); Implement blue green infrastructure (BGI) for flood mitigation and environmental justice (Hamel et al., 2021; Hoover et al., 2021; Sinnett et al., 2018; Wilfong et al., 2022).
Connectivity and the Green and Blue infrastructure	Create ecological corridors to connect natural and urban spaces (Gašparović et al., 2022; Heim Lafrombois et al., 2022; Kooy et al., 2020); Use GIS to map fragmentation and prioritize reconnection actions (Hasala et al., 2020; Probst et al., 2022; Zheng & Barker, 2021); Integrate green roofs, rain gardens, and bioswales to increase climate resilience (Simpson & Winston, 2022; Song et al., 2024; Walker, 2021).
Governance, Public Participation, and Socioenvironmental Justice	Establish interagency collaboration between urban planning, water resources, and the environment (Elderbrock et al., 2020; Kvamsås, 2021; Reu Junqueira et al., 2023); Engage local communities from the design to maintenance of the GI (Conway et al., 2022; Heim Lafrombois et al., 2022; Mcfarland et al., 2019; Wilfong et al., 2023); Create policies that prevent gentrification and ensure equitable distribution of benefits (Fink, 2018; Heck, 2021; Hoover et al., 2021; Walker, 2021). Foster popular participation through environmental education and participatory decision-making (Dean et al., 2022; Nasr & Potteiger, 2023; Wilfong et al., 2023).

Monitoring, Technology and Adaptation	Develop tools to optimize the location and efficiency of GI (Chen et al., 2024; Liu & Wu, 2022), such as the Green Infrastructure Cost-Effectiveness Rating Index (GICRI) (Reu Junqueira et al., 2023); Use hydrological modeling to assess the impacts and cost-benefit of GI solutions (Chen et al., 2024; Mcfarland et al., 2019; Probst et al., 2022); Create evidence-based guidelines to standardize the GI use in urban plans (Elderbrock et al., 2020; Matsler et al., 2021; Sinnett et al., 2018); Monitoring the evolution of the TVB through sensors and satellite images (Gašparović et al., 2022; Kooy et al., 2020; Probst et al., 2022).

Source: Prepared by the authors, 2025

The integration of green infrastructure (GI) and the *Trame bleue* into the URP can contribute to building resilient and sustainable cities. Multiple strategies, such as those mentioned in the table above, should be incorporated into the planning and regeneration of urban and regional spaces, so that the sustainability of GI is not limited to ecological benefits but serves the entire population, avoiding discrimination and inequality.

The combination of strategies such as the incorporation of GI from the early stages of urban projects, the application of nature-based solutions (NBS) and the renaturation of water systems contribute to the efficient management of stormwater, the preservation of biodiversity, the mitigation of the impacts of climate change, and the unbridled growth of cities. The *Trame bleue*, composed of urban water systems such as rivers, streams and wetlands, becomes a central axis for strengthening ecological connectivity and increasing urban resilience. To achieve egalitarian social benefits, it is necessary to create specific legislation, encourage popular participation, and ensure good coordination among other agents. Academia can contribute to governance by promoting education and monitoring these strategies, facilitating the use of advanced technologies, such as hydrological modeling and sensor monitoring, which are essential to ensuring the effectiveness of these initiatives. Collaboration between the sectors involved and inclusive governance that values socio-environmental justice is the key to building sustainable, equitable urbanization that is adapted to environmental and social needs.

ANALYSIS AND REFLECTIONS

Green infrastructure (GI) is seen by the authors as the key to addressing contemporary urban challenges, promoting multifunctionality and resilience at many scales and scenarios. Among the proposed solutions, the use of GI in urban planning has proven to be a viable option for addressing water management together with issues of environmental sustainability and equity in society.

According to the authors analyzed, GI sustainability strategies that can be applied in urban planning involve multifunctional approaches that integrate environmental, social and economic aspects. Starting with the integration of GI into urban planning from the initial phases of projects, enabling assertive land use policies and the conservation of natural areas, preventing disorderly urbanization (Feltynowski & Kronenberg, 2020; Liu & Wu, 2022). This integration can be facilitated through public policies and municipal regulations, especially in new urban developments (Johns, 2019; Staddon et al., 2018).

The *Trame bleue* could guide regeneration measures or the planning of new urban areas. Starting with the inventory of water resources and hydromorphological characteristics to create permanent protection areas and direct urbanization, not just seeking late solutions to problems related to flooding. Among the strategies suggested by the authors, the implementation of blue-green infrastructure (BGI) has been highlighted as an effective solution to mitigate floods and increase environmental equity, ensuring that vulnerable communities have access to the benefits of these spaces (Hamel et al., 2021; Hoover et al., 2021; Wilfong et al., 2022). Still related to water resources, the renaturation of water systems is a strategy indicated for the restoration of aquatic ecosystems and the improvement of urban drainage (Gougeon et al., 2023; Matsler et al., 2021). In urban areas, several strategies to increase stormwater infiltration are suggested, including the conversion of degraded urban areas into multi-use and recreational sites, green roofs and vegetated swales. They improve water quality and boost ecosystem services in urban environments (Hamel & Tan, 2022; McFarland et al., 2019; Morris & Tippett, 2023; Woznicki et al., 2018).

Decentralized stormwater control measures (SCMs) are particularly effective during moderate precipitation events, helping to mitigate consequences in vulnerable locations created by urban development pressure (Woznicki et al., 2018). Sustainable road infrastructure planning, such as in Korea (Lee & Kim, 2023) and other linear infrastructures with GI, seek to integrate ecological connectivity and urban functionality, as seen in the renaturalization of water systems and the enhancement of biodiversity in dense urban areas (Gašparović et al., 2022). The implementation of these methods emphasizes the role of GI in restoring natural processes and minimizing the hardships caused by unplanned urbanization.

Beyond hydrological issues, the incorporation of GI in urban and regional planning (URP) is seen as a tool for social justice and environmental equity. Vulnerable populations, historically affected by the lack of stormwater management, can benefit from the implementation of small interventions. Publicly sponsored revitalizations of public spaces, as well as the incorporation of green spaces into urban designs, help to reduce structural disparities (Hasala et al., 2020; Staddon et al., 2018).

The authors also highlight the importance of clear regulation and policy tools to enable and scale GI-based solutions (Staddon et al., 2018). Regulations in Toronto (Canada), Basel (Switzerland) and Portland (USA) requiring green roofs on new developments show how local policies can ensure successful and long-term implementation (Staddon et al., 2018). To fully realize the promise of GI, policies must be aligned with land-use management instruments, with a focus on concentrated growth (Muller & Mitova, 2023), supporting more integrated and resilient urban responses, such as coastal and river flood protection strategies (Axelsson et al., 2020).

The development of specific tools, such as the Green Infrastructure Cost-Effectiveness Rating Index (GICRI) and spatial analyses of hydrological configuration, have been proposed as effective strategies to prioritize investments and identify opportunities for integrating GI with traditional infrastructures (Reu Junqueira et al., 2023; Chen et al., 2024). This approach emphasizes the importance of considering local circumstances when developing solutions, which improves the environmental, social, and economic benefits of GI. The social factor is strongly linked to urban sustainability issues, whether in the distribution or maintenance of GI.

Some authors investigate the social potential of GI, while others do not and instead focus on more technical systems, such as tool development, SCMs, BMPs, LID, and NbS implementation. However, there is a broad consensus that GI is establishing itself as an essential component in the shifting paradigms of contemporary urban planning and in the search for adaptation, sustainability, and equity. Situations of commodification in the processes of appropriation and qualification of waterfronts, such as Minneapolis (Minnesota), Cincinnati (Ohio), San Antonio (Texas) and Fort Lauderdale (Florida), demonstrate gentrification as a significant asset employed by public and private investors (Chevalier, 2004).

Écoquartiers represent an attempt to align urban development with sustainability, but, like many other approaches to GI, they face challenges such as gentrification and integration with the existing urban fabric. As with GI, to ensure their effectiveness, it is necessary to think about the continuum of the urban and regional landscape. It is important that these initiatives are part of a broader urban strategy, capable of transforming not only isolated neighborhoods, but also considering the entire urban landscape and its connections. Still like GI, and as highlighted by Chastenet et al. (2016), continuous evaluation and, when necessary, adaptation of projects is necessary to ensure that *écoquartiers* fulfill their role in urban and regional sustainability, taking advantage of the *Trame bleue*. Sponge cities, on the other hand, by combining traditional Chinese hydrological management practices with modern LID techniques (Chikhi et al., 2023), are more aligned with sustainable urban planning, with the *Trame bleue* as the protagonist. As with the application of any GI approach, according to Nguyen et al. (2019), it is necessary to consider local characteristics in this process, such as climate, hydrology, geology and culture, and it is also desirable that there be collaboration between the various agents involved, from the assisted community to the government.

By examining this sample of articles that deal with the integration of GI and TB in urban planning, different views on the *Trame bleue* and its role in sustainability building strategies are revealed, with three different views emerging on this subject.

The first point of view emphasizes that GI and TB can be considered complementary or even interconnected systems. Although TB is often implicit in the broader scope of GI, with varying degrees of visibility among authors, urban planning that incorporates both infrastructures is considered essential to achieve urban sustainability and resilience. In this context, NBS or GI should be used as multifunctional networks that contain open spaces and water management systems to address issues such as urban water pollution and flooding (Dean et al., 2022; Rojas et al., 2022). The role of TB is seen in this view as a complementary solution, strengthening the functions of GI, particularly in terms of water resource management, flood control and water quality improvement. Even so, although this is a widely discussed topic, the expression TB or blue infrastructure may not even appear in searches, as in Carter et al. (2017), or may not even be named as GI, but as Water-Sensitive Urban Design (WSUD) as in Dean et al. (2022).

The second point of view also mentions GI and TB as an important strategy for sustainable urban planning. Although TB is not always evident, the great potential of its ESs in water and urban management is demonstrated (Elderbrock et al., 2020). However, its integration with GI is clear, particularly in flood management, water purification and improvement of urban quality of life (Elderbrock et al., 2020; Hamel et al., 2021; Sinnett et al., 2018). The interaction between vegetation and water, and its ES (Liu & Wu 2022), provides multifunctional solutions that mitigate flooding and regulate the hydrological cycle while providing benefits such as improving biodiversity and creating recreational spaces (Schubert et al., 2017). This approach also addresses the challenges of gray infrastructure, including the suppression of natural watercourses, highlighting the transformative role of TB in restoring aquatic ecosystems (Gašparović et al., 2022). The third viewpoint manifests GI and TB as components of a larger urban management system, while focusing more on methodologies and approaches related to water systems. Although regions and their river basins and the macro-landscape are considered, with these authors, specific solutions are explored, with little attention paid to the connectivity necessary for the design and revitalization of landscapes in urban and regional planning. TB, which consists of urban wetlands, lakes, and water bodies, is seen here as an important mechanism to retain and improve urban water quality (Hamel & Tan, 2022; Chen et al., 2024). Integration with decentralized solutions, such as LID, is emphasized as a technique to increase hydrological linkages (Chen et al., 2024) and restore aquatic ecosystems (Simpson & Winston, 2022). The authors highlight that this approach relieves traditional drainage systems, increasing urban resilience and promoting sustainability and adaptability to future climate change.

When analyzing collaboration between government agencies, institutions, and popular participation, social justice is not a strong theme in the overall sample of articles studied, but the importance of institutional collaboration is universal. Positive and fluid communication between actors involved in GI research, planning, and implementation, as well as sufficient dissemination, are seen as essential for the long-term success of the project. According to Kambites and Owen (as cited in Mell, 2010), connectivity between people, spaces, and various physical and administrative boundaries are essential components of good GI planning. However, a non-integrative or fragmented planning process hinders the successful adaptation of federal policy to the local level (Elderbrock et al., 2020; Mell, 2010; Wilfong et al., 2023).

FINAL CONSIDERATIONS ON THE PRESENCE OF TB AS A SUSTAINABILITY STRATEGY IN THE CONSULTED BIBLIOGRAPHY

After the analysis carried out in this study, it can be concluded that the main strategy in the search for sustainability in the URP is the integration of GI into it. This is broken down into other important strategies, such as the use of the *Trame bleue* to guide the planning itself, in addition to greater visibility of the GI in this process. Strategies such as the renaturation of water systems and the promotion of nature-based solutions are already taking place, but in a disconnected and fragmented manner. In addition to the usual holistic approach, greater integration is necessary, which can be facilitated through public policies and municipal regulations, popular participation and inter-institutional governance. The participation of academia in this dynamic is of great importance, especially in dissemination, multiplication, education and assistance in continuous monitoring and hydrological modeling, connecting the technical staff with the other agents involved.

The presence of TB and the main themes addressed were presented differently in the article sample, and water resources were not identified as a guiding factor in urban and regional planning. Few studies have examined the potential of using TB as a driving force in URP. Its presence in the articles examined was linked to reactive and mitigation efforts for disasters such as floods. The sample could also be divided into subgroups based on their main topics, such as governance, water management in urban planning, environmental justice, urban planning and development related to sustainability challenges, urban ecosystem services, and NBS.

GI is a broad and multidisciplinary concept that, when incorporated strategically and holistically into practice, can address a wide range of urban concerns, from water management and climate change mitigation to human well-being and environmental sustainability. This demonstrates that it is a consistent strategy and is aligned with the UN Sustainable Development Goals (SDGs) for the development of Sustainable Cities and Communities (SDG 11) and Climate Action (SDG 13) (Global Goals, n.d., n.p.). Some barriers to its adoption, such as acceptability and maintenance, are caused by variations in its design, which may differ depending on the geographic region or the scientific field of interest.

According to the research of the authors studied in this sample, many of these problems can be overcome by considering the local context and the individual needs of communities, thus helping to popularize GI through information and education. This study contributes to the international scientific debate by identifying water management issues that planners, policymakers and other actors face when developing or revitalizing urban and regional areas with GI to mitigate or solve environmental problems. However, the complexities of these processes highlight the need for further research on the *Trame verte et bleue*, or BGI, and its socio-environmental impacts, the effectiveness of its systems and solutions, governance and, most importantly, the perception of the *Trame bleue* as a driving force in the development of urban and peri-urban spaces.

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APPENDIX

Table – Reference and titles of the articles analyzed

Reference	Title
Axelsson et al., 2020	Urban policy adaptation toward managing increasing pluvial flooding events under climate change.
Carter et al., 2017	Adapting cities to climate change – exploring the flood risk management role of green infrastructure landscapes.
Conway et al., 2022	Who participates in green infrastructure initiatives and why? Comparing participants and non-participants in Philadelphia's GI programs.
Cousins & Hill, 2021	Green infrastructure, stormwater, and the financialization of municipal environmental governance.
Dean et al., 2022	Accelerating the adoption of water sensitive innovations: community perceptions of practices and technologies to mitigate urban stormwater pollution.
Elderbrock et al., 2020	A guide to public green space planning for urban ecosystem services.
Feltynowski & Kronenberg, 2020	Urban green spaces—an underestimated resource in third-tier towns in Poland.
Fink, 2018	Contrasting governance learning processes of climate-leading and -lagging cities: Portland, Oregon, and Phoenix, Arizona, USA.
Gašparović et al., 2022	Impacts of Zagreb's urban development on dynamic changes in stream landscapes from mid-twentieth century.
Giner et al., 2019	Promoting green infrastructure in Mexico's northern border: The Border Environment Cooperation Commission's experience and lessons learned.
Gougeon et al., 2023	Impact of bioretention cells in cities with a cold climate: modeling snow management based on a case study.
Hamel et al., 2021	Blending ecosystem service and resilience perspectives in planning of natural infrastructure: Lessons from the San Francisco Bay Area.
Hamel & Tan, 2022	Blue–green infrastructure for flood and water quality management in Southeast Asia: Evidence and knowledge gaps.
Hamlin & Nielsen-Pincus, 2020	From gray copycats to green wolves: policy and infrastructure for flood risk management.
Hasala et al., 2020	Green infrastructure site selection in the Walnut Creek wetland community: A case study from southeast
Heck, 2021	Greening the color line: historicizing water infrastructure redevelopment and environmental justice in the St. Louis metropolitan region.
Heim LaFrombois et al., 2022	Planning for green infrastructure along the Gulf Coast: an evaluation of comprehensive plans and planning practices in the Mississippi-Alabama coastal region.
Hoover et al., 2021	Environmental justice implications of siting criteria in urban green infrastructure planning.
Chen et al. , 2024	Optimization of the integrated green–gray–blue system to deal with urban flood under multi-objective decision-making.
Johns, 2019	Understanding barriers to green infrastructure policy and stormwater management in the City of Toronto: a shift from gray to green or policy layering and conversion?
Kooy et al., 2020	Nature Based Solutions for urban water management in Asian cities: integrating vulnerability into sustainable design.
Kvamsås, 2021	Addressing the adaptive challenges of alternative stormwater planning.
Kvitsjøen et al., 2021	Intensifying rehabilitation of combined sewer systems using trenchless technology in combination with low impact development and green infrastructure.
Lee & Kim, 2023	Green space ecosystem services and value evaluation of three-dimensional roads for sustainable cities.
Liu & Wu, 2022	Scenario analysis in urban ecosystem services research: Progress, prospects, and implications for urban planning and management.
Matsler et al., 2021	A 'green' chameleon: Exploring the many disciplinary definitions, goals, and forms of "green infrastructure".
Matsler et al., 2023	Institutionalizing barriers to access? An equity scan of green stormwater infrastructure (GSI) incentive programs in the United States.

Reference	Title
McFarland et al., 2019	Guide for using green infrastructure in urban environments for stormwater management.
Mei et al., 2018	Integrated assessments of green infrastructure for flood mitigation to support robust decision-making for sponge city construction in an urbanized watershed.
Morris & Tippett, 2023	Perceptions and practice in Natural Flood Management: unpacking differences in community and practitioner perspectives.
Muller & Mitova, 2023	The Hardening of the American Landscape: Effects of Land Use Policy on the Evolution of Urban Surfaces.
Nasr & Potteiger, 2023	Spaces, systems and infrastructures: From founding visions to emerging approaches for the productive urban landscape.
Nguyen et al., 2019	Implementation of a specific urban water management - Sponge City.
Probst et al., 2022	Blue Green Systems for urban heat mitigation: mechanisms, effectiveness and research directions.
Reu Junqueira et al., 2023	Developing and testing a cost-effectiveness analysis to prioritize green infrastructure alternatives for climate change adaptation.
Rojas et al., 2022	Assessment of the flood mitigation ecosystem service in a coastal wetland and potential impact of future urban development in Chile.
Schubert et al., 2017	Implementation of the ecosystem services approach in Swedish municipal planning.
Simpson & Winston, 2022	Effects of land use on thermal enrichment of urban stormwater and potential mitigation of runoff temperature by watershed-scale stormwater control measures.
Sinnett et al., 2018	The translation and use of green infrastructure evidence.
Song et al., 2024	Perspective swap from central Europe to east Asia: How relevant is Urban Environmental Acupuncture in small-scale green space development in the context of the republic of Korea?
Staddon et al., 2018	Contributions of green infrastructure to enhancing urban resilience.
Chen et al., 2024	Multi-objective decision-making for green infrastructure planning: Impacts of rainfall characteristics and infrastructure configuration.
Walker, 2021	Engineering gentrification: urban redevelopment, sustainability policy, and green stormwater infrastructure in Minneapolis.
Wang et al., 2023	Green infrastructure optimization considering spatial functional zoning in urban stormwater management.
Wilfong et al., 2023	Shifting paradigms in stormwater management – hydrosocial relations and stormwater hydrocitizenship.
Wilfong et al., 2022	Diffusing responsibility, decentralizing infrastructure: hydrosocial relationships within the shifting stormwater management paradigm.
Willems et al., 2020	How actors are (dis)integrating policy agendas for multi-functional blue and green infrastructure projects on the ground.
Woznicki et al., 2018	Effectiveness of landscape-based green infrastructure for stormwater management in suburban catchments.
Zheng & Barker, 2021	Green infrastructure and urbanisation in suburban Beijing: An improved neighbourhood assessment framework.
Zuniga-Teran et al., 2019	Challenges of mainstreaming green infrastructure in built environment professions.

Source: Prepared by the authors, 2025