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BLUE-GREEN INFRASTRUCTURE OF A REGENERATIVE CITY

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ABSTRACT: This paper explores the challenges and opportunities associated with implementing blue-green infrastructure (BGI) in urban environments, particularly within regenerative cities. It addresses how BGI initiatives can align with urban sustainability goals, especially in densely developed areas where traditional infrastructure practices often hinder the integration of new ecological solutions. The study employs a narrative literature review and case studies to identify and categorise formal-legal, organisational, and financial barriers to implementing BGI projects in urban areas. The analysis includes examining legal documents, scholarly articles, and real-world examples, providing insights into common obstacles and practical implications for urban planning. Findings reveal significant regulatory, technical, and administrative challenges to BGI implementation, particularly related to the inflexible nature of local planning regulations and the need for interdisciplinary collaboration. The paper outlines practical recommendations, such as adjusting local policies, enhancing stakeholder engagement, and valuing ecosystem services to facilitate BGI projects. While the study highlights existing challenges, further empirical research on the long-term impacts of BGI in various climatic and urban contexts is recommended.

KEYWORDS: blue-green infrastructure, regenerative city, local authorities, urban areas

Introduction

Contemporary urban challenges compel a reflection on shaping cities that will be sustainable and regenerative. Girardet (2017) indicates that regenerative cities are the future of urbanisation, where humans interact with nature to restore local ecosystems. Wahl (2017) emphasises that sustainability alone is insufficient, necessitating actions aimed at active environmental regeneration. Regenerative is characterised by a holistic approach, a long-term perspective, and the adoption of an evolutionary paradigm in which natural resources will be actively restored as human systems co-evolve with nature. Simultaneously, ongoing challenges and the climate crisis force urban land managers to undertake adaptive and mitigative actions that often require immediate implementation (Aboagye & Sharifi, 2024). This opens the door to a conflict between the desire for quick and lasting results and long-term planning, considering various trends emerging in both the micro- and macro-environment. All these efforts are further situated within the realm of the public sector, whose legal, organisational, and financial frameworks often create natural obstacles to achieving effectiveness and efficiency while limiting innovation (Onrubia-Fernández & Fuentes, 2017). Moreover, investment actions are frequently conducted in densely developed urban areas with diverse functions and complex ownership structures.

In the face of the outlined challenges, implementing blue-green infrastructure (BGI) projects, which have represented a real opportunity to solve a range of issues, is at least hindered if we can speak of their optimality. Researchers indicate the need for more strategic planning for BGI investments or its tendency to focus on a single objective (Kuller et al., 2021; Matsler et al., 2021; Meerow & Newell, 2017).

To effectively analyse the possibilities and obstacles in implementing blue-green infrastructure in urban areas, theoretical postulates for BGI implementation were identified, followed by an outline of operational barriers encountered during the planning and execution of such projects (for this purpose, besides a literature review, a set of examples from administrative practice was collected and presented). The discussion aimed to answer the question of to what extent these theoretical postulates can be reflected in the practical implementation of BGI projects by local governments and how obstacles in this area can be effectively eliminated. In conclusion, the study presents findings and suggests directions for further research.

The primary research methods included a narrative literature review to provide a theoretical context and an overview of the current knowledge and research on BGI, identifying and characterising operational barriers to BGI implementation in cities and presenting case studies illustrating the issues discussed.

Implementation of BGI – Theoretical Postulates

Blue-green infrastructure includes natural and semi-natural ecosystem elements, such as parks, rivers, water reservoirs, green roofs, and walls, which serve environmental, social, and economic functions (Xie & Bulkeley, 2020). Properly integrated blue-green infrastructure contributes to mitigating various effects of urbanisation, such as heat islands and pollution, while enhancing water retention and supporting local ecosystems (Mell, 2010; Alves et al., 2019). An essential aspect of this concept is the regeneration of the urban environment, which can foster the development of so-called regenerative cities (Girardet, 2017). The theoretical postulates regarding BGI implementation cover various aspects, such as spatial planning, integration with existing infrastructure, and ecological, social, and economic benefits (see Fig. 1).

Almaaitah et al. (2021) emphasise that BGI is a vital tool in climate change adaptation, offering various benefits for urban areas affected by unregulated stormwater and meltwater runoff. Implementing BGI solutions can enhance cities' resilience to extreme weather events, addressing areas such as stormwater and meltwater management and utilisation, minimising flood risks, reducing the urban heat island effect, combating drought, adapting to and mitigating climate change, supporting biodiversity and restoring natural and semi-natural ecosystems in urban areas. Increasing biodiversity and the availability of green spaces in cities improves air quality, and the functional diversity of urban spaces positively impacts residents' mental health and provides a range of ecosystem services.

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For example, Tache et al. (2023), referring to Bucharest as a city where the average green space per capita is significantly below EU recommendations, highlights that implementing BGI strategies could improve the quality of the urban environment. As a recognised leader in BGI implementation, Portland has widely developed the use of green roofs, rain gardens, and stormwater retention systems. O'Donnell et al. (2020a) demonstrated that these investments improved stormwater management and created new habitats for local species, enhancing city biodiversity. Kozak et al. (2020) highlight that incorporating BGI elements into the urban landscape promotes the formation of ecological corridors that support species migration and improve ecosystem quality. Viezzer et al. (2022) indicate that BGI creates a connected network of natural and semi-natural areas that generate a wide range of ecosystem services, including improved air and water quality.

Figure 1. Theoretical Postulates for the Implementation of Blue-Green Infrastructure in Cities

The primary motivations for using BGI included optimising stormwater management in urban areas and minimising flood risk. It aimed to leverage natural processes, such as infiltration and retention, to manage stormwater in a way that mimics the natural hydrological cycle. Liu et al. (2019) demonstrated that BGI can significantly reduce flood risk by decentralising infrastructural elements, and by using solutions such as rain gardens, bioswales, and green roofs, cities can better manage intense rainfall, enhancing resilience to floods and inundations. In cities where traditional drainage systems are overwhelmed, BGI can provide alternative, more sustainable, and practical solutions (Thorne et al., 2015).

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O'Donnell et al. (2017) also indicate that BGI enhances city resilience and improves residents' quality of life by creating recreational spaces and enhancing urban aesthetics. These spaces can serve as meeting places that foster social integration and support the mental health of residents. Schiappacasse and Müller (2015) observe that the effective implementation of green infrastructure strategies requires initiating a broad dialogue and cooperation between different sectors. Involving the community in the planning and implementation process of BGI projects can increase acceptance and support for these initiatives, which is crucial for their success. In terms of public health, BGI has the potential to improve residents' quality of life by increasing access to greenery and water. Grochulska-Salak et al. (2021) points out that integrating green and blue systems into the urban structure can improve residents' mental and physical health.

In the context of BGI planning, it is also essential to utilise modern technologies and geospatial tools. Tache et al. (2023) propose an analytical model that can be used to assess blue-green connections in metropolitan areas, which may enable better urban planning and space management. This approach allows for identifying key areas that can be transformed into BGI spaces, enhancing their functionality and accessibility.

Finally, a systemic approach is necessary for such projects, both at the planning stage (including strategic planning) and during design and implementation. Janiszek and Krzysztofik (2023) emphasise that implementing BGI effectively requires integrating actions in public spaces, which increases cities' resilience to climate change-related threats. In this context, spatial planning should promote the development and efficient implementation of green infrastructure by integrating it with strategic planning.

Januchta-Szostak (2020) presents a synthetic overview of the effects of BGI implementation and related synergies, highlighting direct and indirect areas of impact, including water and wastewater management, flood safety, urban climate and air quality, urban ecosystems and biodiversity, spatial order, quality of life, and public health (see Fig. 2).

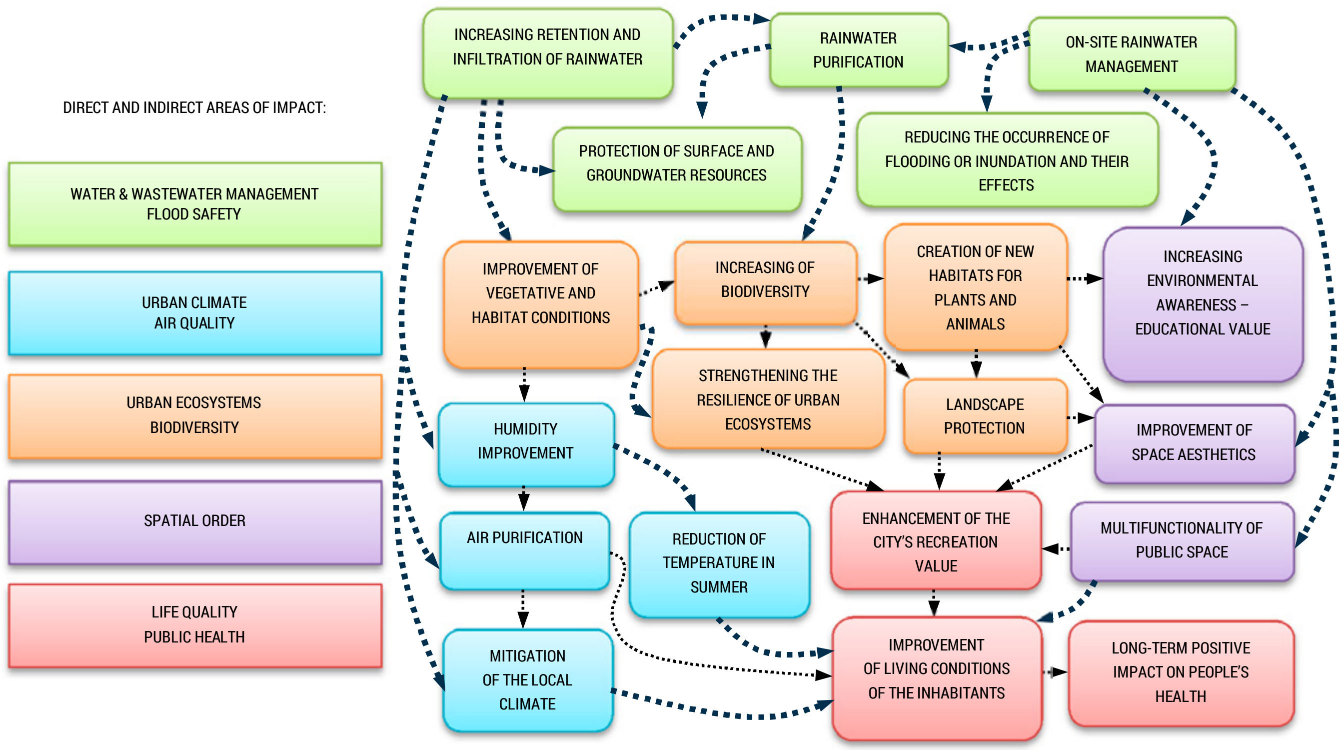

Figure 2. Synergy Effects in the Implementation of Blue-Green Infrastructure
Source: authors' work based on Januchta-Szostak (2020).

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This raises the question of how BGI implementation aligns with the concept of the regenerative city. As Zinowiec-Cieplik (2020) suggests, regenerative urban planning extends and integrates the ideas of eco, innovative, and green cities, resulting in modern solutions that merge the functional-spatial structure of metropolitan areas with natural city systems. Girardet (2017) indicates that regenerative cities are the future of urbanisation, where humans interact with nature to restore local ecosystems. Wahl (2017) emphasises that sustainability alone is insufficient, calling for actions aimed at active environmental regeneration. J.T. Lyle published a handbook in 1994, advocating for circular processes of matter and energy circulation to ensure the renewability of resources consumed in construction and consumption processes. The concept of a regenerative city thus implies that human settlements should not only minimise the negative impacts of their activities but also actively contribute to environmental regeneration and improve the quality of life for residents.

A 2024 report by the Infuture Institute, identifying key trends in the contemporary world, classifies the regenerative city as one of the emerging trends under the category titled "Sustainable World" (Infuture Institute, 2024). The primary drivers for the development of regenerative cities include:
- Growing awareness of environmental issues such as global warming, pollution, and biodiversity loss,
- The adverse effects of climate change on cities, including extreme weather events and rising sea levels,
- Development of green technologies, such as renewable energy sources, innovative city management systems, and advanced waste recycling methods,
- Urbanisation and the increasing population in cities necessitate new solutions for housing, infrastructure, and services,
- Rising social awareness about the impact of surroundings and public spaces on well-being, including mental and physical health, as well as interpersonal relationships, social pressure,
- Increasing financial and environmental costs of traditional urban construction and design methods,
- New legal regulations promoting sustainable development.

The theoretical postulates for implementing blue-green infrastructure in cities largely align with the reasons for realising the abovementioned regenerative city concept. This is the most desirable direction for urban development today. In practice, however, implementing these assumptions encounters numerous obstacles.

Implementation of BGI – Operational Obstacles

Applying BGI solutions addresses several contemporary factors that have a particularly pronounced impact on urban areas. These include the increasing frequency of extreme weather events (intense rainfall, strong winds, etc.) and their consequences (floods, inundations, waterlogging), ongoing climate change (rising annual temperatures, droughts, prolonged heatwaves), "side" issues such as the urban heat island effect, air pollution, the limited effectiveness of existing solutions (flooding, waterlogging), outdated "traditional" technical infrastructure, as well as global trends and a growing awareness of these issues.

However, administrative practice shows that large-scale implementation of BGI solutions takes time and effort. Based on a narrative literature review of the past 10 years, critical obstacles in implementing blue-green infrastructure projects have been identified (see Figure 3). Researchers most commonly categorise these barriers into four main groups: legal, financial, organisational, and technical/technological obstacles.

Legal obstacles primarily concern national and local regulations that need to optimise the application and protection of BGI in urban areas. Antoszewski et al. (2023) conducted a comprehensive analysis in this area, highlighting the limitations arising from the lack of a clear definition of BGI in Polish law, which results in insufficient legitimisation. This leads to a prioritisation of traditional infrastructure over BGI solutions. Related issues identified by the authors include the absence of a complete definition of BGI and ecosystem services in the Polish legal system, the limited influence of the scientific community on shaping BGI, the complexity of legal regulations concerning BGI protection, the use of unreliable ecophysiographic studies in developing local spatial development plans,

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and the non-mandatory nature of local spatial development plan for entire municipalities. They also raise the issue of legal protection for various elements of BGI, referencing, among other things, land use and legal protection of specific areas under separate regulations, such as forests, aquatic ecosystems, or specific classes and types of agricultural land.

Legal Obstacles

- Lack of adaptation of the legal system to flexible and modern solutions like green roofs or rain gardens
- Legal frameworks prioritizing traditional infrastructure (zoning plan regulations, requirements in environmental decision-making processes, etc.)
- Lack of clear guidelines for the design, maintenance, and integration of BGI with traditional infrastructure
- Variations in local regulations and administrative conditions
- Restrictions regarding land ownership

Financial Obstacles

- Capital intensity of investments, both at the design and maintenance stages
- Long-term/deferred economic benefits of BGI
- Lack of sufficient economic justification for investment (e.g., lack of ecosystem service valuations)

Organizational Obstacles

- Obstacles in the collaboration of various stakeholder groups – governments at different levels, residents, designers, contractors
- Lack of awareness among decision-makers, leading to a preference for traditional solutions
- Need for an interdisciplinary approach, which is difficult within functional-hierarchical structures of public administration
- Lack of local policies and strategies for BGI implementation
- Limited public awareness

Technical/Technological Obstacles

- Integration with existing infrastructure
- Uncertainty of hydrological performance
- Concerns about reliability
- Specialized knowledge and skills required at the design stage
- System complexity

Figure 3. Operational Obstacles to the Implementation of Blue-Green Infrastructure in Cities

Source: authors' work based on Thorne et al. (2015), Almaaitah et al. (2021), Kim and Tran (2018), Singh et al. (2023), Kapetas and Fenner (2020), O'Donnell et al. (2020a), O'Donnell et al. (2021), Zhao et al. (2023), Ncube and Arthur (2021), Ghofrani et al. (2020), Tang et al. (2018) and Antoszewski et al. (2023).

Furthermore, many spatial planning and environmental protection regulations must be adapted to modern concepts like BGI, leading to legal uncertainty (Biela et al., 2023). In this regard, Węcławowicz-Gyurkovich notes that existing spatial development plans may be too rigid to allow for the flexible implementation of innovative solutions, such as rain parks or green roofs (Węcławowicz-Gyurkovich et al., 2024). Local regulations and administrative interpretations during decision-making processes, such as building permits, environmental impact decisions, or consultations with institutions like Polish Waters, may pose challenges. In some cases, overly strict standards can hinder agreement and, consequently, the implementation of innovative solutions. Antoszewski et al. (2023) effectively summarise this, pointing out that Polish law complicates BGI planning due to the lack of holistic planning tools that would enable data collection and the creation of, for example, master plans in this area.

Financial obstacles are primarily centred around the costs of BGI investments, both during the planning and implementation phases and in the operation and maintenance stages. In the article "Influence of Blue-Green and Grey Infrastructure Combinations on Natural and Human-Derived Capital in Urban Drainage Planning,"the authors emphasise that blue-green infrastructure may initially be perceived as more costly. Still, its long-term economic benefits, such as reduced stormwater management costs and improved quality of life, can outweigh the initial expenditures (Ncube & Arthur, 2021). Conversely, Tayouga and Gagné note that in some cases, green infrastructure can be less expensive than traditional infrastructure. For instance, bioretention, as an alternative to conventional pipe systems, may be less costly during construction, with potential long-term savings over time (Tayouga & Gagné, 2016). This suggests that cost comparisons should consider the entire lifecycle of the infrastructure. Meanwhile, Dong et al. (2021) and Qiu et al. (2020) indicate that if green and grey infrastructure have similar cost efficiencies, combining both types can yield additional benefits, suggesting that BGI may effectively complement traditional solutions. A challenge in compelling valuation may lie in the public sector's failure to account for social and environmental costs and benefits in investment profitability analyses, as these factors lack direct monetary value and expenses across the infrastructure's entire lifecycle.

Organisational obstacles also hinder the implementation of BGI in cities. A primary challenge is the need for collaboration among various stakeholders, including different levels of local government, residents, designers, and contractors, throughout its planning, execution, and operational phases. Such collaboration is critical for successfully implementing BGI; however, it often encounters difficulties due to differing interests and priorities among these groups (Gill et al., 2007; Kabisch et al., 2017). Studies show that a lack of integrated management approaches for BGI leads to inefficiencies and stakeholder conflicts (O'Donnell et al., 2017; O'Donnell et al., 2020a). This collaboration also requires the involvement of local communities, which is often overlooked in the planning process (Huyen & Orange, 2023).

Another obstacle classified as an organisational challenge is the low level of awareness among decision-makers, which leads to a preference for traditional infrastructure solutions. Many decision-makers need to recognise the long-term social, ecological, and economic benefits of implementing BGI, resulting in limited financial and institutional support for these projects (Hansen & Pauleit, 2014; Kim & Tran, 2018). The tendency to invest in short-term solutions may also be due to budgetary pressures and a need for more tools to assess long-term environmental effects. Studies indicate that local government decision-makers often need to be aware of potential benefits beyond simple economic calculations that can arise from implementing BGI (Kozak et al., 2020; Tzoulas et al., 2007). Additionally, more multi-criteria analysis tools must be used in the decision-making process. Obtaining permits for project implementation is preceded by a formal and technical-legal review (such as applications for building permits, approvals for road investment projects, and decisions on public-purpose investments, depending on conditions). This process often includes an environmental impact assessment within the framework of decisions on environmental conditions. Other conditions may be considered during the negotiation and consultation, but the process and outcome are highly individualised. None of these elements account for the long-term social, economic, and environmental effects, synergies between them, etc. There are also yet-to-be-widely accepted methodologies for conducting such analyses or incorporating them into administrative procedures.

Moreover, in public administration structures, which are often functional-hierarchical, integrating different fields of knowledge (e.g., ecology, urban planning, engineering) is challenging (O'Donnell et al., 2020a). Effective BGI implementation requires collaboration among experts from various fields, which is difficult to achieve within traditional administrative frameworks (O'Donnell et al., 2021). An interdisciplinary approach is crucial to understanding the complexity of issues associated with blue-green infrastructure and developing effective management strategies (Almaaitah et al., 2021). The need for local policies and strategies for BGI implementation also presents a significant obstacle. Many cities need more precise plans for BGI development, leading to chaotic and inconsistent implementation of these solutions (Kapetas & Fenner, 2020). Without appropriate local policies

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supporting BGI, these projects may be considered optional rather than integral to urban planning (Rynio & Adamiczka, 2023).

Finally, but importantly, there needs to be more public awareness of the benefits of BGI. Residents often need help identifying how BGI could improve their quality of life, leading to resistance to new projects (Yildirim et al., 2022). Raising public awareness is crucial for gaining support for BGI initiatives and encouraging active citizen participation in the planning process (Bocheńska-Skałecka & Walter, 2020).

The implementation of blue-green infrastructure also faces several technical and technological challenges. A vital issue is integrating BGI with existing infrastructure. Many cities already have extensive infrastructure networks that have not been adapted to incorporate new BGI elements, such as green roofs or bioretention (Niedziela-Wawrzyniak, 2023). This requires a well-thought-out design concept and modifications to existing systems, which can involve high costs and complex administrative procedures (Mell et al., 2017). Examples from various cities show that a lack of harmonisation between new and existing solutions can lead to inefficiencies and increased risk of failures (Januchta-Szostak, 2020), which, combined with uncertainty over the hydrological performance of BGI, poses another significant challenge. Many BGI projects are based on assumptions about their capacity to manage stormwater. Still, the need for long-term data on their effectiveness under different climatic and hydrological conditions raises concerns. Studies indicate that this uncertainty can lead to delays in investment decisions and reluctance among decision-makers to adopt innovative solutions. Concerns about BGI reliability can also affect the implementation of such solutions (Leng et al., 2021). Many individuals and institutions fear that new technologies may not meet expectations in terms of efficiency and durability, potentially leading to adverse outcomes such as flooding or environmental degradation (Żółtaszek & Stodulska, 2021). Therefore, thorough risk analyses and performance testing are essential to build trust in BGI as an effective stormwater management tool (O'Donnell et al., 2017).

Specialised knowledge and skills required in the BGI design phase are another significant limiting factor. BGI demands an interdisciplinary approach, combining engineering, ecology, urban planning, and water management expertise. Unfortunately, in many cases, there is a need for more adequately qualified specialists, which can lead to design errors and inefficiencies in BGI project implementation. The system complexity of BGI, due to its multifunctionality and interactions with various elements of the urban ecosystem, adds to the challenge. Implementing BGI requires understanding complex interdependencies between infrastructure components and their impact on the urban environment. This complexity can lead to difficulties managing and monitoring BGI effectiveness, affecting local communities and decision-makers' acceptance and support (Lupa, 2020).

In summary, implementing blue-green infrastructure encounters numerous obstacles across various domains, requiring an integrated approach and cooperation among different fields, stakeholders, and entities. Overcoming these barriers will enable the effective implementation of BGI, bringing environmental, social, and economic benefits.

Selected Practical Implications of BGI

Sometimes, the adopted and implemented solutions are not optimal or cannot be implemented due to formal obstacles. An example of this can be seen in specific local spatial development plan provisions, where the content may need to be revised for currently promoted solutions and new technical possibilities. For implementing BGI, the provisions in these documents related to managing stormwater and meltwater are significant. The example below presents the local spatial development plan's original provisions for Luboń near Poznań, effectively preventing small retention solutions from paving roads within the plan's area. Such provisions in the original document were derived from conditions established during consultations with administrative bodies responsible for environmental protection. Over time, these provisions have become a natural barrier, preventing the implementation of BGI solutions in the city (see Table 1).

Table 1. Sample Provisions in Local Spatial Development Plans Limiting and Permitting the Implementation of BGI for Stormwater and Meltwater Management

Document title	Provision Content	Characteristics
Resolution No. XLIX/263/2010 of the City Council of Luboń dated September 30, 2010, on the local spatial development plan of the City of Luboń – "Lasek – Nowiny St. Area"	§5. Regarding the principles of environmental, nature, and cultural landscape protection, it is established that: 4) stormwater and meltwater from (…) roads are to be directed to the storm sewer system; 5) uncontaminated stormwater and meltwater are to be managed within the building plot area.	This provision prevents the implementation of BGI investments, such as infiltration wells, rain gardens, bioswales, or other small retention facilities.
Resolution No. LXVII/522/2024 of the City Council of Luboń dated March 14, 2024, amending the resolution on the local spatial development plan of the City of Luboń – "Lasek – Nowiny St. Area"	§2. In the resolution (…), the following changes are introduced: 1) §5 point 4 is amended to read: „4) management of stormwater and meltwater in accordance with separate regulations;" 2) §5 point 5 is amended to read: „5) allowing the implementation of facilities and devices for the retention of stormwater and meltwater."	This provision allows for the implementation of BGI investments, such as infiltration wells, rain gardens, bioswales, or other small retention facilities.
Resolution No. XXXVII/272/2017 of the City Council of Luboń dated September 28, 2017, on the adoption of the local spatial development plan "Lasek – section of Nowiny Street"	2. Regarding the principles of environmental, nature, and cultural landscape protection, it is established that: 6) protection measures for surfaces designated for vehicular traffic should be maintained to prevent the infiltration of contaminated stormwater into the soil and groundwater environment. 9. Regarding the principles for the modernization, expansion, and construction of technical infrastructure, it is established that: 9) disposal of stormwater and meltwater: a) to the storm sewer network, while allowing management within the building plot boundaries in accordance with separate regulations, b) from public and internal roads: discharge into the storm sewer network, c) surface discharge of stormwater and meltwater outside the property boundaries is prohibited.	This provision allows for the implementation of BGI investments, such as infiltration wells, rain gardens, bioswales, or other small retention facilities.

Source: authors' work based on the contents of resolutions of the City Council of Luboń.

Figure 4. Condition After Heavy Rainfall in an Area with Traditional Grey Infrastructure

Another challenge lies at the intersection of traditional stormwater and meltwater transport infrastructure with BGI solutions (see Figs. 4 and 5). In the design of both types of infrastructure, it is common practice to base calculations on long-term average rainfall, limiting the ability to construct "oversized" infrastructure. Given that high-intensity rainfall events are rare and most observed data consists of low to medium-intensity rainfall, the probability of extreme rainfall decreases as its intensity increases. For engineering purposes, such as in storm sewer design, it is generally assumed that knowing the variability of instantaneous rainfall intensity is less critical than understanding the average intensity over a specified duration (Licznar, 2018).

Additionally, obtaining permits for activities such as discharging stormwater or meltwater into water bodies or the ground from storm sewer overflows or combined sewer system storm overflows is challenging, as permits are only granted for average values and not for peak values associated with intense rainfall events. This limitation significantly complicates the effective integration of BGI with traditional infrastructure. Figure 5 illustrates the state of BGI during heavy rainfall, while Figure 4 shows the condition of streets equipped with "traditional" storm sewers under the same rainfall event.

Figure 5. Condition After Heavy Rainfall in an Area with Blue-Green Infrastructure (BGI)

Postulates for Enhancing the Effectiveness of BGI Implementation in Cities, Including Regenerative Cities – Discussion

Among the postulates that can enhance the effectiveness of implementing blue-green infrastructure (BGI) in cities, including regenerative towns, the following can be identified: (1) the integration of blue-green infrastructure into spatial planning policies and the flexibility of local legal provisions in this area, including the reduction of legal barriers; (2) the flexibility of administrative procedures and processes by adapting them to the current state of knowledge and technical-organizational solutions related to BGI, along with strengthening interdisciplinary collaboration and raising awareness among designers and decision-makers; (3) the inclusion of non-economic values in the profitability analysis of infrastructure investments (intangible benefits, ecosystem services, etc.); (4) building public support for BGI projects through raising social awareness and education in this field; and (5) utilising technological, geospatial, and process modelling and design tools (see Fig. 6).

For the effective implementation of BGI, urban policies should formally designate BGI as a central element of spatial planning. This requires legislative changes to adapt the legal framework to modern solutions and establish clear guidelines for designing, maintaining, and integrating BGI with traditional infrastructure (Biela et al., 2023; Węcławowicz-Gyurkovich, 2024). Regulatory frameworks, which currently favour traditional infrastructure, must evolve to include the benefits and requirements of BGI (Antoszewski et al., 2023; Thorne et al., 2015). The implementation of BGI also necessi-

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tates broad collaboration across different fields and entities. Overcoming competency isolation within public administration through training programs, interdisciplinary approaches, and promoting collaboration with experts can enable more comprehensive planning, design, and maintenance of BGI solutions in line with the regenerative city model, which focuses on restoring local ecosystems and enhancing urban resilience (Almaaitah et al., 2021).

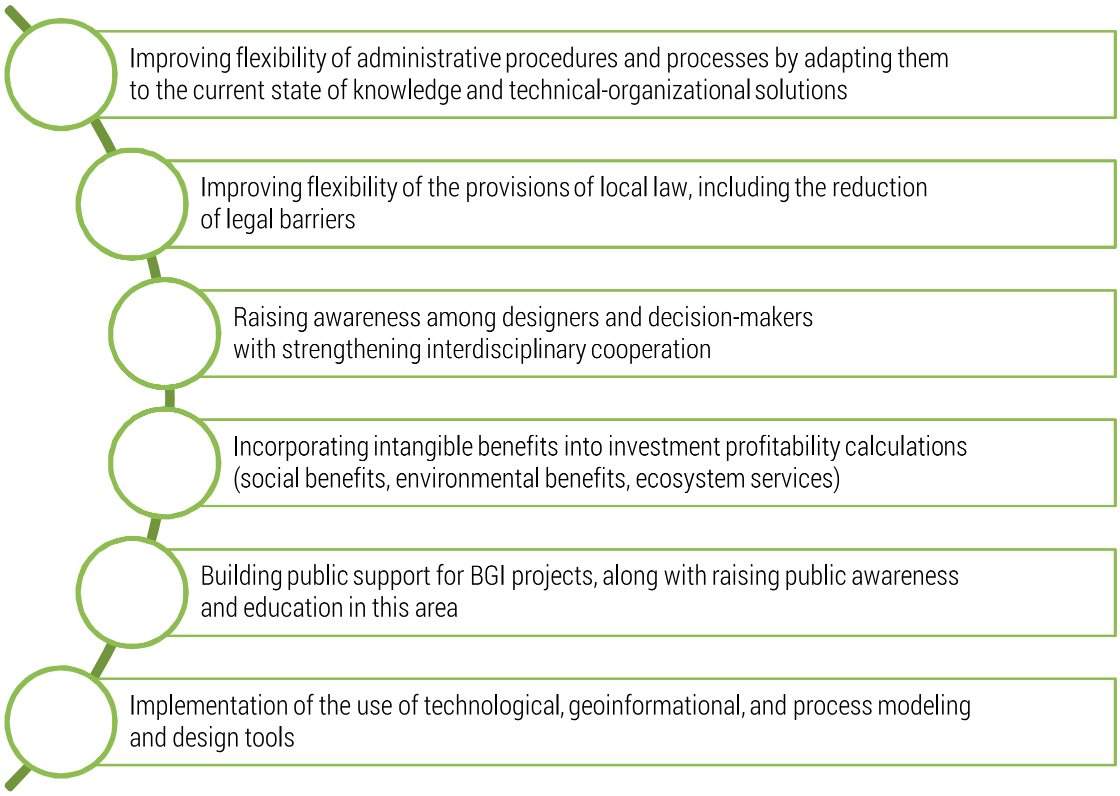

Figure 6. Postulates for Enhancing the Implementation of BGI Solutions in Cities

A systematic approach to planning, aligned with the regenerative city model and prioritising resilience and sustainable resource management, could further support these efforts (Januchta-Szostak, 2020; Mell et al., 2017).

Traditional investment assessments often need to pay more attention to the long-term social and environmental benefits of BGI, which can discourage its implementation. Including the valuation of ecosystem services and social impacts in cost-benefit analyses can help municipalities better justify the economic value of BGI, which aligns with the goals of regenerative cities (Ncube & Arthur, 2021). This challenge is compounded by limited understanding among decision-makers and the public of the benefits BGI can bring, potentially hindering support for these projects. Educational campaigns and participatory planning processes can engage residents, build a sense of responsibility, and strengthen support for regenerative practices in cities, building resilience through community involvement (Grochulska-Salak et al., 2021; Yildirim et al., 2022).

Another valuable tool may be modern geoinformation systems and analytical tools, which offer significant potential for mapping, monitoring, and optimising BGI networks. Using these tools in BGI planning and management enables more precise analysis and decision-making, ensuring that BGI solutions meet local hydrological and environmental needs, even under variable climate conditions (Tache et al., 2023).

Adopting these postulates can bring cities closer to the regenerative model, in which BGI supports environmental restoration and strengthens urban resilience and social well-being. Implementing these approaches requires coordinated efforts among decision-makers, stakeholders, and local communities, supporting a city model that actively regenerates and promotes sustainable development.

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Conclusions and Further Research Directions

Implementing blue-green infrastructure (BGI) presents a significant challenge for contemporary cities, especially in regenerative city trends promoting human-nature coexistence and the restoration of local ecosystems. In this context, it is essential to adapt legal and administrative regulations to the specific requirements of BGI, raise environmental awareness among decision-makers and local communities, and promote interdisciplinary collaboration. Such collaboration can help achieve a comprehensive understanding and realistic assessment of the benefits of BGI implementation, considering not only direct financial costs but also intangible benefits. Properly planned and implemented BGI will enhance urban resilience to climate change and improve residents' quality of life.

In this regard, it also seems relevant to continue research on the long-term impact of BGI on stormwater and meltwater management and residents' quality of life under various climatic and hydrological conditions. Additionally, exploring methods of integrating BGI with the concept of regenerative cities is crucial, particularly in the context of synergies between BGI and other forms of green infrastructure. A critical research method should be analysing case studies from administrative practice, as only specific implementations can provide insights into potential barriers, problems, and the causes of possible failures.

Carrying out these research directions could provide valuable information that would contribute to better BGI implementation, support the regenerative city concept, and strengthen urban resilience in the face of contemporary global challenges.

The contribution of the authors

Conceptualisation, An.B., Ar.B. and B.F.; literature review, An.B.; methodology, Ar.B. and B.F.; writing, An.B., Ar.B. and B.F.; conclusions and discussion, An.B., Ar.B. and B.F.

The authors have read and agreed to the published version of the manuscript.

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BŁĘKITNO-ZIELONA INFRASTRUKTURA MIASTA REGENERATYWNEGO

STRESZCZENIE: W artykule przeanalizowano rolę błękitno-zielonej infrastruktury (BZI) we wspieraniu rozwoju miast regeneratywnych, w których interakcja człowieka z naturą ma na celu odbudowę ekologiczną oraz zwiększenie odporności miejskiej. Poprzez narracyjny przegląd literatury oraz studia przypadków z praktyki administracyjnej zidentyfikowano kluczowe wyzwania w implementacji BZI. Przeanalizowano i opisano przeszkody prawne, organizacyjne, finansowe i technologiczne, zwracając szczególną uwagę na wpływ lokalnych regulacji planistycznych. Wyniki wskazują, że choć BZI może odpowiadać na potrzeby adaptacji klimatycznej i poprawiać jakość życia miejskiego, bariery prawne i proceduralne często utrudniają jej wdrażanie. Skuteczna implementacja BZI wymaga reform legislacyjnych, współpracy interdyscyplinarnej oraz zaangażowania społecznego. W pozostałych rekomendacjach wskazano na konieczność integracji BZI w politykach planowania przestrzennego, uwzględnienia wartości pozafinansowych w analizach opłacalności oraz wykorzystania zaawansowanych narzędzi geoinformacyjnych dla bardziej precyzyjnego planowania i projektowania nowoczesnych rozwiązań BZI.

SŁOWA KLUCZOWE: błękitno-zielona infrastruktura, miasto regeneratywne, władze lokalne, obszary miejskie