Acta Sci. Pol.
Architectura 23 (2024), 12–31
aspa.sggw.edu.pl ISSN 1644-0633 (suspended) eISSN 2544-1760 DOI: 10.22630/ASPA.2024.23.2

ORIGINAL PAPER

Received: 11.12.2023
Accepted: 29.12.2023

FOSTERING SUSTAINABLE URBAN DEVELOPMENT: INTEGRATING SCHOOL AREAS TO SUPPORT THE CITY'S GREEN-BLUE INFRASTRUCTURE

Maja Sutkowska[1]✉, Anna Stefańska[2], Magdalena Daria Vaverkova[2, 3], Yasuhiro Matsui[4]

[1]Faculty of Architecture, Warsaw University of Technology, Warsaw, Poland
[2]Institute of Civil Engineering, Warsaw University of Life Sciences – SGGW, Warsaw, Poland
[3]Faculty of AgriSciences, Mendel University in Brno, Brno, the Czech Republic
[4]Graduate School of Environmental Science, Okayama University, Okayama-city, Japan

ABSTRACT

The effects of the climate crisis disproportionately affect people living in densely populated urban areas, presenting a major challenge for the 21st century. Urban administrators face a significant challenge in implementing sustainable development goals into practice, especially within the constraints of the current infrastructure. This paper evaluates how school zones – characterised by a significant amount of biologically active areas – are integrated into the city's infrastructure to support the multiple uses of natural resources that improve urban living standards. A comprehensive analysis of current legislation, a review of the scientific literature, and a case study of selected schoolyards and school campuses, and renovations of these types of sites over the past decade focus on the evolution of school grounds and the formulation of green spaces and green-blue infrastructure. The paper's conclusions outline the possibilities embedded in the evolution of schoolyards in the pursuit of sustainable development functioning and a list of the potentialities of urban ecological initiatives.

Keywords: green-blue infrastructure, schools, smart city, sustainability

INTRODUCTION

The United Nations (UN) estimates that over half of the world's population currently resides in urban areas, a particularly pronounced trend in developing countries. By 2050, the number of people living in cities is expected to increase to 68% (Allam, Bibri, Chabaud & Moreno, 2022). As a result, there is a growing need for intelligent infrastructure to support human functioning in densely populated areas. Today's accelerating urban development must be supported by sustainable measures to minimise the consumption of natural resources and to change the negative impact on the surrounding environment. The increasing awareness of designers and users contributes to non-anthropocentric issues and bio-polises (Kleszcz, 2021). The new approach to sustainable cities treats them as integrated systems like smart cities (Allam et al., 2022). The increasing population in urban areas requires expanding living space for education and technical infrastructure such as roads and utilities to ensure the city's viability and the residents' comfort. Sustainable development has three pillars: social, economic, and environmental (Dalampira & Nastis, 2020; Jeronen, 2020). The presence of nature in the city is not only an important factor for water retention, temperature regulation, and air purification.

Maja Sutkowska https://orcid.org/0009-0000-4706-5029; Anna Stefańska https://orcid.org/0000-0002-5070-3877;
Magdalena Daria Vaverkova https://orcid.org/0000-0002-2384-6207; Yasuhiro Matsui https://orcid.org/0000-0001-6536-8699
✉msutkowska.arch@gmail.com

Residents also need to relax, rest, and enjoy recreation (Gu & Zheng, 2010; Shah et al., 2021). Due to increasing urbanisation, green spaces in cities are becoming scarce (Brahimi, Benabbas, Altan, Nocera & Costanzo, 2023), often a privilege of wealthy neighbourhoods (Shah et al., 2021). Modern urban development involves green-blue infrastructure (GBI) to serve the city and its residents regardless of ownership status. In this approach, green spaces become a focal point of the city's purification grid, and the search for these spaces, also associated with closed functions, is increasingly necessary. School campuses are among the areas worthy of attention due to the usually significant amount of green space adjacent to them (Brandli, Salvia, da Rocha, Mazutti & Reginatto, 2020; Zhu, Zhu & Dewancker, 2020). The article analyses the possibilities and ways of using GBI on school campuses and related green spaces. This study analyses whether green spaces on school grounds can be designed as part of a GBI that forms a local green enclave. The selected literature on the subject is presented further, showing the state of research on the analysed problem, followed by an analysis of the possibility of applying GBI in contemporary schools in the world and in Poland. The article concludes with a roadmap for good solutions to support GBI in educational institutions.

LITERATURE REVIEW

Green-blue infrastructure

The rapid development of civilisation and human expansion has led to the deterioration of natural resources and the quality of human life (Mittal & Ravi, 2015; Ahmad et al., 2020; Nathaniel, Nwulu & Bekun, 2021). Constant exposure to poor-quality air and water and increasingly demanding access to the elements of nature are leading to a deterioration in the condition of both nature and people. To prevent this, governments, international organisations, and grassroots initiatives by residents are trying to reverse how people use natural resources. An example of this is following sustainable development so as not to harm but also not to live at the expense of future generations. One of the sustainable development goals (SDGs), adopted at the UN Summit in September 2015 includes a movement towards greening, with the possibility of citizens participation (Vidal, Barros & Maia, 2020; Moczek, Voigt-Heucke, Mortega, Fabó Cartas & Knobloch, 2021; Goel & Vishnoi, 2022; Lombardía & Gómez-Villarino, 2023). Goals 3, 11, 13 and 15 address health and well-being, sustainable cities and communities, action on climate change, and the protection of life on land (Omer & Noguchi, 2020; Xu et al., 2020). The need to integrate new solutions into the urban fabric assumes that the GBI's inherent multifunctionality will provide social benefits while supporting biodiversity conservation and climate change mitigation and adaptation goals. However, a limitation of this approach is still the lack of clear guidelines and the exact conditions that would prevail for social benefits to accrue from applying GBI strategies for different ethnic and age groups (Andersson et al., 2022). Nevertheless, there is an apparent push to introduce the GBI as a key link in urban planning focused on the SDGs goals.

Since no clear legal interpretation of the GBI exists, many different interpretations are emerging. Some understand it as a system of different green and blue areas. Others see GBI as a planning strategy for networks of natural and natural-based, semi-natural or protected areas with local and global impacts (Macháč, Brabec & Arnberger, 2022). Several reviews cover different aspects of GBI, including its potential as a climate change adaptation strategy, its impact on ecosystems and human health, and its role in the food-energy-water nexus (Almaaitah, Appleby, Rosenblat, Drake & Joksimovic, 2021; Shah et al., 2021). The reviews highlight the importance of GBI in mitigating urban heat, managing stormwater, and promoting sustainability and resilience in cities. While some studies highlight the benefits of integrating green-blue-grey infrastructure, others point to further research to understand the complexities associated with this integration (Ying, Zhang, Zhang & Bilan, 2022). Overall, the literature underscores the importance of GBI as a strategic planning and design tool to address urban challenges and promote sustainable development.

The role of GBI's is to improve economic, social, and environmental indicators through the multifunctional use of natural resources. The successful examples of green infrastructure (GI) in cities mitigate the urban heat island effect and create more sustainable and comfortable urban environments. Such infrastructure appears to be a socially acceptable solution that can be easily implemented in school park areas (Corrigan, 2023):

- Green roofs: The adoption of green roofs has been effective in combating urban heat islands by providing natural insulation, reducing surface temperatures, and promoting evaporative cooling.
- Tree canopies: Planting and maintaining tree canopies in urban areas has proven to be an effective strategy for shading and reducing surface temperatures, thereby mitigating the urban heat island effect.
- Rain gardens and bioswales: These GI features help manage stormwater, improve water quality, and help reduce the urban heat island effect by promoting evaporative cooling and creating more thermally balanced urban environments.
- Parks and green spaces: Creating parks, gardens, and other green spaces within cities has successfully reduced the urban heat island effect by providing shade, lowering surface temperatures, and promoting evaporative cooling.

City's GI manifests itself as parks, gardens, plazas, open lawns, or forests. At the same time, blue infrastructure (BI) consists of rivers, river tributaries and canals, retention ponds, basins, reservoirs, bioretention ditches, infiltration ditches, and rain gardens. The GBI connections are most often green--blue corridors. Creating interconnected networks of water bodies and green spaces, known as green-blue corridors, has proven successful in promoting biodiversity, improving air quality, and creating more resilient and livable urban environments. This contrasts grey infrastructure, which consists of roads, paved riverbanks, parking lots and other impervious surfaces (Macháč et al., 2022). Surveys show that residents value green spaces and, especially, the presence of trees (Trzaskowska, Renda, Adamiec & Kułak, 2023), a sustainable development strategy. The GBI is one of the best practices in local systems management for building urban resilience.

Smarter cities

The idea of smart cities based on smart solutions is to create infrastructural and technologically connected urban areas (Kumar, Singh, Gupta & Madaan, 2020; Šurdonja, Giuffrè & Deluka-Tibljaš, 2020). The concept was defined in the 20th century as the virtual city began to merge with reality. Smart cities are designed to provide a high quality of life, efficient management of resources and progressiveness. It considers the basic pillars: smart people, smart economy, smart governance smart mobility, smart environment. Smart city focuses on the entire urban system, integrating all subsystems, and is designed to improve safety, support urban development, and counter natural disasters (Jiang, 2020; Kutty, Abdella, Kucukvar, Onat & Bulu, 2020). The amount of data collected for these purposes, supported by Internet of Things (IoT) systems, can make predicting and proactively responding to weather phenomena possible. Natural resources such as parks and waterways are just part of the infrastructure needed for sustainable development. When these resources are well managed, cities will become smarter.

Urban infrastructure areas are primarily grey infrastructure. They are divided according to their main functions: security, transportation, communication, lighting, water, and wastewater infrastructure and heating. Smart city combines many different systems of the urban landscape. One of them could be ecosystem services (ES). The key to success is a systems approach considering the individual context and situation. The GBI helps mitigate the broader impacts of challenges such as climate change, outdoor recreation, and social activity spaces. On the other hand, there is evidence of problems with the equitable availability of GBI and its benefits. Harnessing the potential of GBI as a systems approach in ES, combined with the need for new legal and ownership regulations (Andersson et al., 2019).

Smart solutions such as advanced sensor technologies, data analytics, and IoT can improve the efficiency and effectiveness of green-blue infrastructure. They enable real-time monitoring, informed decision-making, and adaptive management for long-term urban development. Nature-based strategies include restoring and maintaining natural bio-networks in urban environments. These measures provide numerous environmental benefits and help adapt to and mitigate climate change (Hassan, Shahbaz & Gallardo Lopez, 2023).

Since 2010, New York City has implemented a GI Plan using a geographic information system (GIS) that enables the collection, management, analysis, and mapping of various spatial data types. As part of the plan, GIS is being used to monitor project progress and manage GI resources. In addition, a GI co-benefit calculator has been made available. This publicly available web-based tool allows designers and planners to identify different types of GI and their parameters to estimate costs and assess environmental, social and economic aspects. The tool is also publicly available (Nowak, 2023).

Researchers' interest in the GBI topic has increased since 2018 and this significantly growing trend continues until March 2021 (de Macedo, Barda Picavet, Puppim de Oliveira & Shih, 2021; Veerkamp et al., 2021; Janiszek & Krzysztofik, 2023), with a large lead in the United Kingdom (UK). After that time, interest is still seen, but the topic develops slower. Poland ranks fourth behind Australia and Germany. Interest in this strategy is emerging mainly in developing countries, but more and more countries are trying to implement GBI solutions (Chandwani, Singh, Satpute & Dabir, 2021).

In Pakistan, federal, provincial, and local authorities launched the Clean and Green Pakistan Strategy (CGPS) program in 2019 to promote green growth (GG). Among other things, the strategy relied on the involvement of educational institutions. Promotion was done through research and encouraging young people to develop innovative ideas (Mumtaz, 2021). Studies show that young people in Japan know the role of GI (Tanaka, Mao & Furuya, 2022), which is also related to the *mottainai* approach (Jakimiuk et al., 2023).

Green-blue infrastructure in school areas

The city comprises people, and the next generation of innovators is in schools today. Improving educational institutions' operations also influences young people's sense of responsibility for their surroundings, not only those who will graduate in the future with majors related to the construction sector. The following aspects can be considered in education while supporting the GBI of urban structures.

Water

Water at schools comes from canals, rivers, or ponds. They can also be rain gardens, retention ponds, or cisterns. This prevents drought and protects against flooding. Elements of blue infrastructure can support the GBI system in areas where flooding is possible. As global warming intensifies, storms are becoming increasingly violent. Satellite data spanning nearly four decades has shown an increase in the frequency of intense hurricanes, cyclones, and typhoons (Kornei, 2020; Alimonti, Mariani, Prodi & Ricci, 2022). Cities struggle to handle such large amounts of water at once through its sewage system, resulting in flooding (Dąbrowska et al., 2023). This is often due to the outdated design of sewage systems, as seen in Warsaw, where the system was built in the 1960s (Sobieraj, Bryx & Metelski, 2022). However, technologies exist to combine sanitary and storm sewer systems into a combined sewer system. However, rebuilding the existing infrastructure is very costly and incompatible with the principles of sustainable development. Cities are considering such solutions for major infrastructure renovations and for new projects (Qin, 2020).

Trees and perennials

Older trees contribute much more to the environment; they produce more oxygen than newly planted trees. Therefore, their cutting should be kept to a minimum. Native and non-toxic species should be planted. Trees provide shelter for birds that nest in their crowns. Trees regulate the local microclimate, provide shade on hot days, and collect water, such as willow. European folklore and internet sources suggest that some trees repel insects, including mosquitoes. Many plants are believed to have mosquito-repelling properties, but this requires further investigation in the European climate. Mosquitoes require stagnant water for breeding. It is believed that cones from the black alder tree alter their pH when they fall into the water, making it unfavourable for larval development. Another practiced method involves the use of black walnut (*Juglans nigra* L.) and white walnut (*Juglans regia* L.). They bring medical benefits, as they have antibacterial, antifungal, antioxidant, and many other properties (Nael Abu Taha, 2011). Juglone, a toxin in walnut trees, is safe for humans and may prevent cancer growth (Thakur, 2011). However, toxins that may be released from tree roots, bark, and leaves (Kong, Xuan, Khanh, Tran & Trung, 2019) are believed to repel insects. However, this should be studied similar to the Chinese research, which was inspired by folk knowledge and evaluated selected plant species used by the population. Research has found that *Artemisia indica* Willd. shows the most promise among the selected specimens in China (Gou et al., 2020). In Thailand, plants known to repel insects include turmeric (*Curcuma longa* L.), ginger (*Zingiber officinale* Roscoe), pandan (*Pandanus odorus* L.), cinnamon (*Cinnamomum zeylanicum*), clove (*Syzygium aromaticum* L.), and lemongrass (*Cymbopogon citratus*), (Tisgratog, Sanguanpong, Grieco, Ngoen-Kluan & Chareonviriyaphap, 2016). Research is also being conducted in countries where malaria is a problem. In Europe, smaller plants such as pine (*Pinus* spp.), lavender (*Lavandula* spp.), peppermint (*Mentha ×piperita*), garlic (*Allium sativum* L.), rosemary (*Rosmarinus officinalis* L.), and thyme (*Thymus* L.) are also present, whose essential oils have been proven to repel insects. However, precise information on the conditions under which this action would be most successful is still lacking (Singh, Singh & Mohanty, 2012).

Biodiversity and animals

Biodiversity is a path to a resilient city, thanks to the diverse adaptations of animals and plants to climatic conditions (Snep & Clergeau, 2020; Mehan & Mostafavi, 2023). Different plants cope with different weather conditions. Monoculture crops have higher risks, hence the need for fertilizers and pesticides (Winkler et al., 2023). Therefore, a better solution is a flower meadow planted instead of a lawn, reducing the urban heat island effect (Ignatieva, Haase, Dushkova & Haase, 2020; Mody et al., 2020; Winjkler et al., 2023).

Like any venture, community gardening requires a high degree of agreement among all participants. Children often compete, but if they are well trained, they will take care of the garden together. This instills a sense of responsibility and competence in the young people and fosters the idea that the growing generations will take care of the GBI in the city, just as they took care of the community garden at school.

The presence of both domesticated and wild animals has a positive impact on children's development. Wild animals appear near schools in search of food or shelter. Farm schools are where animals are raised, and children learn to care for them. An example of such an approach is the Montessori Farm School Folwark Białka, one of the schools within Poland's Warsaw Montessori Family network. This school operates with a work-study program, where children aged 12–18 live, learn, and work by running a farm and, eventually, a hotel. The school has started in the 2022/2023 semester for 10 students but now accommodates 50 students. The director drew inspiration from the exemplary Hershey Montessori Farm School in Ohio. Initially, the director established an urban-based school with farm elements in Warsaw, Poland.

There is an herb garden and an organic greenhouse where students can grow and sell vegetables at a nearby market. They also have a small chicken coop, from which the rooster had to be removed after the first year due to complaints from residents of Warsaw's Mokotów district about early morning crowing. In the new location in Białka, there is a beehive for children to plan, purchase, invest, produce honey, and sell it. This way, they learn about economic independence through making mistakes independently and learning from them. They have lambs, goats, chickens, cats, and dogs. They are also considering having horses, as it is a frequent request from the students. The concept of farm schools appears in many countries but is still not very common.

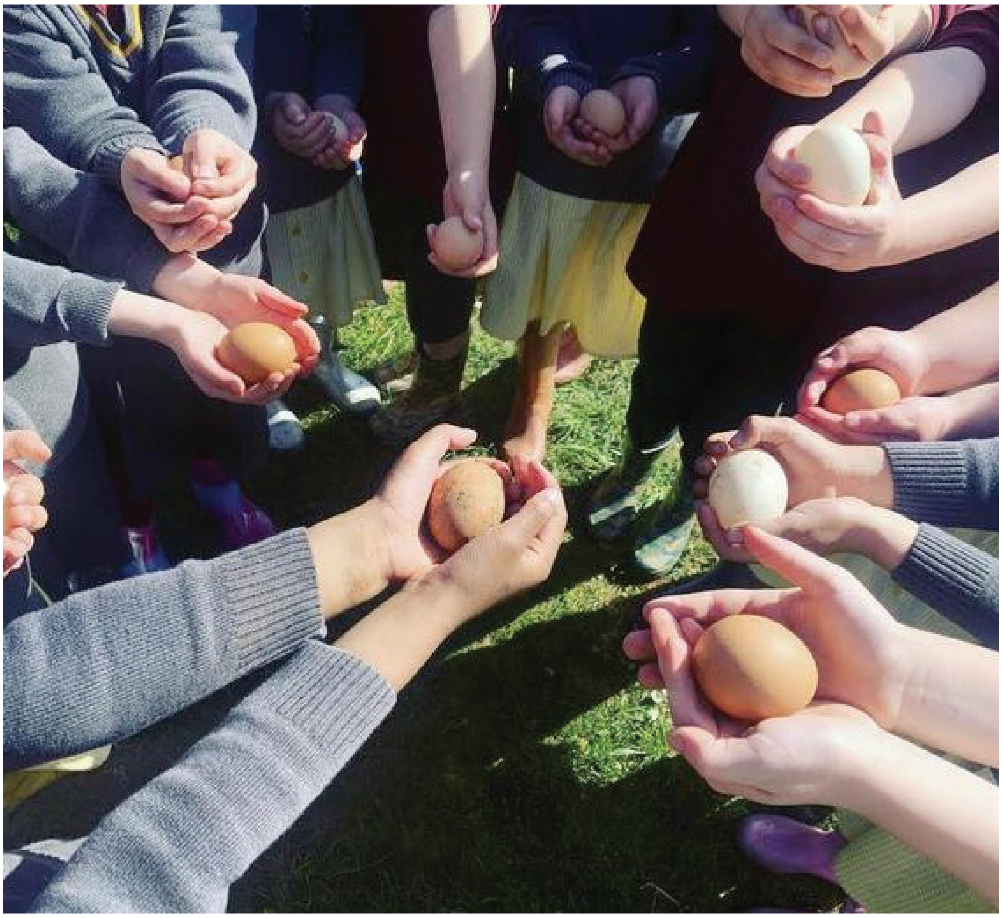

Fig. 1. St Anthony's Catholic Primary School, Farm and Forest School, Hampshire, UK

Source: ©St Anthony's Catholic Primary School [n.d.].

In the UK, St Anthony's Catholic Primary School, with elements of a farm school (Fig. 1), also gives children opportunities to take care of animals and learn. The farm school is not intended to train farmers but to raise responsible, cooperative, resourceful individuals who understand where their food comes from and recognise that humans are not the most important species on Earth, emphasising the importance of biodiversity and animal welfare.

Aspects of the green-blue infrastructure of schools

The number of new schools in urban areas is increasing, in direct proportion to the influx of new residents. The example of Polish structures shows a steadily increasing share of schools in cities and thus an increasing share of the potential to develop a network of green spaces in the city. Figure 2 shows the change in the share of primary schools (Grades 1–8) in cities and villages in Poland between the 2015/2016 and 2022/2023 school years. In Warsaw alone, there are currently 216 primary schools. In particular, elementary schools, for which the district is still the predominant form of admission according to Polish standards, should have a maximum access radius of up to 500 m^2, and the recommended area of a plot of land for a school should be 1.5–2.0 ha (Dąbrowska-Milewska, 2010).

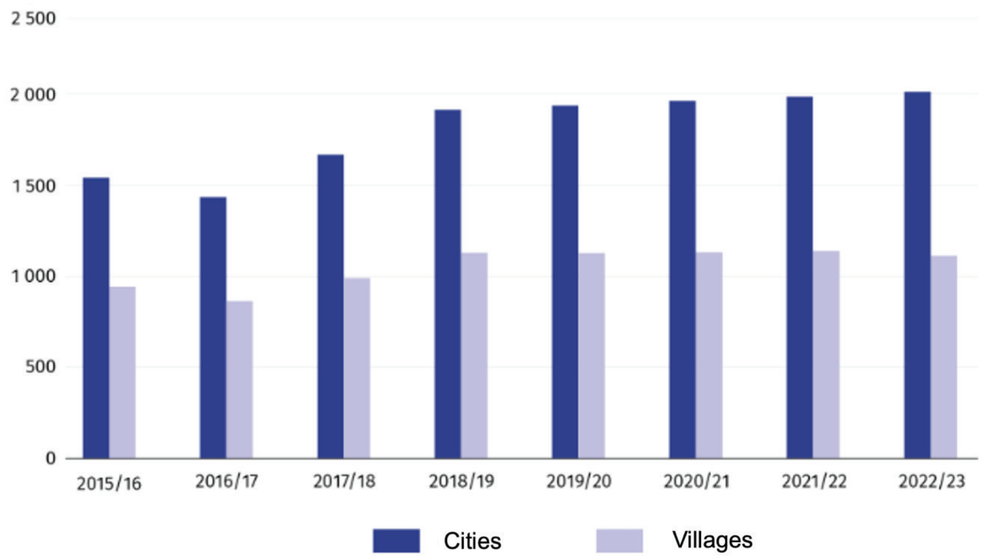

Fig. 2. Comparison of the number of children in urban and rural elementary schools. In the 2022/2023 school year, 35.6% of students in rural areas attended elementary schools for children and adolescents, and 64.4% in urban areas

Source: Główny Urząd Statystyczny [GUS], (2023).

From this example, it can be seen that the potential for possible GBI solutions connecting elementary schools is considerable, assuming that the schoolyard areas also include green spaces and outdoor playgrounds and that the surface of the roofs may also indicate additional possibilities for their use.

MATERIAL AND METHODS

The subjects of the analysis are selected examples of green space developments for children's use in school facilities. These are green areas and playgrounds where developments in which aspects of GBI have been used. The purpose of the study was to compare the realisations in Poland against the background of European investments. The selected examples were analysed regarding the feasibility of implementation and the quality of the specific fintech infrastructure solutions. The analysis results also present the participation of individual stakeholders such as owners, designers, people responsible for the maintenance of the place or users – students and their guardians, in the innovation of solutions implemented in the facilities.

RESULTS

Sundby School by Henning Larsen, Nykøbing Falster, Denmark, 2020–2025

The school was designed according to SDGs and involves the local community, as anyone can come and use its facilities (Fig. 3). It is designed with a circular floor plan, and its shape appears to grow out of the ground due to the irregular green roof. In addition to classrooms, the school has a library, a cafeteria, sports facilities, and facilities with music equipment. The school has received Nordic Ecolabel certification, which considers energy consumption and climate. The walls of the school are thatched.

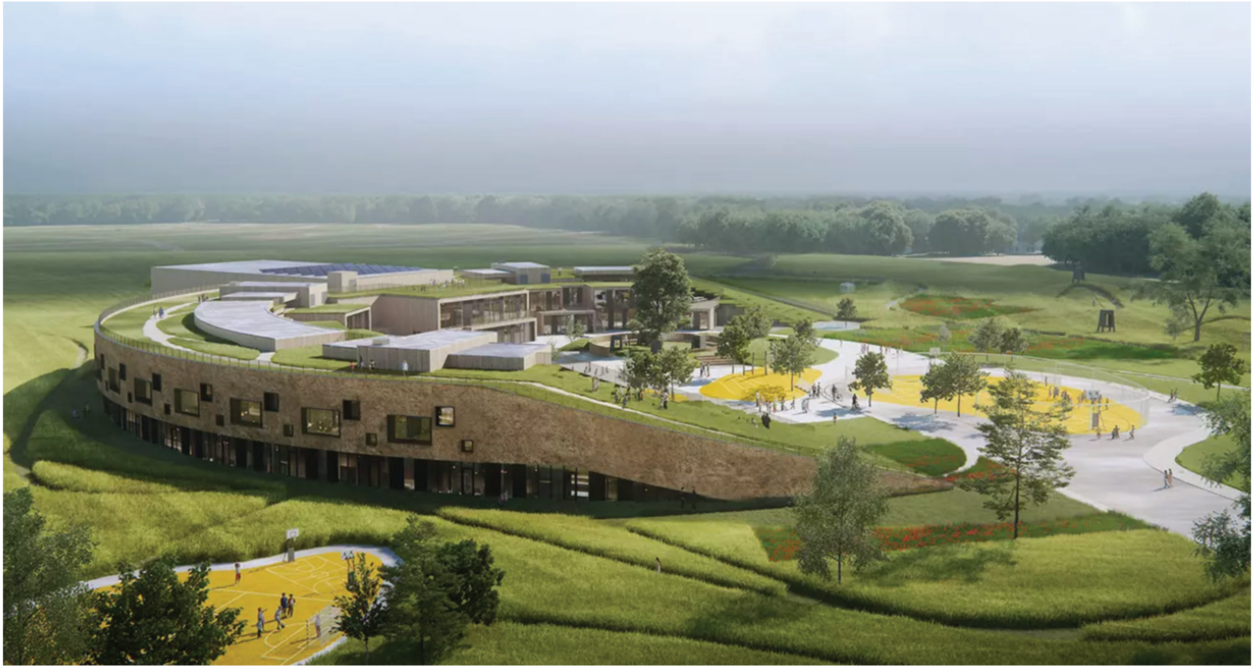

Fig. 3. Sundby School by Henning Larsen, Nykøbing Falster, Denmark

Source: Henning Larsen (2020).

In this case, the roles of the different stakeholders vary. In the case of the above facility, the city can do a favour by financing innovative design solutions that support GBI. This also encourages investors since the city's goal is to become resilient, and GBI plays a key role in this context. A profit-oriented investor can use higher quality materials and engineering solutions with co-financing. Investing in developed infrastructure, especially in public buildings, can also attract publicity and interest by winning environmental competitions and being open to visitors who want to learn about new technologies. Teachers should encourage children to take care of the gardens. The role of parents is to participate in the garden's care and encourage the children. It would be the children's responsibility to use the space safely and to keep it clean and in good shape to support GBI.

Playground Biberland by Gudrun Lang, Hamburg, Germany

The playground in Hamburg's Neugraben-Fischbek neighbourhood is the first water playground in Germany (Fig. 4). It can be used in any weather, including rainy days. The playground consists of cascading channels, watercourses, reservoirs, and equipment. The area collects rainwater from the surrounding streets. The total catchment area is approximately 34 ha, and the playground area is 2,000 m^2. The collected water slowly seeps into the ground, relieving the pressure on the stormwater drainage system. It is worth mentioning that sanitary and rainwater sewers in many Polish cities sanitary and rainwater sewers are combined in the same installation, so this solution becomes a sustainable alternative. However, there are doubts about the content of the runoff water in which children are supposed to play. There may also be a problem with the amount of water, so the current is not too strong, and the water is not too deep.

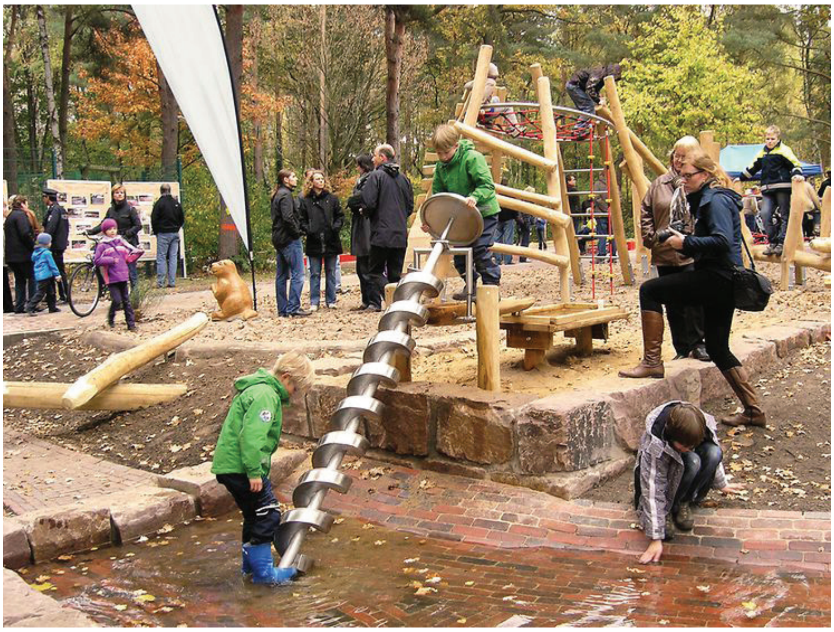

Fig. 4. Children's playground Beiberland by Gudrun Lang, Hamburg, Germany

Source: Hamburg.de [n.d.].

Using this example, we can see that cities must plan and find how to deal with occasional excess water naturally in an era of global warming and rapid weather changes. Weather and topographic data collection in the smart city concept greatly supports such studies.

There is a concept of forest schools, one of which is that children are not afraid of weather changes and like to play in the rain. Forest school does not require a large forest, and it is not a regular school. It is a form of hands-on outdoor learning experience in natural environment. It started initially in the USA in 1927 and then developed in Europe in the 2000s: Scandinavia, Scotland, Ireland, and the UK (Emine & Gökhan, 2020). Finally, a training program for forest schools practitioners was developed. Methodologies of forest schools are closely connected to sustainable development. The benefits include confidence, self-esteem, physical motor skills, emotional development, and connection to nature. In addition, outdoor activities promote creativity, teamwork, achievement, manual skills, and understanding of nature (Aydemir & Yiğit Gençten, 2023). Compared to regular schools, children are found to be healthier and have better cognitive functions as they consciously absorb nature with all the senses. Nowadays, in the age of digitalisation, children spend less and less time outdoors (Sella, Bolognesi, Bergamini, Mason & Pazzaglia, 2023). Forest schools sessions should be implemented in every school so that every child can benefit from being in nature. Bringing GBI elements into schoolyards would support this goal. The role of parents and guardians of children should be to organise outdoor play more often, regardless of the weather. Further research on how children can play with water and learn water safety at the same time would be advisable.

A break from the Lawn, University of Cambridge, 2020

King's College's Flower Meadow project (Fig. 5) is an experiment to transform traditional lawns on the 1772 campus into wildflower-filled meadows. By 1984, 97% of wildflower meadows were lost in England and Wales (Griffiths-Lee, Nicholls & Goulson, 2022). The goal of the project was to improve the area's aesthetics and promote biodiversity and environmental awareness among the college community. The experiment was to stop mowing. There were objections saying that this was tantamount to breaking a 300-year tradition. Nevertheless, an ecological space was created to encourage flora and fauna's growth and promote the harmonious coexistence of humans and nature.

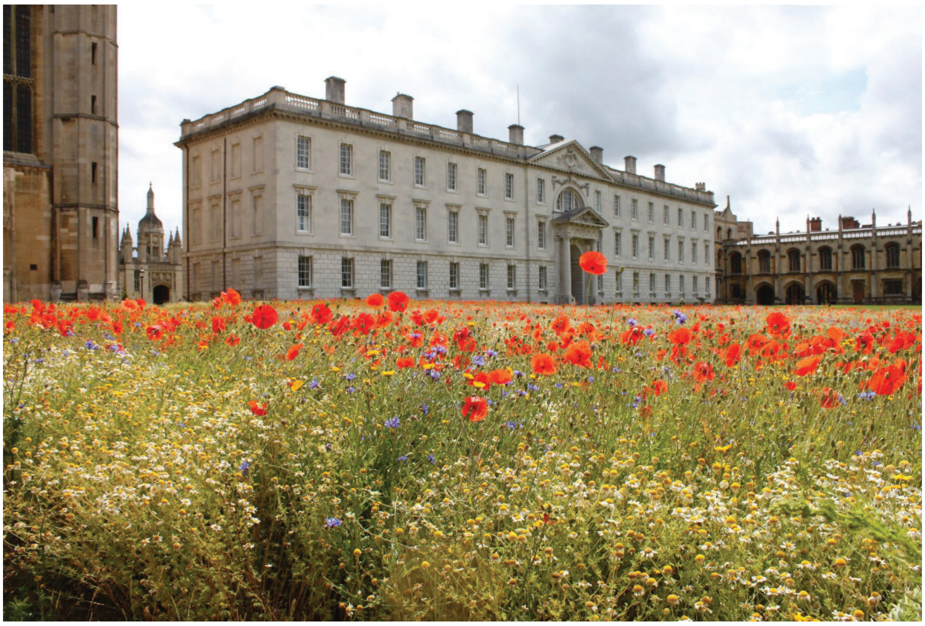

Fig. 5. A flower meadow at the University of Cambridge, UK

Source: ©Geoff Moggridge 2020.

The Flower Meadow has had considerable success within a few years of its inception. Dr Cicely Marshall, a researcher at King's College and the Department of Plant Sciences at Cambridge University, conducted a study to monitor the effects. One of the findings was that of the 33 species sown, 84 are now growing. The wild meadow has become a place of high ecological value, attracting various insects. It has also become popular for nature observation and environmental education, attracting students, employees, and the local community. In addition, the meadow reflects 25% more light than a mowed lawn. This is one way to address the effects of climate change on the urban environment and create green spaces in the city. Wildflower meadows provide multiple benefits to all humans, and pollinators, such as bees, butterflies, and other insects. In addition, living plants absorb pollutants and become an important part of the urban ecosystem (Rózová, Pástorová & Kuczman, 2023).

The Flower Meadow project is an inspiring example of an innovative environmental initiative that benefits both the environment and the academic community. Its success can motivate other educational institutions and local communities to undertake similar conservation efforts. After all, just because we have been mowing lawns for years does not necessarily mean we must keep doing so.

Blue-Green School Project MERITO foundation, Ventura County, California, USA, 2019–2021

The Multicultural Education for Resources Issues Threatening Oceans (MERITO) project was funded primarily by the U.S. Environmental Protection Agency (EPA), the California Coastal Conservancy, and the Channel Islands Harbor Foundation. The goal was to train teachers to teach their students about water science, water conservation, stormwater runoff prevention, composting, and recycling. Other topics also included watershed, coastal, and island ecology. The project was also aimed to improve students' critical thinking and problem--solving skills through project-based learning. The learning context was the local environment. The project resulted in original proposals to conserve water, reduce waste on school grounds, and protect local watersheds and aquatic ecosystems, primarily to prevent flooding and fires. The plan was to implement the best proposals at five campuses in Ventura County: Sunkist Elementary in Port Hueneme, Montalvo Elementary in Ventura, McKinna Elementary in Oxnard, and Berylwood Elementary in Simi Valley. Parts of the project that focused on flood control included calculating runoff volumes, repairing old and damaged rain gutters (paid for by the school), installing rain barrels, mapping existing vegetation, and designing and constructing a bioswale in an existing native plant garden adjacent to the street.

Early – Years Starter Kit, Rotterdam's Green-Blue Schoolyards program, 2019–2022

The project aimed to introduce more greenery to the school grounds. The premise was to address climate to support children's development in educational outdoor projects. The project was also intended to be helpful as a green enclave for the local community. The program focused on five schools from areas with fewer public green spaces and higher socioeconomic vulnerability, chosen to cover different parts of the city to equalise access to GBI for different residents.

The implementation process was with schools in less green neighbourhoods. They were subsidised with 80,000 euros per school per year between 2019–2022. Activities with social participation elements were required, and participants should be children, parents, and neighbours. The funding would make the areas accessible to residents after school hours.

Opportunities seized: The study found that a strong vision, with the child at the centre of the project, helped build resilience to budget constraints and resistance from school communities. Maintaining and refreshing this vision was essential to ensure the project's sustainability and change the attitudes of education staff, managers, contractors, and parents.

The search for co-funding opportunities and rational management of expenditures made it possible to combine investments related to the Green-Blue Schoolyards program with existing climate adaptation efforts, resulting in larger amounts of money allocated for this purpose.

A data-driven selection process, considering both the environment's quantitative characteristics of the environment and the school's qualitative motivations of the school, enabled the selection of made projects best suited to local needs and increased the involvement of school communities.

Involving schools in project implementation helped anchor the program in the communities and increased local ownership of the maintenance of new green and blue spaces. Technical support from the Speeldernis, drawing on their experience in designing outdoor playgrounds and engaging communities, played an essential role in the program's success. Their activities supported the adaptation of designs to individual school needs and enabled the exchange of experience and support between schools.

Missed opportunities: Implementing the Green-Blue Schoolyards program has encountered difficulties related to complex systems that required the cooperation of many stakeholders with different visions and goals. Negotiating budget constraints, risk aversion, and differing community views on outdoor education and maintenance standards make project implementation difficult. Significant efforts are being made to build and co-create stakeholder visions to address these challenges before implementation. However, with schools at the forefront of projects tailored to their neighbourhoods, piecemeal implementation requires increased coordination to ensure quality control. While other cities manage similar programs centrally, Rotterdam minimises this problem with technical support from the Speeldernis. In addition, inconsistencies between city and national policies on regulations and funding limit the ability of schools to align programs with a child-centred vision. National action is needed to address these inconsistencies.

'Climate in metropolis schools' – Tri-City Project Gdańsk-Gdynia-Sopot, Poland, 2021–2024

A project similar to the one in Rotterdam is a joint project of three cities in Poland. As part of the political action for climate education, the Gdańsk-Gdynia-Sopot Metropolitan Area (OMGGS) 2021 launched a project called Climate in the Schools of the Metropolis. This project tries to educate locally and introduce local solutions without a global connection to the GBI. It is funded by a grant from the European Economic Area Fund and the Polish state budget and involves 40 schools from large cities and smaller towns participating. Educational activities will be carried out, and in addition, by the spring of 2024, each school will have implemented a GBI element, such as a green wall, compost pile, rain garden, or retention pond. At the time of writing, the project has completed a phase of teacher training, competitions, exhibitions, and meetings. The project's strengths are in supporting environmental learning in schools and creating examples for other centres.

The key stakeholders are city and school administrators, teachers, parents, and children. The city has provided funding and partners. Their role is to coordinate the project. Their role is to specify the needs of the school. Teachers have received training on climate change mitigation and adaptation. Their role is to share this knowledge and encourage students to participate and benefit from the project actively. The role of parents was to keep up to date with project news to help them participate, for example, in competitions organised by the project. Children should learn and actively participate in the project.

Primary school in Książenice by PALK Architekci, 2011–2012

The primary school in Książenice is located next to an open green space. The area next to the school was designed with the sustainable use of greenery in mind (Fig. 6).

Fig. 6. Storm gardens on school grounds in Książenice

Source: ©Piotr Hardecki 2012.

The designers noted that plants can be a teaching tool instrument in classes on ecological and biological topics. Therefore, the children can grow flower beds in the garden. A rain garden was also designed as part of the GBI. These are retention reservoirs 20–30 cm deep retention basins that fill with water during rainfall and slowly release water into the soil. The evaporating water creates a microclimate that prevents drought and excessive heat. The development around the school is both a green enclave with a local ecosystem and adjacent to a large open green space that is part of the GBI. If the rain gardens are lower than the surrounding land, they can be preserved for a larger land.

Climate-friendly school – Sendzimir Foundation, development at the King Maciuś I Primary School in Warsaw, Poland, 2022–2023

One of the best Polish examples of an attempt to integrate a school site into an urban GBI system in Warsaw is the Climate Friendly School project, which started in January 2022. The Sendzimir Foundation, in partnership with the Wawer District Office of the City of Warsaw and PS Paaby Prosess Edu Action from Norway, has created an educational centre for the people of Warsaw. As the largest district in Warsaw, Wawer is often flooded during periods of heavy rainfall. For this reason, a project involving a development project at the King Maciuś I Primary School No 195 in Warsaw focuses on rainwater management using green-blue infrastructure. The plan was to create 27 rain gardens throughout the site. The project also includes elements such as a flower meadow, insect and butterfly houses and bird feeders (Fig. 7). Species of designed vegetation have been selected to support native species and the aesthetics of the space. They planned to refresh and replenish the pots in the vegetable garden. The project had a solid educational foundation. Teachers nationwide could benefit from free training and lesson plans with children. The project was informed by a consultation and design workshop with the school's students in April and May 2022. JAZ+ Architekci completed the final project.

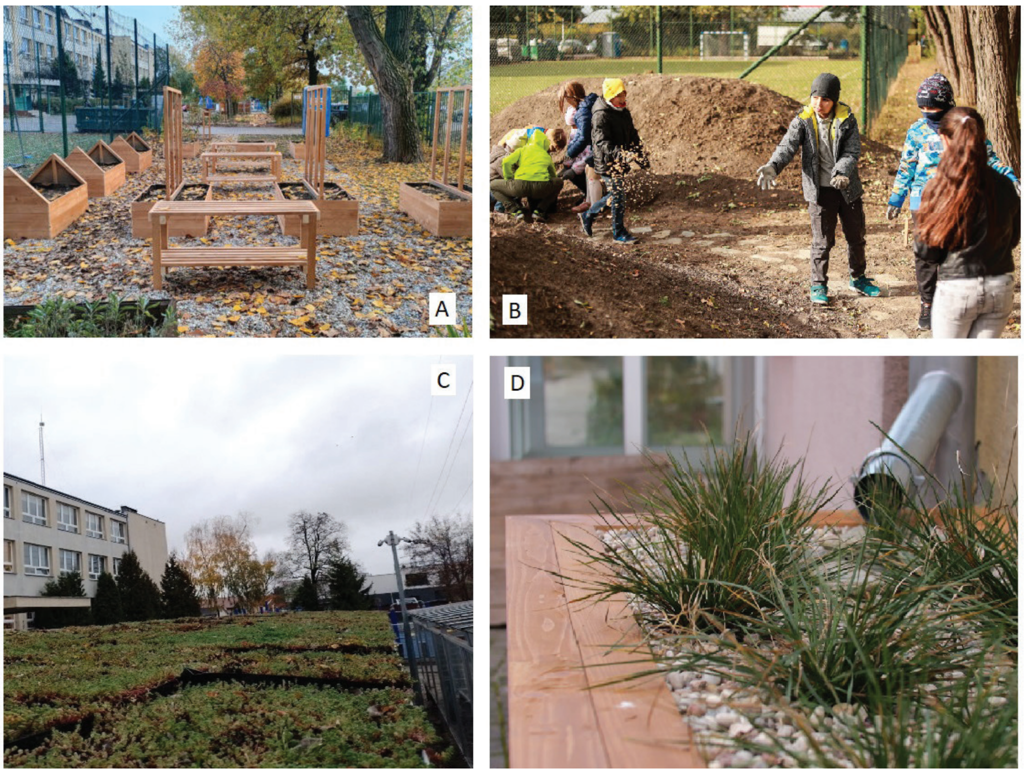

Fig. 7. The King Maciuś I Primary School in Warsaw, Poland: A – edible garden; B – flower meadow; C – green roof; D – raingarden

Source: JAZ+ Architekci [n.d.].

The implementation was planned for the fall of 2023 to become a part of the GBI of the Wawer district. A demonstration system of GBI facilities was built up at the school, with an educational path informing about ways to mitigate and adapt to the adverse effects of climate change. The work was participatory: the whole school community was involved (Fig. 7). This project is becoming an example for other schools of how a school site can support the city's GBI while meeting the objectives of the SGDs.

DISCUSSION

Implementation/incorporation of green-blue infrastructure in school areas

The GBI offers many benefits in cities, including environmental, social, and economic advantages. Implementing GBI brings several key benefits to the city, which can be grouped into three main categories: Environmental, Social, and Economic. The environmental benefits meet the key aspects of the Environmental Protection Agency – EPA (2023), which are:

- Stormwater management: GBI helps reduce and treat stormwater at its source, improving water quality and reducing the risk of flooding.
- Air quality improvement: Vegetation in GBI helps remove pollution and improve air quality in urban areas.
- Biodiversity enhancement: GBI supports the preservation of urban biodiversity by providing habitats for various species.

Among the social benefits, there are two main factors, which are health and well-being and aesthetic and recreational values, which are in line with Brear's statements (Brears, 2023):

- Health and well-being: GBI positively impacts human health by encouraging outdoor activities, reducing stress, and improving overall well-being.
- Aesthetic and recreational value: Green and blue spaces create pleasant and attractive environments for recreational activities, promoting a higher quality of life for urban residents.

The critical factor in implementing GBI is the economic benefit factor, which enables the potential to implement new strategies in new and retrofitted areas. The key aspect includes the property value and the creation of new specialised job positions in the market:

- Property values: The presence of GBI, such as green spaces and vegetation, can increase property values and enhance the aesthetic appeal of urban areas.
- Job creation: Implementing GBI can lead to creating jobs in construction, maintenance, and related GI sectors.

The possibility of implementing green roofs, green walls, flower meadows, or natural playgrounds teaches the youngest generation how to take care of the environment. It allows them to benefit from the positive effects of introducing greenery into the human space. Combining GI with BI in school and children's areas improves the microclimate quality and the environment closest to children.

The simplest steps to incorporate GBI into school gardens are a flower meadow, a water pot, and small animal features such as insect hotels. Rain gardens with water harvesting and filtration basins are other steps to introduce better water use. Examples of exposing children to nature include frequent use of shelters and feeders for animals and insects and vegetable gardens.

Studies of Austrian schools show that implementing GBI on school grounds can sometimes be problematic. There are technical issues – complex systems such as green walls require constant weeding and clearing of clogged gutters. In addition, green facades and living walls are expensive. Schools often lack the budget to hire qualified companies to maintain the greenery. The solution can be crowdsourcing, crowdfunding, and networking, using informal connections between schools and stakeholders as the main crowd capital.

A positive development is seen when the funders are municipal services subsidies, local companies or district councils.

Despite extensive knowledge about the positive impact of GI on people and the environment, it is rarely incorporated into public investments such as schools. The main reason for this neglect is the lack of sufficient knowledge about how to finance such projects. The research project MehrGrüneSchulen (Engl.: More Green Schools) launched in Austria to develop financing scenarios. Research shows that children can be involved in the planning, implementation and maintenance of GI elements in the school environment. Children learn responsibility, cooperation, sustainability and other skills. Another challenge is resistance from staff, parents and even students (Teichmann, Korjenic, Sreckovic, Veit & Hartmann, 2023). The concerns of staff and parents are related to the perceived danger of children to nature.

As the King's College example shows, creating a flower meadow is relatively easy. Coghill, the Head Gardener of King's College Cambridge, gives advices on how to start a wildflower meadow (Garget, 2023). In May, stop mowing the lawn and watch what grows on it. To keep the lawn looking neat, it is necessary to mow the edges – these are also important habitats for wildlife. Buying cuttings of ready-made flowers and planting them among the grasses is possible. A more advanced way is to buy wildflower seed mixes. Be sure to choose local species appropriate to the soil and region. It is also worth remembering that wildflowers grow in soils with low nutrient content. Sometimes, this requires removing up to 30 cm of the topsoil from the garden. In King's College the topsoil removal was not necessary (Marshall et al., 2023).

Vegetable gardens are also a good step in planning long-term strategies and appointing a responsible person for educational functions. They are moderately labour and cost-effective and, if maintained systematically, produce the desired results of learning responsibility and gardening skills and a harvest that can be eaten.

While school based GBI offers many benefits for sustainable urban development and educational enrichment, addressing the potential trade-offs and risks associated with safety, maintenance, and governance is crucial to ensure successful implementation. Potential challenges include safety concerns, maintenance challenges, and governance issues. Safety concerns can arise from increased interaction with natural elements such as water bodies and vegetation, which con pose risks to children if not properly designed and supervised. For example, water features must be safe for all ages and abilities, with measures in place to prevent drowning or waterborne diseases. In addition, vegetation in school areas must be chosen to avoid plants that are toxic or may cause allergies.

Maintenance challenges are another consideration, as GBI elements require ongoing maintenance to ensure functionality and aesthetic appeal. This includes regular maintenance of vegetation, water features, and other infrastructure components. Schools must allocate resources for maintenance or partner with local authorities and communities to share the responsibility. Governance issues may also arise, particularly in coordinating the integration of GBI into existing urban systems and ensuring equitable access. There may be conflicts between stakeholders, such as school administrators, urban planners, and residents, over the use and management of these spaces. Clear policies and collaborative frameworks are needed to address these governance challenges and to ensure that the benefits of GBI are maximised for all community members.

CONCLUSIONS

The paper highlights the importance of integrating GBI into school areas as a strategic approach to foster sustainable urban development, enhance biodiversity, and improve the quality of life for city dwellers. It makes a valuable contribution to urban planning by offering insights into the multifunctional use of GBI and its role in creating smarter, more resilient cities. The study provides evidence that implementing GBI in school zones can enhance biodiversity (by providing habitats for various species), health and well-being (by encouraging outdoor activities), aesthetic values (green and blue spaces create attractive environments for recreation), economic value (by increasing property values), and educational value (by educating children about environmental stewardship and improving the microclimate and environment).

Research on the long-term impact of GBI in school areas is needed to examine the relationship between exposure to GBI in school environments and its influence on educational outcomes, student behaviour, and overall academic performance. It is also recommended that long-term impact assessments be conducted to evaluate the effects of integrating GBI into school campuses on environmental sustainability, student well--being, and community engagement. In cities, there is need to examine how GBI in school campuses can contribute to climate resilience and adaptation is necessary, considering factors such as extreme weather events and heat island effects.

The most necessary action points for future research are to foster collaborative partnerships between academic institutions, local governments, and community stakeholders to co-create research initiatives that address the practical implementation of GBI in school settings. Scientists, designers, and school authorities should advocate for the integration of GBI research findings into local and regional policy frameworks, emphasising the importance of evidence-based decision-making in urban planning and educational development.

Complementary research findings on using GBI in school settings are still lacking. However, it was important to analyse them; this stage was to disseminate the most up-to-date knowledge. It is worth noting that some of the examples analysed have not yet been implemented, so conclusions from the project are lacking.

The GBI is widely believed to provide cities with active and healthier lifestyles, lower stress levels and improved mental health, better stormwater management, reduced heat island effects, and increased property values. However, there is a lack of accurate data on designing GBI to achieve these goals optimally. The GBI system could be supported by, among other things, advanced technologies to monitor and collect data on climate and water levels, enabling faster response and ongoing implementation of solutions. The city would then function as a Green-Blue Smart City. New York is already trying to integrate nature and technology.

Grassroots initiatives that allow for implementing selected elements of the GBI can be seen where institutions have limited budgets, or the legal system does not explicitly allow for implementing planned changes. Participatory activities involving the local community, often the school community, have the greatest impact. The most important part of these projects is building the evidence base – educating teachers, children, and residents. Once established, the most important thing is to continue the work and maintain the garden and retention pond. That is why ecological knowledge is responsible for posing it on to the next generation. In this way, knowledge spreads, and future generations can use this knowledge to go out into the world and develop innovative solutions.

Further projects are needed, under the auspices of governments, in which top-down strategies can be established for all schools as networks of interlinked GBIs within the urban structure, which would constitute centres for climate education – a hub for collecting and analysing information from sensors in the city. Following Western European models, it would be good if the school's green space was also open to the public after school.

Authors' contributions

Conceptualisation: M.J. and A.S.; methodology: A.S. and M.V.; validation: A.S. and M.V.; formal analysis: M.J. and A.S.; investigation: M.J. and A.S.; resources: M.J. and M.V.; data curation: M.V. and Y.M.; writing – original draft preparation: M.J. and A.S.; writing – review and editing: M.V. and Y.M.; supervision: M.V. and Y.M.; project administration: A.S. and M.V.

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

REFERENCES

Ahmad, M., Jiang, P., Majeed, A., Umar, M., Khan, Z. & Muhammad, S. (2020). The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: an advanced panel data estimation. *Resources Policy*, *69*, 101817. https://doi.org/10.1016/j.resourpol.2020.101817

Alimonti, G., Mariani, L., Prodi, F. & Ricci, R. A. (2022). A critical assessment of extreme events trends in times of global warming. *The European Physical Journal Plus*, *137* (1), 1–20. https://doi.org/10.1140/epjp/s13360-021-02243-9

Allam, Z., Bibri, S. E., Chabaud, D. & Moreno, C. (2022). The '15-Minute City' concept can shape a net-zero urban future. *Humanities and Social Sciences Communications*, *9* (1), 1–5. https://doi.org/10.1057/s41599-022-01145-0

Almaaitah, T., Appleby, M., Rosenblat, H., Drake, J. & Joksimovic, D. (2021). The Potential of Blue-Green Infrastructure as a Climate Change Adaptation Strategy: A Systematic Literature Review. *Blue-Green Systems*, *3* (1), 223–248. https://doi.org/10.2166/bgs.2021.016

Andersson, E., Haase, D., Kronenberg, J., Langemeyer, J., Mascarenhas, A. & Wolff, M. & Elmqvis, T. (2022). Based on Nature, Enabled by Social-Ecological-Technological Context: Deriving Benefit from Urban Green and Blue Infrastructure. *Ecology and Society*, *27* (4). https://doi.org/10.5751/ES-13580-270418

Andersson, E., Langemeyer, J., Borgström, S., McPhearson, T., Haase, D., Kronenberg, J., Barton, D. N., Davis, M., Naumann, S., Lina Röschel & Baró, F. (2019). Enabling Green and Blue Infrastructure to Improve Contributions to Human Well-Being and Equity in Urban Systems. *BioScience*, *69* (7), 566–574. https://doi.org/10.1093/biosci/biz058

Aydemir, F. & Yiğit Gençten, V. (2023). The Connection Between Forest School and Preschool Programs: A Comparison Study. *Journal of Qualitative Research in Education*, *36*, 243–60. https://doi.org/10.14689/enad.36.1711

Brahimi, M., Benabbas, M., Altan, H., Nocera, F. & Costanzo, V. (2023). Enhancing Urban Microclimates: Potential Benefits of Greenery Strategies in a Semi-Arid Environment. *Sustainability*, *15* (23), 16380. https://doi.org/10.3390/su152316380

Brandli, L. L., Salvia, A. L., Rocha, V. T. da, Mazutti, J. & Reginatto, G. (2020). The role of green areas in university campuses: Contribution to SDG 4 and SDG 15. In W. Leal Filho (Eds), *Universities as Living Labs for Sustainable Development: Supporting the Implementation of the Sustainable Development Goals* (pp. 47–68). Cham: Springer. https://doi.org/10.1007/978-3-030-15604-6_4

Brears, R. (2023, 11 May). *Exploring the Benefits of Blue-Green Infrastructure in International Cities*. Our Future Water.

Chandwani, D., Singh, R., Satpute, R. & Dabir, V. (2021). *Blue-Green Infrastructure for Environmental Sustainability: A Bibliometric Analysis*.

Corrigan, S. (2023). How to Build Resilient Cities with Green Infrastructure. *Citygreen*.

Dąbrowska, J., Menéndez Orellana, A. E., Kilian, W., Moryl, A., Cielecka, N., Michałowska, K., Policht-Latawiec, A., Michalski, A., Bednarek, A. & Włóka, A. (2023). Between flood and drought: How cities are facing water surplus and scarcity. *Journal of Environmental Management*, *345*, 118557. https://doi.org/10.1016/j.jenvman.2023.118557

Dąbrowska-Milewska, G. (2010). Standardy urbanistyczne dla terenów mieszkaniowych –wybrane zagadnienia. *Architecturae et Artibus*, *2* (1), 17–31.

Dalampira, E. S. & Nastis, S. A. (2020). Back to the future: simplifying Sustainable Development Goals based on three pillars of sustainability. *International Journal of Sustainable Agricultural Management and Informatics*, *6* (3), 226–240. https://doi.org/10.1504/IJSAMI.2020.112089

Environmental Protection Agency US [EPA US], (2023). *Benefits of Green Infrastructure*. Retrieved from: https://www.epa.gov/green-infrastructure/benefits-green-infrastructure [accessed: 08.12.2023].

Garget, J. (2023). *A Break from the Lawn Can an Iconic Meadow Seed Wider Change?* University of Cambridge. Retrieved from: https://www.cam.ac.uk/stories/kings-wildflower-meadow-a-break-from-the-lawn [accessed: 08.12.2023].

Główny Urząd Statystyczny [GUS], (2023). Edukacja w roku szkolnym 2022/2023 (wyniki wstępne). *Informacje Sygnalne* z 29.06.2023. Retrieved from: https://stat.gov.pl/files/gfx/portalinformacyjny/pl/defaultaktualnosci/5488/21/1/1/edukacja_w_roku_szkolnym_2022-2023-wyniki_wstepne.pdf [accessed: 05.12.2023].

Goel, R. K. & Vishnoi, S. (2022). Urbanization and sustainable development for inclusiveness using ICTs. *Telecommunications Policy*, *46* (6), 102311. https://doi.org/10.1016/j.telpol.2022.102311

Gou, Y., Li, Z., Fan, R., Guo, C., Wang, L., Sun, H., Li, J., Zhou, C., Wang, C. & Wang, Y. (2020). Ethnobotanical Survey and Evaluation of Traditional Mosquito Repellent Plants of Dai People in Xishuangbanna, Yunnan Province, China. *Journal of Ethnopharmacology*, *262*, 113124. https://doi.org/10.1016/j.jep.2020.113124

Griffiths-Lee, J., Nicholls, E. & Goulson, D. (2022). Sown Mini-Meadows Increase Pollinator Diversity in Gardens. *Journal of Insect Conservation*, *26* (2), 299–314. https://doi.org/10.1007/s10841-022-00387-2

Gu, X. N. & Zheng, Y. F. (2010). A Review on Magnesium Alloys as Biodegradable Materials. *Frontiers of Materials Science in China*, *4* (2), 111–115. https://doi.org/10.1007/s11706-010-0024-1

Hamburg.de [n.d.]. *Regenspielplatz* [photograph]. Retrieved from: https://www.hamburg.de/image/8719062/4x3/750/563/c5c775ea150923de8595ceaf90e95218/DR/b-4-regenspielplatz.jpg [accessed: 05.12.2023].

Hardecki, P. (2012). *Szkoła podstawowa w Książenicach* [photography]. ArchiUp. Retrieved from: https://d33zkd7szfej2z.cloudfront.net/fullsize/uploads/realizations/7bc3048f225dbb9828080ee00a74c74880bc3847.jpg [accessed: 05.12.2023].

Hassan, Z., Shahbaz, B. & Gallardo Lopez, F. (2023). Enhancing Blue/Green Infrastructure for Resilient Urban Environments: Smart Solutions and Nature-Based Strategies. In *3rd International Congress on Engineering and Life Science ICELIS 2023* (p. 50). https://doi.org/10.61326/icelis.2023.18

Henning Larsen (2029). *Sundby School* [visualisation]. Retrieved from: https://henninglarsen.com/en/projects/featured/1976-sundby-school [accessed: 05.12.2023].

Ignatieva, M., Haase, D., Dushkova, D. & Haase, A. (2020). Lawns in cities: from a globalised urban green space phenomenon to sustainable nature-based solutions. *Land*, *9* (3), 73. https://doi.org/10.3390/land9030073

Jakimiuk, A., Matsui, Y., Podlasek, A., Koda, E., Goli, V. S. N. S., Voběrková, S., Singh, D. N. & Vaverková, M. D. (2023). Closing the Loop: A Case Study on Pathways for Promoting Sustainable Waste Management on University Campuses. *Science of The Total Environment*, *892*, 164349. https://doi.org/10.1016/j.scitotenv.2023.164349

Janiszek, M. & Krzysztofik, R. (2023). Green Infrastructure as an Effective Tool for Urban Adaptation – Solutions from a Big City in a Postindustrial Region. *Sustainability*, *15* (11), 8928. https://doi.org/10.3390/su15118928

JAZ+ Architekci [n.d.]. *Warszawa: przebudowa podwórka szkoły w Wawrze*. Retrieved from: https://jazplus.pl/projekt/warszawa-przebudowa-podworka-szkoly-w-wawrze [accessed: 05.12.2023].

Jeronen, E. (2020). Sustainable Development. In S. Idowu, R. Schmidpeter, N. Capaldi, L. Zu, M. Del Baldo, R. Abreu (Eds), *Encyclopedia of Sustainable Management*. Cham: Springer. https://doi.org/10.1007/978-3-030-02006-4_193-1

Jiang, D. (2020). The construction of smart city information system based on the Internet of Things and cloud computing. *Computer Communications*, *150*, 158–166. https://doi.org/10.1016/j.comcom.2019.10.035

Kleszcz, J. (2021). *Bio-polis. Wizja miasta nieantopocentycznego*. Zielona Góra: Oficyna Wydawnicza UZ.

Kong, C-H., Xuan, T. D., Khanh, T. D., Tran, H-D. & Trung, N. T. (2019). Allelochemicals and Signaling Chemicals in Plants. *Molecules (Basel, Switzerland)*, *24* (15), 2737. https://doi.org/10.3390/molecules24152737

Kornei, K. A. (2020, 21 May). As the Planet Warms, Intense Storms Become More Common. *Eos*, *101*. https://doi.org/10.1029/2020eo144483

Kumar, H., Singh, M. K., Gupta, M. P. & Madaan, J. (2020). Moving towards smart cities: Solutions that lead to the Smart City Transformation Framework. *Technological Forecasting and Social Change*, *153*, 119281. https://doi.org/10.1016/j.techfore.2018.04.024

Kutty, A. A., Abdella, G. M., Kucukvar, M., Onat, N. C. & Bulu, M. (2020). A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations sustainable development goals. *Sustainable Development*, *28* (5), 1347–1365. https://doi.org/10.1002/sd.2088

Lombardía, A. & Gómez-Villarino, M. T. (2023). Green infrastructure in cities for the achievement of the un sustainable development goals: a systematic review. *Urban Ecosystems*, *26* (6), 1693–1707. https://doi.org/10.1007/s11252-023-01401-4

Macedo, L. S. V. de, Barda Picavet, M. E., Puppim de Oliveira, J. A. P. & Shih, W-Y. (2021). Urban green and blue infrastructure: A critical analysis of research on developing countries. *Journal of Cleaner Production*, *313*, 127898. https://doi.org/10.1016/j.jclepro.2021.127898

Macháč, J., Brabec, J. & Arnberger, A. (2022). Exploring Public Preferences and Preference Heterogeneity for Green and Blue Infrastructure in Urban Green Spaces. *Urban Forestry and Urban Greening*, *75*. https://doi.org/10.1016/j.ufug.2022.127695

Marshall, C. A., Wilkinson, M. T., Hadfield, P. M., Rogers, S. M., Shanklin, J. D., Eversham, B. C., Healey, R., Kranse, O. P., Preston, C. D., Coghill, S. J., McGonigle, K. L., Moggridge, G. D., Pilbeam, P. G., Marza, A. C., Szigecsan, D., Mitchell, J., Hichs, M. A., Wallis, S. M., Xu, Z., Toccaceli, F., McLennan C. M., & Eves-van der Akker, S. (2023). Urban Wildflowers

Meadow Planting for Biodiversity, Climate and Society: An Evaluation at King's College, Cambridge. *Ecological Solutions and Evidence*, *2*, 1–18.

Mehan, A. & Mostafavi, S. (2023). Building resilient communities over time. In *The Palgrave encyclopedia of urban and regional futures* (pp. 99–103). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-87745-3_322

Mittal, I. & Ravi, G. K. (2015). Natural Resources Depletion and Economic Growth in Present Era. *SOCH – Mastnath Journal of Science & Technology*, *10* (3), 24–28. https://ssrn.com/abstract=2920080

Moczek, N., Voigt-Heucke, S. L., Mortega, K. G., Fabó Cartas, C. & Knobloch, J. (2021). A self-assessment of European citizen science projects on their contribution to the UN Sustainable Development Goals (SDGs). *Sustainability*, *13* (4), 1774. https://doi.org/10.3390/su13041774

Mody, K., Lerch, D., Müller, A. K., Simons, N. K., Blüthgen, N. & Harnisch, M. (2020). Flower power in the city: Replacing roadside shrubs by wildflower meadows increases insect numbers and reduces maintenance costs. *PloS ONE*, *15* (6), e0234327. https://doi.org/10.1371/journal.pone.0234327

Moggridge, G. (2020). *Kings' wildflower meadow – a break from the lawn* [photography]. University of Cambridge. Retrieved from: https://www.cam.ac.uk/stories/kings-wildflower-meadow-a-break-from-the-lawn [accessed: 05.12.2023].

Mumtaz, M. (2021). Role of Civil Society Organizations for Promoting Green and Blue Infrastructure to Adapting Climate Change: Evidence from Islamabad City, Pakistan. *Journal of Cleaner Production*, *309*. https://doi.org/10.1016/j.jclepro.2021.127296

Nael Abu Taha (2011). Utility and Importance of Walnut, Juglans Regia Linn: A Review. *African Journal of Microbiology Research*, *5* (32). https://doi.org/10.5897/ajmr11.610

Nathaniel, S. P., Nwulu, N. & Bekun, F. (2021). Natural resource, globalization, urbanization, human capital, and environmental degradation in Latin American and Caribbean countries. *Environmental Science and Pollution Research*, *28* (5), 6207–6221. https://doi.org/10.1007/s11356-020-10850-9

Nowak, P. (2023). Implementing Blue-Green Infrastructure in the Urban Landscape Based on Selected of European and Cities and Around the World. *Space&FORM*, *2023* (55), 249–273. http://doi.org/10.21005/pif.2023.55.D-02

Omer, M. A. & Noguchi, T. (2020). A conceptual framework for understanding the contribution of building materials in the achievement of Sustainable Development Goals (SDGs). *Sustainable Cities and Society*, *52*, 101869. https://doi.org/10.1016/j.scs.2019.101869

Qin, Y. (2020). Urban flooding mitigation techniques: A systematic review and future studies. *Water*, *12* (12), 3579. https://doi.org/10.3390/w12123579

Rózová, Z., Pástorová, A. & Kuczman, G. (2023). Development of Flower Meadows in an Urbanized Environment. *Ekologia Bratislava*, *42* (3), 218–229. https://doi.org/10.2478/eko-2023-0025

Sella, E., Bolognesi, M., Bergamini, E., Mason, L. & Pazzaglia, F. (2023). Psychological Benefits of Attending Forest School for Preschool Children: A Systematic Review. *Educational Psychology Review*, *35* (1), 1–30. https://doi.org/10.1007/s10648-023-09750-4

Shah, A. M., Liu, G., Meng, F., Yang, Q., Xue, J., Dumontet, S., Passaro, R. & Casazza, M. (2021). A Review of Urban Green and Blue Infrastructure from the Perspective of Food-Energy-Water Nexus. *Energies*, *14* (15). https://doi.org/10.3390/en14154583

Singh, B., Singh, P. R. & Mohanty, M. K. (2012). Toxicity of a Plant Based Mosquito Repellent/Killer. *Interdisciplinary Toxicology*, *5* (4), 184–191. https://doi.org/10.2478/v10102-012-0031-4

Snep, R. P. H. & Clergeau, P. (2020). Biodiversity in cities, reconnecting humans with nature. Sustainable Built Environments. In V. Loftness (Ed.), *Sustainable Built Environments* (pp. 251–274). New York: Springer. https://doi.org/10.1007/978-1-0716-0684-1_296

Sobieraj, J., Bryx, M. & Metelski, D. (2022). Stormwater Management in the City of Warsaw: A Review and Evaluation of Technical Solutions and Strategies to Improve the Capacity of the Combined Sewer System. *Water*, *14* (13), 2109. https://doi.org/10.3390/w14132109

St Anthony's Catholic Primary School [n.d.]. *Our Farm School* [photography gallery]. Retrieved from: https://www.saint-anthonysfareham.co.uk [accessed: 05.12.2023].

Šurdonja, S., Giuffrè, T. & Deluka-Tibljaš, A. (2020). Smart mobility solutions – necessary precondition for a well-functioning smart city. *Transportation Research Procedia*, *45*, 604–611. https://doi.org/10.1016/j.trpro.2020.03.051

Tanaka, Y., Mao, Y. & Furuya, K. (2022). Young Citizens' Perceptions of Informal Green Space – A Study of Japanese High School Student's Place Attachment and Desire to Live in Rural Areas. *IOP Conference Series: Earth and Environmental Science*, *1092* (1). https://doi.org/10.1088/1755-1315/1092/1/012011

Teichmann, F., Korjenic, A., Sreckovic, M., Veit, H. & Hartmann, D. (2023). Financing Green Infrastructure in Schools: A Case Study in Austria. *Sustainability*, *15* (20), 14985. https://doi.org/10.3390/su152014985

Thakur, A. (2011). Juglone: A Therapeutic Phytochemical from *Juglans regia* L. *Journal of Medicinal Plant Research*, *5* (22), 5324–5330

Tisgratog, R., Sanguanpong, U., Grieco, J. P., Ngoen-Kluan, R. & Chareonviriyaphap, T. (2016). Plants Traditionally Used as Mosquito Repellents and the Implication for Their Use in Vector Control. *Acta Tropica*, *157*, 136–144. https://doi.org/10.1016/j.actatropica.2016.01.024

Trzaskowska, E., Renda, J., Adamiec, P. & Kułak, A. (2023). The Preferences of Public Space Users as to the Introduction of Various Forms of Greenery in the Old Town of Lublin, Poland. *Bulletin of Geography. Socio-Economic Series*, *61* (61), 19–35. https://doi.org/10.12775/bgss-2023-0023

Veerkamp, C. J., Schipper, A. M., Hedlund, K., Lazarova, T., Nordin, A. & Hanson, H. I. (2021). A review of studies assessing ecosystem services provided by urban green and blue infrastructure. *Ecosystem Services*, *52*, 101367.

Vidal, D. G., Barros, N. & Maia, R. L. (2020). Public and green spaces in the context of sustainable development. In *Sustainable cities and communities* (pp. 479–487). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-95717-3_79

Winkler, J., Koda, E., Červenková, J., Děkanovský, I., Nowysz, A., Mazur, Ł., Jakimiuk, A. & Vaverková, M. D. (2023). Green space in an extremely exposed part of the city center "Aorta of Warsaw" – Case study of the urban lawn. *Urban Ecosystems*, *26*, 1–14. https://doi.org/10.1007/s11252-023-01380-6

Xu, Z., Chau, S. N., Chen, X., Zhang, J., Li, Y., Dietz, T., Wang, J., Winkler, J. A., Fan, F., Huang, B., Li, S., Wu, S., Herzberger, A., Tang, Y., Hong, D., Li, Y. & Liu, J. (2020). Assessing progress towards sustainable development over space and time. *Nature*, *577*, 74–78. https://doi.org/10.1038/s41586-019-1846-3

Ying, J., Zhang, X., Zhang, Y. & Bilan, S. (2022). Green Infrastructure: Systematic Literature Review. *Economic Research – Ekonomska Istrazivanja*, *35* (1), 343–366. https://doi.org/10.1080/1331677X.2021.1893202

Zhu, B., Zhu, C. & Dewancker, B. (2020). A study of development mode in green campus to realize the sustainable development goals. *International Journal of Sustainability in Higher Education*, *21* (4), 799–818. https://doi.org/10.1108/IJSHE-01-2020-0021

WSPIERANIE ZRÓWNOWAŻONEGO ROZWOJU OBSZARÓW MIEJSKICH: INTEGRACJA OBSZARÓW SZKOLNYCH NA RZECZ WSPIERANIA ZIELONO-NIEBIESKIEJ INFRASTRUKTURY MIASTA

STRESZCZENIE

Konsekwencje kryzysu klimatycznego w nieproporcjonalnym stopniu dotykają ludzi mieszkających gęsto zaludnione obszary miejskie, co stawia deweloperów przed poważnym wyzwaniem w XXI wieku. Administratorzy miejscy stoją przed poważnym wyzwaniem podczas wdrażania celów zrównoważonego rozwoju w praktyce, zwłaszcza w ramach ograniczeń obecnej infrastruktury. W artykule oceniono, w jaki sposób strefy szkolne – które charakteryzują się znaczną liczbą obszarów biologicznie czynnych – są włączane do infrastruktury miejskiej w celu wspierania różnorodnego wykorzystania zasobów naturalnych, poprawiających standardy życia w mieście. W celu scharakteryzowania ewolucji terenów szkolnych oraz kształtowania przyszkolnych terenów zieleni i zielono-niebieskiej infrastruktury przeprowadzono kompleksową analizę obowiązujących przepisów, przegląd literatury naukowej oraz zaprezentowano studium przypadku wybranych obiektów szkolnych, a także renowacji tego typu obiektów z ostatniej dekady. We wnioskach opisano możliwości, jakie niesie ze sobą ewolucja podwórek i kampusów szkolnych w dążeniu do funkcjonowania zrównoważonego rozwoju oraz wymieniono listę potencjałów miejskich inicjatyw ekologicznych.

Słowa kluczowe: zielono-niebieska infrastruktura, szkoły, inteligentne miasto, zrównoważony rozwój