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Research Article

Blue—green architecture: A case study analysis considering the synergetic effects of water and vegetation

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Abstract Blue—green infrastructure is a network of natural and near-natural areas that has a positive effect on the quality of urban environment. This multifunctional planning approach addresses different issues and objectives depending on whether the focus is on the blue (water) or the green (vegetation) elements. Green-motivated projects aim to densify urban vegetation and include the growing sector of building greening. A good climatic effect of vegetation can be achieved by sufficient irrigation. In many cases, this approach results in additional water requirements. Blue-motivated projects consider water accumulation in cities (e.g., by heavy rainfall) as a waste product and look for solutions for local drainage and evaporation. These planning approaches offer only one-sided solutions and create no sufficient interfaces between water availability and water demand. Based on four case studies, this work examines the extent to which blue—green projects take advantage of the possibilities for the synergetic use of resources. The projects are analyzed graphically by applying the daily tools of architects as a scientific method. A graphic presentation of the blue and green components makes existing solutions and missing links visible. Analytical results show that buildings can be considered to be an interface for blue—green systems. Moreover, the possible synergies are often overlooked during the planning process. This fact highlights the need for a new planning approach that interlinks blue and green aspects that are already in the early planning stages.

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1. Introduction

The demands placed on urban environments are constantly increasing. Social and ecological challenges lead to a worldwide densification of inner-city areas. Furthermore, the competition for space leads to a functional overlapping and strong sealing. Urbanized areas have a higher air and surface temperature and a lower insurability compared with natural ones. The annual average air temperatures in cities are 1–3 °C higher than that in surrounding landscapes (Fryd et al., 2011). This temperature difference is also known as the urban heat island (UHI) effect, which has several causes. Sealed grounds prevent the infiltration of precipitation, which results in low surface evaporation. Apart from this aspect is the waste heat generated by energy consumption. UHI consequences include increasing energy demand, air conditioning costs, air pollution, heat-related illness, and mortality (ARUP, 2014). This effect is expected to be intensified by climate change (Kenward et al., 2014).

One circumstance that will in any case be aggravated by climate change is the rise in extreme weather events, such as heavy rainfall and long drought (Hassol et al., 2016). In July 2011, during a cloudburst in Copenhagen, over 150 mm of rain fell within 2 h, resulting in extensive flooding. Copenhagen City decided to initiate the development of a city transformation plan that would optimize water retention in the city by integrating blue–green elements (American Society of Landscape Architects, 2016). Other cities must also revise their water management schemes due to heavy rain and floods (Stokman et al., 2015). Other meteorological changes place cities under stress. Persistent periods of heat and drought have a negative impact on energy consumption and health. The heatwave that hit Europe in 2003 is estimated to have caused over 30,000 deaths (Mann, 2018). Dryness leads to an imbalance between water availability and water demand. The need for plant irrigation increases in dry phases, whereas water supplies simultaneously decrease (Schoenberg et al., 2014).

The integration of natural elements into cities is an effective method to counteract the effects of UHI and the consequences of extreme weather events (Gunawardena et al., 2017). Urban green provides water retention and slow evaporation, which in turn has a positive impact on the microclimate. The term "blue–green infrastructure" (BGI) refers to the combination of blue (water) and green (vegetation) components in distinction to gray infrastructure, such as roads, settlements, and canals. The concept was developed at the level of infrastructure and landscape. This concept has already been successfully applied on that scale. Architecture and buildings can be an integral component of BGI if they embody the inherent principles and objectives and thus become part of the network.

1.1. Definitions and functions of BGI

The concept of BGI has yet to be generally understood. The term "green infrastructure" (GI), also known as "urban green infrastructure" (UGI), is common. In the case of GI, the definitions in the literature also vary, especially with regard to the integration of "blue" components. A commonly cited definition of GI comes from the European Commission. "Green infrastructure can be defined as a strategically planned network of valuable natural and semi-natural areas with further environmental elements, which is designed and managed in such a way that a broad spectrum of ecosystem services is guaranteed in both urban and rural areas and biological diversity is protected" (European Commission, 2014).

A good overview of the spectrum and possibilities of BGI results from projects that have already been successfully implemented. For this reason, the definitions of the planning and execution of engineering offices are also relevant. The engineering company, Arup, which has implemented numerous notable projects in this field, defines GI as follows: "the system of open spaces, natural areas, urban woodland and parks; green streets, squares and public realm; rivers and waterways; and smaller scale interventions such as green roofs, walls and façades — all of which lie within the physical networks of cities themselves and their immediate hinterlands, and perform essential ecosystem services" (ARUP, 2014). The following subcategories are listed in the "Green Infrastructure Cards" developed by Arup: demographics, urbanization, water, climate change, waste, energy, and food (Rabe, 2015). The integration of water is an optional component but not mandatory. This list also illustrates the area of tension in which the projects operate in a great variety of requirements.

Ramboll, a company that implements climate adaptation and flood risk management projects worldwide, provides another definition for BGI in which the interaction of green and blue becomes the key feature: "BGI combines hydrological functions with urban nature, landscaping and urban planning. Blue (water) and green (nature, squares and parks) serve to protect against floods and other impacts of climate change." (Ramboll, 2018). This description shows the interdisciplinary approach of BGI, but it remains at the conceptual level on a large scale. Small interventions are not considered.

In the following, BGI is used as an umbrella term for projects of all scales in the urban environment, where blue and green elements are combined and have a multifunctional impact in urban space. Under this definition, a wide range of issues and solutions is addressed. In addition, BGI cannot be assigned to one profession. The perspective on the topic also changes depending on the discipline.

The combination of blue and green elements depends on location, scale, season, and weather; moreover, it can provide various functions regarding social, ecological, and design aspects and make cities resilient to climate change (Fryd et al., 2011; Hansen et al., 2017; Klemm et al., 2017). The resulting multifunctionality is a mandatory component of BGI (Brears, 2018, p. 10). Some core functions are the improvement of microclimate, air quality, and public health (Klemm et al., 2017). On an urban scale, the positive effects of BGI include sound insulation, air cleaning, fine dust binding, rain water retention, and aesthetic aspects (Pfoser et al., 2014). These blue–green functions regarding supply, regulation, and culture can also be summarized as ecosystem services. Such functions enable urban nature and biodiversity that have a considerable value for society (Kowarik et al., 2017).

1.2. Application of BGI in architecture

The use of blue—green systems at the building level is less common than in landscape planning. Rather, many individual components can be part of a blue—green network. Sustainable water management in buildings includes, for example, the collection and reuse of rainwater as service water for irrigation or cooling. When rainwater runoff seeps into the ground, resulting in the enrichment of groundwater, the aim is often to compensate for the negative effects of the ground being sealed by the building. The separate collection of gray water remains an absolute exception. The internal treatment of gray water in buildings remains to be a cost-intensive specialized solution even though it is amortized over the life cycle by saving drinking water (König, 2013a).

Building greening is an important component of BGI. Green roofs and façades appear in many different variations. Green roofs are usually classified in accordance with their established categories (extensive/intensive). Nevertheless, extended concepts, such as marsh plant and retention roofs, have been developed over time.

The systematic installation of roof and façade greening and the plantation of trees and green spaces near a building can positively affect the direct and indirect energy consumption of buildings. Heating and cooling energy can be saved through shading (trees and facade greening), cooling by evapotranspiration (all green elements), and insulation (green roofs) (Fryd et al., 2011; Pfoser et al., 2014).

2. BGI-related planning concepts

BGI bundles planning concepts that deal with the blue (water) and green (vegetation) aspects. The differences of the subcategories lie in motivation and approach. Blue-motivated projects mostly result from urban water management, flood protection, and decentralized rainwater management. By contrast, green-motivated projects aim for the densification and optimization of urban vegetation. For this reason, blue-driven projects can be grouped under water sensitive urban design (WSUD) and green-driven projects under GI. Fig. 1 shows the classification through which BGI is based by breaking down the contained planning concepts into blue and green approaches. All concepts can include blue and green components. The differences do not lie in the applied elements but in the questions from which the projects are motivated. The interconnection of these objectives comes together in BGI.

2.1. WSUD—blue-motivated projects

The WSUD concept is a further development of conventional water management and integrates the disciplines of urban and landscape planning. WSUD allows all aspects of the urban water cycle to be considered and to approach the natural water cycle (Hoyer et al., 2011, p. 18). The implementation of WSUD includes the following solutions: rainwater use, wastewater treatment, detention and infiltration, conveyance (e.g., open stormwater channels), and evapotranspiration (Hoyer et al., 2011, p. 21). These elements partly use plants and urban green, whether in biotopes, green roofs, or rain gardens. The application of WSUD occurs at different scale levels (Wong, 2006). With regard to buildings, this concept includes not only the retention of precipitation to reduce runoff but also the resource-efficient treatment and reuse of waste water on site. This concept has no term in the current literature. We describe the approach here as "blue architecture" (Fig. 1).

In general, disposal problems with water are present in cities. Wastewater is produced in varying qualities and at different times and must be disposed by a central system. The amount of domestic wastewater only slightly varies. A major problem is the acute overload of the system due to cloudbursts. WSUD also considers this issue and provides various solutions for flood prevention and stormwater management (Brears, 2018, p. 10). Enlarging the canal system and adapting it to new conditions is not an economical solution (Deister et al., 2016, p. 12). Instead, various vegetated and nonvegetated solutions exist to reduce surface runoff (Perini, 2017; Sabbion, 2017). Mechanisms that absorb water and return it to the natural water cycle or enable intermediate storage are implemented to relieve the sewerage system and prevent local flooding in the event of heavy rainfall (Deister et al., 2016).

Fig. 2 shows the planning procedure for blue-motivated projects on an urban scale. Heavy rainfall events lead to a massive increase in the amount of water, which overloads the sewer system, at certain points. Flood protection requires local opportunities for water reuse, retention, and

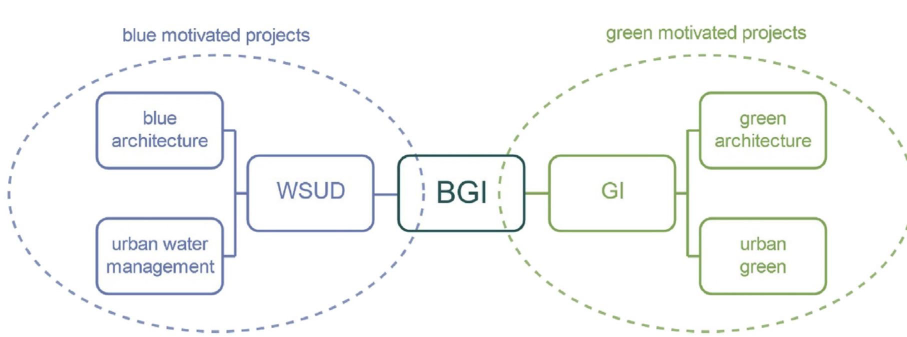

Fig. 1 Blue—green infrastructure: subordinate and related planning concepts according to blue and green motivated approaches.

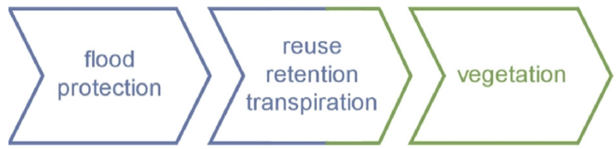

Fig. 2 Planning approach of blue-motivated projects.

transpiration. The connection with vegetation is a logical consequence, resulting in blue—green solutions.

Vegetated systems include rain gardens and wetland ponds. The dimensioning of this blue—green retention mechanisms that are approached from the "blue" side is based on the amount of water that is expected as precipitation. In some cases, the buffered water is used for irrigation during dry periods. The design of green elements is not the goal of greening, as in the case of GI, but it is a medium for water retention. The positive effects of greening can also be observed here to a certain extent. However, the design options are limited.

For this reason, projects that arise from the "urban water management" or "blue architecture" point of view are covered by the umbrella term, BGI. However, the motivation clearly comes from water handling and disposal and uses vegetation as an instrument.

2.2. GI—green-motivated projects

The green components of BGI originate mainly from GI and consequently combines two elements, namely, urban green and green architecture. The initial idea here, as previously described, is to solve climatic, ecological, and social problems by integrating vegetation into cities (Pötz and Bleuzé, 2012). The design quality for the urban environment is also an important goal. In addition to urban green, such as parks, green squares, urban forests, and renaturalized river landscapes, green architecture is gaining importance. The advantages of green roofs and façades have been extensively researched and proven (Pfoser et al., 2014). An increasing number of cities is prescribing the greening of flat roofs. A pioneer in this field is Hamburg City, which passed a "green roof strategy" in 2014 (Bürgerschaft der Freien und Hansestadt Hamburg, 2014). A major development is currently happening in the field of vertical greening. The French botanist and artist, Patrick Blanc, is receiving great attention in the field of façade greening because of his vertical gardens. These systems have a positive effect on the urban climate and are of aesthetic quality (Blanc et al., 2009). However, vertical gardens also receive justified criticism because fragile systems require a permanent water supply and are often supplied with drinking water (CNN, 2009).

The relatively new concept of "Baubotanik" develops the interweaving of buildings and plants even further. Instead of merely adding green systems to architecture, the plant itself becomes an elementary component here. The growth behavior and seasonal cycle of the vegetation are integrated into the design concept of the building structure (Ludwig et al., 2012). Urban green and green architecture have something in common, that is, vegetation, as an ecological and creative functional carrier, forms the starting point. An adequate water supply must be ensured to keep vegetation alive.

Many facilities, such as parks and city green areas, that are part of GI require no artificial irrigation and only need to be watered in exceptional cases during long drought periods. In the case of building greenery, in particular with intensive green roofs and wall-bound vegetation, irrigation is often mandatory and integrated into the overall concept. Plants have a specific water requirement that depends on many factors and cannot be precisely quantified. However, plants, as flexible systems, can also buffer fluctuations in water supply and adapt their requirements accordingly (Köhler, 2012, p. 145). Water consumption of plants results from the difference between potential evapotranspiration and effective precipitate in relation to change in soil moisture (Frenken and Gillet, 2012). Therefore, plants with a high evaporation capacity have a high water requirement. This notion indicates that even green systems that normally require no irrigation can tolerate and evaporate a specific excess of water. This effect is particularly favorable to the microclimate and can be used in a manner by which excess water can be brought out onto green areas that are unnecessarily dependent on irrigation. For example, green roofs are suitable for this purpose.

Several possible solutions are available to ensure an adequate water supply. On the one hand, plants with a high drought resistance can be chosen. This approach keeps the need for (additional) irrigation low. On the other hand, water concepts that are fed from a sustainable source can be developed. The classical approach at this point is to store rainwater in cisterns. However, a connection to the local water network for extreme cases is often unavoidable. The resulting water concepts mostly include rainwater or other alternative water sources. However, these concepts are based on the connection to the local water network for good measure. In particular, the projects are planned in accordance with demand. This notion implies that the required amount of irrigation water is determined and then made available. Fig. 3 describes this procedure.

Climate change increases the causes of drought stress for trees and also leads to an increasing need for artificial irrigation (Roloff, 2004, p. 190; Schoenberg et al., 2014). The use of locally generated water is an ecologically, economically, and resource-efficient solution to cover this water demand. Different water sources can be considered. The use of rainwater is convenient in many ways. Rainwater is often of good and constant quality. Large contamination is rare. However, the availability strongly fluctuates. By contrast, groundwater is a constantly available water source and has a high quality because it is naturally filtered and purified. Nevertheless, groundwater cannot be used as irrigation water at all sites. Access to groundwater is expensive and strictly regulated to maintain the ecological balance (Pötz and Bleuzé, 2012).

Fig. 3 Planning approach of green-motivated projects.

3. Blue—green architecture and integrated systems

The combination of blue and green approaches into one planning strategy enables the coordination of water demand and water availability. This coordination ensures a balanced use of resources, contributes to microclimatic improvement, and makes a remarkable contribution to resilient adaptation to climate change. Fig. 4 explains the two-sided procedure for BGI. The objectives of GI and WSUD are combined into an integrated system that includes blue and green elements according to local conditions. This notion means that different types of wastewater occurring in the city are directly managed on site and linked with high-quality vegetation elements in terms of design and microclimate. Only a synergetic consideration of the green and blue approaches guarantees an effective, flexible, and adaptable solution. If the question of water supply is considered in close connection with water management, then suitable interfaces can be developed.

As described in the Introduction section, the implementation of this strategy concerns all areas of urban design. This study is conducted from an architectural point of view; the focus is on buildings and their immediate surroundings. According to the definition of Köhler (2012, p. 14), this concept also includes technical structures, such as bridges, because any type of building can be greened. Buildings have a high potential to form green and blue interfaces. First, buildings take up a large amount of space in the city. Thus, buildings should be prioritized in the consideration. Second, buildings always have a certain amount of water flow. Buildings are connected to the water supply and sewage system. Third, buildings benefit from greening in many ways. Fourth, the implementation options are flexible and various. Buildings can greatly vary depending on the local conditions, and solutions for existing and new buildings are available.

This work investigates the extent to which a two-sided approach in the planning of blue—green projects of different dimensions can strengthen synergies and thus achieve a good climatic impact and high resource efficiency. The following case studies present an analysis of the existing projects to determine the extent to which a synergetic approach is already established, and at which points development potential remains. This work uses a graphical analysis of projects as a core method to map out the role of blue and green elements in the analyzed case studies. The theses, questions, and strategies of this work relate to the Central European region. Locations with a different climate must be considered and evaluated differently.

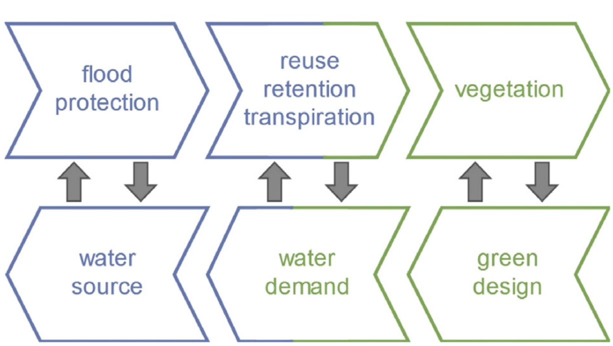

Fig. 4 BGI: Combining blue and green motivated planning approaches into one integrated strategy. The procedure is already established on the urban and landscape scale but not on the building scale.

4. Case studies

In this section, four case studies, which are examples of BGI, are presented. The projects were selected to represent a broad spectrum of approaches and implementation from an architectural point of view. These studies illustrate the current planning practice and highlight the strengths and weaknesses of blue—green planning and implementation. The analysis focused on the synergetic combination of green and blue elements. For this purpose, the existing vegetation and water flows in the project and the surrounding area were examined to identify possible interfaces and optimization potential.

The four case studies were selected in accordance with the following criteria: The High Line in New York City and the Potsdamer Platz in Berlin were planned on an urban scale. Both projects are located in large cities and respond to local conditions. Nevertheless, these projects have different questions. The High Line is a classic green project that focuses on an aesthetically pleasing effect. With regard to the Potsdamer Platz, a rainwater management concept is developed to ensure a decentralized drainage in a dense inner-city area. Two further projects, namely, Bosco Verticale in Milan and Block 6 in Berlin, operate on a building level and illustrate two complementary design approaches. In Bosco Verticale, the entire building was designed with an objective of extensive façade greening. Block 6 aimed to provide a self-sufficient water management system that also included the recycling of gray water.

The analysis of the four case studies was based on a comprehensive literature research. If no technical literature was available, then the information was supplemented by gray literature. The following questions were highlighted: What was the motivation behind the project? On which concept were the blue and green components based? What type of greening was used? What were the water flows within the project and in the surrounding area? To what extent did a synergetic link between water supply and greening exist?

The results of the analysis were visualized in drawings. These illustrations show the existing vegetation and the amount of water in the surrounding area. Drawing is a classic tool used by architects to illustrate connections and causalities. During the drawing process, open issues became visible. The result also made it possible to illustrate the existing and missing synergies. The drawings aimed to show the actual state neutrally and not to interpret the results. This mapping was initially performed without evaluating the results. The parallel existence of green systems and water flows clarifies the inconsistency of the synergetic connection.

4.1. High Line

The High Line in New York City is a project that illustrates the mechanism by which the existing gray infrastructure can be turned into a green one while considering climatic and social aspects. The park is located on an elevated railway line, which was overgrown with plants after its closure. The transformation into a linear park was based on this appearance and completed in 2014. The idea behind the project was to replant partially the plants that had sown themselves over the years. This task was performed to ensure that the plant selection adapted to the local conditions and provide a visual impression of the wild High Line (Fiehn, 2013). This preselection of vegetation was supplemented by resistant plants that could stand the difficult conditions of the thin soil and the low supply of water and nutrients (Yudina, 2017). The natural occurrence on the east coast of the USA and a high tolerance to drought were considered (Fiehn, 2013). The design shows a new dissolution of boundaries between architecture, nature, and infrastructure (Stokman, 2018). The paving system of the paths could retain up to 90% of the rainwater, making it available to the planting beds for irrigation (Yudina, 2017). Precipitation is insufficient to maintain the green appearance during summertime. In this case, the plants are manually watered (Friends of the High Line, 2018).

On the basis of the reasons described, the High Line is an example of a project developed using the green approach. The design for an attractive green open space was the priority, whereas the accompanying water concept played only a subordinate role. Fig. 5 shows that numerous water strands in the immediate vicinity were not integrated into the project. The surrounding buildings were excluded despite the high density. No connection to the neighboring buildings, which could serve as water sources with rainwater or gray water, was present. The design focus was on aesthetic quality and recreational value and not on the development of a networked concept.

The High Line concept illustrates the events that occur when a project is designed to keep water requirements as low as possible and, if necessary, to cover the demand as sustainable as possible. Although this concept is a resource-saving approach, the low water consumption leads to reduced evapotranspiration, which in turn limits the cooling effect on the urban climate.

4.2. Potsdamer Platz

The Potsdamer Platz in Berlin is an important traffic junction and has a turbulent history. In the early 90s, the square was redesigned. The aim was to achieve zero rainwater runoff despite the high degree of sealing and include water as a design element (Grant, 2012, p. 89; Hahn, 1994, p. 3; Hoyer et al., 2011, p. 100). The project required a combination of different retention mechanisms to achieve this goal (Fig. 6). The 12,000 m^2 of green roofs directly

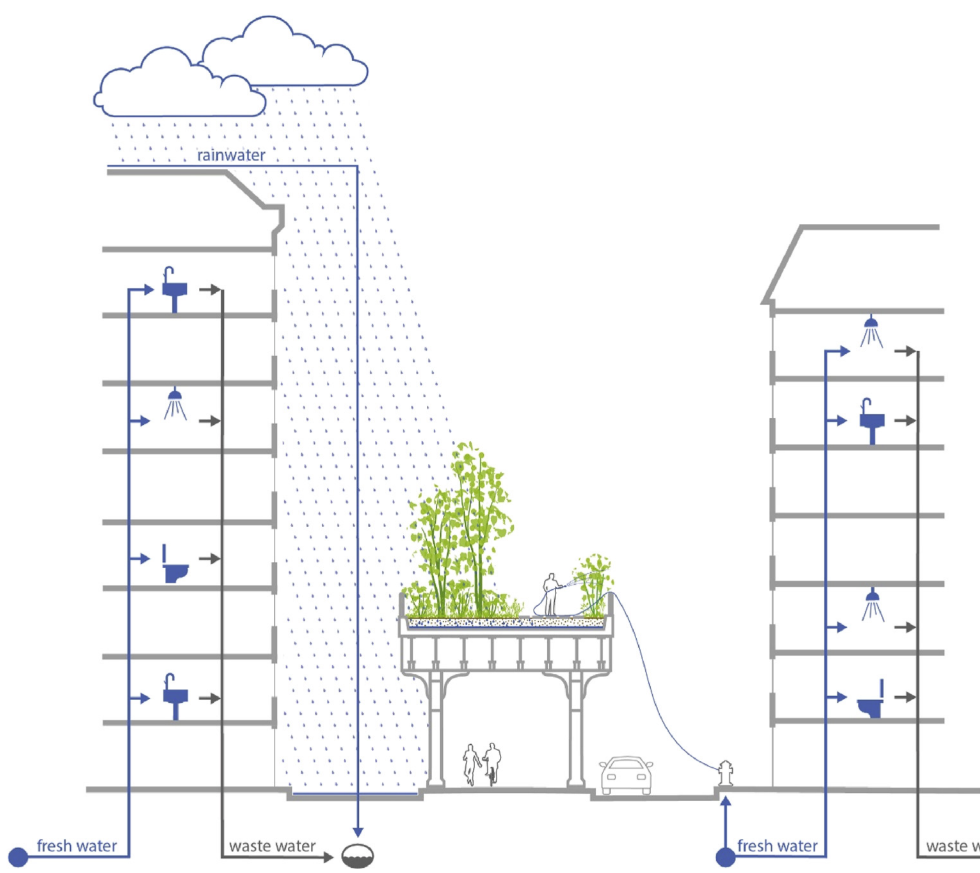

Fig. 5 High Line: The vegetation concept has a low water requirement even though a huge amount of urban water sources are available in the immediate vicinity. The microclimatic effect remains below the possibilities.

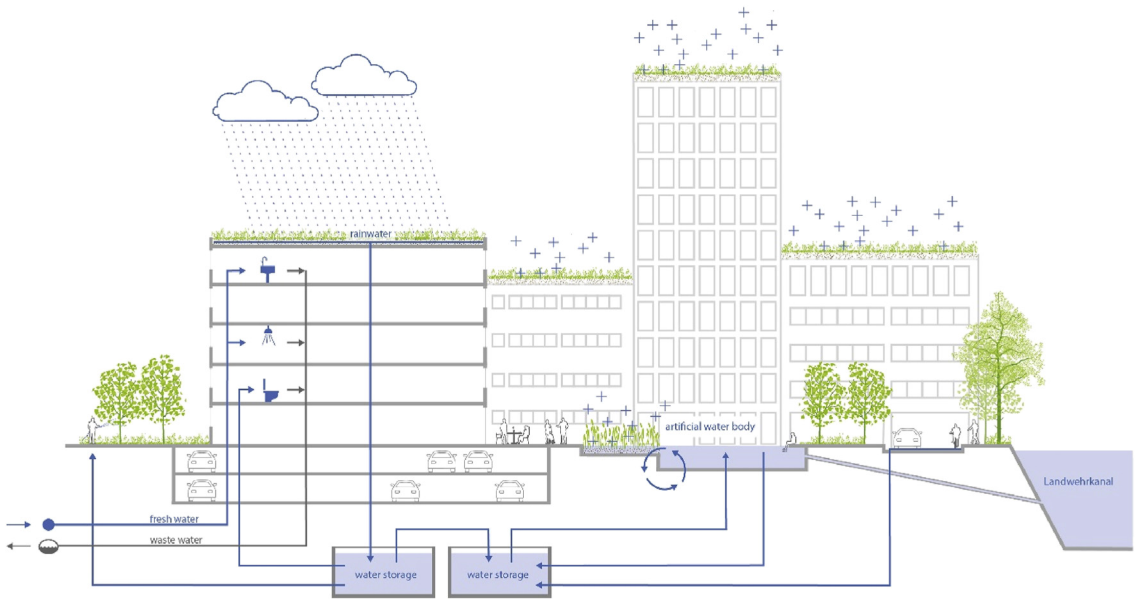

Fig. 6 Potsdamer Platz: The rainwater management system achieves zero runoff by combining different retention options. Green roofs and artificial water bodies collect and evaporate precipitation.

evaporates more than half of the precipitation (Grant, 2012, p. 89; Hoyer et al., 2011, p. 104). The water discharge is led into five cisterns with a total volume of 2600 m^3. An additional storage capacity of 1300 m^3 is provided by the newly created artificial water areas due to fluctuations in the water level (Dreiseitl and Grau, 2006). These reservoirs also take on other functions, especially those in connection with water quality. The vegetated biotopes along the lakes remove particulates and ensure ecological balance (Hoyer et al., 2011; Senatsverwaltung für Stadtentwicklung Berlin, 2017b). The combination of retention mechanisms used here is successful. The possibility of discharging large quantities of surplus water into the nearby Landwehr Canal only becomes effective three times every 10 years. This quantity corresponds to the value of an unsealed site (Dreiseitl and Grau, 2006, p. 48; Pötz and Bleuzé, 2012, p. 183). Approximately 85% of the annual precipitation is retained on roofs and in water surfaces, evaporates, or flows off in a throttled way. The remaining 15% of the annual precipitation can be used for flushing toilets in office buildings and irrigating green areas (Senatsverwaltung für Stadtentwicklung Berlin, 2017b).

The question with regard to blue–green strategies clearly comes from the blue side. The handling of rainwater is progressive and successful. The experience by means of water surfaces also has a great design and integrative quality. Vegetation plays a subordinate role. A room for optimization remains available, especially with regard to building greening. The possibilities for synergetic links are partially exploited either. This fact includes gray water that is not separated and not integrated into the water concept. For the inner-city area, relieving the sewerage system even with a high sealing is a great achievement. This system prevents flooding and its consequential damages. Nevertheless, such a procedure requires high construction costs. The necessary infrastructure with huge water reservoirs and corresponding connections has yet to establish itself as a standard. In such a case, blue–green strategies could combine microclimatic advantages with a reduction in storage volume.

4.3. Bosco Verticale

The Bosco Verticale in Milan was completed in 2015. The project aims to be an example for sustainable housing and contributes to reforestation and naturalization in the city (Stefano Boeri Architetti, 2018). The two towers are covered with dense vegetation of 20,000 plants, of which 700 are trees (Giacomello and Valagussa, 2015). The selected trees must withstand the temperature fluctuations from −1 °C to 31 °C that are common in Milan and cope with the special conditions of height (wind load). The trees were pregrown to ensure that they are prepared for their later location (Stefano Boeri Architetti, 2018). From a design point of view, this task was intended to achieve the optimal possible coverage with greenery. Therefore, this project is clearly green motivated. The water concept was adapted to the greening. The numerous positive effects of vertical greening have been proven. For this reason, the plants of the Bosco Verticale positively contribute to the energy balance of the building. This assumption could not be definitely verified. The data published by Giacomello and Valagussa (2015) were based on simulations and estimations and were not experimentally measured. A simulation of the façade showed that the solar gains and losses from planting are offset on an annual average. The energy savings that can be recorded compared with a flat façade are therefore the same as those that can be achieved by shading a façade with an unplanted balcony alone (Giacomello and Valagussa, 2015, p. 55). No reliable data on the microclimatic effect are also available, but evapotranspiration is assumed to lead to an improvement. Air filtering and fine dust reduction can also be assumed (Giacomello and Valagussa, 2015).

The calculations for water consumption were based on projections. Irrigation automatically occurs through a central system that uses groundwater. The irrigation of the plants with gray water was examined but rejected (König, 2013a). Each tower has a water tank connected to pumps that distribute the water section by section in the building. Sensors control the humidity in the beds, that is, watering is only on demand, resulting in high water efficiency (Giacomello and Valagussa, 2015).

In general, the use of groundwater in buildings is unrecommended. The architects Hildtrud Pötz and Pierre Bleuzé wrote in their handbook on "Blue—green grids" that groundwater resources should be protected and can only be used with permission and under certain circumstances (Pötz and Bleuzé, 2012, p. 179). The situation in Milan justifies an exception. The groundwater level has been rising for years as a result of the decrease in industry. The city council recommends the use of groundwater for new buildings to minimize the consequences, such as flooded garages (König, 2013b; Migge, 2004). A positive side effect of the groundwater pump is that heat pumps are installed to use the groundwater as an energy source for generating hot water (König, 2013a).

The Bosco Verticale represents a classic green-motivated approach at the building level. A building of the highest aesthetic quality has been created and is receiving international attention. The water concept responds to local conditions and meets the requirements of a synergetic and networked approach. The climatic advantages also make the project successful. Nevertheless, the blue—green concept can be critically questioned. This concept contains no integrated rainwater management, and the gray water of the apartments goes unused into the public sewerage system (Fig. 7). Consequently, the backflow of irrigation water further increases the volume of wastewater, and the city's sewerage system is heavily charged. This notion means that the building generates a large amount of waste water instead of reducing the load on the central system.

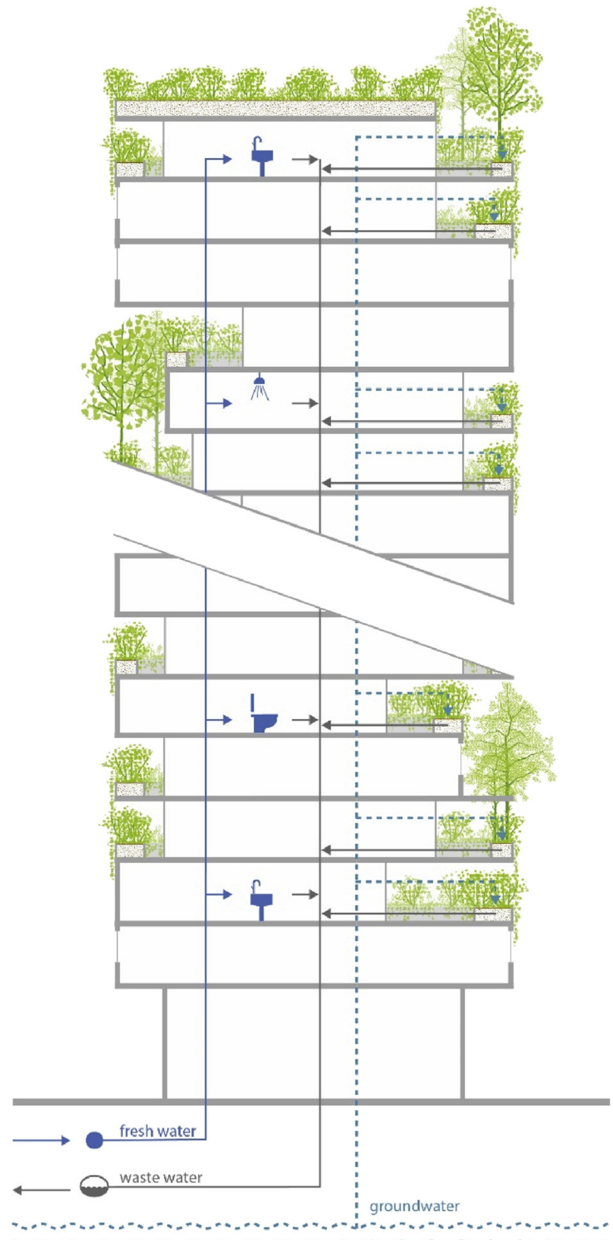

Fig. 7 Bosco Verticale: Groundwater is used for irrigation and loads the sewerage system additionally.

4.4. Block 6

The original design for Block 6 was developed as part of the International Building Exhibition (IBA) 1987. This innovative water concept combines the use of rainwater and graywater (Million et al., 2018, p. 142). The residential complex in Berlin's city center with approximately 250 residents has a separate pipe network for gray and black water, and it is efficient for water saving (Million et al., 2018, p. 22). Fig. 8 shows the original planning that included a constructed wetland to treat the gray water. The generated process water was used for toilet flushing and irrigation. This process resulted in a daily saving of 80 L of freshwater per person (Hahn, 1994). Another discharge from the constructed wetland supplied a groundwater enrichment plant that infiltrated purified gray water. The roof areas were greened to 50% to ensure that they can directly evaporate part of the rainwater.

The excess rainwater was collected in a pond in the inner courtyard, which had such a high water quality that it could be used for bathing. A zero discharge of rainwater into the public sewerage was achieved for the entire property (Hahn, 1994).

The gray water was more polluted than usual due to the water-saving behavior of the tenants. The constructed wetland was unable to cope with this contamination. The wetland was overloaded and did not achieve the required water quality. For this reason, the wetland was shut down in 1993. In 2006, the entire plant was rebuilt (Fig. 9). Since

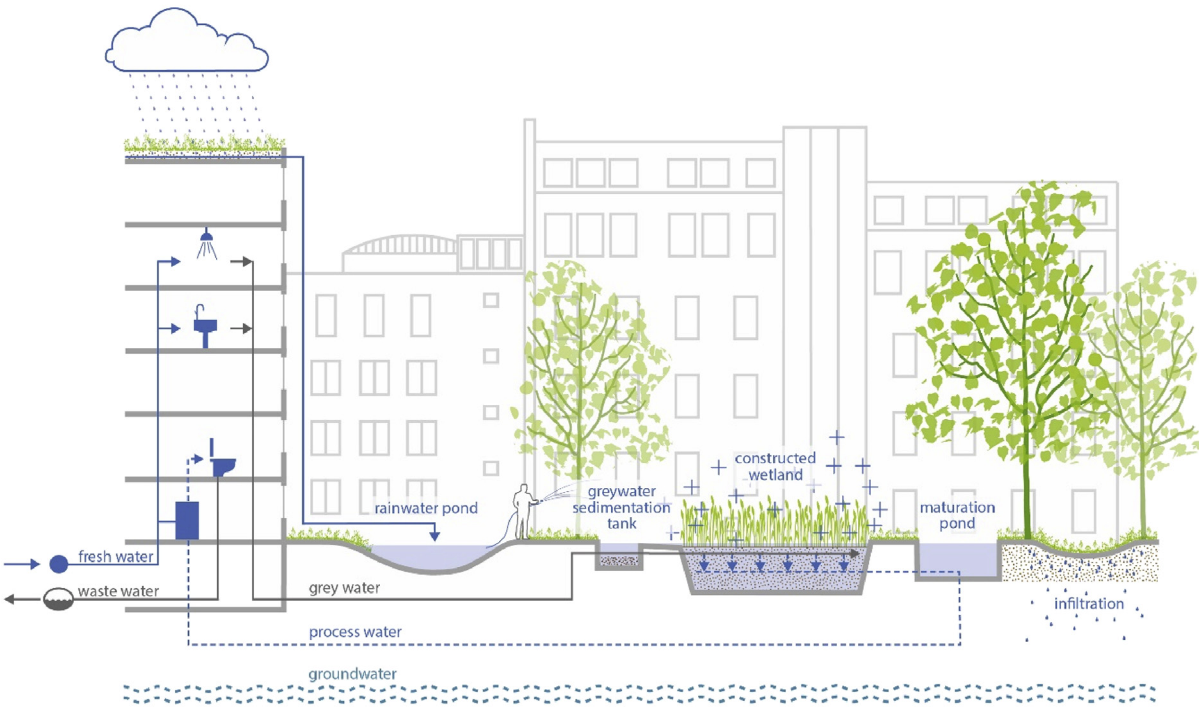

Fig. 8 Block 6 IBA 1987: The original concept included a constructed wetland for gray water treatment and a rainwater pond.

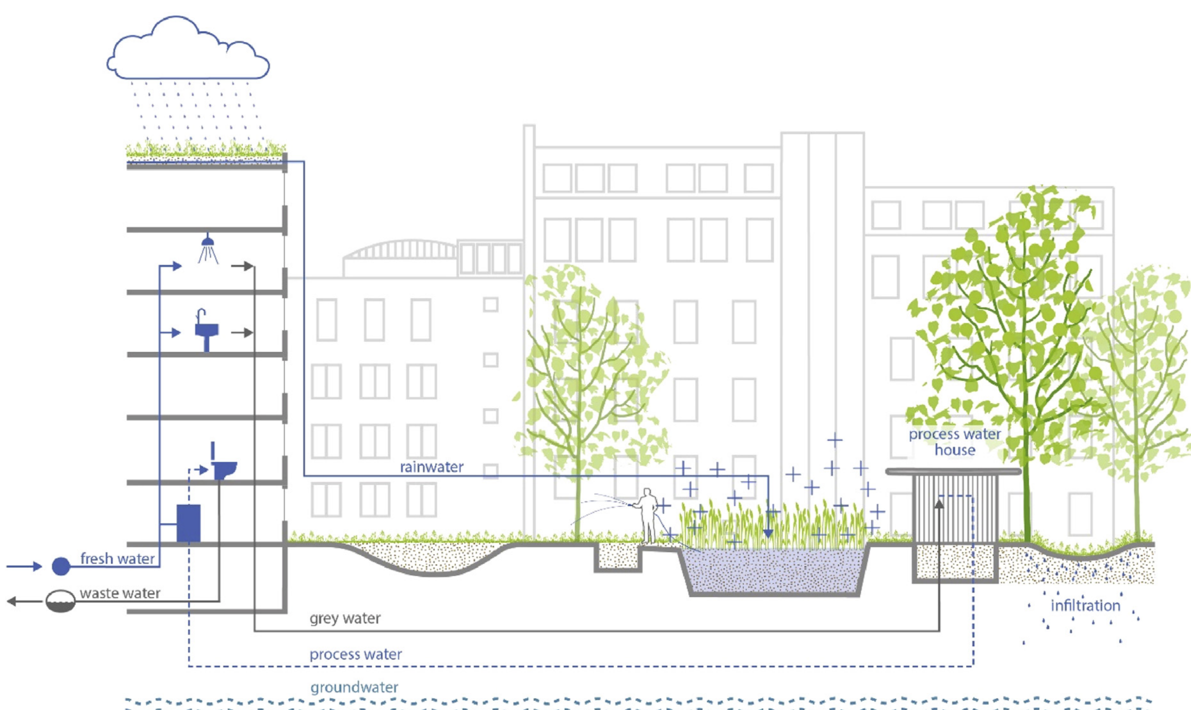

Fig. 9 Block 6 refurbishment 2006: The gray water is now treated in a mechanical—biological system that is located in the newly built process water house. The former constructed wetland contains rainwater.

then, the gray water has been mechanically and biologically cleaned in a process water house. The former constructed wetland now contains the rainwater and can still drain any surplus water for groundwater recharge. The former rainwater pond was filled up (Senatsverwaltung für Stadtentwicklung Berlin, 2017a).

A further component was added to the system in 2013. A greenhouse was installed next to the process water house.

This greenhouse uses the purified gray water for food production (fish and vegetables) and the black water of the apartments for nutrient extraction (Million et al., 2018). This test unit belongs to the research project, Roof Water Farm (RWF), which investigates the use of treated wastewater and nutrients from buildings for urban farming in roof greenhouses. The integration of the test unit into the existing water concept creates further synergies.

The elaborate water concept of Block 6 makes it a blue-motivated project. Overall, this concept is technically and conceptually advanced. Almost all water flows are considered in the system and combined in a useful manner. The compact inner-city plant shows solutions for the decentralized management of various types of wastewater. Green elements, such as green roofs and courtyard greening, are also integrated and improve the microclimate. The partnership with RWF complements the concept with urban farming. However, the project is less developed in terms of building greening and architectural design. A large part of the external areas is required for technical installations. This situation reduces the quality of open space and gives preference to the technical solution.

5. Discussion and conclusion

In the field of BGI, numerous possibilities of approaches and scales for implementation are available. The four case studies examined in this work exemplify the difference of the possible questions and realizations. The focus of the analysis is on the question of the synergetic linking of blue and green approaches. Among the main findings is the unexploited potential of the blue–green projects. A concluding evaluation of the projects is performed through a tabular comparison in Table 1. The following criteria and aspects are included in the evaluation:

- the strength of the blue and green concepts considering the local conditions and the impact and innovation of the blue and green solutions;
- the quality of existing and newly created synergetic effects, which became apparent in the graphical analyses; and
- the architectural design and qualitative aspects of the project based on the international recognition in the professional environment.

The evaluation is performed in three gradations, namely, +, ++, and +++. The following section explains the individual aspects of the evaluation in the four projects.

Table 1 Comparison of case studies.

	Blue concept	Green concept	Synergetic Effect	Design
High Line	+	++	+	+++
Potsdamer Platz	++	+	+	++
Bosco Verticale	+	+++	++	+++
Block 6	+++	+	++	+

The water concept (+) of the High Line is strongly minimized and does not go beyond the discharge of the precipitation on the paths into the beds. Alternative water sources and storage options are not integrated. The green concept (++) is successful, but no synergies (+) are created. Notably, the successful design (+++) of the High Line has received international recognition.

The water concept (++) of the Potsdamer Platz, apart from the gray water, is mature, whereas the potential of the greenery (+) has only been used to a minimal extent. The blue–green synergies (+) remain marginal. A comprehensive greening of the buildings and the open space would also have upgraded the design quality (++).

The Bosco Verticale has a highly developed green concept (+++) and design (+++), whereas the blue concept (+) remains. Nevertheless, the special feature of the rising groundwater levels in Milan creates a synergy (++).

The blue concept of Block 6 (+++) covers all water flows. However, the green concept (+) is purely functional and creates little usable free space. Certain elements, such as the constructed wetland, create blue–green synergies (++), which have no design claim (+).

The comparison shows that all projects have either a good green or blue concept. The projects with a strong green concept are of higher design quality compared with the blue ones. The synergistic effects are partially exploited in any of the four case studies. However, small-scale projects perform well here. The correlation of low synergetic effects and one-sided conception reveals the deficit in the actual planning approaches and therefore calls for a new planning method. Only a systematic approach that includes blue and green objectives guarantees synergetic solutions for blue–green architecture. When transdisciplinary teams develop individual concepts according to local conditions, the resulting projects can create multifunctional and flexible systems. Blue–green projects developed in an integrated approach make cities resilient to climate change. These projects can react to extreme weather events and form active components of adaptation strategies. Comprehensive water management, combined with aesthetically pleasing and microclimatic effective greening, counteracts the consequences of heavy rainfall, persistent drought, and rising temperatures and creates an urban environment worth living in.

Networked approaches, such as blue–green architecture, are regarded as an old invention. This knowledge has been lost in the growing specialization within the professions. In the 1970s, the Austrian artist Friedensreich Hundertwasser came up with the idea of "tree tenants", who can be regarded as forerunners of modern facade greening and plays ecological and aesthetic roles. The artist's idea was to plant trees in apartments, so that they grow out of windows, and tenants can pay their rent with oxygen production, dust and noise absorption, and rainwater cleaning. Hundertwasser also expected health and happiness from the tree tenants (Habarta, 1985).

Although Hunderwasser's designs are no longer up to date, at their core, they contain valuable information on the mechanism by which built environment and nature can interact to create a city worth living in. BGI is a reliable method to improve the adaptability to climate change and the high competition for urban space. The concepts and case studies that have been discussed show the clear need for an enhanced integration of the existing approaches to strengthen their effectiveness.

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