Water and Sustainable Design

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Article Outline

Glossary

Blue-green infrastructures (BGI) new professional practices that integrate the diverse disciplines needed for comprehensive water design through an approach to water management that protects, restores, and emulates the natural water cycle with extensive landscape (green infrastructure) i
mprovements.

Deluge period of abnormally high rainfall that may result in severe flooding.

Drought a prolonged period of abnormally low rainfall that may result in a shortage of water.

Green infrastructures an approach to water management that protects, restores, and emulates the natural water cycle.

Technical water systems the integration of design and engineering of green and gray infrastructures, into solutions for deluge, drought, and water contamination. Technical water systems combine water retention and infiltration techniques with water storage, treatment, and reuse through the integration of green (natural landscape) and gray (constructed) systems.

Water contamination water that is fouled by agricultural, industrial, construction, and human waste due to inadequate containment, aggravated by flooding.

Water-sensitive regenerative cities the successful integration of water at the beginning of the planning process, comprehensively and beautifully designed.

Watersheds the natural path of rainfall and stream flows given the topographic and geologic construct of the land, flowing into rivers, lakes, wetlands, or the sea.

Introduction

Good water is even more urgently important to us than our daily food. Water in the built environment is everywhere [1], but not always visible and often not in our thoughts. In architecture and engineering, we manage and control water in an infrastructure of pipes, canals, and storage facilities that are mostly hidden and therefore not in the day-to-day consciousness of the average citizen. We take water's services for granted, making use of its enormous qualities and performance attributes to produce and transport energy, regulate temperatures, enable chemical reactions including the production of concrete, transport waste and trash, produce food, and many other useful services.

The traditional urban fabric systems that control, regulate, and enable water flows and metabolic processes are deeply interwoven and depend on a permanent and steady water supply; and the balance of not too much and not too little water is the focus of those technical infrastructures.

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In contrast to these traditional urban fabric systems, water in the natural environment is never static but in a state of constant flux. In reaction to changing weather and precipitation, the water flow has a dynamic interaction with the terrain and greenery and is the environment's resilient language with potential to create living systems and enhance evolution. The blue and green elements in nature are the drivers for a living landscape and a sustainable natural environment.

The almost unpredictable, ever-changing characteristics and processes of water in the landscapes have always challenged the human desire for beauty, safety, comfort, and independence. Yet innovative responses in architecture are only just emerging. In today's urban fabrics, buildings of any function are mostly conceived as shelters. They separate an inner space from the outer environment. For the first time in history, due to our very high standards of insulation, air control, integrated intelligent control systems, light regulation, etc., we can live in buildings in the urban fabric for weeks and months almost without any contact with the natural environment. Cities are like perfect machines with supporting infrastructures that seem to make the natural environment a by-product. Until now, dependency on nature has been treated as a relic of the past. Today, and even more so in the future, we can clearly see how interrelated humans are with the nature that surrounds them.

Water Challenges to Be Met by the Built Environment

With the increasing intensity of hurricanes, superstorms, cloudbursts, and the rise in sea level countered by heat waves and droughts, the water-related environmental challenges are increasing for the built environment.

In light of those environmental challenges, sustainable water concepts and systems that work interactively with the water regime are gaining in public awareness. Sustainable designers have begun to map the historic watersheds and landscape mix that supported locations for millennials. It seems that today we are at a turning point and more than ready for integrated water solutions in the sustainable built environment.

If we compare infrastructures in the natural environment with those in urban settings, a significant difference appears in most cities today: Natural structures work with flexible space assignments and resilient principles. One of the characteristics of nature's water management is the dynamic reaction and balance to a range of events, from a subtle change in water availability to an unexpected deluge or drought. Ultimately, it is all about allowing processes to develop over time and having enough multifunctional space, such as retention areas, bioswales, constructed wetlands, and others to operate as a dynamic buffer zone.

Water Contributions to the Built Environment

One of the main characteristics of water systems is the ability to recover from climatic extremes, enabling biodiversity and ecosystem services. In the last few decades, nature's responses to stress have become highly relevant and a focus for innovative architects, landscape architects, and engineers. Engaging blue-green infrastructures to recover from environmental stress while simultaneously providing better air, balanced acoustics, increased biodiversity, and finally livability is the subject of many pilot projects around the world. These projects foster awareness and encourage architects and other disciplines to overcome the traditional silos in the profession.

Today, architecture for sustainable built environments demands a true paradigm shift for water design and is making huge critically needed steps forward. The design approaches and technologies for sustainable water management are being extensively explored and tested with success, to be further illustrated.

Water Technologies and Functionality for a Sustainable Future

Wherever rainwater and stormwater touch the building or the ground, sustainable water management must begin, since all surfaces are a collecting facility, as well as a potential source of pollution. Therefore, the management of these areas, their design, and maintenance are of upmost importance.

The materials selected for rooftops and surfaces influence the quantity and quality of water. The vegetation of green roofs, for example, can filter out pollution like heavy metals or particulates that are harmful to water supplies. Water retention and some level of evaporation and infiltration in the design of roof and ground surfaces can avoid the peaks of runoff flow and calm the erosive process.

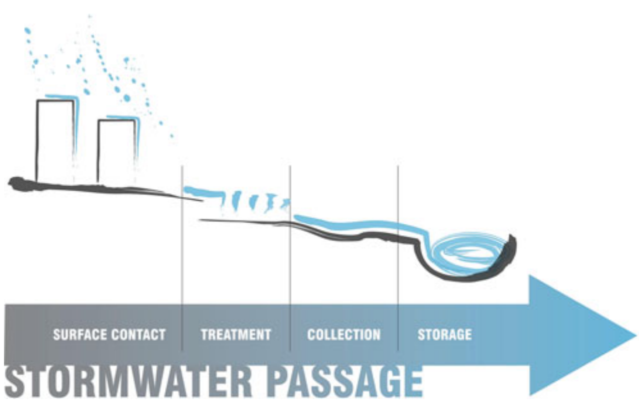
In addition, captured rain and stormwater are the best resources to recharge the groundwater aquifer and refill lakes and rivers and, therefore, should be filtered and released in the best quality. Rainwater should be collected, harvested, and reused [3] for irrigation at a minimum or used to subsidize the drinking water as in Singapore's ABC Water Program (Figs. 1 and 2).

In addition to the management of storms and rainwater, cities also need to be designed for climate resiliency to anticipate sea level rise. The CloudBurst program [4] of Copenhagen recommends design strategies to drain stormwater out to the sea, to store stormwater, and to make buildings resilient in the face of rising water.

Since fresh water of drinkable quality is becoming a limited resource in many more regions of the world, we must carefully use and recycle water matched to each purpose. There is no reason to use processed, potable drinking water to transport our excrements and trash. Every drop of potable water should be used at least three times – for drinking, for gray water uses such as irrigation, and for black water uses such as toilets. Sustainable designers seek the complementary actions of avoiding the sources of water pollution and reclaiming the water, transport, energy, and nutrient qualities of each drop of water – the metabolic processes inherent in nature.

Eighty percent of the water in the built environment is used for our food production with enormous energy consumption and contamination that leave a very negative footprint. Most of that negative footprint is not visible in the urban environment, resulting in almost no awareness by the final consumers. Sustainable solutions, those with a nutrient-holistic and water-sensitive approach, demand a different form of agriculture in both rural and urban areas. There are important examples of this approach including the "Urban Farmers" in Basel and the Netherlands, the "Aquaponic Gardens" in New York City and Singapore, and the "Biodynamic Farm movement" including the Hawthorne Valley in New York State.

Water also has a critical social and quality of life function. Water catchment systems can be interactive and communicate the power and beauty of nature to citizens. To work sustainably



Water and Sustainable Design, Fig. 1 Rainwater should be collected, harvested, and reused. Diagram of Stormwater ABC Water Guidelines. (Credit: Herbert Dreiseitl)

Water and Sustainable Design, Fig. 2 Both quality and quantity controls are key to rainwater collection, harvesting, and reuse. BGI Toolkit. (Credit: Giovanni Cossu (LCL Ramboll))

with water, we need to create multifunctional and shared systems and spaces. Smart, flexible shared places such as plazas, parks, and fields can absorb and contain water after a big storm but allow recreation and social activities the next day. Scharnhauser Park in Stuttgart and Bishan-Ang Mo Kio Park in Singapore demonstrate this in a very convincing way.

In 2006, the Public Utilities Board and National Water Agency of Singapore began a program entitled ABC Waters – Active, Beautiful, and Clean – that aims to realize the full potential of an integrated blue-green infrastructure (BGI) approach. By treating rainwater as a prime resource to fill reservoirs and water bodies, the ABC Waters' program is a strategic initiative that works with the entire urban catchment of the island. Instead of channeling rainwater away from the city, areas within the urban development are used for rainwater collection. This also helps to contribute to the country's water security. The program was implemented with the expectation that it will lead to multiple projects by private developers. Estimated 150 projects are on their way to be realized in the next 20 years.

One of the pilot projects, and by far the largest, was the transformation of 3.2 km of the Kallang River and 62 hectares of Bishan-Ang Mo Kio Park (Fig. 3).

This is a classic BGI project [5] with a strong social component of over 3 million visitors per year. The design was carried out under the leadership of landscape architects in an interdisciplinary planning process, which included on-site test studies and hydraulic modeling with flow simulations. This BGI was designed to accommodate the dynamic process of a natural river system, which includes fluctuating water levels and widths to make sure unexpected problems are accounted for. A special focus on security led to the creation of a special safety system in case of sudden water rises in the open river valley. Elements from the concrete canal – previously on the site – were recycled and reused as substrate in the riverbed and on a specially formed platform for artwork.

Today, the park comprises a vibrant urban river with natural elements, although it is still very

Water and Sustainable Design, Fig. 3 The 62 hectares of Bishan-Ang Mo Kio Park, Singapore, has been transformative for the environment and quality of life. (Photo Credit: Herbert Dreiseitl)

Water and Sustainable Design, Figs. 4 Fostering closer connection with water (Bishan-Ang Mo Kio Park Photo Credits: Herbert Dreiseitl)

much formed and shaped by the people that use it. Better hydrological capacities, upgrading parameters of limnology, efficient erosion control, and other advances were possible through appropriate bioengineering techniques and reshaping of the river profile (Figs. 4, 5, and 6).

Water and Sustainable Design, Figs. 5 Quality of life gains are matched by better hydrological capacities, erosion control, and other advances in water management and use. (Bishan-Ang Mo Kio Park Photo Credits: Herbert Dreiseitl)

Plants and bedding materials were used to stabilize the banks to withstand the erosive energy of high water flows while at the same time creating diverse stream habitats for native plants and animals. Not only is there a significant increase in biodiversity, there is also a completely new atmosphere that has resulted in connecting the people in the neighborhood together. Socioeconomic factors play into this development, and a detailed study was done on the effects of the BGI on real estate values and other parameters.

The Bishan-Ang Mo Kio Park has won numerous awards and is seen as a new vision and role model for BGI which addresses the dual needs of water supply and flood management while creating spaces for people and nature in the city.

Innovative Waterscapes and Blue-Green Infrastructures

The emergence of new professional practices that integrate the diverse disciplines needed for comprehensive water design is contributing to the literature on innovative waterscapes. The following excerpt from Strengthening Blue-Green Infrastructure in our Cities [6] captures the philosophy and design potential of innovative waterscapes proposed by Herbert Dreiseitl and Bettina Wanschura (Ramboll Liveable Cities Lab), Matthias Wörlen and Manfred Moldaschl (Zeppelin University) Nirmal Tulsidas Kishnani and Giovanni Cossu (NUS National University of Singapore) and James Wescoat and Karen Noiva (MIT).

Water and Sustainable Design, Figs. 6 Symbotic relationship between Urban Infrastructure and Natural Systems. (Bishan-Ang Mo Kio Park Photo Credits: Herbert Dreiseitl)

Blue-Green Infrastructures as Tools for the Management of Urban Development and the Effects of Climate Change

The conventional approach to urban water infrastructure has been to use quantitative models to predict future water demand and then to construct additional infrastructure to meet this demand. This approach prioritizes technology and large physical interventions which attempt to manipulate natural processes to suit the needs of humankind. However, the focus on "gray" infrastructure – so-called because of the massive amounts of concrete and metal typically involved – is progressively showing deficiencies and limitations in meeting the additional stresses to urban water supply and management induced by rapid urbanization, impervious land cover, and climate change.

In some cases, the reliance on gray infrastructure can actually contribute to these stresses. For instance, the conventional approach to urban stormwater runoff has been to collect precipitation in a connected sewer system and to transport it out of the city as quickly as possible [7]. As cities have grown, impervious land cover has increased which generates a larger volume of stormwater runoff in a shorter period of time, overwhelming existing sewers and increasing flooding. Gray infrastructure will also fail to mobilize the many potential socioeconomic benefits of water in enhancing the aesthetics of the urban fabric and the quality of life.

In response to these changing times, decision-makers are starting to look beyond the gray and experimenting with less conventional approaches to infrastructure. Blue-green infrastructure (BGI) offers a feasible, economical, and valuable option for urban regions facing challenges of climate change. It complements and in some cases mitigates the need for gray infrastructure. BGI represents a paradigm shift that recognizes the importance of and value in including the role of urban hydrology within urban water management. The "blue" recognizes the importance of the

Water and Sustainable Design, Fig. 7 The critical shift from gray to blue-green infrastructures in Bishan-Ang Mo Kio Park, Singapore, in 2008 and 2013. (Photo Credit: Atelier Dreiseitl)

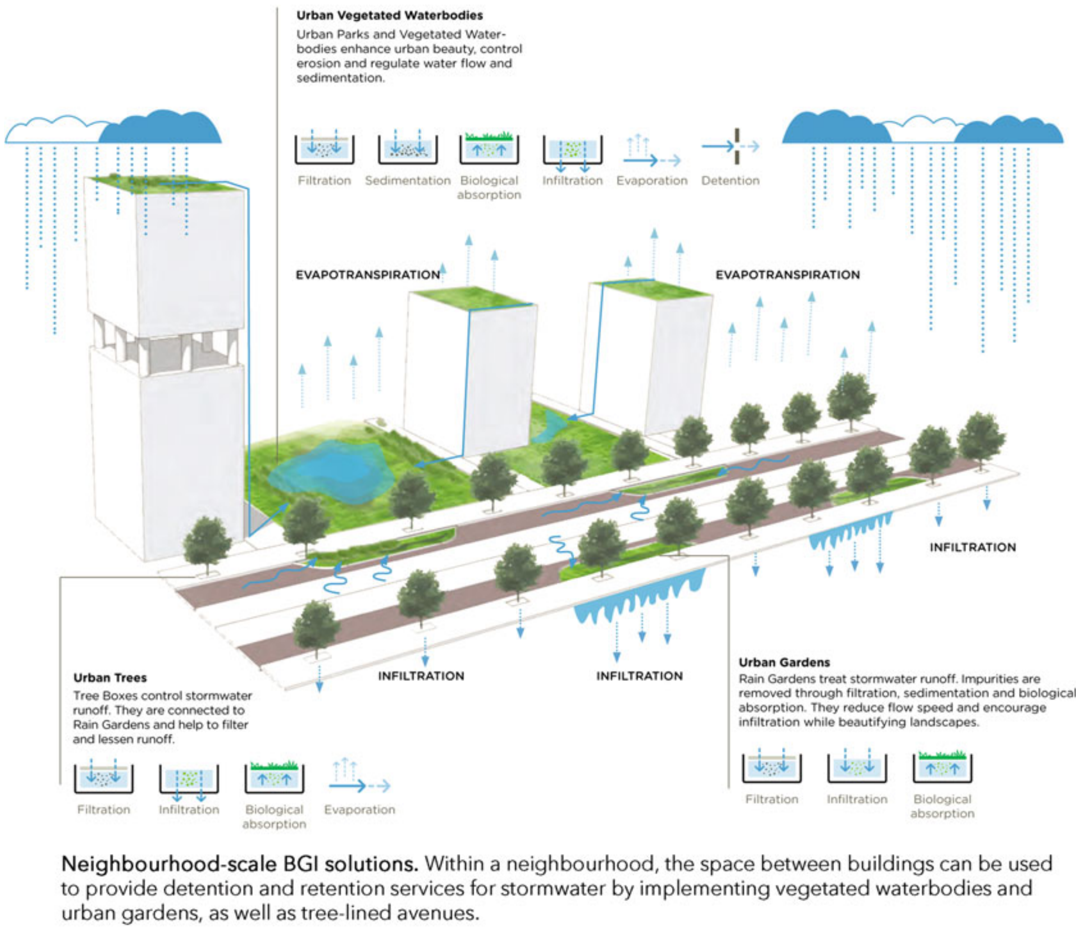
physicality of water itself, while the "green" connects urban hydrological functions with vegetation systems in urban landscape design. The resulting BGI has overall socioeconomic benefits that are greater than the sum of the individual components (Fig. 7).

In this context, the Liveable Cities Lab (LCL) initiated a research project "Enhancing Blue-Green and Social Performance in High Density Urban Environments" [8]. The goal of this research was to move toward a more comprehensive understanding of underlying concepts contributing to the effective implementation of BGI. This entry summarizes the key results of the project and focuses on challenges, obstacles, and successes of selected BGI case studies.

The Definition of BGI

The topic of green infrastructure is now a well-established concept in urban environmental planning, policy, research, and design, and awareness and understanding of its potential benefits for ecology and society have increased. The term green infrastructure often refers to projects that include vegetated design elements such as parks, green roofs, greenbelts, alleys, vertical and horizontal gardens, and planters. Such green infrastructures are recognized and intensively discussed with respect to the ecosystem services they provide – services that are especially valuable in densely populated urban areas [9].

However, "green" infrastructure is a bit of a misnomer, as infrastructures of this type are often closely linked with and even defined by "blue" processes. Blue infrastructure technically refers to infrastructure related to the hydrological functions, including rainwater and urban stormwater systems as well as surface water and groundwater aquifers. In urban design blue infrastructure is traditionally discussed as a matter of resilient provision for water supply and water security. Such water infrastructure may be natural, adapted, or man-made and provides functions of slowing down, decentralization and spreading, soaking into the underground, and evaporating and releasing water into the natural environment. This must critically include flow control, detention, retention, filtration, infiltration, and different forms of water treatment like reuse and recycling (Fig. 8). In general, blue infrastructure addresses aspects of water quantity as well as quality control. The BGI paradigm marries these two types of



Water and Sustainable Design, Fig. 8 BGI must critically include flow control, detention, retention, filtration, infiltration, and different forms of water treatment. Neighbourhood Scale Solutions. (Graphic Credit: Giovanni Cossu (LCL Ramboll))

infrastructures and values together in a union that is greater than the sum of its parts.

Benefits of BGI

BGI integrates hydrological and biological water treatment flows into systems where green features are seamlessly overlapping with blue features. Together blue and green infrastructures strengthen urban ecosystems by evoking natural processes in man-made environments and combining the demands of sustainable water and stormwater management with the demands of urban planning and urban life. As a result, BGI systems have positive impacts on the urban metabolism of natural resources (added green values) and on the experience and behavior of people using these infrastructures (added social values). A selection of the benefits associated with the implementation of BGI in dense urban areas is presented below.

Water-Related Benefits

BGI effectively controls the quantity of stormwater but also improves water quality. Quality-related benefits of BGI include the following: (i) plant roots in combination with soil absorb nutrients and purify infiltrating water and also improve the general water quality in urban catchment areas, thereby reducing energy demands and costs associated with water treatment; (ii) BGI contributes to the avoidance of overheating and oxygen shortage caused by high temperatures of concrete materials.

Quantity-related benefits of BGI include (i) BGI enhances on-site retention of stormwater, which protects valuable wetland areas, reduces the need for designated downstream areas for flood buffer zones, and reduces the risk and impact of flooding; (ii) the natural unsealed surface allows water to seep into the ground, recharging underlying aquifers and balancing the groundwater level.

Climate Change Adaptation and Biodiversity

Besides benefits directly related to water and plants, BGI has a huge potential to modulate the urban climate by reducing urban heat island effects, balancing diurnal temperature fluctuation, and supporting natural air ventilation.

BGI also reduces the bioclimatic impacts of land cover changes such as desiccation of urban soils and associated wind-borne air pollution and dust hazards. By managing and modulating hydroclimatic variability and weather extremes, BGI enhances the adaptability and resilience of urban infrastructures.

BGI also increases urban biodiversity as it improves rich biotopes and landscape connectivity, protects aquatic ecosystems, and creates biodiversity-rich zones to sustain flora and fauna.

BGI Enhances a City's Beauty and Aesthetics

BGI helps to reconnect people with the natural environment through the active integration of water and greenery in which the boundaries between the two are blurred and made accessible. Blue elements of urban design tend to have the strongest positive associations, and when combined with green elements, this positive effect is magnified. The perception of the relative beauty of the blue elements seems to be related to their scale and size, as well as how the edge conditions for public access are implemented.

Societal Benefits of BGI

BGI creates upgraded space for recreation, exercise, and social activities and therefore helps to improve human physical and mental health. These amenities reduce individual and public health costs. BGI supports social interaction and social integration as it increases the tendency to use open spaces for activities in groups and the commitment to spend time with families, neighbors, and communities.

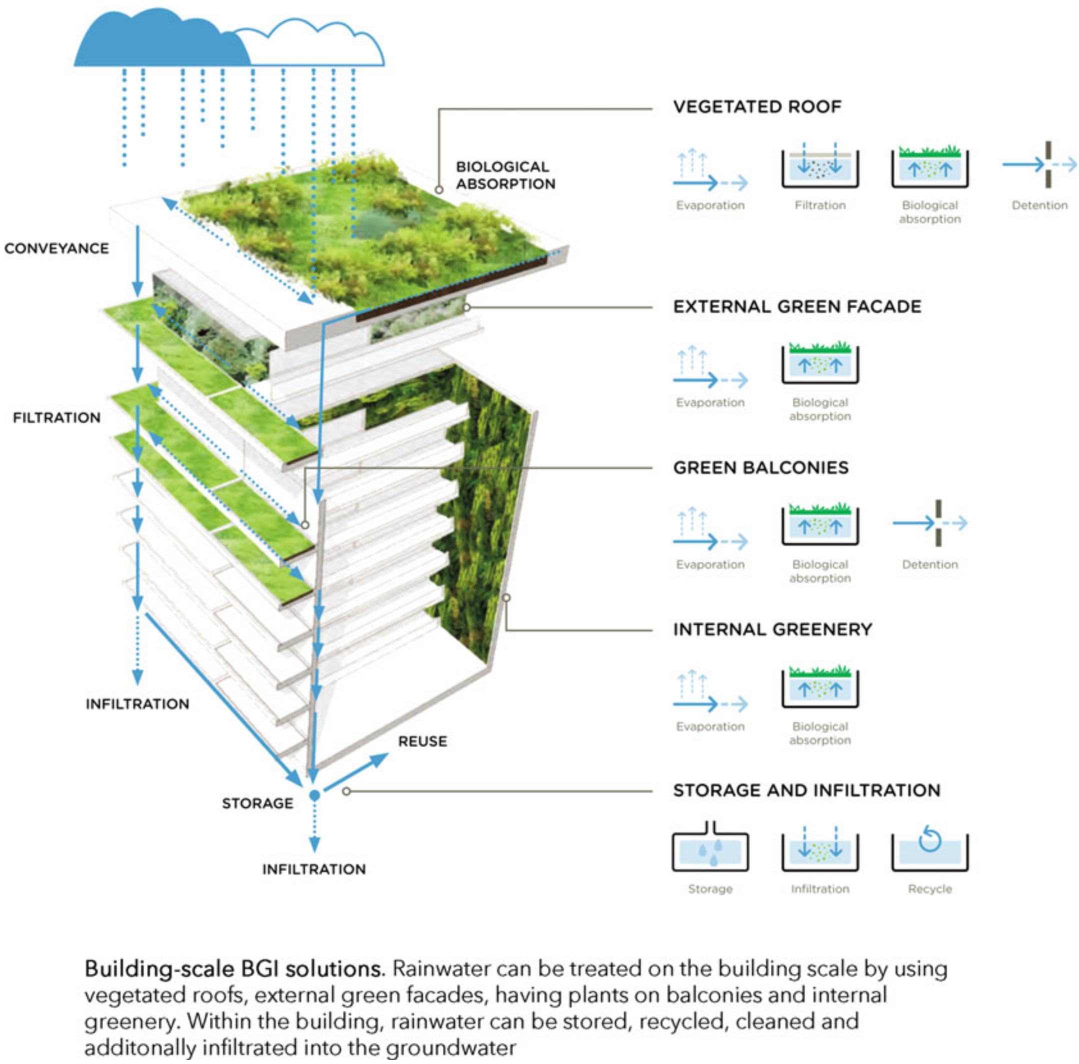
By improving social and aesthetic attractiveness of surrounding land and buildings, BGI increases property values and real estate values. The creation of blue-green infrastructure signals a city's overall attractiveness and livability and increases the reputation of a city's governmental institutions to take care of their residents' living conditions.

Finally, BGI supports biophilia – people's affinity with nature – as it reconnects people with natural forms, elements, and processes that have major benefits for human happiness and the willingness to protect nature.

Main Challenges for Successful Implementation of BGI in Dense Urban Areas

The main constraints on implementing sustainable urban stormwater and environmental management in a changing climate are not technological. Rather, they involve shifts in vision, policy, design, and the urban planning culture. The transition of urban water management from standard gray to blue-green implies a change in the social and political setting of a city. BGI relies on the capabilities in a city to negotiate forms and outcomes with all civic stakeholders, as well as to be aware of unintended consequences in the wider context (spatial, social, temporal).

As BGI is still a rather unknown approach in many cities, practitioners, politicians, and citizens have to be convinced that BGI is able to guarantee at least the same level of security as older established solutions and that it can provide new types of security for climate resilience. Water planners otherwise tend to fall back upon the gray infrastructure approaches followed under historical climatic conditions or install redundant blue and green infrastructure elements at low levels with higher costs to avoid risk. This has limited the wide implementation of BGI elements and techniques to achieve multifunctional urban landscapes on a holistic catchment scale. BGI is a valuable and viable opportunity for creating



Water and Sustainable Design, Fig. 9 BGI creates multifunctional landscapes with an ecological approach to sustainable urban stormwater practice. (Building-Scale Solutions Graphic Credit: Giovanni Cossu (LCL Ramboll))

multifunctional landscapes with an ecological approach to sustainable urban stormwater practice (Fig. 9).

A paradigm shift is needed to ensure that urban water management moves beyond the conventional engineering mind-set to a more holistic approach that includes knowledge about societal values and ecosystem services. Such a paradigm shift has begun to be appreciated, but many decision-makers still remain unaware of the value of BGI or how to operationalize it.

BGI Case Studies

In order to provide a more balanced picture of BGI challenges relevant around the world and in a variety of contexts, the Liveable Cities Lab used several selection criteria to generate in-depth case studies, including climate, governance systems, and variations in the history of BGI development types, as well as the designed functionality within the BGI. The cases chosen for the study represent several continents (America, Europe, and Asia) and a range of climate types including the tropical rainforest climate (Singapore), the tropical wet and dry climate (Mumbai), and the humid continental climate (Germany, Denmark, etc.). For each case study, positive and negative lessons were identified and an attempt made to generalize these lessons as good practices important for current and future BGI planning and implementation in cities.

Case studies on the project level included the following: Emerald Necklace, Boston (USA); Hannover-Kronsberg (Germany); Bishan-Ang Mo Kio Park (Singapore); Khoo Teck Puat Hospital and Yishun Pond (Singapore); and Ulu Pandan Park Connector (UPPC) (Singapore).

Case studies on city level included Hamburg (Germany); Portland, Oregon (USA); Copenhagen (Denmark); New York City (USA); Jakarta (Indonesia); and Mumbai (India).

A selection of these case studies is presented below.

BGI in Hannover-Kronsberg, Germany

Hannover-Kronsberg (Germany) is a residential area with 3000 dwellings built from 1992 to 2000 as an exhibit for the World Exposition 2000 titled "Mensch-Natur-Technik" (Human-Nature-Technology). Following Agenda 21, the Habitat II Model, and the standards for sustainability included in the local Agenda 21 of the Deutsche Städtetag (German Association of Cities), Kronsberg, was set out as an innovation project that would deploy ecological solutions to enhance urban life and sustainable living. The expo-concept clearly focused on energy efficiency optimization, soil management, rainwater management, waste concepts, and environmental communication.

Originally a topic of medium importance, rainwater management became one of the central issues as hydrological and technical studies showed that a residential district with standard drainage system in this area would have major impacts on the regional water flows. In order to make construction and development environmentally sound despite this difficult situation, a semi-natural drainage concept was developed to minimize the effects of development on the natural water balance and to safeguard infiltration and groundwater refill (Fig. 10).

BGI in Portland, Oregon (USA)

Portland is known as one of the most forward-thinking cities in the USA in terms of promoting

Water and Sustainable Design, Fig. 10 Hannover-Kronsberg, Germany, uses ecological BGI solutions to enhance urban and sustainable living. (Photo Credit: Herbert Dreiseitl) and advocating sustainability [10]. To start, Portland purchased and permanently protected more than 33 km^2 of ecologically valuable natural areas from future development and has continued to show a strong commitment to environmentally conscious land use, including an approach to land conservation and enhancing green areas (Parks Vision 2020). Portland has also emerged as a pioneer in promoting compact city design through municipal policy.

In 1996, a Stormwater Policy Advisory Committee (SPAC), stakeholders from landscape architecture, architecture, engineering, institutional organizations, and the stormwater treatment industry were assembled to generate recommendations and guidelines for urban stormwater engineering and design.

In 2010, Tanner Springs Park was created through intense community participation to address the challenges of a compromised neighborhood built on a former wetland and creek bed. Tanner Springs Park transformed the Pearl District through BGI, using stormwater runoff to feed a natural spring and a natural cleansing system. Today, ospreys dive into the water, art performances unfold on the floating deck, children splash and explore, and others take quiet contemplation in this natural refuge in the heart of the city means that this park is the realization of the dreams and hopes of local people (Fig. 11).

Since that time, Portland has been recognized as a leader in "green" stormwater management with a number of award-winning BGI projects including the "Portland Ecoroof Program" the "Green Streets" project and a number of pervious pavement projects. Portland's multi-stakeholder governance structure presents an interesting institutional context in which BGI projects have been successful.

BGI at Khoo Teck Puat Hospital and Yishun Pond (Singapore)

Khoo Teck Puat Hospital (KTPH) is one of the most recent of seven public hospitals in Singapore. It is set out to widen the perspective on healthcare in Singapore to include healing spaces in which the design of the physical environment actively contributes to wellness. This translated into the integration of biophilic elements. The KTPH design brief spoke explicitly of a patient-centric approach, predicated on access to daylight, ventilation, views, and the presence of gardens and nature. Patient and visitor areas are placed around a landscaped central garden. This garden opens up to an adjacent Yishun stormwater pond from which it taps vistas and breezes. Visitors from nearby housing estates now use the hospital's public spaces for enjoyment alongside patients and other official visitors. In 2005, KTPH team expanded its blue-green footprint by

Water and Sustainable Design, Fig. 11 Tanner Springs Park transformed the Pearl District in Portland, Oregon, through BGI. (Photo Credit: Herbert Dreiseitl)

Water and Sustainable Design, Fig. 12 The KTPH hospital in Singapore has a lush BGI central garden flowing into a waterfront walking trail. Khoo Teck Puat Hospital (KTPH) and Yishun Pond, Singapore. (Photo Credit: Giovanni Cossu (LCL Ramboll))

adopting the adjacent Yishun Pond a gray infrastructure for water storage. The Hospital now has a lush BGI central garden flowing into a waterfront promenade with an energizing walking trail that wraps the lake (Fig. 12). The former gray infrastructure retention pond now gives a picturesque view for pedestrians, as its concrete edge has been softened with planting, and artificial floating wetlands have been added attracting new species.

BGI in Hamburg (Germany)

Hamburg is situated on the river Elbe and hosts one of the largest harbors in Europe. Situated only 6 m above sea level and increasingly hit by heavy rainfall, severe flooding and associated damages increasingly threaten central Hamburg. The high density of buildings and imperviousness surfaces increase the risk of flooding and severely challenge the existing rainwater system. In 2009, Hamburg introduced an initiative to develop a rainwater adaptation plan – RISA – in which all relevant agencies (water, park and urban green, traffic, environment) were required to cooperate and develop comprehensive and holistic guidelines for a satisfactory infrastructure intervention. BGI is expected to have a prominent position in the new design, especially since individual, smaller-scale BGI projects (e.g., Kleine Horst in Hamburg Ohlendorf) have proven to be very successful.

BGI in Copenhagen (Denmark)

Copenhagen, the capital and most populous city in Denmark, is known internationally as an outstanding example for high livability and future-oriented urban design. Surveys have shown a high degree of public awareness and political support for sustainability- and livability-related issues. Climate adaptation in response to global warming is one of the major topics worthy of special attention in Copenhagen since it is a coastal town that

Water and Sustainable Design, Fig. 13 A new generation of blue-green infrastructures for Copenhagen addresses essential city services such as mobility, recreation, health, and biodiversity. VANDPLUS Project info Viborg – sùnës Dispositions plan. (Photo Credit: Ramboll)

is at increased risk from flooding due to the rising sea level combined with increased frequency of extreme precipitation events.

Moving to address the increased flooding risks, the Copenhagen Climate Adaptation Plan of October 2011 promoted the incorporation of BGI, especially retention areas, within the urban landscape. Led by Ramboll Studio Dreiseitl, the strategy addresses key issues of flood management and water quality while seeking to create the greatest possible synergy with the urban environment (Fig. 13). A “CloudBurst” tool box of urban interventions, such as CloudBurst boulevards, CloudBurst parks, and CloudBurst plazas, provides the basis for a dynamic and multifunctional system. This new generation of blue-green infrastructures addresses essential city services such as mobility, recreation, health, and biodiversity, creating a strategic and feasible approach to ensure long-term resilience and economic buoyancy.

Copenhagen is rich in social resources (knowledge, institutional capability, financial capital) that are required in the step-by-step restructuring of the densely populated and built-up inner-city areas – those that have experienced the most frequent and intense flooding. Copenhagen provides an interesting case for examining aspects of political and institutional framing and negotiations for BGI – implementation.

Modeling of BGI-Induced Change on Urban Society

In order to assess the societal (including ecological and economic) impacts of BGI implementation, the authors modeled the BGI-induced change of an urban society’s capability for livability, sustainability, and resilience. In particular we employed a socioeconomic capital-based accounting model, based on the “Polychrome Sustainability” approach of Manfred Moldaschl. The implementation of BGI in dense urban areas was analyzed as a change in an urban society's pool of resources for a decent life, according to criteria of livability, sustainability, and resilience. Therefore, all relevant resources are defined as different forms of societal capital: the natural, built, human, social, symbolic, and financial capital. As a consequence, financial capital can be treated equally in the context of all other capitals relevant for quality of life and long-term social development.

In our study, the term "capital" is used for all relevant societal resources. While the term capital is usually understood as financial capital, i.e., a final monetizable outcome of economic transactions, the modern understanding of the term has broadened this meaning, applying it more generally to other types of resources used in society. In a nutshell we follow a triple bottom line methodology to take economical, ecological (defined as natural capital), and social sustainability as three pillars that represent distinct dimensions for evaluation. However, we suggest applying a more detailed and elaborated version of the social pillar to include human capital, social capital, and symbolic capital.

Human, social, and symbolic capitals are types of immaterial capital, a type of capital that is considered to differ crucially from financial capital and natural capital both in their forms of manifestation and in their forms of (re-) production. Immaterial capital may or may not be monetized. The different categories of immaterial capital are inseparably linked to human competences and/or social relations. Immaterial capitals often follow a more generic logic such as trustful behavior is built on trust and enhances trust.

BGI Benefits for Health and Well-Being: Bishan-Ang Mo Kio Park

The effects of BGI implementation on human health, public well-being, financial assets, long-term economic resources, and other human values have been identified through the case study and comparative analysis of the Bishan-Ang Mo Kio (BAMK) Park in Singapore. Solving serious flooding and water quality challenges with this park led to a dramatic increase in accessible open space for neighboring communities, with

Water and Sustainable Design, Fig. 14 (BAMK) Park in Singapore led to a dramatic increase in accessible open space for neighboring communities; Tai Chi in Bishan-Ang Mo Kio Park, Singapore. (Photo Credit: Herbert Dreiseitl)

Water and Sustainable Design, Fig. 15 The old concrete canal in Bishan-Ang Mo Kio Park

Water and Sustainable Design, Fig. 16 A unique BGI plan to replace the concrete channel and create a naturalized waterway in Bishan-Ang Mo Kio Park, Singapore. (Photo Credits: Herbert Dreiseitl)

benefits for social life and improved awareness of these communities in ecology and the environment (Fig. 14).

The highlight of this project is the revitalization of the river. The unique plan to break the concrete channel and create a naturalized waterway was initiated for the first time in Singapore. Designed on a floodplain concept, people can enjoy recreational activities along the riverbanks during dry weather and during heavy rain; the park land adjacent to the river doubles up as a conveyance channel, increasing carrying capacity by 40%. This enables multiple land uses within the park, creating more spaces for the community as well as ecologically valuable and diverse habitats (Figs. 15 and 16). To date, the park has seen the park's biodiversity increase by 30% with 66 species of wildflower, 59 species of birds, and 22 species of dragonfly identified – with some being identified as rare in a city environment.

Water and Sustainable Design, Fig. 17 The number of park visits has doubled from 3 to 6 million persons/year in Bishan-Ang Mo Kio, Park, Singapore. (Photo Credit: Herbert Dreiseitl)

As a result of the redevelopment of BAMK into a naturalized park, the number of park visits has doubled from 3 to 6 million persons/year (Fig. 17). It was found that after the BGI upgrade to BAMK, nearly 50% of all park users were engaging in active physical activities, such as jogging, bicycling, skating, or intense walking. It has been estimated that the positive impact on physical health for the community is substantial, estimated at SGD 16–43 million (which is 12–31 million USD at 2013 exchange rates). Moreover, the researchers also identified mental health benefits attributable to BAMK's ability to attract social life and to encourage social integration.

The combination of natural beauty and the dual physical assets of a park and a river appeals to people. As they get close to the water and appreciate nature's rhythms and wonder, their experience of water and their sense of responsibility to their environment change, leading to collective goals to be better stewards of the environment.

Conclusion: Water's Position in Sustainable Urbanism

History will record that the political and design leaders of the past narrowly reduced the role of water to the most basic technical and engineering services, as liabilities and not assets. Yet, water has always been a critical driver in shaping cities, defining location, and creating character and atmosphere [11].

After generations of industries have used rivers as dumping grounds, cities worldwide are now turning their faces to the water and looking for ways to rejuvenate our natural resources. Green-blue infrastructures are becoming more and more important as a dynamic resource to balance and stabilize life processes and as a backbone for livability. Water has a strong positive biophilic effect on people and defines the symbolic capitals of cities like Amsterdam, Sydney, New York, Venice, and Pittsburgh just to mention a few. There are a number of critical guidelines for bringing all of the regions' water resources into a vision for the future:

Ten Guidelines for Working with Water in Sustainable Urban Design

1. **Think fluid, resilient, and regenerative**; water is the best teacher to have the right attitude in design, and technical and aesthetic solutions have to be in line with the nature of this most dynamic and lively substance.
2. Follow and search for **multifunctional solutions**; water is always interacting with its surroundings and has a strong impact on air, temperature, energy, metabolic systems, as well as flora and fauna.
3. Use water as a **balancing regulator** to reduce temperature extremes and reduce dust and sound pollution; combine blue-green infrastructure to filter; and avoid environmental stressors and shocks such as climate change and sea level rise.
4. Combine **energy** with water-related systems; too much energy is used for pumping and processing water; and decentralization and gravity-based solutions should be prioritized to reduce significant energy consumption.
5. Work with regenerative systems and **food production**; more than 70% of the world's water is used for food production and processing, and we have to implement systems that are regenerative and local nature-based solutions.
6. **Reduce water consumption** to a minimum and **reuse water** in cascading system; balance systems between local and regional decentralized systems and larger, centralized systems.
7. Avoid and **upcycle waste** in the metabolic process of water; water is most stressed by waste, so avoid using water as a transport medium for waste, finding better solutions for recycling and upcycling waste.
8. Ensure **access to water for all**; equity and social justice need to be respected in water-related planning process; and involve stakeholders and the public as a means to care for social equity.
9. Bring **beauty** in all water design, as water is intimately connected to beauty; respect the human fascination with water and the biophilia effect, which we so much need today.

Water is key to our survival in cities and rural areas. It is critical to measure, count, and quantify the impacts of water design, capturing the value and character of water's flexible and ever-changing qualities. The future depends on the design of our water and landscape systems as a central tenet of a sustainable built environment.

Bibliography

1. Dreiseitl H, Grau D (2009) Recent waterscapes planning, building and designing with water. Birkhäuser, Basel, pp 74–78. ISBN 978-3-7643-8984-0
2. Schröpfer T (2015) Dense+ green: innovative building types for sustainable urban architecture. Birkhäuser, Basel, pp 48–60. ISBN 978-3-03812-579-0
3. Cities as Living Systems (2016) Urban solutions, 8. Centre of Liveable Cities, Singapore, pp 14–21, Interview with Dreiseitl. H. Retrieved from https://www.clc.gov.sg/docs/default-source/urban-solutions/urban-solutions-8-full.pdf
4. Baykal A (2012) Cloudburst Management Plan 2012, The city of Copenhagen Technical and Environmental Administration, Copenhagen pp 1–28
5. President's Design Award Singapore, Design of the Year 2012, Bishan-Ang Mo Kio Park. (2012). Retrieved Feb 2019, from https://www.designsingapore.org/presidents-design-award/award-recipients/2012/bishan-ang-mo-kio-park.html
6. Dreiseitl H, Wanschura B (2014) Strengthening blue-green infrastructures in our cities. Ramboll, Liveable Cities Lab
7. Liptan TW (2017) Sustainable stormwater management: a landscape-driven approach to planning and design. Timber Press, Portland, Oregon
8. Wörlen M, Wanschura B, Dreiseitl H, Noiva K, Wescoat J, Moldaschl M (2016) Enhancing blue-green infrastructure and social performance in high density urban environments: summary document. Ramboll Liveable Cities Lab, Uberlingen
9. Yudelson J (2012) Green building trends: Europe. Island Press, Washington, DC, p 23. ISBN 978-1597264778
10. LOFT Publications (2009) Sketch landscape. Page One Publishing, Singapore, pp 270–291. ISN 978-981-245-738-7
11. Dreiseitl H (2015) Liveable cities; the art of integrating today what we need tomorrow. FuturArc J 38:22–31. BCI Asia