RAMBOLL ENVIRON

BLUE-GREEN INFRASTRUCTURES AS TOOLS FOR THE MANAGEMENT OF URBAN DEVELOPMENT AND THE EFFECTS OF CLIMATE CHANGE

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INTRODUCTION

Cities and their decision-makers today face many complex challenges that are associated with balancing urban development and its impact on the environment. The trend towards urbanization continues at a break-neck pace worldwide – with a majority of the world's population now living in cities, and an expected increase to 66% by 2050. Consequently, the demand for new infrastructure construction is expected to increase commensurately. These infrastructure expansions are aligned with enormous costs.

Among the various elements that jointly constitute a city's infrastructure there is one in particular that, perhaps more than all of the others, shapes a city and supports urban activity and human life – that element is water. Water is necessary for human life and a broad variety of economic activities.

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. That approach prioritizes technology and large physical interventions which attempt to manipulate natural processes to suit the needs of humankind. However, that focus on "grey" 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 grey 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. 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. Nor does grey infrastructure 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 grey and experimenting with less conventional approaches to infrastructure. Blue-Green Infrastructure[1] (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 grey 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 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.

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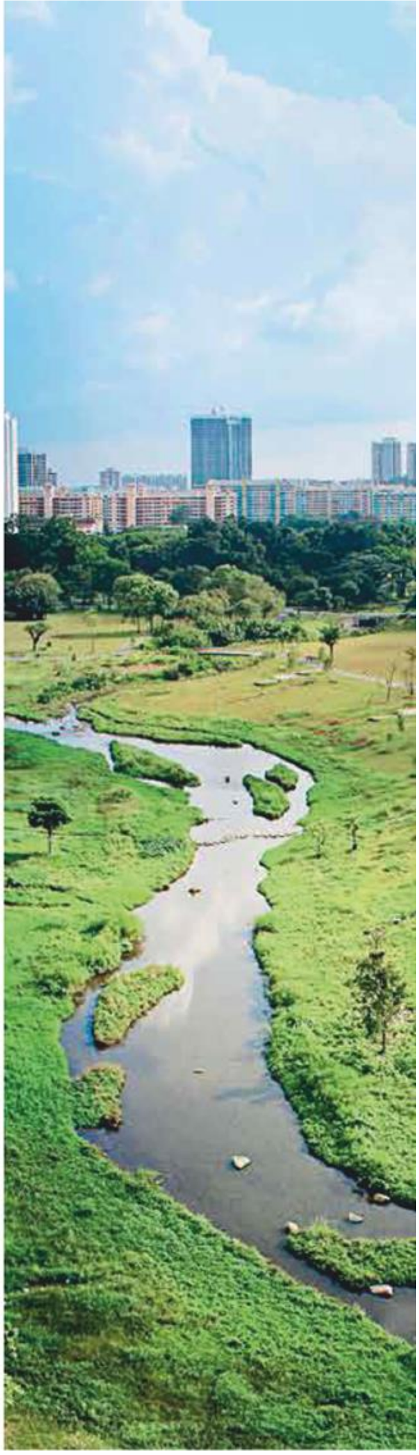
[1] We use "blue-green infrastructure" synonymously with "sustainable urban drainage", "low impact development", "water sensitive urban design", "Water Sensitive Cities", "Modified rainwater management" while acknowledging that some differences may exist in the localized use of these terms, as described by Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J. L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., Viklander, M. (2015): SUDS, LID, BMPs, WSUD and more.

In this context, the Liveable Cities Lab[2] (LCL) performed a research project "Enhancing Blue-Green and Social Performance in High Density Urban Environments". The goal of this research was to move towards a more comprehensive understanding of underlying concepts contributing to the effective implementation of BGI. This article summarises the key results of the project, and focusses 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, while 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.

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 storm water 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, evaporating and releasing water into the natural environment. This includes flow control, detention, retention, filtration, infiltration and different forms of water treatment like reuse and recycling. In general, blue infrastructure addresses aspects of water quantity as well as quality control. The BGI paradigm marries these two types of 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 trains 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 combine the demands of sustainable water and storm water management with the demands of urban planning and urban life. As a result, such systems have positive impacts on the urban metabolism of natural resources (added green values) and on the experience and behaviour of people using these infrastructures (added social

[2] LCL is a laboratory dedicated to support cities by envisioning the future development. We do this by addressing global challenges such as demographic changes, urbanisation and climate change through a multi- and trans-disciplinary approach. The subject research project was performed in collaboration with teams from National University of Singapore, Harvard Graduate School of Design, MIT and Zeppelin University. The research was funded by the Ramboll Foundation.

values). A selection of the benefits associated the implementation of BGI in dense urban areas is presented below.

a) Water-related benefits

BGI effectively controls the quantity of stormwater but also improve water quality. Quality-related benefits of BGI include the following: (i) Plant roots in combination with soil absorb nutrients and purifies 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 in the riverbed.

Quantity-related benefits of BGI include: (i) BGI enhances on-site retention of stormwater, which protects valuable wetland areas, reduces the need for designation of downstream areas as 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.

b) 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.

It 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 infrastructure.

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

c) 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.

d) 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, neighbours, 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 liveability 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 willingness to protect nature.

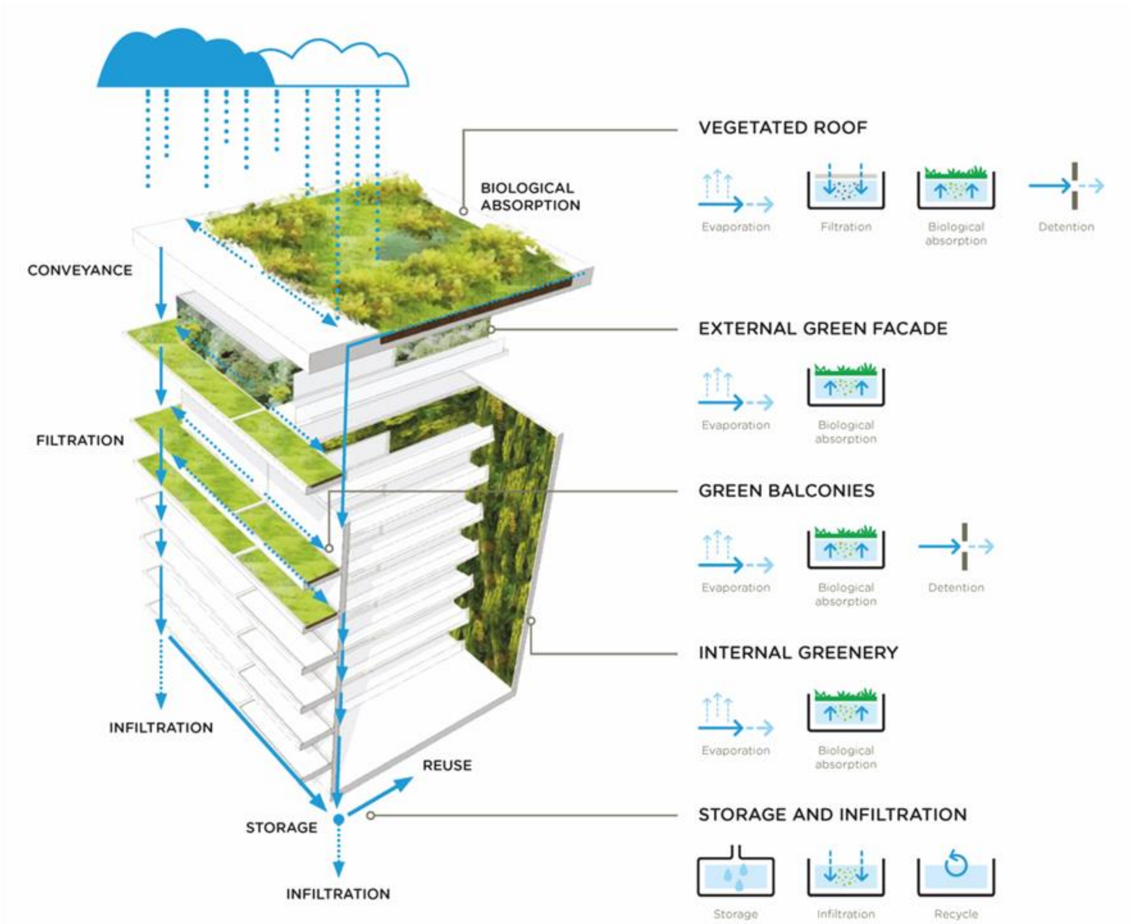
MAIN CHALLENGES FOR SUCCESSFUL IMPLEMENTATION OF BGI IN DENSE URBAN AREAS

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 grey to blue-green implies a change in the social and political setting of a city and therefore it relies on the capabilities in a city to negotiate forms and outcomes of this change with all different civic stakeholders as well as to be aware of unintended consequences in the wider (spatial, social, temporal) context.

As BGI in many cities is still a rather unknown technology, 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 grey infrastructure approaches followed under historical climatic conditions or install redundant blue and green infrastructure elements at low levels and thus 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 often is not seen as valuable and viable opportunity for creating multifunctional landscapes with an ecological approach to sustainable urban stormwater practice.

Therefore, we believe that a paradigm shift is needed and that urban water management must move beyond the conventional engineering mindset 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 such an approach or how to operationalize it.



Building-scale BGI solutions. Rainwater can be treated on the building scale by using vegetated roofs, external green façades, having plants on balconies and internal greenery. Within the building rainwater can be stored, recycled, cleaned and additionally infiltrated into the

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 LCL used several selection criteria for 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 project level included the following: (i) Emerald Necklace, Boston (US); (ii) Hannover-Kronsberg (Germany); (iii) Bishan-Ang Mo Kio Park (Singapore); (iv) Khoo Teck Puat Hospital and Yishun Pond (Singapore); and (v) Ulu Pandan Park Connector (UPPC) (Singapore).

Case studies on city level included: (i) Hamburg (Germany); (ii) Portland, Oregon (US); (iii) Copenhagen (Denmark); (iv) New York City (US); (v) Jakarta (Indonesia); and (vi) Mumbai (India).

A selection of these case studies is presented below.

a) Emerald Necklace, Boston

The park system "Emerald Necklace" has been a continuously evolving example of blue-green infrastructure over the past 130+ years. Designed by landscape architect Frederick Law Olmsted toward the end of his career in the 1880s, the Emerald Necklace was a breakthrough project in urban environmental design.

It stands as an early model for addressing functional issues of urban stormwater management on tidal rivers, and it has been emulated in other cities in the U.S. and internationally. Seven major blue-green components comprise the Emerald Necklace, linking sanitary and stormwater sewerage improvements with river corridor parks, urban ponds, an arboretum and subwatershed, and Boston's largest public park. This early design precedent underwent major changes in its underlying assumptions since the 1910s when its tidal outlet was dammed, at which point it became a freshwater reservoir.

The long history of the Emerald Necklace and changes to its program allowed a long-term evaluation of its performance as a BGI both in social and environmental terms and thus offers guidance and important lessons for designing contemporary urban BGI initiatives that will withstand the test of time and changing political, financial, and cultural circumstances. Therefore it is an especially useful precedent for assessing future BGI development opportunities in cities.

b) Hannover-Kronsberg (Germany)

Hannover-Kronsberg (Germany) is a residential area with 3000 dwellings built 1992-2000 as an exhibit for the World Exposition 2000 titled "Mensch-Natur-Technik" (Human – Nature – Technology). Referring to Agenda 21, the Habitat II Modell 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 combine urban life and sustainable housing. 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 safe-guard infiltration and groundwater refill.

c) Khoo Teck Puat Hospital and Yishun Pond (Singapore)

Khoo Teck Puat Hospital (KTPH) is 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, 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 alongside patients and other official visitors. In 2005, KTPH team expanded its blue-green footprint by adopting the adjacent Yishun Pond, linking its central garden to a waterfront promenade overlooking the pond and a walking track around it. The former grey pond now gives a picturesque view as its concrete edge was softened with planting, and artificial floating wetlands were added to the pond.

d) Hamburg (Germany)

Hamburg is situated on the river Elbe and hosts one of the biggest harbours of Europe. Situated only six meters above sea level and increasingly hit by heavy rainfall, severe flooding and associated damages increasingly threaten central Hamburg. The high built density and surface imperviousness increase the risk of flooding. All these factors increased the pressure to adapt 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.

e) Portland, Oregon (US)

Portland is known as one of the most forward-thinking cities in USA in terms of promoting and advocating sustainability. To start, Portland purchased and permanently protected more than 33 km2 of ecologically valuable natural areas from future development and has continued to show a strong support for 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), with stakeholders from landscape architecture, architecture, engineering, institutional organizations and the stormwater treatment industry was created, that gave important recommendations and guidelines for urban stormwater engineering and design. Meanwhile Portland is also a recognized leader in "green" stormwater management including a number of award-winning BGI projects. These projects include 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.

f) Copenhagen (Denmark)

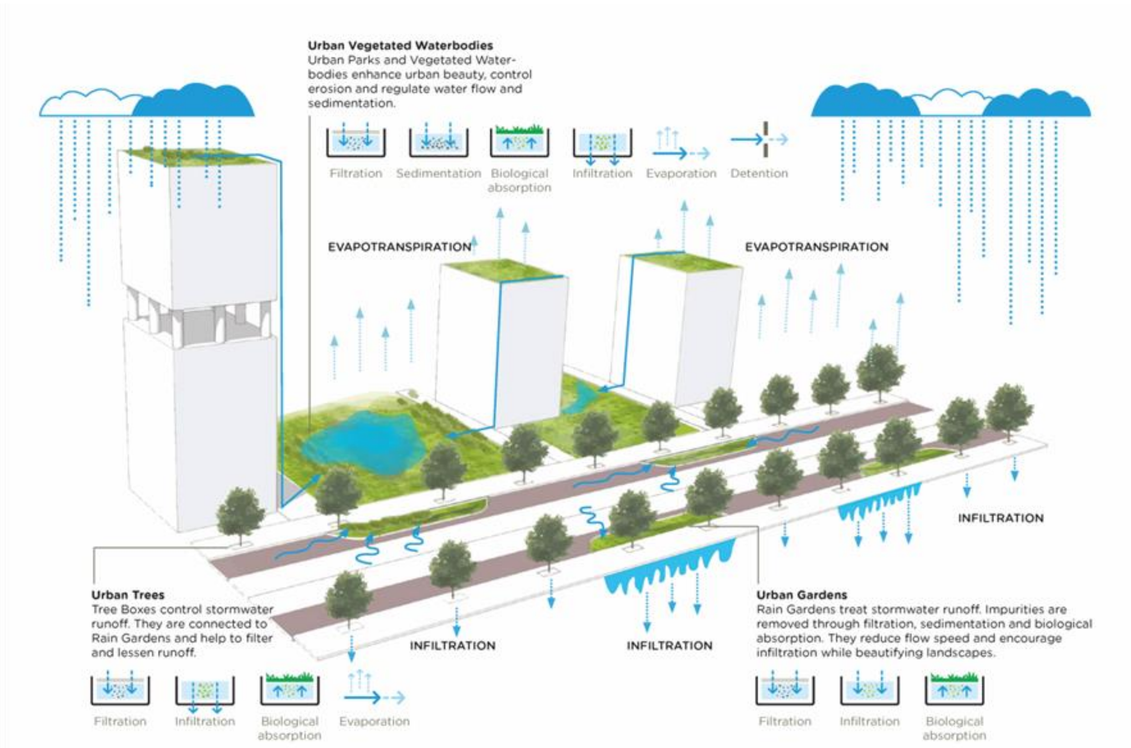
Copenhagen, the capital and most populous city in Denmark, is known internationally as an outstanding example for high livability and future-oriented urban design. Surveys have shown a high degree of public awareness and political support for sustainability- and livability-related issues. Climate adaptation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

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, which are also 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 of BGI-implementation.

MODELLING OF BGI-INDUCED CHANGE ON URBAN SOCIETY

In order to assess the societal (including ecological and economic) impacts of BGI implementation, we modelled the BGI-induced change of an urban society's capability for liveability, sustainability and resilience. In particular we employed a socio-economic capital-based accounting model, based on the "Polychrome Sustainability" approach of Manfred Moldaschl[3] . The implementation of BGI in dense urban areas was analysed as a change in an urban society's pool of resources for a decent life, according to criteria of liveability, sustainability and resilience. Therefore, all relevant resources are defined as different forms of societal capital: the natural, built, human, social, symbolic and the financial capital. As consequence, the financial capital is treated largely equal to all other capitals relevant for the 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 in so far



Neighbourhood-scale BGI solutions. Within a neighbourhood, the space between buildings can be used to provide detention and retention services for stormwater by implementing vegetated waterbodies and urban gardens, as well as tree-lined avenues.

[3] See e.g.: Moldaschl, M. (ed.) (2007): Immaterielle Ressourcen: Nachhaltigkeit von Unternehmensführung und Arbeit I. Vol. 3. Rainer Hampp Verlag; Moldaschl, M. (2013): Ressourcenkulturen messen, bewerten und verstehen: Ein Analyseansatz der Evolutorischen Theorie der Unternehmung. In: Klinke, S., Rohn, H., and Becke. G. (ed.): RessourcenKultur. Vertrauenskulturen und Innovationen für Ressourceneffizienz im Spannungsfeld normativer Orientierung und betrieblicher Praxis, p. 111-140.

as we hang on its idea to take economical, ecological (defined as natural capital)2, and social sustainability as three pillars that represent distinct dimensions for evaluation. But as an extension of this basic concept, we suggest applying a more detailed and elaborated version of the social pillar.

Therefore we define Societal Capital as immaterial capital that takes certain forms: 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 as well as 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 as e.g. trustful behaviour is built on trust and enhances trust.

On this basis, the effects of BGI implementation on human health, public well-being, financial assets, other long-term economic resources and other human values have been identified through case studies and comparative analysis.

KEY RESULTS AND LESSONS LEARNED

The case studies identified a number of successful implementations of BGI projects. Additionally, a number of constraints for the implementation of BGI, as well as approaches to overcome these constraints, were identified. A selection is presented below.

a) Examples for joint budgeting and beyond

BGI in Singaporean projects is financed by joint budgeting of different agencies and private investors. KTPH Hospital in Singapore provides an excellent example:

From an early planning stage there was the idea to integrate the Yishun Pond element with the recreational area of the hospital. Yishun Pond was originally a large water reservoir, framed and embedded in concrete – epitomizing the aesthetics of the conventional grey infrastructure approach. The KTPH Hospital renovation called for better integration of Yishun Pond with other parts of the hospital's landscape, as well as for more multi-functional use.

These targets were considered significant functional changes by the agency overseeing Yishun Pond (PUB) and which required efforts between relevant agencies to collaborate and negotiate on matters of construction and operation costs. Finally KTPH paid SGD 2 million for the construction of the waterfront promenade. NParks (the park agency) paid SGD 1.2 million for landscaping, footpath upgrading and park lightening. PUB invested SGD 2.5 million for the softening of spillway channel, the marshland, and the soft edge treatment of a vertical drain wall. The Housing and Development Board of Singapore (HDB) paid SGD 4.0 million for the construction of a lookout tower, a sheltered pathway, and pedestrian bridge.

It seems to have been a necessary experience for these agencies to cooperate on coordinate project plans and budget for KTPH. The experience provided an opportunity for these agencies to work through some of the obstacles to integration and cooperation that would continue to impede the implementation of future BGI. Fortunately, these agencies were able to successfully negotiate and navigate these regulatory hurdles, and in doing so built institutional capacity.

In addition to the potential for agencies to use a joint financing approach to BGI, there are increasingly options for more direct forms of financing. An example is for BGI costs to be financed through users, such as by a surcharge on the existing water tariff: BGIs in Hannover-Kronsberg are financed by allocation on citywide water charge and PUB, the Singapore's National Water Agency, has the sole competence for charging.

b) Institutional support is essential

All cases prove the importance of higher level political support. If drivers of BGI do not manage to get this support (such as in the case of Hamburg), it is practically impossible

to be successful. In contrast, in Singapore the Prime Minister was a strong and loud supporter of the BGI-focused ABC Waters Program, while in Hannover-Kronsberg the importance of the project to the World Expo 2000 garnered strong backing from the City of Hannover and the regional government of Lower Saxony.

Institutions, acting as intermediaries can also provide the effective political support that is required for a successful BGI adoption. For instance, in the Boston case, the Parks Commission was the initial driving force for the Necklace construction, while in Hannover-Kronsberg the need for sustainable rainwater management brought political support from a regional forest commission.

In some cases the implementation of BGI was only possible because of broad civic support and community engagement. Portland is an example of a city where adoption of BGI was very much a community-driven effort. Even Singapore, where the support for BGI was originally top-down-driven, keeps its BGI momentum now extremely popular with citizens in part because of a large public awareness campaign to overcome objections and in part because of the huge success of Bishan-Ang Mo Kio Park as a pilot BGI project.

c) Climate-related ecosystem services of BGI

Cynthia Rosenzweig from the Columbia University Center for Climate Systems Research led an interdisciplinary research project on behalf of the Energy Research and Development Authority of New York State, modelling planting trees along streets and in open spaces, building living (or green) roofs (i.e. ecological infrastructure) light surfaces, light roofs, and living roofs as measures for New York City's heat island mitigation. The resume: "The most effective way to reduce urban air temperature is to maximize the amount of vegetation in the city with a combination of tree planting and green roofs. Applying this strategy reduced simulated citywide urban air temperature by 0.4°C on average, and 0.7°C at 1500 EST, a time of day that corresponds to the peak commercial electricity load. Simulated reductions of up to 1.1°C at 1500 EST occurred in some neighbourhoods in Manhattan and Brooklyn, primarily because there was more available area in which to plant trees and install vegetated roofs in these boroughs. In Manhattan, most of the mitigation would involve greening rooftops high above the street, whereas in Brooklyn, a more balanced combination of the two strategies could be employed."

The Heat Island Group at the Berkeley Lab made a very prominent study about the relation of urban heat Island to urban surfaces in California, reporting: "Cities that have been 'paved over' do not receive the benefit of the natural cooling effect of vegetation. As the air temperature rises, so does the demand for air-conditioning. This leads to higher emissions from power plants, as well as increased smog formation as a result of warmer temperatures. In the United States, we have found that this increase in air temperature is responsible for 5–10% of urban peak electric demand for a/c use, and as much as 20% of population-weighted smog concentrations in urban areas. (…) On a large scale, the evapotranspiration from vegetation and increased reflection of incoming solar radiation by reflective surfaces will cool a community a few degrees in the summer. As an example, computer simulations for Los Angeles, CA show that resurfacing about two-thirds of the pavements and rooftops with reflective surfaces and planting three trees per house can cool down LA by an average of 2-3K. This reduction in air temperature will reduce urban smog exposure in the LA basin by roughly the same amount as removing the basin entire on-road vehicle exhaust."

d) Examples for increasing effectiveness, adaptability, and resilience within the case studies

Because of their multiple benefits and comparatively low associated investment costs, a promising business case can typically be made for BGI projects. BGI projects in New York City and Copenhagen provide good examples for situations relevant to many other cities.

New York City

New York City (NYC) is in a decades-long period of green infrastructure expansion, with the number and types of programs increasing dramatically since 1996. Much of this green infrastructure falls under the category of BGI by integrating blue and green elements. While investment in green infrastructure within the metropolis began as early as 1996, efforts were ramped up in 2005 – long before Hurricane Irene in 2011 and Hurricane Sandy in 2012 – after NYC was required by court order under the Federal Clean Water Act to invest over USD 2 billion to mediate the negative impacts of its stormwater runoff in waterways, particularly those from its Combined Sewerage Overflows (CSOs). As a consequence, the NYC government decided in 2010 to employ BGI as the primary measure to meet this request with its Green Infrastructure Plan.

This Plan is built around the idea, that in NYC "the cost of grey investments such as 50-million gallon underground storage tanks is significantly increasing" and at the same time the "New Yorkers need and want sustainability benefits such as more open space, improved air quality, more shade, and increased property values. In this new reality, the City must strive to get the most water quality and sustainability benefits out of every dollar it invests." In other words, NYC began to aggressively pursue BGI after recognizing that a comparable grey infrastructure solution would be substantially more expensive; and would also lack any additional social value. Since 2010, NYC has prepared to spend up to USD 1.5 billion over the next 20 years to implement BGI on 10% of NYC's combined sewer areas2 "as an alternative to the current all-Grey Strategy that costs billions more, reduces less CSO volume, and foregoes sustainability co-benefits".

There is clear evidence that BGI has already served as an effective technology mitigate precipitation-induced flooding. For example, Franco Montalto et al. studied the effect stormwater retention associated with a BGI project area, The Nashville Greenstreet, in Cambria Heights in Queens, NYC during Hurricane Sandy (in October 2012) and Hurricane Irene (in August of 2011) . Montalto et al. found substantial reduction in peak stormwater flow that was attributable to the BGI: "The Nashville Greenstreet significantly reduced the stormwater load that these two extreme events would have had on the local combined sewer system. The site infiltrated 100% of the total amount of rainfall and runoff directed to it during Sandy, and 79.3% of the total inflow during Irene. The monitoring effort suggests that Greenstreets can be effective strategies for reducing the impact of extreme precipitation events on combined sewer systems, and should be considered a key component of efforts to build up regional resilience to climate risks."

Copenhagen

Ramboll Management Consulting conducted a socio-economic analysis of two alternative masterplans to fight flooding in the catchment areas of Vesterbro and Ladegårdsåen in Copenhagen during the course of precipitation events. This socio-economic analysis compared the cost-benefits of a grey subterranean with those of a comparable BGI solution, focusing on the overall Net Present Value (NPV) of both projects. The benefits considered included reduction of air pollution, real estate taxes, reduction of insurance damages, increase in real estate value and upgrade savings. The analysis found a positive NPV for both types of infrastructure – in other words, the benefits were found to exceed the combined costs of investment and operational costs. However, the NPV of the BGI project was found to outperform that of grey infrastructure – 142 million EUR to 72 million EUR, respectively, which is 187 million USD to 95 million USD in terms of 2013 exchange rates. Inspection of the costs and benefits indicated that these differences arose primarily from the significantly lower investment costs associated with the BGI vs. the grey: (260 million EUR vs. 368 million EUR, respectively), which is 343 million USD vs. 486 million USD in terms of 2013 exchange rates.

e) Examples of the benefits of BGI on health and well-being

The restored Bishan-Ang Mo Kio (BAMK) Park in Singapore enhances the access of neighbouring communities to this open space. This has led to benefits for social life and improved awareness of these communities to ecology and the environment.

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.

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, which implies a substantial positive impact on physical health estimated at SGD 16-43 million (which is 12-31 million USD to 2013 exchange rate). The researchers hypothesized that the mental benefits of the BGI are attributable to BAMK's ability to attract social life and to encourage social integration.

Recommendations for implementing BGI. For successful implementation of Blue-Green Infrastructure, decison-makers need to be aware of sever key components.

f) BGI as measure to increase a city's reputation in Malmö and Freiburg

Malmö, Sweden

The city of Malmö, historically an industrial city, was faced with both declining population and economic activity in the 1990s. Today Malmö is marketing its image as an "eco-center". A key part of their image is a recent development project that also features BGI elements. Malmo's Western Harbour transformed what was previously an industrial site into an eco-residential development. The new development showcases an attractive development focused on sustainable design. The project was funded through a joint partnership between private and public ventures and also integrated community engagement. The project met its sustainability objectives, which included energy neutral, on-site waste recycling and on-site stormwater management, by using solar panels, wind turbines, public transport, and green roofs. Stormwater runoff is managed through green roofs, which is collected by open paving channels and canals. This stormwater strategy reduced the development's pressure on the city's water treatment system while creating natural environment in the area.

The success and experience of the project were shared within the community, and knowledge was transferred to key stakeholder groups and the wider community. In particular, the innovative strategies used in the development's design (including the green public transport system, the waste management strategy, energy efficiency, ecological design, and water management) were documented for this purpose. The development now attracts many study tours annually. The organizations and agencies involved in the project benefitted from a significant increase in reputation as visible drivers of BGI. Internationally, Malmö served as a model for Chinese eco-cities like Tangshan and Caofeidian .

Freiburg, Germany

There are a number of cities that have demonstrated similar transformations in their reputation. For example Freiburg in Germany is now known for being a pioneer in ecological policy and urban planning. In the 1990s a sustainable model district for 5500 residents was constructed in the Vauban area of Freiburg, which today serves as a flagship for sustainable urban design. Vauban is internationally known for its rainwater infiltration system, as well as other innovative technologies for sustainable architecture and urban design. On the whole site no rainwater drains exist; all stormwater runs to two rigole-trench infiltration ditches. Nearly all the rainwater is managed on-site. Vauban was presented as "German Best Practice" at the Habitat II Conference 1996 in Istanbul and won the title "Sustainable Capital".

g) Green infrastructure and tourism in Singapore

The tourism sector contributed 4% to Singapore's gross domestic product (GDP) and supports some 160,000 jobs based on 15 million visitors spending 56 million days in Singapore in 2014 (STB, 2015, p.2). Since the first tree planting day in 1968 by the then Prime Minister Lee Kuan Yew, urban green infrastructure has been an instrument to attract tourists and in shaping the city's image. Meanwhile Singapore has been promoting a "City in a Garden" concept that is stated on nearly every site in Singapore. An example of iconic green infrastructure is Singapore's Botanic Garden, which is a UNESCO World Heritage site and hosts some 4.2 million visitors a year (300,000 visitors at the Singapore Garden Festival in July 2015). Other parks, like Gardens by the Bay, are frequently marketed as a picturesque tourist attraction.

BGI might not be the primary attraction for international tourists to a particular city. Nevertheless, they can significantly enhance the experience of a city for a tourist. That many famous and popular tourist sites are BGI, such as NYC Central Park, the swimming facilities at Islands Brygge in Copenhagen, and the Skyrise Greenery in Singapore demonstrate this. Furthermore, when tourists have a positive experience with BGI they may return home with an increased awareness of and demand for it. BGI as a tourist attraction can be directly connected to a further increase in BGI when tourists get conscious about it.

h) Increasing property values

Copenhagen, Denmark

The Municipality of Copenhagen was hit by a high intensity precipitation event in 2011. The resulting damages from flooding generated an estimated EUR 800 million in insurance claims. As a response, the municipality created a flood adaptation plan, with the focus on identifying critical and high risk areas and designing solutions for adapting to these events in the future. Rambøll has driven design of a detailed flood adaptation plan for two high-risk areas: Vesterbro and Ladegårdså. During a flood event, the water can either be transported or stored in traditional subterranean structures such as drainage pipes, sewers, storage chambers, etc. Alternatively the water can be handled by terrain-based solutions, where blue and green elements disperse the water. The alternative solutions have a large impact on the design and feel of the city. Green and blue elements act as urban lungs and also provide recreational areas. Trees and bushes assist in capturing and filtering air pollution, augment biodiversity, increase property values, and create a pleasant-looking urban area. In contrast, blue and green elements can obstruct traffic patterns and reduce road capacity. It is therefore necessary to plan according to local needs. Besides design of the master planning and of the Flood Adaptation Plan, a socio-economic cost benefit analysis was conducted by Rambøll.

Bishan-Ang Mo Kio Park (BAMK), Singapore

Similar effects to property values were observed in Singapore in the course of the BAMK renovation. In 2014 and in 2015 the Ministry for Environment and Water Resources used a hedonic price model to analyse the effect of BAMK on the nearby real estate. The research showed that implementing BGI in the park resulted in an average increase of 2-4% and that the overall value of the park could be calculated to be SGD 100-200 million, which is USD 75-150 million.

i) Cost effectiveness of BGI in new housing development project at Hannover-Kronsberg

In the newly built residential area of Hannover-Kronsberg, BGI is used as functional and cost-effective stormwater runoff drainage infrastructure. The intention was to introduce BGI as a supplement to conventional grey infrastructure, which would have required a need for an upgrade of the already constructed drain capacity in the wider area.

Given the topographical conditions, a conventional grey drainage system would have had large impact on the urban water balance, as the flow of stormwater is subject to a large fluctuation – normally storage levels are quite low but come close to overflow in times of heavy rain. At the same time, increases of impervious surfaces would have reduced groundwater recharge, which sooner or later would lead to a dehydration of a nearby wetland and adjacent forest.

Consequently, on-site retention and infiltration by BGI was chosen as best option, even though soil had comparably low permeability and did not allow for complete on-site infiltration For this reason, an expansive concept with combined outflow, storage, and delayed drainage was implemented with the aim to optimize groundwater recharge. BGI was implemented with a Swale-French drain infiltration design to increase on-site retention and groundwater recharge and guarantee a high level of flood protection to Kronsberg and the downstream areas.

According to a cost comparison carried out after the development was completed, decentralized rainwater management for public spaces is more economical for the City Water Treatment Services than conventional drainage systems. Minimizing the areas sealed by paving and buildings reduces the need for rainwater retention facilities. Removing the need for street drains and environmental compensation measures according to nature conservation law also saves money.

Looking at the capital investment cost, the decentralized BGI approach to stormwater management was around 8% more economical than a conventional drainage system. The construction costs were EUR 11,599,167 while the costs for a conventional drain construction were estimated at EUR 12,606,412.

The specific investment costs worked out at around EUR 34/m2 of built area. The viability studies performed by private-sector property developers showed that 'the investment costs of decentralized rainwater management are to be assessed as on average about 25% higher than conventional drainage.' However, according to the water table of charges, a 70% reduction in rainwater disposal charges more than compensates for this difference.

j) Co-ordination between stakeholders is essential for the implementation of BGI

Prior to the implementation of a BGI project, the BGI designers for Bishan-Ang Mo Kio Park in Singapore – Studio Dreiseitl – had to convince officials at the water agency (PUB), the parks agency (NParks), and the construction companies of the robustness and capacity of BGI as a drainage and cleansing infrastructure. This required several major efforts by the designers. In the end, the designers decided on their own risk and initiative to build a smaller-scale pilot project to run test trials of the system performance. This pilot project had to be constructed parallel to the original, concrete canal and discharge water from the canal in the newly build riverbed to demonstrate its resilience against soil erosion.

The water engineers were concerned that the BGI design would lead to large quantities of soil erosion, which would reduce the capacity of the system for flood protection and cleansing functionality, and – most importantly – would endanger the quality of drinking water in the water reservoirs downstream. This was a legitimate concern, since these downstream reservoirs provide a substantial amount of Singapore's water. In the end, the ability of the designers and the national agencies to work together to address these concerns led to a very popular, award-winning design – in short, a success.

RECOMMENDATIONS

For a successful implementation of BGI, seven category groups were found to be the most relevant. The recommendations made below are aspects of these categories.

a) If BGI is unknown or rare in your city

Many cities are accustomed to using conventional water technology. But as infrastructure challenges are increasing and require new solutions for diverse needs, we have to consider the smartest solutions. These recommendations will show the way forward, if this technology is not well-known in your city.

A strong vision is the engine for change:

- Make efforts in public relations and convince the urban community about the benefits of BGI;
- Use visions of liveability and prosperity to show the advantages of BGI (e.g. for Climate Resilience, Green City Vision, Biophilia, Sustainable Urban Design, Water Sensitive and Water Wise City).

Employ pilot projects as learning tools:

- Pilot projects can become paradigm examples and have a high relevance for other cases;
- Pilot projects offer opportunities to test and execute experiments to deepen the understanding of needs and open up opportunities for BGI under diverse local conditions;
- Pilot projects serve as long-term references and are effective for fostering a BGI planning culture;
- Pilot projects demonstrate the long-term financial, social and ecological benefits and win-win effects;
- With pilot projects, key officials and the wider public can be convinced of the feasibility of BGI.

Look for windows of opportunity to initiate BGI:

- Cities are in need of long-term adaptation processes to cope with current and future challenges. These challenges are the "gateways" for implementing BGI. Water-related health issues, climate change mitigation and adaptation, biodiversity loss, and other disasters have proven to be promising gateways. But action is needed to move beyond old habits and business-as-usual;
- Often the need for renovation or upgrading of old, grey infrastructure offers good opportunities, as the comparative cost advantage of newly built BGI over grey infrastructure renovation can be very significant;
- Instead of a complete restructuring of the urban system, a step-by-step approach can take place, as the decentralised, adaptive character of BGI is very flexible.

Mobilise people, citizens and social capital for BGI-projects:

- Drivers of BGI often rely on the direct support of networks of professionals, NGO activists, and civil society;
- Involvement of people from the affected neighbourhoods and catchment of BGI-projects fosters public awareness and civic support;
- Identify persons and groups with a particular level in society to elicit volunteerism and enable these partners to support and strengthen BGI advocacy.

Build up capacity for further BGI-projects in your city:

- A critical mass of BGI-practitioners in your city can help to create momentum for further BGI-projects: Use external expertise at an early stage to develop guidelines (e.g. best practice examples, handbooks with recommendations, toolboxes) and to build up BGI-capacities in your city;
- Recognition of good practice examples through public competitions and publications can be very helpful and support the movement toward BGI cultural capacity and development in a city.

Overcome silo mentality:

- Establish leaders and offices with high competence for integration, situated directly under the mayor's office;
- Involve external consultancy and promote knowledge exchange across departments;
- Promote policy integration and inter-agency coordination to ensure knowledge exchange;
- Support professionals who can transcend institutional boundaries;
- Support BGI-related interdisciplinary training programmes and workshops, staff rotation and career programmes;
- Support BGI-related professional networks and associations across departments.

Take care of operation and maintenance:

- Case studies show that long-term costs for operation and maintenance (O&M) of BGI are often not foreseen or budgeted. It is crucial to have a clear picture of the lifecycle costs; and long-term funding for maintenance and to clarify the responsibilities for maintenance in advance;
- Operations, maintenance, and programming are the most creative processes in BGI.

Implement joint budgeting and mixed financing, as BGI has multiple purposes and provides benefits for different stakeholders:

- Real estate owners and insurance companies can "earn" by investing in budgets for flood prevention and climate resilience;
- Merged and joint budgets can secure funding for increased inter-agency involvement and coordination, especially cross-agency budgets for BGI (earmarked money);
- Develop programme budgets and funding incentives across departmental lines.

b) If BGI is not yet institutionalised as a standard technology

Cases studies also show that BGI, however implemented in some remote areas of a city, did not break through as standard technology yet. Urban decision-makers and lobby groups therefore are advised to build high institutional capacity.

Focus on know-how transfer by standards and guidelines:

- Set standards and build up necessary knowledge and experience in a handful of projects;
- Document the acquired knowledge in handbooks and guidelines to allow transferring single-project experience to future projects at different scales;

- Implement effective, enforceable and sanctionable BGI-guidelines and regulations in urban planning processes (drainage regulations, exact requirements for rainwater inflows, etc.);
- Be aware and promote that institutionalisation helps to reduce transaction costs and create new paths of development.

Create partnerships and networks for BGI:

- Build effective collaborative working relationships with external actors to enhance strategic capacity;
- Establish BGI-networks and regard them as resources irrespective of single projects
- Push BGI-networking on an institutional level e.g. by platforms and clearinghouses.

The full report titled **"Strengthening Blue-Green Infrastructure in our Cities - Enhancing Blue-Green infrastructure & social performance in high density urban environments"** co-ordinated by Ramboll's Liveable Cities Lab can be accessed through: https://issuu.com/ramboll/docs/blue-green_infrastructure_lcl_20160?e=4162991/36504872

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