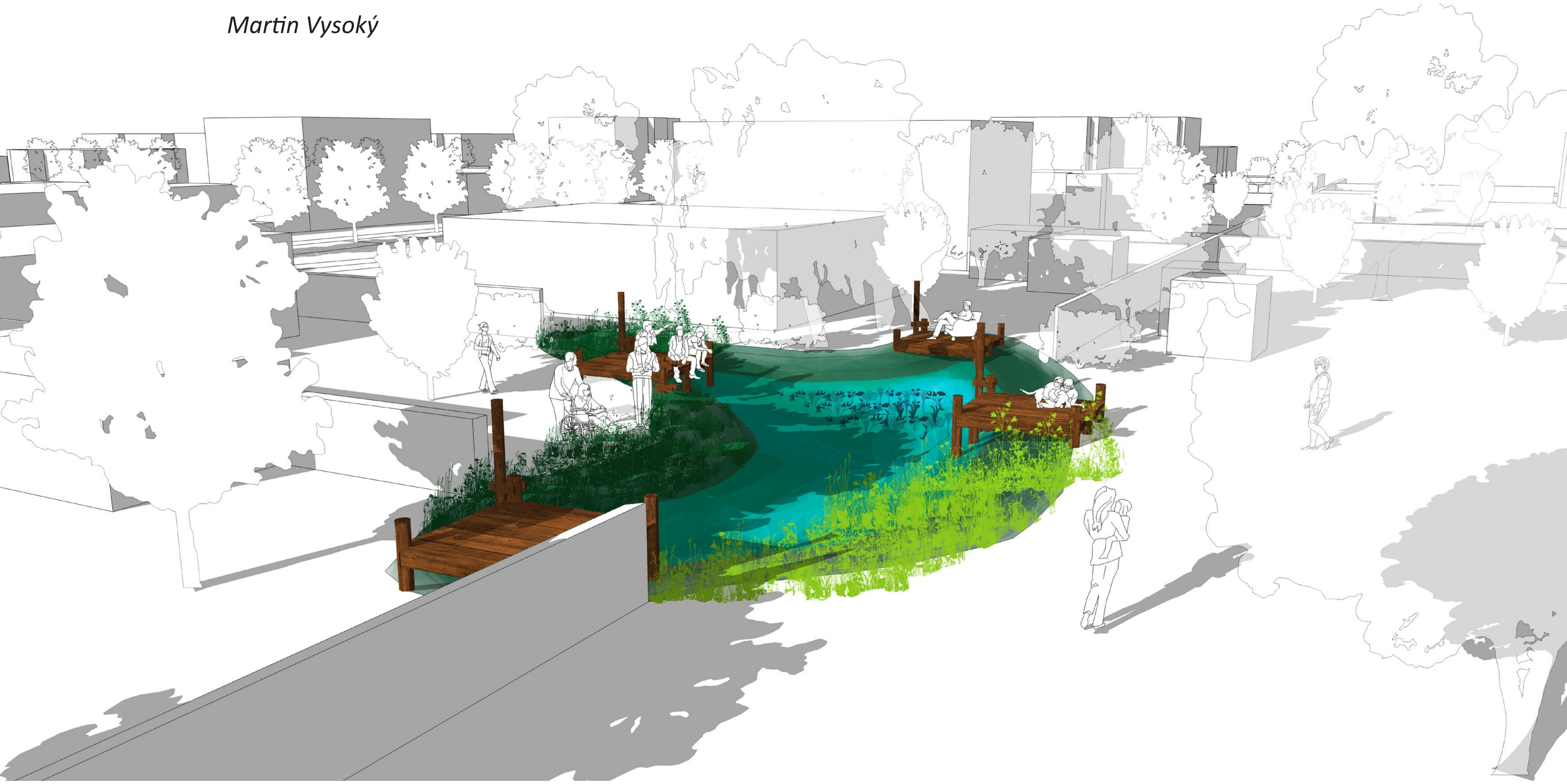
Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Landscape Architecture, Horticulture and Crop Production Science

Water Sensitive Neighbourhood

Klimatsäkrat grannskap

Martin Vysoký



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Abstract

Climate change is an issue that is no longer being ignored. Cities world-wide are adapting their existing and new structures to a changing climate. This need to address climate changes creates an opportunity to make cities more economically stable and at the same time more liveable for people and thriving for nature.

This master‘s thesis focuses on climate adaptation in Denmark, where extreme rainfall that creates floods in urbanized areas is a major threat and therefore it becomes one of the nation‘s main concerns. The thesis is done in partnership with Ramboll, a Danish Consultancy Company experienced in holistic planning and the implementation of services for climate adaptation and flood risk management. The partnership is based on a work on one of their ongoing climate adaptation projects, which is used as a case study for this master thesis.

The case study assesses flood risks in one specific area in Denmark, during extreme periods of rain. Then, based on these findings and findings from on-site investigations, it creates a proposal for the implementation of climate adaptation measures on the site, with regards to local conditions and local knowledge of the area. As a result, the proposal recommends ways to improve conditions for urban life in the area while strengthening the resiliency of the current drainage system against extreme rainfall.

To provide background for the case study, a brief summary of theories connected to Water-Sensitive Urban Design (WSUD) and Blue-Green Infrastructure (BGI) is included and both terms are defined. This includes also a description of the main strategic principles for planning this infrastructure in an urban landscape on a large scale and an introduction of a model for handling rain water in small-scale private spaces. The theories and methods are then applied to the case study.

This master’s thesis provides insights from climate adaptation practice. It can be seen as an example of how to create a climate adaptation proposal, which then can be utilised by Ramboll for future practical application.

Table of Contents

INTRODUCTION

1.1 Preface

1.2 Background and motivation

1.3 Objectives

1.4 Problem statement and research questions

1.5 Methodology

Figure 1 - a water shortage in Mexico

Figure 2 - a flood in Copenhagen

1.1 Preface

Our planet is thirsty for more integrated water solutions. The world's population is increasing at the rate of 80 million people per year. Soon more than half of the world's population will live in urban areas- a trend that further contributes to a higher demand for clean water. (UN 2014)

At the same time, climate change causes diverse imbalances in different parts of the world. In terms of water, some regions are suffering from drought (Figure 1) while others are drowning (Figure 2). Urbanisation buried nature beneath concrete and asphalt. It is stopping the rain from feeding the aquifers, causing floods and creating urban heat islands that raise temperatures further and increase the demand for water. (Kimmelman, M. 2017)

CLIMATE CHANGE is the long-term shift in weather patterns in a specific region or globally. It refers to changes in a region's overall weather patterns, including precipitation, temperatures, cloud cover, and so on. Climate change is caused by factors such as biotic processes. Certain human activities have been identified as significant causes of recent climate change. (Ecolife 2017)

The effects of climate change will have different impacts in different parts of the world. Let´s narrow this wide phenomenon to the geographical context where this thesis is being written – in Denmark, Europe.

"Europe's Atlantic countries will suffer heavier rainfalls, greater flood risk, more severe storm damage and an increase in "multiple climatic hazards", according to the most comprehensive study of Europe's vulnerability to climate change yet." (Neslen, A. 2017) Denmark is one of the European Atlantic countries where we could see such events (Figure 2).

The lack of integrated infrastructural planning causes cities to experience a backlash from unpredictable events, which climate change brings. The present challenges force the world to enter a so-called transition period where current infrastructures are being reconsidered and transformed in order to make them more resilient towards climate change.

This process of modifying our current urban structures while integrating new ones will take many different forms, depending in which sector an initiative will happen. The water sector today is undergoing a great deal of innovation driven by the need for urgency where climate change can no longer be ignored. One example is in Denmark, where they have taken a very active approach towards processes that relate to climate adaptation.

CLIMATE ADAPTATION *"is about taking deliberate and considered actions to avoid, manage or reduce the consequences of a hotter, drier and more extreme climate and to take advantage of the opportunities that such changes may generate".* (VCCCAR, 2017)

Climate adaptation was not always a major priority on Demark's agenda. The situation has changed after the biggest city in the country - Copenhagen - was hit on July 2, 2011 by an extreme storm event that caused 6 billion Danish kroner (DKK) damage to the city. (Gerdes, J. 2012)

"The storm was a wake-up call for the importance of Climate Adaptation, which became a primary concern for the country. Three years later, another extreme storm event hits the city, furthering the focus on climate change and proving that this was not a one-time occurrence." (Goring, 2016)

According to the largest European insurance company, in the last 35 years, flood disasters in Europe have doubled. Globally there were 384 flood disasters in 2016, compared with 58 in 1980. (Neslen, A. 2017) The character of these disasters is mostly severe convective storms that impact the environment with cloudbursts.

CLOUDBURST is a definition that is used in Denmark for an extreme amount of rain in a short period of time.

The traditional city infrastructure is not capable of handling such unexpected events and therefore there is a need to find new, more resilient and sustainable ways to deal better with rain water in urban environments. Because this issue usually concerns several different parties at once, it was therefore necessary to initiate a cross-sectoral and multi-disciplinary debate.

"Investors, politicians, municipalities, utilities and consultancies in Denmark came together and began discussing how to address the issue through organised events. Due to the sheer scale and impact of cloudburst events, an overall strategy needed to be created. Climate adaptation needed to be an integral part of local plans and to be included as an intrinsic part of new developments. Municipalities began dividing their regions into storm water catchments and undertaking large-scale hydrological models and updating other data to map vulnerable risk areas. The water utility companies started to finance solutions to try and handle cloudburst events but the volume requirements are just far too much for traditional piped solutions to be enough." (Goring, 2016), (Cathcart-Keays, A. 2016), (Klimatilpasning, 2013)

Governments are challenged to decide where to prioritise their investments in order to improve current living conditions and optimise the use of resources effectively.

The aim of Denmark's climate adaptation process was to reflect on how to lower the risks posed by the consequences of climate change. The issue was approached with input from many different sectors, from different fields of expertise in a collaborative spirit that is one of the prerequisites to moving things forward. Luckily, Denmark has a strong tradition in a collaboration that gives this process great strength (Figure 3). The close collaboration was important in order to approach the issue holistically and prepare a good ground for a more integrated way of solving the challenge.

"Traditional drainage solutions such as underground concrete reservoirs and cloudburst piping are becoming less viable as more and more utilities are taking up space. In addition, these traditional cloudburst solutions are not even used a majority of the time due to the nature of cloudburst events. Available space is one of the most valuable resources in cities and in an ideal scenario cloudburst solutions would only take up space when they are required. The challenge between climate adaptation and available space has resulted in a focus on multi-functional surface solutions that combine stormwater systems with other city infrastructure. However, the process of trying to specify multifunctional surface solutions while still working at a strategic catchment scale is not easy. As a result, the Copenhagen Concretization Plans were commissioned." (Goring, 2016), (Cathcart-Keays, A. 2016)

These plans link strategy with site-specific, so-called Blue-Green Infrastructure solutions, which have the capacity to regulate water quantities and therefore improve water resiliency in cities.

BLUE-GREEN INFRASTRUCTURES (BGI) are flexible, multifunctional, (typically) surface systems that integrate ecological treatment of water within designed components that contain green elements (vegetation and soil) that are seamlessly integrated with blue elements (water features like surface water, water systems, etc.) in the built environment. (Dreiseitl, Wanschura, 2016)

The overall and primary aim of these solutions is to enable natural drainage conditions for urban water through linkage of individual BGI components. Such an approach is called Water Sensitive Urban Design.

WATER-SENSITIVE URBAN DESGIN (WSUD) is an interdisciplinary approach within fields of water management, urban design and landscape planning. The objective is to create synergy between the demands of

Figure 3 - collaboration across disciplines

Figure 4 - one of emerging climate adapation projects in Copenhagen: Taasinge Plads

Figure 5 - climate adaptation proposal: Soul of Nörrebro

sustainable water management and demands of urban planning and thus bring the urban water cycle closer to a natural one. (Hoyer, 2011)

When the process of climate adaptation is approached holistically, it can open up opportunities for synergies among a number of areas of urban development. This can be achieved when Water Sensitive Urban Design is integrated into overall urban planning. Cities around the world are increasingly concerned with improving their resilience against the effects of climate change. (State of Green, 2016)

"The Copenhagen Concretization Plans provide guidelines and principles on how to incorporate storm water solutions into the city. However, the municipality of Copenhagen can only do so much by itself. Private properties and homeowners have to make the decision themselves to be part of the solution. It can still be difficult to convince developers and landowners that they should invest in these solutions. Therefore, the next step in Copenhagen was to raise awareness and have more involvement. This step not only involves developers, but also stakeholders, communities, and investors; including public participation and outreach strategies." (Goring, 2013), (Klimatilpasning, 2013)

In the country that is famous for urbanist Jan Gehl - a pioneer of bringing more of the human scale into cities and providing a great influence on the quality of urban life - it is becoming a fascinating issue to observe. Climate adaptation gives another layer of complexity to a well-established Danish planning culture, mainly in terms of how to plan and adapt cities for unpredictable events while maintaining their already-established good urban living standards. The human-centric planning approach is being challenged with this question.

We can already see positive results in recent projects that have embraced this challenge, such as Taasinge Plads (Figure 4). This specific project is part of a larger project called Klimakvarter Østerbro (Climate Resilient Neighbourhood Østerbro), that makes individual interventions related to climate adaption together with local residents. There are other planned projects such as Soul of Norrebro (Figure 5), which even aims to provide local inhabitants with the possibility of growing and planting trees for maintaining and establishing Blue-Green Infrastructures in their surrounding area. These projects not only create dignified living conditions for people in the cities while protecting them from the cloudbursts, but also reconnect them with nature and therefore strengthen a more vital and balanced relationship between city and nature.

The issues regarding cloudbursts in Denmark turned into an opportunity to rethink overall urban planning, specifically how to design or re-design public space, so it becomes not only water sensitive but also more liveable for its inhabitants.

"Today, we are seeing these cloudburst solutions being implemented into current and future development through municipality local plans. Already we are experiencing the co-benefits of cloudburst economics through a multitude of indicators. Synergy projects between municipalities, water utilities and philanthropists are becoming catalysts for development in areas that were previously neglected." (Goring, 2016), (Klimatilpasning, 2013)

BGI solutions can generate a chain of benefits through their multifunctional character. They have the capacity to make outdoor spaces more attractive for people while creating the opportunity for diversity in plant and animal species. They moderate the urban heat island effect, air pollution, water quantity and quality at its source. Through the provision of such multilayered benefits, they can provide effective use of space.

The sooner cities start to work on solving these challenges, the sooner their vulnerability against outer negative effects will lower and the gain of benefits could start to accumulate.

Denmark's experience can be a lesson for other cities in order to avoid a similar scenario in their location before it is too late. The process of embracing responsibility and working actively on climate adaptation is a long-term task for each authority. Cities are the main drivers of change because they are in the forefront in facing the current biggest challenges. Climate change is not the only challenge that cities face (e.g. demographic changes, urbanisation, environmental problems, natural resource shortages, and globalisation are other calls that cities need to address). Therefore, it is necessary to make a best use of every available square meter of a space in order to give an answer on more than one issue at the same time. Evidently, the realm where the implementation of adaptation measures will take a stance can be directly on our doorstep.

This thesis aims to discuss this Danish planning culture, to explore it and contribute to it while taking it as an example of today's contemporary practices.

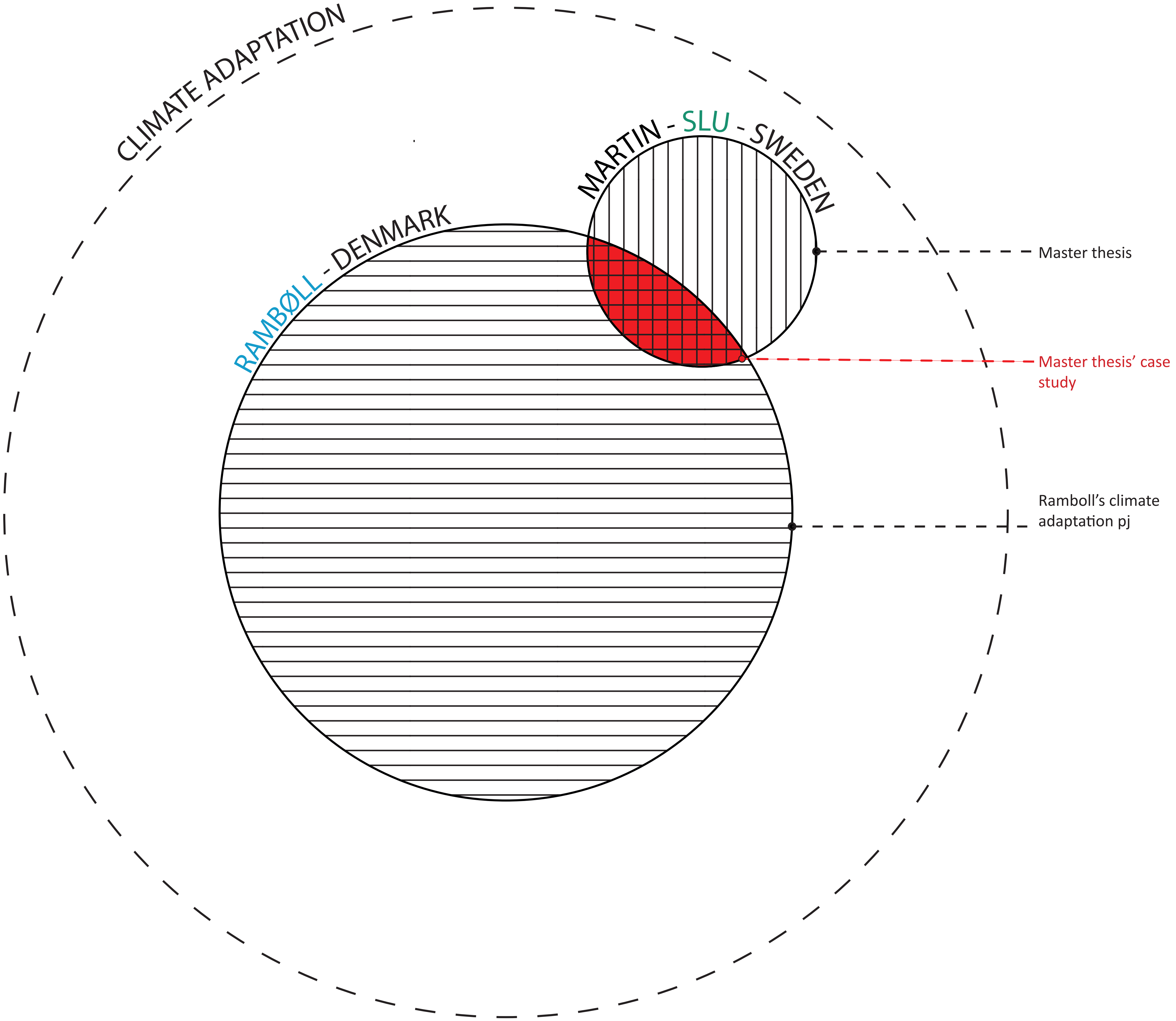


Figure 6 - illustration of collaboration

1.2 Background and motivation

This Master's thesis is being written in partnership with the Consultancy Company Ramboll, which invited me, as a student at Swedish University of Agricultural Sciences in Alnarp, Sweden, to their office in Copenhagen, Denmark.

Swedish University of Agricultural Sciences (SLU) is a university that has a mission to contribute to an ecologically, socially and economically sustainable development. The university creates fertile academic ground where these values are strongly cultivated during our education. Therefore, naturally, I feel a sense of the need to contribute to thriving relations and healthy ecosystems while reconciling the needs of people and nature that share the community.

Both Ramboll and SLU aim to contribute to climate adaptation, which is one of the prerequisites of sustainable development.

Ramboll is a engineering, design and consultancy company founded in Denmark in 1945. Their office, where I worked as a master's student, is called Climate Adaptation and Green Infrastructure department. They provide services that help cities to lower the risks posed by the consequences of climatic changes. They work with diverse infrastructural projects within the water sector around the globe.

Since Denmark initiated works on climate adaptation strategies, Ramboll has been the forefront Consultancy Company involved in the process. In the greater Copenhagen area, they have assisted in developing several climate adaptation plans and three Cloudburst Concretization plans for Copenhagen. Ramboll encompasses an interdisciplinary team of hydraulic engineers, civic engineers, landscape architects, urban planners and economists. Together, they deliver a uniform and holistic solution covering all diverse aspects and levels of resiliency planning. (Ramboll, 2017)

My stay at Ramboll allowed me to expand my theoretical knowledge about climate adaptation, to get a first-hand knowledge of up-to-date practices in regards to climate resiliency planning and to apply it to one of their ongoing projects. It further enabled me to become familiar with the team of experts with different background and nationalities.

The core of the partnership between SLU and Ramboll is established through my work on Ramboll's large climate adaptation project that is used as a case study for the master thesis (Figure 6). This collaboration creates mutual benefit – for a quality of outcomes of the thesis and for Ramboll, who can use the advantage of the master thesis' deliverables during their work.

The way the MSc work is approached – between academic and professional practice – allows me to question a theory with a practice or vice versa. The master thesis can provide a good inside look into freshly-established and operational practice that deals with climate adaptation issues within the current political, technological and societal borders in urban environment.

1.3 Objectives

The main objective of the thesis is to identify and define flooding issues in the Kalenderkvarteret neighbourhood, Denmark, during extreme periods of rain, and – based on these findings and findings from on-site investigations – create a climate adaptation proposal, which will allow implementation of BGI (Blue-Green Infrastructure), on the site, with regards to local conditions and local knowledge of the area.

The MSc work will result in a set of planning documents (Cloudburst masterplan, Cloudburst concretization plan, etc.) that will give advice on improving the resiliency of the current drainage system and conditions for urban life in the area. The proposal of BGI will also include proposals of new potential places for recreation and regulation of traffic in the neighbourhood. Site observations and interviews with local inhabitants of Kalenderkvarteren will help define their current demands and already established uses of the space. The current and new uses of the space will be reconciled in the proposal in order to create favourable conditions for urban life while improving storm water resilience in the neighbourhood.

This MSc thesis encompasses a theoretical summary of theories connected to BGI, including strategic principles for planning this infrastructure in an urban landscape on a big scale and a brief introduction of a model for implementation of BGI components in small-scale private spaces.

This master thesis can be seen as an example of how to create a climate adaptation proposal, which then can be utilised by Rambo ll for future practical application.

1.4 Problem statement and research questions

Today Denmark is undergoing major climate adaptation processes (see in Preface chapter). These processes take place most often in urban landscapes where the risks are most concentrated and therefore current urban structures are being transformed, so that they can cope with the unpredictable effects of climate change. Denmark is one of several European countries that are highly exposed to cloudburst events. These events are expected to be more frequent and intense in the future.

Low-lying and highly-urbanised areas with high cover of impermeable surfaces and the presence of traditional combined sewer infrastructure are the most vulnerable areas in terms of flooding. The flooding in these areas can negatively influence individuals and communities and create a cost that not only accounts for physical damage of infrastructure alone but also relates to socio-economic costs such as delays in transport and halts in production. (Gerdes, J. 2012)

The research questions relate to one such flood-prone urban area in Gladsaxe, Denmark, where Ramboll was hired by local authorities as a primary consultant for the climate adaptation. This area and its context will be used as a case study for the MSc thesis (Figure 7).

The formulation of the first research question is based on the presence of a risk of floods that can create socio-economical losses and a current lack of favourable conditions for urban life in the studied area. The research question is:

How can the current public sewer infrastructure at the selected site area in the Kalenderkvarteret neighbourhood be retrofitted in order to improve its water resilience against 100-year rain events and its current urban living conditions?

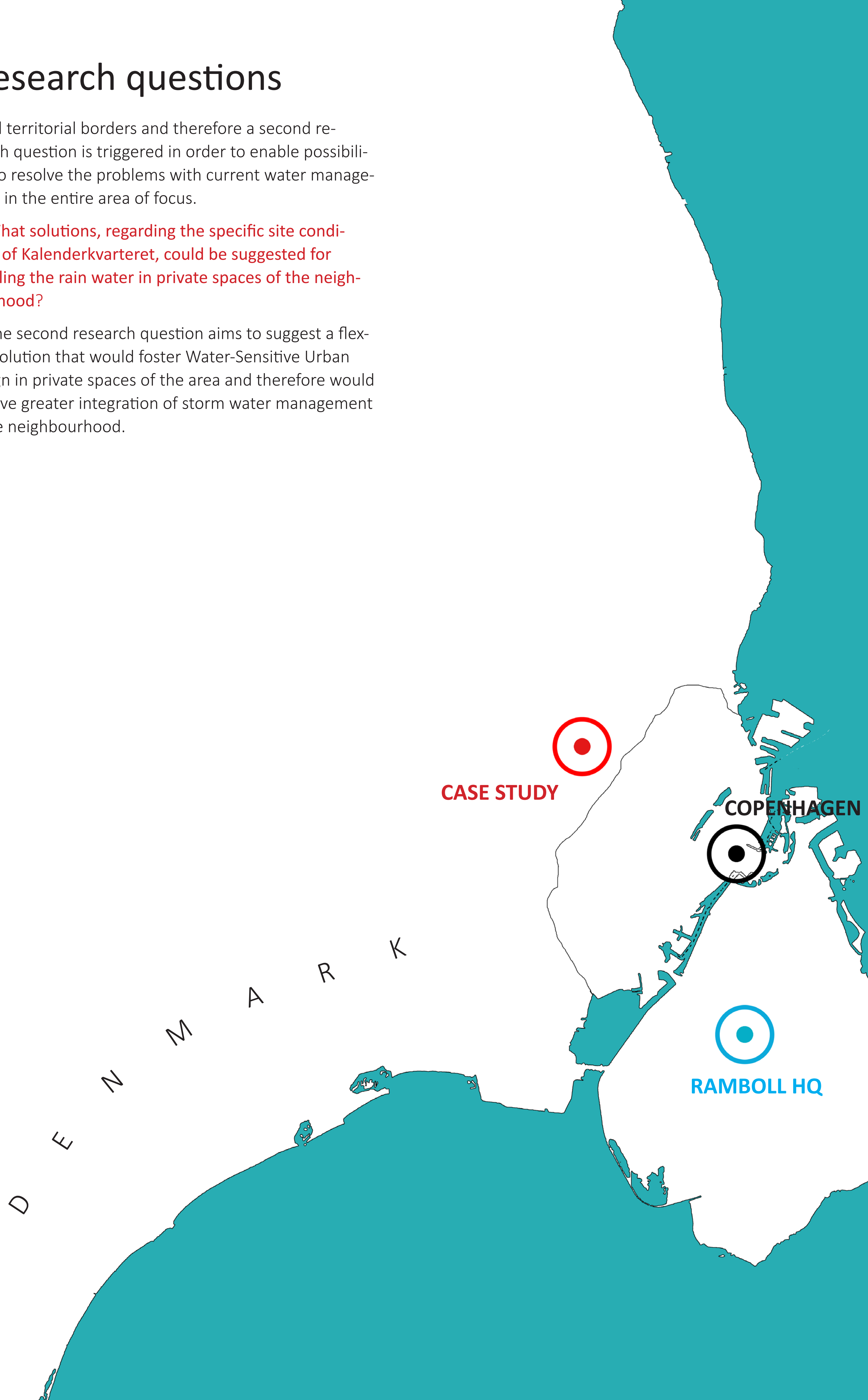
A rain event relates to the probability of how often a precipitation with a certain frequency, duration and intensity falls. In terms of 100-year rain events, it corresponds to the most intense precipitation measured within a short period of time that occurs every 100 years. Such a rain event for the Copenhagen area specifically occurred on the 2nd of July in 2011 where around 150 mm of rainfall was measured within two hours. (Ramboll, 2017)

The goal is to find the answer how to improve water resilience in the area in terms of handling 100-year rain events while at the same time creating better physical conditions for urban life. The physical space of solving these issues is determined by the social territorial border of public space in the area.

However, the issue of flooding does not respect the social territorial borders and therefore a second research question is triggered in order to enable possibilities to resolve the problems with current water management in the entire area of focus.

What solutions, regarding the specific site conditions of Kalenderkvarteret, could be suggested for handling the rain water in private spaces of the neighbourhood?

The second research question aims to suggest a flexible solution that would foster Water-Sensitive Urban Design in private spaces of the area and therefore would achieve greater integration of storm water management in the neighbourhood.



1.5 Methodology

The master thesis consists of five parts: the introduction, theoretical frame, methodological considerations, case study and reflections.

The introduction includes an overview of the issue of climate change in relation to water management and urban planning with the narrative to Denmark's context. It describes the background of the thesis and states the problem that it aims to resolve with the help of formulated research questions.

The theoretical part helps to gain an understanding of key principles and features that relate to Water-Sensitive Urban Design approach (WSUD) and Blue-Green Infrastructure (BGI). It starts with a more in-depth definition of both terms and their synonyms. Further, it describes the main observed benefits of BGI and sums its functions. Last but not least it includes a brief description of the most commonly-used BGI components in the urban landscape.

The third part encompasses methodological considerations for planning BGI in an urban setting in strategic levels. It will refer to Ramboll's previously-developed methodology that is known as Cloudburst Formula, which is a comprehensive toolbox used for a navigation of every climate adaptation project. It will emphasise main strategic principles for planning the Cloudburst plan, which is a key instrument in proposing the BGI in urban landscape.

Further on, this chapter will describe a model for implementation of BGI components in small scale – on private property – that is used in Denmark.

The fourth part comprises a case study. It will demonstrate the applicability of the theory, Cloudburst Formula and the model through the climate adaptation proposal. The proposal deals with current climate issues that affect an existing specific site in Gladsaxe, Denmark. This site is going through a climate adaptation process where Ramboll is hired as the primary consultant.

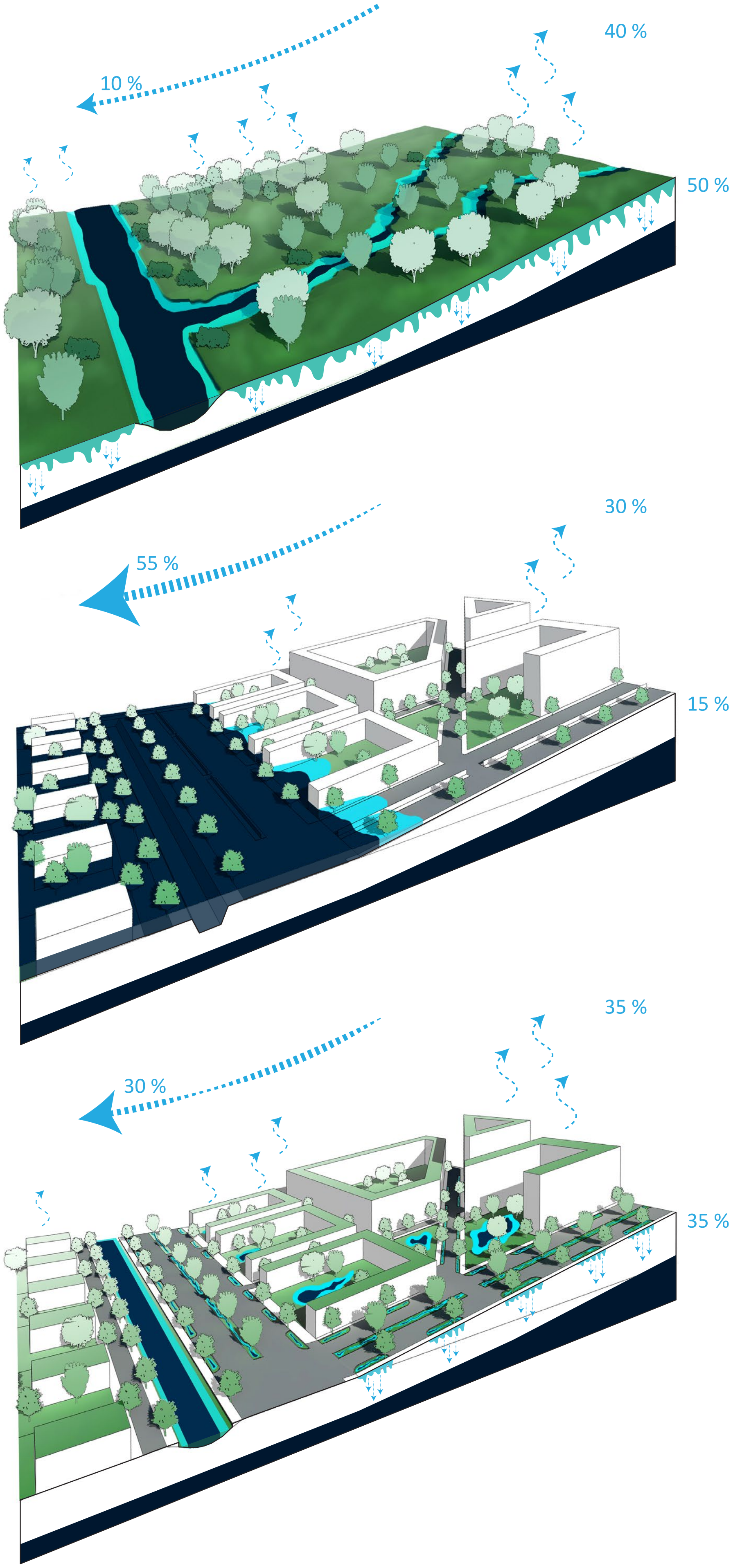
The last part of the MSc thesis will reflect on the climate adaptation proposal. It will discuss the possible applicability of the project, its limitations and perspective.

Figure 7 - context of master thesis' research

II

THEORETICAL FRAME

2.1 Definition of WSUD and BGI



RURAL CONDITIONS

Typically with impervious surface between 0 - 10 %. Most of rain water is infiltrated or evapotranspirated a rest run-offs into water bodies.

URBAN CONDITIONS WITHOUT WSUD

Usually consists of impervious surface between 75 - 100 %. Most of rain water is surface run-off, the rest is evapotranspirated and very little infiltrated.

URBAN CONDITIONS WITH WSUD

It can consists of between 35-50 % of impervious surfaces.
Rain water in such conditions leaves the area proportionally.

Figure 8 – three different states in relation to impact on water management. From the top: rural conditions, urban conditions without WSUD (state of functionality where BGI features are separated) and urban conditions with WSUD (state of integration where BGI features overlap); (adopted from Woods Ballard et. al., 2016)

"There is growing recognition that the traditional (so-called "grey") approach to infrastructure will be insufficient to meet the growing pressures from urbanisation and additional stresses associated with climate change and energy scarcity." (Dreiseitl, Wanschura, 2016) The grey approach refers to traditional engineering solutions (concrete channels, concrete pipes, etc.) that are not effective in handling extreme rain events.

Together with urbanisation, the grey approach alters natural landscape and therefore negatively affects a water cycle. The water cycle harmonises water circulation through evaporation, precipitation, infiltration, groundwater recharge and transpiration of water through plants. All these natural processes are either reduced or erased by urbanisation. *"Traditional engineering storm water management uses concrete canals, pipes and storage basins, but like highways, these systems create jams when over capacity. In an extreme event, storm water is rapidly transported downstream and storage basins are overloaded. Storm water treatment systems collapse as the peak water too quickly exceeds maximum capacity, resulting in untreated water flowing into rivers and other waterways."* (Tu, 2016) Untreated water can carry toxic pollutants into water bodies, thus creating environmental and health risks.

A new approach towards storm water management in urban setting is therefore in urgent need in order to keep up with growing pressures in the most optimal way. The new approach is called Water Sensitive Urban Design and it recognises storm water run off as a resource rather than a nuisance or liability. (Fletcher, 2014)

Water-Sensitive Urban Design (WSUD) *"is a term used to describe an approach to planning and designing towns and cities through integrated and sustainable approaches to water management. It looks at the water cycle as a whole and how urban environments can best be developed to bring about healthy ecosystems by integrating the whole water cycle."* (Stephenson, 2013)

This term applies at all scales and densities and all levels of urban water governance - community, institutional and government.

WSUD is commonly used in England and Australia. In the USA, they recognise this approach as "Best Management Practices". In New Zealand, it is coined with a term "Low Impact Design". In Denmark, they express it as "Local Drainage of Rain Water". (Fletcher, 2014)

So far each country where this practice is recognised has developed its own specific term but all of them advocate for the same outcome: to bring back natural water cycle into cities.

The storm water is traditionally being treated as a redundancy that is necessary to be hidden away from the surface and thus out of sight. (Hoyer, 2011). The WSUD presents a paradigm shift in planning and design that is contingent with the shift in our perception and is associated with the following statement: the water adds value to space when it is visible on the surface and thus is acknowledged as an integral part of our build environment

The practical solutions that address this approach in a build environment are most often called "Sustainable Urban Drainage Systems". This can be described as a solution-based technology that mimics the natural drainage conditions.

Sustainable Urban Drainage Systems *"are drainage systems that are considered to be environmentally beneficial, causing minimal or no long-term detrimental damage. They are managing surface water as close as possible to where it falls by mimicking natural paths and processes."* (SUSdrain, 2017)

This term is closely related to a water-engineer terminology and is mainly emphasising the water management of these systems. It does not mean that it does not deliver other functions and benefits that these systems can bring. However, not addressing it fully can result in disregarding its other qualities like ecological, social or aesthetic. For example, aesthetic qualities are very important because they influence public perception and consequently acceptance of this infrastructure by the public. (Hoyer, 2011)

In order to be able to communicate more widely, especially while addressing the full chain of the benefits and functions of these multifunctional systems to diverse stakeholders, the term "Blue-Green Infrastructure" can have a more flexible use and sound. The abstract terms "green" and "blue" can easily be associated with the physical elements that this infrastructure connects.

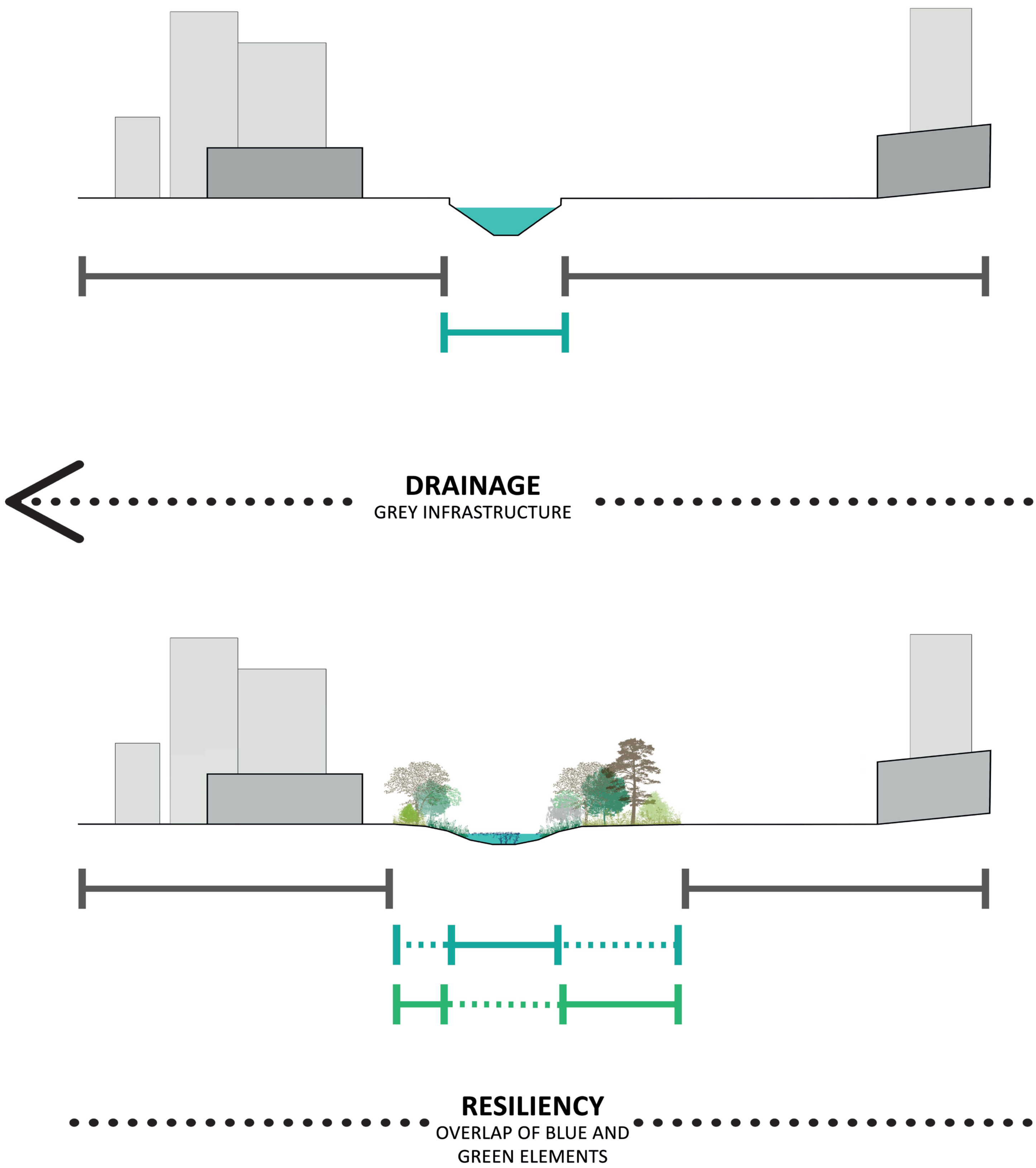
The term "green" relates to green infrastructure, which gained its wide recognition two centuries ago when cities needed to rethink unhealthy urban living conditions. Today this concept is widely used for revitalising densely populated areas through many versatile green elements, such as parks, vertical or horizontal gardens and alleys. More and more benefits of this infrastructure for ecology and society are gradually recognised, namely through ecosystem services. (Dreiseitl, Wanschura, 2016)

The term "blue" relates to blue infrastructure that contains hydrological functions. *"It includes 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, decentralisation and spreading, soaking into the underground, evaporating and releasing water into the natural water environment."* (Dreiseitl, Wanschura, 2016)

Essentially, the blue infrastructure controls water quantity and water quality. The green infrastructure strengthens these functions and compliments them with reduction of air pollution and heat island effect. At the same time, the green infrastructure fulfils its primary function of amenity, spatial organisation of place and establishing opportunities for a recreation. *"The Blue-Green Infrastructure paradigm marries these two types of infrastructures and values together in a union that is greater than the sum of its parts."* (Dreiseitl, Wanschura, 2016)

Blue-Green Infrastructures (BGI) "are adaptable systems and can be efficient on a variety of different scales, depending on attributes of the local urban context, such as available space, topography, and climate. These systems include vegetation (the "green") as well as hydrological features (the "blue") within urban design interventions." (Dreiseitl, Wanschura, 2016)

Typical conditions in cities refer to "drainage" and "functionality" (Figure 10). "Drainage" means that there is a predominance of impermeable surfaces, lack of vegetation and underground piping and concrete channels for storm water. "Functionality" refers to conditions



where grey, blue and green infrastructures are adjacent but functionally separated from each other.

The WSUD approach can be indicated where the blue and green elements overlap. Such parts address "resiliency" because these systems have the capacity to preserve the original state after being exposed to stressful water events. Repetition of such systems can result in an ongoing process of integration that can have a different level of intensity. The state of "full integration" can be articulated in the form of a storm water chain that consists of individual BGI components (such as green roofs, bioswales and rain gardens) that are linked together. The more links are put together, the stronger the chain is and consequently, more integration is achieved. The start of the chain will usually be any grey infrastructure (like buildings, roads or even small garden sheds). The end point will be at the lowest point in the area (that can be, for example, a river or low-lying park). (Dunett, N. 2007) The storm water chain (which is a synonym for BGI) aims to link these two points through interconnected BGI elements.

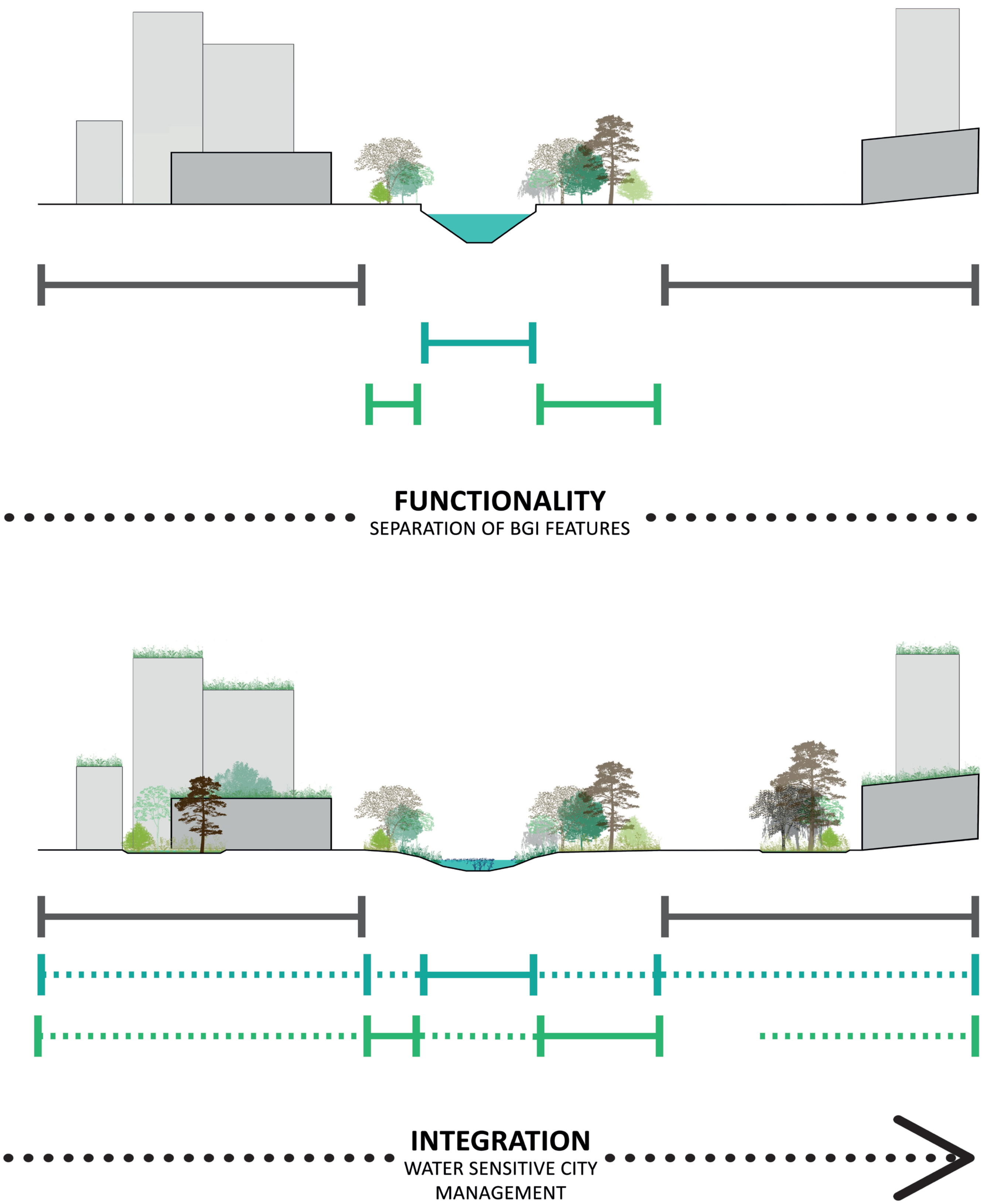


Figure 10 – illustration of different gradients of BGI in relation to urban infrastructure (adopted from Dreiseitl, H. and Wanschura, B., 2016)

2.2 Benefits

If BGI is well integrated into the urban fabric in regards to its context, it can provide a wide range of benefits. BGI can directly enhance aspects related to sustainability, resilience and liveability.

See Attachment A1 in order to see a list of benefits.

2.3 Components

The components of BGI are technical solutions for enabling sustainable and resilient storm water management. They correspond to specific water management needs and specific site constraints. *“Appropriate selection of methods is important for the success of any system, but there is not necessarily a “right answer”. In fact, the ideal solution is often several methods appropriately linked.”* (Hoyer, 2011)

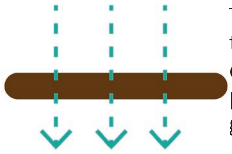
See Attachment A2 in order to see a list of components.

2.4 Functions

The primary function of each BGI component is to enhance water quality or water quantity or both. Each component has a very strong capacity to enhance spatial organisation of a physical space and influence the way it is used by people. Further, it can stimulate social functions like recreation and DIY design (do-it-yourself design) potential for evolving of human individual creative activities. Lastly, it provides habitat for flora and fauna.

Regulation of water quantity

Evaporation
This is the process of water changing from a liquid into water vapour.



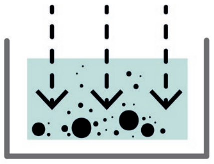
Infiltration
This is the process of water soaking into the ground. This process directly reduces water quantity. It restores hydrologic processes – mainly in terms of recharging groundwater resources.

Retention
Rainwater is retained at one place for a period of time. It can be used at a later stage or when it is ready it can be released to the surface drainage or water bodies. (Public Utilities Board, 2009)

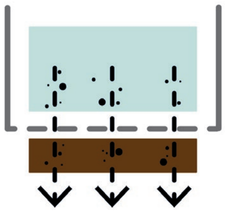
Conveyance
It controls and transports the surface runoff to a next or a final receptor. Controlled conveyance is important in order to link (through roads, pipes and trenches) various components of the BGI together.

Regulation of water quality

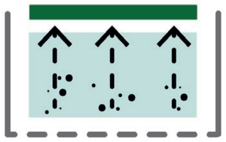
Sedimentation
It is a mechanical removal process of solids and particles that carry pollutants. *“Sedimentation is achieved by reducing flow velocities to a level at which the sediment particles fall out of suspension. Care has to be taken in the design to minimise the risk of re-suspension when extreme rainfall events occur.”* (Woods Ballard, B. 2016)



Filtration
Filtration is a natural process of separating the pollutants from contaminated water within the soil medium before it reaches the aquifer.



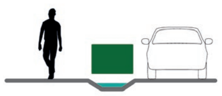
Phytoremediation
Phytoremediation is a series of complex biological processes which are regulated by plants that have the ability to cleanse water and soil from pollutants. Plants can degrade, extract, contain, or immobilise contaminants such as metals, pesticides, explosives, oil, excess nutrients, and pathogens from soil and water. Phytoremediation has been identified as a cost-effective, non-invasive, and publicly acceptable method of removing environmental contaminants.

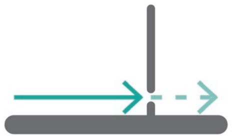


Spatial design

Structural functions
The structural elements of the BGI can co-organize a large open space into a few smaller spaces. The vegetation can create a different degree of densities in space - from sparse to very dense. The BGI can create a soft gradient between different social territories (between private and public, through the creation of semi-private or semi-public spaces). The BGI structures can help to create such smooth transitional zones through accompanying large, impersonal or unused spaces.

Soft edge
In certain situations it is necessary to separate activities or different social territories that are not compatible (for example noisy activities from calm activities or those private from the public). Physical linear elements of BGI can create this separation in the form of a soft edge with the possibility of keeping the visual connection between these places while making water visible on the surface. The soft edges separate one function from another without making a visible barrier.





Detention
It slows down the surface runoff and extends its duration which reduces peak flow rate. The principle of this function is the usage of storage volume and fixed outlet. (Woods Ballard, B. 2016)

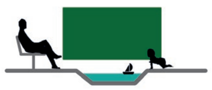
Storage
It is the direct capture and use of rainwater on-site for domestic use or irrigation of land.

Creation of habitats

Biodiversity
The majority of the BGI components work with different elevations where different vegetation thrives. This can create more diverse and complex mixes of a planting material that has a direct positive effect on wildlife and habitat value. *"The most effective wildlife-friendly landscapes take the form of 'mosaics' of different habitats: grasslands, wetlands, woodlands and scrub. Rain gardens provide an opportunity to work with this frame-work. Such 'ecotone' structures maximise wildlife value."* (Dunnett, 2007) In the optimal case, the diverse animals have the possibility to migrate between these areas.

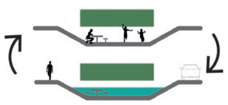
Social functions

Do-It-Yourself capacity
The problems of drought or flood are difficult to solve solely through institutions and other parties that are not directly interested. The citizens who are direct recipients of these negative effects of climate change have the opportunity to take an active role in problem-solving and use their individual skills and abilities directly.
Certain BGI components are very flexible and user-friendly solutions that can be used for so-called Do It Yourself Design (DIY Design). It is not necessary for the creation process of BGI to be entrusted solely to professionals who are not directly interested. Directly-interested groups (such as users who inhabit the site) can play a vital role in the implementation of these solutions in situ while upgrading and beautifying their own surroundings. However, it is not wise to entrust the whole design and construction process solely to inexperienced users. The involvement of both parties can be a most vital option, depending on the difficulty of each BGI solution.
In areas where there is an urgent need for such solutions, the citizen empowerment can take over the process of design and implementation and benefit from strong ownership and a deeper connection within their surrounding. The output of this function is the cultivation of individual skills, raising the sense of community and ownership.



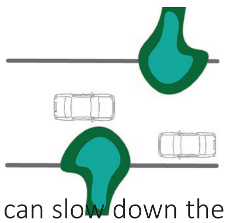
Recreation
Thoughtful usage of the spatial design function of the BGI can provide a place where people can meet and at the same time do a variety of different activities. This possibility can be most useful in densely-populated areas where everyday life is in constant movement from one place to another. BGI can provide an oasis, a large or small checkpoint on the way to everyday duties or a destination for optional and social activities. Places where people can gather and meet are essential for human interaction. People attract people. People need places for walking and for staying. (Gehl, 2010)
The BGI can contain elements for comfortable seating, for sport or for other recreational and social activities that can be subject to design within the BGI.

Dynamic use
BGI can provide more variety of optional social uses during the dry period and necessary functions during a wet or cloudburst period.



Aesthetics
BGI can provide strong visual and sensory pleasure. The combination of vegetation and water is a fascinating landscape element. Such aesthetic qualities naturally attract people to come close.

Traffic regulation
BGI takes its place of implementation very often on the motorised streets where traffic dominates other street functions. It can play an important role in the regulation of over-motorized streets where urban life is neglected. Usage of BGI components can slow down the traffic flow. This is especially beneficial in urban living areas where drivers are looking for shortcuts or on streets that are too long and thus motivate drivers to drive faster.



III

METHODOLOGICAL CONSIDERATIONS

3.1 Planning strategy for implementation of BGI on large scale

3.1.1 Cloudburst formula – a planning strategy for climate adaptation

3.2 Model for implementation of BGI by private property owners

3.2.1 Examples of solutions implemented on a private property

3.1 Planning strategy for implementation of BGI on large scale

The process of planning BGI is a comprehensive task. It requires a multidisciplinary team where traditional design skills of hydraulic engineers are combined with advanced modelling expertise. Landscape architects and urban planners contribute to the spatial design of BGI and economists provide the economic assessments that are necessary for safe and informed decision-making. (Strobaek, N. Nielsen, C. 2013)

The strategic planning of BGI typically can be performed on many levels of detail. In this case, a more general description of the methodology will be explained to make sure that all important steps are touched upon.

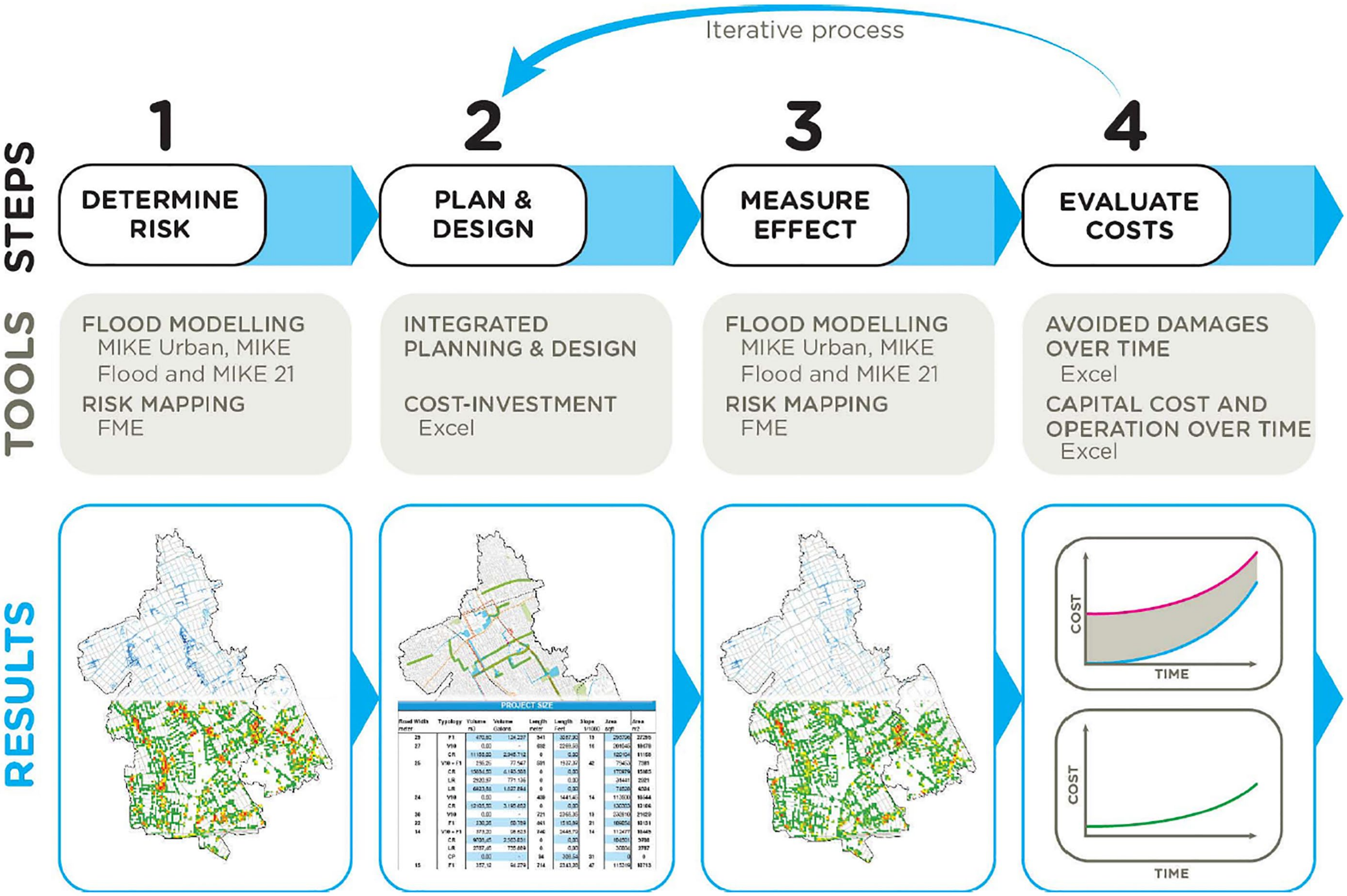


Figure 17 - four key steps of Cloudburst Formula

3.1.1 Cloudburst formula – a planning strategy for climate adaptation

Ramboll's climate resiliency planning practice developed strategy that can enable the climate adaptation of built environment. This strategy was and is being currently implemented world-wide (in cities such as Singapore, New York, Copenhagen and Gothenburg).

Ramboll calls this planning strategy "Cloudburst formula". It is a comprehensive approach that is based on informed decision making and integrated planning. Essentially, it determines risks of flooding, applies principles of WSUD and evaluates the socio-economic impacts before and after adaptation, which is useful for informed decision making.

The formula consists of several unified principles that drive the overall planning process. The planning process uses comprehensive empirical GIS data that relate to a studied site (such as climate, geology, sociology and hydrology). It analyses them and overlays them spatially at multiple levels (neighbourhood, district or municipal scale) in order to identify potential synergies and cumulative effects.

It applies the following four key step principles (Figure 17):

Step 1

This is the analytical part that determines and assesses risk areas that are vulnerable to extreme rain periods.

Step 2

The plan that aims to resolve the problems in the most effective way is proposed with its estimated operational and investment costs.

Step 3

On the basis of the proposed plan, risks are measured again together with a new estimate of the cost of damage in order to document the adaptation effect of the proposal.

Step 4

The outcomes are incorporated into a direct cost analysis. The aim is to compare investment and to avoid damage costs over time. If the effect or cost of the developed plan does not meet predetermined standards or thresholds, Step 2 is repeated in order to address adequate service level of the proposal and its associated costs. (Ramboll, 2017)

In order to get a more practical understanding of the Cloudburst formula, these four principles are elaborated in six sub-steps (Figure 19) that make the formula operational.

1. Data and investigation

In every climate adaptation project, the first step is to collect a set of empirical data. Typically these data relate to natural conditions (such as climate, geology and terrain), hydrological conditions (level of ground water and soil infiltration rate), society (e.g. demography), land-use and ownership (for example identification of privately and publicly owned areas), economic figures (such as costs from insurance companies) and current infrastructures (data about sewer infrastructure, buildings, roads and vegetation).

2. Mapping and modelling

Previously-gathered empirical data that can be represented spatially are shown through the desktop analysis on a set of maps (including green areas, services, etc.).

Certain data are used as the basis for a modelling. A modelling is necessary to understand hydrological conditions in the area and how the cloudburst events influence the area, especially in terms of vulnerability against floods.

To produce initial hydrological information a glass model is created through ArcGIS (which is Geographic Information System (GIS) for working with maps and geographic information) and FME (which Feature Manipulation Engine used for integration of geo-spatial data).

A glass model can provide an understanding of the effect of extreme rain in an area without considering underground sewer infrastructure. *"This initial GIS analysis is not as comprehensive as hydraulic modelling as it does not factor in the sewer system but it does provide a very quick understanding of physical properties of storm water in the area during these extreme rain events."* (Ramboll, 2017)

A glass model consists of three outputs: Watershed (catchment areas), Blue-spot analysis and Flowlines.

Watershed helps to understand how large an area is impacted by local storm water. This creates a border in the area that is called a catchment area. Blue-spot analysis locates low-lying dips in the land. These areas can be potentially vulnerable to flooding. Flowlines indicate how and where the storm water will flow on the surface during cloudburst events. (Goring, 2016)

This model helps to do a quick screening of potential risks. Its outputs are further used in the planning and design steps.

Still, it is important that a hydraulic model is prepared for the area to support this initial analysis and specify the risks in greater detail. (Ramboll, 2017)

For the creation of a hydraulic model, a MIKE software is used in order to determine the most accurate risks in terms of flooding in the current built area before and after implementation of the solutions.

This programme is a GIS-based software system. It simulates the integrated water flow dynamics between storm water systems (sewers, basins, rain gardens) and surface areas (permeable and impermeable surfaces) in a 2D terrain model. (Ramboll, 2017)

These simulations are usually done with two different return periods- typically one with a higher probability (such as a 10-year storm water event) and one with lower probability (such as a 100-year storm water event). Both events usually have a different scale of negative impact on the area. When comparing the simulations of high and low return periods, areas with high return periods are typically more negatively affected (in terms of physical damage or injuries).

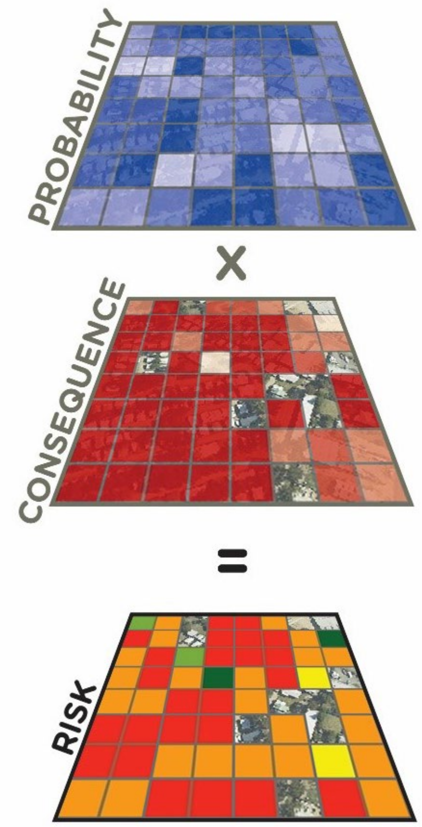
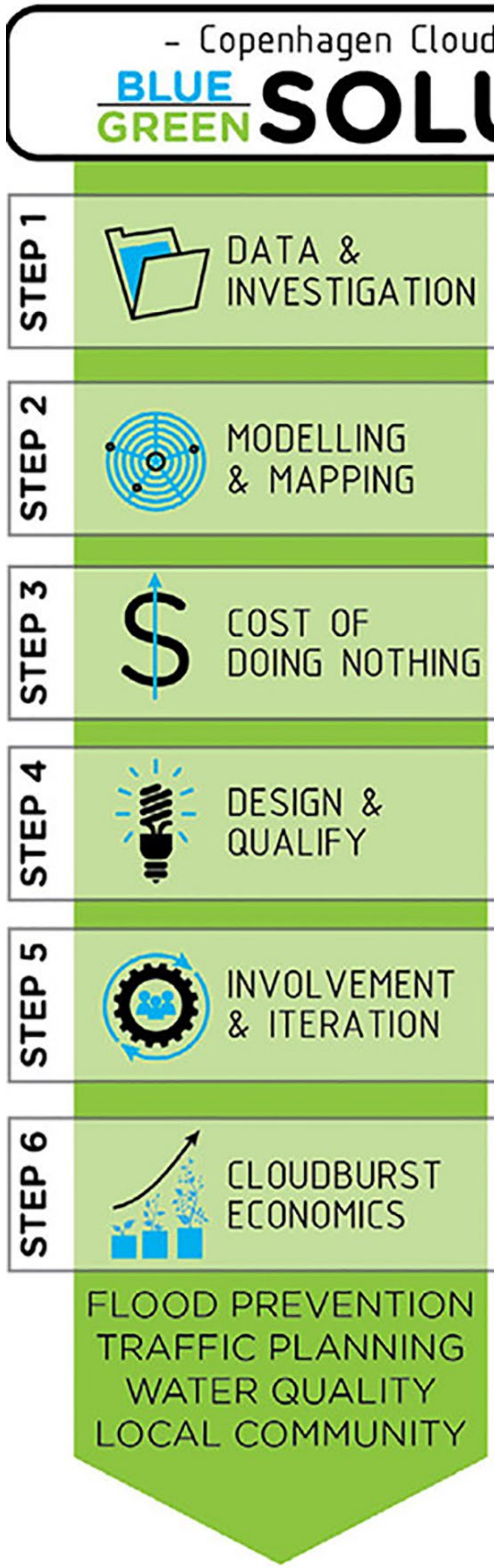


Figure 18 - principle of Risk Assessment Analysis

The key figure for each return period is estimated, based on projection of Intensity-Duration-Frequency of the rain that is related to the climate context where the model is going to be simulated.

Risk Assessment Analysis



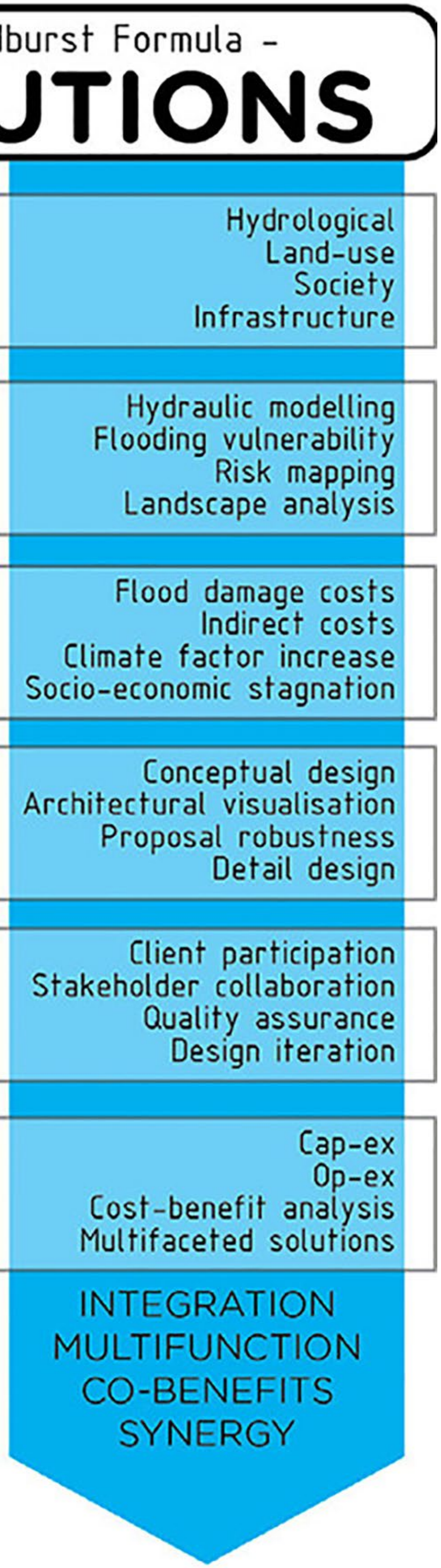


Figure 19 - complete Cloudburst Formula

The simulated probabilities (return periods) from the hydraulic model are used for further analyses. In terms of Risk Assessment Analysis, these simulations of different scenarios help to locate the potential risks (Figure 18). The Risk Assessment Analysis helps to determine the physical effect of a spatially-represented flood risk in the actual build environment (Figure 21). (Ramboll, 2016)

3. Cost of doing nothing

Simultaneously during analysis, economic costs can be estimated for each flood scenario. This requires a combination of statistical data on demography and geographical data on critical infrastructure with experience-based costs of damages. This information is overlaid with risk assessment analysis. The criteria are a set of well-defined assumptions for damage unit costs. This is usually developed in close cooperation among the stakeholders and Ramboll. (Ramboll, 2017)

The outputs are used to estimate direct flood damage costs per year (Figure 22). Typically it compares economic costs between two return periods relating to the current situation with no adaptation. In later stages, these situations are further compared with a master plan in order to document its effect regarding avoided damage and costs.

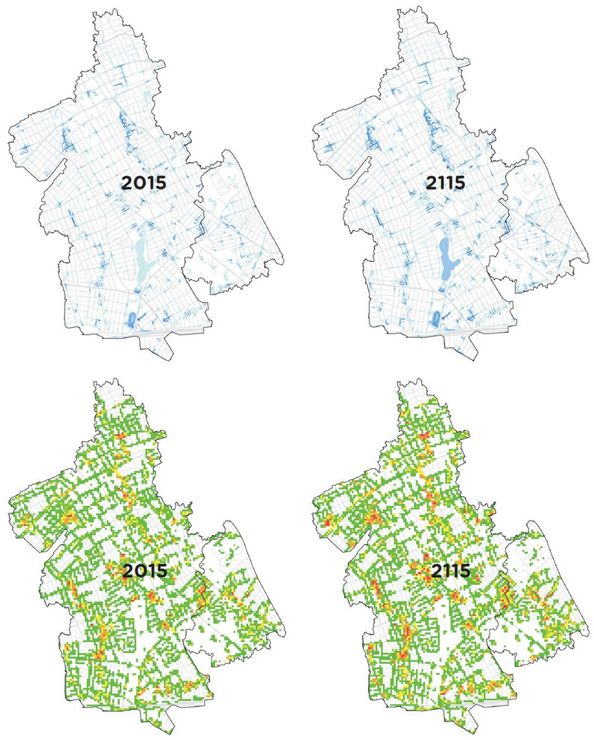


Figure 21 - determination of flood risks based on two different rain events

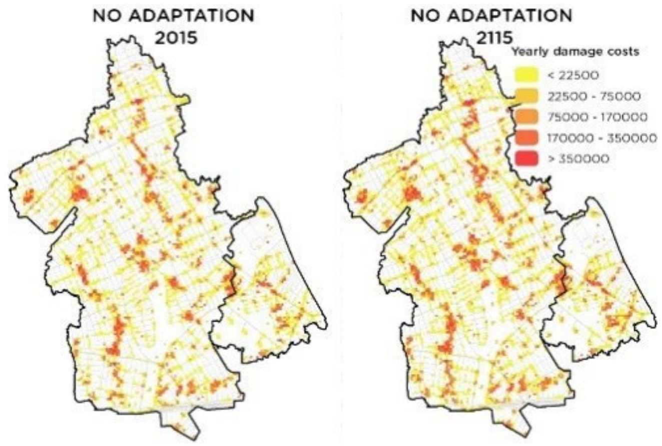


Figure 22 - determination of yearly damage costs based on documented flood risks

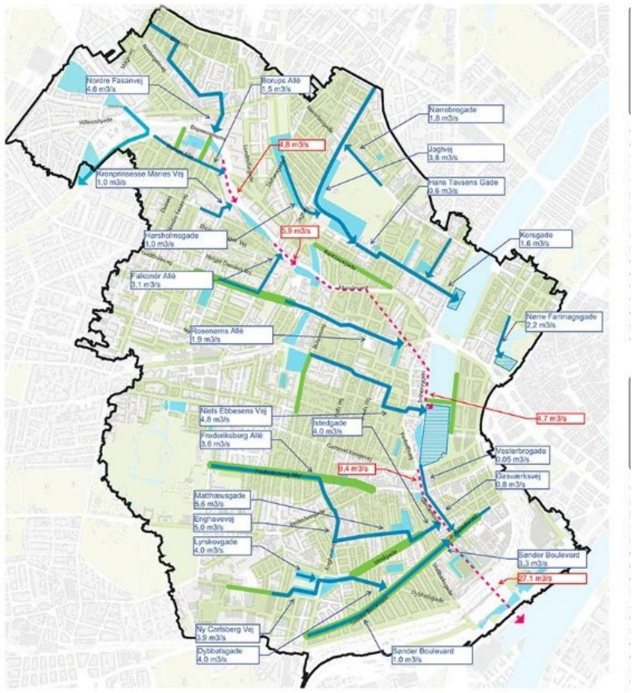


Figure 23 - an example of Cloudburst Master plan

4. Plan and design

This step has a dual purpose: it develops a plan with designed BGI components and estimates associated capital investment and operational costs. (Ramboll, 2017)

This part usually produces two documents: A Cloudburst masterplan (Figure 23) which operates on the conceptual and strategic level of storm water management and a Cloudburst Concretization Plan which details the Cloudburst Masterplan (for example how the area is going to be designed spatially and what BGI components will be used for the storm water management).

The Cloudburst masterplan is a storm water plan that is developed specifically for every climate adaptation project that covers large-scale areas (on a neighbourhood, district or municipality scale).

The existing and planned infrastructure is studied and then it is determined what function of storm water management each node of the street or area will have. The decision is made with regards to whether it can transport, retain or delay storm water before it continues downstream. (Ramboll, 2017)

The plan of BGI can be understood as an interconnected storm water chain. Each part of the chain has its function according to how rain water is handled.

The storm water chain can consist of five different elements: cloudburst road, retention street, central retention area, local retention area and cloudburst pipe. These elements are used as universally-applicable flood mitigation strategies. (Ramboll, 2017)

Cloudburst road

It is used for transporting rain water from one point to another.

Retention street

It retains and delays water in upstream connections before water eventually reaches a central or local retention area.

Central retention

These areas are proposed in larger open spaces where it is possible to retain or delay storm water, so that downstream cloudburst roads or retention streets can be established in smaller dimensions. Typical implementation of retention areas is proposed on parking lots, in parks, skating parks, playgrounds, etc. (Ramboll, 2016)

Local retention

These are areas with small-scale solutions (e.g. rain gardens or basins) for individual plots or communal areas. They deal with storm water directly where it lands. (Ramboll, 2016)

Cloudburst pipe

This principle uses traditional piping solutions. It is typically used in low-lying areas, where limited terrain alterations do not permit the transport of water out of the area. (Ramböll, 2017)

The initial step is to identify the source location of the problem and to consider possible ways to control rain water closest to the source of where it falls. In practice, it means to start to search upstream in the catchment and identify high-lying impermeable areas and look for possibilities to infiltrate or retain the rain water there first. The main thought is to strive to create a decentralised storm water system where water can be handled locally within the local retention area.

However, it is not always possible to control all rain water locally at its source, especially during a heavy cloudburst. In that case, the overflow is transported downstream through green streets/cloudburst streets or, if there is no other option, through cloudburst pipes into the closest low-laying area where it can infiltrate or be retained. This area is then called a central retention area because it links other storm water chains through interconnected BGI components. The storm water chain does not have to be linear. "The secondary chains and smaller chains can link in with the main chain in the same way that streams and tributaries join the main river." (Dunett and Clayden, 2007) The central retention area works as a stopping point for rain water to remain and soak in.

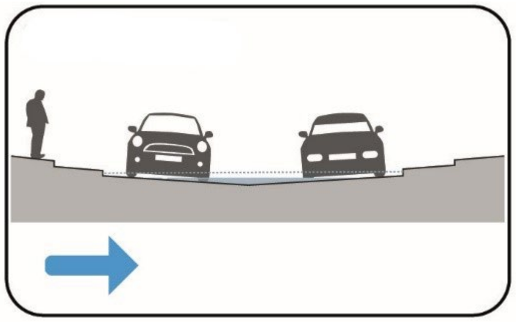


Figure 24 - Cloudburst road

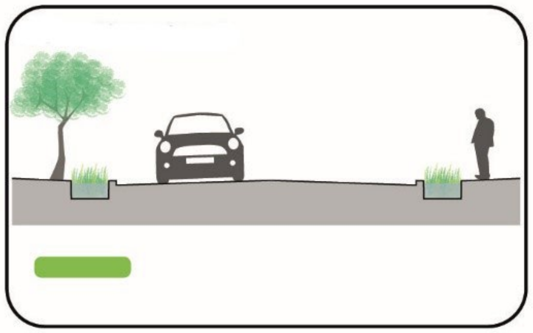


Figure 25 - Retention street

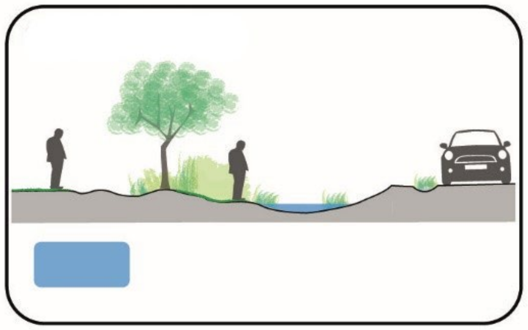


Figure 26 - Central retention area

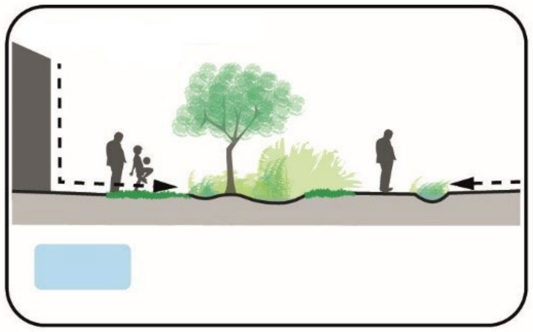


Figure 27 - Local retention area

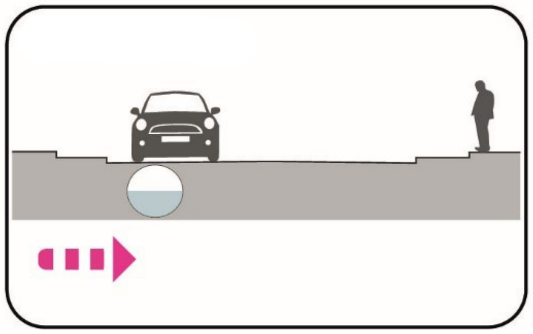


Figure 28 - Central retention area

Each transport and retention area or street is designed in detail in the Cloudburst Concretization Plan. This creates the possibility of assigning other co-functions of BGI (like spatial design, regulation of water quality, social and habitat functions) that have the capacity to address local demands while respecting local conditions. These functions are conditioned through organisation and selection of BGI components that correspond to proposed principles in the Cloudburst Masterplan. The concretization plan ensures that the multifunctional potential of a space is addressed. It provides a detailed design of new storm water management that addresses new urban life opportunities along with current functions.

5. Involvement and iteration

In this stage, the project is ready for the participation of concerned stakeholders (Figure 29) and can be further adjusted.

Figure 29 - stakeholders participation

“Relevant stakeholders go through the process of understanding where flood waters flow, where water can be stored or conveyed, which limiting or supporting frameworks or decisions apply, and finally where connections to other plans for the urban environment can be established, (such as parks or bike lanes). Stakeholders might go through the process several times as the design must be updated when new knowledge is obtained.” (Ramboll, 2017)

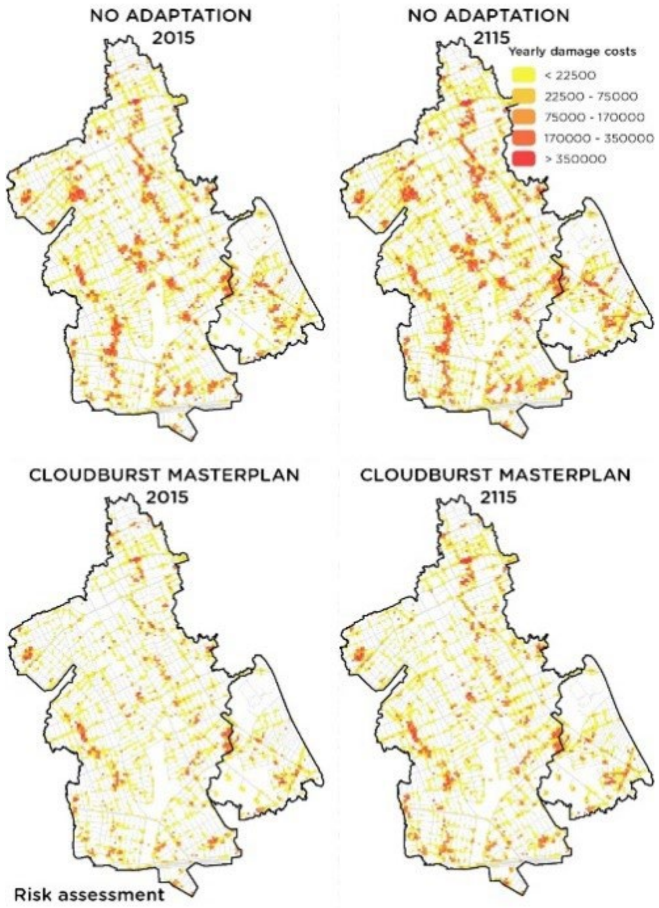


Figure 30 - new iteration of documentation of risks and damage costs with new proposal

New hydraulic simulation is done based on an adjusted proposal in order to test its water resiliency. At the same time a calculation of the yearly flood damage costs on basis of the proposal is done and compared with the current situation (see step 3 and Figure 30). This iterative process can be repeated more times.

6. Cloudburst economics

This last step helps to evaluate the overall economic impact of the proposal through Cost Benefit Analysis (CBA). Compared to Direct Damage Cost Analysis from the third step, *“the CBA is considering also the social and environmental costs and benefits associated with a project. It is a strong tool to communicate the wider social impacts and co-benefits of a masterplan to relevant stakeholders and decision-makers.”* (Ramboll, 2017)

Essentially, it consolidates the third step (“measure effect”) of the formula. In addition to Direct Damage Cost Analysis, CBA evaluates avoided social costs (injuries, mental stress and anxiety) and environmental costs (cleansing of polluted water) together with created benefits that are both social (health benefits, recreational value, aesthetic value) and environmental (pollutant removal and carbon sequestration).

All negative impacts in CBA are considered as costs while all positive impacts are considered as benefits (see Figure 31). The total costs and total benefits are compared and the result estimates a so-called “Net Present Value”, which provides information to help determine whether social and environmental benefits can outweigh the costs and therefore prove cost-beneficence of the project. (Ramboll, 2017)

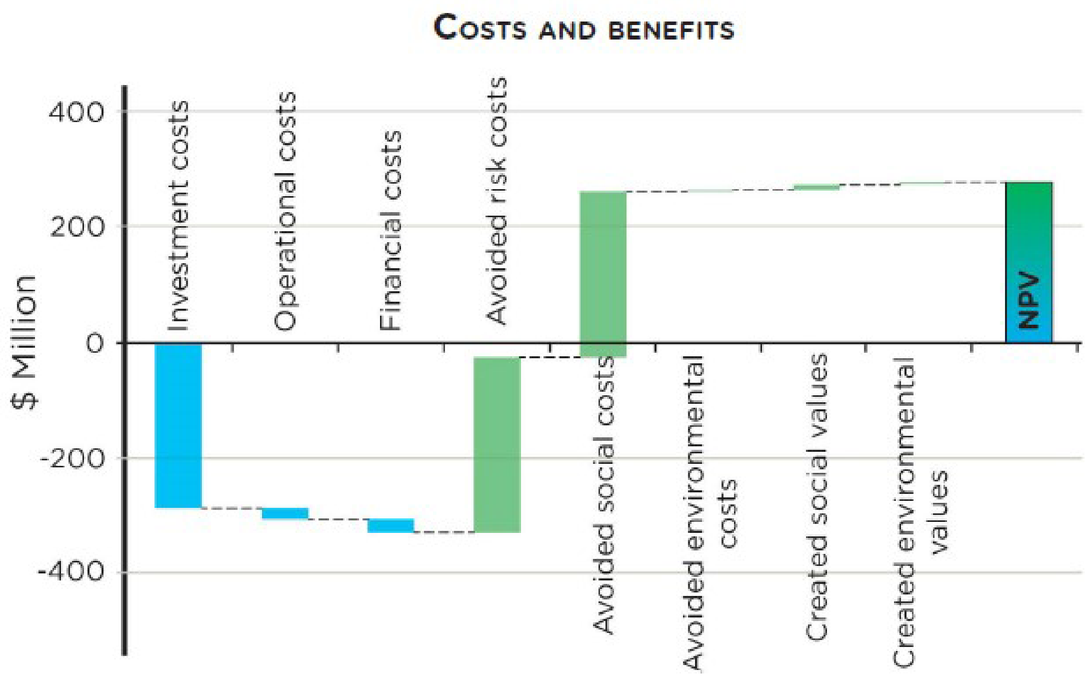


Figure 31 - Cost-Benefit Analysis

3.2 Model for implementation of BGI by private property owners

The previous chapter showed the comprehensive planning strategy which can be used in order to plan and design BGI into its urban landscape.

Most often, a substantial part of these solutions is implemented on public property that is owned by the municipality and the water company.

However, private property also represents a significant part of the area that is affected by rain water. Private areas often contain a large proportion of green space and collectively they present important opportunities for influencing water management in the cityscape. (Dunnett, 2007)

Yet, as it was mentioned in the MSc's Preface, *"the municipality of Copenhagen can only do so much by itself. Private properties and homeowners have to make the decision themselves to be part of the solution."* (Ramboll, 2016)

Politicians can create favourable and supportive conditions that give the opportunity to their citizens (residents, business, schools and communities) to take an active part in a climate adaptation process.

These conditions should include informing people about the effects of climate change, educating them about what individuals can do and explaining local benefits of climate adaption and mitigation. Further, it is necessary to create supportive conditions in the form of guidance that can be available for individuals to take them through a climate adaptation and mitigation process from the beginning to the end. Financial compensation should be available for individuals who decide to take part in the process. This can take the form of an indirect subsidy that is offered to private property owners who use BGI solutions for managing their storm water and reducing their impervious surface area. (Hoyer, 2011)

The following model represents an example of a practical method for implementation of BGI in the private sector in Denmark. This model consists of the supportive framework that guides individuals from the beginning to the end of the process of BGI implementation.

Description

The municipality of Gladsaxe has taken a very active part in climate adaptation. Its projects encompass public and private projects, some completed and some still in progress. A large part of its land use consists of the living sub-urban area and small businesses. The municipality realised that in order to achieve climate adaptation effectively it would need to create conditions that enable active participation of individuals.

The result was a mutual agreement between Gladsaxe and the water company Nordvand to give financial support to citizens in handling storm water on their private property with a model called "Regnvand på egen grund" (Rainwater on your lot). This model works as a tool that individuals can use for their guidance. If the private property is a good candidate for applying BGI solutions the owner can receive financial compensation. At the same time, it is necessary to ensure that the implementation of these solutions is legitimate and that it functions correctly. To ensure that, the following criteria that act as guidance are followed by the individuals before receiving financial compensation for any implemented BGI solution.

Criteria and guidance

Before using the model it is necessary for the applicant to fulfil the following criteria:

1. A private space should be located where the soil has good infiltration conditions for rain water and where the ground water level is not too high.

The applicant can check via the municipality webpage if her/his land is suitable for infiltration. It is also possible to apply for a review of the site when the infiltration conditions are unclear. An applicant must send the electronic application to the Environmental department, which will give her/him a license for infiltration on her/his site. If this requirement is confirmed, the applicant can start to think about possible solutions for managing the rain water locally.

2. The storm water that the landowner must handle must be managed within private property territory; therefore each private territory should function as a local retention area. There should not be any overflow into the public underground sewer system.

The web page showcases different BGI solutions that owners can choose to apply. This is done through use of the storm water chain that connects individual BGI components.

In practice, it results in similar principles that were described for designing a large storm water chain of BGI elements in the Cloudburst Masterplan. It typically focuses on an individual private area that usually consists of a single house with sufficient outdoor space for the design of a small storm water chain. The typical source of storm water run off is the roof of the building. Conventionally, from the roof, all storm water goes through downpipes into the public sewer. The new goal is to disconnect the downpipe and use methods of storage, transportation and retention of the rain water on-site. The most common BGI components used for this scale are green roofs, rain barrels, storm water planters, gullies, soakaways and rain gardens.

3. The owner must handle from 50% to 100% of rain water in order to get financial compensation.

The maximum financial compensation that an owner can get is 23 795.95 DKK. This is in case the owner can handle 100% of the rain water within her/his private property. If the owner can manage only 50% (that is the minimum amount) of rain water, the financial compensation will be 0,50 x 23795,95 = 11 897,97 DKK. There is an excel sheet available on the webpage that allows the applicant to calculate the amount of water from the surface area of impermeable surfaces that are located on her/his private land.

4. The private pipe that leads storm water from private property into the public sewer infrastructure must be disconnected by the water company.

In this step, the homeowner must submit an electronic application to the water company for disconnection, followed by an on-site inspection and consultation with a representative of the water company. As a result, the owner should receive financial compensation that can be used for the creation of a storm water solution, which can be completed either alone or with a consultant chosen from the list that is available on the web page.

3.2.1 Examples of solutions implemented on a private property

Gladsaxe organises tours for interested citizens to see BGI solutions that have been adopted on private land. Five selected private gardens are used to demonstrate these solutions. The following figures show two private gardens with their specific BGI solutions.

Figure 32 - a private garden that uses a gully, a bioswale and one big rain garden to handle rain water

Figure 33 - a detail view on the gully and disconnected downpipe

Figure 34 - the bioswale that transports rainwater from the gully into the rain garden

Figure 35 - a photo of the rain garden that collects rain water together with a view on a second downpipe with the gully in a background

Figure 36 - another private garden with diverse BGI solutions that consists of two rain gardens, gullies, storm water planters and small dry basin

Figure 37 - a view on the rain garden in the front of the house with gully and stormwater planter in the background

Figure 38 - the storm water planter in the back garden which is directly connected on the downpipes

Figure 39 - the rain garden collects rain water from the storm water planter. During heavy rain the excess rain water from the rain garden can over-flow into a nearby dry basin.

Figure 40 - the dry basin, which during dry periods can be used as a fireplace and during heavy rain it can retain rain water

IV

4.0 CASE STUDY: MAKING KALENDERKVARTERET WATER SENSITIVE

4.1 Background

Ramboll is currently working on a large-scale climate adaptation project known as Kagså. They have allowed me to use it as a case study for my master's thesis.

Kagså is a joint project between two municipalities – Gladsaxe and Herlev, both located in the greater area of the city of Copenhagen called Storkøbenhavn (Greater Copenhagen).

This project was established in June, 2014 with the aim of managing water unbalances, which cause discharge during rain events into a small urban creek called Kagså. This open creek is not resilient enough to handle extreme rain events and therefore it becomes a broad issue (including socio-economic risks and damage risks to private and public property).

The creek is located exactly on a territorial border between these two municipalities and is part of a green strip called Kagså Park, which passes through many different neighbourhoods. The axis of this green area forms the border for the project area (Figure 41), which Ramboll is being commissioned to develop.

The mutual agreement between these two municipalities has set the following goals, which Ramboll plans to achieve:

- The project should calculate and propose solutions for the maximum volume of water that can be handled in the initial project area.
- Blue-green infrastructure should be prioritised in the design solutions over grey infrastructures.
- Solutions should handle such a volume of water that it will minimise flooding of: (a) priority infrastructure (b) property (c) other infrastructure in descending order of priority.
- An overflow of waste water from a sewer into the creek must be handled.

In the agreement, two other sectors are involved, which are directly responsible for the current sewage infrastructure in the area – the water companies HOFOR and Nordvand. They have recommended that the Ramboll project should also:

- highlight potentials for recreation.

With these instructions, Ramboll has started to seek possibilities for retaining rain water in the project area.

A design proposal was created and on its basis, simulations of cloudburst events were conducted through a hydraulic model.

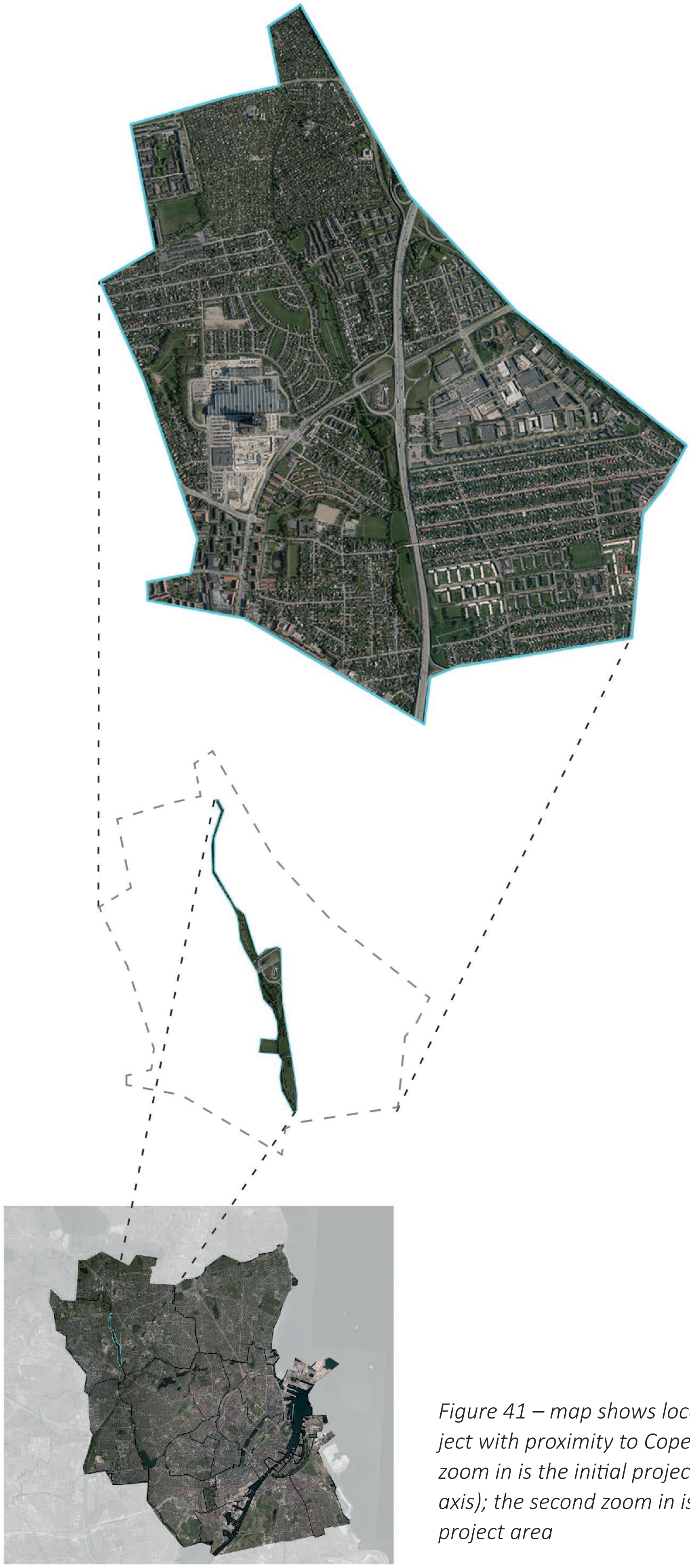


Figure 41 – map shows location of the project with proximity to Copenhagen; the first zoom in is the initial project area (the green axis); the second zoom in is the current project area

After the comprehensive hydraulic calculations, it was determined that the area itself does not have enough capacity to accommodate storm water and therefore it is necessary to look for more potential outside of the Kagså Park territory. Therefore the initial project area was extended upstream from the current catchment to the surrounding area, where housing and other land-uses exist. (Figure 41).

4.2 Objectives

These are the main objectives for a climate adaptation project within the case study that is based on the Kalenderkvarteret neighbourhood. The objectives are formulated in regards to the main MSc objectives, as well as the concerns of Ramboll and various stakeholders.

1) The first objective is to explore issues in Ramboll's project area in relation to flood risk. The aim is to identify areas that are vulnerable and define the negative effects. This analytical study will identify and define the issues that still remain in the current project area even after Ramboll's proposal for Kagså Park is implemented.

2) The next objective is to select a specific site for the case study that is located in the project area that Ramboll is developing.

3) The third objective is to use this specific site for the creation of a climate adaptation proposal. Through a synthesis of results from the analytical research, the goal will be to propose an evidence-based and flexible landscape solution that improves urban life in the specific area while also providing a flexible storm water management system.

4) The proposal should enable the capability of delaying and leading storm water run off mainly on the surface. By making this possible it should prevent the need of constructing an additional underground concrete pipe for storm water. When possible, the proposed BGI should provide recreational function.

5) The fifth objective is to consider the applicability of the model "Regnvand på egen grund" for collecting storm water on private property. Then, on the basis of local conditions, the goal is to address BGI solutions for private property owners which could be linked with proposed BGI solutions in public spaces. When possible, the storm water from households should not enter the existing combined sewer system. Instead, storm water from private spaces should enter Kagså Park together with storm water run off from public spaces. The proposed interventions on private spaces should require minimal physical and economical effort from the residents.

4.3 Planning strategy

The work on the case study is done in close partnership with Ramboll; therefore, the planning strategy for the case study has been developed using Ramboll's prescriptive Cloudburst formula. This will create a work that can be easy to understand by Ramboll and a reader because it is the same method that was explained in the previous chapter (see Part III).

The aim is not to follow meticulously all the steps of the formula, but rather to reflect on them and then to select only those steps that must be followed in order to create a proposal.

The selected steps are done in accordance with the aims and scale of the MSc case study.

Ramboll's strategy is based on four main steps (Figure 17). In order to fulfil the main aim – the creation of the proposal – the work on the case study will concentrate on the first two steps (Figure 42). The remaining two steps will be considered during the process of working on the case study. If the two last steps (documentation of effect and evaluation of cost) are undertaken, it could result in a more accurate recommendation for what would need to be edited in the proposal in order to reach an optimal balance between cost and safety.

The final outputs will be available for Ramboll to facilitate new iterations.

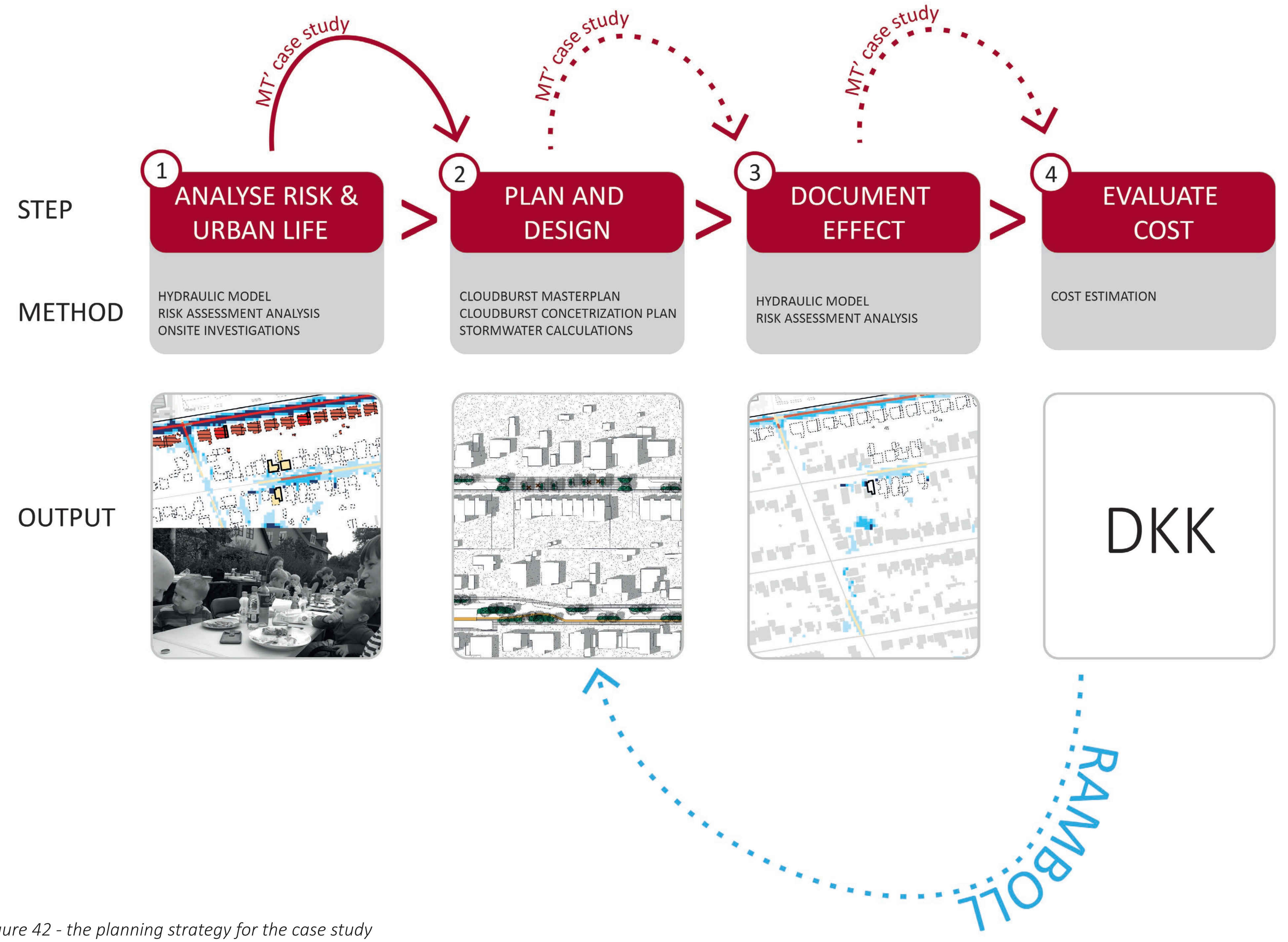


Figure 42 - the planning strategy for the case study which takes an example from Ramboll's Cloudburst Formula

Planning process

The working process alternates between my individual work (red colour in Figure 43) and my collaborative work with Ramboll (blue colour in Figure 43). At the beginning (for example during data collecting, modelling and mapping) this process is more dependent on Ramboll's available data. Later the process becomes more individual.

1. The first step is to study Ramboll's Kagså project and collect geo data on the project area.

2. Because the Kagså project is on a large scale and the problem of floods affects all the areas differently, a Risk Assessment Analysis (RAA) is conducted in order to narrow the research. This is done with use of Ramboll's geo data and most importantly their hydraulic model that simulates extreme rain events.

3. After the RAA is conducted, key risk areas are identified. One key risk area is selected to narrow down the case study to a scale that is suitable for the creation of a proposal for climate adaptation of this specific area.

The results from RAA are used for the calculation of the so-called "Cost of doing nothing", a scenario that can occur when no climate adaptation measures are implemented. This process will focus on a calculation of the costs associated with physical damage in the selected area.

4. Again, more data is assembled specifically for the selected area and then the on-site investigation is made in order to collect data about local conditions and local knowledge. The on-site investigation consists of an observation study, photo-documentation and interviews with local inhabitants.

5. Collected data are visualised through desktop analysis on the maps and local hydrologic surface conditions are analysed through making geo-models in ArcGIS.

6. After all evidence about the specific area is revealed through the analytical part, the next step is to use these insights to create a proposal that will resolve problems and address potentials while preserving current functions. This is done through the creation of a Cloudburst Masterplan and a Cloudburst Concretization Plan that will propose BGI solutions in public space.

In a situation where BGI solutions suggested for public spaces will not have enough capacity to cope with a 100-year rain event, then interventions for private spaces are suggested in order to create a stronger integration of BGI into the neighbourhood.

7. Alternately, the effect of the proposal during a 100-year rain event is documented and a rough cost estimation is processed.

8. The created proposal can be considered in the future for further iterations and involvement with the clients and public. On the basis of a proposal, a Cost-Benefit Analysis can be processed in order to estimate net-presented value and therefore provide assistance in making an informed decision about the possible execution of the proposal.

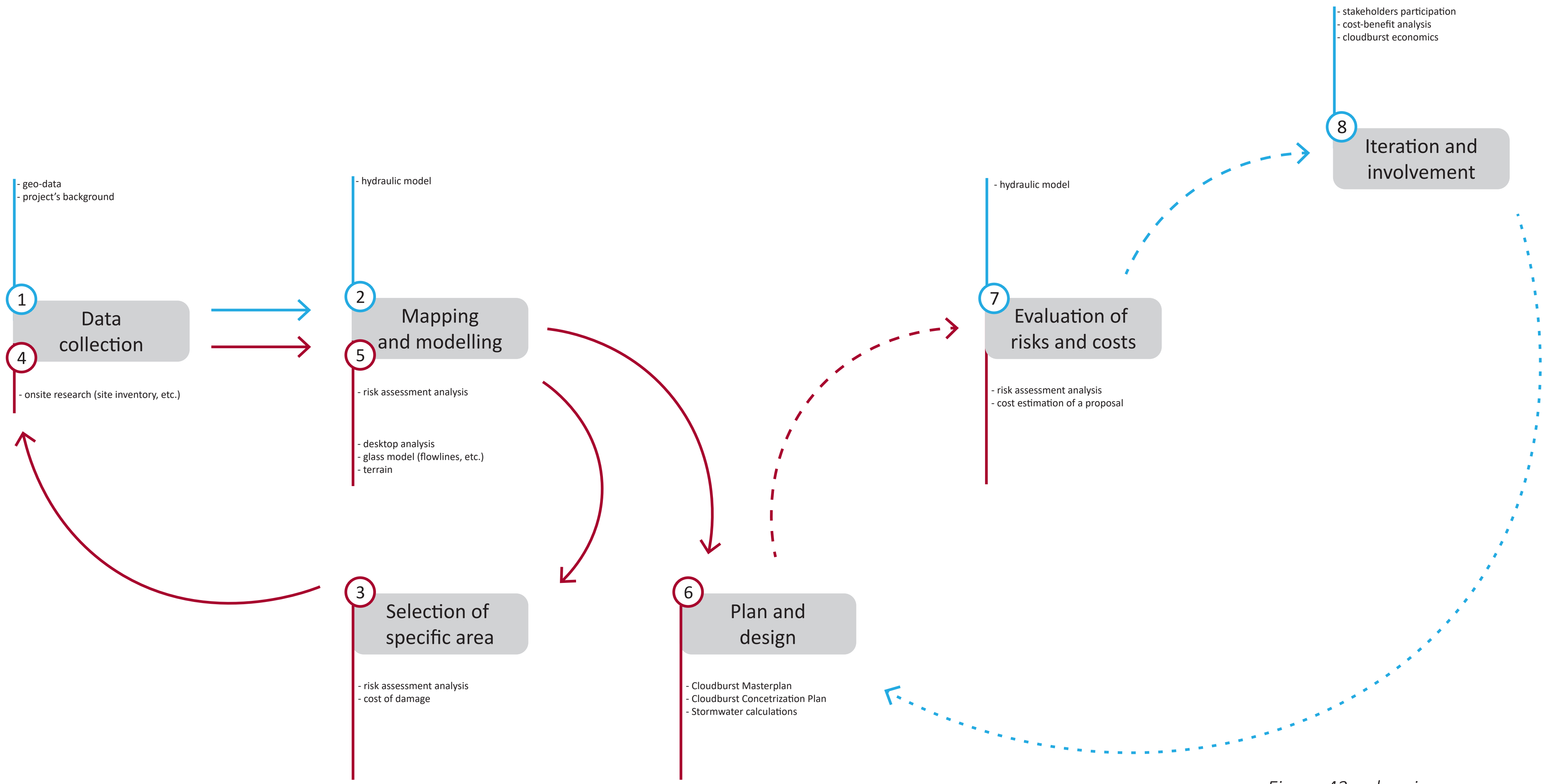


Figure 43 - planning process

4.4 Analytical frame

4.4.1 Risk Assessment Analysis

The analysis is based on Ramboll's hydraulic model of a 100-year rain event. This simulation is made with considerations of planned terrain changes in Kagså park, which will in future have the role of a central retention area to retain volumes of rain water from surrounding areas.

The aim of the analysis is to interpret and locate on a map the degree of vulnerability and its effects in the project area in relation to a most extreme flooding scenario.

Input for the analysis

- Hydraulic model with simulation of a 100-year rain event
- Buildings
- Roads and sidewalks
- Fire station
- Public transport hubs
- Hospital

Method

The ArcGIS programme was used to preform the analysis with the application of following tools from its toolbox: Reclassify, tools for conversion of raster to polygon and vice versa, Network analysis (to identify accessibility) and Raster Calculator (to calculate multiple values).

Criteria

The analysis was based on several assumptions, which work as criteria. All criteria are based on aspects of physical damage and accessibility. The criteria were first discussed and formulated with Ramboll's expert on risk assessment – Henrik Thorén – before making an actual analysis.

There are two entry values used in the analysis: 2, which is causing damage or inaccessibility and 0, which indicates no vulnerability to infrastructure in terms of accessibility or damage (always represented by the colour grey).

Originally, there was also value 1, which could indicate difficulty for full accessibility and low-risk damage, but this value is not entered in order not to multiply the complexity of the analysis.

Physical damage

The analysis Is done only for buildings in the project area. It represents a situation where water that is higher than 20 cm from the ground reaches part or whole buildings in the project area.

Buildings

Based on this assumption a criterion is formulated for a building:

High risk of physical damage – water level is above 20 cm and reaches part or whole building – value 2

Accessibility

This analysis is done via Network analysis. It determines the shortest path from point A to point B. Here one point always represents a building and the second point is the nearest public transport hub (to represent accessibility from every building in the project area to a public service) or a fire station and an ambulance (to represent accessibility of emergency services to every building in the project area).

Inaccessible routes are those where water covers the whole width of the road or sidewalk. This concern was more difficult to fulfil during the process of analysis because ArcGIS cannot identify such routes automatically. Therefore it was necessary to check every node manually and occasionally delete such types of error (Figure 44). Depending on the scale of the project area, such a process can be quite time consuming.

Figure 44 – Node where dark blue pixel represents water that is higher than 30 cm. The pixel does not cover the whole width of the street; therefore it is not the real thread for the traffic. However, because it is located directly on the polyline, the programme would recognize it as inaccessible.

Buildings

For public transport services an assumption is to calculate the shortest walking path from a building to its nearest public station hub. A quick review to confirm the station itself is not flooded is done first.

No access to public transport services – can not be accessed from a building because water that is above 10 cm is flooding all possible routes to a public transport hub(s) – value 2

For emergency services, the aim is to calculate the shortest drive path from the closest fire station and hospital to every building in the project area. No accessibility corresponds to a situation where all possible routes from the nearest fire station or hospital to a building are inaccessible because of flooding higher than 30 cm.

Based on these assumptions a criterion is formulated for firemen service and ambulance service:

No access of firemen service – can not access a building because water is flooding all possible routes to a building – value 2

No access of ambulance service – can not access a building because water is flooding all possible routes to a building – value 2

Roads and paths

Roads and paths can contain driveways for cars, cycle paths for cyclists and sidewalks for a pedestrians. All roads are analysed in regards to all three functions and paths are analysed separately only for pedestrian use.

Inaccessible for cars – water is above 30 cm – value 2

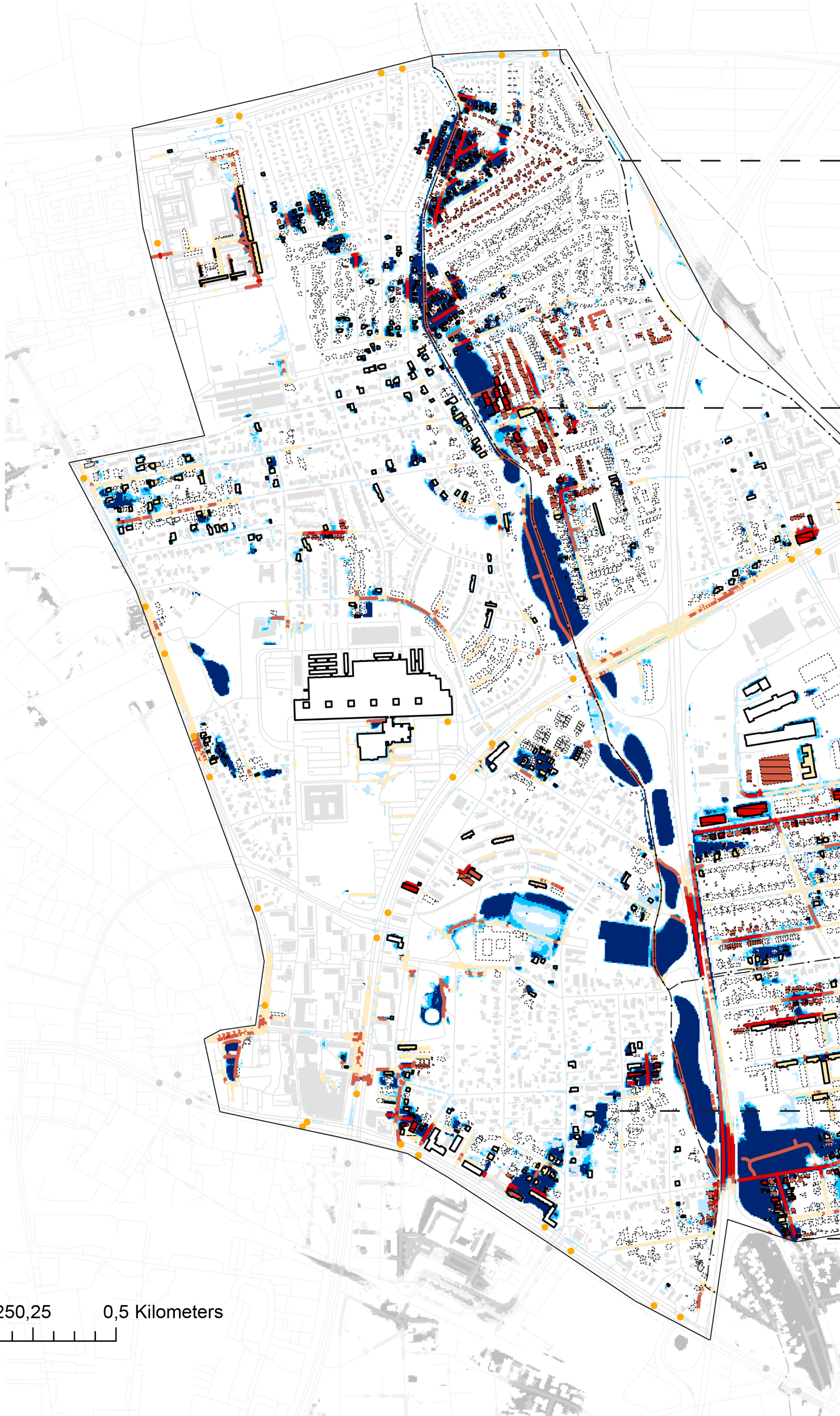
Inaccessible for cyclists – water is above 20 cm – value 2

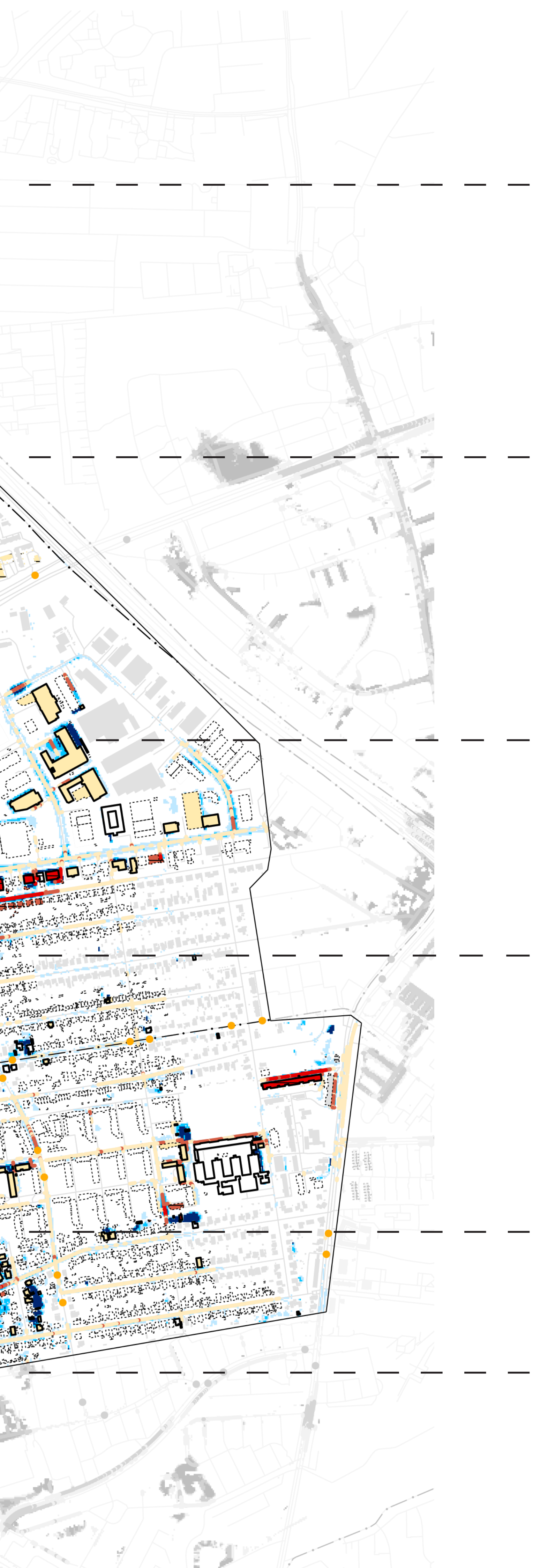
Inaccessible for pedestrians – water is above 10 cm – value 2

4.4.1.1 Key risk areas and selection of specific area

The RAA (Figure 45 or see Attachment 1) indicates diverse intensities of risks in terms of damage and inaccessibility in the project area. The analysis can show a great amount of detail; if we zoom in on the certain node or a building we can identify its degree of vulnerability, which is based on a number of risks to which it is being exposed. We can identify what kind of risk(s) affect it based on colour, the outline of a structure or hatch and colour of the overlapping flood. It is also possible to zoom out and see – based on the concentration of colours – where risks are mostly located.

The most concentrated risks are in six different locations in the project area.





Key risk areas

Kolonihaverne Øst

It is a big garden colony in the north of the project area.

Kagså Kollegiet

This key risk area includes mainly student houses and residential buildings.

Industrikvarter

This area consists of industries and small businesses in the south.

Kalenderkvarteret

It is a living area that is represented by residential houses.

Eventyrkvarteret

This affected area has mixed land-use which is composed of commercial areas, administrative buildings, businesses and living areas.

Villakvarteret

It is living area in the south with residential buildings.

Selection of a specific area

In total, six key risk areas were identified through RAA that are the most vulnerable in terms of a 100-year rain event. From these areas, one is going to be selected as a specific area for a master's thesis case study. The selection is preceded by the fulfilment of following criteria:

- *in the area, there must be a high presence of flood risk*

The area must contain problem(s) related to current water management in order to study it and solve it.

- *the area should be a neighbourhood /community where it is possible to meet local inhabitants during their everyday activities*

If the area contains a community of people who share the same area it is more possible to meet people who have an opinion about their immediate surrounding. Local inhabitants should be easy to access while respecting their privacy.

- *the size and complexity of the area (in terms of different land-uses) should be adequate and manageable in order to achieve the MSc thesis's objectives*

For example, the size of the area should be manageable in order to do the on-site research.

- *the border for the selected site should be defined by an identifiable neighbourhood/community and when it is possible, the catchment boundary should match the identifiable neighbourhood's boundary*

The area should be easy to identify. In terms of storm water management, it is important to define the catchment boundary to see from what terrain the rain water drains (see page xx). This can better frame the water issue in the neighbourhood/community.

- *the selected area should have a combined sewer system*

Nordvand´s current long-term goal is to change the combined sewer system into a separate one that does not mix storm water with waste water. If the area has a combined sewer system, then it becomes a good candidate for an intervention because it is a priority to undertake climate adaptation measures in these areas.

Villakvarteret and Kalenderkvarteret most accurately fulfil these criteria. Because Villakvarteret does not contain information about the sewer system and also because in comparison with Kalendarkverater there is less infrastructure affected by floods, Kalenderkvareter was selected for further study.

4.4.1.2 Risk Assessment of Kalenderkvarteret

The most concentrated risks that have linear character are in the north-west part of the neighbourhood. The water there drains from the hard surfaces of the nearby industrial area. This negatively affects the accessibility of the buildings and presents a risk of physical damage. The risks in the south-west corner of the neighbourhood have "island character". These are lower-positioned areas in the neighbourhood where water accumulates from other surrounding streets with hard surfaces. These areas contain buildings that are at risk of physical damage and are inaccessible to emergency services and public transport. More than half of the buildings, mainly in the west part of the neighbourhood, would not have access to public transport during a 100-year rain event.

A rain event does not affect the functionality of local public transport because there is no part of the bus route where a flood could prevent a bus to continue.

Through the neighbourhood there is a cycle path that connects Herlev with Gladsaxe which is affected by the event and makes it inaccessible for cyclists to pass.

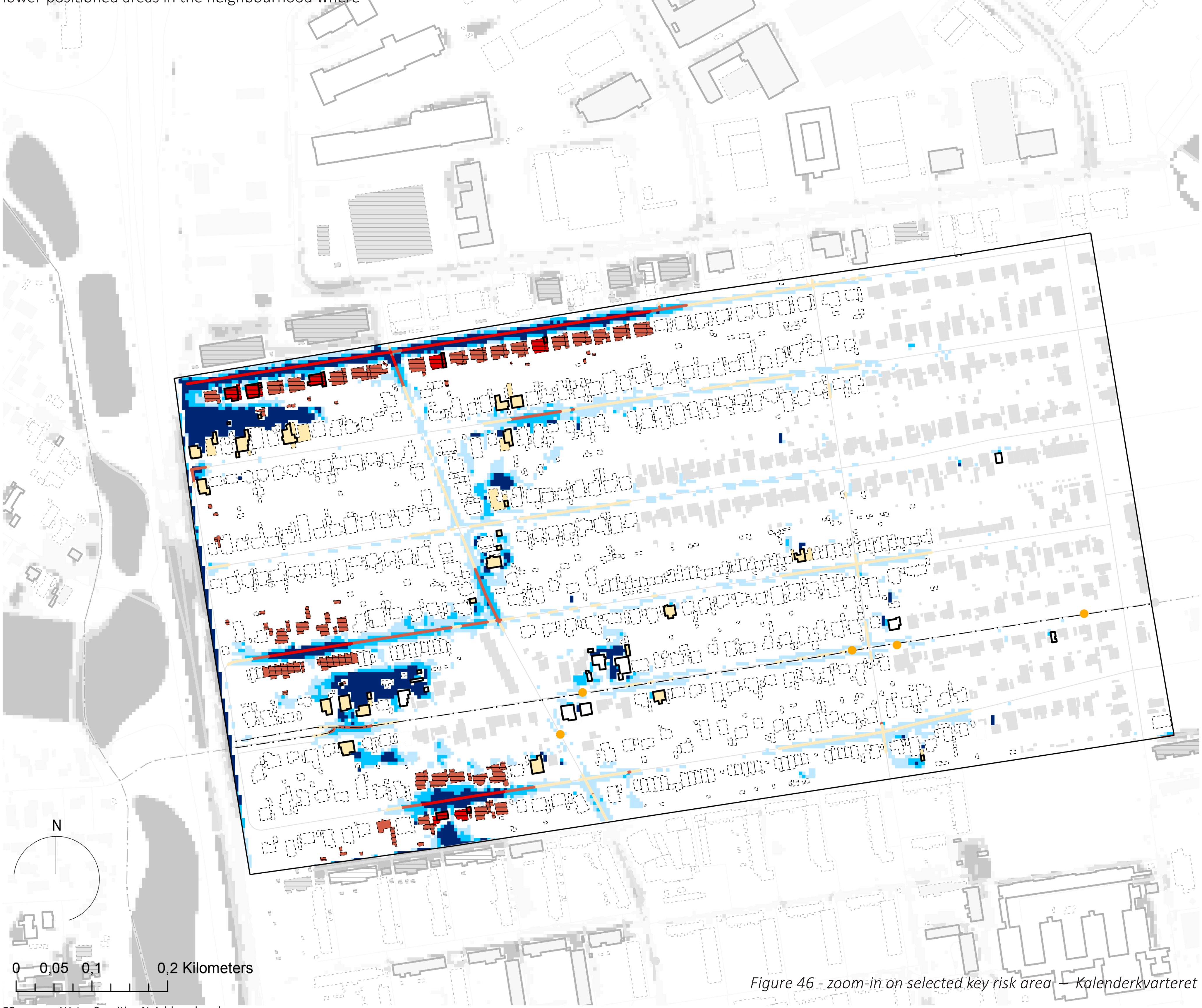


Figure 46 - zoom-in on selected key risk area — Kalenderkvarteret

Legend

buildings with no access to emergency services

buildings with no access to public transport

buildings with high risk of damage

cyclepaths

roads and sidewalks

buildings

project area border

transport hubs

Risk value of inaccesibility and physical damage - buildings

2

4

6

8

Risk value of inaccesibility - streets and paths

2

4

6

Water high of 100-year flood

10 cm

20 cm

30 cm

Summary of risks in the Kalendarkvarteret neighbour-hood without climate adaptation

8% of the buildings (49 out of 630 buildings) are at high risk of damage

63 % of the buildings (399 of 630 buildings) are at high risk of inaccessibility to public transport

7% of the buildings (45 of 630 buildings) are at high risk of inaccessibility of emergency services

37% of public space is inaccessible for pedestrians

16% of roads are inaccessible for cyclists

9 % of roads are inaccessible for cars

4.4.2 Cost estimation of damage in site area without climate adaptation on a basis of 100-year rain event

Based on figures from a Danish organization called ”Forsikring & Pension” it is possible to calculate a direct physical damage cost that relates to building properties. This organization annually collects claims from all Danish insurance companies and presents them in a structured manner. The statistics contain a number of reported damages caused by flooding from 2006-2013. The avarage insurance costs are structured according to different types of building categories. From these variables, average insurance costs relates for exmaple to offices, industrial buildings, multi-story buildings, residential houses, etc. (Ramboll, 2014)

The neighbourhood consists of buildings that belong to the category of residential houses and outdoor small houses. The overall damage cost for the selected site could be 1 482 353,36 DKK (34 residential houses together with 15 small outdoor houses) during 100-year rain event. Yearly damage costs accounts to 14 823,5 DKK.

4.4.3 Site description

Location

The Kalenderkvarteret neighbourhood is part of a district called Mørkhøj that belongs to the municipality of Gladsaxe. The municipality of Gladsaxe is part of Greater Copenhagen that surrounds the capital city of Denmark – Copenhagen.

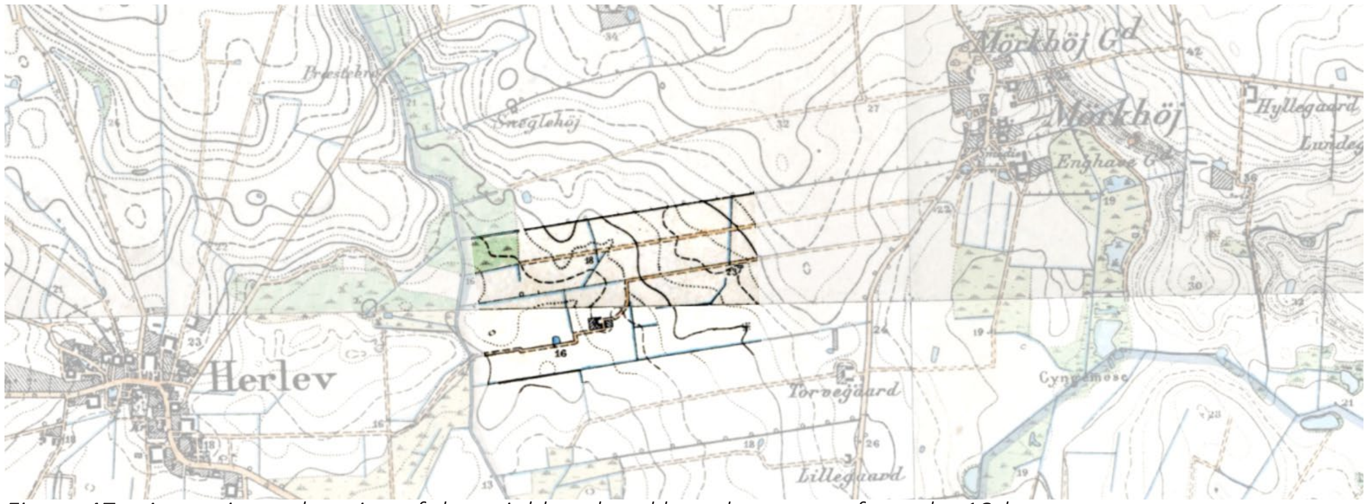


Figure 47 – Approximate location of the neighbourhood based on a map from the 18th century.

History

Historically in the 18th century (Figure 47), the area where the neighbourhood is located used to be farmland with scattered natural areas (usually bogs and meadows) along with open ditches that were draining water from the fields into Kagsa creek.

Earlier maps (Figure 48) show typical city development that emerged after the Second World War that is characterized by the creation of suburbs – residential communities lying immediately outside of a city.

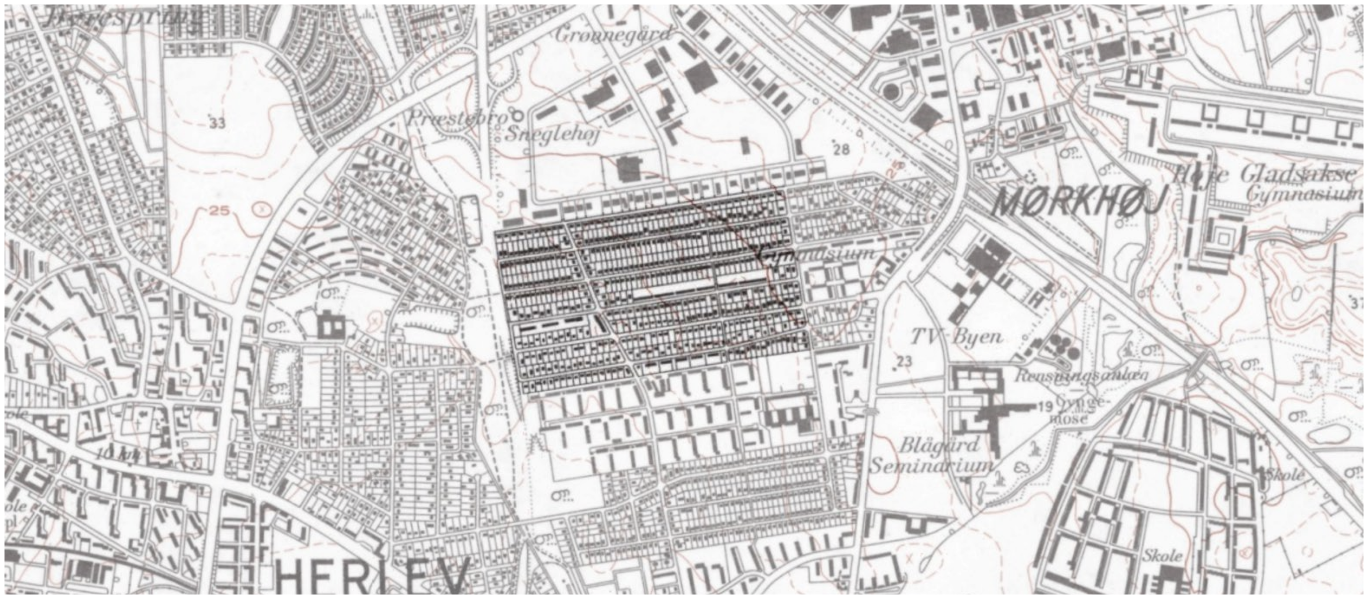


Figure 48 – Map of the neighbourhood between 1953 - 1976 when the industrial area in the north emerged.

Housing typology

It is defined by houses placed along the street with sidewalks and a road for the traffic. The housing typology is dominated by a diversity of single houses (Figure 49), row houses (Figure 50) and a few town houses (Figure 51) while some of them also have basic shops on the ground floor level.

Figure 49 – example of a single house in the neighbourhood

Figure 50 – example of row houses in the neighbourhood

Figure 51 – example of townhouses in the neighbourhood

Street typology

There are two different types of streets in the neighbourhood. One type is 10 meters wide and the other is 12,5 meters wide.

The 10-meter streets (Figure 52) include quite narrow sidewalks always on both sides of the streets except the most northern street – Octobervej – where the sidewalk is only on one side of the street along the houses. Part of the edge of both sidewalks is used for cars to park even though there is no officially-marked parking lane. The rest of the street is used as a driving lane for both directions.

The 12-meter streets (Figure 53) include the same functions as the 10-meter street but all of them have bigger dimensions. Additionally, in certain parts of the neighbourhood, the driving lanes of these streets are used for cyclists and buses.

Climate

The area has a warm and temperate climate with a significant amount of rainfall during the year.

Average annual temperature: 8.3 °C

Average annual rainfall: 629 mm

Highest average rainfall: 69 mm (usually in July)

Lowest average rainfall: 32 mm (usually in January)

Geology and groundwater

Most of the area contains clay soils, which are typical with low porosity and therefore are not that efficient in the infiltration of rain water. There is a high level of groundwater in most of the area. Groundwater is used as the main resource of drinking water in Denmark; therefore there are strong restrictions on the use pesticides or other toxins in the area in order to prevent ground water from risk of contamination.

Climate adaptation aims

The municipality of Gladsaxe prioritized areas that are selected to undergo climate adaptation. The neighbourhood is listed among another 13 priority areas inside of municipal territory. (Gladsaxe, 2013)

Specifically, in the neighbourhood, the aim is to retrofit the combined sewer system with a system where waste water and rain water are treated separately. Such system is called separate sewer system, which is a traditional piping infrastructure. The climate adaptation in the neighbourhood should be completed in 2020. (Nordvand, 2013)

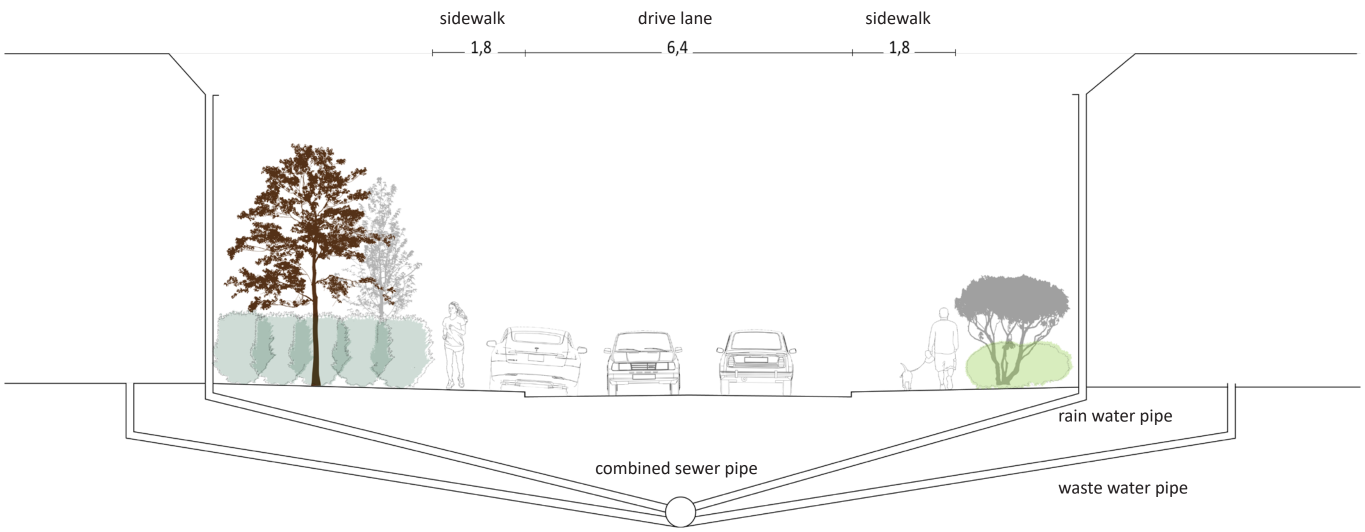


Figure 52 – type of 10-meter street

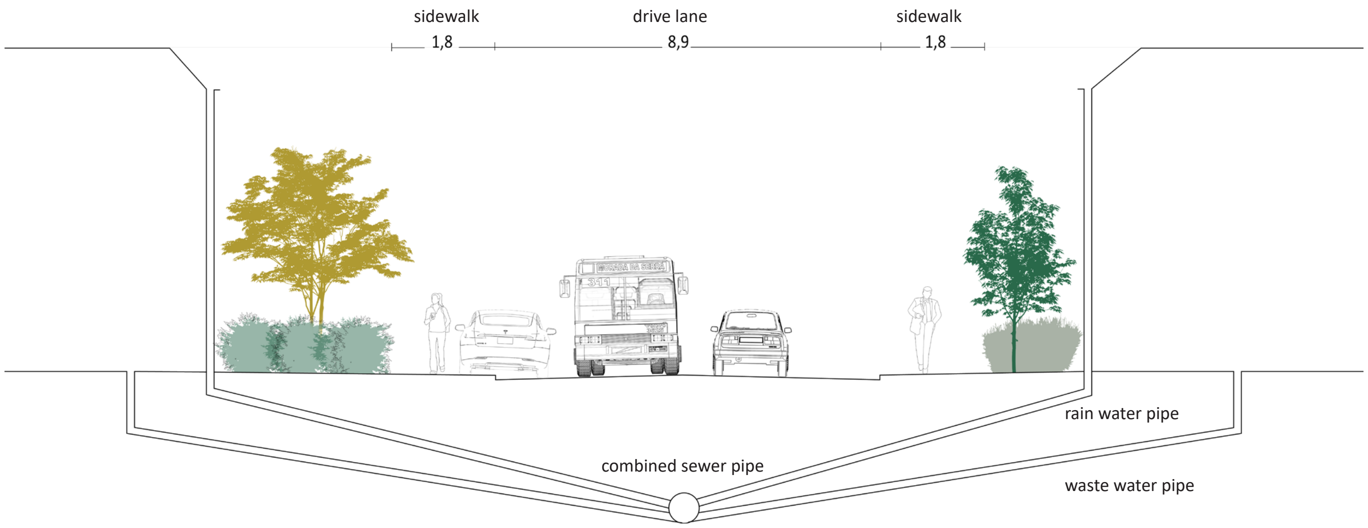


Figure 53 – type of 12,5-meter street

4.4.4 Desktop analysis

The analysis (Figure 54) shows the location of different functions in the neighbourhood and its surroundings. It is evident that the neighbourhood consists mainly of residential houses that are separated by streets. There are a few semi-private recreational spaces in the neighbourhood that are in close proximity to town houses or row houses. One small grocery shop and a pizza restaurant are located in town houses in the south-west. A supermarket is located in the south in close proximity to the neighbourhood's border. In the west part there is a recreational park – Kagsa – which is separated from the neighbourhood by the highway. There is a cycle path that leads from the park through the neighbourhood and a bus line that joins the same street from the south. In the north, there is a huge industrial area with small businesses. In the south there are many residential houses with their own semi-private recreational spaces. In the south-east, there is a primary school with public sports areas. The western part of the neighbourhood is separated by a major traffic street.

Figure 54 - desktop analysis

4.4.5 On-site investigations

4.4.5.1 Observations

Between the 30th of August and the 4th of October, 2016 I conducted observations of movements of pedestrians and cyclists in the Kalendervarteret neighbourhood. For this purpose, six cross-roads were selected in the west part of the neighbourhood where the most diverse functions are concentrated. The study uses the method of Jan Gehl (2008) for this task.

Observations were made during sunny or cloudy weekdays and weekends, always once in the morning (from 08:00 – 09:00 a.m.) and once in the late afternoon hours (16:00 – 17:00 p.m.) for each cross-section.

Figure 55 - map of observations

The aim of the study was to determine which nodes of the streets are most frequently used in order to recognize prevailing flows of the movement of pedestrians and cyclists. The study also observes how pedestrians move while they are crossing the cross-sections.

Findings

The study revealed that during the weekdays, the observed streets are more used by cyclists than pedestrians and on weekends there are more pedestrians than cyclists. This is probably because most of the residents of Kalenderkvarteret go during weekdays for their mandatory activities outside of the home and cycling is a good way to commute. Weekends are most suitable for optional activities that encourage a walk through the neighbourhood.

Further study revealed that the social composition of observed people consists of half men and half women with the middle age group prevailing, followed in descending order by pensioners, adults, youngsters and children.

The map of the study (Figure 55) shows that the most concentrated urban life is at the cross-section where Rybjerg Alle crosses Juni Alle. Both streets are very concentrated with pedestrians and cyclists because they connect the neighbourhood with other parts of the district.

Juni Alle is only one the official cycle path in the neighbourhood; however, it was observed that the full length of Rybjerg Alle is also an important connection for cyclists. It is used by cyclists who are commuting from the northern districts to the south, and in certain nodes, observation showed almost the same frequency of cyclists (14 / hour) as Juni Alle.

Both streets (Juni Alle and Rybjerg Alle) inside the neighbourhood are lacking cycle marks on the streets. Cyclists are very careful while they are passing through the neighbourhood. They face obstacles like parked cars, passing cars or cross-sections where they have to give priority to cars.

In terms of pedestrian frequency below the nodes Rybjerg Alle and Juni Alle, the most pedestrians were documented in descending order: on Augustvej, Septembervej, Maj Alle and Aprilvej. The fewest pedestrians were documented on Oktobervej. None of the cross sections have marked crossings; therefore, people use their own short-cuts to cross from one side to another. The way they cross each cross-section is documented on the map (Figure 55).

4.4.5.2 Site inventory of residential buildings, unused private and semi-private green spaces

During an on-site visit, all buildings and green spaces inside the site border that are visible from the street were observed and noted on the map.

This map (Figure 56) documents residential buildings that have a clear visual connection with the street (Figure 57). This documentation is motivated on the basis of an assumption that originates in the publication Life Between Buildings (Gehl, 2008). The idea is that if “more eyes are on street“ then the safer these places are and the more there is urban life on the street. (Gehl, 2008) A building with a clear visual connection to the street is recognized when there are windows that face the street and there is no visible barrier (for example high fence, high vegetation, etc.) that could prevent the visual connection between the window and the street.

During this documentation, private (Figure 57) and semi-private green spaces (Figure 58) that appear as unused and do not contain any specific features except lawn, small growing plants or gravel surface are noted on the map. The documented spaces do not have any solid barrier between the sidewalk and the front garden. They do not contain any hard surfaces. In terms of unused private green spaces, the inventory is done only for private front gardens (Figure 57) that are in between buildings and sidewalks.

Figure 56 - map of the site inventory

Findings

The inventory (Figure 56) shows that there are 186 houses with a clear visual connection with a street, 177 unused private green spaces and 9 unused semi-private green spaces inside of the site border.

Figure 57 – example of building with a clear visiual connection with the street and unused private green space

Figure 58 – example of unused semi-private green space

4.4.5.3 Site inventory of local values, problems and potentials

This onsite research documents values, problems
This on-site research documents values, problems and potentials that are manifested in the physical space inside of the neighbourhood and its immediate surroundings. These aspects of the site are interpreted subjectively from an on-site visit through the photo documentation of existing places during a walk. The walk was done through all the streets in the neighbourhood. For the documentation of the surrounding area, places were selected from Google Maps and then visited and photo-documented.

The aspects of the site (values, problems and potentials) are later questioned through interviews with local inhabitants.

Values

Recreational areas

There is good access to a big recreational park called Kagså (Figure 59). It contains a path for cyclists and pedestrians, open lawns, meadows, a small creek and a few patches of forest.

In the south part of the neighbourhood there are residential areas that contain public green areas for recreation and children's play (Figure 60).

Inside the neighbourhood, there are a few semi-private green areas with usually an empty lawn with non-specified function (Figure 61).

Services

The neighbourhood is in close proximity to many services such as health care, education (Figure 62), shops (Figure 63) and public transport (Figure 64).

Figure 59 – Kagså Park is a big recreation area in the

Figure 60 – a public recreational area in the south part of the neighbourhood

Figure 61 – an example of one of the few semi-private green spaces in the neighbourhood.

Problems

Insufficient canalization system

During the site visit very short but very intense rain hit the neighbourhood (Figure 65). Luckily, this rain event was not strong enough to cause any difficulties. Still, it was enough to indicate one weak node in the neighbourhood where the canalisation system could not handle rain water properly.

Noise from the highway

The west part of the neighbourhood is separated from Kagså Park by the highway (Figure 66). This creates constant noise and can negatively affect the well-being of local inhabitants.

Busy traffic on Rybjerg Alle

Busy traffic on Rybjerg Alle can negatively affect the safety of more vulnerable street users – pedestrians and cyclists (Figure 67).

Lack of places to sit

The neighbourhood does not contain enough opportunities for pedestrians to sit (Figure 68). This can be a problem especially for elderly people who have lower mobility capabilities to reach recreational areas outside of the neighbourhood.

Lack of places for children to play in the north-west part of the neighbourhood

Some families in the north-west part of the neighbourhood have play equipment for their children in a garden (Figure 69). This can solve the problem when families have difficulty to access the playgrounds in their immediate surrounding. At the same time, it could be a disadvantage as it prevents their children from interacting with other children in the neighbourhood.

Figure 62 – local primary school that is close to the neighbourhood.

Potentials

Engagement of local inhabitants towards climate adaptation

Some of the front gardens of the buildings in the neighbourhood indicate conscious or unconscious "do-it-yourself" actions towards climate adaptation (Figures 70- 74).

Unused spaces with hard surfaces

In the neighbourhood there are many empty spaces that do not indicate any specific function and typically on corners of crossroads there are hard surfaces that people only pass around (Figure 75).

Wide open streets

The neighbourhood contains wide open streets that are dominated with driving lanes for motorised traffic. Most of the streets in the neighbourhood are very quiet, and driving lanes are used primarily by local inhabitants for their daily commute (Figure 76).

Figure 63 – local supermarket that is close to the site border of the neighbourhood

Figure 64 – bus line 166 provides public transport in the neighbourhood

Figure 65 – the photo indicates one weak canalisation node on Rybjerg Alle during a very short cloudburst.

Figure 66 – a view on the highway from a bridge that connects Kalendarkvarteret with Kagså Park.

Figure 67 – photo of busy traffic on Rybjerg Alle.

Figure 68 – crossings are small centralities where people often meet. Most of them do not contain any street furniture for sitting.

Figure 69 – local residents with their own play equipment for their children

Figure 70 – use of crushed stone can partly preserve the function of soil to infiltrate rain water while the owners can still use it for parking their cars

Figure 71 – documentation of efforts to divert rainwater from the roof into the flowerbed by the fence. However, this could create difficulties for the neighbours who could receive overflow as well

Figure 72 – same principle as in previous figure but with more space, volume and most importantly access to public sewer where water can overflow without exposing neighbours to risk of overflow into their territory

Figure 73 – an effort to create a rain garden that is in progress or unfinished

Figure 74 – opposite approach from the previous photo. The owner - who personally provided information about his intentions during on-site research – is creating in front of the house a smooth, steep slope up towards the house to protect it against floods that might reach the house from the street. In his back garden, he uses soak-aways to retain and infiltrate rain water from another side of the roof.

Figure 75 – corners that are next to crossroads contain unused and empty hard surfaces

Figure 76 – an example of wide streets with sporadic motorized traffic

4.4.5.3 Interviews with local residents

The case study aims to promote participation with local inhabitants of the neighbourhood before the design process of a proposal.

The hypothesis for the case study is: the participation process must be done before presenting any idea to the local inhabitants in order to receive more diversified feedback from them together with their concerns and thoughts relating to their neighbourhood.

The aim of the interviews is to expand further on the chapters "Site inventory of residential buildings; unused private and semi-private green spaces" and "Site inventory of local values, problems and potentials" with local knowledge collected from the residents of the neighbourhood.

Collected on-site data will be used for a creation of solutions in the Cloudburst Concretization Plan. These data will help to design and organise Blue-Green Infrastructure solutions with respect to identified values and concerns in the neighbourhood.

Figure 77 – residents from Aprilvej are having common dinner on their street

Method

A semi-structured qualitative interview is used based on A. Bryman and H. Bernard methods.

My aim was to show an interest in the interviewees' point of view and be flexible and responsive to a direction that they took during the interview. (A. Bryman, 2012) I selected questions that were short and clear and that acted as an invitation for the respondents to think and speak about the issues more widely and respondents could feel free to follow new leads while not exercising excessive control from my side. (H. Bernard, 2006)

Circumstances

The interviews were conducted between the first and second of April, 2017, in english, during partly sunny days, with the temperature around 17 degrees in the afternoon hours.

Respondents who were interviewed were people living in the neighbourhood. The interviews were done in front of the respondent's house or on the sidewalk in the neighbourhood.

Before asking questions to a respondent, a short introduction was made that took care to explain my role and the reason for doing the interview.

I introduced myself as a student who is writing his MSc thesis under the Consultancy Company Ramboll. The reason for conducting the interview is because of outdated and insufficient water management that in future will need necessary intervention. Because this intervention will be done in their surrounding area, it is now a good opportunity to get to know more about the neighbourhood and people who are living there before the intervention is undertaken.

The open questions given to the respondents aimed to find answers regarding problems, potentials and values in the neighbourhood.

At the end of every interview, the respondent was told that there would be an opportunity to express more comments again later (such as through a notice on the municipality web-page), but if they already had any thoughts that they would like to share, they could write an email through a contact information that I shared with them.

Selection of interviewees

- random residents of the neighbourhood that were approached on the street in their neighbourhood

Interpretation of the data

The residents expressed their general satisfaction with living in the neighbourhood. The neighbourhood is quite a unique place to live because it compromises several values that make living in the neighbourhood similar to life in a "little village" (for example one of the respondents described it as a "little village" because of the neighbourhood's distinct border that is well defined by other areas – industry in the north, the main road on the east, residential areas in the south and highway in the west).

They confirmed the problem of floods that damage basements and negatively affect accessibility in the neighbourhood.

There is awareness in the neighbourhood about mitigating flooding issues and several neighbours used the model "Regnvand på egen grund" (see chapter Model for implementation of BGI by private property owners) that gives financial compensation to landowners who are handling rainwater within their private property. However even with the presence of this model the implementation of it is not that easy. One of the respondents describes that most of the residents automatically reject the model because of its administrative difficulties. Additionally, financial compensation usually is enough for an underground solution (e.g. soakaway) and rain barrels but other solutions (e.g. rain gardens and bioswales) are too expensive. The soakaway was possible to use in the neighbourhood two years ago but after that, the land in the neighbourhood was recognised as unsuitable for infiltration. The municipality restricted use of this solution or any other that requires the function of infiltration in the neighbourhood. This lack of possibilities makes it even more difficult for private property owners to implement BGI solutions.

There is openness and motivation from residents toward the implementation of these solutions on their private land (that is documented in Figures 70-74 and now also confirmed during the interviews) but it is necessary to make the process of making their application for financial compensation more user-friendly and the actual process of implementing the solutions less economically demanding.

From the perspective of residents, the traffic on Juni Alle and Rybjerg Alle (Figure 67) is a problem because it affects their safety. Cars are driving too fast because the road is very straight and long. At the same time they are using it as a short-cut in order to reach the nearby highway.

The highway (Figure 66) affects the west part of the neighbourhood with noise that is a common concern for people who live there and they add that it is more difficult to sell a house in that part of the area because of this problem.

Minor problems like less powerful new lighting bulbs in public streets or occasional thefts and noisy youngsters from surrounding neighbourhoods were mentioned during interviews but not frequently.

Respondents reported that occasionally they have informal common activities (such as dinners – Figure 77 – and parties) on their street with other neighbours or they visit surrounding neighbourhoods where they have more possibilities for recreation (Figure 60), take their kids to playgrounds and meet with people other than the ones in their neighbourhood. At the same time, they have expressed a wish to have such places inside the neighbourhood where it is possible to relax while meeting with neighbours from their street.

Some of the respondents were passionate gardeners who are usually gardening in their back garden or in the front garden where they can interact with their neighbours. However, some houses are lacking a green front garden because it contains hard surfaces. One of the respondents explained that there are situations where people already bought the house like that and therefore do not have the opportunity to have a green front garden. In some parts of the neighbourhood there are situations where there is only one isolated green front garden. The respondent expressed sadness that because of this situation there is less chance to interact with people through gardening, especially for elderly people who live alone. For elderly gardeners it is problematic to move their garden tools and equipment back and forth between their back garden and their front garden.

Respondents also expressed the idea that streets could be more green and could contain trees (with reference to cities like Munich or Berlin where they use tree alleys in the neighbourhoods).

The residents from row houses in the neighbourhood confirmed that they collectively own and maintain semi-private green areas (Figure 61) and use them primarily for their children to play (for example football). Further, they reported that small patches of semi-private green spaces (Figure 58) are used only for cutting the grass.

4.4.6 Modelling
4.4.6.1 Terrain

The map (Figure 78) shows a digital terrain model (DTM) from ArcGIS of the site area and its surrounding.

Findings

The terrain is gradually sloping from the northeast towards the southwest with the lowest point in Kagsa park and highest in the west part of the industrial area.

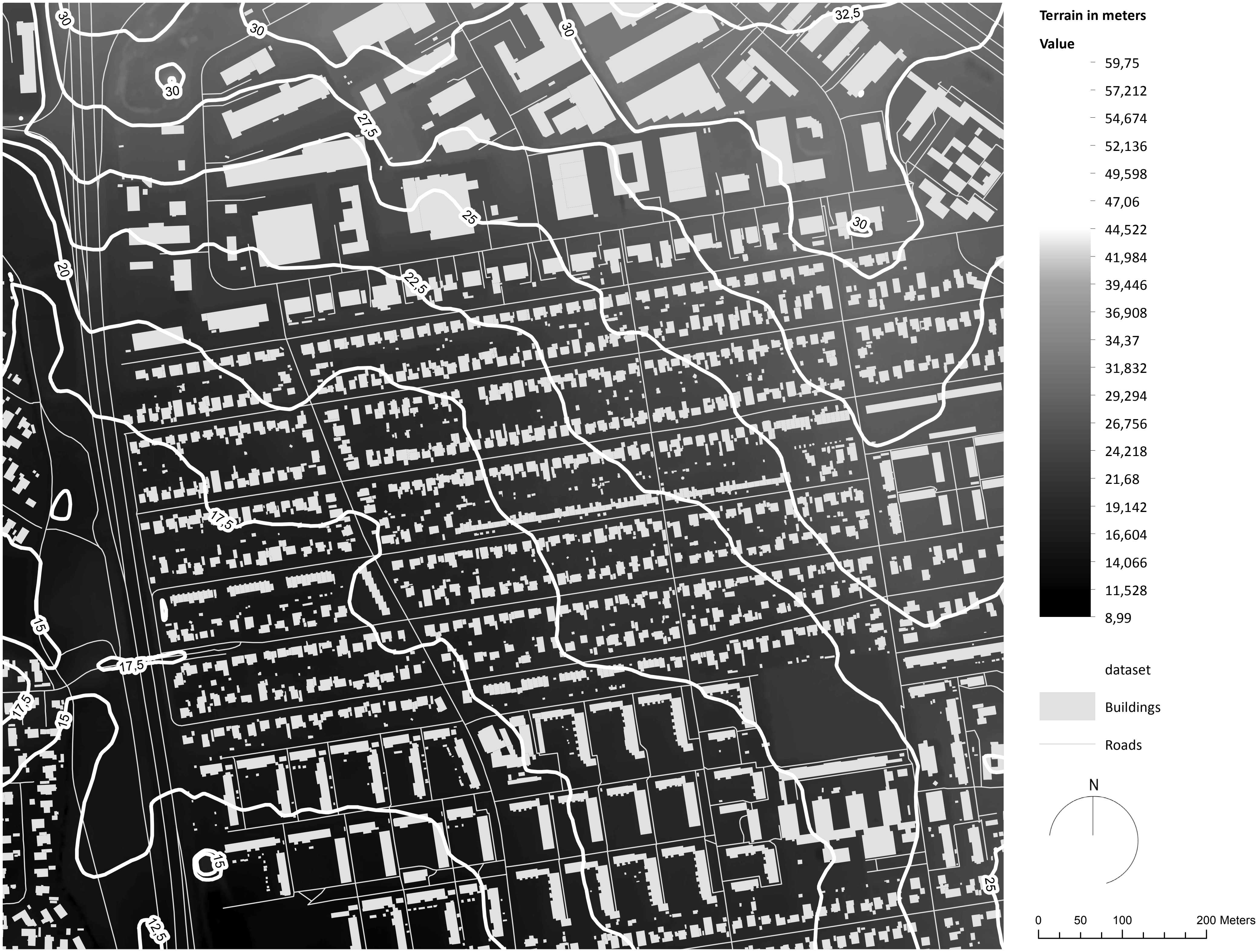


Figure 78 – map of DTM

4.4.6.2 Blue-spot analysis

This map (Figure 78) shows small sudden depressions (blue spots) in the land that are necessary to analyse separately. They can be understood as very small catchments, which can get filled with water.

In the site area, blue spots represent places where terrain gets suddenly lower and has delineated, elevated edges, or garage entrances that are excavated close to a building, or swimming pools.

Only places where terrain gets suddenly lower because of terrain elevation will be analysed in order not to multiply the complexity of the analysis.

Findings

Most of the blue spots are concentrated in private territory (Figure 78). The analysis contains only blue spots that have a depth of more than 20 cm. These spots can get filled easily with rainwater during a 100-year rain event.

Based on the criterion of RAA, the water that can cause damage to property is water that is higher than 20 cm. There are only two such blue spots in the area and they are located in southwest part of the neighbourhood, marked with a red outline. Other blue spots fill either swimming pools, garage entrances that are excavated in front of the building, or terrain depressions that don't present any risk of damage to a property.

Figure 78 – map of blue spots

4.4.6.3 Flow lines model with catchment area

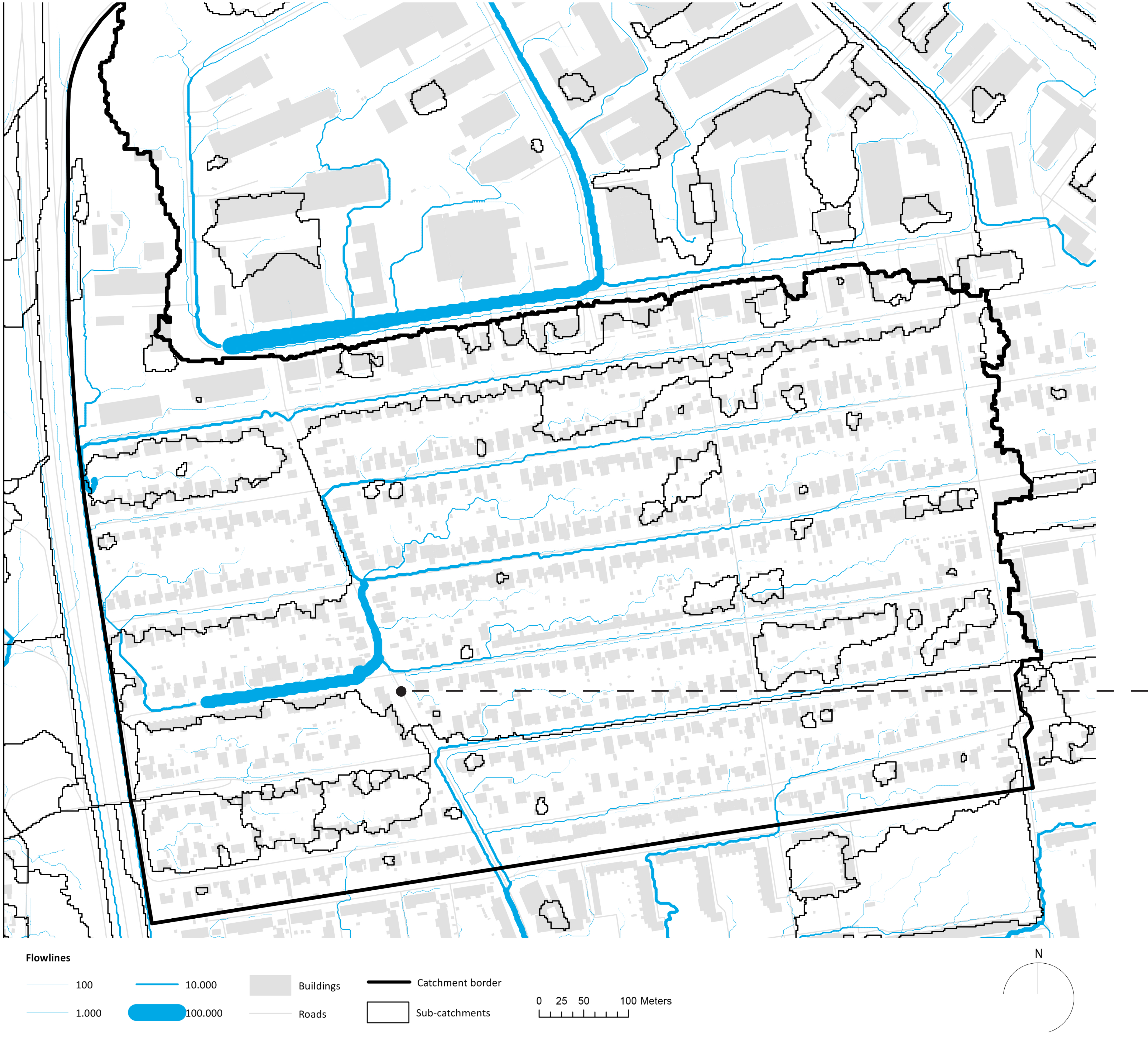


Figure 79 – map of flow lines with catchment areas

The flow lines represent how and in which direction rainwater will flow in the area. Such simulation is performed on the existing terrain (that includes the heights of built structures) without considering any underground drainage infrastructure. Therefore, all terrain acts like a glass surface (this simulation is also known as glass model). This gives a good understanding of where to place future solutions in order to collect draining water from the terrain.

The catchment is an area that drains water through the same terrain. This is particularly useful for delineation of an area in order to calculate amounts of rainwater that will fall on a surface that is inside of the catchment.

The model (Figure 79) was done in ArcGIS with the usage of tools Basin, Fill, Flow Accumulation and Flow direction.

Findings

The flow lines model (Figure 79) shows that flow lines have a tendency to head towards the same direction as was already mentioned in the terrain model – from northeast towards southwest while following the direction of the streets in the area.

There are only a few small elevations in the area that need a closer look to see where the direction of flow lines changes. This has a practical reflection while planning BGI, because normally (during everyday rain) these areas will drain only the water that falls on its surface, and therefore it is better to place future solutions a bit lower so they can collect water from these elevations. The model that is presented is quite general and this type of area is usually located on a street where are no flow lines.

To get a better understanding how water flows in these particular areas, Scalgo software was used (Figure 80). Scalgo is a web-based application that shows flow lines in more detail. I discovered this tool after making this model, and I have used it to see better detail of flow lines.

The thicker line of the catchment area that is shown in the model is a selected catchment for the site area. It consists of smaller sub-catchments, which are included as well. The delineating catchment area is important for later specification of rainwater volumes that drain through the same terrain inside of the catchment.

The selected catchment is a combination of generated storm water catchment and site area that I am allowed to develop based on the site border. The generated catchment partly stretches into the north part of the industrial area where there are a lot of hard surfaces – which explains why the northwest part of the neighbourhood is so often flooded. Only the south part of the catchment is based on the site border and does not represent generated catchment. This border is an extension of the original catchment that did not cover the rest of the site border of the neighbourhood. It means that the proposal will aim to control rainwater from this extra area as well and therefore other areas that are lower will receive less water, which will put less pressure on their drainage system.

It is possible that during cloudburst events, water will enter the site area from areas outside the selected catchment boundary. The proposal will not include a plan to handle this potential water because there are future planned climate adaptation projects that will aim to handle water within these areas (for example neighbouring Industrikvarter in the north of the neighbourhood).

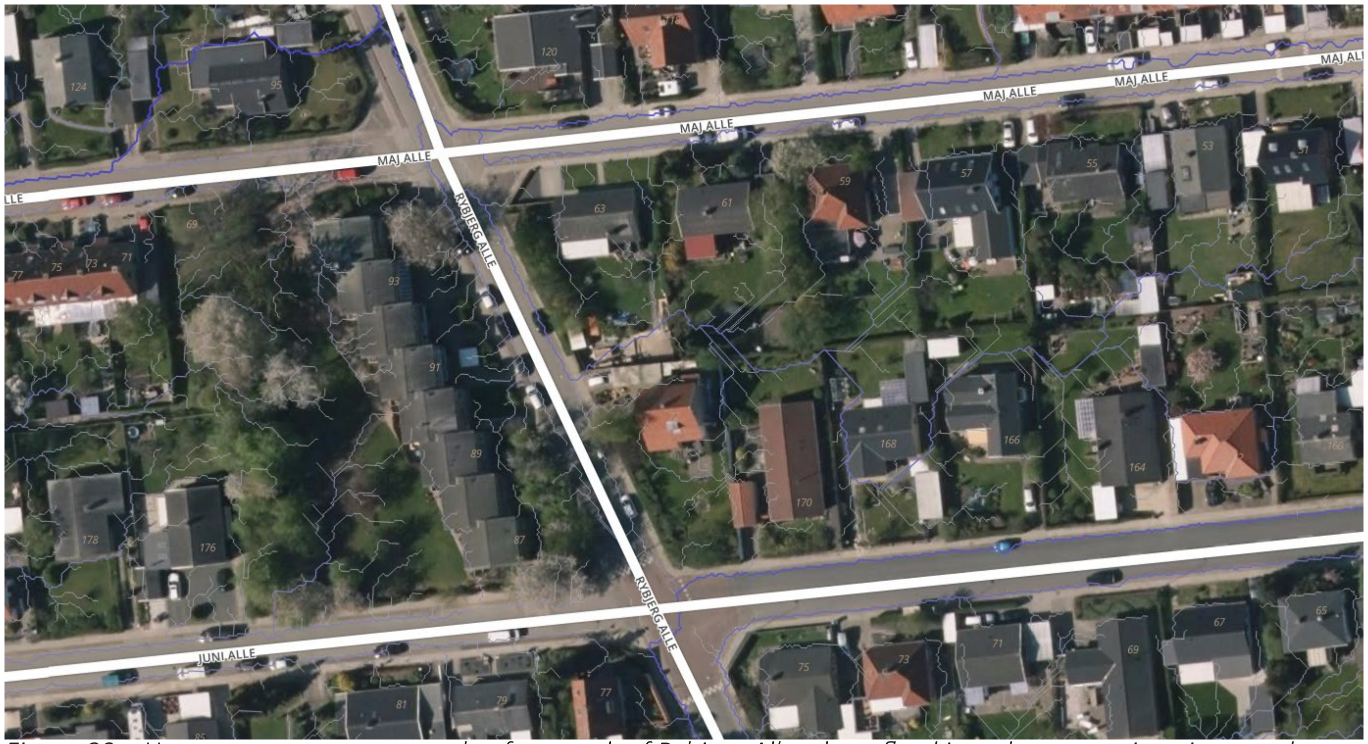


Figure 80 – Here we can see an example of a stretch of Rybjerg Alle where flowl ines do not continue in a southwest direction, as do most of the flowlines. Instead, from the middle, they lead towards north and south because this particular node is elevation.

4.4.6.4 Permeable and impermeable surfaces

In the later part of the case study, it is necessary to specify volumes of rainwater. For this aim, it is necessary to identify how many hectares that the catchment area covers and what surfaces it contains. The surfaces can be either permeable (for example meadows, lawns and forests) or impermeable (for example asphalt paths, parking lots and roofs). A permeable surface has the capacity to retain some rain water. Impermeable surfaces cannot retain any rain water; therefore all rainwater that hits impermeable surfaces will not lose any of its volume.

Findings

On the basis of the map (Figure 81) it was calculated that catchment covers 49,6 ha. Of this, 19,5 ha contain permeable surfaces (green areas) and the remaining 30,1 ha covers hard surfaces (asphalt paths, parking lots and roofs of the buildings).

Figure 81 – map of permeable and impermeable surfaces

4.4.6.5 Hydraulic models

Ramboll's hydraulic engineers have done two simulations for the area based on two different extreme rain events.

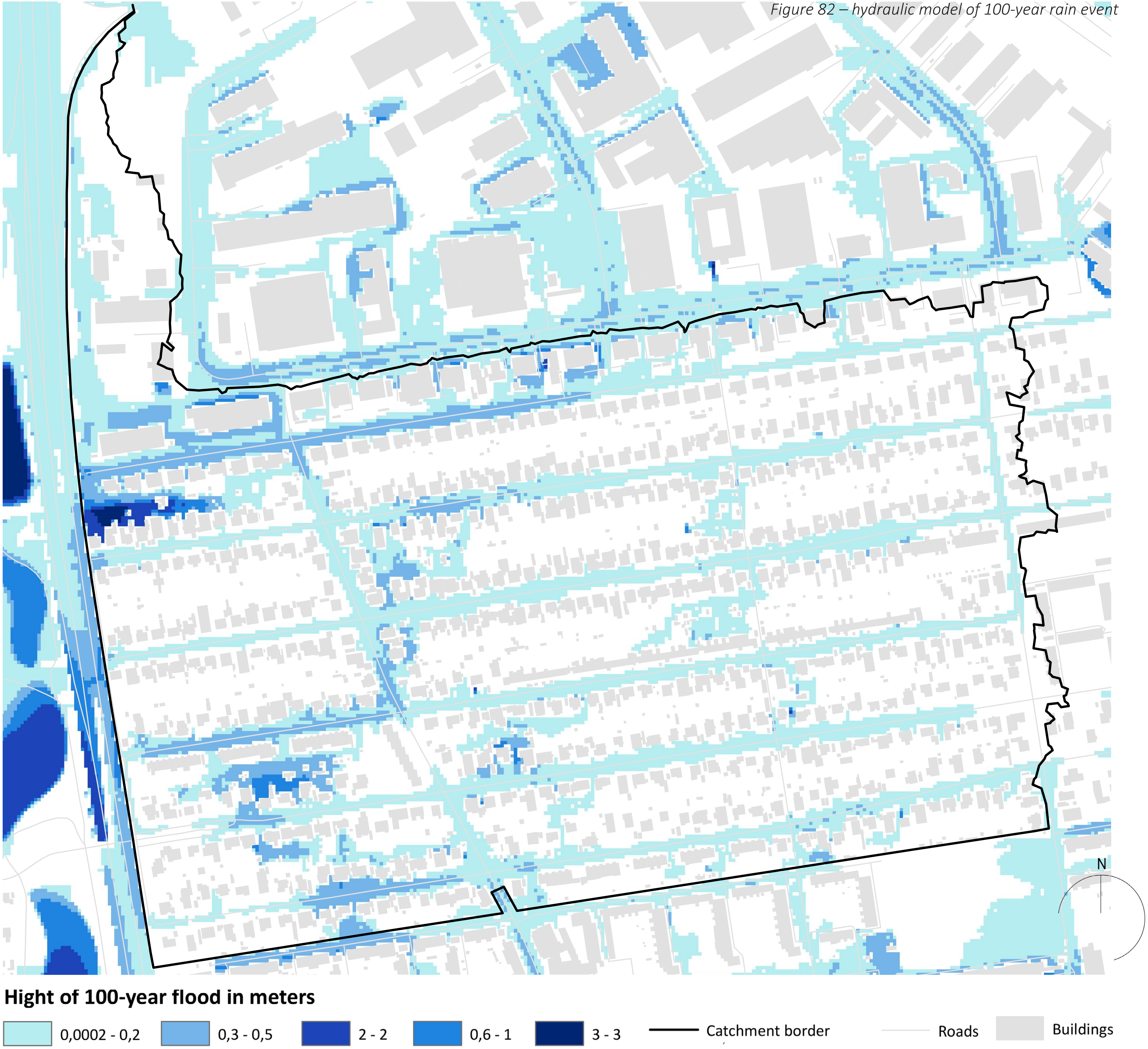
One represents a 100-year event with rainfall of 119,6 mm, which is less probable to happen, but more severe, and another 25-year rain event with rainfall of 84,7 mm which is more probable to happen in the future but less severe.

Both simulations were done with the aim to test how current water management in the area can handle these two events together with proposed changes in Kagsa park, which can retain volumes of rainwater.

Findings

Even after these planned changes, we can see that

Figure 82 – hydraulic model of 100-year rain event



particularly the Kalendarkvarteret neighbourhood is being seriously affected by floods (for more details see a chapter with RAA, where the simulation of 100-year rain event was used as the basis for the analysis of issues during this extreme rain event).

With the usage of the software FME Workspace, it is possible, on the basis of simulation, to calculate how many cubic meters of flood stays in the catchment during both extreme rain events.

In terms of a 100-year rain event, it is 18 430 m3, which is equivalent to seven Olympic swimming pools.

For a 25-year rain event, it accounts to 8 302 m3, which equates to three Olympic swimming pools.

Figure 83 – hydraulic model of 25-year rain event

4.5 Plan and design

4.5.1 Cloudburst Masterplan

Cloudburst Masterplan (CM) describes how a new storm water system is organized in the neighbourhood (Figure 86). It proposes Blue-Green Infrastructure that is combined with a traditional piping system, but only at places where it is necessary.

BGI is represented with retention streets that retain, detain and convey volumes of rainwater. These retention streets are planned in a way that all rainwater from the catchment can flow through them; therefore, they are proposed on most of the street nodes of the selected site in accordance to the Flowlines model (see chapter Modelling).

The proposed BGI will regulate water quality and water quantity of the rainwater before it reaches the central retention area where these processes will further continue. This will be done mainly through retaining volumes of water, slowing it down, and partly through evapotranspiration (when vegetation has grown to adult size). Contaminated rain water that carries pollutants from roofs and roads will be purified mainly through sedimentation in BGI features and partly through filtration through the substrate and phytoremediation through the plants.

Retention streets lead rain water from all the streets in the site area to the lowest points in the catchment area. After that, it is necessary to transport rain water under the highway through cloudburst pipes to future central retention areas in Kagså park.

CM suggests to reconnect existing small storm water pipes at private properties that currently drain rainwater from roofs into the combined sewer system. The suggestion is to connect them with proposed BGI features on the street instead, in order to separate rain water from waste water and allow it to continue its natural water cycle (Figure 84). Combined sewer systems could be preserved and used for transport of wastewater only. Rainwater that does not fall on roofs of private property will enter the nearest proposed BGI feature through draining from the terrain and the streets. All BGI features will be connected with small plastic 100 mm pipes, which will slowly detain rainwater in between BGI components during everyday rain. If one magazine reaches its rain water capacity, water will be conveyed into another neighbouring BGI component along the street. This can happen particularly during extreme rain periods. If rainwater reaches the last BGI component, it will be further transported through proposed or existing cloudburst pipes.

Cloudburst pipes are big concrete pipes which are used for transport of rain water from the neighbourhood into the central retention area. These pipes are in CM, proposed based on the existing separate sewer system and a planned separate sewer system in the area. The system that already exists in the area is located in the north in an industrial area and it is also placed on Octobervej in the neighbourhood (see attachment 2). The planned one is Ramboll's proposal that contains a plan of a separate sewer system for the neighbourhood (see attachment 2).

CM respects the already-existing separated sewer system in the north part and it is suggested to connect BGI elements on the sewer approximately every 200 meters (Ramboll, 2017) This street would then become more resilient because this node is most affected by floods (see chapter 4.4.1.2 Risk Assesment of Kalenderkvarteret). The storm water pipes that are shown in Ramboll's proposal are suggested only at places where it is necessary to transport rainwater. BGI is prioritized over storm water pipes in the site area.

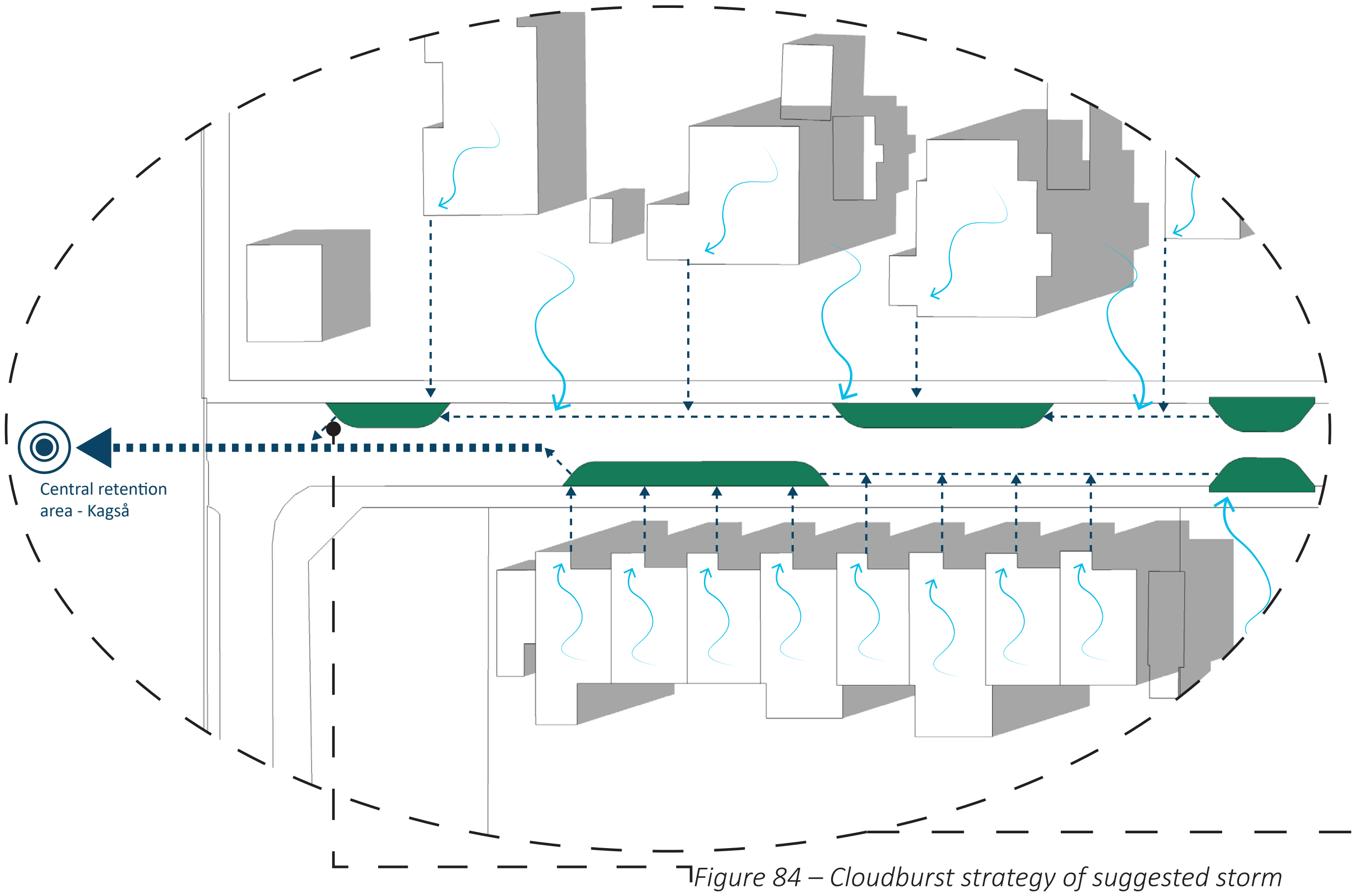


Figure 84 – Cloudburst strategy of suggested storm water chain

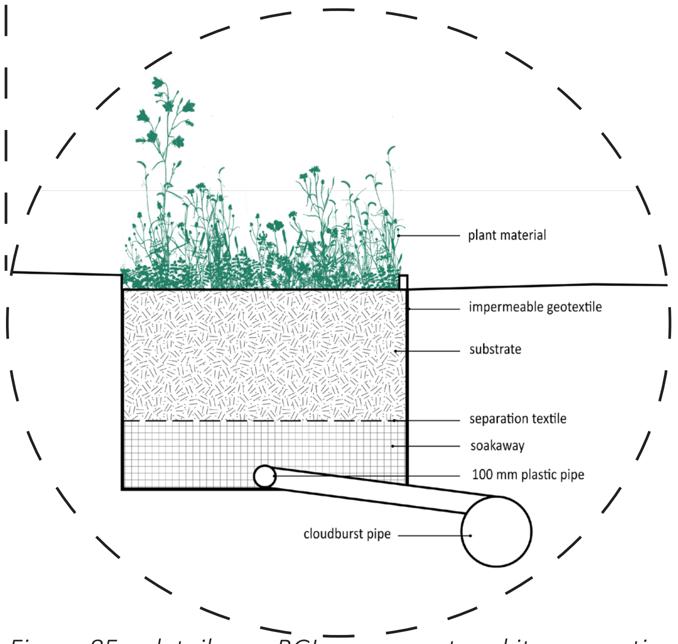


Figure 85 – detail on a BGI component and its connection to cloudburst pipe

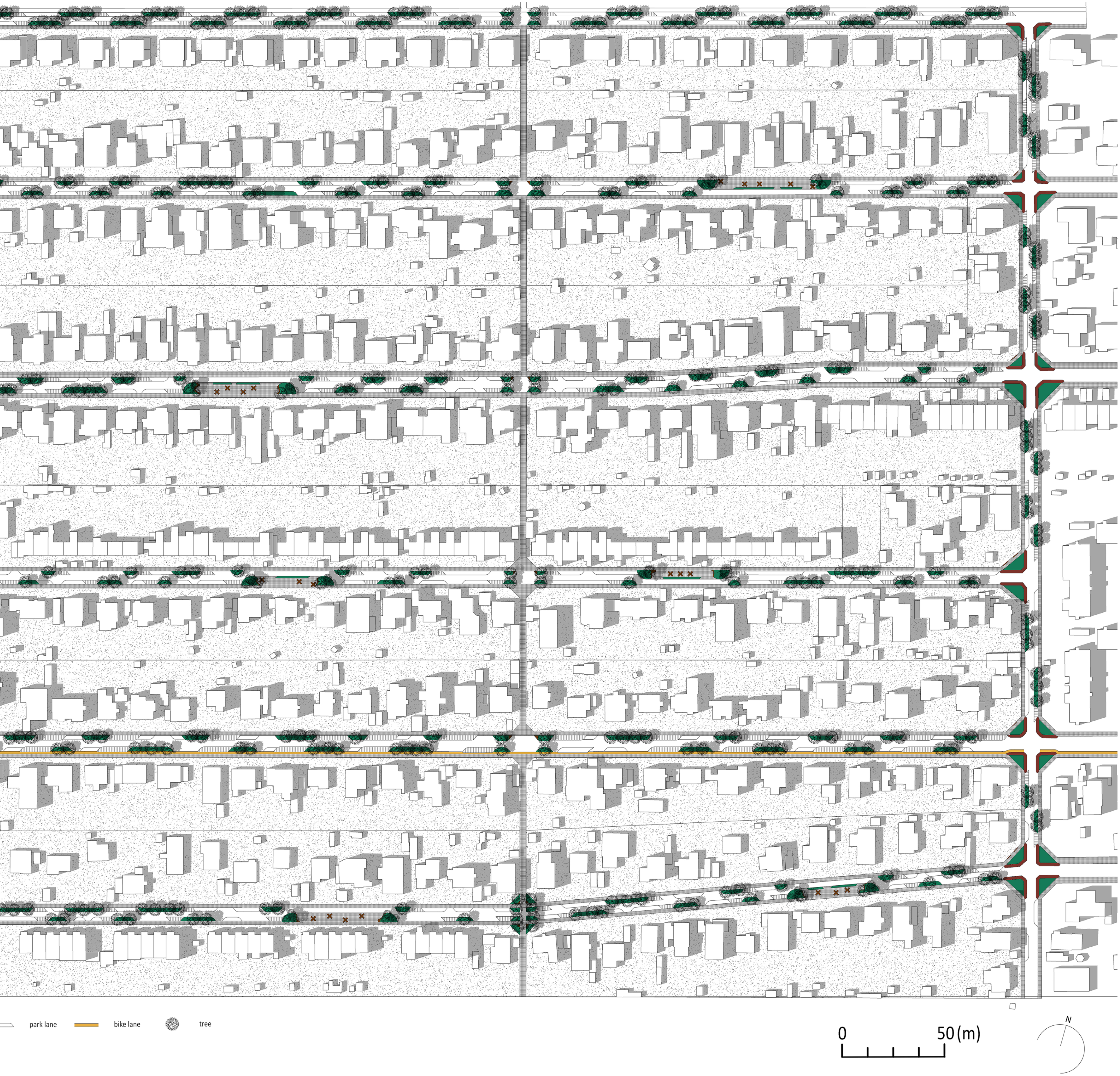
Figure 86 – Cloudburst Masterplan

4.5.2 Cloudburst Concetrization Plan

On the basis of the Cloudburst Masterplan, all planned solutions are designed in detail in the Cloudburst Concentration Plan (CCP) (Figure 87 and attachment 3).

Proposed retention streets consist mainly of rain beds and several bioswales, with sizes and shapes that are designed specifically to its context. Together with handling rain water, they moderate traffic, increase safety and optimize all street-uses while creating new recreational functions in the neighbourhood.

Figure 87 – Cloudburst Concetrization Plan


park lane
bike lane
tree
0
50 (m)
N

4.5.3 Sections and visualizations

Harmonizing street-uses and improving their safety

The design of BGI elements respects current street uses – pedestrian traffic, motorized traffic (including buses) and cyclists while taking into consideration residents and their properties (for example their private entrances to their parking places) that surround the street's edge.

Therefore, the development of retention streets does not concentrate solely on the placement of the BGI elements themselves, but also focuses on adjusting dimensions of other street functions in order to integrate BGI with these current uses and also to compliment them (Figure 88 and 89).

This mainly requires respect for the dimensions of the streets (12,5 m and 10 m widths) and recommended limits for dimensions of different street uses while at the same time respecting and preserving the function of existing car entrances of private property owners.

A new cycle way is facilitated on Rybjerg Alle because results from an observation study showed that there is a high frequency of cyclists who pass through it, even though there are are no marks or signs of a cycle way. The street has a dimension of 12,5 m, which provides enough space to integrate this function.

The current street limit (40 km/hour) is suggested to be lowered to 30 km/hour for all 12,5-meter streets with a shared lane. ”This is a safe speed for cycles to ride in mixed traffic and presents low risks to people walking along and crossing the street“. Global Street Design Guide, 2016) For the rest of the streets, it is suggested to lower the speed to 20 km/hour, which is the recommended speed for residential streets where play and other social activities are presented (Figures 98 – 99). (Global Street Design Guide, 2016)

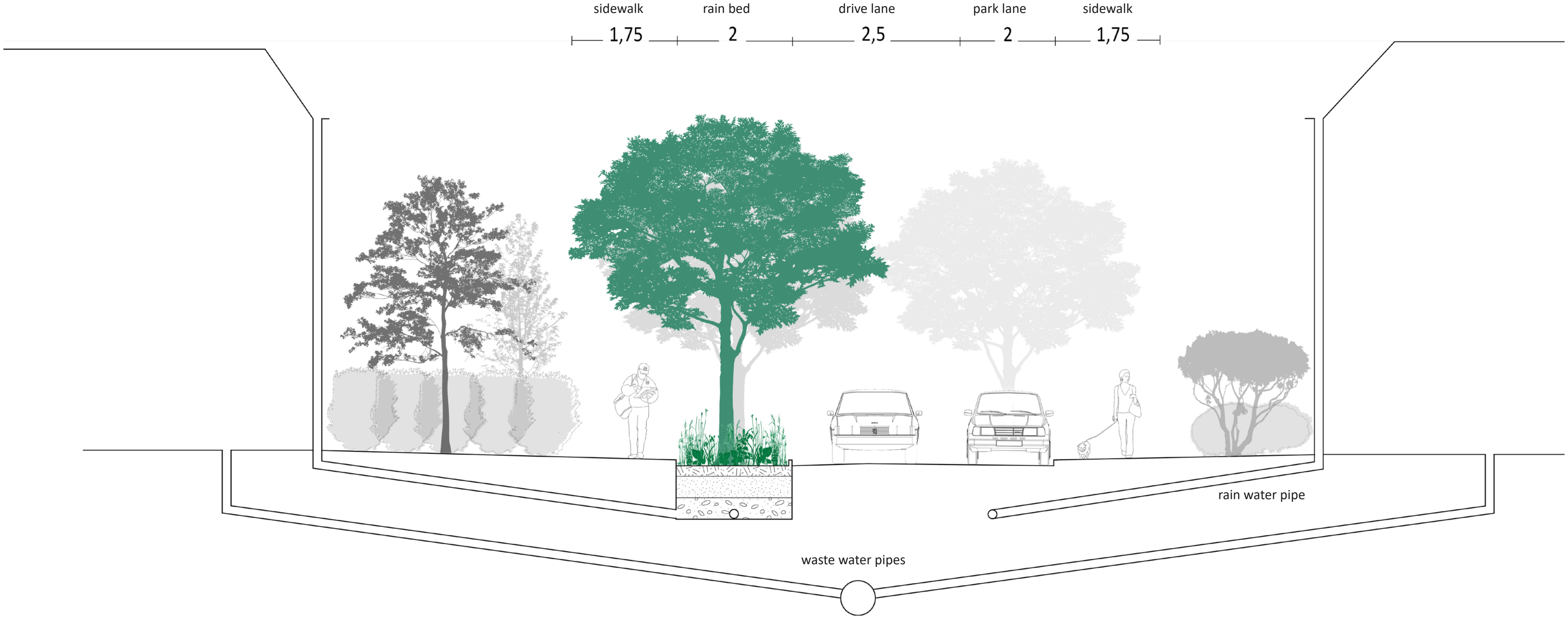


Figure 88 – section of 10-meter street – Existing measured minimal width of the sidewalk (1,2 m) for pedestrians is extended in the proposal to the width of 1.75 m, which nearly matches with the minimum recommended width (1,8 m) for people on wheelchairs. (GSDG, 2016) Sidewalks are separated from motorized traffic by either rain beds or parking lanes, where parked cars or vegetation can create a safety buffer against passing traffic. Width for the drive lane was decreased to a minimal single drive lane. There are newly-marked parking lanes along the sidewalk's edge. The minimal dimensions for these two street-uses are based on Danish traffic recommendations. (Ramboll, 2017)

Figure 89 – section of 12,5-meter street – This street typology, in addition to a 10-meter street, contains bus traffic and cycle traffic. Width of all functions on this street compare to a 10-meter street is extended but width of parking lanes stays the same. The enlargement is particularly necessary for passing points and a drive lane that contains the minimal width for bus traffic. The length of passing points was increased up to 15 meters.

The cycle way is situated only on one side of the street and is placed at the same level as the sidewalk, as it is done in Copenhagen. Sidewalk and cycle ways are protected by rain beds or parked cars. For the other direction, cyclists can use a shared line that is for both – motorized traffic and cyclists. This cycle facility is called "Contraflow Cycle Street" and it fits into small-scale streets where vehicular speeds are low. (GSDG, 2016)

12,5 - meter streets with diverse traffic

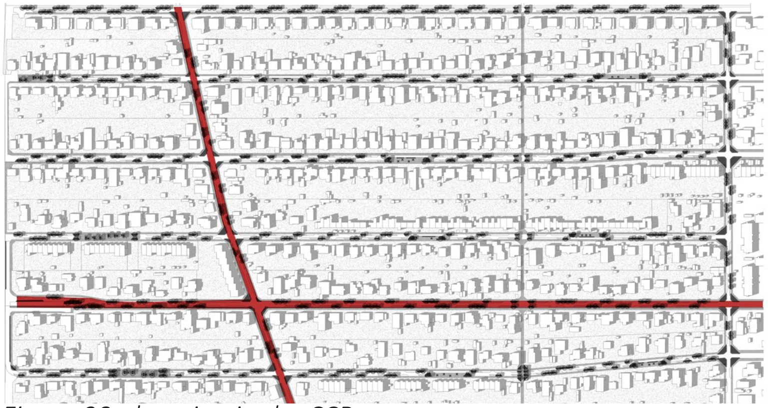


Figure 90 - location in the CCP

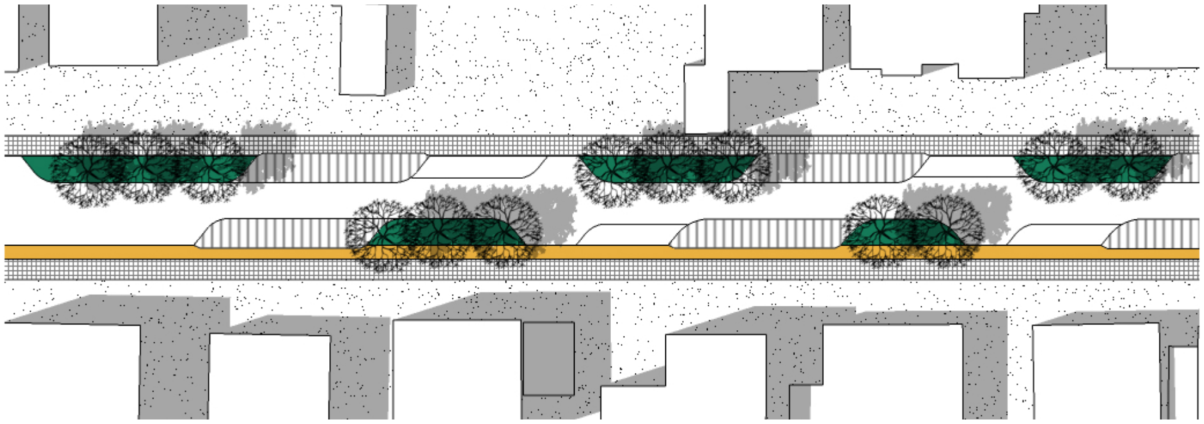


Figure 91 - CCP detail

Figure 92 – When it is possible, passing points are situated in front of the private car entrances in order to automatically prevent other cars from parking there, allowing them to park on marked park lines instead. Cyclists and pedestrians are protected either with vegetation, which provides the function of a safe edge, or with parked cars, or cars that are slowing down at passing points. In a situation when two drivers from opposite directions meet, the driving lane can shift temporarily into a passing point; this lowers vehicle speeds.

Intersections

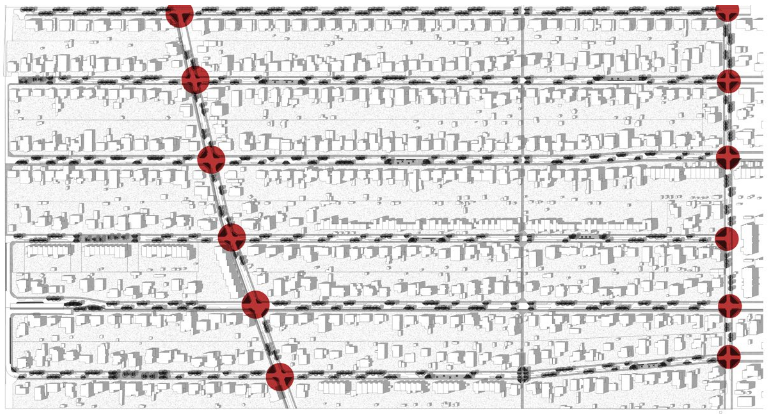


Figure 93 - location in the CCP

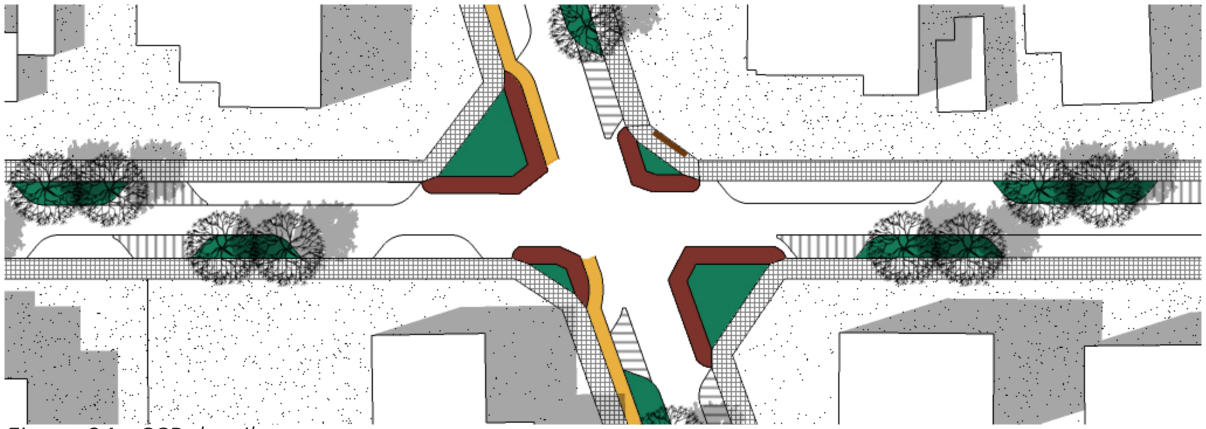


Figure 94 - CCP detail

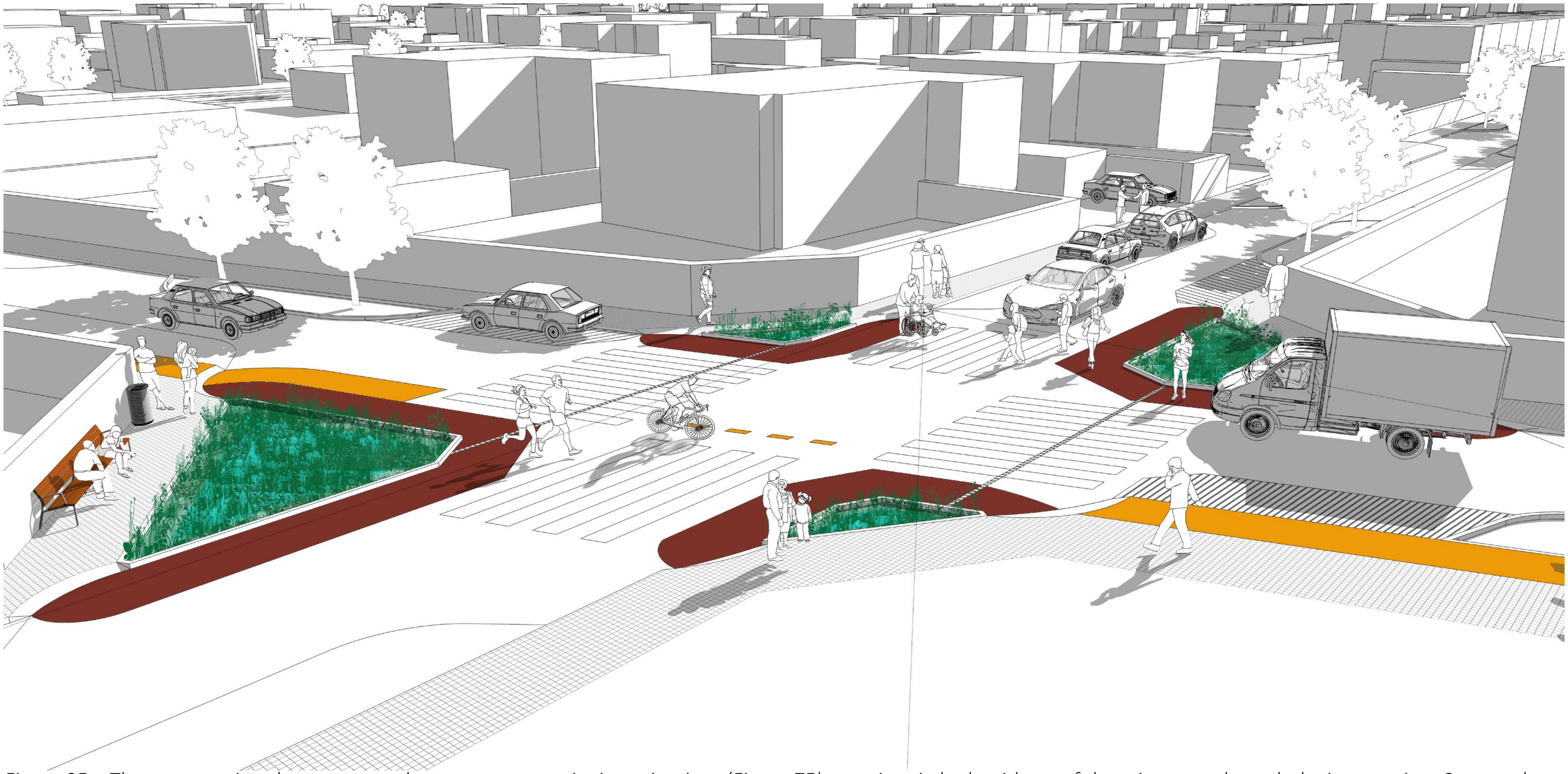


Figure 95 – The cross-sections have narrowed corners, which are marked with a different colour in order to signal and shorten crossing distances for pedestrians. The unused empty corners that were identified during on-site investigations (Figure 75) contain rain beds with low vegetation, which enables a clear visible angle for the drivers who want to pass through the intersection. Trenches are used in order to enable smooth transport of the rain water through the intersection. Corners that were identified as the most frequent for pedestrian movement and get most sunlight contain city furniture, where people can sit and relax, right next to a rain garden.

New recreational opportunities and stimulation of social activities

Another specific function of proposed BGI is to provide the generally-accessible recreational spaces that are sought by neighbourhood residents. New recreational spaces are suggested directly on the public street so that all residents can feel eligible to access them. Such places could act as common areas where diverse activities could take place. According to Christopher Alexander's study, common areas "make people feel comfortable outside their buildings and their private territory, and therefore allows them to feel connected to the larger social system." (Alexander, 1977)

These spaces are suggested on the neighbourhood streets, where the recommended speed limit is 20 km /hour, in front of the buildings where at least two of these spaces have a visual connection to the street, and at the same time are easily accessible for all local residents.

BGI facilitates a soft edge for these spaces and makes the big street feel smaller and more intimate. The be-

10 - meter streets with local recreational areas

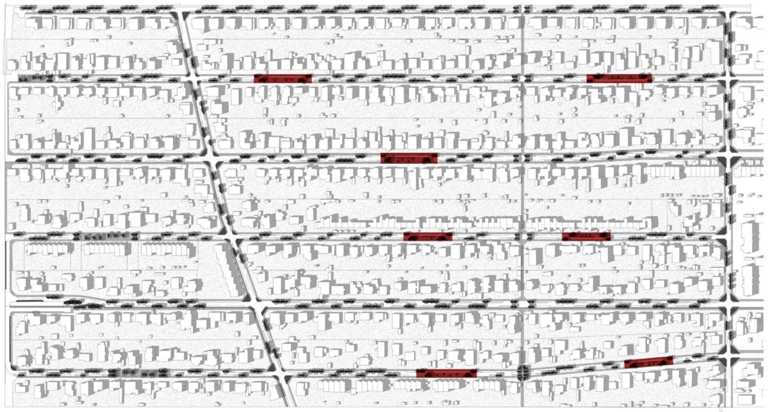


Figure 96 - location in the CCP

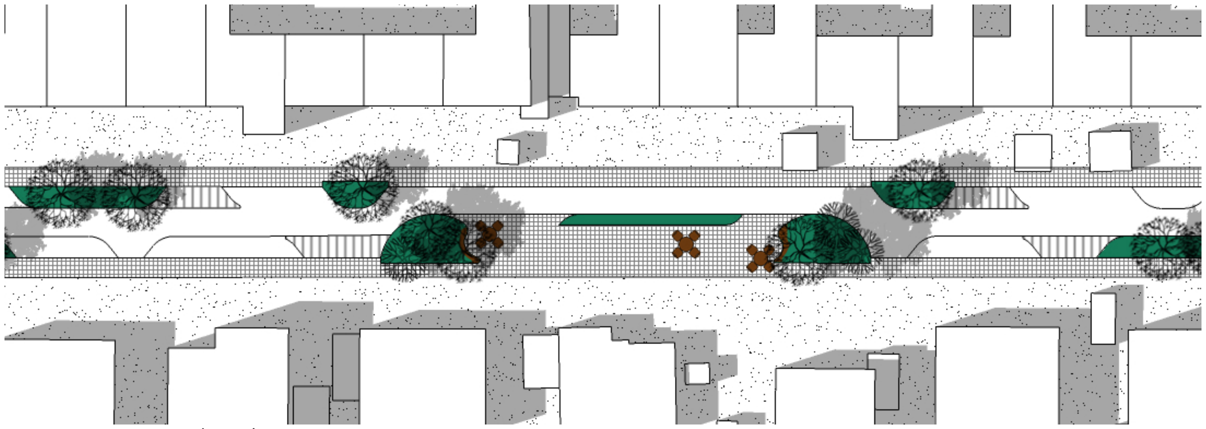


Figure 97 - CCP detail

Figure 98 - first type of recreational area that consists of sidewalk extension and BGI elements (rain beds and bioswale) which protect the area against traffic that is allowed to pass through.

ginning and end of these recreational areas are marked with proportionally bigger BGI elements that partially extend into a sidewalk. At the same time, they smoothly shift the direction of the drive lane in order to make cars ride extra-slowly around these areas (Figure 98).

The recreational spaces can be utilised according to even more specific residents' needs, similar to what they did to spaces in Kartoffelraekkerne, Copenhagen, where one space contains more play equipment, and another more chairs and tables (Figure 100). These spaces can, therefore, facilitate diverse social activities that are desired by local inhabitants. Such spaces can contain functions for sitting, children playing, meeting or even gardening, where BGI features can be used for growing plants or as an educational tool for local schools, where students can get practical knowledge about the water cycle and storm water management.

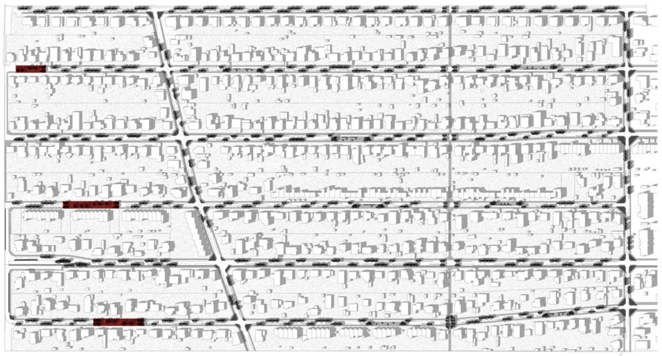


Figure 99 - location in the CCP

Figure 100 - CCP detail

Figure 100 - example of existing recreational area (Kartoffelraekkerne) in between residential buildings

Figure 102 - second type of recreational area consists of big rain beds that marks entrances into recreational area. Motorized traffic is not allowed to pass into this type of recreational area (the same principle is applied in Kartoffelraekkerne - Figure 100), except residents who have there their own parking places in front of their house. Further, it consists of small rain beds that structure the recreational area into several smaller and more intimate places.

4.5.4 Storm water calculations of BGI solutions in public space

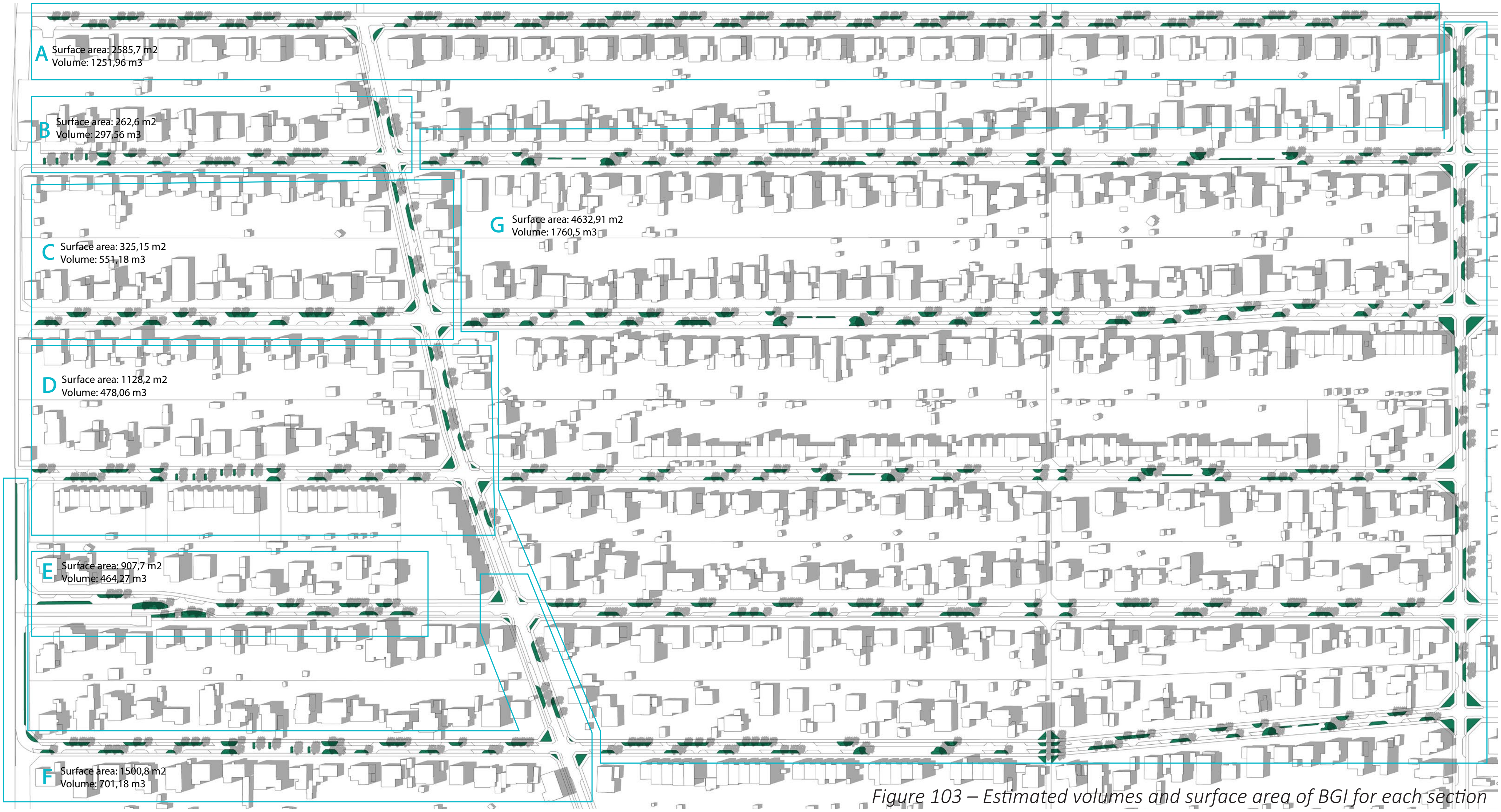


Figure 103 – Estimated volumes and surface area of BGI for each section

Estimation of capacity of proposed BGI solutions

First, it is necessary to estimate the capacity of proposed BGI in order to know how much rainwater solutions can retain.

The capacity for every BGI component is determined based on the surface area (m2) that it covers, the porosity of substrate and depth of magazine. In order to estimate the approximate depth for BGI solutions, Ramboll's proposal of separate sewer infrastructure was studied (Attachment 2). It reveals depths of proposed storm water pipes in the area, which can be used in analogy to estimate the depths of every proposed BGI feature. On the basis of this plan, depths are estimated and 2% sloping added in the equation, in case there would be a need to connect the solutions with separate storm water pipe. The pipe must always be placed lower than BGI solutions in order to allow for smooth discharge.

If we look at the figure, the solutions in "G-area" can be designed into the maximum depth of 0,95 m. These solutions will contain only substrate in its magazine with 40% porosity. The solutions that are in other areas (A-F) can be designed into bigger depths (with the recommendation of maximum 3 meters), and therefore together with one meter of the substrate can also contain soakaways, which have a porosity of 98% and can, therefore, be much more effective in retaining rain water.

On the basis of these parameters, it was calculated that proposed BGI solutions in public spaces can retain 8470,65 m3 of rainwater.

Estimation of rain water volumes

Then, with the use of the CDS excel sheet, it is possible to estimate how much rainwater will be in a selected catchment area during a selected rain event. The CDS is a predefined excel sheet that is used by hydraulic engineers to automatically specify rain water volumes based on entered hydraulic parameters.

Hydraulic parameters contain:

A rain event for which the calculations are estimated.

A safety factor, which secures that future solutions will be lasting, as it is predicted that cloudbursts will increase. The safety factor is a predefined parameter for each rain event and in practice it artificially raises estimated rain water volumes for safety reasons.

Square meters of catchment area must be estimated (in ha) and this area can be further divided into permeable and impermeable surfaces. For the permeable surfaces, there can be applied reductions, as some of the water can be infiltrated. It is important to note, however, that in terms of the 100-year event, all surfaces act as impermeable. The last parameter is the capacity of a pipe (l/s) for transport of the rainwater.

The following CDS calculations are made for a 100-year rain event and a 10-year rain event, which is standard practice at Ramboll for almost every climate adaptation project.

For these calculations, the reduction is included only in a 10-year rain event, and it is only 0,8 as most of the soil in the area has low conductivity. The capacity of the pipe was estimated based on Ramboll's proposal with a separate storm water system. There are two proposed pipes that transport water outside of the catchment area. The one with the smallest capacity was selected in order not to create overestimated results.

100-year rain event without a central retention area

Catchment area: 49,6 ha

Safety factor: 1,54

Cloudburst pipe: 59, 7 l/s

Capacity of proposed BGI: 8470,65 m3

Estimated volume of rain water: 102 619 m3

Proposed BGI can retain 8 % of rain water volumes during 100-year rain event; the rest has to be retained in a central retention area.

10-year rain event without central retention area

Catchment area: 49,6 ha Permeable area: 30,1 Impermeable area : 19,5 ha Reduction: 0,8

Safety factor: 1,34

Cloudburst pipe: 59, 7 l/s

Capacity of proposed BGI: 8470,65 m3

Estimated volume of rain water: 29 738 m3

Proposed solutions can retain 28 % of rain water volumes during a 10-year rain event; the rest has to be retained in a central retention area.

The calculations specify how much volume from the selected catchment area can be retained only through proposed BGI solutions. The calculations do not count in a planned central retention area; therefore, new calculations are made on the basis of a hydraulic model, which includes the central retention area in the calculation. Because there is no available simulation for a 10-year rain event, the 25-year rain event will be used instead.

25-year rain event with the central retention area

Catchment area: 49,6 ha

Volume of rain water: 8 302 m3

Capacity of proposed BGI: 8470,65 m3

Solutions together with central retention area can retain 100 % of rainwater during a 25-year rain event.

100-year rain event with the central retention area

Catchment area: 49,6 ha

Volume of rain water: 18 430 m3

Capacity of proposed BGI: 8 470,65 m3

BGI solutions together with central retention area can handle 46 % of rain water. The 54% that stays in the catchment area accounts to 9 959,4 m3.

If we aim to answer the first research question fully, we need to consider all available potentials that are in Kalendarkvareter neighbourhood and therefore it is necessary to look beyond public territory – to private spaces in the neighbourhood, where the second research question asks what BGI solutions could be implemented there? These potential spaces could provide additional volumes and therefore decrease the risks even more.

4.5.5 Cloudburst tactics for private spaces

There are several potentials in the neighbourhood that were identified during the analytical frame (see chapter 4.4.5.2 and 4.4.6.2). This chapter will provide a suggestion for each different private typology and later will estimate a total volume of all potential BGI solutions in private spaces.

Private and semi-private rain gardens

There are, in total, 177 private front gardens and semi-private front gardens in the neighbourhood that have the potential to use their empty space for the construction of a rain garden (see chapter Site inventory of residential buildings; unused private and semi-private green spaces), if private property owners or co-owners would allow it. The question is that if 20% of private front-gardens were transformed into rain gardens, how much volume in total it could provide? And how much volume would it hold if half of the semi-private front gardens could be transformed into rain gardens?

The assumption for semi-private rain gardens is based on average size of available space, 0,9-meter depth of the magazine, and corresponds to the illustrated design (Figure 104).

The private property owners could benefit from the solution in terms of less demand for maintenance compared to mowed lawn, higher amenity value and collective contribution to climate adaptation and mitigation of flood risk.

Semi-private wet basin

The analytical part of the thesis identified two blue spots in the neighbourhood (see Blue-spot analysis), which could cause flood risk to the buildings that are in their close proximity. The suggestion is to transform these two terrain depressions into the semi-private pond and allow it to collect rain water. This solution is inspired by the existing formation of ponds in Gladsaxe that provide a soft edge between private properties (Figure 106 and 107). Private property owners could receive direct benefits of such a solution in terms of new amenities, recreational value and prevented risk from flood damage.

Semi-private dry basin

There were identified (see chapter Site inventory of residential buildings; unused private and semi-private green spaces) three semi-private green spaces that are collectively maintained and used by people who live in nearby row houses. These spaces are used mainly for children to play. If the terrain of green spaces could be lowered, it could still provide space for children to play but at the same time, it could retain extra volumes of storm water during wet periods.

Figure 104 – Existing downpipe could be disconnected at the bottom of the building and rainwater could be led through terrain to the newly-established rain garden. The rainwater from the rain garden would be discharged through existing storm water pipe into the nearest public BGI feature. During extreme rain, it could overflow through terrain and trench, which would be under a sidewalk into the nearest BGI feature on the street.

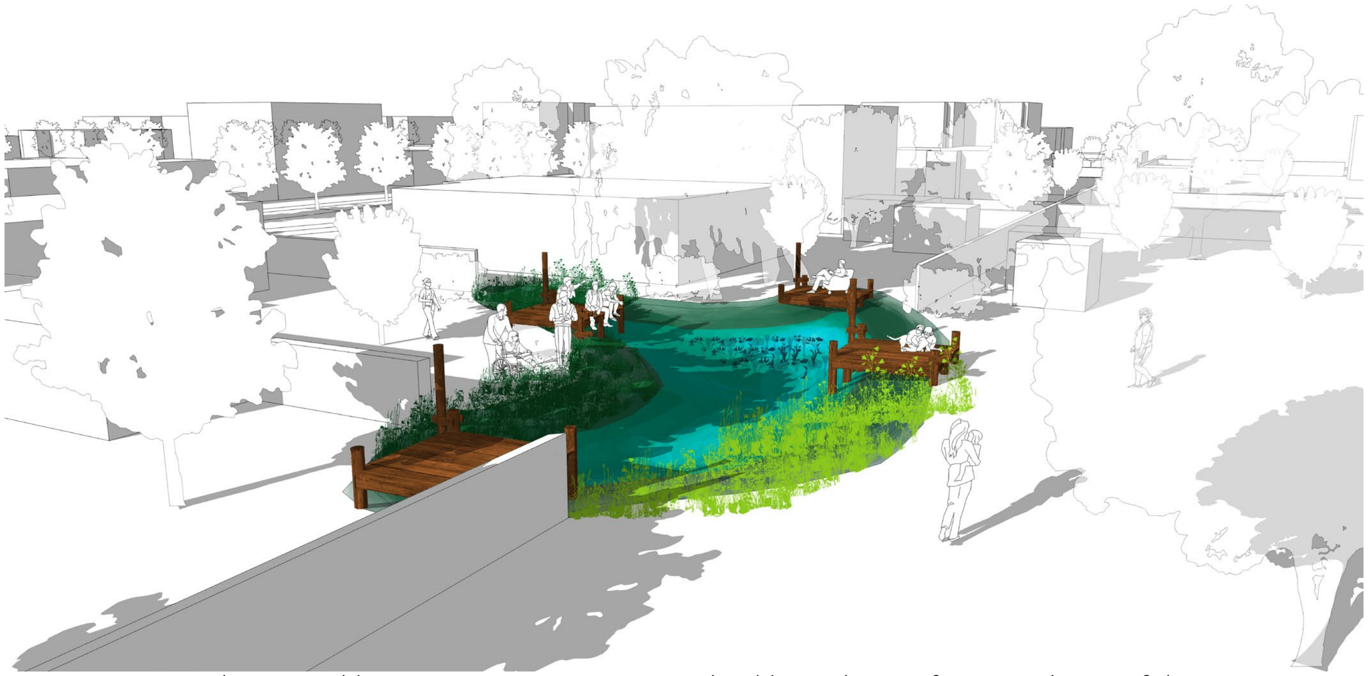


Figure 105 – Wet basin would contain permanent water with additional space for rain volumes. If the water were to exceed the magazine's volume, it could be discharged through the outlet into the nearby cloudburst pipe.

Figure 106 - "shared pond" at Haspegårdsvej, Gladsaxe that local residents use as part of their back-garden

Figure 107 - another bigger "shared pond" is at Gorkis Alle, Gladsaxe

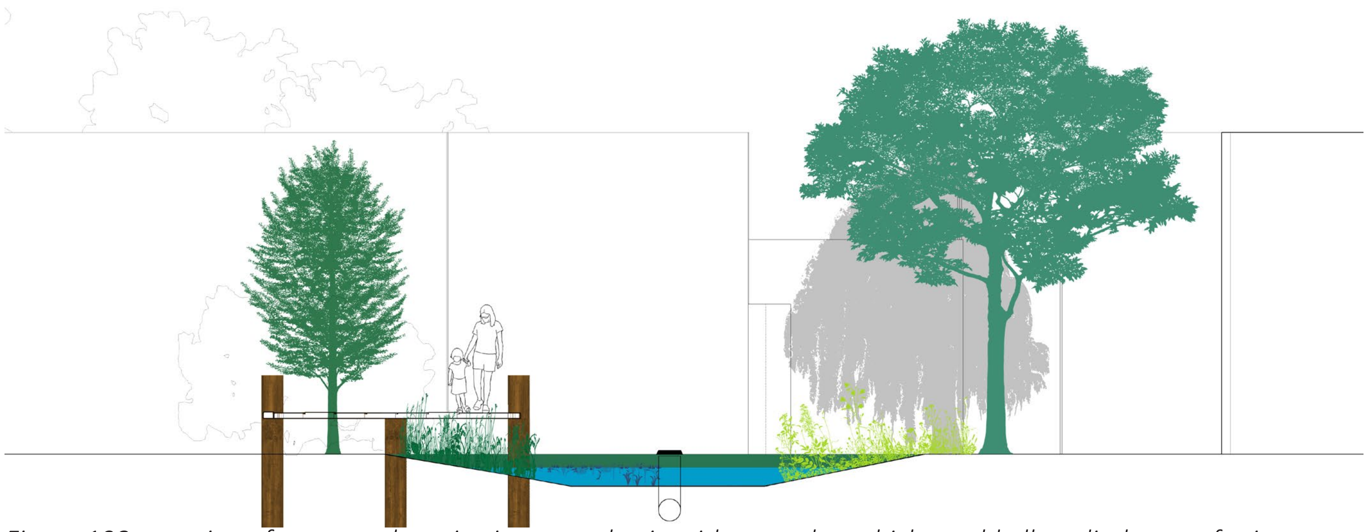


Figure 108 - section of suggested semi-private wet basin with an outlet, which would allow discharge of rain water into cloudburst pipe during periods of heavy rain

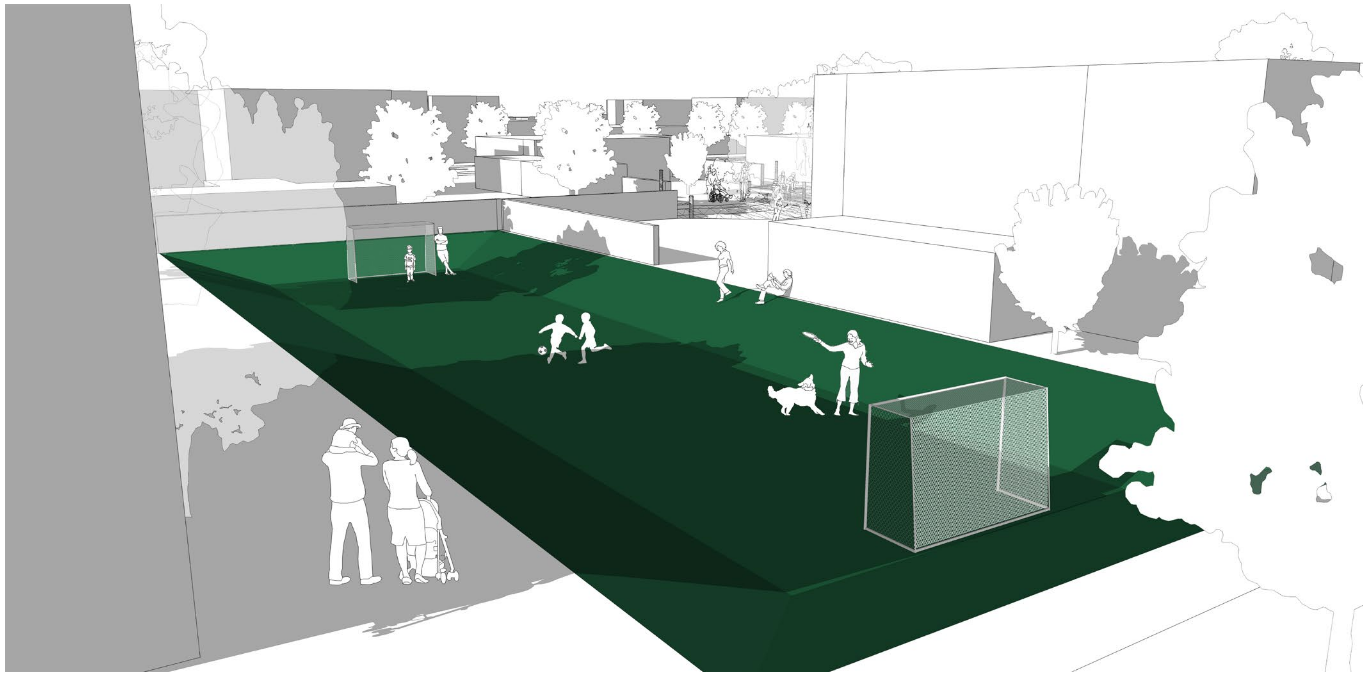


Figure 109 – a semi-private dry basin could provide a dynamic use of space – sports activities during the dry period and temporary volume retention during the wet period. This volume could be slowly drained through perforated pipes that would be right under the dry basin. Rainwater would be discharged into the nearest cloudburst pipe.

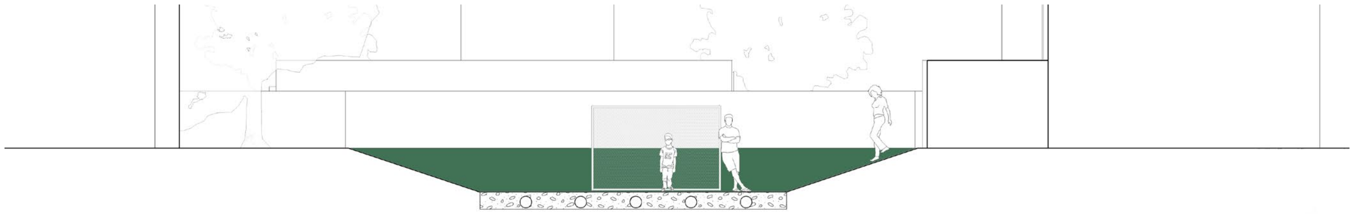


Figure 110 - section of semi-private dry basin during dry conditions

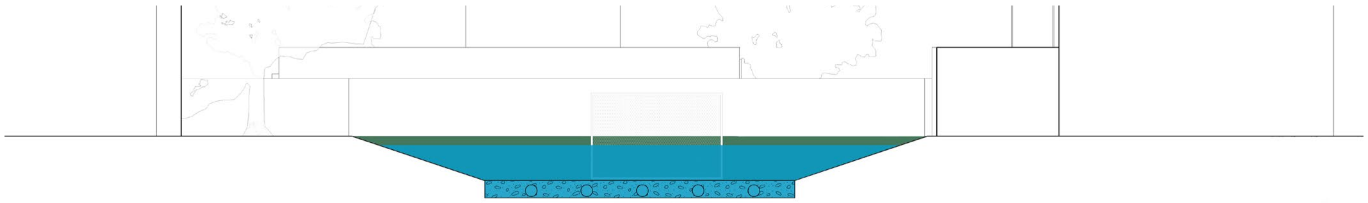


Figure 111 - section of semi-private dry basin during wet conditions where rain water is being slowly discharged through perforated pipes

4.5.6 Storm water calculations of Cloudburst tactics for private spaces

Potential spaces for implementation of BGI are calculated in accordance with suggested BGI solution.

Private and semi-private rain gardens

Number of empty front-gardens (private): 177

Number of empty front-gardens (semi-private): 6

Number of potential front-gardens: 35 (20% out of 177)

Number of potential front-gardens: 3 (50% out of 6)

Average surface area of empty front-garden: 25 m2

Total surface area of empty front-garden (private): 875 m2

Total surface area of empty front-garden (semi-private): 89 m2

Depth of magazine: 0,9 m Porosity: 40 %

Total volume: 347 m3

Semi-private dry basin

Number of semi-private green spaces: 3

Total surface area of semi-private green spaces: 1000 m2 (together with 3 meters wide slopes)

Depth of magazine: 1 m

Total volume: 1000 m3

Semi-private wet basin

Number of blue spots that span on private spaces: 2

Current volume of both depression with 20 cm of water in it: 1045 m3

The total potential volume of both semi-private wet basins full with 50 % of permanent water in each: 522 m3

Sum of all BGI solutions at private and semi-private spaces

The overall volume of all suggested solutions on private and semi-private spaces is 1869 m3.

4.6 Evaluation of risks and costs

4.6.1 Risk Assessment of site area with climate adaptation

Figure 112 - map of Risk Assesment Analysis of 25-year rain event

buildings with no access to emergency services
buildings with no access to public transport
buildings with high risk of damage
cyclepaths
roads and sidewalks
buildings
project area border
transport hubs

Risk value of inaccesibility and physical damage - buildings

2
4
6
8

Risk value of inaccesibility - streets and paths

2
4
6

Water high of 100-year flood

10 cm
20 cm
30 cm

It was calculated that proposed BGI solutions for public spaces in the neighbourhood, together with the proposed central retention area in Kagsa park can handle 8470,65 m3 of rainwater within delineated catchment area (49,6 ha). Proposed solutions have a maximum capacity to handle 100% of rainwater that corresponds to a 25-year rain event. These solutions, together with suggested BGI solutions, at private spaces in the neighbourhood could retain 10 339,7 m3 of rainwater, which corresponds to 56 % of retained rainwater during a 100-year rain event. The 44% of rainwater represents a potential flood, which could appear in the neighbourhood during such a rain event. This amount of flood (8 090 m3) is almost the same as a flood after a 25-year rain event (8 302 m3; see chapter Hydraulic model). The difference is only 212 m3 of rainwater, therefore this simulation could correspond to the situation when the neighbourhood is hit with the 100-year rain event and all suggested BGI solutions were implemented even though it wasn't simulated on basis of these proposed changes.

In order to be able to evaluate possible risks that would remain in the neighbourhood, a new Risk Assessment Analysis is processed based on an existing hydraulic model of a 25-year rain event, in order to compare risks related to 100-year rain event before and after the implementation of suggested BGI solutions for public and private spaces.

Summary of risks that would remain in the neighbourhood after climate adaptation:

Two percent of the buildings (13 out of 630 buildings) are at high risk of damage (before 8% of the buildings ((49 out of 630 buildings)) were at high risk of damage).

Eight percent of the buildings (50 of 630 buildings) are at high risk of inaccessibility to public transport (before 63 % of the buildings ((399 of 630 buildings)) were at high risk of inaccessibility to public transport)Zero percent of the buildings (45 of 630 buildings) are at high risk of inaccessibility of emergency services (before 7% of the buildings ((45 of 630 buildings)) were at high risk of inaccessibility of emergency services)

18 pecent of public space is inaccessible for pedestrians (before 37% of public space was inaccessible for pedestrians)

Six percent of roads are inaccessible for cyclists (before 16% of roads was inaccessible for cyclists)

Zero pecent of roads are inaccessible for cars (before nine percent of roads was inaccessible for cars)

4.6.2 Cost estimation of damage in site area with climate adaptation measures

It's possible to assume that damage cost in relation to 100-year rain event for the selected site could be 417 154 DKK (10 residential houses together with 3 small outdoor houses). A yearly damage cost accounts to 4 171 DKK. That is a 72% decrease of damage cost in comparison with the situation with no climate adaptation measures (see the chapter Cost estimation of damage in Kalenderkvarteret neighbourhood without climate adaptation measures).

4.6.2 Cost estimation of proposal

A rough cost estimation of construction budget is done in order to get a clue about an approximate cost of suggested solutions in public space. The final costs are not exact and don't include a complete list of all items. However, the emphasis was taken to take into account all items that represent a significant cost for a construction of proposed solutions.

The costs of all items are based on Ramboll's figures from their previous projects. Knowledge about an onsite construction of solutions is obtained in order to know needed items and their standard dimension requirements for a successful process of construction.

The cost estimation is made for the proposal which includes BGI solutions in public spaces for which was estimated that have a maximum capacity to handle 25-year rain event (see chapter Stormwater calculation of BGI solutions in public space). For suggested BGI solutions at private spaces, the cost estimation is done as well and this cost is valuated together with BGI solutions at public spaces separately.

The cost estimation differs between items that are necessary for the development of functional BGI that enhances current water management and items that relate to a construction of suggested extra functions (for example construction of new cycle ways and new recreational spaces are calculated as „extra costs").

At the same time, cost estimation is calculated for Ramboll's proposal for a new stormwater infrastructure (see Attachment 2). Ramboll's proposal is designed to handle maximum 5-year rain event. In order to do a comparison of both proposals, I have asked Ramboll's hydraulic expert Henrik Sonderup to make a rough guess, based on his professional experiences, in order to know how much approximately a diameter of proposed stormwater pipes would need to be increased in order to handle 25-year rain event in the area. This guess is based on assumption that proposed stormwater pipes would need to increase their diameter approximately + 0,2 m.

As a result, the cost estimation could provide a good idea of how big investment would be needed in order to avoid risks of a 25-year rain event in the selected site lower the risks of 100-year rain event to risks and costs that correspond to a 25-year rain event.

Traditional stormwater infrastructure - proposal	Unit	Unite Price	Quantity	Total price
Braking up etc.				
Braking up and removing asphalt	m2	150 DKK	11727	1 759 050,0 DKK
Excavation and dispposal of soil	m3	350 DKK	23452	8 208 200,0 DKK
Stormwater pipes				
Ø400mm concrect pipe	lm	1 700 DKK	1800	3 060 000,0 DKK
Ø600mm concrect pipe	lm	2 600 DKK	889	2 311 400,0 DKK
Ø800mm concrect pipe	lm	5 000 DKK	1317	6 585 000,0 DKK
Ø1000mm concrect pipe	lm	10 000 DKK	1099	10 990 000,0 DKK
				22 946 400,0 DKK
Roads reconstruction				
Asphalt concreat layer, stability gravel and base gravel	m2	2 048 DKK	11727	24 011 032,5 DKK
Uncategorized				
Manhole Ø1250	apiece	40 000 DKK	80	3 200 000,0 DKK
Total cost				**60 124 682,5 DKK**

Blue-Green Infrastructure - proposal	Unit	Unite Price	Quantity	Total price
Braking up etc.				
Braking up and removing asphalt	m2	150 DKK	17458,59	2 618 788,5 DKK
Excavation and dispposal of soil	m3	350 DKK	12086,65	4 230 327,5 DKK
BGI solutions - public spaces				
Plantings	m2	300 DKK	8377,12	2 513 136,0 DKK
Edge fill	lm	200 DKK	6058,6	1 211 720,0 DKK
Substrate (1 m depth)	m3	240 DKK	8377,12	2 010 508,8 DKK
Soakaways (stormwater cell)	m3	2 000 DKK	5272,6	10 527 928,0 DKK
Ø100mm plastic piping	lm	500 DKK	7073,47	3 536 735,0 DKK
BGI solutions - private spaces				
Plantings	m2	300 DKK	1264	379 200,0 DKK
Substrate	m3	240 DKK	964	231 360,0 DKK
Ø100mm plastic piping	lm	500 DKK	1645	822 500,0 DKK
Trenches	lm	1 200 DKK	114	136 800,0 DKK
Excavation and dispposal of soil	m3	350 DKK	1964	687 400,0 DKK
Roads reconstruction				
Asphalt concreat layer, stability gravel and base gravel	m2	2 048 DKK	8556,2	17 518 819,5 DKK
New cyclepath				
New asphalt	m2	500 DKK	1663,2	831 600,0 DKK
Cloudburst pipes				
Ø600 concrete pipe	lm	2 600 DKK	385	1 001 000,0 DKK
Ø800 concrete pipe	lm	5 000 DKK	519	2 595 000,0 DKK
Manhole Ø1250	apiece	40 000,00 DKK	15	600 000,0 DKK
Uncategorized				
Trees	apiece	8 000 DKK	644	5 152 000,0 DKK
Furniture	apiece	10 000 DKK	28	280 000,0 DKK
Pavement	m2	450 DKK	3300	1 485 000,0 DKK
Trenches	lm	1 200 DKK	160	192 000,0 DKK
Road marking and signs	per road	10 000 DKK	8	80 000,0 DKK
Total cost for BGI at public spaces				**48 555 963,3 DKK**
Total cost for BGI at public and private spaces				**50 813 223,3 DKK**
Total cost for BGI at public spaces with extra functions				**56 984 563,3 DKK**

Findings

The calculations of costs for both proposals were made. As a result proposed BGI for public spaces is less expensive compared to proposal with traditional stormwater infrastructure. The investment cost of BGI is lower than invesment cost for traditional sewer infrastructure even if all extra functiions and suggested solutions at private spaces would be taken into account.

4.6.3 Summary and evaluation

In order to sum up all findings that relate to risks and costs, a short recapitulation is done.

Damage costs

On a basis of Risk Assessment Analysis (see chapter 4.4.2 Cost estimation of damage in site area without climate adaptation) it was calculated that yearly damage cost in relation to 100-year rain event is 14 823 DKK. Yearly damage cost for 25-year rain event would be 16 686 DKK.

Investment costs

Cost estimation evaluated BGI as less economically demanding than traditional storm water infrastructure (see chapter 4.6.2 Cost estimation of the proposal). The total cost for BGI at public spaces without extra functions is 48 555 963 DKK. When also extra functions are implemented the investment cost would be 56 984 563 DKK. If also suggested BGI at private spaces is included this investment cost is in total 59 241 823 DKK, which is 3 140 119,2 DKK less than alternative with traditional storm water infrastructure.

Evaluation

The proposal with suggested solutions at public spaces could avoid physical damage risks to a private property in site area up to 25-year rain event that means that every year 16 686 DKK of direct damage cost could be avoided.

In term of a 100-year rain event every year 4 171 DKK from physical damage could be avoided.

However, its apparent that invesment cost for the proposal is much higher than estimated avoided damage cost. Therefore it can be concluded that this proposal, which addresses alternative with maximum rainwater capacity wouldn’t be economically viable for this specific site area because avoided risks are much lower than estimated investment cost for implemeting climate adaptation measures.

V

REFLECTIONS

5.1 Consclusions

5.2 Discussion

5.1 Conclusions

Based on the Ramboll's Cloudburst Formula and onsite investigations, a proposal related to climate adaptation for a selected area of the Kalenderkvarteret neighbourhood was created. In order to address both storm water resilience and urban living conditions, suitable BGI elements were selected and prioritized over the traditional storm water infrastructure. The process of retrofitting current sewer infrastructure resulted in a combination of both infrastructures with the prevailing use of BGI components.

The main intention was to utilize benefits and functions of BGI that are listed in Part II and consider its applicability for the neighbourhood in order to resolve its specific site issues that were documented in analytical phase.

Risk assessment analysis proved that current storm water management in the neighbourhood is insufficient during extreme rain events. On the top of that it drains rain water and waste water into one closed combined sewer system, which does not allow rain water to continue its natural water cycle. These storm water managment problems were driving issues that initiated the process of renewal of neighbourhood. As a result of climate adapation processes, the proposal with BGI was created. The storm water calculations helped to evaluate the proposal as more effective compared to its current situation because it introduces functions, which were previously missing. Functions such as retention and detention. These functions help to retain rain water volumes and slow down rain water drainage, which is the effective way how to manage rain water during the extreme rain events. The proposal preserves current combined sewer system that no longer mixes storm water with waste water and is suggested to be used for transport of waste water only. Such a system provides needed separation of rain water that allows continuation of its natural water cycle. Additionally, it can have a positive impact on water quality because BGI components have a function to certain extent cleanse storm water runoff from a pollutants, which are typically presented on streets with motorized traffic.

The spatial experience of urban life in the neighbourhood is limited to the streets in the neighbourhood. In order to secure and elaborate the qualities of urban life condition in the neighbourhood, it was important to do the site inventory and compare it with unfolded insights from a local citizens. Moreover, analysis of movements of pedestrians and cyclists helped to identify their prevailing movements on the streets. These findings helped to inform design proposal that organizes BGI features in a current urban structure in a way that could enhance urban life with many of its benefits and functions that were listed in Part II.

Local residents expressed a wish for safer and greener streets with recreational function inside of the neighbourhood. Therefore, firstly previously dominated motorized traffic is harmonized with other street-uses. Analysis with movements of cyclists and pedestrians helped to decide where to integrate new cycle-ways and where to create most suitable opportunities for pedestrians to sit, which was one of the other needs expressed during interview with local residents. In addition, BGI features create the benefit of calming traffic and function as a soft edge, protecting pedestrians from motorized traffic. That can have a direct positive impact on the safety of all street-users who move through the neighbourhood with lowered risk of a traffic accident. Safer street conditions can give the possibility to make new recreational green spaces that can provide new meeting places desired by local inhabitants inside the neighbourhood and encourage social interaction and integration. The green streets and green recreational spaces can contain diverse vegetation that enhances biodiversity and moderates urban climate. Such spaces can be for people more inviting to stay outside longer and be more active, which can have a positive effect on their individual well-being.

The proposed BGI on the streets could raise the property value of all buildings within the project area as they are in close distance to the solutions that can contain vegetation with high aesthetical value. This can be especially appreciated by property owners who have difficulty selling their houses because of highway noise which lowers property values. The benefits of the proposed BGI can compensate for the negative effect of noise on the property value of the buildings in the area.

Therefore, it can be concluded that a proposed BGI can improve existing drainage conditions in a selected site in the neighbourhood. It can also improve current urban living conditions for the local community and it can improve the well-being of individuals while mitigating the negative impact on an environment.

The second research question expands the scope of research from public territory to private, where more potential available space for handling rainwater is located. The potential linkage of solutions between private and public territory could, even more, improve water resilience against a 100-year rain event in the neighbourhood and it could create even more benefits in the neighbourhood (for example sense of ownership and shared responsibility).

The suggested solutions on private land would include rain-beds, dry basins and wet basins. These solutions would retain and delay rainwater and would be connected to the proposed BGI in public spaces.

It can be concluded that the proposal would have enough capacity to handle rain water that relates to the 25-year rain event. In case of the 100-year rain event, the flood risks could be lowered only to certain extent.

As a result, risks that would remain in the neighbourhood during the 100-year rain event are significantly lower when compared with the current situation with no climate adaptation (see chapter 4.6.1 Risk Assessment of site area with climate adaptation and chapter 4.4.1.2 Risk Assessment of Kalenderkvarteret). It is important to highlight that this conclusion applies only to the delineated catchment area (see chapter Flowlines) which includes the selected site area. It is possible that during a 100-year rain event, flooding from a higher catchment could overflow into the delineated catchment area. Fortunately, this area where the higher catchment is located is prioritized for the implementation of climate adaptation measures as well. (Gladsaxe, 2013) This gives hope that the risk of overflow into the delineated catchment area could be lowered.

On a basis of the economic calculations, it can be concluded that the proposal wouldn't be economically viable because the damage costs that it could avoid being too low compared to the investment cost for the implementation of BGI.

Therefore it can be recommended to do a new iteration of the proposal and create new alternative on basis of previous proposal where it's rainwater capacity would be reduced to an extent that would provide an optimal stormwater management service for a lowest investment cost.

5.2 Discussion

Reflections on what has been carried out and achieved, in relation to set goals and research questions

The master thesis's goals were to:

- Define and identify flooding issues in a studied site area
- Create a proposal for a specific site that will reconcile current functions with a new and will suggest ways to improve conditions for both urban life and storm water resilience against extreme rain periods

These objectives were narrowed to two research questions:

- How can the current public sewer infrastructure at the selected site area in the Kalenderkvarteret neigh-bourhood be retrofitted in order to improve its water resilience against 100-year rain events and its current urban living conditions?
- What solutions, regarding the specific site condi¬tions of Kalenderkvarteret, could be suggested for handling the rain water in private spaces of the neigh¬bourhood?

A flood risk assessment analysis helped to grasp a large area and to divide it into key risk areas. One of these areas were further selected as a specific site area in order to continue research further. This analysis proved to be a successful tool to identify and define major risks that could happen in the area during extreme rain periods in term of physical damage and inaccessibility. It helped to select an adequate site to continue furthering the objectives. Above that, it addressed also main costs related to physical damage during extreme rain. Yet, to address full costs the research would have to continue further and other affected infrastructures would need to be studied together with socio-economic costs related to inaccessibility. As a result, it could provide more accurate and complete damage costs with a good clarity, which can be useful information for better dimensioning of a proposal.

The proposal suggested a new flexible storm water system and succeeded to address improvement of a resilience against cloudburst events in the neighbourhood. It was documented that it could safely handle 25-year rain event and it could lower risks that would be caused by a 100-year rain event. However, the proposal was not supplemented with any of its alternatives that could possibly provide its different sizing options (large, medium or small). Other alternatives might be useful to consider because the current proposal didn't succeed economically, which might automatically withdraw it from consideration for retrofitting of the current infrastructure. Its dimensions are higher than investment costs that are too high if we consider damage costs that the proposal could avoid.

A work with BGI solutions enabled to address many of its benefits, which relates to urban living conditions. The proposal was able to tackle these aspects through the sound organisation of BGI components into the current urban fabric in a way that it has potential to enhance urban life together with the integration of new storm water functions. BGI could act green spaces that could provide new opportunities for recreation and socialization, increased biodiversity, moderation of urban climate and traffic calming on motorized streets.

Another objective of the research was to provide flexible ways how storm water could be handled at private spaces in the neighbourhood on the basis of local site conditions. This resulted in a suggestion of 3 examples of small cloudburst interventions that could be shown to local residents who could consider their implementation. However, the acceptance and applicability of these solutions would need to be discussed with them in order to prove its relevance.

Critical discussion on Ramboll's approach

The urban landscape is complex in the sense that it consists of social, economic and ecological systems that respond to climatic changes. It requires their broad understanding before intervening them. The Ramboll approach offers one of many ways how to initiate climate adaptation processes where these systems are studied and edited through multidisciplinary profession practice. The usage of their Cloudburst Formula provides ways how to gain quite broad understanding and opportunity to work with these complex systems. However, there are certain limitations and precautions that one must take into account when working with this complexity within this approach.

Firstly, the correctness and precision of the results depend to a big extent on the reliability of the used empirical data (like for example terrain data that are used for example for hydraulic modelling). If data would not be reliable (which can refer for example to its low level of detail) it could lead to overestimation or underestimation of results and that could create inappropriate climate adaptation actions.

Secondly, the Cloudburst Formula provides primarily problem-solving approach that is supported by an extensive technical and economic expertise. Still, it lacks enough methods that could put more focus on the analysis of current conditions of urban life. It doesn't mean that these aspects are ignored or not taken into account at all but possibly adding to its setup one more extra step that would focus on more in-depth onsite investigations could provide a better understanding of site's urban living conditions. These findings were important the during work on the proposal for the master thesis' case study and therefore BGI solutions were planned and developed in a way that it could support and improve also urban living conditions.

Last but not least, the formula provides major attention to issues that relate to ways of handling rain water quantities in an urban environment in a most optimal way. Yet, it doesn't give enough attention to address rain water quality, which is another important aspect when we deal with rain water in the urban environment. A rain water runoff can often carry pollutants, which should be treated as well as they can be drained into water bodies where valuable ecosystems are often presented.

My neutrality as a researcher working so close to the company and critical discussion of sources and references

Working so close to the company gave me great opportunity to engage with professionals who had different competence than me. I have got valuable in-depth experience of current professional practice that deals with climate adaptation. However such opportunity has also its cons, which I have been acquainted with later. The master thesis is very influenced by expertise and knowledge by the company (Ramboll) that works with climate adaptation. It would be relevant to provide a comparison with the practice of another commercial company or other existing approaches in order to increase its scientific value. Even though I was constantly questioning their methods as a researcher working under them I didn't question it with another related professional outside of the company who could provide another perspective. If this would be taken into account during my research the overall work could benefit from it and could provide better scientific value.

With similar providence it is necessary to read the list of benefits. Its effects are being continuously researched and one must take into account that maybe what works in one culture might not work in another because people tend to use outdoor space differently and for example, greener outdoor spaces might not automatically mean that people will spend more time outside.

Another reflection relates to the usage of data that is already edited by the company where the thesis was written. This refers namely to use their hydraulic model or the insurance figures, which they have collected. These data were very roughly explained in the thesis. Their more in-depth research could justify its clarity. For example, insurance data that relates to damages of building property during extreme rain events were calculated on the national level of Denmark. It would give it more clarity if instead of these general national insurance figures would be used figures that were reported to the address where the damage occurred and where the proposal is undertaken.

Critical discussion on the proposal

Climate adaptation can be looked upon as a good excuse for a needed renewal of neighbourhood where retrofitting of current insufficient storm water management can work as a catalyst to address issues that are not only related to storm water management but also these that relate to the quality of urban life. Onsite investigations provided insights about current conditions of urban life in the neighbourhood and the proposal suggested solutions that react to them. It uses advantages of BGI to not only regulate water in term of improved storm water resilience but it also addresses benefits that relate to improved livability conditions like beauty, stimulation of social interaction and integration, better conditions for physical and mental health or moderation of urban climate. Further, it has potential to increase biodiversity and property value of buildings that are along the streets where the proposal suggests the BGI solutions.

The benefits of improved storm water resilience were directly evaluated and their positive effect on a decreased flood risks was showed through new assessment of flood risks that remained after suggested changes. Nevertheless, in order to evaluate the rest of potential benefits, it would need to be necessary to continue the research further. For example through discussion with clients and local residents about the proposal, further development of the proposal (for example detailing the proposal) and its implementation. These next steps would need to be conducted and its effects evaluated to better estimate its created values.

However, above this all, a good question to think about would be: is any change of the current sewer system in the neighbourhood really necessary? The answer is probably yes, because the current combined sewer system in the neighbourhood has a certain lifespan and will need to be soon or later replaced. Therefore, it is adequate to think about a future alternative, which could be done either through the implementation of the primary separate sewer system or BGI solutions. The economic calculations of the investment cost of both variants estimated that BGI solutions are cheaper and could provide more benefits than the other alternative. Therefore the alternative where BGI is prioritized could be most likely considered as a right choice.

The proposal that was made for the case study was evaluated as economically too demanding because investment costs are too high in comparison with costs for damaged building infrastructure during extreme rain periods. Yet, it is important to mention that the building infrastructure was the only infrastructure that was included in the cost calculations. It is possible to assume that other infrastructures (traffic, sewer infrastructure, etc) will be damaged as well and this could result in additional cost. Also, socio-economic cost like halts in production because people can't access their workplaces during extreme rain is another possible reality that is not included as well. After taking this into consideration the currently underestimated results might be more accurate.

However, if we continue with the conclusion that investment cost for retrofitting of new storm water infrastructure in the neighbourhood is too high but still necessary in order to secure functional storm water management it's needed to suggest the right economical equilibrium. This might be achieved if the current dimensions of BGI components in the proposal would be decreased to its minimum in order to provide optimal service level for a minimal investment costs. However, this would require new iteration of the proposal.

This reflection of needed iteration of the proposal points on how complex climate adaptation really is. Everyone who is working with it should be aware of that these projects can affect social, economic and environmental systems and always look for options how to evaluate them properly. Paying closer attention to getting broader understanding and have sincere reflection during planning processes of these measures could help to make them even more beneficial for our future urban landscapes.

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List of figures

Attachments - A

Attachment A1 - List of benefits

Natural capital
It provides people with an array of free goods and services also known as Ecosystem Services. It supports the reproduction of natural resources for a human purpose (such as water, energy and air).

Water-related eco-system services

The BGI mimics natural processes and through its integration into urban fabric can mitigate negative effects of urbanisation and insufficient water management- namely through recharge of a ground water level, reduction of a peak discharge of storm water and cleansing of storm water before it enters natural ecosystems.

While putting a stronger focus on the biological cleaning process in the BGI the storm water runoff can be purified to such an acceptable level that only ultraviolet treatment is required to classify the water as drinking water. (Public Utilities Board, 2009)

Moderation of urban climate and increased biodiversity

The BGI mimics not only natural drainage processes but also processes related to moderating urban climate extremes that correspond to extreme temperatures known as the urban heat island effect. It mitigates air pollution because atmospheric pollutants are captured by the vegetation and the soil. (Dunnett, 2007 and Coutts, A. 2010). These reductions have a secondary effect of decreasing demand for cooling systems and air filtration systems that are run on electricity.

The BGI provides habitat for diverse species and can enhance their connectivity in terms of ecological infrastructure. (Hassall, C. 2014) *"BGI, therefore, provides opportunities to link fragmented green spaces through a network of corridors in a catchment, thereby connecting isolated populations of species through functional connectivity between aquatic and terrestrial habitats. BGIs themselves can be "stepping stones" or "nodes" through which fauna and flora could move across larger landscapes."* (Dreiseitl, Wanschura, 2016)

Build capital
relates to the designed character of the material and physical features of a city's infrastructure. The BGI is by nature a type of build capital because of its man-made features.

Resilience

The already existing projects of the BGI proved their resiliency and effectivity to handle extreme rain events. The direct effect can be interpreted in increased resilience in a drought (especially in areas with a dry climate) and in increased resilience in an urban flooding in flood-prone areas that are vulnerable especially during a cloudburst events. The BGI helps to slow down water flow and reduce discharge peaks during such events. Cities like New York or Singapore are implementing a BGI infrastructure after they have reflected on limitations of traditional sewer infrastructure when they were exposed to extreme rain events.

Even more severe situations occur in cities such as Los Angeles, which has to face both extremes- cloudbursts as well as drought, which stresses their water resources. *"Ironically, the drought has increased the imperviousness even of natural surfaces, multiplying the intensity of storm water runoff associated with these high-intensity precipitation events. The consequence is that during the drought, these high-intensity precipitation events have induced devastating landslides in urban areas and decreased water quality."* (Dreiseitl, Wanschura, 2016) Los Angeles responded with the adoption of BGI that will help to feed water resources while preventing floods. The urban heat island effect will be mitigated through evapotranspiration from the vegetation that is part of the BGI features.

Example - New York, USA and Singapore, China

Franco Montalto et al. made a study with a focus on the effect of storm water retention associated with a BGI. He has chosen as a project area The Nashville Greenstreet, in Queens, NYC, and has observed the effects during Hurricane Sandy (in October 2012) and Hurricane Irene (in August of 2011). His study revealed a substantial reduction in peak storm water flow that BGI provided: *"The Nashville Greenstreet significantly reduced the storm water 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."* (Montalto, 2013)

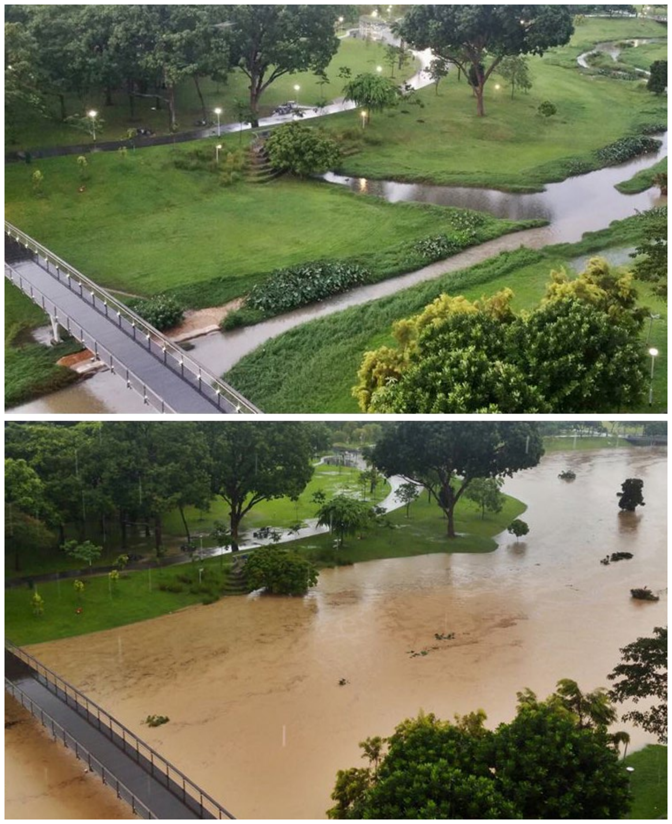

Figure 11 - situation after and during the cloudburst at Bishan-Ang Mo Kio Park (BAMK)

In 2017, a newly revitalized Bishan-Ang Mo Kio Park experienced heavy cloudburst. The figure 11 shows the park during the cloudburst and 1,5 day after where we can clearly see effective resiliency of this infrastructure.

After the cloudburst it was neccessary to do some cleaning of debrits but it is evident that vegetation withstand the pressure.

Beauty

Another asset of the BGI is its amenity, which enables the opportunity to upgrade a city's appearance. An appealing BGI helps to reconnect people with nature and give positive impulses to enhance directly another immaterial capital (human, social and symbolic capital). The combination of blue and green aspects of the infrastructure is especially more beautiful than if these aspects were implemented independently. The places that include the BGI are easier to distinguish because of their correspondence to site topography, native flora and drainage. (Dunnett, 2007)

Social capital
is a power source based on affiliations. It is immaterial capital and it has an effect on personal or impersonal relations to other people that are reflected in commitment, cohesion and social support.

Social interaction and social integration

Social interaction is conditional upon the quality of physical space. *“High-quality social spaces can help to counter the negative impacts of urbanisation on social relationships, including tendencies towards isolation and depersonalization.”* (Dreiseitl, Wanschura, 2016) The BGI can provide diverse space to various communities (composed of families, associations and friends) for their recreation, social interaction and integration.

Social identity

The BGI has big potential in strengthening social identity. *“Processes of identity building are complex. They are usually based on learning through social interactions and mutual perception – e.g. in seeing oneself through the eye of another under conditions that are socially structured by norms, expectations, practices, and opportunities.“* (Mead, 2009) These processes can help individuals relate to the bigger social group (for example family members with their neighbours). *“This identity-based relatedness is of tremendous importance for the consumption, reproduction, and generation of common resources (e.g. liveable urban conditions, public infrastructure, peace, trust etc.). It provides the basis for pro-social sharing of resources and the sanctioning of antisocial behaviour.”* (Ostrom, 1990) The BGI can create various opportunities for stimulation of social integration.

Figure 13 - a process of redesigning bioswales in villa Rosaria together with local dwellers

Example - Buenos Aires, Argentina

In Buenos Aires, where the level of poverty is high, the poorest social groups are forced to build their informal settlements on disadvantaged sites. Villa Rosaria one such informal settlement that has the characteristic problem of periodic floods because of its disadvantaged flood-prone location. The problem affects all inhabitants of villa not only through direct harmful effects of flooding but also with the spread of mosquitos and disease created by uncovered and uncontrolled standing water.

The inhabitants naturally, with the use of their local knowledge about their area, created their own alternative of BGI without deeper knowledge. The result is a series of interconnected swales around road edges (Figure 13).

However, without professional guidance, they did not succeed- the flooding was not completely eliminated and the problem of standing water got even worse because of inaccurate work with elevation.

A local NGO got to know about this serious situation in the villa and came to help. The NGO called TECHO has an engineering background and decided to re-introduce the idea of the BGI to local inhabitants in a more functional way.

After a few meetings (Figure), they decided to implement the proposal as it was an opportunity to improve their tragic situation. The inhabitants started to raise funds through their local resources by selling food and clothing or doing small social works to pay for the physical work and usage of heavy equipment for excavating the soil.

One of TECHO workers explains that this creation wouldn’t be financially possible without the direct engagement of locals through the overall process of re-structurization of the previous BGI. Further, he explains that the direct process of involving inhabitants during ideation and construction of the BGI has helped them to strengthen their community sense, especially their trust in the community, because their efforts not only helped each other but also resulted in the increased appeal of their surroundings. The final functional BGI structures now associate local inhabitants with positive emotions of pride and success, which is completely different from the previous situation.

Human capital
concerns personal competences and capabilities. It relates to individual physical and mental health, strengths of persons or knowledge.

Physical and mental health

In densely-urbanised areas, people are lacking sensual and spiritual connection with nature. This can have a negative cumulative effect in the form of weak physical and mental health. The BGI offers natural spaces, which support both active and passive recreation, help to provide relief from work and stress and also decrease the prevalence of lifestyle-related diseases, including hypertension, diabetes and obesity.

Example - Singapore, China

The revitalised park Bishan-Ang Mo Kio Park in Singapore (Figure 11) has a great effect on the well-being of local communities. *“It was revealed 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.”* (Dreiseitl, H., Tovatt, O., Wanschura, B. 2015)

Spiritual connection with nature and education

The BGI reconnects people with nature, which is one of the prerequisites to help people understand natural processes. Exposing people to nature is a great way to cultivate a relationship with the natural environment. Especially for children in their early age, this awareness can be very rewarding in the long-run. The BGI spaces can communicate directly about the natural water cycle and ecosystem services to individuals but also to social groups such as schools and communities.

Figure 12 - students are actively involved during construction of the bioswale

Example- London, England

Hollickwood Primary School in London is a great example of how the BGI can work as an educational tool for local students while solving the water related problems. The school’s open ground for children’s play periodically suffered from a water logging and flooding. Moreover, the storm water runoff was feeding a nearby brook with the pollutants.

The process of designing BGI infrastructure took into account the needs of children and teachers. “Staff, parents and children at Hollickwood school were very enthusiastic about this project and were very keen to be involved at each stage. This has meant that the SuDS quickly became a talking point in the school and is now central to school life.” (SUSdrain, 2014)

The BGI features didn’t reduce the area of informal play space at all but enormously increased opportunities for children to interact with the BGI during play and also during formal outdoor learning sessions, where they can learn about wetlands and surface water management. *"Children at Hollickwood are now much more aware of the need to manage rainfall sustainably and about the value of wetlands for people and wildlife. Added to that, they have fun, new places to play in*." (SUSdrain, 2007) Children can grow up together with BGI that becomes part of their everyday life. It provides children with experience and first-hand knowledge about such sustainable water features.

Symbolic capital
is a type of immaterial capital related to attributes of positive value to persons, organisations, firms, cities and states. It exists in forms of reputation, image, and tradable brand names.

Iconic value and tourism

There is an evident competitiveness among all word cities to attract people by reaching some certain positive status – to be rated as "most liveable cities". The annual survey is done through organisations such as Monocle which ranks cities according to their liveability conditions. The recognition of good reputation is something that cities can earn. Cities are therefore challenged to cultivate their values and unique features, especially in this era where cities are being challenged with the negative effect of globalisation and over-standardisation of the urban landscape. The BGI can play an important role in making each city more authentic and unique.

The BGI is a very inclusive concept, which can be appreciated by various groups of people and individuals.

It is proven that the BGI increases the reputation of cities by strengthening modern urban values such as sustainability, resilience and liveability.

BGI is recognised as an innovative approach which combines functionality together with aesthetics and beauty. The future-oriented urban design is very appealing to tourists because it creates iconic value in the overall image of a city.

Example - Malmö, Sweden

Historically, Malmö used to be one of the most industrial cities in Scandinavia. Today the city is going through the visible process of transformation that rapidly enhances a city's reputation through a strong emphasis on sustainable development. One of the key transformations was the redevelopment of a certain part of Malmö's Western Harbour- where the industry was previously highly concentrated- into the eco-residential district. This transformation resulted in the first climate-neutral district in Sweden that uses 100% renewable energy and a decentralised storm water system, which is a key part of the image of this development.

"The development now attracts many study tours annually. The organisations 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." (Dreiseitl, Wanschura, 2016)

*Figure 14 - Western Harbour in Mal*mö

Financial capital
relates to direct as well as indirect costs and benefits resulting from economic impacts.

Property value

It is proven that the properties that gain access to the green urban spaces are also valued more highly. For example, J. Crompton in his empirical study gained insights about 30 research projects where, after receiving access to the park, their value increased by 20%. (Crompton, 2010)

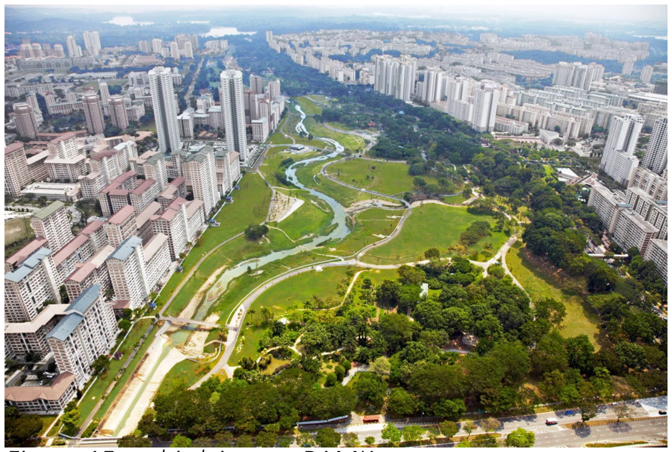

Figure 15 - a birdview on BAMK

Example - Singapore, China

Similar effects were observed in Singapore after the revitalization of Bishan-Ang Mo Kio Park (BAMK). In 2014 and in 2015 the Ministry of Environment and Water Resources based their study on the hedonic price model in order to analyse the effect of BAMK on the nearby real estate. The results of the research showed that implementing BGI in the park affected an average increase of 2-4% of real estate value of the properties. (Dreiseitl, Wanschura, 2016)

Health benefits

The BGI provides spaces for physical activities that help to reduce mental stress and increase life satisfaction. These health benefits reduce individual and public health costs.

Attachment A2 - List of components

The following list includes some of the essential components of BGI. The solutions can be further modified according to the site-specifics. Different country-specific guidelines can provide additional information with regard to the construction and dimension of the solution. (Hoyer, 2011)

Green Roofs

Definition

Green roofs comprise a multi-layered system that covers the roof of a building with vegetation that is planted over a waterproofing membrane. They can intercept, retain and delay the volume of stormwater runoff and purify it.

They can reduce storm water runoff and also slow it down. "Because roofs represent approximately 40-50 % of the impermeable surfaces in urban areas, green roofs have a potentially major role to play in reducing the amount of rainwater rushing off these surfaces." (Dunnett, 2007)

When roof surfaces are planted with diverse plants they can enhance biodiversity. If the soil medium has enough depth it can be used for more intensive green roof solution such as urban farming. These soft structures can create rooftop space for social gatherings and interaction. Green roofs have become very popular for so-called grass root organisations with movements towards sustainability. Green roofs are great solutions for densely-urbanised areas such as New York or Copenhagen where residents have adopted this solution for their urban farming movements.

Functions:

Retention, Detention, Filtration, Phytoremediation

Co-functions:

Aesthetics, Soft structures, DIY, Biodiversity

Rain barrels

Definition

A rain barrel (or water butt) is a medium-sized container for harvesting the rain water. It is connected directly to the downpipe. Stored water can be used for small-scale uses. The storage volume can be quite large; one barrel can store around 250 l of water.

A rain barrel can follow right after a green roof as an effective stop for the water in a storm water chain. Since it cannot be really effective against a cloudburst, it would be good if it were linked with a gutter or swale, which can be right under the rain barrel when it gets full.

The possibility of storing water can potentially create cost savings and it has beneficial effects while watering the plants- it contains no chlorides, it has zero hardness and it contains fewer salts then treated municipal water. (Dunnett, 2007)

Functions:

Storage, Detention

Co-functions:

DIY

Stormwater planters

Definition

It is an above-ground raised planting container that can receive the rain water from the roof through a disconnected downpipe. It contains soil and plants.

Planters are sited directly against a building or can even be integrated into it through the incorporation of structural walls into the foundation of the building. They can provide a storm water management function and vegetation in the smallest of schemes. (Dunnett, 2007)

Excess water can overflow from the storm water planter into the storm water chain or- when it's not possible- into the conventional drainage system.

Functions:

Retention, Detention, Filtration, Phytoremediation

Co-functions:

DIY, Biodiversity, Aesthetics

Permeable paving

Definition

Permeable paving includes various pervious materials that are used to allow retention of storm water through the surface while providing conditions for pedestrian and vehicular traffic. This component aims to control and reduce storm water runoff at the source and improve water quality by filtering pollutants in the underground layers.

This solution is effective if the native soil is well-drained and slopes are not higher than 5% in order to allow good soaking conditions. It is primarily suited for roadways with low-traffic speed and volumes. (San Mateo County, 2011)

It can support speed reduction of the traffic through the surface differentiation in areas where cars have more limited access.

Functions

Retention, Infiltration, Sedimentation, Filtration, Conveyance

Co-functions

Aesthetics (subject to design), Traffic regulation

Soakaway

Definition

It is an underground modular system that consists of blocks (stormwater cells) that are easy to construct and very effective for retention of stormwater. It is a very good solution in densely-urbanized areas with a lot of underground infrastructures and high traffic, especially in areas where there is too little space to include other solutions that need space on the surface. When possible, stormwater cells can be combined with other surface solutions (rain gardens, permeable paving and so on) and help to retain extra volumes.

Functions

Retention, Infiltration

Street gutter

Street gutters (known also as gullies, rills or channels) are a shallow linear non-vegetated BGI feature used for transporting water in order to link other BGI components and release water there.

Keeping water on the surface can increase aesthetics of the place while making it easier to maintain the storm water system instead of burying this linkage underground through piping. A gully can create a soft edge between two different spatial functions without making a visible barrier.

Functions

Conveyance

Co-functions

Soft edge, Aesthetics (subject to design)

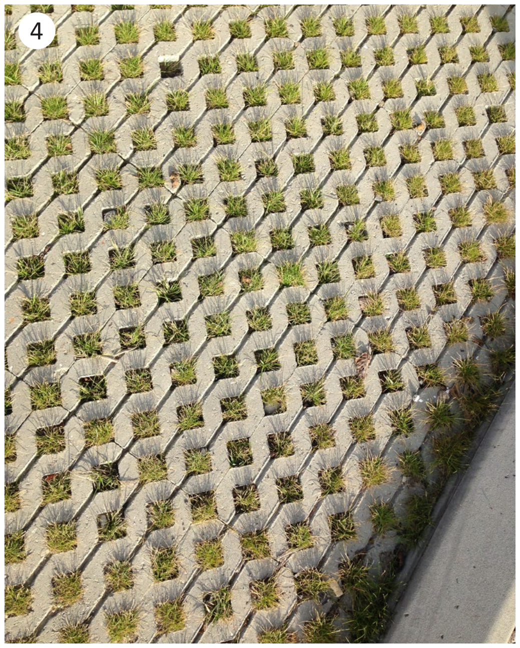

Image 1 - Greenroofs
Image 2 - Rain barrel
Image 3 - Street gutter
Image 4 - Permeable paving
Image 5 - Stormwater planter
Image 6 - Soakwaway

Bioswale

Definition

Bioswales are linear and narrow vegetated drainage features that delay and transport storm water.

They can also partly filter storm water if soil conditions don't require the use of an impermeable base. They are usually quite shallow, perfect for slowing down the water that interacts with plants and soil that allows sediments and associated pollutants to settle out. (San Mateo County, 2011)

Swales are mostly used along streets or parking lots. They provide an amenity to the surroundings and can softly separate conflicting functions, such as motorised traffic from sidewalks.

In terms of maintenance, the key routine is to ensure that inlet and overflow points are clear of any blockage from litter, debris and sediments.

Functions:

Retention, Detention, Conveyance, Filtration, Phytoremediation, Sedimentation

Co-functions:

Soft edge, Soft structure, Traffic regulation, DIY, Biodiversity

Rain gardens

Definition

Rain gardens are also known as rain beds. They are shallow planted depressions used primarily for infiltration, detention and filtration of storm water runoff.

They create an important stop-point for the water in an overall storm water chain as they can usually manage larger volumes of storm water than other BGI components. Their bottom is usually designed flat without any longitudinal slope in order to maximise storage potential for the storm water.

In low-density areas, rain gardens usually have soft edges and gentle side slopes. In high-density areas they have high-rise hard edges with vertical slopes in order to increase their capacity. (San Mateo County, 2011)

Functions

Infiltration, detention, retention, filtration, sedimentation, phytoremediation

Co-functions

Soft edge, Soft structure, Traffic regulation, DIY, Biodiversity

Constructed wetlands

Definition

These are man-made wetlands with the primary function of purifying stormwater runoff with the secondary focus on retention. Constructed wetlands are shallow and include extensive vegetated waterbodies where water can fluctuate during seasons.

Constructed wetlands are designed primarily to remove and dissolve contaminants. The wetland needs to be configured in order to provide its hydraulic efficiency and sustain its healthy vegetation. For that reason the wetland consists of three zones that ensure its vitality: "an inlet zone (designed as a sedimentation basin to remove coarse to medium sized sediments), macrophyte zone (a shallow heavily vegetated area to remove fine particles and soluble pollutants) and high flow bypass channel (to protect the macrophyte zone). (ABC guide, 2014)

Functions:

Retention, Infiltration, Detention, Filtration, Phytoremediation, Sedimentation

Co-functions:

Aesthetics, Biodiversity, Soft structures

Detention basins

Definition

Detention basins are typically grassed structures or hard surfaces structures, also known as dry ponds. They attenuate storm water runoff by providing temporary storage and controlled release of detained runoff. They are mainly dry, except during and immediately after rain events. (SUDS manual, 2007)

"They can be constructed to serve more than one purpose and can be used as car parks, playgrounds or sports fields. When constructed for dual purposes, the detention basin should be usable for the function other than stormwater detention for most of the time. Where dual use is intended, the recreational area should have a relatively low flooding frequency e.g. one to five year return period, depending on its use." (SUDS manual, 2007)

Functions

Retention, Detention, Sedimentation

Co-functions

Aesthetics, Soft structures

Infiltration basins

Definition

These are man-made vegetated basins (also known as sedimentation basins or wet ponds) with permanent water. Infiltration basins can infiltrate rain water into subsurface soils. *"They facilitate the recharge of groundwater resources and the replenishment of surface water base flows, and remove stormwater pollutants via filtration processes occurring within the unsaturated soils beneath the system."* (SUDS manual, 2007)

They are one of the final elements in the storm water chain where water primarily infiltrates and secondly purifies. They are usually located in the downstream area of a storm water chain.

Functions

Infiltration, Sedimentation, Phytoremediation

Co-functions

Soft structures, Biodiversity, Aesthetics

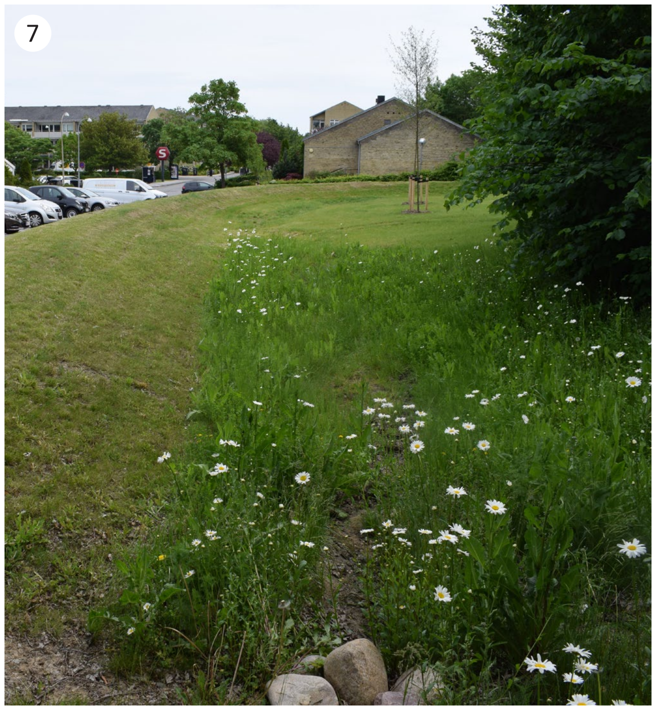

Image 7 - Bioswale
Image 8 - Rain bed
Image 9 - Constructed wetland
Image 10 - Dry basin
Image 11 - Wet basin

Attachment A3 - Collected data from onsite interviews

This is a collection of noted responses from interviewed local residents who directly answered questions in regards to neighbourhood values, problems and potentials or who spoke about them indirectly during their participation.

Total number of interviewed local inhabitants: 17

Values:

- peaceful, attractive and safe neighbourhood with a sense of community and long history
- good relations with neighbours
- quiet (east part of the neighbourhood)
- making common activities on the streets (parties, dinners, etc.)
- kids have many nearby schools, playgrounds and sports areas to choose from
- neighbours share responsibility for common areas
- front gardens are not only good for gardening but also a good way to socialise and relax
- the presence of environmental awareness (willingness to use sustainable energy and treat water responsibly)
- good accessibility to services, shops, work, public transport and big recreational areas (Kagså Park and to a natural park Smørmosen in the north)
- green strip in the north part of the neighbourhood hides the industrial area

Problems:

- sewer system does not have enough capacity - water flows into basements and creates difficulties in accessing the public street
- complicated access with public transport to Herlev, the west area (behind the highway)- there is no good bus line to that area and therefore it is necessary to transfer more times
- new light bulbs do not light up the streets as much as before
- sometimes two cars park next to each other from both sides of the streets and it can be complicated for bigger vehicles to pass (ambulances, firetrucks)
- youngsters from social housing (in the east and south) are noisy and do not behave well, some thefts reported
- noise from the highway
- it is not easy for local inhabitants to use Gladsaxe's model "Regnvand på egen grund" (see the chapter Model for implementation of BGI by private property owners) in order to collect rain water locally
- it is difficult for old people to move garden equipment between the back garden and front garden
- too many hard surfaces in the neighbourhood
- cars are driving too fast on the main street (which leads through Juni Alle and Rybjerg Alle) and therefore it is necessary to be more cautious when crossing the street
- cars are often parked on the crossroad's (with reference to a place where Juni Alle and Rybjerg Alle intersect) and therefore it is difficult to see passing cars from a driver's perspective.

Potentials:

- public streets could be more green (for example with tree-alleys in the street)
- there could be more green recreational places to sit and opportunities to meet with neighbours inside of the neighbourhood
- there could be more opportunities to do gardening with the neighbours
- the model for handling rain water on private property could be improved- make it more accessible (user-friendly) and give higher financial compensation (Rain garden costs 60 000 DKK and financial compensation usually cover only 35% of the cost)

Attachments - B

Attachment B1 - Risk Assessment Analysis
Attachment B2 - Ramboll's proposal for storm water infrastructure
Attachment B3 - Cloudburst Concetrization Plan