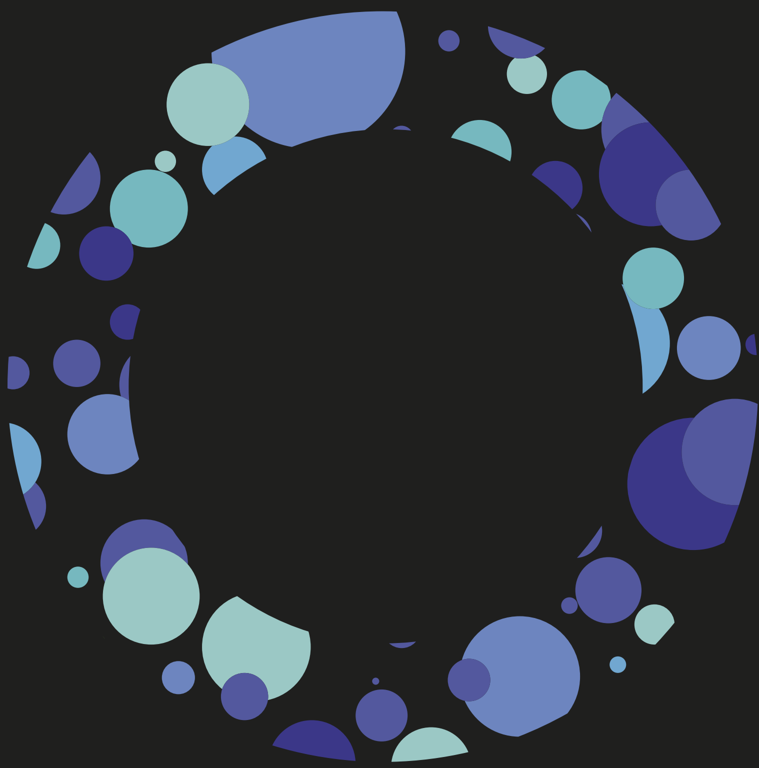

SPONGE CITY

Multidisciplinary project

ERQI SPONGE CITY FINAL REPORT

November 2018

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PREFACE

This document is the result of our research for the Sponge City Project in Wuhan. It is the outcome of our effort to create a model for the Sponge City Programme (SCP) for the ErQi area in the city of Wuhan, China. We, as a group of MSc students of various specializations, chose to work on a multidisciplinary project concerning urban flooding in China, in the hopes of mitigating the effects of rapid urbanization, population growth and climate change. For this, our collaboration with our main partner Arcadis, was crucial. In addition to providing us with a project location, a large amount of data and logistics support, including arranging the initial meetings with the stakeholders, they gave us the opportunity to show the potential of an interdisciplinary approach in China.

Arcadis has been active in China for many years and they have experienced that China is on a very steep learning curve, working hard to develop good practices towards water management. The eagerness to learn from international expertise, and the Dutch in particular, is very present. The recently developed SCP (2014) is an important first step towards the implementation of sound measures, and the challenge now lies in creating a comprehensive approach.

Arcadis is operating here under a government mandate to help designers and developers implement the Sponge City Programme (SCP). When the Sponge City Project Team started this project, Arcadis already performed an initial assessment of the area in which they could use the data from. The assessment was performed at the district scale as well as at smaller scales, per blocks and roads in which they provided specific target to achieve. They also suggested that the area could benefit from including a resilience strategy into the approach because they recognize that the SCP is only effective for small rainfall events. Arcadis is operating here under a government mandate to help designers and developers implement the SCP. As part of this they already performed an initial assessment of the area, suggesting the area could benefit from including a resilience strategy into the approach.

Our interdisciplinary opportunistic approach sought to combine our different backgrounds to identify novel implementations of the SCP in environments under development. We believe there is still a major potential to improve these designs and move beyond merely coping with water.

As we progress from this, we hope that Mr. Jin, chief architect from China International Trust Investment Corporation (CITIC), will be able to implement a more integrated approach to the design and development in the area, further unlocking its potential and value.

This in turn we hope will inspire developers and designers involved in Sponge City Projects to consider an interdisciplinary approach in the design and development of their projects. In this we see an opportunity for CITIC to consider a comprehensive approach that could start in ErQi zone 3, as the design phase is about to begin.

Furthermore, we hope that this project will spark the interest of other students to undertake a multidisciplinary project in a challenging environment, such as China. The SCP is still under development, while it is tested in various pilot cities. This means there is definitely still room to contribute to this programme, possibly with Arcadis as a partner.

We hope you enjoy the reading.

The Sponge City Project Team,
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EXECUTIVE SUMMARY

The report starts in Chapter 1 with an introduction to the Sponge City Programme (SCP) in China and the project area which is the ErQi International Business District in Wuhan. In this chapter, the problem statement, our collaboration with Arcadis and our project goals are also introduced. Chapter 2 delves into our methodology to tackle the brief.

Starting from how we shaped our interdisciplinary approach, we explain our approach towards the project and our decision to include resiliency with the Sponge City concept as an objective. We continue by providing background information on ErQi area in Chapter 3 to get an overall understanding of the planned urban design and potential urban flooding.

To provide a thorough analysis and recommendations for the selection process of adaptation measures to mitigate excess rainfall as part of the SCP in the context of ErQi area, an assessment of the Wuhan Sponge City criteria, a stakeholder analysis complemented by a spatial assessment was performed and described in Chapter 4. Setting the context allows understanding the complexity of the system and its constraints in the implementation of the SCP. Thus, we decided to first focus on the implementation of low-impact development (LID) measures using a multi-criteria analysis (MCA) presented in Chapter 4 and then developed an integrated and resilient system design later in the report. As the Sponge City is not sufficient to cope with high precipitation events (Arcadis, 2017), the project combines sponge city and resiliency principles in an integrated system approach.

The guiding resilient design principles of the Sponge City are further described and explained in Chapter 5 and applied in the opportunistic design process in Chapter 6, bridging the research with the designs. Here the designs of the MengQiao Bridge and the Water Road are presented along with their proposed effects on the urban flooding. Chapter 7 serves to assess the designs through the criteria of the integrated sponge city to improve flood resilience. The following chapter serves to share our conclusions on the challenges for implementing a functioning of the SCP that includes the concept of resilience. It also touches upon the difficulty of implementing the value-based design in a profit-based context.

The final chapter is composed of five parts, all of which is our recommendations. It starts with our recommendations to improve the Sponge City criteria to make them more effective in reaching the goals of the programme. Then we give our recommendations for the selection process of LID followed by what we have learned of this interdisciplinary approach. That includes what we consider to be crucial to achieving a genuinely interdisciplinary process resulting in an integrated design. The final part of the chapter is dedicated to what we believe should be researched further. We believe a more in-depth assessment of the designs with the Sponge City criteria and input of the stakeholders is required for a final design. Further, the working definitions and approach of the Wuhan city government need to be considered, and an approach that assesses the necessary maintenance protocols is necessary.

DISCLAIMER

The Sponge City Project based the design on the information available and given to the team.

This multidisciplinary project was supervised by TU Delft with the collaboration of Arcadis. It is important to note that the report does not necessarily represent the views of Arcadis nor its employees.

The designs presented in this report are the result of the first iterations in the design cycle. Despite the fact that is implementable, it is expected to be optimized to yield a more economical, practical or otherwise improved design. Our recommendation is to assess the economic and structural feasibility of the proposed designs as they are key factors in the decision-making process. Considering these factors may lead to different designs.

The assessment of the Storm Water Management Model is based on an old urban drainage system and not the updated planned one as it was provided later during the project period.

Stakeholders which were engaged in the meeting are given in the appendix E, but it should be noted that none of these stakeholders can be held accountable for the information provided in this report.

Most of the information provided was translated from Chinese to English, and the definition of certain terms used in this report regarding the Sponge City Programme may be slightly different.

This project was set up based on the interests of students. There was no particular collaboration between Arcadis and TU Delft on this topic previously.

The preparation phase for the design project includes, but is not limited to, a literature review, online data collection and analysis of the area, and was executed at TU Delft in The Netherlands from January to July 2018. The project area given by Arcadis at that time was Changjiang New Development District, which is a floodplain area along the Yangtze river. However, once the team arrived in Wuhan at the beginning of July 2018, they were advised to change the project area to the ErQi International Business District mainly due to the lack of data for the previous area selected. Therefore, the preparation phase for the new area given was executed within a few weeks due to limited time. Students from hydraulic engineering had to slightly shift their direction towards water management since ErQi area is located in the inner side of the city and the main issue at this location is pluvial flooding rather than fluvial flooding.

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Our team of this multidisciplinary project is honored with the support of our supervisors Dr. ir. Frans van de Ven and Dr.ir. Fransje Hooimeijer from TU Delft. They both gave us good guidance and their expertise was valuable in the development process of this project. We would like also to express our gratitude to Erik Mosselman who was our external supervisor.

We would like to express our appreciation to the architect in CITIC China group, Mr. Jin, he was the main-key stakeholder in our project and was well involved in our process. We would like to thank him for supporting our project and the useful feedback and suggestions for improvement he provided in our proposed designs.

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In the initial phase of the project, Lisa Andrews, experienced in collaborative planning, helped us a lot by organizing a workshop for defining our interdisciplinary goals. We are very thankful for her contribution that helped us setting the scope of our project, and the proof-reading of our final report.

We would like to thank Edgar Westerhof from Arcadis USA for his advice on how to work with resilience and guiding us to the measures and types of collaboration that are necessary to make this strategy successful. When talking about collaboration we would like to thank Linda Vlassenrood from INTI, who shared her experience on how to organize stakeholder workshops and engagement in the Chinese context which we tried to apply in our meetings. As to our design of the bridge, we would like to thank Meng Qiao for the structural inputs to roughly assess the feasibility of our design.

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LIST OF ACCRONYMS

AST - Adaptation Support Tool
BMP - Best Management Practice
CITIC - China International Trust Investment Corporation
CRTAR - Capture Ratio of Total Annual Rainfall
FSI - Floor Space Index
GIS - Geographic Information System
HID - High Impact Development
L - Layers
LID - Low Impact Development
MCA - Multiple-Criteria Analysis
MHURC - China Ministry of Housing and Urban-Rural Construction
MOF - China Ministry of Finance
MWR - Ministry of Water Resources
OSR - Open Space Ratio
SCC - Sponge City Concept
SCP - Sponge City Programme
SWMM - Storm Water Management Model
T - Return period in year
TSS - Total suspended solids
WPDC - Wuhan Planning & Design Co., LTD.

1. INTRODUCTION

Over the last decades, urban development has radically transformed China especially in terms of land use. The traditional development has turned a high proportion of land cover into impervious surface. As a consequence, this has increased surface runoff volume, diminished infiltration, increased urban heat stress and reduced groundwater level resulting in an increased risk of urban flooding. In addition, the frequency of urban flooding has increased dramatically in recent years (Dai, van Rijswick, Driessen and Keessen, 2018). Urban flooding is accompanied by other negative impacts such as water quality deterioration, losses to the economy, and even casualties. According to the first national pluvial flood report for 351 cities in China in 2010, 62% cities suffered from inundation of streets due to high rainfall events (Yang, 2016). These challenges have led to the creation of the Sponge City Programme (SCP), which was launched by the Government of China at the end of 2014 (Dai et al., 2018). The SCP proposed to tackle pluvial flooding in urban areas. This national urban water programme is also aligned with the Sustainable Development Goal (SDG) 6: clean water and sanitation, SDG 11: sustainable cities and communities and SDG 13: climate action. By 2020, the Chinese government is expecting 20% of urban areas will follow the Sponge city requirements and by 2030, 80% of urban areas are scheduled to comply to the Sponge city requirements. In this chapter, the Sponge City Concept (SCC) and the target area will be introduced, following with the elaboration on the problem statement and the goals of this project.

1.1 Sponge city concept

Low impact development (LID) was first put forward and applied during the 1990's in USA, and previously they were called Best Management Practices (BMPs). LIDs were proposed to mitigate the negative impacts of urbanization (i.e increase in impermeable surface) which lead to more urban runoff. Since then, similar concepts have also been proposed in the United

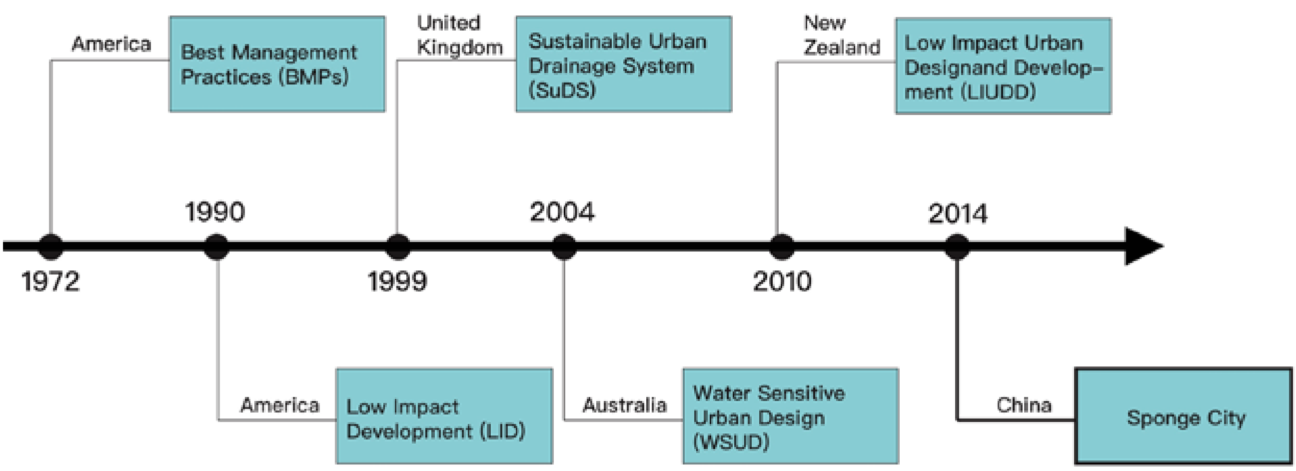


Figure 1. Timeline of the development of LID at the international level (Source: From Chinese stakeholder's presentation)

Kingdom, Australia and other developed countries which also suffer from similar problems (Yang, 2016; Li, Ding, Ren, Li & Wang, 2017).

When looking at these different policies it becomes clear that they all have one thing in common: they all try to achieve sustainable stormwater management through the use of LID measures (also called blue-green measures) to address excessive rainfall. Several LID measures include bioswales, bioretention devices, ponds, green roofs, vegetated filter strips and filter strips. LID approach also includes non-structural measures such as alternative layouts of roads and buildings to minimise imperviousness and to maximise the use of pervious pavement and vegetation, contaminant source reduction and education on alternative behaviours. With the emphasis placed on local control of stormwater in these LID measures, the SCP seeks to promote water responsive cities capable of absorbing and retaining rainwater.

1.1.1 Sponge City Programme in China

Since the SCC is new to China, guidelines and standards are continuously being updated with experiences drawn from pilot projects. The goal of the SCP is to create a city with a water system which operates like a Sponge to absorb, store, infiltrate and purify rainwater and release it for reuse when needed (Arcadis, 2017; Yang, 2016). The primary goals for China's Sponge city programme SCP are: retaining 70-90% of annual rainwater on-site by applying the green infrastructure concept and using LID measures, eliminating water logging and preventing urban flooding, improving urban water quality, mitigating impacts on natural ecosystems and alleviating urban heat island impacts (Li, Ding, Ren, Li & Wang, 2017) .

Figure 2. China's 16 pilot cities including Wuhan (own illustration)

In 2015, the government of China, more specifically the China Ministry of Finance (MOF), with the support from China Ministry of Housing and Urban-Rural Construction (MHURC) and the Ministry of Water Resources (MWR), selected 16 pilot cities for the first implementers of the SCP, including in Wuhan (See Figure 2) (Dai et al., 2018; Li, Ding, Ren, Li & Wang, 2017). Wuhan's inclusion as one of the pilot cities was due to the history of severe flooding and waterlogging. In the past few decades these events have been recurring every three years. The most significant flooding event to affect the city was the Yangtze flood of 1954, during which a significant part of the city was flooded. Wuhan has been progressive in stormwater management even before the existence of the SCP. The Garden Expo Park in Wuhan is an example of a successful Sponge project implemented before the SCP. In this project, around 70% of rainwater is collected and retained and later and reused to irrigate the park (Dai et al., 2018).

1.2 Area of interest

The city of Wuhan and its province, Hubei, have been the site for many important events in the history of China and have been of large cultural importance. Starting as a contested city in the period of the three kingdoms, Wuhan became the site of five foreign concessions during the Second Opium War and was the starting point of the revolution that led to the end of feudal China and the beginning of both the Republic of China and the Communist Party. (Bovenkamp & Fei, 2016, p.7)

In contrast to Shanghai, the other former major treaty port, the city of Wuhan already was a large commercial centre of China at the time it became a treaty port. Building on this heritage the city has developed into a main trading centre for central China (GPC, 2014). Due to its location in the centre of China , the city of Wuhan is developing into a main logistics hub for inland China. The city's location on nodes of the national four North-South and four East-West passenger lines and the global One Belt, One Road initiative, together with its major harbour on the Yangtze river, enable a high growth rate that is visible throughout the city's urban landscape.

Wuhan's location as China's geographical centre within 1000 km of the major cities of Beijing, Shanghai, Guangzhou, Chengdu and Xi'an has further added to the city's growth, as over 1 billion of China's population lives within this radius (Bovenkamp & Fei, 2016). For this reason, the city is seen as a prime candidate for the new phase of development for the Chinese economy apart from the industrial development that propelled Beijing and other coastal cities into prominence.

1.2.1 Location: ErQi International Business District Wuhan

In order to capitalise on this development, the city of Wuhan has initiated several projects, of which our area, the ErQi city district, is located within the Jiang'an International Business district. This area is slated to become a high value development center with several landmarks to be completed in 2021, in time for the 100th anniversary of the Rebellion, that inspired the creation of the Communist party (SOM, 2011).

The ErQi city district is divided into three blocks in different construction phases. The southern section is the first construction phase. In this area, the design is already finished and construction has already started and has nearly been . For the middle part which is the core area, only the design is completed. In this district, modifications to the design can be made, but the main design cannot be altered. For the northern district, a design is not yet completed.

Our focus area is the core area. This area was chosen because it is most suitable to suggest improvements to an existing design given the duration of the project. While our focus is on the middle district, the connection with the middle area to the upper and lower area will be considered.

The vision of the ErQi area is to develop iconic urban development area which brings international corporate headquarters with high-end commercial use and with space for cultural leisure.

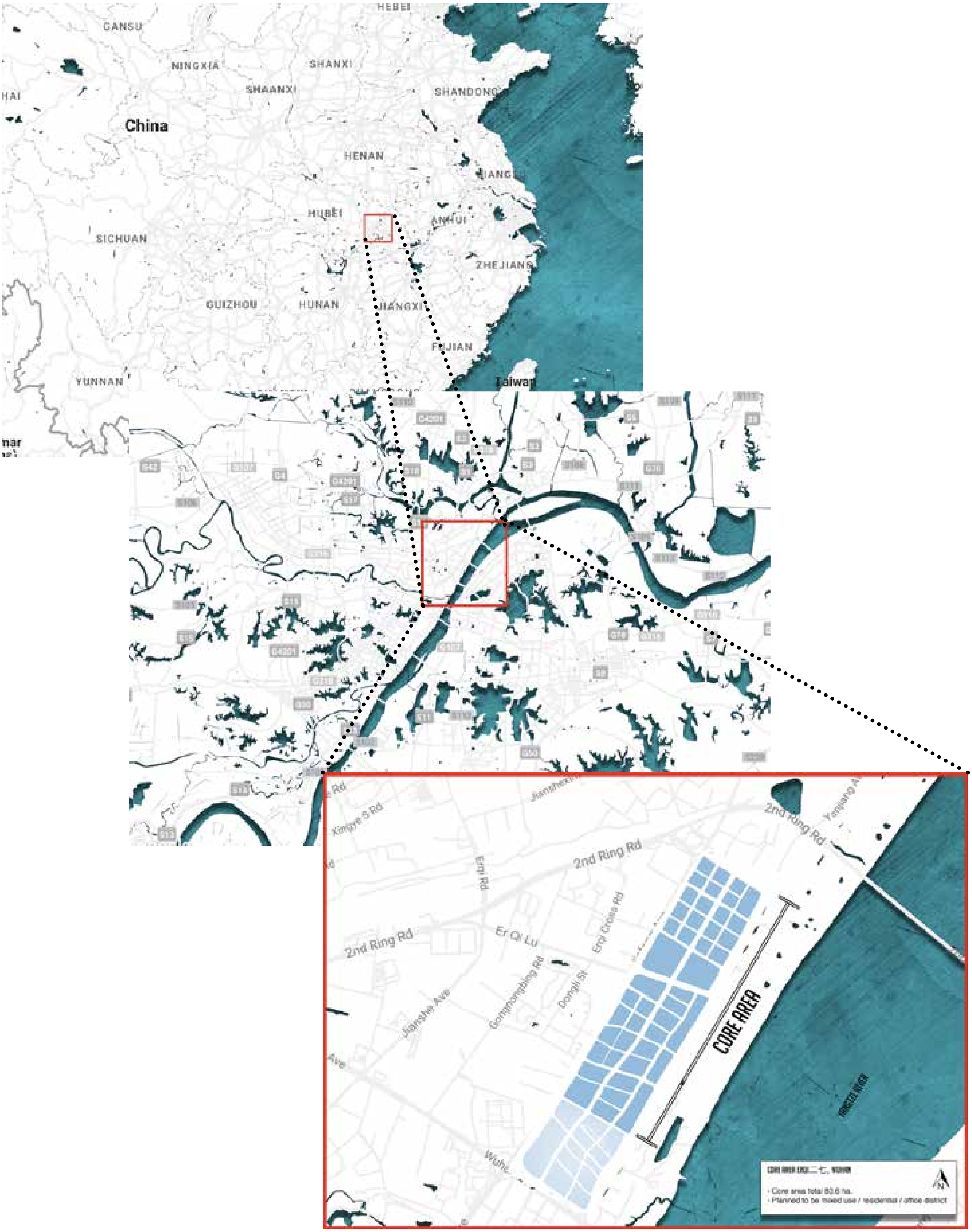


Figure 3. Location of the ErQi area zoom-in (own illustration)

1.3 Problem statement

The current fast paced development in the ErQi project has allowed for exceptionable results in terms of realisation times. This remarkable feat is however accompanied by a strong separation of the stakeholders and an unintegrated approach towards the urban design, thereby leaving urban water management out of the design process.

As the realisation phase takes place during the design phase, the project now calls for the integration of a hydraulic design into the urban design to cope with the SCP requirements from the government, while allowing for the rapid ongoing development of the area.

1.3.1 Implementation of the SCP issues

In theory, in order to get the permit for construction, the ErQi core area needs to comply to the SCP criteria. Therefore, integrating LID adaptive measures into the urban planning is of interest to stakeholders, especially to the designers and developers. However, in the experience of Arcadis, most of the designers for the ErQi area have limited knowledge in the LID measures. This is largely due to the novelty of the SCP. This could explain the difficulties with the implementation of LID in the area. Arcadis has tried to bridge this gap by developing the so called ''Sponge City Design Guidelines" specifically for ErQi area, but there still seems to be need for additional support to provide sufficient understanding for the actual implementation of the LID measures. This is further exacerbated by the fact that Sponge City urban planning was not taken into account in the planning and designing phases of the development. As such, there is limited flexibility in the urban plan and limited space available for the implementation of LIDs, presenting an additional challenge. This challenge can be summarised in the following question which will be addressed in the first part of the report (Chapter 4): *How can designers better select their LIDs according to the site condition?*

Moreover, the area has been divided into blocks and roads to ease the achievement of stakeholders' specific requirements instead of using one coherent approach. This blocks-and-roads approach severely limits the possibilities for LID measures, as they have to be fitted in small available spaces between the structures. Although, according to Arcadis, all targets can still be met by stretching LID's implementation to its ''very extreme" limits. In summary, there would be more benefits to design the core area as a whole in an integrated manner, instead of separated entities.

1.3.2 Urban flooding under extreme precipitation events

When considering LIDs, their effectiveness must also be questioned. This becomes paramount when assessing their effectiveness during high precipitation events, as LIDs are considered crucial in the SCP. That is, however, when complications arise. Under extreme precipitation events with high return periods, LIDs may not be effective since they are designed for rainfall intensities associated with low return periods (T=1 year). According to Li, Yu, Wang and Du (2016) study, the performance of LID is reduced when rainfall intensity and duration increase and waterlogging becomes an issue. Therefore, it is important to consider high impact development (HID) or resilient systems to cope with extreme precipitation events in the urban design. Here, HID or resilient systems are urban systems which can cope with unexpected shocks and be sustainable in the long term. To address extreme precipitation events, the second part of this report will investigate the following question (Chapter 6): *How can we develop an integrated district urban planning while increasing resiliency and urban quality?*

1.4 Project goals

Our goals are not to help the stakeholders meet their targets given by the Chinese Government, but rather to help them to implement the implementation the SCC and provide an integrated design which can cope with urban flooding. In other words, this project hopes to inspire and demonstrate the potential of combining LID measures and HID interventions, while increasing resiliency and urban quality by developing an integrated urban water strategy for the ErQi International Business District.

1.5 Scope of the project

Given the limited time and resources available for the project, the scope of the project is framed around the established project goals. At the Sponge City level, recommendations provided for the implementation of LID measures assume that there is no groundwater infiltration, and that every drop falling in this area needs to be drained (according to the information given by Arcadis). At the resilient level, the integrated design proposed is limited to water engineering and architectural design and the report addresses roughly the structural feasibility, construction and economic consideration underlying the proposal. These plans have only been provided qualitatively, as these aspects will be analysed but no calculations will be made to, for example, determine the total costs. No detailed design of the entire area will be performed because it is irrelevant to the project goals.

Although the Chinese political and institutional framework are important aspects in the understanding of the SCP and in the complete realisation of the project, it is considered beyond the scope of this project. However, additional information provided by the stakeholders regarding these aspects will be mentioned.

In other words, this report will provide a discussion and recommendations on the SCP from a technical point of view, rather than political or financial one.


Figure 4. The original ErQi area (own illustration, July 2018)

2. METHODOLOGY

This chapter is dedicated to explaining our approach towards the project starting from our approach to integrating all our different disciplines in the process. We then explain our approach towards the project and our decision to include resiliency as an objective.

2.1. Interdisciplinary approach

When considering the idea of the multidisciplinary project, it was concluded that this is more of a reactionary approach to the design assignment, where designs come together after they have been made. A more proactive integrated approach is necessary to tackle the design challenges and so it was decided to opt for an interdisciplinary design approach. The goal is to ensure strong collaboration between disciplines throughout the project.

Interdisciplinary is defined as ''each expert understands the methods of the other disciplines and contributes to a more coherent and valued overall project" (Hooimeijer, Bricker & Luchi, 2018). The base of this assignment was inspired by Arcadis' mandate to help the Chinese government to improve the implementation of the SCP. In order to create an integrated design, understanding the methods and considerations of the other design disciplines and their ways of communication are needed. This was approached through workshops, knowledge sharing sessions, communicating through drawings and constant group dialogue (see photos in Appendix A).

One of the major hurdles to be overcome was bridging the difference between the design methods in Civil Engineering, Architecture and Urbanism. The Civil Engineering students started with technical optimisation to meet the specific requirements. The Architecture and Urbanism method relies more on an iterative process where the requirements are reconsidered and together with the desired qualities become guiding themes in the design process.

It became clear that even while operating within the traditional engineering framework the designers applied "designerly methods" as discussed by Van Dooren et al., (2014) where the workshops and group discussions supported by sketching proved to be a laboratory for making the design considerations of the entire group explicit.

With the group focus being on creating additional value by integrating necessary water management measures, this became the guiding theme in the design. As such, the design process of the entire group became an iterative process with each expertise expanding the frame of reference and the design laboratory of sketching, modelling and calculations. This provided a way to combine the analytical thinking, based on the translation and interpretation of data, with the design thinking, that focuses on the development of new knowledge and spatial translation. Every iteration would then be assessed through proactive group discussions and pressure cooker workshops.

Eventually this integrated approach is what led to the choice for an opportunistic approach, as mentioned by Ahern (2007, p.269), as we had noticed that the constraints of the area required a different approach and perspective. Throughout the design,sub-themes were identified by the different team members, according to each specialisation.

Discipline	Sub-research questions by discipline	Tasks
Water Management	**What are the suitable sustainable stormwater management practices for this specific site conditions?** **How can we make the most use of water?** **How can we engage stakeholders in the design process ?**	-Selection of appropriate LID measures -Stakeholder analysis -Technical considerations -Hydrodynamic modelling (SWMM)
Hydraulic Engineering	**How can we create a resilient and safe stormwater system ?** **How can we implement LID measures appropriately?** **What is the storage capacity of the measures we wish to implement?**	-Technical considerations -Analysis of urban pluvial flood risk --Design blue-green measures -Hydrodynamic modelling (SWMM)
Urbanism	**Where are the potential areas for the implementation of LID measures and resilient systems ?** **How can we connect water to the urban landscape at different spatial scales?** **How can we create a more livable sponge city district ?**	-Analysis of the urban planning and identify potential area for LID measures -Development of 3D model of the urban area -Cluster development
Architecture	**How can we retrofit existing infrastructure into blue-green multifunctional infrastructures which could become a model for the Sponge City Programme ?**	-Visual presentations of ideas to stakeholders -Design blue-green multifunctional infrastructure -Detailed design impressions -Creative dimension

Table 1. Division of tasks for the Sponge City Project by disciplines

2.2. Project approach

First of all, an assessment of the Wuhan SCP and of Wuhan itself was necessary to understand the issues that may impede the implementation of the SCP. Then, inputs were gathered from stakeholders who are directly involved in the design of the LID measures during in-person meetings and from the information provided by Arcadis. This information helped to lay the groundwork for future recommendations, while also helping to understand the cause of the issues encountered by the stakeholders. The planned urban land-use structures, functionality, spaces and connections were assessed to identify potential areas for the implementation of LID measures while increasing urban quality. From the stakeholders' input, the analysis of the current site condition, a multi-criteria analysis (MCA) was performed for the selection of appropriate LID measures. The recommendations for the selected LID measures are not only given by typology of land-use, but also spatially through the proposed cluster strategy.

According to the current planned urban design and the recommendations resulting from the MCA and the cluster-strategy, three guiding principles were selected and applied in the design to not only help the implementation of LID to not only help the implementation of the LID measures in an integrated manner, but also increase re-

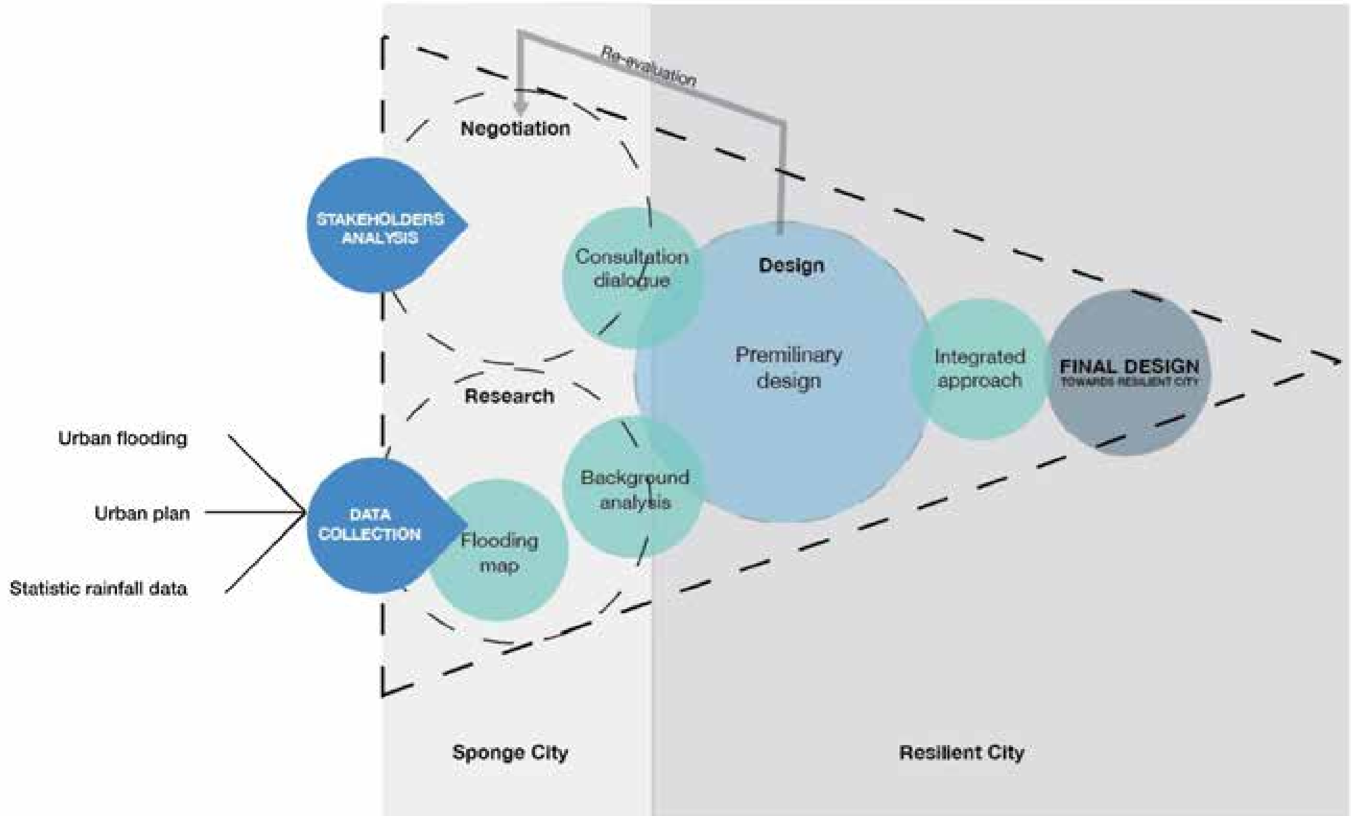


Figure 5. Scheme of methodology (own illustration)

silience of the area. To create an integrated design, the core area of ErQi was investigated as a whole system. Opportunistic strategies here are defined as strategies which are used by seeking new or innovative ‘’opportunities” to provide the current urban elements or configuration with more functionality while increasing urban quality and resiliency (Ahern, 2007). More precisely, LID interventions transformed into HID interventions.

These strategies were applied at multiple scales, districts, neighbourhoods and street scales of the ErQi area and provides architectural impressions for better visualization. Furthermore, proposed designs were modelled using the SWMM tool as a ‘’proof of concept” for an integrated design of the SCP for the ErQi core area.

In our approach, we decided to move beyond the SCP to the SCC, which means that the concept of the Sponge City is considered but not the specific criteria and measures proposed by the SCP. This is due to multiple reasons. One being the return period of rainfall intensities in the programme being 1 year, meaning that the designs are made to cope with a yearly situation. In our opinion, this is not a sustainable approach as more significant events would already lead to system failure. Neither does this allow for the absorption of future variations.

Thus we decided to look at resilience, or the coping capacity when the system fails. The threshold for failure we decided on was the T=100, as this is also the criterium for the road system. In the design of this integrated approach, enabling a capacity between a T=5 and a T=100 situation we adopted the following methodology to develop our design:

The integrated design is located between the Sponge City level and the Resiliency Principle level. Combining both levels will guide us towards our final design (see Figure 6).

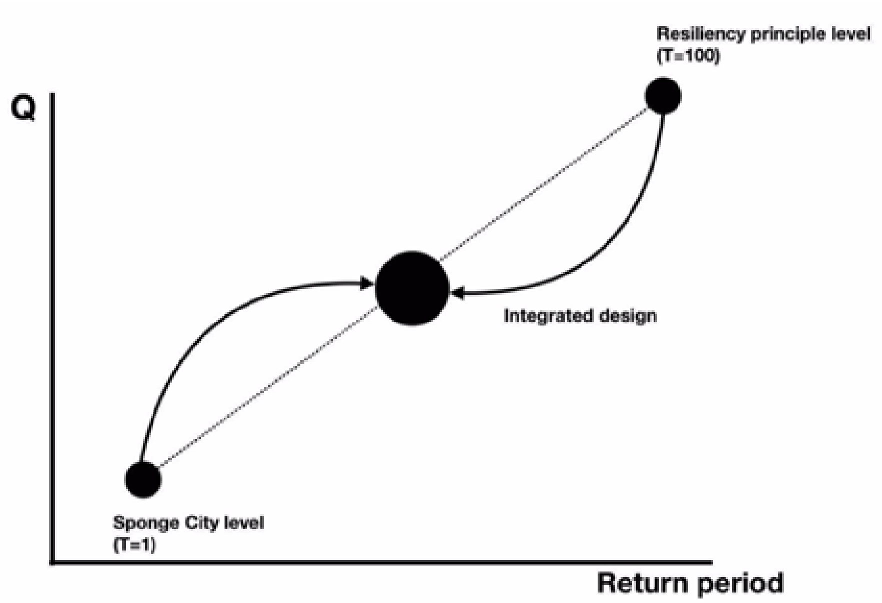


Figure 6. Integrated design approach
(own illustration)

2.3. Principles for resiliency

The SCP is largely concerned with the containment and mitigation of urban flooding in cities due to the increasing occurrence of high precipitation events. Although this is a very important goal, this focus on mitigation of flooding does not show much consideration for the event of failure of the system.

Therefore, to design an urban environment capable of confronting the challenges of changing climatic conditions, the city should not only be concerned with measures to avoid urban water problems, but should also focus on resilience, thereby increasing the ability to rebound quickly after a shock or stress. This approach essentially goes beyond the Dutch approach that is moving from resisting water to adapting to the presence of water.

This begs for a definition of resilience. Edgar Westerhof from Arcadis USA, recommended the use of the Rockefeller Foundation's approach towards resilience. After Hurricane Sandy struck New York City, many, including the Rockefeller Foundation were confronted with the need to adopt a resilience strategy. Here resilience was taken to mean the city's ability to recover from a crisis and the effort needed to do so. Their approach, exemplified through their 100 Resilient Cities initiative, attempts to stimulate the awareness of urban vulnerabilities and the adoption of measures to overcome the ramifications of a crisis. (100RC, 2018) (see Figure 7). It essentially considers the crisis as the zero point in the assessment of the city, with the do-nothing scenario being the control for the resiliency measures, the so-called resiliency dividend (Rodin, 2017).

This approach is not new for Arcadis, being a so called platform partner in the 100 Resilient Cities initiative since 2015 (100RC, 2015). Arcadis believes that resilience has a strong impact on the overall performance of the city in terms of livability and economy. They even go as far as to say that the capability to cope with crises and protect its environment and inhabitants, is directly connected to economic opprtunities and the capacity to attract investment. (Batten, 2015).

Proactive interventions in urban areas as preparation for extreme weather events offer opportunities to explore innovative measures providing co-benefits. However, the increasing complexity of urban systems requires a high level of interdisciplinary coordination and cross-party cooperation to be successful.

As such, it was determined that one of the greater challenges that arises from striving for urban resilience lies in the procedures. The difficulty lies in the fact that this process requires a broad cooperation amongst citizens, corporations and government bodies throughout a dynamic process that enables an adaptive process that is essentially never truly finished (Batten, 2015). What remains as a constant is that for an area to be truly resilient, the co-benefits must go well beyond the solution, in our case urban water management.

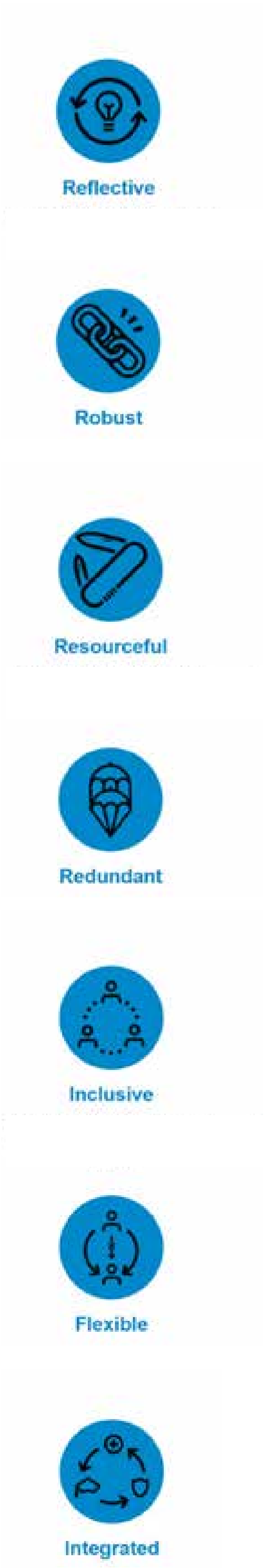


Figure 7. Characteristics of Resilient Systems (Source: https://www.100resilientcities.org/resources/)

In addition to this, it requires a deep understanding of the current situation, with not only the possible shocks, but also the existing chronic stresses taken into account, as they can increase the impact of shocks (100RC, 2018).

In this project, the approach taken towards resiliency revolves around the integrated design that we wish to achieve. As resilience is more of a process than a destination, we determined that the first steps that need to be taken to start the shift from Sponge City to Resilient city consist of exploring the opportunities of the ErQi area. The main goal, or the resilience dividend we strive for is increasing the quality of the area. In this approach the zero action scenario will be taken as ar reference to determine co benefits of the resilience measures included in our design.

3. BACKGROUND ANALYSIS OF ERQI CORE AREA

This chapter describes the current state of the ErQi core area based on the masterplan of ErQi area provided by Arcadis (See Appendix B).The first section features an analysis of the urban area, taking into account the relation to the rest of the city and the spatial conditions in the ErQi core area. The second section addresses the current hydraulic conditions in the area.

This is followed by a paragraph exploring the various hydraulic conditions present in the area e.g. waterlogging, limited availability of space for additional LID measures. The expected variations in the future in Wuhan including population, rainfall, urban development, heat stress and economic growth are taken into consideration in this project and presented in the Appendix C" This thorough analysis will

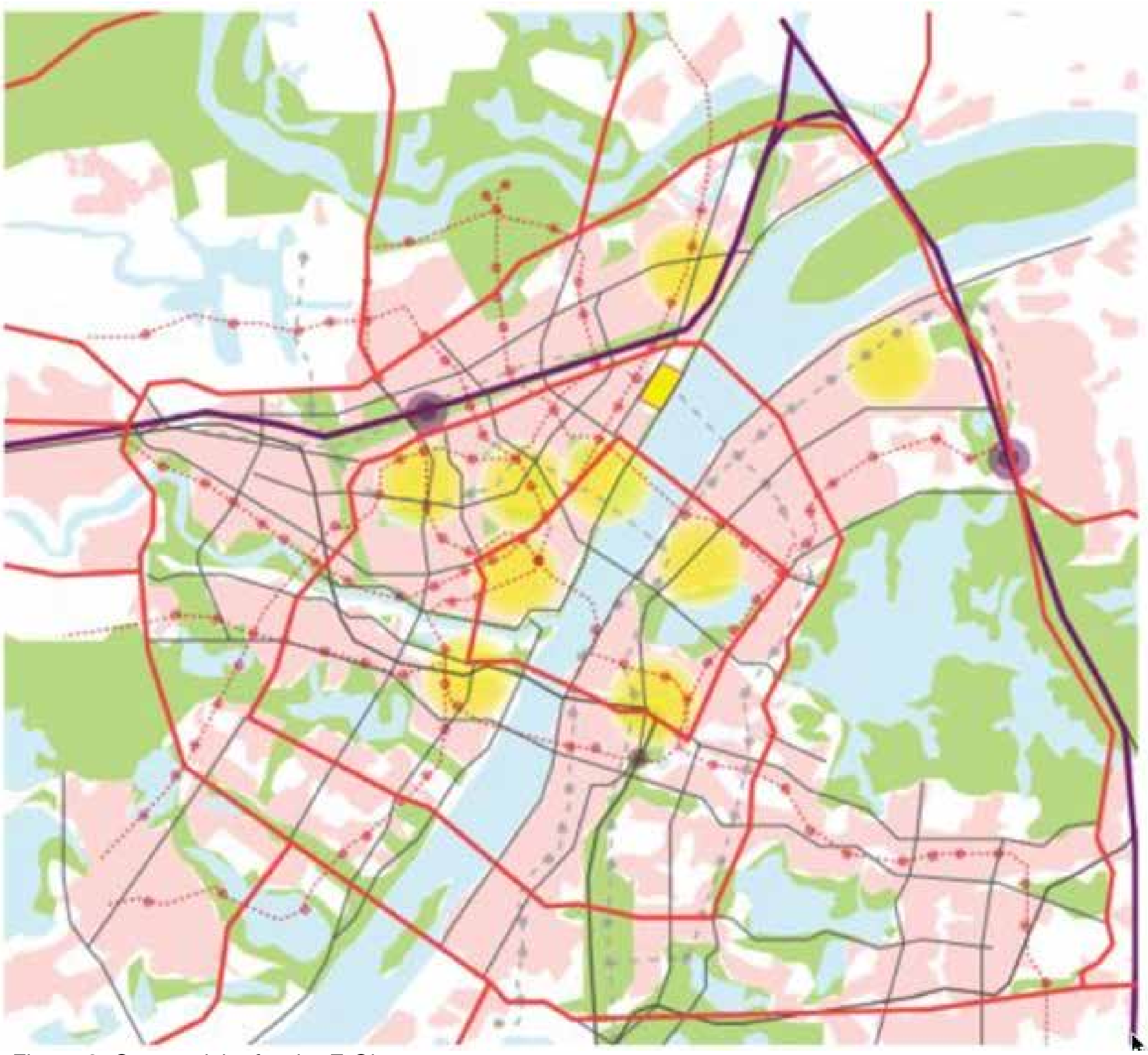


Figure 8. Connectivity for the ErQi area
(own illustration)

contribute to reaching an integrated urban water design.

The map in Figure 8 shows the city of Wuhan, showing the location of the ErQi district within the city of Wuhan. As is visible in the map, the ErQi area is located between the first and the second ring road along the Yangtze river, well connected by roads and metro systems.

ErQi is proposed as an area of high connectivity in the city.

Figure 9. Urban planning of ErQi area
(own illustration)

Figure 10. Elevated walking paths in ErQi area
(own illustration)

This is expected to only increase with the realisation of the new metro line. Adding to this the area is located near existing hubs and the city has the ambition to develop Wuhan into a major metropolis comparable to Beijing and Shanghai (GPC, 2014).

3.1 Urban planning of ErQi area

When viewing the current plan of the ErQi core area, it becomes clear that the area contains a high number of high-rise buildings predominantly in use as residential, commercial or business spaces. An identification of the ground surface and the elevated level in the ErQi core area. Figure 9 shows the buildings ordered by height categories, the public spaces, roads, transit infrastructure and the voids connecting the ground plan to the first underground level.

Figure 10 shows the elevated public spaces and green/gardens. A feature that stands out in this development is the pedestrian bridge which connects much of the core area.

Figure 11. Map public space ErQi area (own illustration)

Figure 12. Planned building height in ErQi area (own illustration)

Public space

As is visible in the map of the core area in Figure 11, the area contains large quantities of public space and one major green element, the park. The map also shows the large number of empty spaces that are connecting the ground level to the first subterranean level of the development.

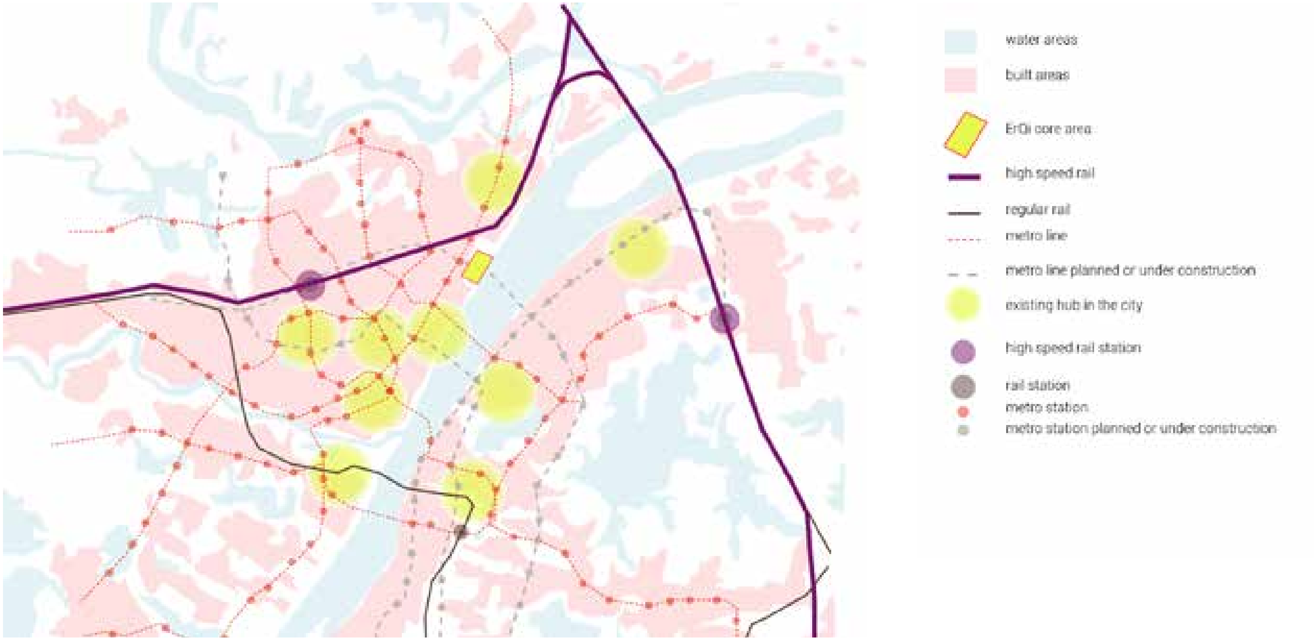


Figure 13. Transit and accessibility area 1 of the ErQi area (own illustration)

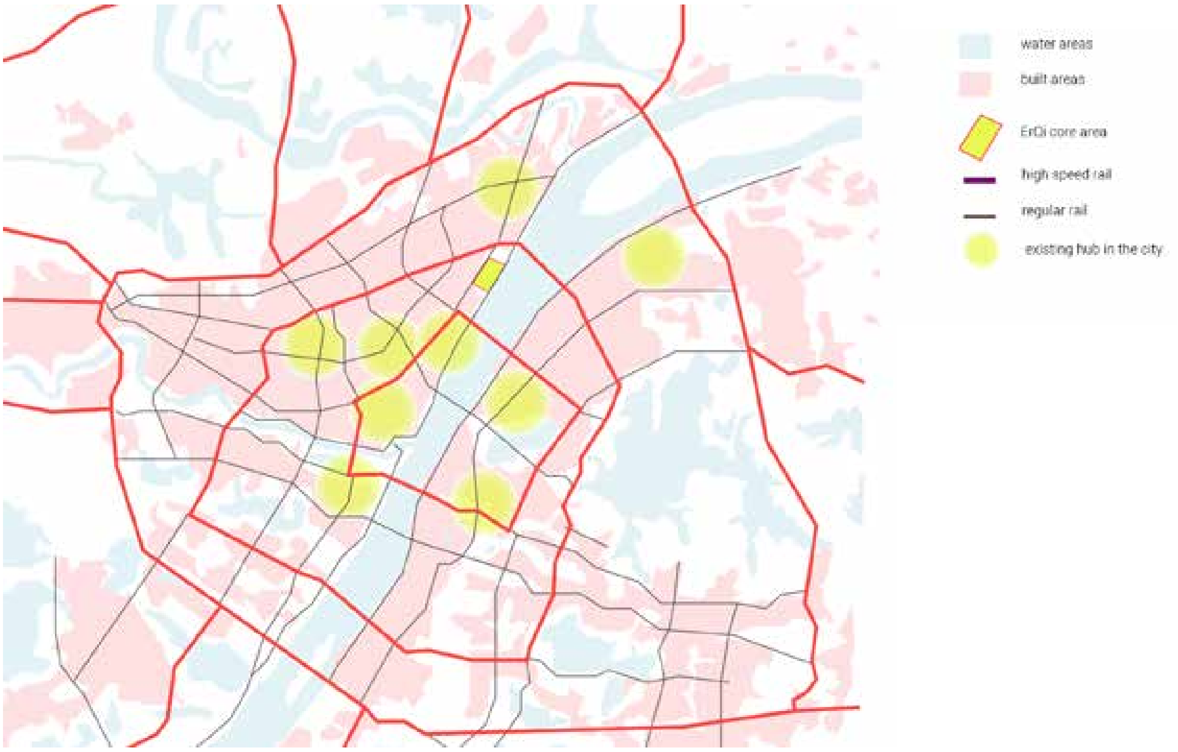


Figure 14. Transit and accessibility area 2 of the ErQi area (own illustration)

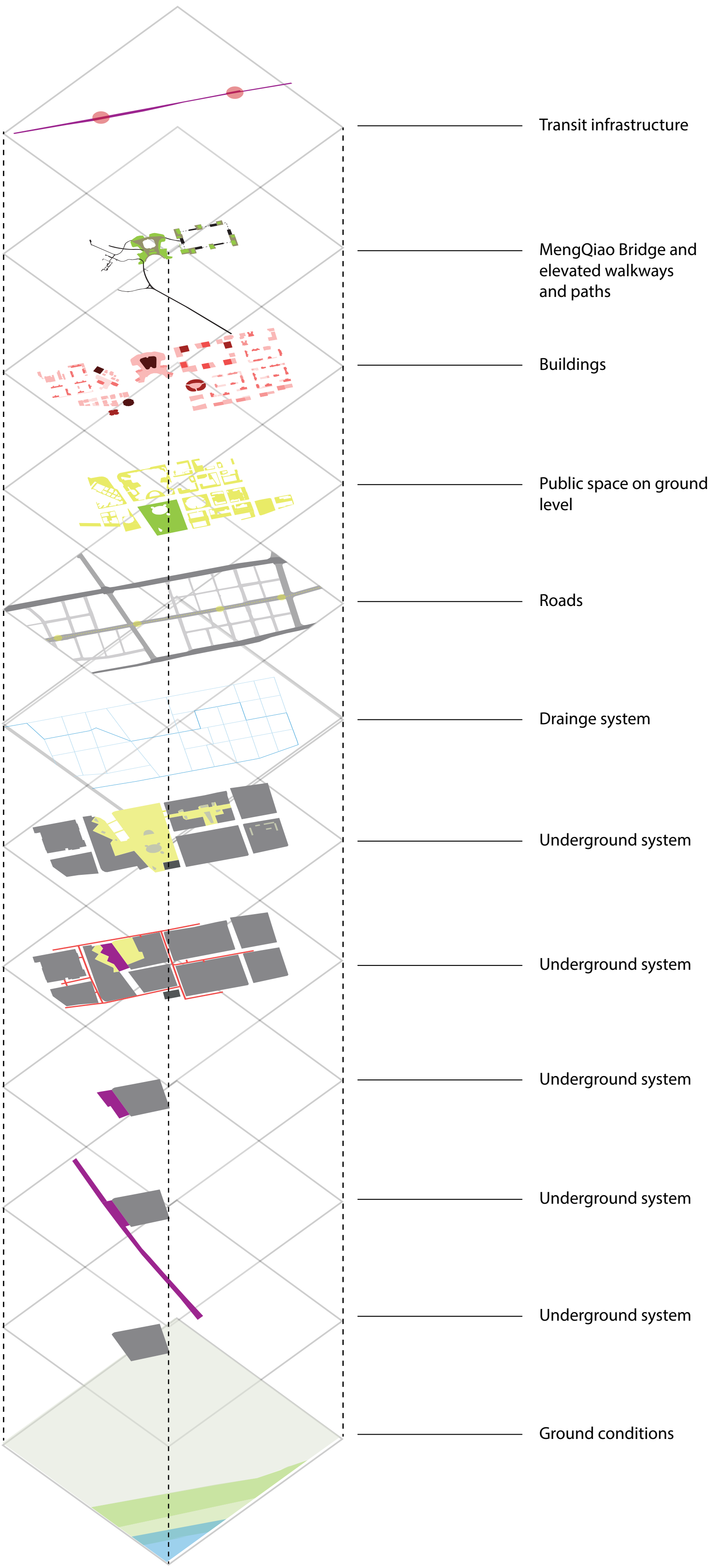


Figure 15. The ErQi layer system in axonometric angle (own illustration)

Buildings
When looking at the buildings that are planned for the area in Figure 12, it becomes clear that this area is set to become a high profile area with a significant number of towers over 100m in altitude, with the ErQi tower being its focal point at over 450m.

Transit and accessibility
The ErQi city district is located in the very center of Wuhan, and is therefore very accessible for multiple types of transport. The area is located between the first and second beltways of the city. Two roads run parallel to the beltways connecting them and making the area very accessible by car. Furthermore, the area will also be connected by metro and tram lines. The metro line passes through the middle of the city district going from east to west. The tram line will be constructed in the middle of the center road, going from north to south.

Underground structures
Most of the block structures will also be built into the underground. This will, for example, be done for parking garages-, or malls. As the designs are now, almost all of the underground will be utilised. This leaves only about 1 to 1.5m of soil between the surface and these underground structures. Therefore, there will be very little infiltration into the subsoil. Therefore, there will be very little infiltration into the subsoil and it will not be effective for the SCP (Li, Dong, Wong, Wang, Kumar & Singh, 2018) Plans for the underground of the core district can be seen in the picture below. The presence of large retail spaces and a metro station extends the public domain into the subsurface and the supporting infrastructures, the parking garages and the transformer facility further extend into the subsurface, thereby displacing soil and groundwater, and limiting available space for infiltration or underground water retention.

Figure 15 presents the various layers in the development area to see how it can be combined and create an to in-

Figure 16. Area with critical infrastructure (own illustration)

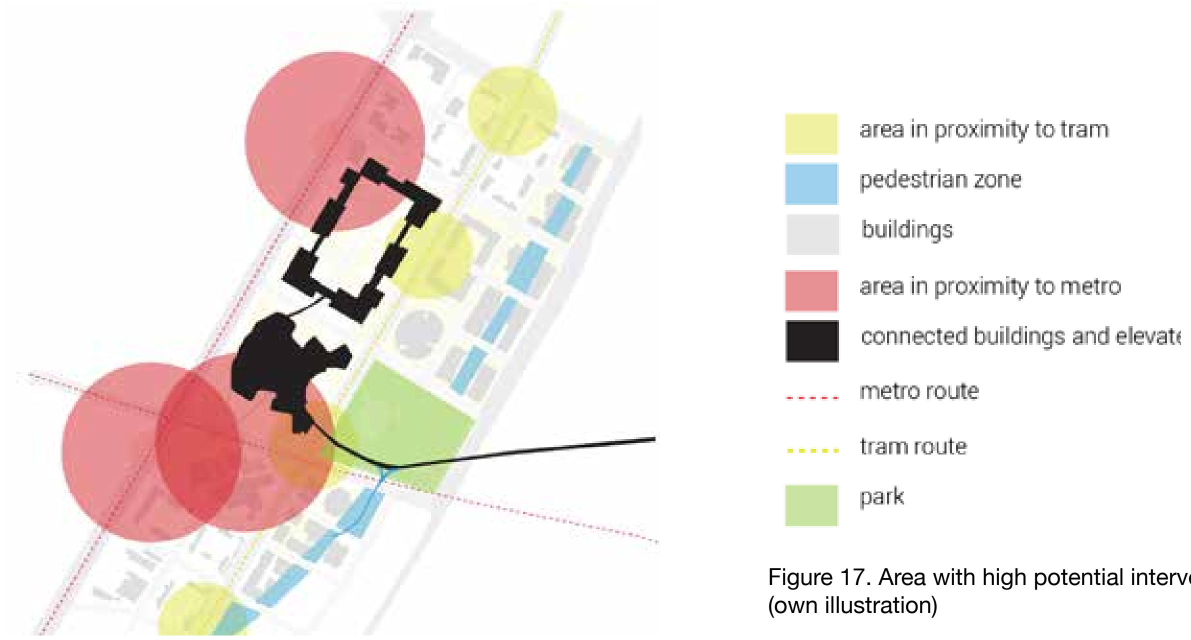


Figure 17. Area with high potential interventions (own illustration)

tegrated design approach of the area. The planned pedestrian bridge shows an interesting element in ErQi area since it is connected to many buildings. It can play an important role during a flooding event to transport people from one place to another. In case of a flooding event, the pedestrian bridge can be used as an emergency pathway since it is located at a higher elevation.

Figure 17 shows areas with a high potential for urban interventions increasing the quality of life based on the urban plan. The red are the parts of the area in close proximity to the metro stations, those in yellow are in close proximity to the tram stations. The green is the large central park, and the blue are wide pedestrian areas that are still in development.

The critical infrastructure and vulnerable urban functions of the core area are highlighted in the Figure 16. Almost the entire city district contains underground structures like malls and parking garages. These underground structures limit significantly the space available for our design.

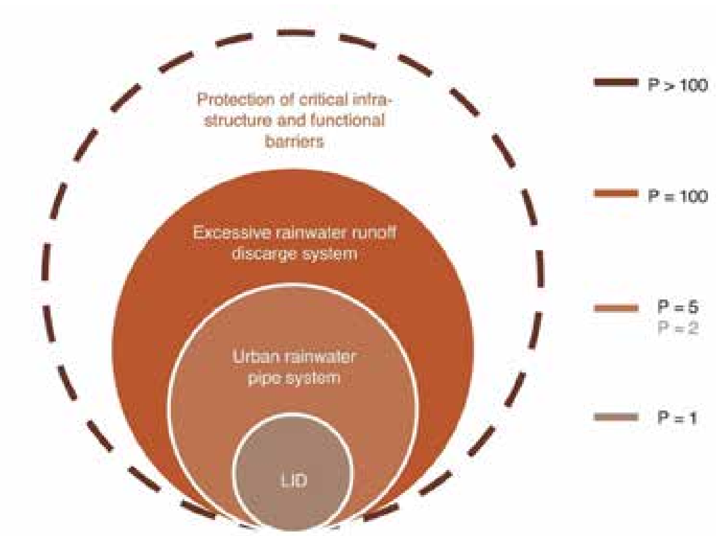


Figure 18. Acceptable failure return period for the ErQi city district
(Source: Arcadis 2017)

3.2 Hydraulic conditions

The area is flat with an elevation ranging between 23.13m and 27.85m NAP. It has a low rate of infiltration with approximately 1m depth of top-layer soil in blocks and 3m for the roads. This is mainly due to the proliferation of underground structures such as shopping centres, transit and parking facilities. With the top-layer soil consisting of a clay layer with a thin layer of silt soil, the infiltration capacity is further limited. The groundwater level is between 0.8m and 3m below the ground level. Moreover, the current urban design plan does not have any open water surface and there was originally no natural floodway corridors in this area. (Arcadis, 2017).

The total acceptable designed return period for flooding for the ErQi district is once every 100 years (T=100). This level is reached by the drainage system planned in the district, which will be connected to two pumps. For this definition of failure, waterlogging is permitted and the defining criterion is that the streets cannot be flooded. Within this drainage system, the individual elements like pipes or culverts have a failure return period of around 2-5 years. Next to the drainage system, there are also the requirements for the SCP. The LID measures should only fail once every year (T=1).

In addition to the SCP, Arcadis suggests to implement resilient infrastructures. The measures taken for resilience are seen as an additional protection, on top of the implemented drainage system.

Figure 19 shows a return period of 100 years, there is water on the street but at a low risk (≤0.15m). Therefore, it can be concluded that ErQi area is designed for a low risk of flooding. It is a separated system.

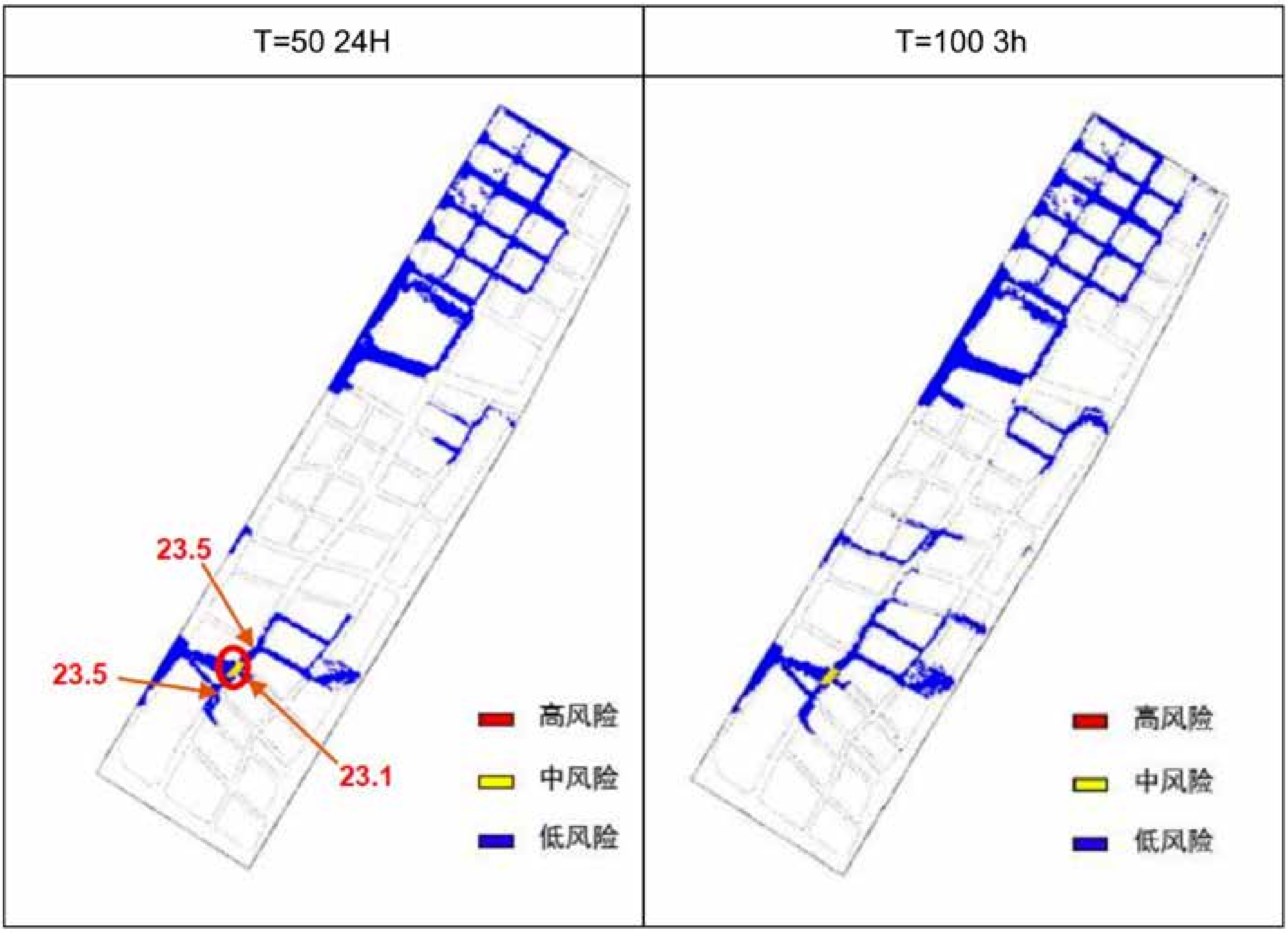


Figure 19. Waterlogging for T=50 (24h) and T=100 (3h). Legend : High risk in red (≥0.4m), Middle risk in yellow (0.15m<h<0.4m) and low risk in blue (≤0.15m) (Source: Arcadis 2017)

4. SELECTION PROCESS FOR SUITABLE LID MEASURES

As mentioned in section 1.3.1, designers and developers are facing various challenges in the implementation of the MCA. The limited knowledge of stakeholders in LID measures, limited space available in the area as well as the restrictive LID measures proposed in the SCP further increase the challenge in selecting appropriate LID measure for the specific social, economical and political conditions of the area. In order to select suitable LID measures using the MCA approach, understanding of several aspects of the area is needed. Those are the spatial typology of the area, the stakeholders' interest and the Sponge City criteria. These important factors will help guide the designers to identify which LID measures are most appropriate for a project location of their interest.

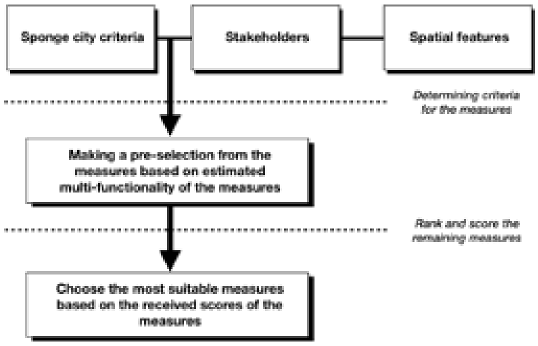


Figure 20. Evaluation scheme to select suitable LID measures (own illustration)

Our original concept was to integrate the stakeholder and the spatial analysis method in the multi-criteria analysis. This was unfortunately not possible due to the initial lack of spatial data. Surprisingly though, the spatial data did support the statements from before and the multi-criteria analysis. Figure 20 shows the evaluation scheme to select suitable LID measures.

The following chapter will first present in details the three main factors related to the core area of ErQi : 1) SCP criteria, 2) Stakeholder analysis and 3) Spatial typology. Amongst the various available LID measures, few will be pre-selected and presented in section 4.4. These information will feed into the MCA. The MCA is based on the PRIMO-Chain method which will be presented in section 4.5. Then, the process of the MCA is explained to finally lead to the results of the suitable LID measures depending on the function of the area.

4.1.Wuhan Sponge City criteria

The following information was retrieved from the ''Wuhan Sponge City Planning and Design Guideline" written by the Wuhan Municipal Bureau of Water Resources and Land Resources and Planning Bureau, jointly issued by Wuhan Urban and Rural Construction Committee Wuhan City Garden and Forestry Bureau. It is important to note that the information below was translated from Chinese to English.

The seven main criteria are defined by ''Wuhan Sponge City Planning and Design Guideline" which are capture ratio of total annual rainfall, peak runoff coefficient, Total Suspended Solid (TSS) reduction, pervious pavement ratio, depressed green ratio, green roof ratio and stormwater resource utilization. Stormwater resource utilization is a suggested criteria but not mandatory. The criteria are for both blocks and roads. From the Wuhan Sponge City Planning and Design Guideline, there is no specification of

Nr.	Targets for the blocks	Definition	Target value for the area
1	Capture ratio of total annual rainfall	The ratio between the annual capture water volume and the actual annual rainwater volume	Based on the land-use approx. >70%
2	TSS reduction	The Total Suspended Solid (TSS)	>50% reduction rate of TSS is required for all blocks and roads in the core area
3	Peak runoff coefficient	The peak runoff coefficient gives the ratio between the amount of water transported through the sewerage and the total volume of precipitation	Based on land-use
4	Depressed green ratio	It is a green measure which is lower than the surrounding ground elevation.	>25% of the total green surface
5	Pervious pavement ratio	It allows stormwater to percolate through the surface material.	Building, community, square >50% Urban park>55% Sidewalk and roads >100% of the total pavement surface
6	Green roof ratio	Roofs which have a soil layer with vegetation lying on the top of a conventional roof.	30-85% surface of rooftops of buildings which are not higher than 30m
7	Stormwater resource utilization	Depending on the land use type, ≥40%-50% of water used for irrigated urban green measures, road washing and other ecological use needs to come from harvested stormwater.	New built blocks ≥40% Green parks ≥50%

Table 2. The 7 main targets defined by ‘Wuhan Sponge City Planning and Design Guideline

Land-use	CRTAR	Design capture rainfall depth (mm)
Business	>65%	20.8
Green	>85%	43.3
Residential	>65-75%	20.8-29.2

Table 3. CRTAR and corresponding design capture rainfall depth for Wuhan (Source: ‘Wuhan Sponge City Planning and Design Guideline)

the scale of the blocks, it can be defined at the neighborhood scale, district scale or even city scale. For ErQi core area, Arcadis has divided blocks at the neighborhood scale. Every block has its own specific land-use type and its own target to achieve.

1. Capture ratio of total annual rainfall (CRTAR)
There is a controversy on the definition of CRTAR in Chinese governmental document . In the "Definition of terminology" chapter of "Sponge City Planning and Design Guidelines of Wuhan City", the CRTAR is defined as the ratio of annual captured water volume and the total annual rainwater volume. The captured water is the rainfall which is controlled (not discharged) from the total rainfall in a year. In other words, the captured water.should be reused or permeated into the groundwater or be stored on-site for the entire year rather than drained directly to the drainage system.

Another national document, the "National technical guideline of Sponge City Contribution", also provides the same definition of CRTAR. However, in the appendix of this document, another approach is used to define CRTAR by introducing a relationship between CRTAR and the design rainfall volume. In this section, CRTAR is seen as an index to determine the value of the rainfall capture capacity. The actual corresponding method is based on statistical data.

The daily rainfall volume of the last 30 years of local statistical data are first ranked from high to low values. The low values which are below 2mm/day are neglected. Next, according to the daily rainfall ranking, each daily rainfall value is given the same probability. The probability of lower than every daily rainfall data is cumulative, and the probability in percentage is used as CRTAR. The daily rainfall value is used as the design capture rainfall depth. Different areas have different climatic conditions and different daily rainfall ranking. Therefore, there are different relations of CRTAR and design capture rainfall depth. In this light, if the target CRTAR of Wuhan City is 70%, the design capture rainfall depth is 24.5mm. The capture capacity of the area after a rainfall event should be larger than 24.5mm. One generally accepted understanding of the term "capture" in CRTAR is that the rainwater flow through the LID measures and is delayed without the requirement of one year storage duration. As for the term "annual" in CRTAR, one explanation is that the statistical data should be selected annually.

The second understanding seems to break the literal meaning of "Capture ratio of total annual rainfall", but which is widely accepted and obeyed by most people. In appendix D, the nation file provides the chart of different design capture rainfall depth under different CRTAR of several important cities. Besides depending on the land-use, the target for CRTAR is also different with the corresponding design capture rainfall depth as shown in Table 3.

When assessing the target of CRTAR of one block, CRTAR should be first converted into a design capture rainfall depth (mm). And then, the design capture rainfall depth should be converted into a design capture rainfall volume by multiplying the block area. The actual water capture volume is the sum of all storage capacity of each measure in the block after a 3-hour design rainfall with return period of one year. If the actual capture rainfall volume is larger than the design capture rainfall volume, this block would achieve the CRTAR target, and not vice versa.

TSS reduction
To calculate the reduction rate to achieve the target of 50% reduction rate for non-point source pollution control objective, the following formula is provided in the guideline:

$$M\_ss = 17.02H-143.637$$

where M_ss is the runoff pollutants load modulus [kg/km^2] and H is daily average rainfall [mm]. Then, M_ss is multiplied by the area of the block or the road to obtain the actual TSS [kg/day]. Finally, the TSS target would be TSS_actual * 50%. The TSS-reduction would then have to be determined using the TSS reduction of each of the implemented measures and see if the sum is equal to TSS-actual * 50%.

Another method suggested which can be used without calculating the actual TSS is use a table with different LID measures provided with the corresponding pollutant removal rate (PRR) [%] (see annex) provided in the guideline. In other words, ∑(A_ratio * PRR) >50% where A_ratio is ratio of the area of the measure over the total area of the block or road. The table of pollutant removal rates per measures is given in Table 4.

Individual facilities	Pollutant removal rate (in SS, %)
Permeable brick pavement	80-90
Permeable cement concrete	80-90
Permeable asphalt concrete	80-90
Green roof	70-80
Complex bioretention facilities	70-95
Penetrate the pond	70-80
Wet pond	50-80
Rainwater wetlands	50-80
Cisterns	80-90
Rain cans	80-90
Transfer of grass planting ditch	35-90
Dry planting grass ditch	35-90
Seepage pipe / canal	35-70
Vegetation buffer zone	50-75
Artificial soil percolation	75-95

Table 4. Pollutant removal rates per measures (Source: Wuhan Sponge City Planning and Design Guideline)

Peak runoff coefficient
The peak runoff coefficient gives the ratio between the amount of water

Land category	Runoff coëfficiënt
Residential land	≤0.6
Public Management and Public Services Land	≤0.6
Commercial service land	≤0.65
Industrial land	≤0.65
Transport and public facilities land	≤0.65
Green space	≤0.2
Other sites	≤0.2

Table 5. Target value for the peak runoff coefficient for different land use (Source: Wuhan Sponge City Planning and Design Guideline)

transported through the sewerage and the total volume of precipitation. The peak runoff is determined by the land use. Table 5 shows the target value for the peak runoff coefficient for different land use.

To assess those targets, Wuhan government suggests to use the weighted average method based on the given runoff coefficient (see appendix D).

Depressed greens ratio, pervious pavement ratio and green roof ratio
Those targets are simply the ratio over the total green surface, pavement surface or total roof surface. Pervious pavement and green roof are specific LID measures while depressed green included, but not only, bioswale, tree pit retention and ditch.

From this understanding, it can be concluded that the SCP requires specific criteria to be met while using specific LID measures to be used. This only increases the challenge of implementing suitable LID measures in this area.

It is for these reasons that the Sponge City Project Team decided to move beyond the SCP to the SCC as mentioned in section 2.2. The first three criteria remains while the last three criteria are neglected for the selection process of suitable LID measures. This allow to increase the use of alternative LID measures which could be used in this area. From now on, the SCC will be used rather than the SCP.

4.2 Stakeholders analysis
Our main stakeholders are government, developers, designers and Arcadis Wuhan. The land use type of ErQi area was pre-determined and assigned by the government, which is also responsible for the Sponge City Guideline formulation. The ErQi area is mainly divided into two main features: blocks and roads. China International Trust Investment Corporation (CITIC) Limited is the owner of the entire ErQi core area. It sells blocks to different developers, with also different interests, including itself which is shown in Figure 21. Every developer hired design and planning institutes to design part of the entire urban plan. Urban design plans are then ''integrated" and reviewed by CITIC chief engineer. Public spaces such as road and park are managed by the government. However, it is known that WPDC Wuhan Planning & Design Co. is mainly involved in the planning and design of roads. At the end phase of the design, the government will examine the achievement of the Sponge City criteria. To ease the achievement of fulfilling the criteria of the whole area, Arcadis was assigned by the government to scale down scale down the criteria for each block and road.

According to Arcadis experience, most of urban planning designers have limited knowledge in the implementation of LID measures to achieve their SCP criteria. The Sponge City Team was able to meet with two main stakeholders: CITIC and WDPC (see Appendix E for more detailed information). According to them, the top down structure of the SCP does not allow much flexibility and interaction between institutions. Moreover, the limited time allocated for the design of the implementation of LID measures lead to rapid decision making process and higher risk of probability of failure of the design. Scarce resource such as money is another factor which influence the delivered design. Dai et al. (2018) reported similar findings regarding the time constraint. Designers need to also continuously adapt their design to the updated urban design or the updated SCP criteria because it is constantly changing and it becomes time-consuming. Since the policy and institutional aspects are not part of the scope of the project, but are relevant information to take into account, it will only be discussed shortly in the recommendation section.

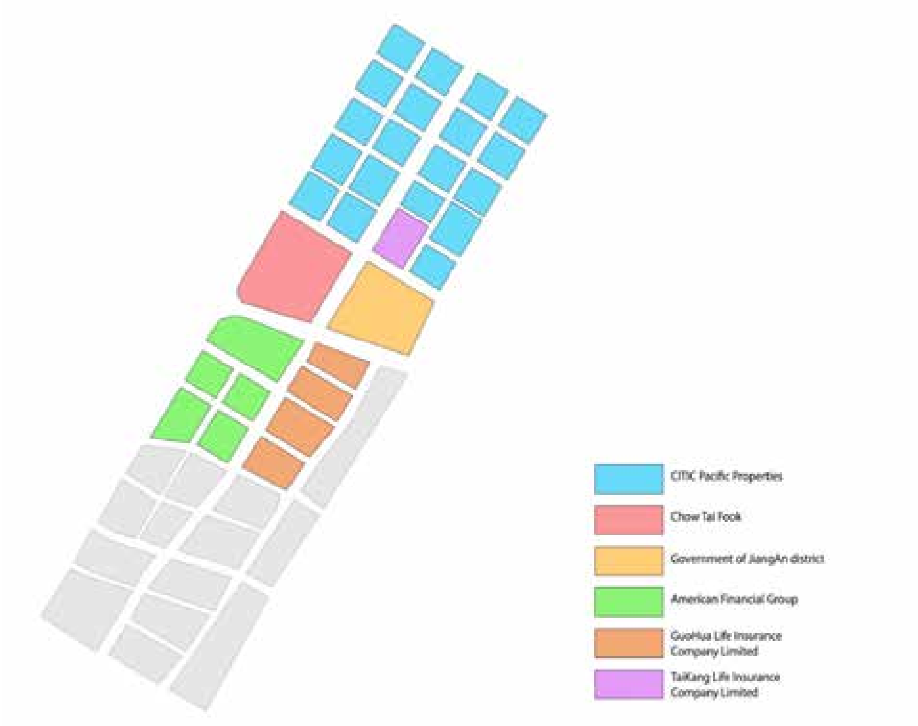


Figure 21. Developers involved in the ErQi area (own illustration)

To understand stakeholders' perception on the main problems faced by the city, the important factors considered when selecting LID measures and their preference in LID measures, we prepared a survey to collect more information from stakeholders. In total, 9 completed surveys were collected from the stakeholders from WPDC (see Appendix E for more detailed information).

The main conclusion drawn from the stakeholders' meetings and surveys' results are that:

1] Maintenance of LID measures is a problem to ensure its full functionality in the long term. For example, over time, plants die or trash accumulates and block the infiltration which also decrease the aesthetic value of the landscape.

2] Stakeholders are aware of the importance of heat stress and biodiversity. However, they do not know how to reduce heat stress to reduce heat stress and/or increase biodiversity using LID measures.

3] The third important factor is the aesthetic value which help to increase the land's value and therefore brings economical benefits.

4] Stakeholders prefer LID measures which are hidden underground or not visible to the public like retention box. According to them, it is easier for maintenance.

These information will be considered for the MCA as well as for the proposed design.

4.3. Spatial assessment

The assessment of the spatial typology is important to understand in order to identify appropriate locations for LID measures. In this section, an in-depth spatial analysis was developed for stakeholders to better understand the current urban typology. The method used for the analysis resulted in quantitative information which can be easily used to compare different areas.

Cluster analysis

Instead of treating the area as a collage of many different blocks, we decided to group them according to their spatial configuration in so called clusters. The analysis showed that there are a lot of similarities between certain blocks. As such this cluster approach allows us to better identify the area and determine suitable locations for interventions in the design according to their spatial and functional characteristics.

The cluster analysis looks at the potential space in the cluster for LID measures to not only help mitigate the effects of large amounts of rainfall, but also seeks to discover possibilities within the cluster to integrate these in order to increase the spatial quality.

For our analysis we took into account the following variables: function, built area, Floor Space Index(FSI), Open Space Ratio (OSR) and Layers (L) were analyzed. The latter four variables were taken in order to be able to quantify the aspect of density and the resulting pressure on the surface, while considering the actual spatial form and its qualities. This method is based on the method Haupt et al. developed in their book Spacemate (2005). In this analysis, 2 versions of the various calculations have been given: one taking the underground parking into account and one that does not take it into account. The method of determining these values is as follows:

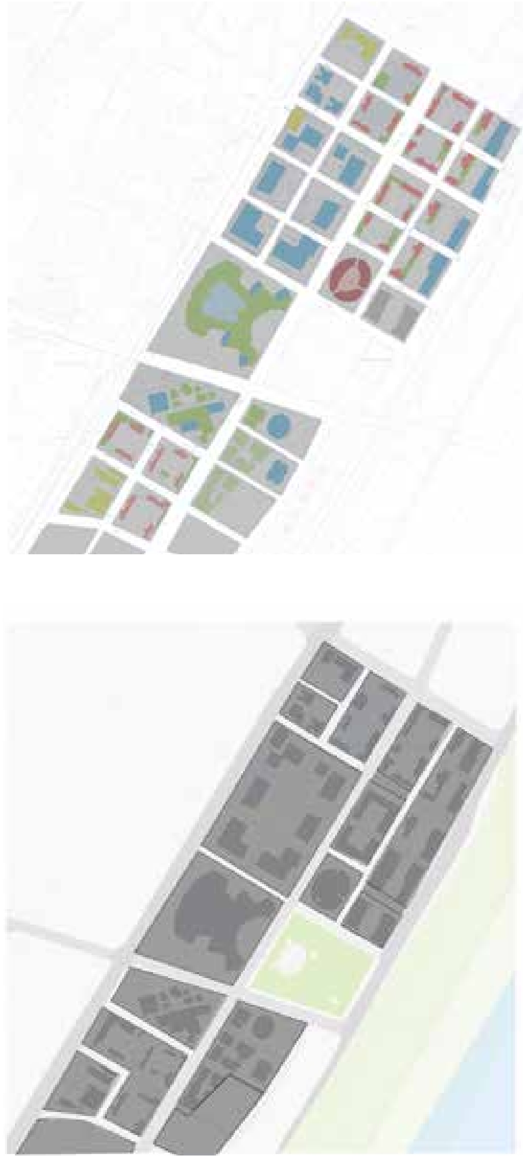


Figure 22. From individual blocks (top figure) and spatial clusters (bottom figure)
(own illustration)

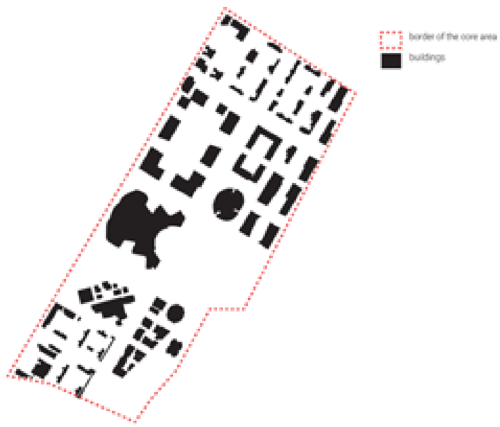


Figure 23. "open space" map
(own illustration)

The function was determined according on the land use map, Arcadis' documents and the urban analysis of the area. The built area and the gross floor area were determined from the documents we received. For the values, the following formulas were used:

FSI = gross floor area/research area
GSI = building footprint/research area
OSR = (research area-building footprint)/gross floor area
L = FSI/GSI

When we look at the entire core area (Figure 25), we can see there is a very high pressure on the open space. While the open space, including roads, accounts for 81% of the area the spatial calculations reveal a very different reality.

Counting the sublevel layers: FSI: 5,56
GSI: 0,188
OSR: 0,146
L: 38

Not counting the sublevel layers: FSI: 3,8
GSI: 0,188

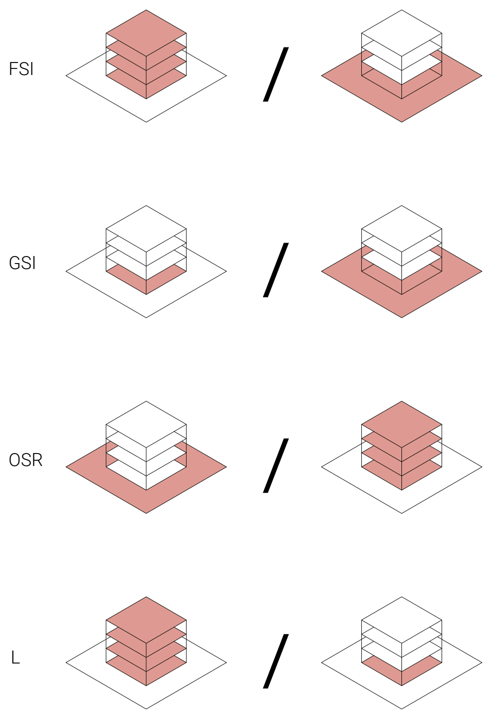


Figure 24. Visualisation of FSI, GSI, OSR, L (Adapted from Haupt, Pont & Moudon, 2005) (Own illustration)

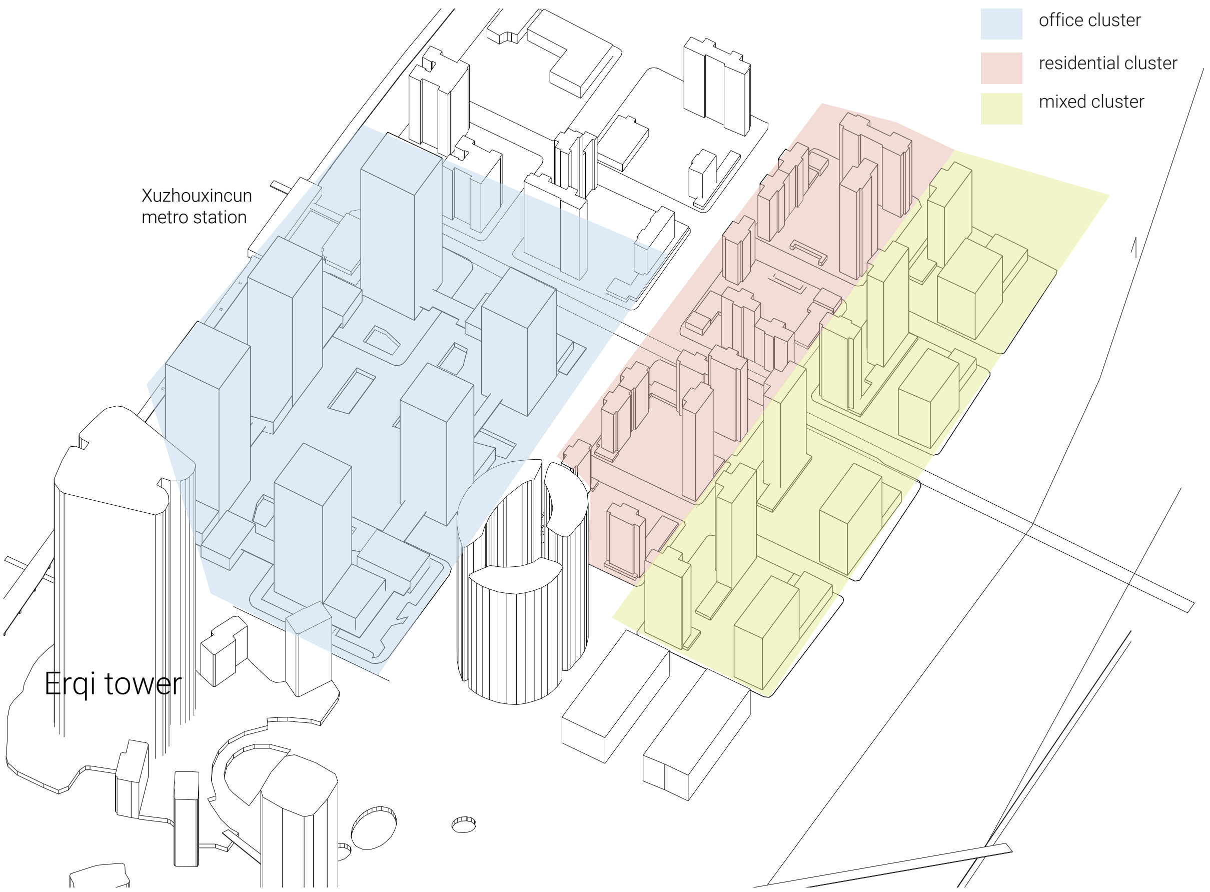


Figure 25. Axonometry of the ErQi area highlighting the selected clusters (Own illustration)

OSR: 0,214
L: 20

This is an area of extremely high density, especially when compared to European environments, and as such a very high pressure on the open space is to be expected. In the following section, 3 specific clusters were considered to be representative of the northern part of the ErQi area. They are also part of the development to be carried out by CITIC. These clusters were the commerce and business cluster, the residential cluster and the mixed area cluster.

The three clusters are (see Figure 25):

1) Commercial and business area cluster
2) Residential area cluster
3) Mixed area cluster

Commercial and Business area Cluster
The Commerce and business blocks are located directly next to ErQi tower and Xuzhouxincun metro station. This cluster consisting of blocks of 24m in height. Each of the blocks in this cluster is connected through elevated walkways and the underground area is directly connected to the public space through depressed public space.

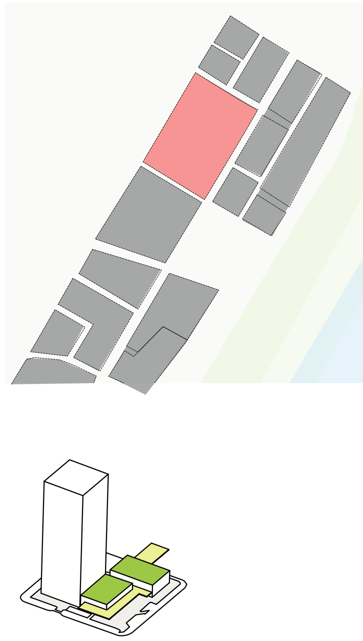


Figure 26. Commercial and Business area Cluster
(own illustration)

While on average only 26.2% of the area is built (including the roads), the calculated values show a very high density per square meter of the open space. When we would exclude the roads the space would be even further limited.

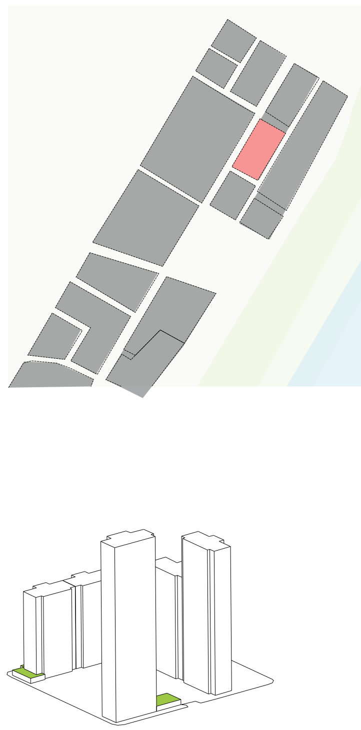
Values including the double layered parking:

FSI: 7,30
GSI: 0,262
OSR: 0,106
L: 27,86

Values excluding the underground parking:

FSI: 5,30
GSI: 0,262
OSR: 0,13
L: 20,23

Residential Area Cluster
This area, located between the commercial and the mixed area, consists primarily of high rise residential towers, surrounding a possibly private courtyard.



Values including the double layered parking:

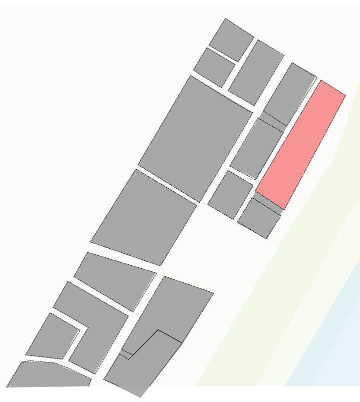
FSI: 6,10
GSI: 0,18
OSR: 0,134
L: 33,91

Values excluding the underground parking:

FSI: 4,10
GSI: 0,18
OSR: 0,20
L: 20,5

Mixed Area Cluster

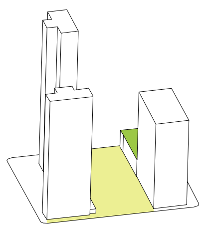
This area along the Yangtze river consists of mixed use blocks, with commercial and business functions along the dike and residential buildings lining the other side of the blocks. Here a city ordinance limits the buildings along the dike to a height of 100 m, while the residential towers have no such limit.



The availability of a large open space between the residential and the commercial buildings, with the heritage railroad passing through offers the opportunity for the realisation of a high quality public space.

Values including the underground parking:

FSI: 6,10
GSI: 0,18
OSR: 0,134
L: 33,91



Values excluding the underground parking:

FSI: 4,10
GSI: 0,18
OSR: 0,20
L: 33,91

4.4 LID-measures

The various LID measures which were used in the selection process were retrieved from the list provided in the Adaptation Support Tool (AST) developed by Deltares (see Appendix F.1). The AST provides 62 LID measures and a selection assistant for ranking based on their applicability and assessment tool to estimate the effectiveness applied adaptation measures (Deltares, 2016). From this extensive list of LID measures, a pre-selection was made by elimination according to the information collected in the previous sub-sections and our knowledge to shorten the list. The resulting list can be divided in four categories:

Water elements
The first category of LID is the measures which use some form of water element to both store stormwater and reduce the heat in the surrounding areas. The benefit of water elements is that these measures are multi-functional, as they tackle both heat stress and the need for water storage capacity. One of the downsides is that these measures often need regular maintenance, or they quickly lose their function. Examples of water elements are ponds, fountains, water circulation systems and water squares.

Building solutions
The second category of LID measures are measures which can be installed on structures. These are mostly measures to increase the water storage capacity of the district, as they cannot prevent heat stress in the streets below. The extent to which these measures can be implemented are determined by the structural strength of the building. These measures are especially useful in an densely urban area as there is limited spaces available on the ground. Examples of building solutions are green roofs, green façades and water roof.

Adding green spaces to the street level
The next category of LID measures is adding green spaces to the street level of the city. Green spaces provide space for water retention, reduce the heat in the area and provide possibilities for infiltration. One important aspect to take into consideration is that most of the underground area in Wuhan is only 1.5m deep, as most of the underground area is constructed into. One important aspect to take into consideration is that the subsurface layer is only between 1 to 1.5m deep because of the underground infrastructures. This means that the infiltration is very limited. Examples of adding green space to the street level are green adding vegetation in streetscape, constructing a urban park or urban forest, green ventilation grids and tree/bioretention cell.

Soil modification
The final category which is soil modification refers to modifications which affect the soil or build constructions into the soil to influence its characteristics. This can be done to improve the infiltration to the groundwater table or to create pathways for the water to flow to the drainage systems. Since the average available subsurface layer is 1.5m, measures which only improve infiltration capacity of the soil are not useful for this context. Examples of soil modification are underground storage blocks, constructing ditches, improve soil infiltration capacity and surface drains.

4.5 PRIMO-Chain method
From the LID measures presented above, a selection method is proposed to define which measures to implement in which situation. The selection method will help determine the applicability of the methods to the ErQi Sponge city project. PRIMO-chain (Ven, 2016) is chosen for the method to be used.

PRIMO-chain is chosen for the method to be used. The PRIMO-chain is a method used widely to determine whether the measure can be applied and it can be maintained (Ven, 2016). This method is used widely to determine whether the measure can be applied and if it can be maintained. The PRIMO-chain consists of the following attributes:

- **P**olicy
- **R**egulation and Legislation
- **I**mplementation capacity, execution capacity
- **M**aintenance, enforcement and performance evaluation
- **O**rganisation and financing

The limiting attribute is defined as the weakest link in the chain. Therefore, all the attributes need to be covered for the measure to be successful. This method is applied separately based on different functions of the area such as residential areas, commercial and cultural areas and road areas. Commerical and cultural areas were combined together in this analysis because the goals are similar. This is because these functions have different performance goals and implementation capacities, and therefore have to be analysed separately. To convert qualitative information into quantitative information, the MCA is used. The aesthetic attributes is a subjective attribute and therefore, depends on the person who is performing the selection. In this analysis, it is considered as part of the overall performance evaluation attribute.

4.6 Multi-Criteria Analysis

The MCA consists of four steps. First of all, the values for each of the criteria needs to be determined. The used criteria have been taken from the PRIMO-chain, and are shown in section 4.5. The criteria were compared to each other on which are deemed to be more important, and graded from 1 to 5. The meaning of the grade is shown in Table 6 . The resulting factor for each of the criteria can be found in the appendix F.2.

Grade comparison criteria	***Value meaning***
1	*less important*
2	*little less important*
3	*equally important*
4	*little more important*
5	*more important*

Table 6. Criteria used for the MCA approach
(Source: PRIMO-Chain)

Then, the measures are compared to each other using the criteria stated in section 4.5. This comparison is divided in two sections : 1) for investment costs and maintenance and 2) for other factors. For the comparison of cost, real data were used to compare the measures with. Therefore, for the analysis of these factors the costs of the measures per 100m^2 was compared to each other and then normalized to a factor between 0 to 1, with 1 being the cheapest and 0 the most expensive. The analysis for the other factors is more abstract, as it is difficult to give a grade on policy. Therefore, for the other criteria, the measures were ranked to each other and then afterwards normalized to a number between 0 to 1. Here again 1 was the highest rank and 0 was the lowest rank.

Finally, the scores of the measures is combined with the factors for the criteria. The score of the measure is therefore multiplied with the factor of the specific criteria. These scores per criteria are then summed up into a final score of the measure. The measures with the highest scores are deemed most suitable for the situation based on the given criteria.

4.7 Results and conclusion

LID measures for roads areas

The main goal for the roads is to prevent waterlogging. Therefore, most of the measures improving the storage capacity and retention of water were analysed. The results of the MCA for the roads in ErQi can be found in Appendix F.2.

From the MCA, three measures scores were relatively close to each other. These were the bioswale, surface drains and ditch or infiltration strip. For the infiltration strip, the extra costs for changing the soil and the placement of drainage would still need to be taken into account. Also surface drains are already commonly in use along roads as they are essential to prevent waterlogging. The remainder measures are bioswales and ditches which can be seen as potentially recommended measures. Since the stakeholders are not favourable to ponding water, as it reduces the aesthetics of the street, it can be concluded that bioswale could be a more favourable measure. The vegetation in the bioswale provides a higher aesthetic value even when filled with water while increasing the storage capacity.

LID measures for commercial and cultural areas

As mentioned previously, the commercial and cultural areas were combined because their goals are similar, which is to create an attractive environment. For commercial purpose, it is important to attract businesses to the area, while for cultural purpose, the area needs to attract people to come and enjoy the area.

Since the goal of these areas is to increase the attractiveness of the area, the measures analysed in the MCA were mostly measures which have both practical functions and high aesthetic value. As a result, soil improvement measures were neglected in this analysis because they are contributing less to the attractiveness of the urban environment. The main measures analysed were water elements, building solutions and adding green spaces to the street level.

The results of the MCA for the for the commercial and cultural areas can be found in Appendix F.2. The highest scoring for these areas are green/blue roofs and park or urban roofs. For the roof measures, the high score was mostly due to the current regulation making green roofs mandatory for new development. For the urban park, the high score was due to several reasons: the low construction cost, the simplicity of its implementation and the high performance it provides. Green roof and urban park, both contribute to an increase in storage capacity and increase in the aesthetic value.

LID measures for residential areas

The top three from the results of the MCA are similar to the results of the commercial and cultural areas. The first one is adding green to the streetscape, which is an easy way to increase storage capacity and decrease heat stress while taking little space. The other two measures are the roof measures, it is important to note that green roofs and water roofs are ineffective for buildings higher than 30m due to structural limitations, and most of the buildings in ErQi core area exceed this height(Arcadis, 2017).

Final score	Roads	Commerce/Culture	Housing
1	Bioswale	Park or urban forest	Adding green in the streetscape
2	Surface drains	Green roofs with drainage delay	Green roofs with drainage delay
3	Ditch or infiltration strip	Bioswale	Water roof

Table 7. The MCA results

5. GUIDING PRINCIPLES OF THE SPONGE CITY DESIGN

Meetings with stakeholders and the analysis of the site conditions of the ErQi core area resulted in a better understanding of the issues which impede reaching the targets of the SCP. The goal of the Sponge City Project is to develop further resiliency in the ErQi area, going beyond criteria of the SCC and SCP. In this section, creative thinking and innovation were introduced to overcome the aforementioned obstacles and provide opportunities for integrated and resilient design.

The current system under the SCP divides the ErQi core area into blocks and roads; however to develop an integrated and resilient design, the system should be considered as a whole , and not the sum of all the blocks and roads. As such, the targets of the SCP for the individual blocks and roads were not taken into consideration in the proposed designs, which will be discussed in the following section. These designs will be guided by the following Principles, as seen in the 100RC resilient characteristics: Resourcefulness, Robustness and Redundancy. The Sponge City Project adopted these Principles to help the transition from the Sponge City concept based on LIDs to achieve integration and resiliency in the city.. The section below describes the three principles in detail: Resourcefulness, Robustness and Redundancy.

Principle 1 : Resourcefulness
- Resourcefulness is defined in this report as the ability to recognize alternative ways to use resources which are embedded in the urban setting to prepare for extreme situations, rather than using conventional methods such as flood gates or sand bags. This strategy also aims at transforming urban elements into multifunctional elements while optimising the space.

Principle 2: Robustness
- Developing a robust design is defined as reducing variation of an urban element without eliminating the causes of the variation. In other words, the designed system should be independent of external variation, in this case, extreme rainfall. Robustness also means that in case the urban element fails, it happens in a safe way with no disproportionate damage to the people and the area. Therefore, when design thresholds are exceeded, there will be no disastrous consequences.

Principle 3: Redundancy
-The strategy of designing with redundancy entails that the system which is designed has a larger capacity than necessary. The needed capacity is therefore multiplied by a certain safety factor, or designed for a slightly larger design criteria than is required. As climate change is expected to increase the intensity of rainfall, systems can be designed for higher rainfall events.

6. DESIGNING FOR RESILIENCE

With the three guiding principles as mentioned above, the Sponge City Project team, with an interdisciplinary approach, developed two innovative, integrated and resilient design proposals: a pedestrian bridge (called ''Meng Qiao Bridge Design") and a main tramline (called ''Water Road Design"). These two designs were selected to improve the resiliency of existing infrastructure and the area as a whole, based on the scale, the flexibility of the design, the detailed information available, the SCC, the interest of the main stakeholders (CITIC and WPDC) and inspired from existing resilient water infrastructures (see appendix G). The designs will be explained in further detail below.

Design 1:

The MengQiao Bridge

6.1.1 Design process

The ErQi district is a densely built area and so two main vertical layers of stormwater sub-catchment can be identified at the district scale: ground level sub-catchment and building roof sub-catchment. The building roof sub-catchment represents 21,4% (or 761,601m^2) of the total area, which is a substantial amount with a large potential to collect stormwater, a required LID measure in the SCP.

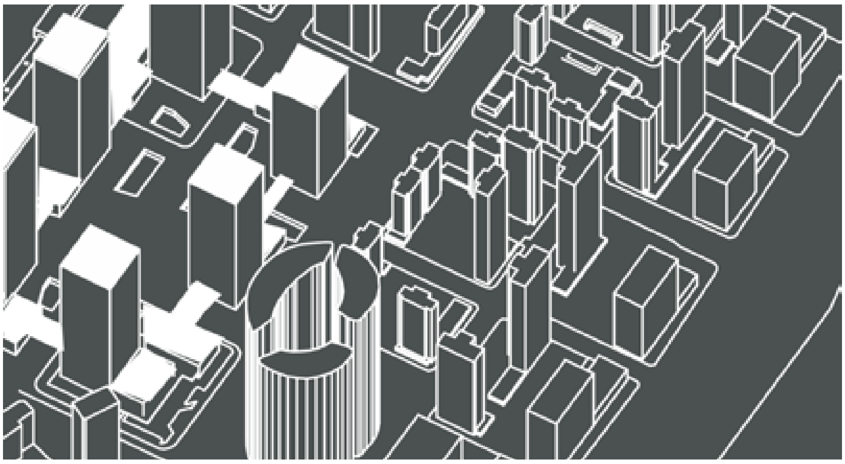


Figure 27. Section of ErQi area highlighting in white the building roofs (own illustration)

When adding the planned pedestrian bridge layer on top of the waterlogging (rainfall event of T=100 years for a duration of 3h) layer, as shown in Figure 28, it becomes possible to bring stormwater from a low storage capacity area to a high storage capacity area (the park) by using the bridge as a conveyance system and thus, reducing the pressure load on the urban drainage system. Moreover, the planned pedestrian bridge extends to the Yangtze River, so stormwater can also be conveyed directly to the river when the storage capacity in the park is full.

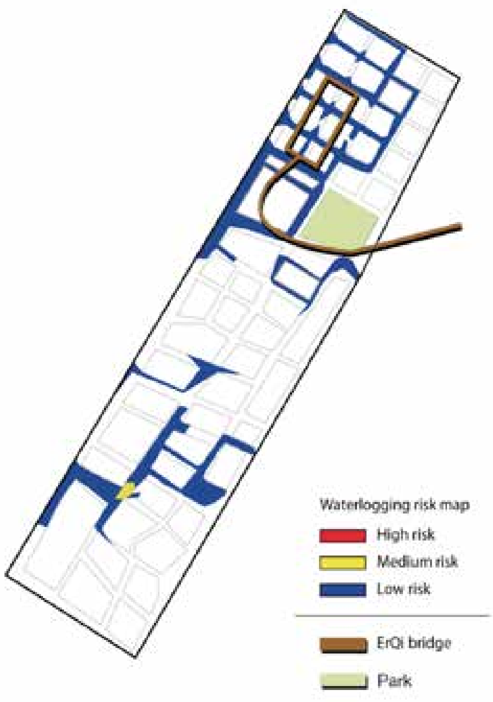


Figure 28. Waterlogging and pedestrian bridge in ErQi area (own illustration)

6.1.2 General design

This design proposes to connect the building roofs in the office cluster (see Figure 28) to the pedestrian bridge (detailed visual designs are provided in Figure 29). The catchment from the roofs represents around 30% of the total surface of this cluster.

The design of the pedestrian bridge is based on the original design in which the main elements are kept, such as the overall shape, the main path and dimensions of the bridge. It not only takes advantage of an existing planned infrastructure, but it also transforms the bridge into a multifunctional infrastructure and reduces the hydraulic loads to the drainage system. This follows the **resourcefulness** principle which recognises alternative ways to capture water and increasing the multifunctionality

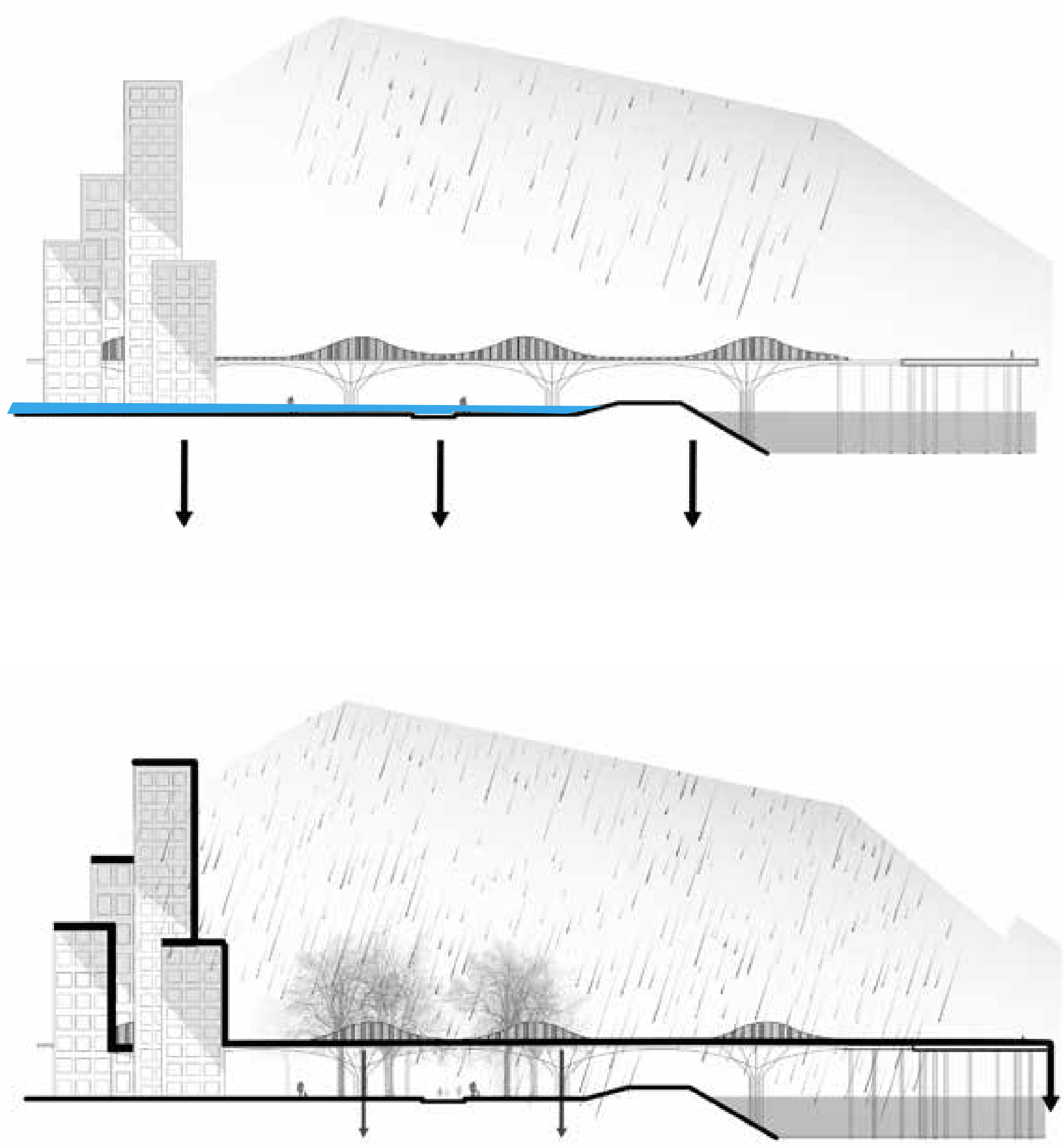


Figure 29. Current design (top illustration) and improved design (bottom illustration) of the MengQiao bridge (own illustration)

of the pedestrian bridge by adding a second function. Since there are currently no existing examples of such a structure with a water path with high load capacity, an Arcadis bridge engineer[1] calculated the approximate capacity load of the bridge under the proposed design. According to these estimations, Arcadis approved the feasibility of the bridge design. The current planned pedestrian bridge is designed to withstand 5kN/m², which is a very large capacity (CITIC information) that can possibly carry the water load; however, further investigation is necessary on the structural component should it be implemented.

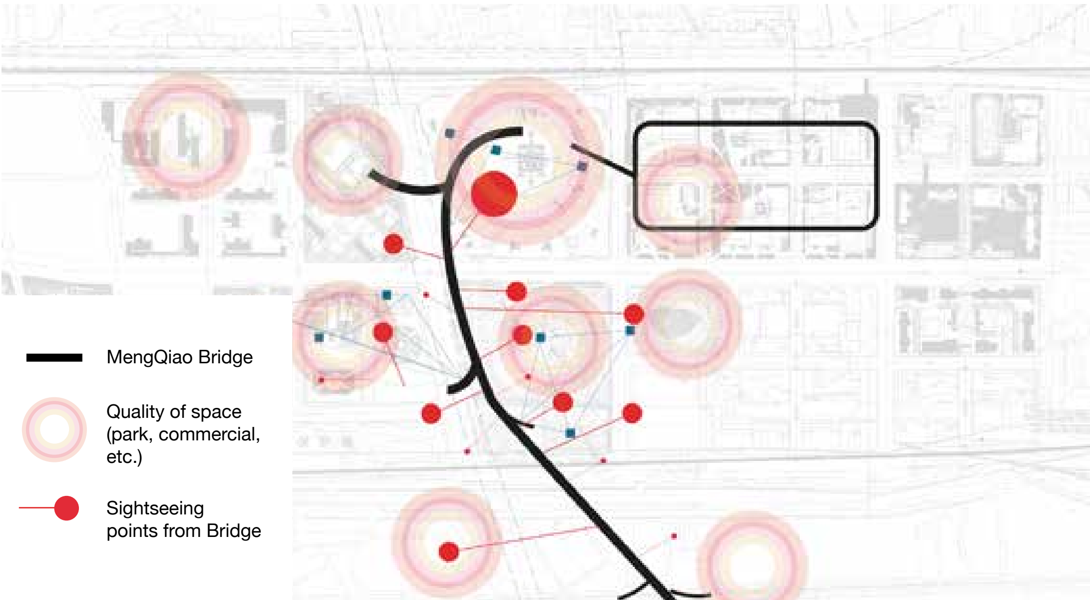


Figure 30. Original ErQi bridge plan (own illustration)

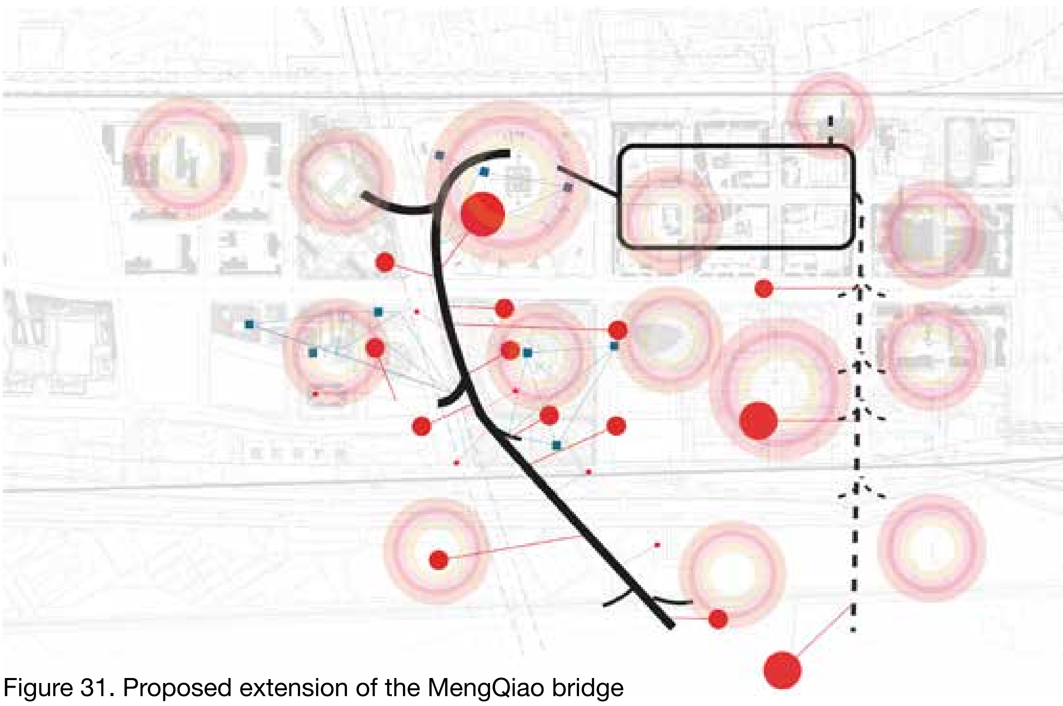


Figure 31. Proposed extension of the MengQiao bridge (own illustration)

CITIC is planning to extend the bridge further towards the north-east side, but they have not defined the path yet. A design was proposed with the additional path as shown below in order to increase pedestrian traffic in the mixed land-use area and reduce urban water logging. This design also maximises the roof area to capture stormwater which can be conveyed by the bridge to the Yangtze river. Besides, it will also improve the pedestrian experience and the connection towards the famous pedestrian area (See Figure 30 & 31).

The design also proposes the integration of multiple LID measures on the bridge such as adding vegetation, a small water square, porous pavement and a green façade. Including a green façade on the bridge would offer shadow during the summer for pedestrians and strengthen its connection with the park. Here, examples of LID measures on the bridge are only listed in Appendix F.3 thoughno specific design is provided. It is important to note that these LID measures implemented on the bridge will not substantially increase the "sponginess" of the bridge, however, it increases the urban quality while raising awareness on the Sponge City concept.

6.1.3 Detailed design

Meng Qiao Bridge can become a landmark of the area and a model of integration of the SCC. The water square benthemplein

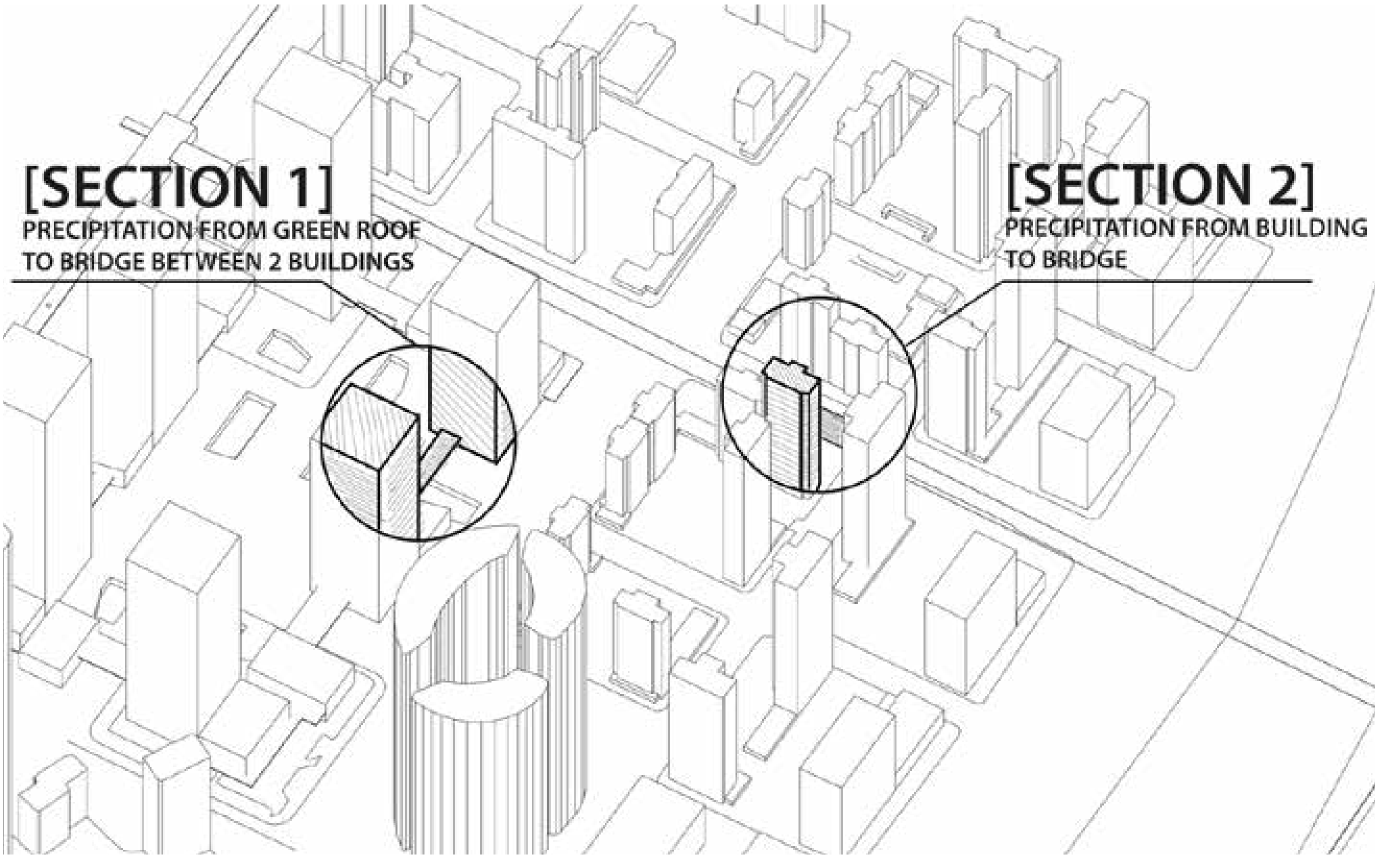


Figure 32. Views of the sections (own illustration)

in Rotterdam, which is an infrastructure which combines water

[1] The pedestrian bridge "MengQiao" is named after Arcadis bridge engineer who helped the Sponge City Project Team in the structural design feasibility. It also happens to mean *Dream Bridge.*

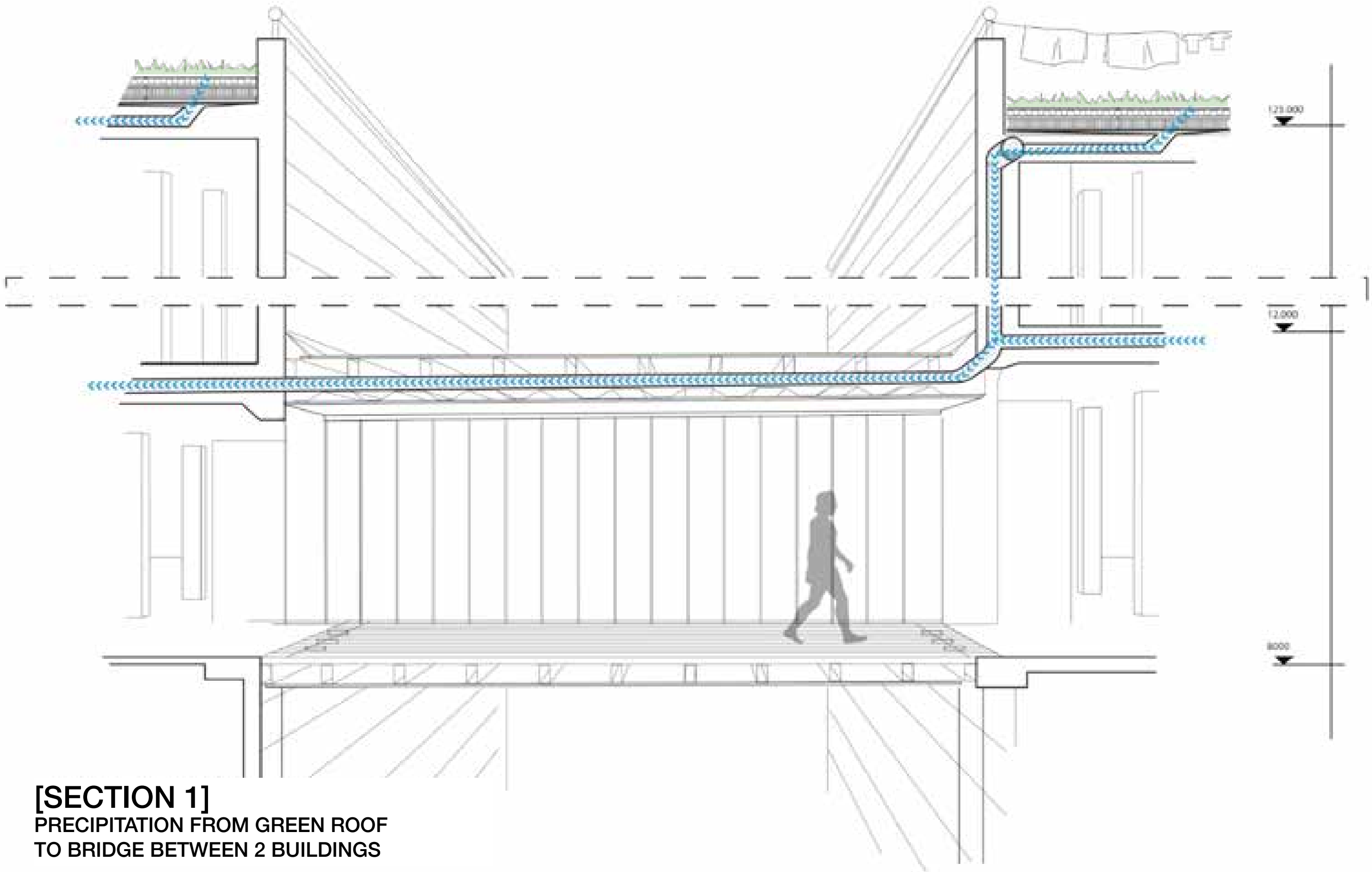


Figure 33. Wate path from the green roof to the building section
(own illustration)

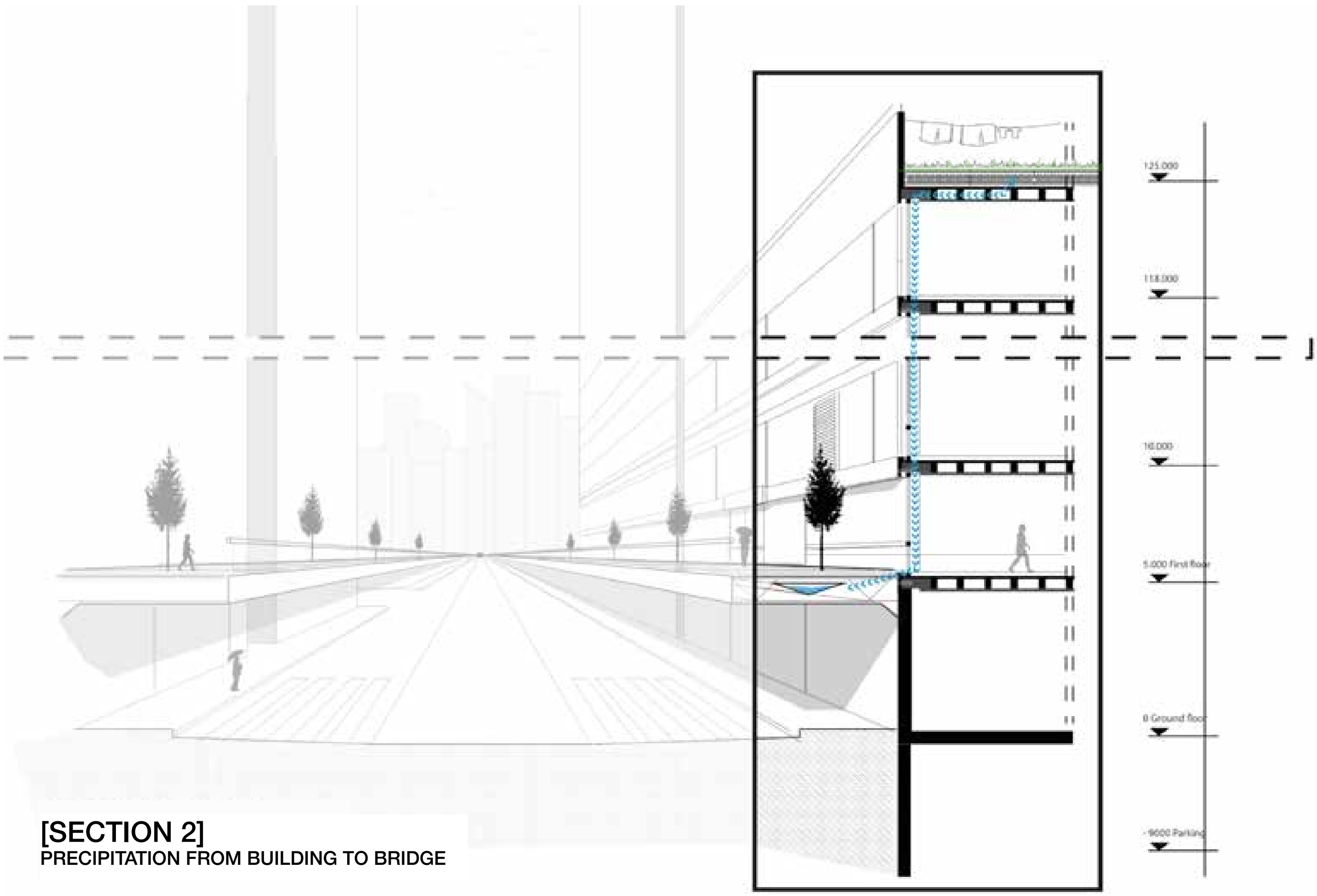


Figure 34. Water from the building to the bridge
(own illustration)

storage with the improvement of the quality of the urban space, has been used as an inspiration for the design of Meng Qiao bridge for resiliency, particularly for its multifunctionality (see Appendix G). The bridge floor is slightly tilted to allow water to flow towards the lower side of the bridge and infiltrate through the porous pavement and convey under the bridge like an open channel. This tilted design of the bridge avoids stagnant water on the surface and allows pedestrians to safely walk on the bridge. Under a heavy rainfall event, the conveyance system is filled up to the surface and can flow out of the bridge. This design is robust because when the system capacity is full, the excess water flows out of the bridge to ensure its continuous functioning. The pedestrian bridge is also designed with redundancy. It has a capacity for a rainfall intensity of a return period of every 5 years (T=5 years). More explanation and detailed calculations are provided in section 7.1.

1] Bridge under dry condition
2] Bridge under rainy weather T = 1 rainfall event
3] Bridge under heavy rain weather T= 5 rainfall event
4] Bridge under heavy rain weatherT= 100 rainfall event

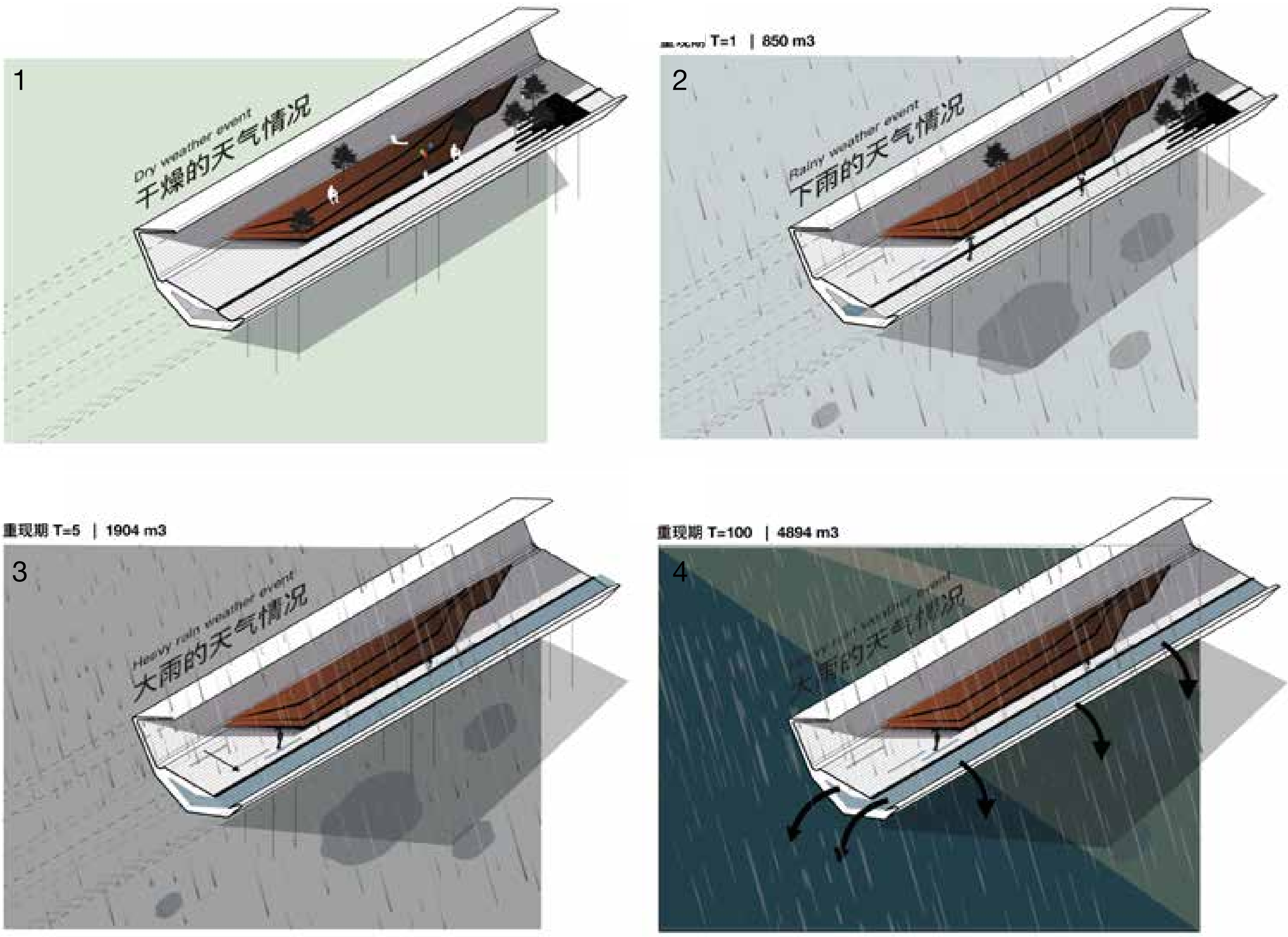


Figure 35. The MengQiao bridge during different rain events. (own illustration)

Figure 36. Impressions of the MengQiao bridge in the ErQi park
(own illustration)

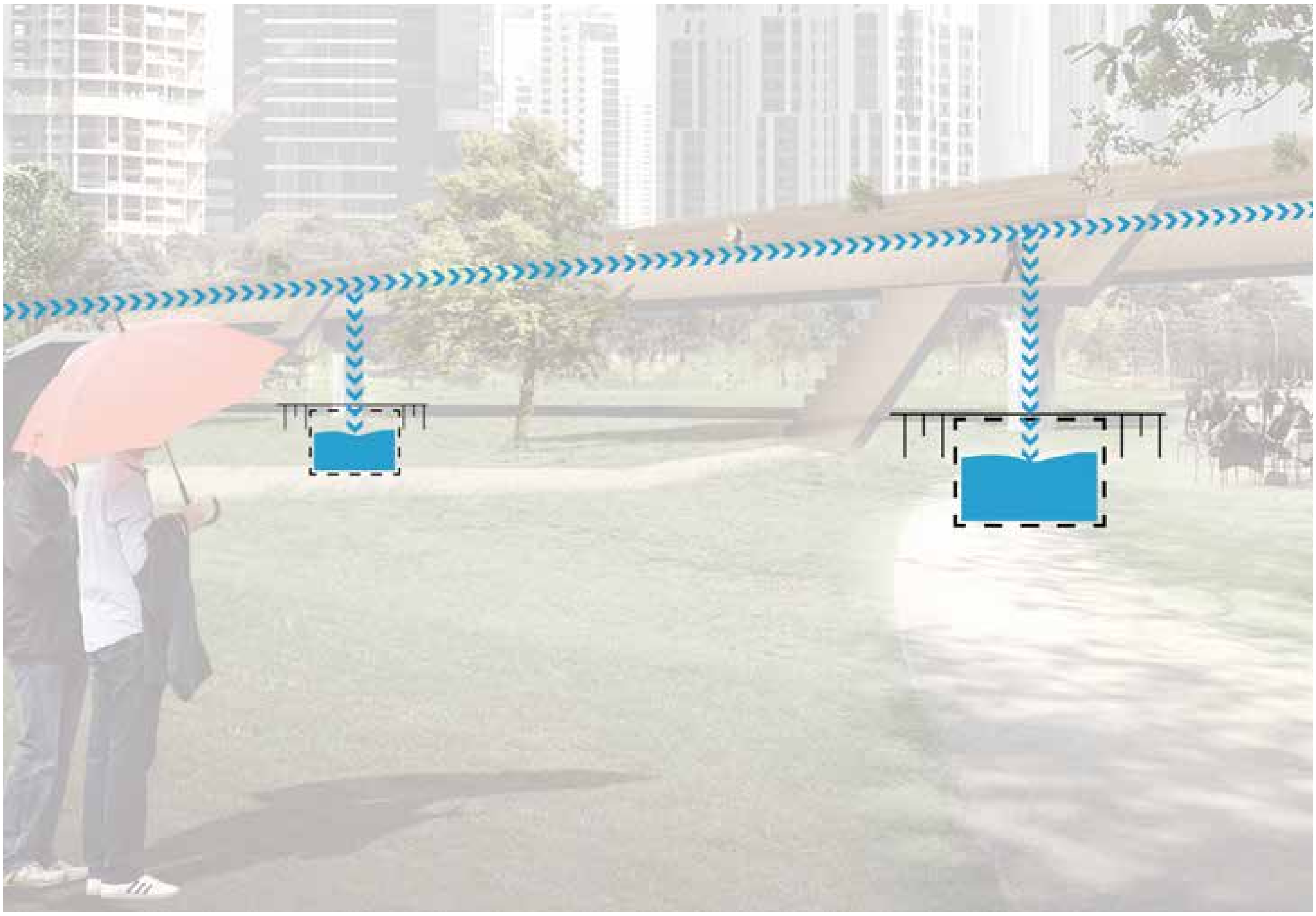


Figure 37. Impression of the water flowing to the park through the columns of the bridge (own illustration)

Once the stormwater collected from the roof reaches the park, it would flow around the columns of the bridge and fall into a pond as represented in igure 37 and then redistributed in the park. This proposed design aims to increase the visibility of water while providing more storage. The detailed design of the ‘’water column” has not been developed.

The current park design is provided by CITIC, which is in Appendix H.1. Detention, retention and biofiltration are suitable urban water management processes to implement in this area because it provides sufficient retention time for water to be in contact with plants and trees for bioremediation and maximise the function of water purification in the park. A water square is also valuable for its twofold effect of storing more water while providing recreational value and decreasing urban heat stress. Based on this, some LID measures are chosen in the park which include a wetting surface, porous pavement, ponds (ponds under the bridge column and ponds in the park), wet ponds, a rain garden and a water square. Since the thickness of the soil is 6 meters in this part of the ErQi area, there is enough underground space to design underground tanks.

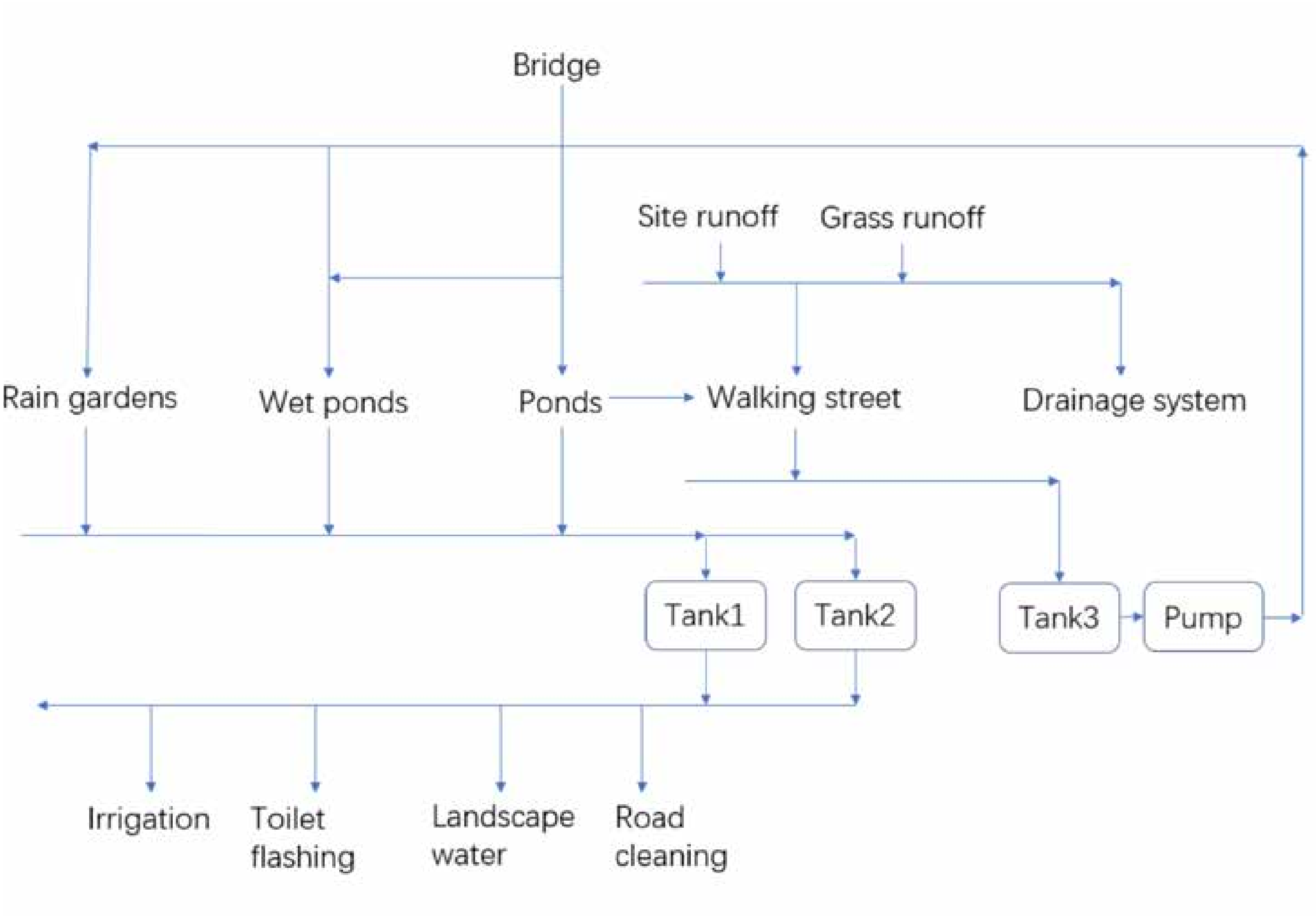


Figure 38. Scheme of the water circulation system in the park.
(own illustration)

To improve water capacity from the bridge and increase water resource utilisation in the park, which is also a recommended criterium by the SCP, a simplification of the water circulation system scheme was designed and shown in Figure 38. This design scheme is also used for the modelling purpose which is explained in section 7.1. When it rains, water in rain gardens, wet ponds and ponds are collected into Tank 1 and Tank 2 prior to a biofiltration treatment. In addition, it is assumed that site runoff and grass runoff will go either toward the pedestrian walkway or to the drainage system, if the pedestrian walkway is full. Water collected from the pedestrian walkway is stored in Tank 3 temporarily and treated before it is transported by a pump to the rain garden and wet ponds for further water purification. Finally, treated water in Tank 1 and Tank 2 are reused for different functions such as irrigation, toilet flushing, aesthetic landscape usage and road cleaning.

As maintenance is an important aspect for the stakeholders to consider, the Meng Qiao Bridge was carefully designed to make maintenance as easy as possible. The surface of the bridge remains smooth to allow cleaning with ease. The first iteration of the design included an open channel integrated in the bridge to make water visible during a rainy event (see Appendix K). However, with an open channel, trash can accumulate which would decrease the aesthetic value. Therefore, the second and final iteration only allowed water flowing through the porous pavement.

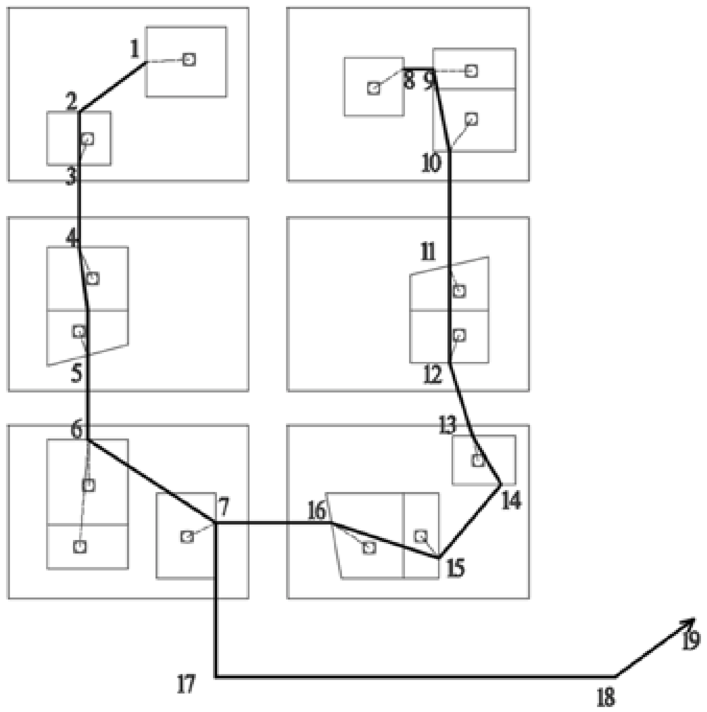


Figure 39. General view of water conveyance system (own illustration)

6.1.4 Technical aspects

Dimensions of water conveyance system

The dimensions of the water conveyance system on the bridge are designed by using the Storm Water Management Model (SWMM). The return period of design rainfall is 5 years. The water conveyance system which goes through the cluster in the northern business area is designed as a pipe and its cross-section is circular (from point 1 to point 16 in Figure 39). The section of the bridge in the park is considered as an open channel and its cross-section is parabolic (from point 17 to point 19).

The bridge length is calculated according to the planned pedestrian bridge and the area of the roofs of the building is determined according to the urban plan provided by Arcadis. Based on this information, a SWMM model was built and adjusted to the diameter of the pipes and the dimension of the channel on the bridge accordingly.

The bottom slope of the pipes and channel is designed as 0.0015 to enable continuous flow towards the park and/or the Yangtze river. The final design of water conveyance system is shown in Table 8.

The bridge length is calculated according to the planned pedestrian bridge and the area of the roofs of the building is determined according to the urban planning provided. Based on these information, SWMM model was built and we adjusted the diameter of the pipes and the dimension of the channel on the bridge accordingly.

The bottom slope of pipes and channel is designed as 0.0015. The final design of water conveyance system is shown in Table 8.

Reach name	Inlet point	Outlet point	Diameter/ Height(m)	Top Width(m)	Length(m)	shape of section
TB1-2	1	2	0.55	/	40	circular
TB2-3	2	3	0.55	/	30	circular
TB3-4	3	4	0.6	/	43	circular
TB4-5	4	5	0.6	/	82	circular
TB5-6	5	6	0.6	/	48	circular
TB6-7	6	7	0.65	/	120	circular
TB8-9	8	9	0.4	/	12	circular
TB9-10	9	10	0.5	/	62	circular
TB10-11	10	11	0.5	/	55	circular
TB11-12	11	12	0.55	/	68	circular
TB12-13	12	13	0.6	/	42	circular
TB13-14	13	14	0.6	/	50	circular
TB14-15	14	15	0.6	/	58	circular
TB15-16	15	16	0.6	/	81	circular
TB16-7	16	7	0.65	/	42	circular
TB7-17	7	17	0.55	2.25	330	triangle
TB17-18	17	18	0.55	2.25	537	triangle
TB18-19	18	19	0.55	2.25	300	triangle

Table 8. Dimension of water conveyance system

According to the results, the pipe size required for our design is relatively larger than the normal size for stormwater pipe for building. Depending on the thickness of the construction of the bridge, it was suggested to install two or more small pipes rather than one large diameter pipe when the water conveyance system goes where waterlogging occurs during high rainfall event.

6.1.5 Conclusion

In conclusion the MengQiao bridge design started as an opportunistic approach to the problem presented in the commercial area. By using the planned infrastructure of the pedestrian bridge and adapting it to function as a carrier for rainwater, a problem can become an opportunity for the area. In this case it helped that the infrastructure of the bridge only needs to be adapted, giving a second function to it. The outcome could have been vastly different had there been no bridge.

Design 2:
The Water Road

6.2.1 Design process

The main street is located in the middle of ErQi area stretching from north to south (see Figure 40). Developers are planning to construct a tramline to increase accessibility of the area in the future. The current design shows a long strip of grass with tram rails between two roads (see Figure 41). With the planned pedestrian bridge and underground connected infrastructures, pedestrians can easily and safely use multiple pathways to get from one point to another. The main street is currently designed for modes of transportation such as cars, trams, buses, taxis and bikes. The proposed tram line is identified as a critical infrastructure as it connects the the northern part of ErQi area to the south and facilitates rapid evacuation in case of urban flooding.

Figure 40. Location of the tram line in the main road of ErQi core area (own illustration)

6.2.2 General design

A bioswale was opted for based on the results from the MCA, described above in section 4.4. The bioswale scored high because the implementation and maintenance costs are relatively low in comparison with other LID measures, and the regulation from the Chinese government mandates that a certain percentage of 'green areas' should be depressed green, with the bioswale as our recommended measure. Therefore, following the SCC, replacing grass along the road by a bioswale in order to increase storage is proposed, applying the principle of **redundancy** to the system. A bioswale can help enhance biodiversity and create a more diverse and pleasing environment for citizens. It is also known to reduce heat stress and improve air quality (van de Ven, 2016). Moreover, to integrate the resil-

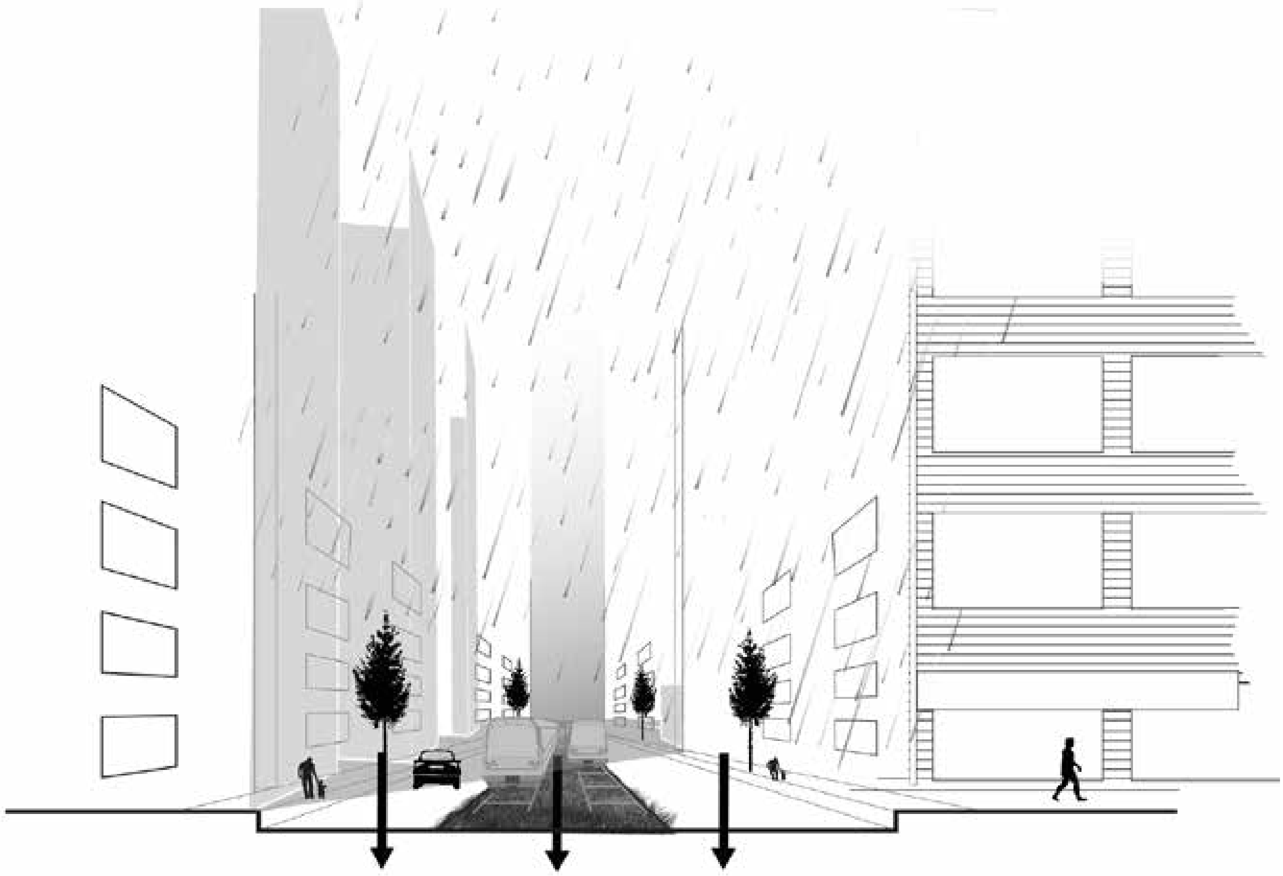


Figure 41. Current situation of the tram line with grass underneath
(own illustration)

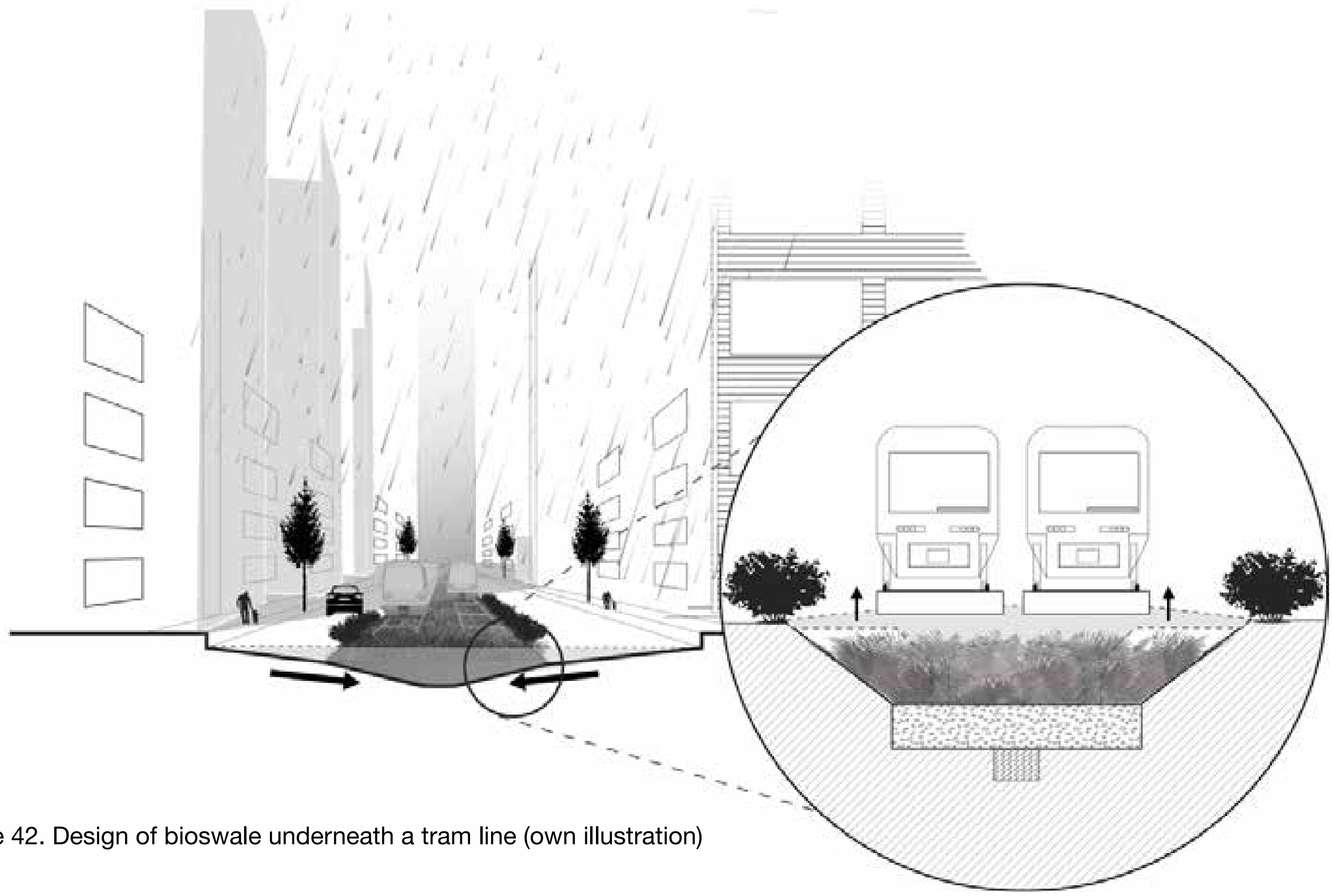


Figure 42. Design of bioswale underneath a tram line (own illustration)

iency component into the design, the designed tramline has been elevated to ensure its continuous functionality during high rainfall events (see Figure 42), increasing system **robustness**, and bold by storing the water underneath the tramline.

6.2.3 Detailed design

As maintenance proved to be a major concern for the stakeholders, the water road design includes the proposal to add shrubbery and other high vegetation at the outer edges to reduce pollution (see Figure 43). This would serve to prevent trash being blown in the bioswale from both sides due to the wind, hence reducing the need for maintenance. We refer to this as smart landscaping.

6.2.4 Technical aspects

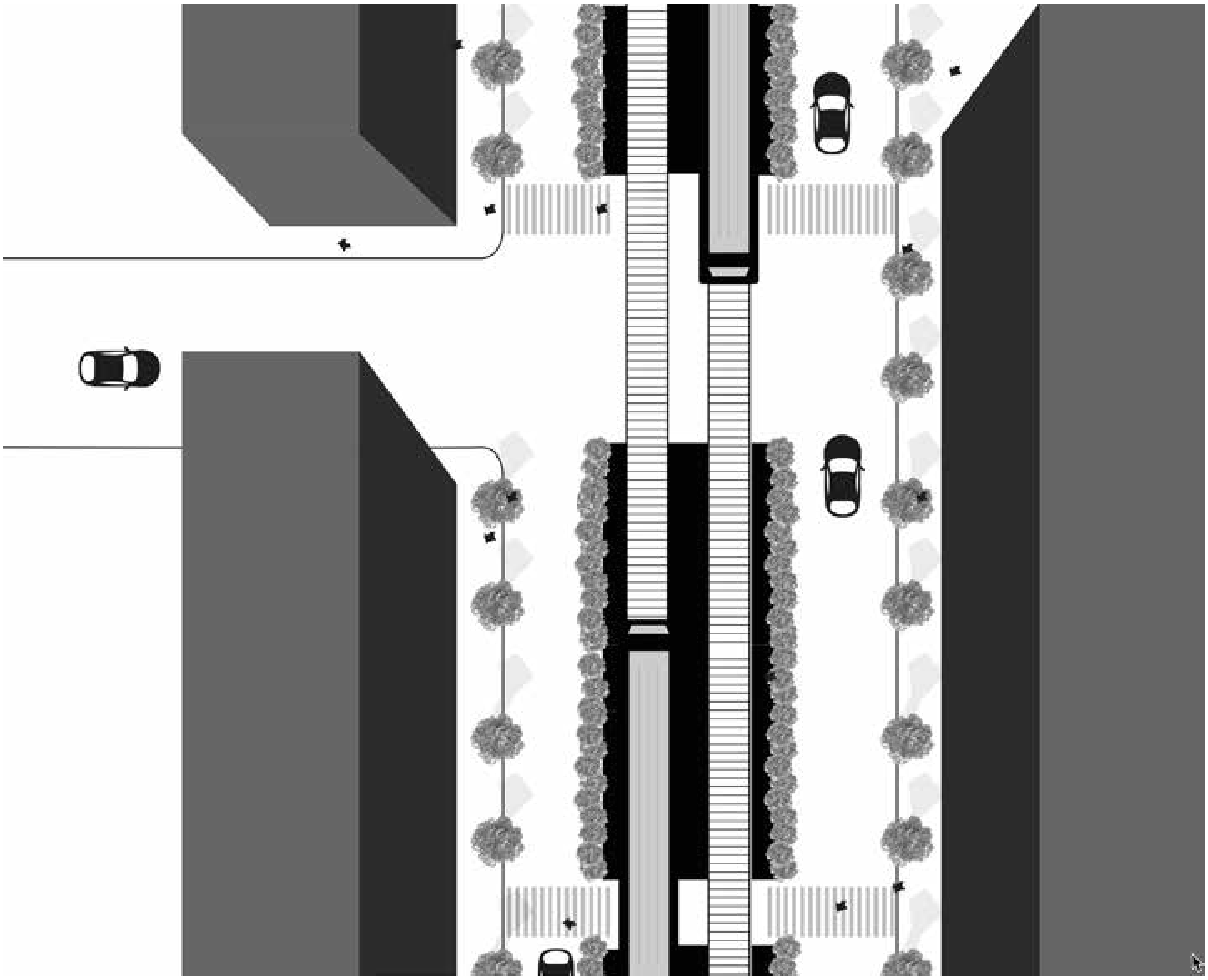


Figure 43. Plan view of the interaction between the bioswale and the tram line (own illustration)

The design of water road concludes four elements: bioswale, weirs,infiltration strip and cover/foliage bioswale. When the bioswale is filled, there are two ways for water to be drained: either by infiltration or by overflow over weirs to the drainage.

Dimension and capacity
The total available width and length chosen for the bioswale are pre-determined based on the road design provided by the designers. The other dimensions had to be determined based on the total capacity needed. The infiltration rate is determined by the hydraulic conductivity and dimension of the infiltration strip.

To determine the infiltration during storm event the Horton equation was used, which is shown below:

$$F_P = F_C + (F_0 - F_C)e^{-kt}$$

Where:

Fp = infiltration rate into soil, in./hr (mm/hr)

Fc = minimum or asymtopic value of Fp, in./hr (mm/hr)

Fo = maximum or initial value of Fp, in./hr (mm/hr)

t = time from beginning of storm, sec

k = decay coefficient, 1/sec

Volume capacity
For the total storage volume needed for the bioswale, the design rainfall of a storm of 3 hours with a return period of 1 year was used according to Sponge City requirements (Arcadis, 2018). The area which will drain into the bioswale is the area of the city district east of the bioswale, as there is a slight slope down towards the bioswale in this area. For the capacity calculations, it was assumed that all of the rainfall of the T=1 storm that falls in the upstream part of the district would have to be stored in the bioswale. For the infiltration during storm event the Horton equation was used, which is shown below:

The used parameters are shown in Table 9. For the infiltration the characteristics of coarse sand was used (Horton, 1940). For initial design the width of the infiltration strip is taken as 5m.

For the slopes, the ideal slope of a bioswale is 1V4H, with a maximum slope of 1V2H (ISWMM Technical Committee, 2013). Since there is limited space available because the bioswale is located between two busy roads , the maximum slope of 1V2H was used. Since we assume that rainfall from eastern part of the core area will flow into the bioswale due to its slight slope down

Parameter name	Value
minimum infiltration rate, Fc	25mm/hour
maximum infiltration rate, Fo	254mm/hour
decay coefficient	0,00115 1/sec

Table 9. Parameter values for Horton equation

towards the bioswale, T=1 rainfall event (Arcadis, 2018) is used to determine the storage volume needed for the bioswale. The calculated storage volume is shown in section 7.2.1. It is important to know the number of crossings or tram stations as these determine the number of culverts needed. The reduction in potential volume as a result of these structures has been estimated without the volume of the water in the culverts being included. Then, the required head over the weirs to calculate the capacity can be determined.

Dimensions and volume capacity of weirs

The capacity needed for the weir can be specified in two different capacities: the capacity for water storage in the weir and the runoff capacity to prevent the bioswale from flooding onto the road. It is assumed that there is no slope along the length of the bioswale. Therefore, all the runoff will be determined by weirs leading to the drainage system. Since the bioswale will be located between two main roads, the failure of the bioswale could lead to failure of the road. Since the design specifications of the road are unknown, the threshold of overflow without flooding the streets could not be determined. Therefore the bioswale is designed with weirs with a large enough overflow capacity leading to the drainage system to ensure no flooding to the road occurs for the design storm of T=100 with a duration of 3 hours.

The rainfall data was provided by Arcadis, and consisted of the amount of rainfall in mm/hour for every 5 minutes. By using the continuity equation, the discharge needed over the weir could be calculated. This is equal to the volume of inflow from the upstream area over time, minus the infiltration volume calculated by Horton and plus initial estimations of volume based on common dimensions of the infiltration strip in the bioswale. For the coefficient of discharge, the coefficient for an ogee spillway is used, which is equal to 0,67 (Bricker, 2018). For the initial value of the width of the weir, a bottom width of 6m was used, which was iterated multiple times during the design process. By doing this,the discharge required for the bioswale and the height dimension of the weir could be determined

Achieving the T=100 capacity requires four weirs: weirs at the outer ends and two circular drainage weirs located at equal distance from each other (see Figure 45). With these characteristics, the head over the weirs required is equal to 0.8m. This was achieved with a weir height of 0.6m and a swale height of 1.4m. The weir height was determined with the required storage capacity for the Sponge city requirements. These requirements are further elaborated in Section 7.2 This height for the bioswale will be used as our proposed design height. With the height, top width and slopes known, the dimensions of the bioswale can be determined. Dimensions are shown in Figure 44.

Figure 45. The location of the weirs in the bioswale (`own illustration)

Runoff calculation weirs

For the runoff, a different design storm was used because roads are designed in such that they should only flood once every 100 years. Since the bioswale will be located between two main roads, the failure of the bioswale could lead to failure of the road. Since the design specifications of the road are unknown, threshold of overflow without flooding the streets could not be determined. Therefore the bioswale is designed with weirs with a large enough capacity leading to the drainage system to ensure no flooding to the road occurs for the design storm of every 100 years.

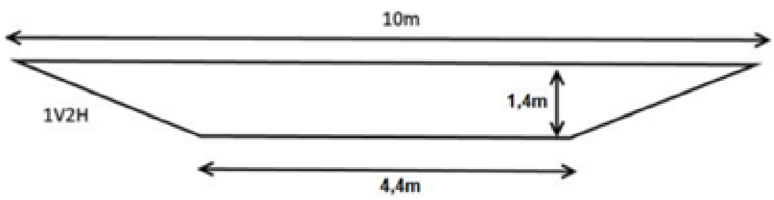


Figure 44. Dimensions of the weirs (own illustration)

For the design storm, the return period of 100 years was used, with a duration of 3 hours. The rainfall data was provided by Arcadis, and consisted of the amount of rainfall in mm/hour for every 5 minutes. By using the continuity equation, the discharge needed over the weir could be calculated. This is equal to the volume of inflow from the upstream area over time, minus the infiltration time calculated by Horton and based on initial estimations on the dimensions of the infiltration strip in the bioswale. With this result, the discharge required for the bioswale could be calculated. Following this, the height dimension of the weir could be determined using the discharge required for the weir(s) using the equation below.

$$Q = C_d \frac{2}{3} B \sqrt{2g} H^{\frac{3}{2}}$$

C_d = coefficient of discharge
B = width of notch
H = head above bottom of notch

For the coefficient of discharge, the coefficient for an ogee spillway is used, which is equal to 0.67 (Bricker, 2018). For the initial value of the width of the weir, a bottom width of 6m was used, which was iterated multiple times during the design process. With the calculated discharge required for the weirs, the head above the weir required can be calculated.

Infiltration strip

Since the volume capacity of the bioswale is not very large compared to the amount of rainfall to be stored, it would be beneficial to have a wide infiltration strip in the bioswale. Therefore, the proposed infiltration strip will be the entire bottom width of the bioswale, which is 4.4m. The infiltration strip consists of three different components (SWMM Technical Committee, 2013). First, there is the modified soil layer, which is the upper layer where the water first infiltrates the ground. This consists of different soil type than clay found in Wuhan. For our design purpose, coarse sand was used. Below that a choker layer needs to be placed. This functions as a filter layer of the water entering the drainage (Virginia Department of Conservation and Recreation,1999). Therefore a stone aggregate choker layer would be better. Finally there is the subbase layer, where the rainwater enters the drainage pipe towards the drainage system. This layer also consists of a stone aggregate, but has a larger grain size so the water can enter the perforated pipe easily.

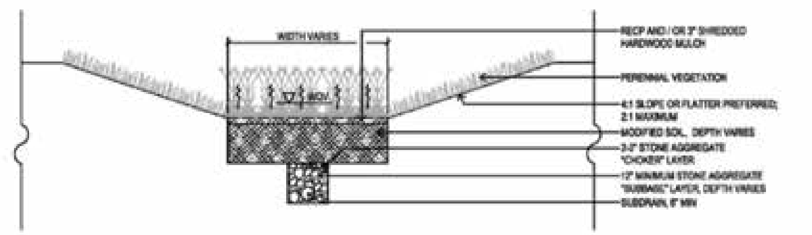


Figure 46. Section of the weirs (Bassels et al., 2014)

From the calculations for the dimensions and Horton's equation of the bioswale, the maximum infiltration which would need to flow through the infiltration drain is known. This is equal to 254mm/hour over 5495m^2, so 1381m^3/hour, or 0.4m^3/s. With that discharge, the Manning's equation is used to determine the dimensions needed for the subdrain. The equation is given below.

$$Q = VA = \left(\frac{1.00}{n}\right) A R^{\frac{2}{3}} \sqrt{S} \quad [SI]$$

n= manning's coefficient
A= area m^2
R= hydraulic radius (m)
S= slope (-)

The Manning's coefficient for PVC was used for the drainage pipe, which is equal to 0.01. There is no natural slope in the bioswale, so the drainage pipe would have to be buried under an angle to improve the flow. For now, the drainage pipe is designed to drop for 1m between start and end of the pipe. This leads to a slope of 0.0007. The corresponding radius for the drainage pipe is 0.14m.

Cover/foliage bioswale
For the vegetation in the bioswale, three zones of vegetation are used. There is the hydric zone, which is the lowest zone of vegetation. These plants must be able to withstand fluctuating

water levels and being submerged for longer periods of time. Grass meets these requirements for low vegetation and could provide a dense cover for the bioswale. Secondly, there is the mesic zone, which is for vegetation of average length. These are often planted on the slopes of the bioswale to prevent erosion to damage the slopes. And finally, there is the xeric vegetation zone. These are mostly trees and high shrubs, and should be adapted for drier conditions.

Vegetation in the bioswale should be natural to the area, as this can provide for year-round coverage and less need of maintenance (Atelier Groen Blauw, 2018). Furthermore, native plants provide high habitat value for animals living in the region.

6.2.5 Conclusion

The results from the MCA for the roads was the starting point which led to the Water Road design. The design uses an LID measure proposed in the SCP at a larger scale. It provides not only an increase in storage capacity and higher biodiversity through the bioswale along the main road of ErQi area but also a higher resiliency for the transport system. This integrated design would not have been possible without the methodology of the integrated approach presented in section 2.2. as well as the main resilient guiding principles.

Figure 47. Impression of the bioswale in ErQi area dry weather event
(own illustration)

Figure 48. Impression of the bioswale in ErQi area rain weather event. Here,
water runs down into the bioswale (own illustration)

6.3 Blue-green network

The MengQiao Bridge and the Water Road can be seen as the first step to creating an integrated blue green network, where the green (ecological) and blue corridors (water) are continuously connected. Turning stormwater into an asset instead of a problem, becoming an attractor for not only increased investment, but also enabling the establishment of ecological corridors along with the mobility corridors and the hydrological corridor. This further increases the viability of the implementation of a blue-green corridor in the pedestrian path (the dotted line in figure 31) which is connected to the extension of the MengQiao Bridge to strengthen the overall system, establishing ErQi as a integrated Sponge city area.

7. PROOF OF CONCEPT

This section aims to specify how the proposed integrated designs relative to stormwater management systems presented in the previous section can contribute to improved urban flood resilience. The MengQiao Bridge design was assessed using the SWMM and the Water Road design was assessed using engineering calculations.

7.1 Assessment of MengQiao Bridge Design
For the assessment, three scenarios (T=1 year, 5 years and 100 years) were modeled using the SWMM. These three simulations demonstrated that the MengQiao Bridge Design could reduce the current water logging pressure of the northern business area under extreme rainfall event.

This assessment focuses on the pedestrian bridge and the park. In the first phase, the amount of stormwater which would flow to the bridge after one storm event was simulated under the three scenarios by modelling the LID measures on the buildings' roof. In the second phase, the potential storage capacity of the park was calculated by designing a rough scheme of the water circulation system in the park (see Figure 43). The type of LID and its area were selected accordingly to ensure the volume of stormwater discharged to park. The excess stormwater which cannot be stored in park will flow to Yangtze River.

7.1.1 Technical assessment

Original SWMM
The original model provided by Arcadis focused on the LID (green/polder roof, depressed green and pervious pavement) preferences for eight blocks and assessed whether each block achieved the target value such as CRTAR and TSS reduction. They modeled three different LID design plans which are 90% polder roof, 50 polder roof and 50% green roof and analyse the LID performance by comparing the water captured volume result with a target storage with a design rainfall return period of once every year.

First of all, they analyzed the site condition and identified local parameters such as area, slope, impervious area percentage and roughness of each block and road by using Geographic Information System (GIS) and imported the analyzed data to SWMM. The model structure is built according to their LID design plans. They built the flow path in each block according to the strategy that the water on higher surface flow into lower surface adjacent and the water in sub-catchment without LID measures flow to sub-catchment with LID measures. Besides, there is no water connection between different blocks. To access the TSS reduction, they created three different nodes to collect the water which flows through different LID measures (green/polder roof, depressed green and pervious pavement) and modeled the

TSS reduction efficiency of LID measures by using empirical formulas. The original model structure is shown in Figure 49.

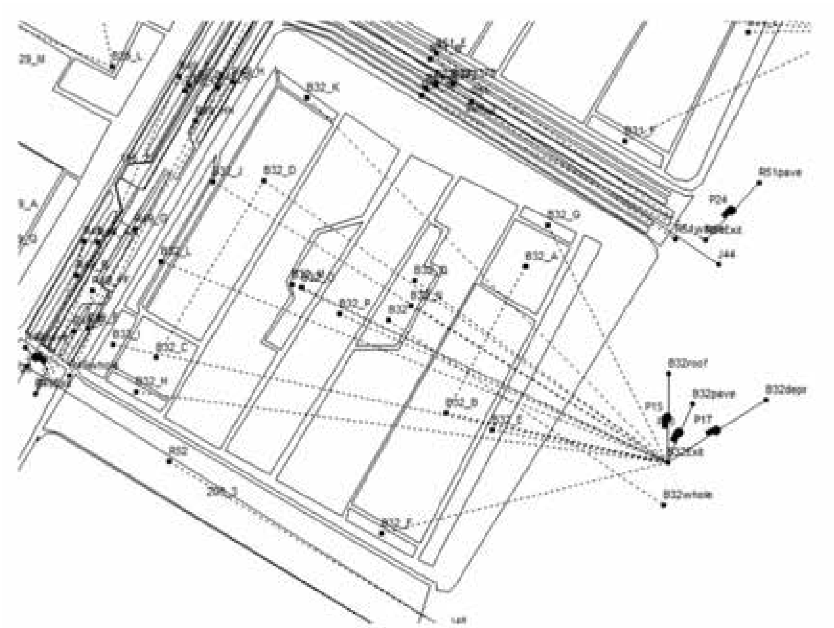


Figure 49. Original model structure SWMM (own illustration)

Modified model structure

The model structure was modified according to the design of the Meng Qiao Bridge. Instead of modelling all LID measures in these blocks, We modelled the building roofs connected to the bridge .

The rainfall would be first collected on the buildings' roofs and would flow through the pipes and then, to the pedestrian bridge. Green roof on the buildings is considered in the design because it delays and also decreases the peak runoff of stormwater flowing on the bridge. The water path on the bridge which flows through the business area is modelled by a circular pipe.After the business area, the water path changes to open water which is modelled by a parabolic channel.

The model structures for the blocks and the park are shown in Figure 50.

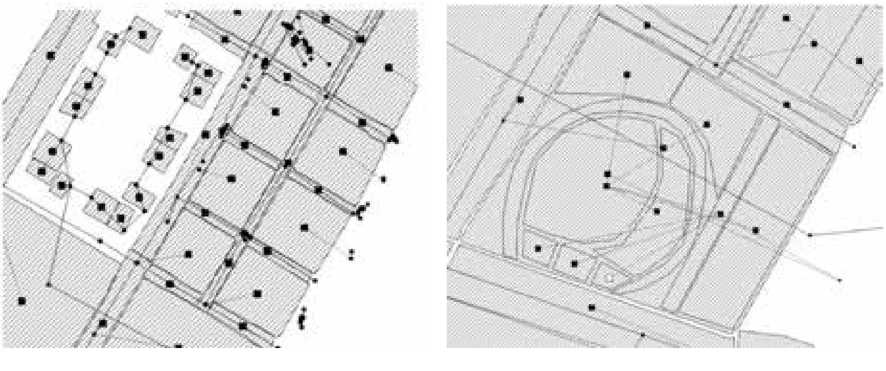


Figure 50. Bridge model structure(left) and park model structure(right) (own illustration)

In the park area, LID measures are added in the SWMM in order to obtain an approximate volume of the potential storage in the park. Since the subsurface layer under this park is occupied by shopping malls, and the models were simulated for short duration rainfall (3-hour rain events) only, groundwater recharge and evaporation were not taken into consideration in the calculations. To use the SWMM, the runoff route should be defined. According to the proposed design, the area was simplified into six elements which are grass, pedestrian path, underground shopping mall, walking street, ponds (including all ponds in the parks) and tanks. Note that tanks are not provided in SWMM as an LID measure option. Regarding the runoff route, we assume that water on grass 1, grass 2 and grass 3 flows to the path and the surface outflow on the path flows to the walking street (see Figure 51). In terms of runoff route, we assume water on grass 1, grass 2 and grass 3 flows to the path and surface outflow on path flows to walking street. Water on grass 4 flows to a water square and water from the depressed shopping mall goes to the drainage system directly. Water is collected from the bridge to the ponds and drained to walking street if it is above a certain height. Therefore, the stormwater systems which are proposed in this design to store water flowing from the MengQiao bridge are ponds, walking street and underneath tanks. These were added in the SWMM. Runoff routing is shown in Figure 50 as well. LID measures are simplified to permeable pavement for the path, rain barrel for the walking street and ponds because the SWMM has limited possible LID measures in the model.

	number	total area(m^3)
Walking street	1	1050
Ponds	6	300
Tanks	3	120

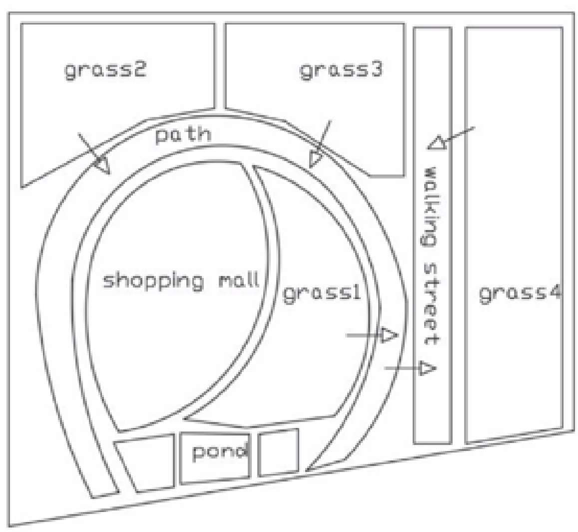


Figure 51. The storage elements in the ErQi park (own illustration)

Parameters

1. Subcatchment

Most of the parameters of subcatchment come from the original model, which includes slope, percentage of pervious and impervious area, depth of depression storage. All the roofs in the study area are simulated by using the same basic parameters, except for the LID set up, area and outlet flow. The actual parameters set up are shown in Table 10.

Subcatment type	Area (ha)	Width (m)	%Slope	% Imperv	N-Imperv	N-Perv	Dstore-Imperv	Dstore-Perv	%Zero-Imperv
Roof	/	/	1	100	0.01	0.18	0.05	0.05	25
Grass 1	1.5	122.47	0.99	5	0.012	0.18	0.05	0.05	25
Grass 2	0.5	70.71	0.99	5	0.012	0.18	0.05	0.05	25
Grass 3	0.323	56.84	0.99	5	0.012	0.18	0.05	0.05	25
Pond (in total)	300	0.5	0.99	100	0.012	0.18	0.05	0.05	25
Shopping mall	0.7272	85.27	0.99	95	0.012	0.18	0.05	0.05	25
Walking street	0.105	32.40	0.5	100	0.012	0.18	0.05	0.05	25
Path	0.8693	93.23	0.5	100	0.012	0.18	0.05	0.05	25

Table 10. Parameters of sub-catchment

2. LID

In the assessment, four types of LID measures are modelled: green roof, water square, pond and pervious pavement. The generalization and parameter set up are shown in Appendix J.1 Bridge Assessment.

3. Conduit

In this model, conduits are used to simplify the bridge model. Conduits were divided into two types. The first type of conduits, which is in the business area, the water path is modelled by a circular pipe. In this model, conduits are used to simplify the bridge model. The roughness is 0.013 and slope is 0.0015.

4. Rain Gauge
Rainfall time series of T=1y,5y and 100y are provided by Arcadis according to Wuhan rainfall events. Rainfall data can be found in Appendix J.2.

7.1.2 Assessment Result

The water volume conveyed by bridge
The water that the bridge conveys comes from the rainfall falling on the buildings' roof. Part of the rainfall volume is delayed by green roofs. Extra rainfall would be discharged to the bridge directly. By using SWMM, the water storage volume of LID measures 24 hours after a rainfall for T=1y, 5y and 100y respectively was determined. The model results of the LID measures performance after rainfall T=1 is shown in Table 11.

Subcatment	LID Control	LID area (m2)	Total inflow (mm)	Surface Outflow (mm)	Drain Outfall (mm)	Initial Storage (mm)	Final Storage (mm)	Stored during event (mm)	Storage Volume (m3)
B24A_G2	green roof	761.6	58.23	0	46.19	1.2	13.26	12.06	9.18
B24B_G2	green roof	1000.3	58.23	0	46.19		13.26	12.06	12.06
B24C_G1	green roof	725.9	58.23	0	46.19	1.2	13.26	12.06	8.75
B24C_G3	green roof	910	58.23	0	46.19	1.2	13.26	12.06	10.97
B25_G2	green roof	804.3	58.23	0	46.19	1.2	13.26	12.06	9.70
B25_G3	green roof	708.4	58.23	0	46.19	1.2	13.26	12.06	8.54
B26_G2	green roof	858.2	58.23	0	46.19	1.2	13.26	12.06	10.35
B27_G1	green roof	1039.5	58.23	0	46.19	1.2	13.26	12.06	12.54
B27_G3	green roof	956.9	58.23	0	46.19	1.2	13.26	12.06	11.54
Total									93.65

Table 11. LID performance after rainfall T=1

From this table, we could know that after a daily rainfall, all the green roofs in northern business area are saturated after one day and the total storage capacity is 93.65 m^3. Similarly after rainfalls for T=5 years and T=100 years, all the green roofs will also be saturated after one day.

By the pedestrian bridge before flowing to the park, the total rainfall volume was first calculated by using the design rainfall depth and the total catchment area. Then, the difference between the total rainfall volumena dn the LID water storage volume was calculated which is the theoretical water conveyed volume. The calculation table of water conveyed is shown in Table 12.

Design Period (year)	Rainfall in depth (mm)	Total building roof area (m2)	Rainfall in volume (m3)	Green roof storage capacity(m3)	Theoretical water conveyed volume (m3)
1	40.8	23204	946.72	93.65	853.08
5	85.36	23204	1980.69	93.65	1887.05
100	219.44	23204	5091.89	93.65	4998.24

Table 12. Water Conveyed Calculation

Finally we ran the model to know the flooding situation of water conveyance system under three scenarios. The model result shows a value fluctuation of the actual water conveyed volume. Besides when the return period of rainfall intensi is equal to 1 and 5 years, there is no water logging of water conveyance system on the bridge. When the return period of the design rainfall is equal to 100 years, the water level will higher than design position but most of the water will also be conveyed by bridge. The comparison of theoretical and modelling water conveyed volume is shown in Table 13.

Design Period (year)	Theoretical water conveyed volume (m3)	Modelling water conveyed volume (m3)	Peak Runoff on the bridge(m3/s)
1	853	850	0.219
5	1887	1904	0.531
100	4998	4894	0.626

Table 13. The comparison of theoretical and modelling water conveyed volume

The outflow of the park

By doing the SWMM for the park, the storage results of LID measures in rainfall T=1 are shown in Table 14.

Subcatment	LID Control	Total inflow(mm)	Surface Outflow (mm)	Drain Outfall (mm)	Initial Storage (mm)	Final Storage (mm)	Stored during event(mm)
Walking street	water square	40.77	0:00	0	0	40.77	40.77
Path	permpavement	152.77	0	0	1.08	153.85	152.77
Pond	Rain Barrel	40.77	0	0	150	190.77	40.77

Table 14. LID measures rainfall T=1

The results show that the walking street, the path and the ponds have more capacity to store water. It is important to note that the path does not receive water directly from the pedestrian bridge, so its potential capacity is not taken into consideration. It can be seen that no surface outflow from the path goes into the walking street. Tank is suggested to be built underneath the ground, therefore it is not in the Table 14 of LID performance, but it also has additional capacity for water collection.

The potential storage capacity of each element and the entire park under the condition of rainfall T=1 is shown in Table 15. A volume of 736.04m^3 water can be transported from the bridge. This means that all water from the MengQiao bridge is redistributed in the park. The storage results of LID measures in rainfall T=5 are shown in Table 16.

	Total area(m2)	total storage depth(mm)	used storage depth(mm)	additional potential storage(m3)
Walking street	1050	300	40.77	272.1915
Path	8692.5	231.21	152.77	681.8397
Pond	1500	300	190.77	163.845
Tank	120	3000	500	300
Park	50283			1417.8762

Table 15. The potential storage capacity of each element and the whole park in the condition of rainfall T=1

It is seen in the table that walking street and pond has extra storage capacity to collect more water from bridge,while the path is fully occupied of water from grass. Including underground tanks, the potential storage capacity of each element and the whole park in the condition of rainfall T=5 is shown in Table 16.

Subcatment	LID Control	Total inflow(mm)	Surface Outflow (mm)	Drain Outfall (mm)	Initial Storage (mm)	Final Storage (mm)	Stored during event(mm)
Walking street	water square	144.35	0:00	0	0	144.35	144.35
Path	permpavement	322.11	10.67	80.23	1.08	232.29	231.21
Pond	Rain Barrel	85.36	0	0	150	235.36	85.36

Table 16. The storage results of LID measures in rainfall T=5

The storage results of LID measures under a rainfall T=100 are shown in Table 18.

According to the storage results, it can be seen that the path and the pond have all a surface outflow and a drain outfall. Therefore, they do not have a storage capacity. The large outflow also make tanks all full. Therefore, during extreme rainfall, there is no potential storage capacity in the park. (See Table 19).

	Total area(m2)	total storage depth(mm)	used storage depth(mm)	additional potential storage(m3)
Walking street	1050	300	144.35	163.4325
Path	8692.5	231.21	231.21	0
Pond	1500	300	235.36	96.96
Tank	120	3000	500	300
Park	50283			560.3925

Table 17. The storage results of LID measures in rainfall T=5

Subcatment	LID Control	Total inflow(mm)	Surface Outflow (mm)	Drain Outfall (mm)	Initial Storage (mm)	Final Storage(mm)	Stored during event(mm)
Walking street	water square	2025.45	894.33	831.11	0	85.36	85.36
Path	permpavement	831.03	218.17	900	1.08	232.29	231.21
Pond	Rain Barrel	219.44	39.44	30	150	300	150

Table 18. The storage results of LID measures in rainfall T=100

	Total area(m2)	total storage depth(mm)	used storage depth(mm)	additional potential storage(m3)
Walking street	1050	300	300	0
Path	8692.5	231.21	231.21	0
Pond	1500	300	300	0
Tank	120	3000	3000	0
Park	50283			0

Table 19. Characteristics of storage capacity in the park during extreme rainfall T=100

The outflow to the Yangtze River

The water from the buildings' roof is collected and conveyed to the pedestrian bridge and part of the stormwater goes to the park and the remaining flows to the Yangtze river (see Table 20).

	Water volume in total (m3)	Water volume to park(m3)	Water volume to Yangtze River(m3)
P=1	853.08	736.04	117.04
P=5	1887.05	560.39	1326.66
P=100	4998.24	0	4998.24

Table 20. Water volume outflow

7.1.3 Limitations and recommendations

1. In the modified SWMM, the pedestrian bridge is generalized by several conduits without the catchment. Only the water transportation function was modelled. The rainfall falling directly on the bridge was neglected. This assumption led to an underestimation of the actual value.

2. Regarding the park area, it is designed to have some rain gardens or small wadies in the grass area which are also capable of storing water. This was neglected in the calculations. Indeed, it was assumed that all water from the grass area would flow to the path or to the walking street, which makes the additional potential storage value more conservative.

7.2 Assessment of the Water Road design

7.2.1 Technical assessment

In the design chapter it was established that for the technical assessment there were two requirements. There are the requirements set for the Sponge city requirements for the region, and there are the safety requirements regarding the roads build parallel to the bioswale.

According to the Sponge City criteria, LID measures are supposed to capture a certain percentage of the rainfall dependent on the land use of the area. This percentage varies from 55% to 85%. This percentage is related to a certain design rainfall which the area is supposed to capture (see Table 21). The capture ratio is further divided per block as shown in Figure 52.

Annual runoff control rate (%)	55	60	65	70	75	80	85
Design rainfall (mm)	14.9	17.6	20.8	24.5	29.2	35.2	43.3

Table 21. Capture ratio to design rainfall (Annual runoff control rate is the capture ratio) (source: own illustration)

With the design rainfall, the required volume to be stored was determined per district block in the core area. Using the data per block, we can calculate the required storage volume of the bioswale. This is given in table 22.

The blue area on the right picture is the area that would drain towards the bioswale, since there is a slight slope with the highest point at the right of the map. The park has a large storage capacity on its own, so the park will not be taken into account. When summing up all the required storage for the blocks which will discharge to the bioswale, the total required volume is 4879m^3.

Next we can calculate the total storage capacity of the bioswale using the dimensions which were determined in the design section of the report. For the storage capacity the volume of the bioswale under the weirs is taken. The total storage volume of the bioswale is shown in Table 22. The height under the weir is 0,6m.

Figure 52. Rainfall capture ratio per block (Arcadis, 2017) (left) and the area of the required storage volume of the bioswale (own illustration) (right)

Since the needed storage capacity for the blocks upstream of the bioswale is 4879m^3, the storage capacity of the bioswale is sufficient.

lenght bioswale (m)	1500
slope	1V2H
Depth (m)	1,2
width slopes (m)	4
width bottom (m)	6
width top (m)	10
total volume (without tram and crossings) (m^3)	12000

total volume below weirs (m)	6660
volume loss tram stations (m)	696
volume loss large intersections (m)	264
volume loss small intersctions (m)	255,6
total volume below weir (m)	5444,4

Table 22. Dimensions and volume of Bioswale
(source: own illustration)

Next to the Sponge city requirements, there is also the safety requirement regarding the roads which run parallel to the bioswale. Since the roads and the bioswale are right next to each other, the flooding of the bioswale would mean a larger load on the drainage system of the roads. Since the drainage capacity and the amount of water going through the drainage of the roads during design storms are unknown, the safety requirement for the bioswale was made equal to the safety requirement of the parallel roads. This prevents the bioswale from becoming an extra risk to the drainage of the roads. This safety assessment was already performed in the design chapter for the bioswale. The results can be found in the design chapter and in Appendix G.

7.2.2 Cost-benefit analysis

To assess the feasibility of constructing a bioswale in the ErQi district, a general assessment of the costs for constructing and maintaining a bioswale of this proportions. These costs are based on the averaged costs for bioswales per m^2 (cnt,2018). These prices are based on European average costs, and will most likely be lower in Wuhan. A bioswale is more expensive than for example simply constructing a cistern. But for the aesthetics of the streets the bioswale would prove a better solution.

Return period	Volume stored by bioswale(m3)	Volume discharged by wells during design storm (m3)	Volume infiltrated during design storm
1 year	54 44,4	5793,0	725,0
100 years	54 44,4	55954,0	681,0

Table 23. Safety assessment of the Bioswale

The developers want to develop a district that is more pleasant to the eye, and the designed bioswale is a LID that both meets the Sponge city requirements and is pleasant to see.

For the maintenance costs it also applies that these are European costs, and will probably be cheaper here in Wuhan. Furthermore, one of the main problems for maintenance in Wuhan is the clearing of trash. We plan to mitigate the trash problem by using the vegetation of the bioswale. By placing shrubbery and trees at the outer edge of the bioswale, these can function as a buffer between the bioswale and the thrash. This would reduce the maintenance costs even further.

7.2.3 Limitations and recommendations

There are a few limitations to the assessment of the bioswale, which will have to be discussed. First of all, the amount of storage capacity needed for the upstream area is not exactly known. Only the requirements of the city blocks are known, so the storage requirements of the stormwater falling on the roads should still be considered. However, part of the stormwater falling on certain roofs of structures would be captured by different measures suggested in this report. This could then again be subtracted from the needed storage capacity. It is therefore recommended to make a more accurate assessment when all measures to be implemented and which areas will discharge to the bioswale are known.

Investment cost per square meter (€)	179,46
Maintenance cost per square meter per year (€)	1,43
Area bioswale (m^2)	10990
Total investment costs (€)	1.972.265,40
Total annual maintenance costs (€)	15.175,70

Table 24. Cost assessment of the Bioswale

Furthermore, there are two more criteria for the Sponge city requirements which have not been covered in this assessment. These are the peak run-off reduction and the TSS reduction. For the peak run-off reduction calculations of the district Arcadis used Infoworks, while the calculations for the bioswale are in Excel. Therefore we could not implement the bioswale in their model. TSS-reduction could be calculated using SWMM, but the current model of the district is incomplete. Therefore the TSS-reduction has not been calculated. Since these are only suggested measures to implement and not a final design that is acceptable for now. But for the final design it should also be calculated whether these requirements are met.

Finally, the cost assessment is made based on the average costs of bioswales per square meter. This is not very accurate, as the price will vary based on the size of the project and the location of the project. It is therefore only an estimation of how much the costs would be. For the final design, the construction and maintenance costs will have to be calculated in detail.

8. CONCLUSION

Through our project, we have learned that the Sponge City Programme (SCP) is still a work in progress that's developing through a trial and error process. The pilot cities, such as Wuhan, are sites for experimenting to inform the policies, in order to better reach the desired goal.

One of the current challenges is that the SCP is not solving the problem of urban flooding due to its uniform design and metrics. The current methodology does not provide a solid base for achieving the goals stated in the SCP with its requirements. We believe that the SCP needs to move towards a more holistic approach with resilience at its core in order to make it more effective in its goal of avoiding major disruption.

That begins at the awareness of the necessity of an interdisciplinary and integrated or system thinking approach. Currently the responsible institutions and companies mostly operate within their own silos, limiting the interdisciplinary design and communication. Our proposal includes the introduction of some type of stakeholder involvement (especially in the design process). Although this is a lengthy process, it increases the potential of achieving synergies in the design. Even with some of the benefits, reducing the inefficient use of resources and increasing the probability of achieving the goals of the SCP, being very clear, introducing stakeholder involvement proves to be a large hurdle.

Another factor to take into account is that, contrary to the system in the Netherlands, which largely operates through a values based approach, the Chinese context of urbanisation is led primarily by a desire to generate profit. This values based approach is grounded in the belief that an intervention should not only increase profit but also benefit to the public goods. In the profit led paradigm resilience measures are often perceived as expensive luxuries instead of indispensable. In order to introduce the benefits of a value based approach to this system it is important to emphasise the long term financial benefits that accompany a value based approach.

We believe that the Chinese context therefore calls for a location sensitive approach where the various parts, in our case the waterplan, becomes an integrated part of the urban plan. In the current situation the water management became more of a problem that needed to be solved. Integrating the water management, and connecting the LID to the urban drainage system, however, creates the potential to realise high quality and desirable spaces for the citizens. By adopting an approach of creating high quality spaces that value water a case can be made for the connection of the LID to the drainage systems via pipes.

When looking at the complete picture, we can see that most of the Chinese cities are densely built, leaving but a limited space available for LID measures. In addition to that, large swaths of space are then assigned to other functions that prove to be non-negotiable, such as car space (evidenced by the large area allocated to car mobility and the parking infrastructure). To mitigate the negative effects this stance has on the availability of space for other functions it then becomes imperative to explore the possibilities of integrating measures in unconventional ways. In our case that meant introducing multifunctionality to the pedestrian walkways and the tramway.

9. RECOMMENDATIONS

As a part of our research, certain recommendations have been made based on the Sponge city project criteria in the future. Therefore, three types of recommendations will be presented: recommendations for the selection of suitable LID measures, recommendations on design strategies and recommendations for future research.

9.1 Sponge City criteria

As presented in section 4.1, several important concepts are not clearly defined in the SCP official governmental documents and may lead to misleading, particularly for the CRTAR. It is therefore suggested to review the concept. The Sponge City criteria should be more flexible and context-dependent to allow designers to apply the criteria efficiently. It is suggested to keep the first three criteria which are CRTAR, TSS reduction and peak runoff coefficient priority and neglect the depressed green ratio, pervious pavement ratio, and green roof ratio. This will allow more flexibility, creativity, and diversity in the urban landscape for suitable LID measures to be implemented effectively. Although meeting the Sponge City criteria is mandatory, the evaluation of the Sponge City criteria of urban design is rather simple. This reduces the incentives to implement LID measures properly. Moreover, the implementation of LID measures should be jointly designed along with the urban drainage pipe network, especially in a context in which all stormwater needs to be drained. Specifically for ErQi area, implementation of LID measures requires to take into consideration the additional piping system when planning and designing. From a long-term perspective, operation and maintenance of LID measures are not sufficiently enforced by the SCP. The difficulties of financing the programme after its implementation further exacerbate its sustainability. It is therefore recommended to include a detailed plan for the operation and maintenance of LID measures in the evaluation of the Sponge City criteria to ensure its functionality and performance over time.

As Wuhan is known to be one of the four “oven” cities, heat stress becomes an crucial problem to be addressed. Although stakeholders are aware of this problem, they may not have the ‘’know-how” to tackle the problem, similar to increase biodiversity in urban areas. Both aspects are not part of the Sponge city criteria as it is difficult to evaluate its implementation. In this case, AST developed by Deltares is one of the tools available which could enhance the understanding of stakeholders about the co-benefits of LID measures. The AST estimates the performance of the measures for some critical metrics including heat stress reduction. It was presented and demonstrated to some of the Chinese stakeholders during the period in Wuhan, and it was positively received by them. This tool could have the potential to be further investigated in the

Chinese context for the implementation and understanding of the SCP. The reuse of stormwater which is currently suggested criteria could become mandatory, especially in urban areas which suffer from heat stress or water scarcity. This water can be reused to cool down the city providing a pleasant environment for pedestrians.

9.2 Recommendations for the selection of suitable LID measures

One of the main issues we encountered was that stormwater management comes as more of an afterthought to the design, not as an integrated part of it. The urban planning of ErQi city district was already designed, and afterward, the water planning had to be fitted into the urban planning. This put many restrictions on what is possible for the stormwater management design, mostly due to limited space being available. If the water element of the design were considered from the beginning of the design process, it would have made the design process more integrated.

Furthermore, the implementation of the LID measures in the city district could be improved. The current approach for reaching the Sponge city requirements is to divide the area into blocks, and each block has its targets to meet. This has been suggested by Arcadis mainly due to the current lack of collaboration between stakeholders and time constraint. This severely limits the possibilities for the implementation of LID measures, as each block will implement small measures where it has space to meet its targets. This is easy for the designers who have to design a park, but for designers which has a small dense housing block, this could become problematic. It is also important to note that LID measures sometimes need to be connected to the drainage system, as the case of the ErQi area. This connection also means that creating small interventions of LID measures for each block also leads to the creation of an elaborate drainage network which requires good coordination from stakeholders to be aligned and integrated into the urban design. Therefore, we suggest that the SCP should provide more space for designers to implement the concept of Sponge City by following specific criteria such as the capture ratio, the peak runoff, and TSS reduction rather than providing specific percentage or ratio of specific LID measures (i.e., green roof or pervious pavement) for the specific land-use type. This recommendations for the SCP provides more flexibility and freedom for the implementation.

However, a more effective approach would be making goals for the entire area and then designing the measures where there is the space for them. The developers would then as a group be responsible for meeting the targets. Although we understand the choice to create different targets for different areas, to counter the shifting of responsibilities among the developers. Perhaps a combination of both approaches, where developers would be forced to cooperate by trading storage capacity could be researched.

One aspect of the selection process which is very different from western methods is the amount of engagement with stakeholders. As engaging the stakeholders in the decision making process and the planning and design phase is often not considered in China, it can lead to potential solutions being overlooked or projects missing their mark. This is then due to a lack of communication on the goals. A suggestion would, therefore, be to include the future inhabitants and the facility managers in order to understand their desires and the operation of the resilient systems. Depending on the scope of the project additional vital stakeholders should be invited from the beginning of the planning and designing phases.

Finally, it would significantly improve the design if ventilation were to be included in the design of the district. Where building ventilation is currently a novel concept, urban wind corridors are not considered most of the time while designing. This has led to Wuhan becoming known as one of the four "Oven Cities"(Wu, 2008), cities that are unusually hot in summer.

Incorporating ventilation in the design could therefore significantly improve the liveability of the city. Considering air flow in the city allows better ventilation and can reduce heat stress while allowing a more pleasant urban environment to walk in for city dwellers during the summer. When selecting LID measures, types and locations which do not block wind to pass should be considered (see Appendix F). Wind patterns which flow in the city need to be known.

9.3 Recommendations of design principle

Our proposed designs for ErQi area are based on three main strategies: resourcefulness, robustness, and redundancy. These design strategies are recommended to be applied for critical infrastructures or primary roads. As the central government is looking for Sponge City Programme models to be scaled up at the national level for new development in urban areas as well as retrofitting or re-designing current urban areas, our design strategies can be used in future design and implementation of the SCP. These design strategies can be combined with appropriate LID measures which can increase urban resilience. As an example, replacing grass by bioswales cannot only increase storage capacity but can also provide significant co-benefits to the urban environment. Connecting green roofs to an urban park as proposed in our design is also another example which illustrates the importance of combining the Sponge city principle to the resiliency principle.

Most of the cities are densely built, and it is expected to increase in the future, leaving limited spaces available to implement or adapt to urban areas. It is therefore in the interest of the Sponge Cities to apply ‘’resourcefulness” as a strategy in their design in order to optimize the use of different urban elements in a multifunctional and resilient way. Moreover, the pedestrian bridge is commonly used as a functional design in urban areas, creating a second level in the cities. The principle of the design of the Meng-Qiao Bridge could be applied in other cities as a way to capture, delay peak runoff and convey water from buildings roof to another area, only if necessary and depending on the site conditions. Furthermore, it is also important to identify and investigate the different level of sub-catchment areas in the vertical layer, especially in urban area. This can create new opportunities from a stormwater management perspective. Robustness and redundancy are two design strategies which are closely linked to each other. To apply robustness to our proposed designs, simple and easy intervention were proposed. Elevating infrastructure or infiltrating water through pervious pavement are an easy and simple way to implement as it does not require any operation and maintenance during flooding events while allowing activities to run continuously (i.e., walking on the bridge or functioning of the tram-line). Furthermore, it is recommended to design redundant infrastructure, if possible, due to the uncertainties of the future. Lastly, careful attention needs to be taken to not fall in the ''copy paste" ideology of the proposed designs in other Sponge cities.

9.4 Recommendation for an interdisciplinary approach

Given the scope and complexity of the implementation of the SCP it is clear that an interdisciplinary approach is necessary. The complexity of the problems for which the SCP is being developed can only be understood when viewed through multiple lenses.

Throughout our project, we learned about several things crucial to the success of an interdisciplinary approach. This ranges from how to start with such an approach to how to ensure the project remains interdisciplinary throughout. Otherwise, the project risks being solely multidisciplinary, meaning that the various disciplines are included, but don't necessarily interact a lot. We believe that to truly capture the potential of including the various disciplines, a common, and interdisciplinary, approach is vital.

The first thing that needs to be established is a basic understanding of how the different disciplines tend to approach an assignment. This to avoid unnecessary frustrations and even conflicts related to the overall functioning of the group.

From here, it is possible to move on to establish a common goal and a shared vision of the project. This requires much communication, an open mind, and patience with one another to include the inputs of the various disciplines and to start identifying each other's strengths and weaknesses.

After this follows one of the more difficult steps of the process. This is where complexity is not shunned but rather embraced. Tackling the project in all its complexity helps identify the various elements that fall within each discipline and untangle this web into more understandable parcels. By doing this collectively, albeit from one's perspective, the effect of bias can be mitigated, and previously unseen relations emerge.

Then, returning to the different approach methods, the team can then conceive of a design method for the project and the methodology. As our project involved research by design methodology, we had to identify what this meant from engineering and a designerly perspective.

By now it will probably be clear that this is a very time-consuming process. It requires much communication, with a solid visual component. The visualization of the methodology, the problem statement, the goals and the design process itself, may seem tedious, but we learned from our own empirical experience that this is the most effective way to avoid confusion. Different disciplines use their language and even definitions of the same terms, so the creation of common terminology requires visualization.

Furthermore, we believe that the best recommendation we can give to make an interdisciplinary project function well is an investment in time. This means an environment with real face to face meetings, with full communication where concepts and approaches are freely discussed. When looking at our experience, we do realize we might have had a slight luxury position regarding the feasibility of this ongoing communication.

This then boils down to the essential part of a truly interdisciplinary approach. Communication. When not enough time is invested in this, the project will be multidisciplinary at best. The various disciplines will be present, but the full potential may be difficult to achieve.

So our advice would be to integrate a type of interdisciplinary approaches, with full communication in practice and education in order to optimize this process and further develop expertise as we believe it becomes easier to do after previous experience. This meaning, working interdisciplinary is a skill that can and should be trained in order to tackle the challenges of our increasingly complex world.

9.5 Future research

There are multiple options for future research which have become clear from our project. First of all, the research performed on this project only provides suggestions and strategies on how and what to design for the ErQi city district. The final design for the water plan of the district should still be made. For this design, it should be calculated whether the implemented measures meet the Sponge city requirements and the safety standards determined for the area. This would have to be done in close cooperation with the developers to get their input and vision on what is possible in their area of the district.

Next, to the water plan for the core area of our project, the Sponge city measures of the area north of the core area still need to design.

This area is very interesting for design, as there is currently no design for the area. This provides much freedom to design the water plan. Also, the water plan for this district can now be simultaneously made. This would mean more possibilities than in the current core area, where the water plan has to be fitted into the already existing urban plan.

Furthermore, more research into the Sponge city requirements set by the municipality of Wuhan is needed. The Sponge City Initiative is relatively new and is still a work in progress. The requirements as they are now are a basic set of rules and guidelines, which give a percentage of for example how much of the roofs must be green roofs, or how much of the pavement must be permeable. These set requirements are both inflexible and inefficient. One example of how this works, in reality, is that permeable pavement has been placed in Wuhan but without soil modifications or extra drainage. Wuhan rests on a clay layer, rendering this permeable pavement ineffective. Therefore, improving the regulations on Sponge cities could improve the efficiency of the implemented measures. It would be good to incorporate the developers as well, as they have initially been left out of the regulation process by the municipality.

Finally, there is the problem of maintenance of the LID measures implemented. The local developers are interested in the green-blue measures, but their biggest concern for the implementation of the measures is the amount of maintenance they will need. Creating a maintenance plan for the blue-green measures in Wuhan and making a plan on how to reduce the maintenance costs might reduce the resistance against the implementation of the measures.

10. BIBLIOGRAPHY

100 Resilient Cities (2015). Arcadis Partners with 100 Resilient Cities to Improve Quality of Life in Cities. Retrieved 20-07-2018, from http://www.100resilientcities.org/arcadis-partners-with-100-resilient-cities-to-improve-quality-of-life-in-cities/

100 Resilient Cities (2018). What is urban resilience. Retrieved 10-08-2018, from https://www.100resilientcities.org/resources/

Ahern, J. (2007). Green infrastructure for cities: the spatial dimension. Paper presented at the Cities of the Future: Towards Integrated Sustainable Water and Landscape Management. IWA Publishing.

Arcadis (2017). Sponge City Masterplan of ErQi Waterfront Business District (PPT)

Arcadis (2017). Sponge City Special Planning of Hankou International Business District (PPT)

Arcadis (2018). Sponge City Design Guidelines - Wuhan Hankou International Business District

Atelier Groen Blauw Urban Green-Blue Grids for sustainable and resilient cities. Retrieved 22-08-2018, from http://www.urbangreenbluegrids.com/

Bacchin, K. T., Ashley, R., Sijmons, D., Zevenbergen, C. and A. van Timmeren. (2014). Green-Blue Multifunctional Infrastructure: An Urban Landscape System Design New Approach. 13th International Conference on Urban Drainage, Sawawak, Malaysia.

Batten, J. (2015). Cities: Survival of the Resilient. In Arcadis (Ed.). Bricker, J. (2018) lecture notes for the course Hydropower Engineering

Bovenkamp, J. v. d., & Fei, Y. (2016). ECONOMIC OVERVIEW OF HUBEI PROVINCE: Netherlands Economic Network in China.

Center for Neighborhood technology. (2018) National stormwater management calculator

Dai, L., van Rijswick, H.F.M.W., Driessen, P.P.J. and Andrea M. Keessen.(2018) Governance of the Sponge City Program in China with Wuhan as a Case Study. International Journal of Water Resources Development, p.578-596

Deltares. (2016). New Orleans' Adaptation Support Tool, User manual.

Fang, J., Yu, G., Liu, L., Hu, S., & Chapin, F. S. (2018). Climate change, human impacts, and carbon sequestration in China. Proceedings of the National Academy of Sciences, 115(16), 4015-4020.

Greater Pacific Capital (2014). The Test of China's Next Stage of Development: The Rise of Wuhan. Sign of the Times. Retrieved 15-08-2018, from http://greaterpacificcapital.com/the-firm/

Hooimeijer, F.L. Bricker, J. & K. Luchi (2018). Interdisciplinary-International research on urban reconstruction after disaster. TU Delft

Haupt, P., Pont, M. B., & Moudon, A. V. (2005). Spacemate: the spatial logic of urban density: IosPrInc.

Horton, R. E. (1941). An Approach Toward a Physical Interpretation of Infiltration-Capacity 1. Soil science society of America journal, 5(C), 399-417.

ISWMM Technical Committee. (2013). Iowa Stormwater Management Manual

Guo, J., Huang, G., Wang, X., Li, Y., & Lin, Q. (2017). Investigating future precipitation changes over China through a high-resolution regional climate model ensemble. Earth's Future, 5(3), 285-303.

Jurries, D. (2003). Biofilters for Storm Water Discharge Pollution Removal. Oregon Department of Environmental Quality, DEQ Northwest Region Document.

LaSalle, J. L. (2015). Wuhan - An Emerging World City .

Li, H., Ding, L., Ren, M., Li, C., & Wang, H. (2017). Sponge city construction in China: A survey of the challenges and opportunities. Water, 9(9), 594.

Maurer, K., Lau, S. (2000) Robust Design

Li, N., Yu, Q., Wang, J. and X. Du. (2016) The effects of low impact development practices on urban stormwater management. International Low Impact development Conference China
Pacific, G. (2018). The Test of China's Next Stage of Development: The Rise of Wuhan.

Li, Z., Dong, M., Wong, T., Wang, J., Kumar, A. J., & Singh, R. P. (2018). Objectives and Indexes for Implementation of Sponge Cities—A Case Study of Changzhou City, China. Water, 10(5), 623.

Rodin, J. (2017). Valuing the Resilience Dividend. Retrieved 20-07-2018, from https://www.rockefellerfoundation.org/blog/valuing-resilience-dividend/

SOM. (2011). WUHAN JIANG'AN RIVERFRONT BUSINESS DISTRICT. Retrieved 16-07-2018, from https://www.som.com/projects/wuhan_jiangan_riverfront_business_district

The Economist (2018) After a good run of Growth, China's economy braces for bumps Retrieved 05-09-2018, from https://www.economist.com/finance-and-economics/2018/04/17/after-a-good-run-of-growth-chinas-economy-braces-for-bumps

Van Dooren, E., Boshuizen, E., Van Merriënboer, J., Asselbergs, T., & Van Dorst, M. (2014). Making explicit in design education: generic elements in the design process. International Journal of Technology and Design Education, 24(1), 53-71.

Ven, F. v. (2016). Water management in urban areas. Delft: Faculty of Civil Engineering and Geosciences.

Virginia Department of Conservation and Recreation, (1999). Virginia Stormwater Management Handbook.

Vokskamp, L.M. and F.H.M. Van de Ven. (2014). Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events.

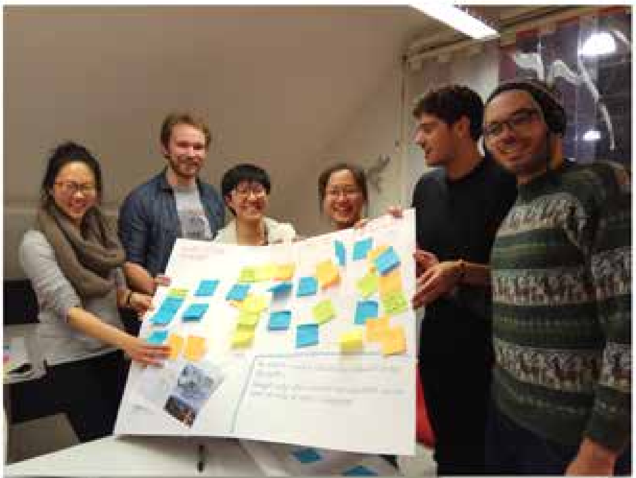
Worldometers. (2018). China population. Retrieved 10-08-2018, from www.worldometers.info/world-population/china-population/
Wu, A. (2008). Wuhan weather.

Wuhan Municipal Bureau of Water Resources and Land Resources and Planning Bureau (2015). Wuhan Sponge city planning and design guidelines.

Yang, J. (2016). Integrating Sustainable Storm Water Management and Urban Planning - A comparative case study between Sponge City in China and Climate Proof City in the Netherlands. Wageningen University.

APPENDICES

Appendix A: Interdisciplinary approach



Appendix B: ErQi urban plan from CITIC

Appendix C: Projecting Wuhan of the future

China's population is the largest in the world, with around 18,5% of the world population being Chinese. Especially in the 1970-1980s, the population increased significantly. Since then, the population growth has shrunk. Even now, with the one-child policy abolished, the population growth has been around 0,5% for the last decade. Therefore, no sudden increase in population is expected for Wuhan. However, urbanisation will be taken into account. Less and less people live on the countryside, and cities have steadily been growing. Therefore the increase of population of Wuhan will be larger than the average population growth of China.

Future rainfall projections for Wuhan

For the needed storage capacity and performance of LID measures, it is important to consider future intensity and duration of the rainfall. According to JunHong Guo (2017), the predicted amount of precipitation will increase with about 0.078 to 0.36mm/day for the coming century. [4] [5] This increase in rainfall could become more or less for Wuhan based on regional variety. The increase in rainfall will have to be taken into account for the storage capacity and maximal run-off for the implemented SCP measures.

Development in Wuhan

In the last 30 years, China has become the second largest economy in the world, mostly due to economic investment in the coastal regions and its largest urban areas (Pacific, 2018). These established mega-cities are in the maturing phase of development, which is why the Chinese are looking inland for further growth. This positions Wuhan at the forefront of a new wave of development in which China not only looks to further develop, but also restructure its economy. Because of the maturing of the Chinese economy and the relocation of scaled manufacturing in China to other developing countries which has a lower labour cost, the inland cities cannot simply copy the coastal cities plan of success. The focus now is on research and development and innovation, to build on intellectual property to develop innovative products.

For Wuhan, it means that it will have to compete with the other Chinese cities (LaSalle, 2015). Market forces now have a larger impact on city development then before, which causes the success of future development to be dependent on innovation, strong industry clusters, talent retention and the city's business environment.

Heat stress in Wuhan

For heat stress, there are two effects to take into account: the regional temperature change and the local temperature. China is the largest producer of greenhouse gases, and has been feeling its effect. The temperature change and rainfall have increased more than the global average for these factors, and as it is now will only increase further. Next to these climate changes for China as a whole, the effects of the urban area of Wuhan itself needs to be taken into account. Wuhan is densely populated, and most of the surface area has been developed. This causes heat to be trapped inside the city, which is why Wuhan is called one of the three “furnace cities along the Yangtze river”

Stimulation of sustainable and/or green development

The local government is putting a lot of effort into stimulating green behaviour in the city. Also related to the sponge city, Wuhan wants to capture 70% of all the rainwater in the city (Arcadis, 2018). In reality, the green development has run into trouble. The land price is high and the developers want to create as much revenue as possible from projects, so most usable land gets paved or built upon. Even if the design plan contains green areas, it is the question whether these will be realised. Therefore, green behaviour is stimulated, but not to an extent at which it will reduce profit.

One green solution that is used for urban planning is used rigorously in Wuhan though is the public metro, which has developed at highbreakneck speed. The first metro line in Wuhan was realized in 2004, including 10 stations. In 14 years, it has grown to 7 lines, with more lines under construction. What can be drawn from this is that if the development can bring profit and further economic growth, the city can quickly adapt to the measures.

Appendix D: Sponge City Programme criteria

Table D.1 Design rainfall corresponding to the CRTAR.

Annual runoff control rate (%)	55	60	65	70	75	80	85
Design rainfall (mm)	14.9	17.6	20.8	24.5	29.2	35.2	43.3

Table D.2 Pollutant removal rate for different LID measures

Individual facilities	Pollutant removal rate (in SS, %)
Permeable brick pavement	80-90
Permeable cement concrete	80-90
Permeable asphalt concrete	80-90
Green roof	70-80
Complex bioretention facilities	70-95
Penetrate the pond	70-80
Wet pond	50-80
Rainwater wetlands	50-80
Cisterns	80-90
Rain cans	80-90
Transfer of grass planting ditch	35-90
Dry planting grass ditch	35-90
Seepage pipe / canal	35-70
Vegetation buffer zone	50-75
Artificial soil percolation	75-95

Table D.3 Runoff coefficient values

Underlying category		Rainfall runoff coefficientφ		Flow runoff coefficientφ
		Average annual rainfall runoff coefficient φ	Average rainfall runoff coefficient φ	
Roofing	Green roof (green roof, the thickness of the matrix layer ≥ 300mm)	0.30	0.40	0.40
	Green roof (green roof, the thickness of the matrix layer < 300mm)	0.40	0.50	0.55
	Hard roof, unpaved flat roof	0.80	0.90	0.95
	Paved stone flat roof	0.60	0.70	0.80
pavement	Concrete or asphalt pavement and square	0.80	0.90	0.95
	Large stones and other paved roads and squares	0.50	0.60	0.65
	Asphalt surface treatment of gravel pavement and square	0.45	0.55	0.65
	Graded gravel pavement and plaza	0.35	0.40	0.50
	Dry masonry or gravel pavement and plaza	0.35	0.40	0.40
	Unpaved dirt road	0.25	0.30	0.35
Pavement	Non-grass-based permeable paving (Engineering permeable layer thickness ≥300mm)	0.20	0.25	0.35
	Non-grass-based permeable paving (Engineering permeable layer thickness <300mm)	0.30	0.40	0.45
	Watering grass planting grass pavement (Engineering permeable layer thickness ≥300mm)	0.06	0.08	0.15

Appendix E: Meetings with stakeholders

E.1. Questionnaire to stakeholders

1. What is your vision of your blocks? What is the main function of your block ?
2. How are blocks connected to each other?
3. Why did you divide your land-use type (commercial, residential, mixed) in this way? Why did you design this layout for each block?
4. What are the elements that make you blocks attractive to live and to work there ? What are the risks (e.g flooding) and how are these risks managed in your plan ?
5. Do you have a good overview of LID measures ?
6. How are you planning to implement the LID measures in your design? And what are the main difficulties you encounter?
7. When you apply the LID measures, what are the benefits that you see? How do you select your measures? What are your considerations (i.e construction time, cost, maintenance, operation, aesthetic) besides meeting the sponge city criteria?
8. Which measures do you think are best applicable in your blocks ?
9. Who is responsible to operate and maintain the LID measures ?
10. Which part of urban design in your area is fixed and how much flexibility do you have in adapting your design ?
11. Would it be interesting to sit together and (1) collaboratively develop a plan on where and how to implement LID measures in your blocks and(2) analyse the benefits and barriers for implementation?
12. What do you think about the AST tool?

E.2. Survey given to stakeholders (example)

In total, 9 completed surveys were collected from the stakeholders from WPDC. The survey was given in Chinese and an example can be found on the next page.

Survey with WDPC

	1	2	3	4	5	6	7	8	9	AVG	RANK
Question 1 - Important targets											
Flood	90	100	80	80	100	100	100	100	80	92,2	1
Heat stress	90	80	20	80	70	70	80	60	40	65,6	3
Biodiversity	100	20	0	40	0	0	50	80	60	38,9	4
Water quality	100	60	100	100	100	80	30	90	100	84,4	2
Drought	80	40	40	0	60	60	0	0	0	31,1	5
Question 2 - Considerations when selecting a LID											
Construction time	100	100	40	0	60	0	100	0	0	44,4	5
Construction cost	100	80	100	40	70	100	80	100	100	85,6	1
Maintenance cost	100	100	40	80	70	90	40	80	40	71,1	2
Aesthetic	100	80	40	100	80	60	20	70	80	70	3
Knowledge for maintenance	100	60	0	80	100	70	0	60	60	58,9	4
Question 3 - Preference in LID											
Wetting surface	100	N/A	0	0	0	60	20	0	20	25	9
Retention box	90	N/A	40	60	80	70	80	70	60	68,8	4
Green facade	80	N/A	80	100	0	80	60	50	60	63,8	5
Bioswales	90	N/A	80	80	90	100	100	100	100	92,5	2
Green roofs	80	N/A	60	100	70	90	100	90	70	82,5	3
Porous pavement	100	N/A	100	100	100	80	100	90	90	95	1
Water squares	100	N/A	40	60	60	70	20	60	80	61,3	6
Water roof	100	N/A	40	40	0	0	0	50	50	35	8
Green ventilation grids	100	N/A	40	80	80	60	80	40	0	60	7

E.3 Discussion summary with stakeholders

During the period in Wuhan, the team was able to meet with China International Trust Investment Corporation (CITIC) Limited and Wuhan Planning and Design Company (WPDC).

CITIC

CITIC is responsible of the north part of the core area (section in blue). Most of their buildings are connected on the second floor by the ''tree bridge". CITIC is currently designing LID measures in their area and the main difficulties they encounter in the implementation of LID are limited infiltration available in the ground and maintenance of LID measures. According to them, water can easily get polluted by the air pollution and the surrounding environment. Therefore, LID measures with water storage above ground such as wetting surface measures require more maintenance to keep it clean ''visually" and thus, more cost. Moreover, they think that implementing LID measures, especially on the ground may increase subsidence in the surrounding built areas.The aesthetic is an important parameter in their selection of measures. As an example, they mentioned that in Wuhan 3 types of trees are commonly used for landscape design because they are perennial trees which has an aesthetic value even during winter time. Heat stress has not been mentioned as a problem during the discussion.

WPDC

WPDC is mainly involved in the planning and design of roads and they are involved in the consultation and evaluation of the SCP.

The SCPpromotes the use of Public-Private-Partnership for the long-term investment of the SCP, however, it seems to bring little interest from other parties. Moreover, investment for the implementation of the SCPis very low and therefore there is little incentive for the designers to add more value to the LID measures. For high-end area, people may be more willing to pay for the maintenance cost than in the middle and low class areas. The cost of maintenance is usually included in the cost of the rent.

The evaluation phase of the SCPis usually performed by the government or an external party and it is based on the urban design plan they received. There is no regulation yet on the maintenance and the long-term performance of the implemented LID measures. Therefore, there is little interest in ensuring the maintenance of LID measures. Due to the lack of maintenance, urban green landscape usually last for one or two years before it loses its primary functionality such as retaining, delaying and draining stormwater. Some people may use fake plants to increase the aesthetic of the landscape to lower the maintenance cost.

Another problem for the implementation of integrated LID measures in the area is the time constraint. Designers have strict deadline to follow to deliver a Sponge City urban plan. Since the implementation of SCPused a top-down approach, in which the government takes the main decisions, the development occurs efficiently and very fast. However, one of the disadvantages is that there is little dialogue between the government and other stakeholders, therefore there is not much room for discussion and adaptation of the Sponge City Programme of the actual situation.

Appendix F: Selection of LID measures

F.1 Description of LID measures

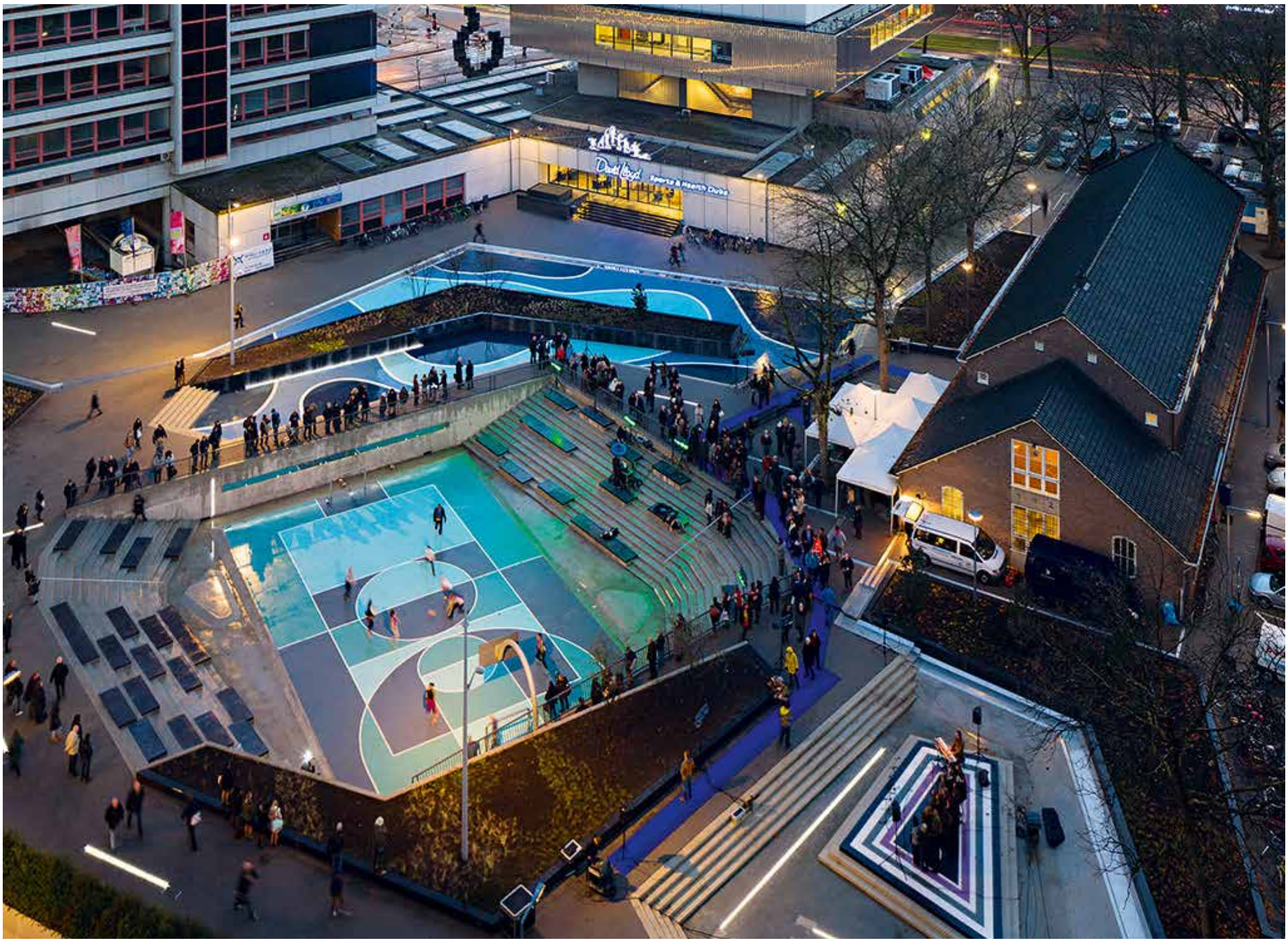
F.1.1 Ponds

A wet pond can function as a retention basin for stormwater, where it is collected and detained. Plants are usually planted at the edge of the pond in order to prove the water quality and for aesthetics. It is also possible to use a dry pond. These are excavated areas that are designed to detain a prescribed amount of water before reaching an overflow elevation at which the pond will spill to a specified outfall location. The benefit for this is that the space for the pond can be used for different activities during dry periods.

F.1.2 Fountains

Fountains can serve as measures to reduce the heat stress in an area by cooling the surroundings due to the evaporation of water. They also provide other social and environmental benefits, such as a means for entertainment or as centerpiece for a design. A water fountain does not contribute to the water storage capacity of the area though. A different option than a fountain is to install a wetting surface. A wetting surface exists of a road, wall, roof or garden which is made wet using a sprinkler system. It cools the surrounding area in the same way as a fountain. Also a waterfall is one of the possibilities.

F.1.3 Water circulation systems
A water circulation system uses pumps to create movement between existing water bodies by pumping the water to one of the water bodies and letting it flow back to the first water body. This prevents stagnant water in these water bodies and increases the water quality. This is especially beneficial in China as urban water bodies are often stagnant water and therefore not very attractive. Although this method improves the water quality, it does not remove pollutants from the water bodies.



F.1.4. Water squares
Water squares are public plazas which catch the storm water during rain events. One of the major benefits of the water square is that it shows the multi-functionality with which these blue-green measures can be implemented. The water square can be designed as such to illustrate its function

of managing water. Depending on the weather conditions the water square is either filled or empty. One of the disadvantages of the water square is that it requires regular maintenance, or it will quickly lose its function as a water retention basin.

F.1.5 Green roofs
A green roof is a multi-layered roof system that is partially or entirely covered with vegetation, which retains the storm water before it flows down to the sewers. Two types of green roofs can be discerned, which are the intensive and extensive green roofs. An intensive green roof is thicker then 15cm, and can support a wide variety of plants and retain more water. However, it is heavier and requires more maintenance then an extensive green roof. Contrary, the extensive roof is thinner than 15cm, can only support specific plants and has less storage, but is less heavy and requires less maintenance. It is also possible to add a drainage delay to the green roof. This causes a constant flux in the green roof once the lower impermeable layer is saturated which spreads the flow downwards over time. This is better than a regular green roof, as these discharge constantly once the storage capacity is reached.

D.1.6 Green façades
A green façade, or living wall is a vertical surface that is partially or entirely covered by vegetation. This systems often include their own irrigation to irrigate the façade during dry periods and a growth medium to provide the vegetation with sufficient nutrients. These living walls have a cooling effect on the area they are in, due to the cooling effect of evapotranspiration of vegetation. They also improve the air quality in the city. However, the green façade doesn't increase the storage capacity of the district.

F.1.7 Water roof
A water roof is basically a roof designed to store water, specifically rainfall water. This type of roof can have multiple functions. Primarily the water roof serves as a temporary storage unit for water, mitigating the runoff effect in the area and providing possibilities for the reuse of the water it stores. It can also serve as a recreational area, as the roof cools the direct surroundings. Blue roofs can be open water surface areas or stored in or beneath a porous media. One of the disadvantages is that a blue roof requires a structurally strong roof to support the structure, and it is in most cases not possible to refit an existing roof with a water roof as they are not designed to support this weight.

F.1.8. Adding vegetation in streetscape
Grasses, shrubbery or trees can be added to the streets to serve a multitude of functions. It improves the aesthetics of the street, provides environmental benefits, improves the air quality and reduces the heat stress in the street. If infiltration is possible, it also reduces the run-off in the area.

F.1.9 Constructing a urban park or urban forest

Constructing a park in the city is an often used method to increase the appeal of the district, as it is useful for multiple reasons. It creates a shadowy area where you can hide from the sun which provides ventilation to the city, therefore combating heat stress. Furthermore the soil, ditches and waterbodies in the park can store storm water, therefore acting as a giant storage basin. This serves to reduce the flooding probability. Finally it also improves the aesthetics and provides space for activities, and in this way improves the value of the property.

F.1.10. Green ventilation grids
One of the main causes of urban heat stress is that there is not enough ventilation in the city, which causes the heat to remain in the city. To increase the ventilation, green ventila-

tion grids can be implemented. These are continuous green stretches through the city, which allow the wind to flow through the city. This delivers cooler air from the surrounding area into the city, and so decreasing the temperature.

F.1.11 Tree/bioretention cell
Two types of cells can be implemented. The first is the tree cell, or suspended pavement. This measures consists of a cell under permeable pavement which provides space for lightly compacted, highly nutritious soil to support trees on the side of the road. This also provides extra stormwater detention in the cells, as the lightly compacted soils have a high porosity. They also provide possibilities for infiltration, if the surroundings allow for infiltration. The second type of cell measures is the bioretention cells. Bioretention cells are more diverse in their types of vegetation, as it also contains grass and shrubbery. They are also typically larger in size than the tree cells. Bioretention cells are storm water features that collect, detain and filter the storm water as it infiltrates down into the retention cell. They typically feature both above and below ground storage of water.

F.1.12 Bioswale
A bioswale is a green landscape element designed to store stormwater to reduce the peak runoff. In addition, the bioswale removes large particles from the water and reduces the pollution of the water. They consist of a low ditch with gentle slopes to the street level, and contains various types of vegetation. If there is space available, they can be designed to have the longest water course to the drainage to increase the retention time. The bioswale also provides opportunities for infiltration, if the subsoil allows it.

F.1.13 Underground storage blocks
The underground storage blocks are modular blocks often constructed under parking lots or other large open paved areas to store rainwater and let it infiltrate into the ground. The blocks have a drainage system connected to the sewer in case the volume of water exceeds the capacity. Since there is little option for infiltration The underground blocks will primarily be used for storage of stormwater.

F.1.14 Constructing ditches
A ditch is a moderate depression in the ground through which water can be channelled. This can be used to store the water and to carry the water downstream from low lying areas, alongside roads and alongside fields. A trench could also be used, which is basically a narrow form of a ditch. They are most typically used in areas that have required drainage like low-lying areas, so it is not very suitable for the high areas in our core district.

F.1.15. Improve soil infiltration capacity
The upper soil layer present at the Er Qi project area is clay, which has a very low permeability. To improve the infiltration into the ground the soil could be dug away and replaced by a different soil type from somewhere else. The problem is that this upper soil layer is only 1m deep, so the wa-

ter will not infiltrate to the groundwater table. Therefore the placement of drainage systems would still be necessary.

F.1.16 Surface drains

Surface drains are placed to collect and convey runoff from rainwater to inlets, storm sewer drain lines and ditches or canals. It is a collective term for structures such as street gutters, catch basins and curb inlets. Depending on how the surface drains are designed they can also provide storage and infiltration capacity.

F.1.17. Porous pavement

Porous pavement is one of the measures the Chinese government has made into a requirement, and is therefore commonly used in Chinese urban planning. This measure allows water to filter through the pavement and infiltrate into the subsoil. However, this measure is hard to implement in Wuhan, due to clay subsoil and the large amount of underground structures. To effectively implement porous pavement in Wuhan the subsoil should be replaced with a more permeable soil and drainage pipes need to be installed below to drain the water.

F.2 Multi-Criteria Analysis

F.2.1 Determination of factors criteria

factors	policy	legislation	implementation capacity	maintenance	performance	financing	final scores
policy	x	1	4	2	3	1	11
legislation	5	x	4	5	4	4	22
implementation capacity	2	2	x	2	4	1	11
maintenance	4	1	4	x	4	1	14
performance	3	2	2	2	x	1	10
investment costs	5	2	5	5	5	x	22

F.2.2 MCA results road

Table F.2.2.1investment cost

	investment costs	normalized
bioswale	7	0,889240506
surface drains	2	0,96835443
Ditch or infiltration-strip	1	0,984177215
Tree pit bioretention	63,2	0
adding green in streetscape	1,5	0,976265823
Shallow infiltration measures, boxes (sand	40	0,367088608
ventilation grid	0	1

Table F.2.2.2 maintenance costs

costs of these measures	k€ per 100m2 per year	normalized
bioswale	0,06	0,9905063291
surface drains	0,04	0,9936708861
Ditch or infiltration-strip	0,05	0,9920886081
Tree pit bioretention	6,32	0
adding green in streetscape	0,3	0,9525316461
Shallow infiltration measures, boxes (sand)	6	0,5673208581
ventilation grid	0	1

Table F.2.2.3 policy

policy	order	score
bioswale	1	0,833333
surface drains	2	0,666667
Ditch or infiltration-strip	3	0,5
Tree pit bioretention	5	0,166667
adding green in streetscape	4	0,333333
Shallow infiltration measures, boxes (sand)	1	0,833333
ventilation grid	6	0

Table F.2.2.4 regulation

regulation	order	score
bioswale	1	0,8
surface drains	2	0,6
Ditch or infiltration-strip	2	0,6
Tree pit bioretention	4	0,2
adding green in streetscape	3	0,4
Shallow infiltration measures, boxes (sand)	1	0,8
ventilation grid	5	0

Table F.2.2.5 implementation

implementation	order	score
bioswale	5	0,166667
surface drains	2	0,666667
Ditch or infiltration-strip	3	0,5
Tree pit bioretention	6	0
adding green in streetscape	4	0,333333
Shallow infiltration measures, boxes (sand)	6	0
ventilation grid	1	0,833333

Table F.2.2.6 performance

performance	order	score
bioswale	3	0,5
surface drains	4	0,333333
Ditch or infiltration-strip	2	0,666667
Tree pit bioretention	1	0,833333
adding green in streetscape	6	0
Shallow infiltration measures, boxes (sand)	1	0,833333
ventilation grid	5	0,166667

final score, determined by multiplying the score of the measure for the criteria with the factor for the criteria

Table F.2.2.7 Final score

	investment costs	maintenance	policy	regulation	implementation	performance	total sum
bioswale	19,56329114	13,86708861	9,166667	17,6	1,833333333	5	67,03038
surface drains	21,30379747	13,91139241	7,333333	13,2	7,333333333	3,333333333	66,41519
Ditch or infiltration-strip	21,65189873	13,88924051	5,5	13,2	5,5	6,666666667	66,40781
Tree pit bioretention	0	0	1,833333	4,4	0	8,333333333	14,56667
adding green in streetscape	21,4778481	13,33544304	3,666667	8,8	3,666666667	0	50,94662
Shallow infiltration measures	8,075949367	7,942492013	9,166667	17,6	0	8,333333333	51,11844
ventilation grid	22	14	0	0	9,166666667	1,666666667	46,83333

F.2.3 MCA results commerce/culture

Table F.2.3.1 investment costs

	investment costs (k€ per 100 m2)	normalized
Green roofs with drainage delay	7,5	0,625
Water roof	5	0,75
Park or urban forest	0,1	0,995
Green ventilation grids	0	1
Cooling with water elements: ponds	4	0,8
Cooling with water elements: fountains	10	0,5
Water squares	20	0
bioswale	7	0,65

Table F.2.3.2 maintenance costs

	maintenance costs (k€ per 100 m2)	normalized
Green roofs with drainage delay	0,5	0,75
Water roof	0,05	0,975
Park or urban forest	0,00625	0,996875
Green ventilation grids	0	1
Cooling with water elements: ponds	0,03	0,985
Cooling with water elements: fountains	1	0,5
Water squares	2	0
bioswale	0,06	0,97

Table F.2.3.3 policy

policy	order	score
Green roofs with drainage delay	1	0,875
Water roof	2	0,75
Park or urban forest	3	0,625
Green ventilation grids	6	0,25
Cooling with water elements: ponds	4	0,5
Cooling with water elements: fountains	5	0,375
Water squares	7	0,125
bioswale	1	0,875

Table F.2.3.4 regulation

regulation	order	score
Green roofs with drainage delay	1	0,875
Water roof	2	0,75
Park or urban forest	3	0,625
Green ventilation grids	6	0,25
Cooling with water elements: ponds	4	0,5
Cooling with water elements: fountains	5	0,375
Water squares	7	0,125
bioswale	1	0,875

Table F.2.3.5 implementation

implementation	order	score
Green roofs with drainage delay	5	0,375
Water roof	4	0,5
Park or urban forest	2	0,75
Green ventilation grids	1	0,875
Cooling with water elements: ponds	3	0,625
Cooling with water elements: fountains	7	0,125
Water squares	8	0
bioswale	6	0,25

Table F.2.3.6 performance

performance	order	score
Green roofs with drainage delay	7	0,125
Water roof	6	0,25
Park or urban forest	1	0,875
Green ventilation grids	5	0,375
Cooling with water elements: ponds	2	0,75
Cooling with water elements: fountains	8	0
Water squares	3	0,625
bioswale	4	0,5

Table F.2.3.7 final score

	investment	maintenance	policy	regulation	implementation	performance	total
Green roofs with drainage delay	13,75	10,5	9,625	19,25	4,125	1,25	44,75
Water roof	16,5	13,65	8,25	16,5	5,5	2,5	46,4
Park or urban forest	21,89	13,95625	6,875	13,75	8,25	8,75	51,58125
Green ventilation grids	22	14	2,75	5,5	9,625	3,75	35,625
Cooling with water elements: ponds	17,6	13,79	5,5	11	6,875	7,5	44,665
Cooling with water elements: fountains	11	7	4,125	8,25	1,375	0	20,75
Water squares	0	0	1,375	2,75	0	6,25	10,375
bioswale	14,3	13,58	9,625	19,25	2,75	5	50,205

F.2.4. MCA results housing

Table F.2.4.1 investment costs

	investment costs	normalized
adding green in streetscape	1,5	0,976265823
private green garden	6	0,905063291
Shallow infiltration measures, boxes (sand)	40	0,367088608
Green roofs with drainage delay	7,5	0,881329114
Water roof	5	0,920886076
Green facades	18	0,715189873
Green ventilation grids	0	1
Tree pit bioretention	63,2	0

Table F.2.4.2 maintenance costs

	maintenance costs (k€ per 100 m2)	normalized
adding green in streetscape	0,3	0,9525316
private green garden	0,06	0,9905063
Shallow infiltration measures, boxes (sand	6	0,0506329
Green roofs with drainage delay	0,5	0,9208861
Water roof	0,05	0,9920886
Green facades	1,7	0,7310127
Green ventilation grids	0	1
Tree pit bioretention	6,32	0

Table F.2.4.3 policy

policy	rank	score
adding green in streetscape	3	0,625
private green garden	2	0,75
Shallow infiltration measures, boxes (san	1	0,875
Green roofs with drainage delay	1	0,875
Water roof	4	0,5
Green facades	6	0,25
Green ventilation grids	6	0,25
Tree pit bioretention	5	0,375

Table F.2.4.4 regulation

regulation	rank	score
adding green in streetscape	1	0,875
private green garden	4	0,5
Shallow infiltration measures, boxes (san	1	0,875
Green roofs with drainage delay	1	0,875
Water roof	2	0,75
Green facades	6	0,25
Green ventilation grids	7	0,125
Tree pit bioretention	5	0,375

Table F.2.4.5 implementation

implementation	rank	score
adding green in streetscape	2	0,75
private green garden	3	0,625
Shallow infiltration measures, boxes (san	7	0,125
Green roofs with drainage delay	5	0,375
Water roof	4	0,5
Green facades	6	0,25
Green ventilation grids	1	0,875
Tree pit bioretention	8	0

Table F.2.4.6 performance

performance	rank	score
adding green in streetscape	5	0,375
private green garden	4	0,5
Shallow infiltration measures, boxes (san	1	0,875
Green roofs with drainage delay	3	0,625
Water roof	2	0,75
Green facades	7	0,125
Green ventilation grids	6	0,25
Tree pit bioretention	1	0,875

Table F.2.4.7 final score

measures	investment costs	maintenance c	policy	regulation	implementation	performance	total score
adding green in streetscape	21,4778481	13,33544304	6,875	19,25	8,25	3,75	72,93829
private green garden	19,91139241	13,86708861	8,25	11	6,875	5	64,90348
Shallow infiltration measures	8,075949367	0,708860759	9,625	19,25	1,375	8,75	47,78481
Green roofs with drainage delay	19,38924051	12,89240506	9,625	19,25	4,125	6,25	71,53165
Water roof	20,25949367	13,88924051	5,5	16,5	5,5	7,5	69,14873
Green facades	15,73417722	10,23417722	2,75	5,5	2,75	1,25	38,21835
Green ventilation grids	22	14	2,75	2,75	9,625	2,5	53,625
Tree pit bioretention	0	0	4,125	8,25	0	8,75	21,125

F.3 Other recommendation LID measures on bridge

F.1 Green garden on bridge

The width of our bridge is 4-6 meters and it is wide enough to become multi-purpose and hold more LID measures. Green garden is a good example to be an enjoyable place for citizens. A case study can be found in Providence pedestrian bridge designed by inForm. This bridge has a board-walk which includes gardens, spaces for sculptures, a sun-deck, outdoor seating and even a built in cafe. This inspires us that we can also put green garden element in our design and turn it to a recreational place.

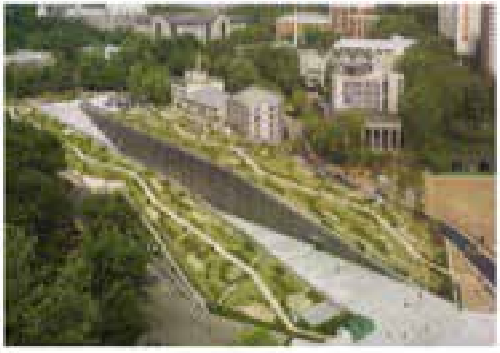
F.2 Green facade on bridge

It is recommended that in some sections of the bridge, green facade can be designed on both sides of the bridge wall. A case study from Mountains & Trees, Waves & Pebbles Project (Guildford Town Center Surrey, British Columbia, Canada) shows a good example that how green facade is implemented in a bridge. This project plants hundreds of plant species on the wall and also emphasizes the beauty pattern. In our bridge, the green facade can be designed on the section across the road, where carbon dioxide on road is absorbed.

Since we transport part of water from bridge to the park, ponds which hold bridge columns are good components that receive water from bridge and store it temporarily. Water can flow to the pond either from insider of the column or from outsider of the column and generates wetting surface meanwhile. The demonstration is shown below.

Appendix G Inspiration case study references for the detailed design

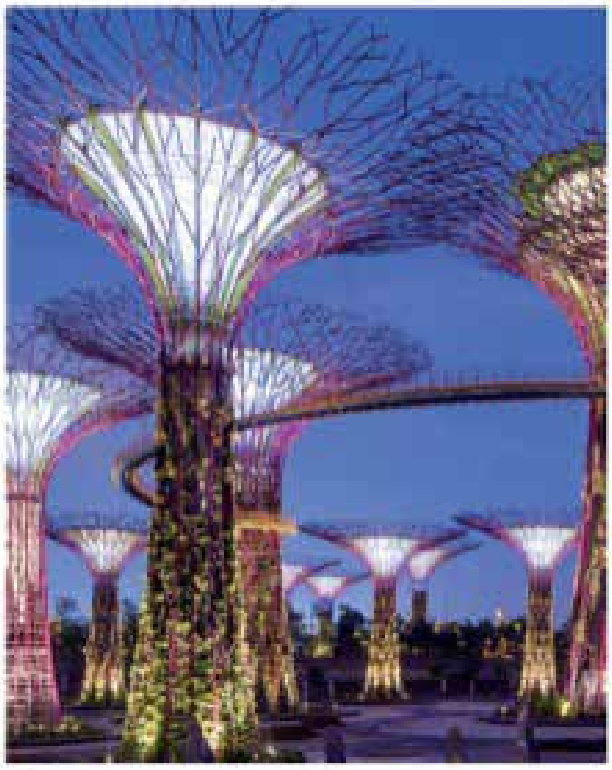
G.1. EWHA Women's University - Seoul, South-Korea



- Dealing with a complex area where the demand of increasing function (like this University) is needed
- Fitting most of the functions under the ground, providing more accessible space on the ground floor.
- Bringing together the different levels of the site.
- Encourages the use of energy efficieny and use of buffer green on the 'roof'
- A new topography which impacts the surrounding landscape in a number of ways

"How to deal with an enourmous amount of new functions that needs to be fitted in the area, while encouragingnew ways of energy efficiency and green measures?"

G.2. Gardens by The Bay - Singapore



- Landmark trees that play a vital role in the garden of Singapore; They act as air exhaust for the two conservatories, as solar panels, but also as chimney stack to repel non-toxic fumes.

- These landmarks enabled special plant species to grow over time, becoming the vertical garden with over 160,000 plant and flower types

"How can the stimulation of green use and energy efficient solutions contribute to the health of the city? "

- The fusion of nature, art and technology, making the supertrees the landmarks of Singapore in just very short period.

G.2. Station Sloterdijk - Amsterdam, The Netherlands

"How to solve the water flooding problem while improving the livability of the (exisiting) area?"

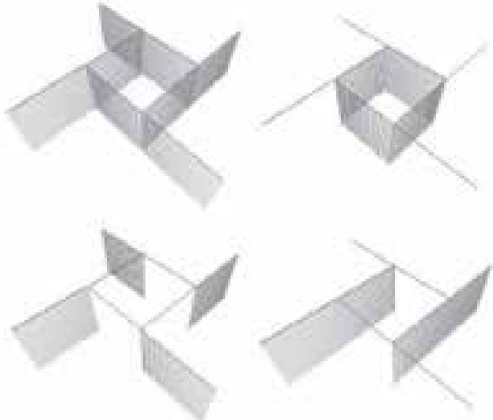
- Transformation from 8000m2 concrete mass to more green and livable area
- By using natural vegetations, the water problems in that area were solved
- 5cm raised integrated infiltration rats providing enough water for temporary storage and drainage of water
- Different use of plants providing enough greenery during every season
- Possible to transform the area without removing the existing construction
- Only possible when the area can handle it socially and spatially

G.3. Kaohsiung Station - Kaohsiung, China

"How to create a green connection between different functions while protecting the people from the tropical heat?"

- Will act as a green connector unifying different modes of transportation and represent Kaohsiung's vision for its future as a sustainable city.
- With different levels integrated, made possible to connect a hotel, commercial buildings, shops, restaurants, and other facilities.
- The sprawling landscaped canopy protects the open public plaza underneath from Kaohsiung's tropical climate like large trees would do.

G.4. Water Pavilion- Zaragoza, Spain



"How to provide shade and shelter for tropical climates in city, while implementing blue measures "

- Use of water as an architectural element by combining this with technology available
- A space that is interactive and reconfigurable in that each wall can potentially become an entrance or exit, while the internal partitions can shift depending on the number of people present.
- Leisure element in the city, while coping with excess water in the city
- Providing shade / shelter for its tropical climate

G.5. Boston Greenway - Boston, USA

"How to deal with major traffic in the city by implementing more green measures in the area, while increasing the livability in the area?"

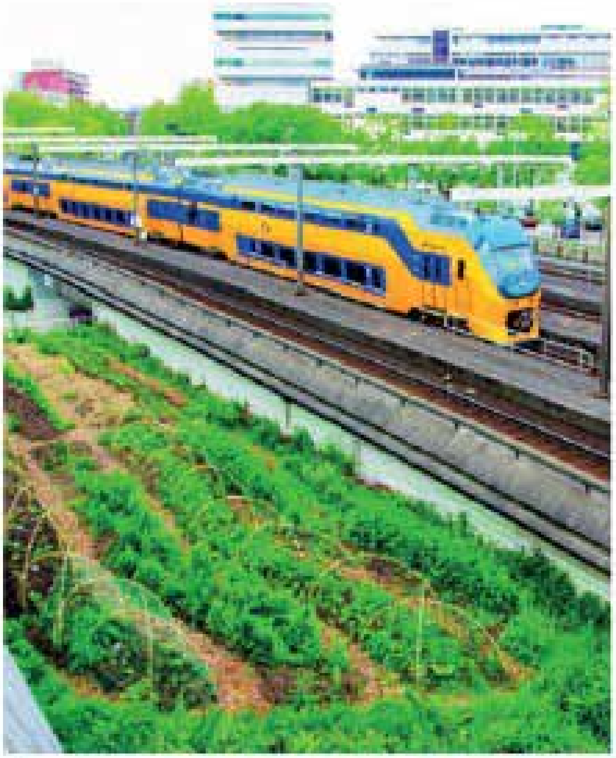
- A massive road infrastructure project which was undertaken to improve the flow of traffic, by putting the existing highway underground
- With the improvements and delay reductions, total vehicle hours on project highways dropped 62 percent from 1995 to 2003.
- Putting the highway under the ground, improved the quality of life in the city beyond the limited confines of the new expressway.
- Clay and dirt from the project were used for local landuse
- The big dig includes miles of new and refurbished sidewalks, close to 900

G.6. Place de la République - Paris, France

- Former stone square, (which was surrounded by traffic) transformed into an urban garden with dense vegetation
- This measure showed an increase of 50% by local people and tourists
- The design of the green ventilation also ensures that sunlight reaches the pedestrian routes
- Initial phase of designing in co-operation with the local people to discuss ideas

"How to avoid the heat island effect while increasing the maximum ventilation and cooling in summer?"

G.7. Water sensitive project - Rotterdam, The Netherlands



"How can a continuous growing city deal with high amount of rainfall, river drainage and rising water level?"

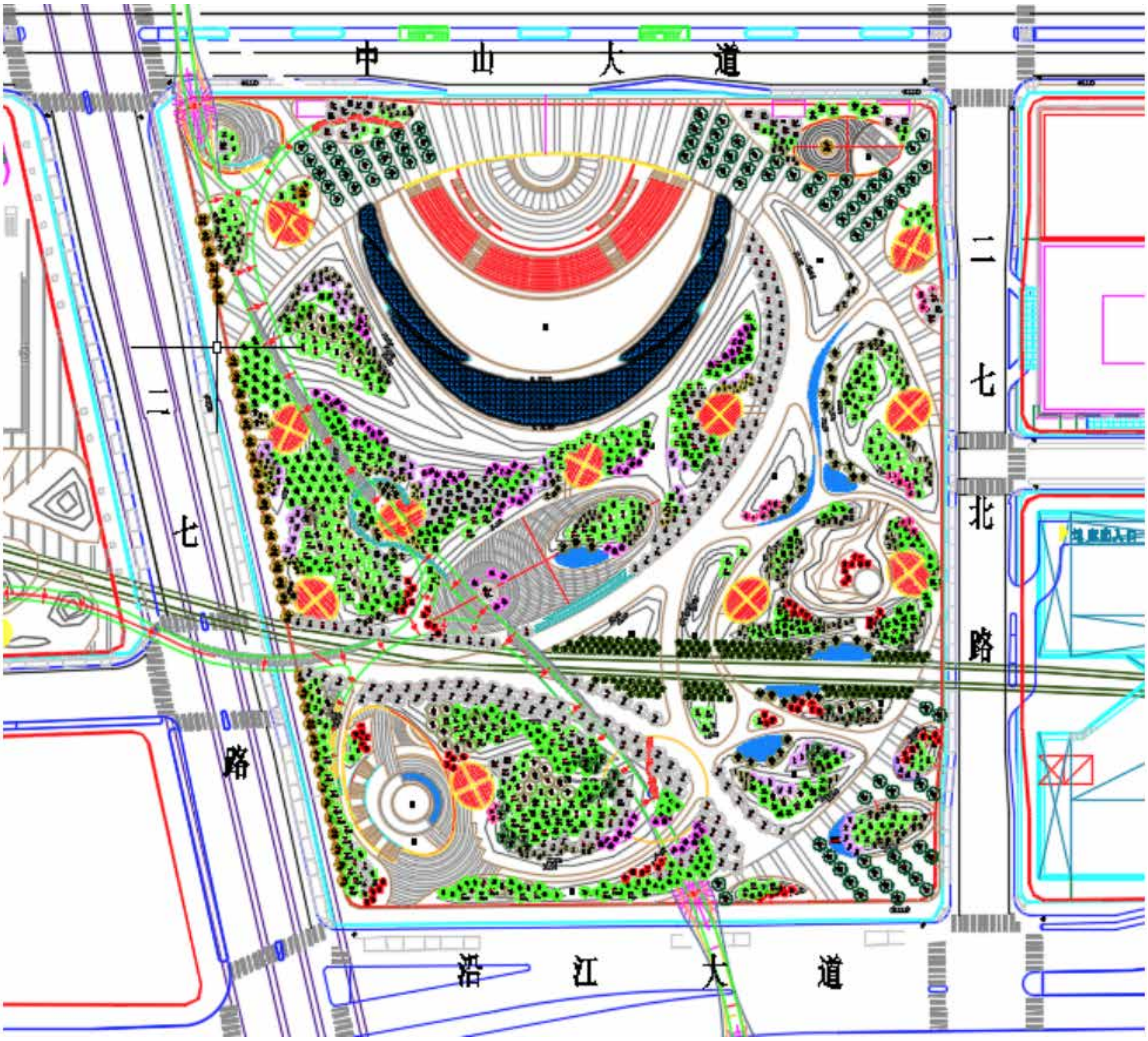
- Last 10 years, different sustainability-programs were initiated to provide the city with various measurments against urban heat and flooding
- Many water squares, green roofs (200.000m2), rooftop parks were initiated, providing more green and more storage for water.
- Rainwater is a valuable resource which should be used locally whenever possible. Visible water drainage results in more awareness and assurance in the long run
- Despite the fact that every growing city has their limits of working in a climate resilient environment, (because of costs and other priorities), it remains necessary that society as a whole appreciates this urgency of

Appendix H: Water Road calculation

H.1. Storage capacity, T=1 year storm

time (seconds)	total rainfall (mm)	total rainfall over total area (m3)	infiltration rate (mm/h)	total infiltration (m3)	total volume of water present (m3)	water height bioswale (m)	weir discharge (m3/s)	new volume left (m3)	new water height (m)
300	4,217066667	1255,694856	196,7434357	90,09209827	1165,602758	0,132575382	0	1165,602758	0,132575382
600	4,318841667	1285,999889	146,6321967	67,14532676	2384,45732	0,271207611	0	3550,060078	0,403782993
900	4,4316725	1319,596962	111,1423974	50,89395613	3653,160326	0,415509591	0	3819,665431	0,434447842
1200	4,557864167	1357,172424	86,00779912	39,38440468	5137,45345	0,58433274	0	5137,45345	0,58433274
1500	4,70048	1399,638427	68,20696505	31,23310608	6505,858771	0,739974837	161,6339555	6344,224815	0,72159063
1800	4,863699167	1448,239382	55,60005206	25,46019051	7767,004007	0,883417198	465,6900343	7301,313973	0,830449724
2100	5,053415833	1504,730366	46,67157969	21,3716942	8784,672644	0,999166588	778,3750679	8006,297576	0,910634392
2400	5,278285	1571,688533	40,34825383	18,4761379	9559,509971	1,087296403	1049,898829	8509,611142	0,967881158
2700	5,5516925	1653,099717	35,86994575	16,42544599	10146,28541	1,154036103	1272,813408	8873,472005	1,009266607
3000	5,895796667	1755,561894	32,69831682	14,97310424	10614,0608	1,207240764	1460,491455	9153,56934	1,041124811
3300	6,350943333	1891,088642	30,45210466	13,94452626	11030,71346	1,254630739	1634,753345	9395,96011	1,06869428
3600	7,001848333	2084,905369	28,86129149	13,21606639	11467,64941	1,304327731	1824,399	9643,250413	1,096821021
3900	8,07577	2404,681654	27,73464522	12,70015629	12035,23191	1,36888443	2080,890576	9954,341334	1,132204428
4200	10,68034167	3180,231936	26,93673141	12,33477826	13122,23849	1,492520302	2602,464409	10519,77408	1,196516615
4500	18,3176	5454,340164	26,3716326	12,0760101	15962,03824	1,815518453	4136,185215	11825,85302	1,345069725
4800	10,73414167	3196,251693	25,97141813	11,89274522	15010,21197	1,707257958	3596,092541	11414,11943	1,298239244
5100	8,711358333	2593,937614	25,68797809	11,7629533	13996,29409	1,591935179	3049,17663	10947,11746	1,24512255
5400	7,700195833	2292,848812	25,48724009	11,67103202	13228,29524	1,504583171	2655,402742	10572,8925	1,202558292
5700	7,04936	2099,05268	25,34507335	11,6059315	12660,33925	1,439983991	2376,096951	10284,2423	1,169727286
6000	6,580011667	1959,297174	25,24438797	11,55982599	12231,97964	1,391262471	2172,393504	10059,58614	1,144174948
6300	6,218380833	1851,616169	25,17308053	11,52717313	11899,67514	1,353466235	2018,614256	9881,060881	1,123869527
6600	5,927323333	1764,949432	25,12257916	11,5040477	11634,50627	1,32330599	1898,631737	9735,874528	1,107356066
6900	5,685689167	1692,999235	25,08681305	11,48766981	11417,38609	1,298610793	1802,231516	9615,154577	1,093625407
7200	5,480378333	1631,864854	25,06148277	11,47607065	11235,54336	1,277928044	1722,79278	9512,750581	1,081978001
7500	5,302756667	1578,975339	25,04354335	11,46785589	11080,25806	1,260265931	1655,907131	9424,350933	1,071923445
7800	5,146858333	1532,554272	25,03083829	11,46203803	10945,44317	1,244932116	1598,558927	9346,884239	1,063112402
8100	5,008401667	1491,326722	25,0218403	11,45791771	10826,75304	1,23143233	1548,630702	9278,122342	1,05529144
8400	4,884220833	1454,350016	25,01546775	11,45499961	10721,01736	1,219405978	1504,598873	9216,418485	1,048273258
8700	4,771911667	1420,908277	25,01095457	11,45293295	10625,87383	1,208584376	1465,341471	9160,532358	1,041916783
9000	4,669611667	1390,446918	25,00775825	11,4514693	10539,52781	1,198763399	1430,014732	9109,513075	1,036113862
9300	4,575850833	1362,528223	25,00549455	11,45043271	10460,59087	1,18978513	1397,971675	9062,619191	1,030780163
9600	4,489449167	1336,800831	25,00389135	11,44969858	10387,97032	1,181525287	1368,707194	9019,26313	1,025848855
9900	4,409446667	1312,978887	25,00275594	11,44917866	10320,79284	1,173884536	1341,820512	8978,972325	1,021266188
10200	4,335054167	1290,827404	25,00195181	11,44881043	10258,35092	1,166782407	1316,989113	8941,361806	1,016988376
10500	4,265614167	1270,150602	25,00138231	11,44854965	10200,06386	1,16015285	1293,949922	8906,113937	1,012979292
10800	4,200574167	1250,783967	25,00097898	11,44836496	10145,44954	1,15394103	1272,485802	8872,963737	1,009208796
				681,6566999			55954,00401		

Appendix I: Current park design



Appendix J. Design Assessment

J.1 LID parameters

Table A) Parameters of green roof
Table B) Parameters of Pervious pavement
Table C) Parameters of Pond
Table D) Parameters of Walking street

A)		B)		C)		D)	
Actual LID type	Green roof	Actual LID type	Pervious Pavement	Actual LID type	Pond	Actual LID type	Walking street
Generalized LID type	Bio-Retention Cell	Generalized LID type	Permeable Pavement	Generalized LID type	Rain Barrel	Generalized LID type	Rain Barrel
Surface Berm Height (mm)	30	Surface Berm Height (mm)	0	Storage-Barrel Height (mm)	300	Storage-Barrel Height (mm)	350
Vegetation Volume Fraction	0.2	Vegetation Volume Fraction	0	Drain Flow Coef.	54000	Drain Flow Coef.	54000
Surface Roughness (Mannings n)	0.15	Surface Roughness (Mannings n)	0.015	Drain Flow Exponent	0	Drain Flow Exponent	0
Surface Slope (percent)	1	Surface Slope (percent)	1	Offset Height	250	Offset Height	300
Soil Thickness (mm)	50	Soil Thickness (mm)	45	Drain Delay (hours)	6	Drain Delay (hours)	6
Soil Porosity	0.437	Soil Porosity	0.33				
Field Capacity	0.062	Field Capacity	0.062				
Wilting Point	0.024	Wilting Point	0.024				
Conductivity	120	Conductivity	194				
Conductivity Slope	45	Conductivity Slope	45				

(Continuation previous table)

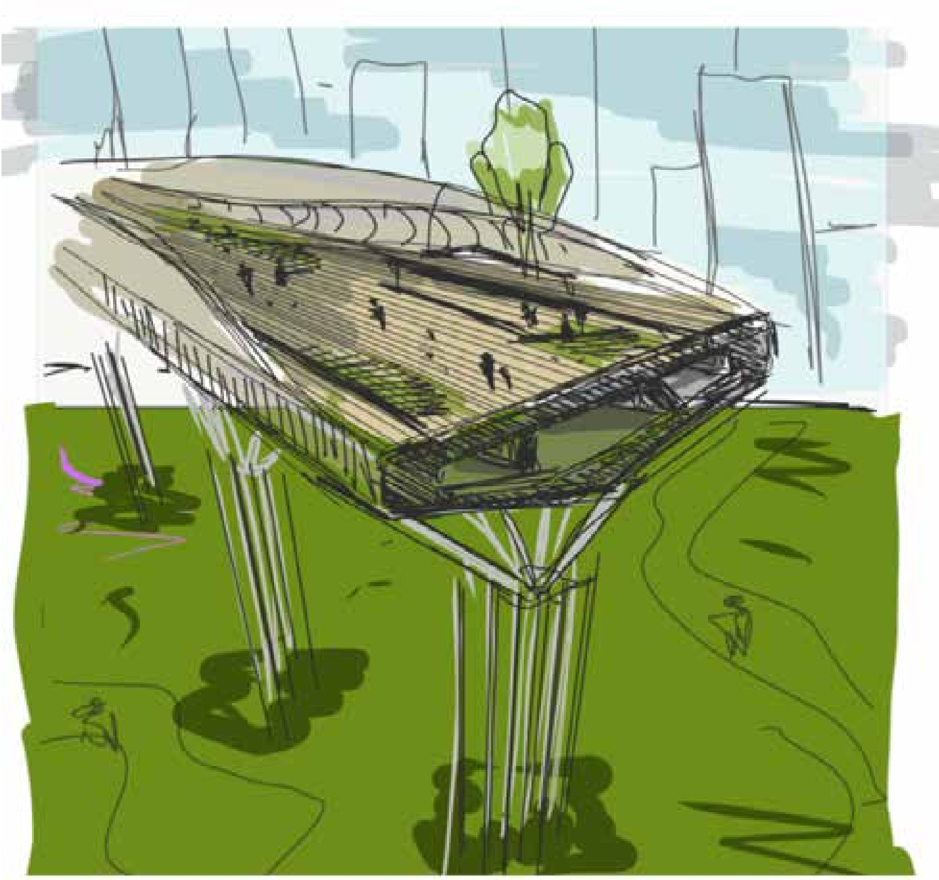
A)		B)		C)		D)	
Suction Head (mm)	49	Suction Head (mm)	49				
Storage Thickness (mm)	0.01	Pavement Thickness (mm)	80				
Void Ratio	0.8	Pavement Void Ratio	0.17				
Seepage Rate	0	Impervious Surface Fraction	0				
Clogging Factor	0	Permeability (mm)	194				
Drain Flow Coefficient	54000	Clogging Factor	0				
Drain Flow Exponent	0	Storage Thickness (mm)	675				
Offset Height	0	Storage Void Ratio	0.99				
		Seepage Rate	0				
		Clogging Factor	0				
		Drain Flow	54000				
		Coefficient					
		Drain Flow Exponent	0				
		Offset Height	450				

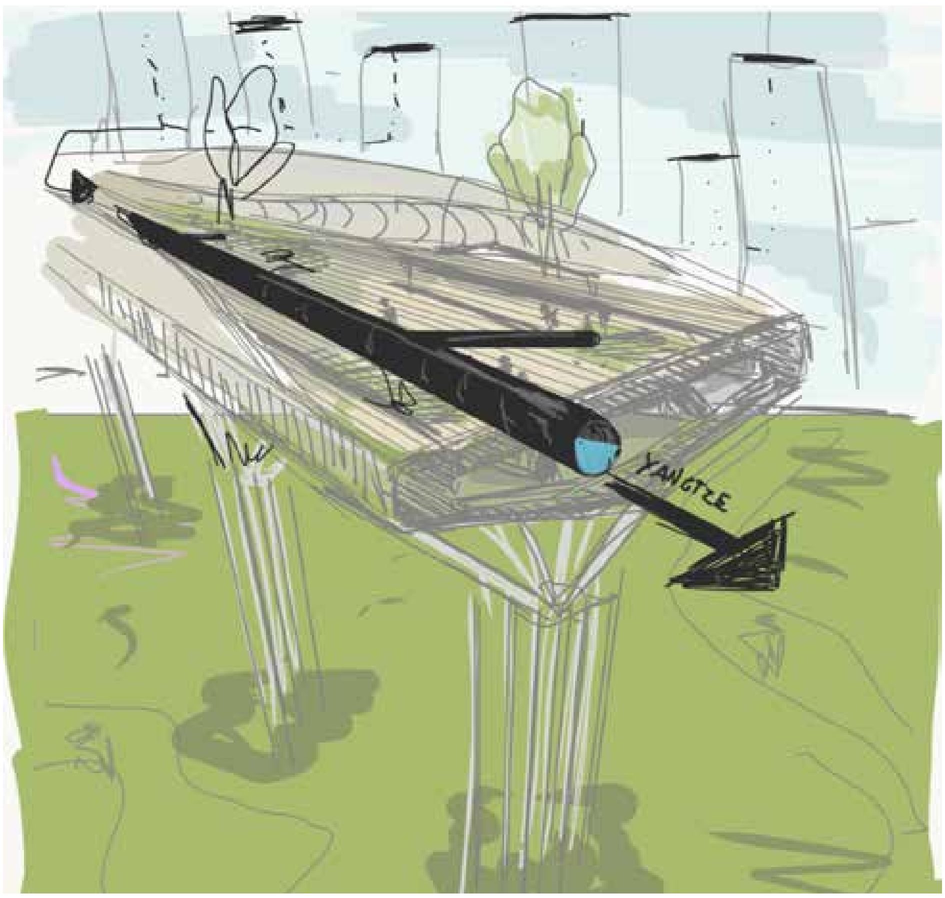
J.2 Rainfall Data

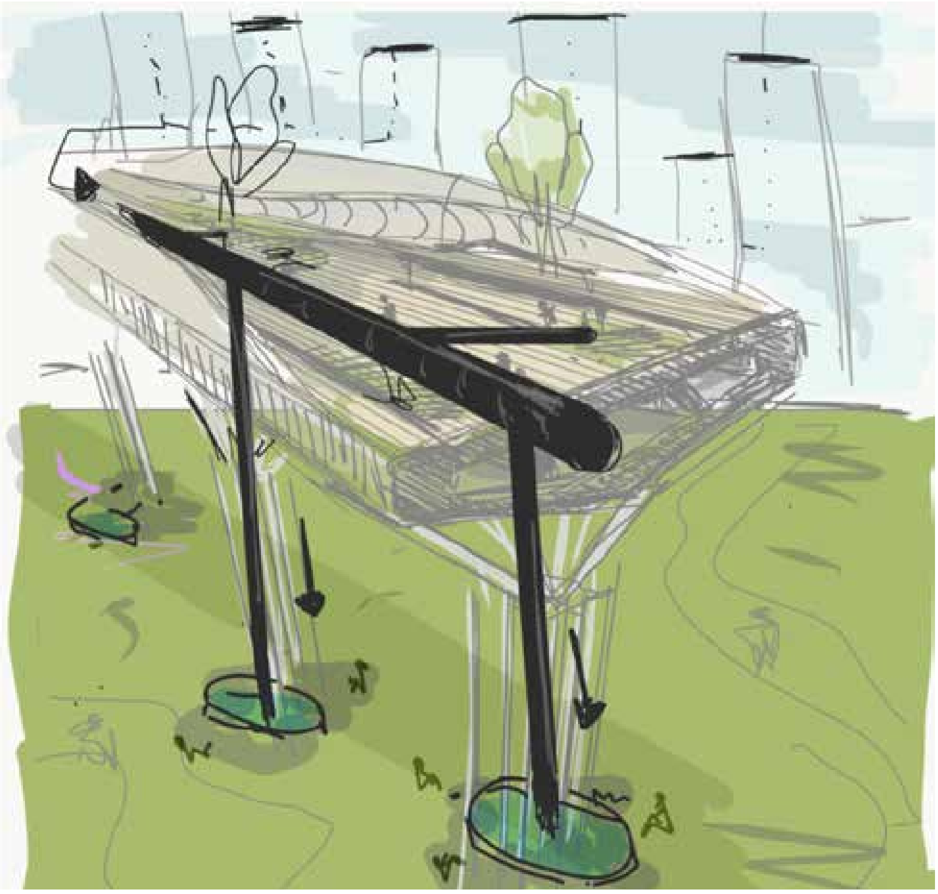
T=1 SWMM input

Min	mm/min	Min	mm/min	Min	mm/min	Min	mm/min
0:01	0.0939	0:46	0.1766	1:31	0.3034	2:16	0.1324
0:02	0.0947	0:47	0.1811	1:32	0.2926	2:17	0.1311
0:03	0.0956	0:48	0.1858	1:33	0.2827	2:18	0.1298
0:04	0.0965	0:49	0.1909	1:34	0.2736	2:19	0.1285
0:05	0.0974	0:50	0.1963	1:35	0.2651	2:20	0.1273
0:06	0.0983	0:51	0.2022	1:36	0.2574	2:21	0.1261
0:07	0.0992	0:52	0.2086	1:37	0.2501	2:22	0.1249
0:08	0.1002	0:53	0.2155	1:38	0.2434	2:23	0.1238
0:09	0.1012	0:54	0.2229	1:39	0.2371	2:24	0.1226
0:10	0.1022	0:55	0.2311	1:40	0.2311	2:25	0.1215
0:11	0.1032	0:56	0.2402	1:41	0.2256	2:26	0.1205
0:12	0.1043	0:57	0.2501	1:42	0.2204	2:27	0.1194
0:13	0.1054	0:58	0.2612	1:43	0.2155	2:28	0.1184
0:14	0.1065	0:59	0.2736	1:44	0.2108	2:29	0.1174
0:15	0.1077	1:00	0.2875	1:45	0.2064	2:30	0.1164
0:16	0.1089	1:01	0.3034	1:46	0.2022	2:31	0.1155
0:17	0.1101	1:02	0.3217	1:47	0.1983	2:32	0.1145
0:18	0.1114	1:03	0.3429	1:48	0.1945	2:33	0.1136
0:19	0.1127	1:04	0.3680	1:49	0.1909	2:34	0.1127
0:20	0.1141	1:05	0.3979	1:50	0.1875	2:35	0.1118
0:21	0.1155	1:06	0.4345	1:51	0.1842	2:36	0.1110
0:22	0.1169	1:07	0.4803	1:52	0.1811	2:37	0.1101
0:23	0.1184	1:08	0.5392	1:53	0.1781	2:38	0.1093
0:24	0.1199	1:09	0.6180	1:54	0.1752	2:39	0.1085
0:25	0.1215	1:10	0.7289	1:55	0.1724	2:40	0.1077
0:26	0.1232	1:11	0.8963	1:56	0.1698	2:41	0.1069
0:27	0.1249	1:12	1.1766	1:57	0.1673	2:42	0.1061
0:28	0.1267	1:13	1.7319	1:58	0.1648	2:43	0.1054
0:29	0.1285	1:14	1.3166	1:59	0.1625	2:44	0.1047
0:30	0.1304	1:15	1.0645	2:00	0.1602	2:45	0.1039
0:31	0.1324	1:16	0.8963	2:01	0.1580	2:46	0.1032
0:32	0.1345	1:17	0.7766	2:02	0.1559	2:47	0.1025
0:33	0.1367	1:18	0.6873	2:03	0.1538	2:48	0.1018
0:34	0.1389	1:19	0.6180	2:04	0.1519	2:49	0.1012
0:35	0.1413	1:20	0.5628	2:05	0.1500	2:50	0.1005
0:36	0.1438	1:21	0.5177	2:06	0.1481	2:51	0.0999
0:37	0.1463	1:22	0.4803	2:07	0.1463	2:52	0.0992
0:38	0.1490	1:23	0.4486	2:08	0.1446	2:53	0.0986
0:39	0.1519	1:24	0.4214	2:09	0.1429	2:54	0.0980
0:40	0.1549	1:25	0.3979	2:10	0.1413	2:55	0.0974
0:41	0.1580	1:26	0.3773	2:11	0.1397	2:56	0.0968
0:42	0.1613	1:27	0.3591	2:12	0.1382	2:57	0.0962
0:43	0.1648	1:28	0.3429	2:13	0.1367	2:58	0.0956
0:44	0.1685	1:29	0.3284	2:14	0.1352	2:59	0.0950
0:45	0.1724	1:30	0.3153	2:15	0.1338	3:00	0.0945
						3:01	0.0939

Appendix K: Design Sketch







Thank you.
谢谢您