A Comprehensive Approach to Evaluate Sponge Cities: Development of an Assessment Framework

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Abstract:

This thesis presents a comprehensive approach of the Sponge City concept by developing an assessment framework that captures the key aspects of the Chinese concept. Sponge Cities, characterized by their use of Green and Blue Infrastructures for urban water management, have gained attention as a sustainable approach to mitigate the impacts of climate change and enhance urban resilience. However, the recently defined concept is in need of tools to help assess the effectiveness and impacts of Sponge Cities. The methodology employed a combination of scientific and gray literature to gather relevant data. On top of providing a better overall understanding of the concept, the analysis produced tools to make the evaluation of cities through the scope of the Sponge City easier. The findings of this research contribute to the advancement of knowledge in the field or urban water management, in particular from the perspective of non-western concept. The developed assessment framework provides a valuable tool for evaluating cities in regards of the key elements promoted by this concept. This work is also embodied in the context of the Paris Agreement and the integration of the Sustainable Development Goals across Nations by 2030.

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PREFACE & ACKNOWLEDGEMENTS

This Master thesis concludes the two years of my studies at Aalborg University in Aalborg. I would like to express my deepest gratitude to all those who have supported and contributed to the completion of this thesis and throughout my entire time during this MSc in Cities and Sustainability.

First and foremost, I would like to extend my sincere appreciation to my supervisor, Martin Lehmann, for his guidance, expertise, and support during the research process. His insightful feedback, constructive criticism, and dedication have been instrumental in shaping and refining this thesis. I can definitely notice some significant improvements in my research and methodology skills since the start of this program and even more during this final semester. I am sure that the learnings gained from this process will undoubtedly help me in the development of my professional career.

Finally, I extend my heartfelt appreciation to all the individuals who have played a role, however small, in the completion of this thesis or during my stay at Aalborg University. Your encouragement, advice, and contributions have been significant and deeply appreciated.

Good reading,

Yannis Fouquet

ACRONYMS

MHURD = Ministry of Housing and Urban-Rural Development

GST = General Systems Theory

BMP = Best Management Practices

LID = Low Impact Development

SUDs = Sustainable Urban Drainages Systems

WSUD = Water Sensitive Urban Design

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INTRODUCTION

Natural or man-made hazards had already impacted people's lives, destroying their homes, affecting them mentally and physically as well as having huge economical consequences to overcome the damages generated (Sendai Framework 2015). Moreover, the situation is not going to improve yet, many hazards are exacerbated by climate change, increasing their frequency and their intensity. Indeed, the rise of the global average temperature, disrupting the climate, is and will affect cities and everything connected to it in one way or another (Fyson et al. 2021; IPBES 2019). Cities are at the same time, actors of this shift but also highly vulnerable, their development is often associated with sealed pavements and a shift from natural infrastructures to artificial ones (Scalenghe and Marsan 2009). They shaped the landscape and their cities in order to fit their requirements, disturbing the natural processes and the water cycle. The lack of knowledge multiplied by climate change led to the incapacity of cities to adapt, resulting in increased risks for the population and other socio-economic issues.

If sealed cities appeared to be the symbol of modernism and technology during the past century, the trend is now changing with the adoption of international agreement like the Aichi Biodiversity Targets, which focus on biodiversity (IPBES 2019). And the United Nations' 2030 Agenda for Sustainable Development (SDGs), with its 17 Sustainable Development goals adopted by 194 parties during the Paris Agreement in 2015 (United Nations 2015). These parties have agreed to reach some defined goals and keep the temperature increase under +1.5°C (UNFCCC 2020). General agreements like the SDGs are pushing nations and so on cities to improve the situation that could benefit the development of concepts on sustainable urban water management such as the Sponge City.

However, these agreements might not be enough, in the fifth Assessment Report (AR5), the Intergovernmental Panel on Climate Change is assessing what could be the future climate by 2100 according to different scenarios called RCPs for Representative Concentration Pathways (Stocker et al. 2014). The scientific community has defined four different scenarios. According to the (IPBES, 2019), objectives of sustainability set by the international organizations cannot be met with the current trajectory, in fact to contain the increase of +1.5°C, global emissions between today and 2030 have to be reduced by 50%. The current trajectory makes it likely that warming will exceed 1.5°C during the 21st century and make it harder to limit warming below 2°C (IPCC-AR6 2023). Further efforts are needed to have a fundamental change across different sectors: economic, social, political and technological factors.

It is undeniable that the climate crisis and human activities are linked, in their report (IPCC-AR5, 2013), the Intergovernmental Panel on Climate Change called for immediate reduction of Greenhouse Gases (GHC) emissions to reduce and slow down as much as possible the impacts of climate change. The different challenges our planet is experiencing and will continue to experience according to the projections and the current pathway we are on will push our society and so on, our cities to evolve and find new ways to reverse the trend but to adapt as well to the new conditions and prepare for more powerful and frequent events.

This master's thesis will have a further look at urban water management and seek to investigate one of the concept aiming at reducing flood risk and water management issues while addressing other problems such as the biodiversity crisis and other socio-economics challenges. The objective of this paper is to develop a Sponge City Assessment Framework based on chosen indicators that constitutes and defines the sponge city concept. In a few words, this study aims to contribute to the development of climate-resilient cities through the scope of Sponge Cities. By doing some investigations on the concept, this thesis seeks to provide an understanding of the Sponge City which could help or guide municipalities and stakeholders to adapt and mitigate the effects of climate in an urban environment. The analysis will be divided in three different parts, the Analysis 1 and 2 will focus on the understanding of the concept and the best way to translate the understanding of it into measurable elements. Then, the Analysis 3 will combine the findings from the previous parts to create the Sponge City Assessment Framework and describe each indicator one by one.

1.1 PROBLEM ANALYSIS

Statistics are showing **(Figure 1),** that the world population is still increasing, especially in developing continents like Africa and Asia. This growing population is also characterized by a shift from rural to urban population. Indeed, we can see with the **(Figure 2)**, that since 2007, the curves crossed and now more people are living in cities. Today the percentage of people living in an urban area around the world is around 55%, that means 4.1 billion people, and they are predicting 5 billion in 2030 and 6,4 billion in 2050 (Gu, 2019). This shift from rural to urban is a global trend, and if, for the current developed countries, it happened during the previous century with the industrialization and the need of labor force with the new industrial methods, developing countries in Asia and Africa are experiencing this tendency in the 21st century (Gu, 2019). Nowadays, the foreign market oriented strategy is based on the cheap labor manufacturing forces from developing countries. The fast economic growth is characterized by rapid urbanization, hundreds of millions of rural surplus laborers flow toward cities and well-developed coastal cities (Gu, 2019). In summary, the growing population in addition to the economic possibilities cities are representing are attracting the rural population seeking for jobs and better quality of life.

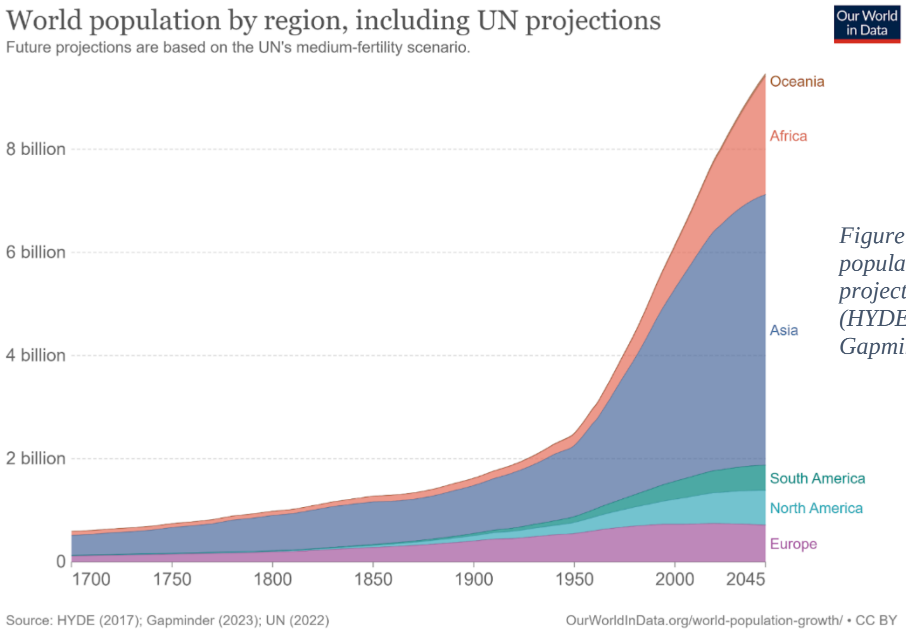
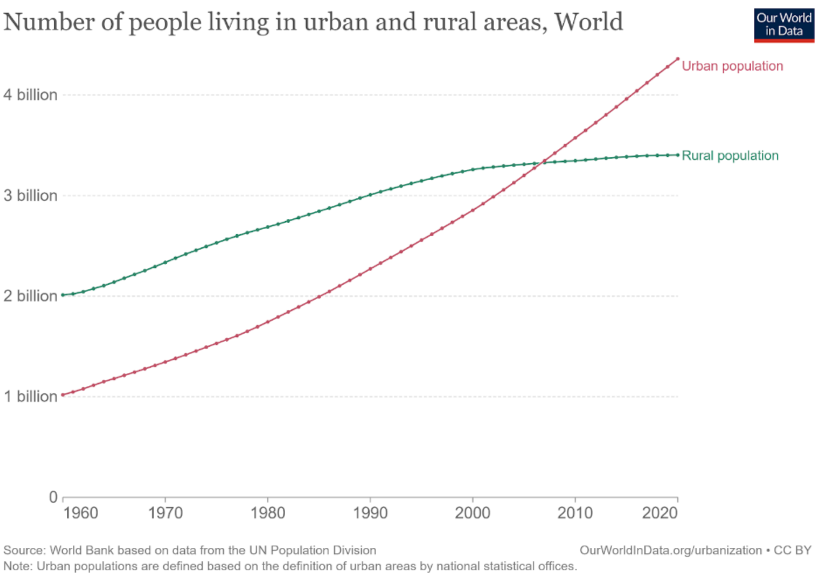


Figure 1: Repartition of the population across continents and projections until the year 2045 (HYDE, 2017; UN, 2022; Gapminder, 2023)

Figure 2: Trend of the world urban and rural population (World Bank based on data from the UN Population Division)



However, the trade-off of this fast urbanization can lead to an additional pressure on the water supply, the wastewater and waste management systems (Sim and Balamurugan 1991). Indeed, in developing countries, water supply and sanitation in urbanized areas are facing many challenges. Three main factors have been identified by (Van der Bruggen, Borghgraef, and Vinckier 2010), such as the growing population, the lack of infrastructure and investments in infrastructure, and limitations to natural water resources. Van der Bruggen, Borghgraef, and Vinckier (2010) are also mentioning that these factors can be significantly influenced by political decisions, instability, poverty and wars. In fact, the lack of basic services such as Water Supply are leading to situations like in the Indonesian capital. Indeed, in order to have access to freshwater, the population of Jakarta are pumping groundwater from the aquifer, which is impacting the city and its inhabitants directly, making the city sink and increasing flooding risks (Erkens et al. 2015; Lubis 2018).

A clear statement to link urbanization and the increase of inequality cannot be made, at least it does not apply everywhere. The study made by (Kanbur and Zhuang 2013), focuses on four Asian countries. Their conclusions revealed that urbanization has increased inequalities in their study area. However, on the other side, the study made by (Wan, Zhang, and Zhao 2022) stated that urbanization helped reduce inequalities in developing countries.

Nevertheless, developing countries in Asia for instance, are struggling to provide basic services to the entire population. Indeed, even if the economy is growing, investments in safe drinking water, sanitation services, solid waste collection and many other services are lacking. Only 50% of the urban population have access to safe drinking water supplied through piped connection, while 20% still lack improved sanitation facilities. In addition, the lack of resources or knowledge from the governments to build wastewater treatment infrastructures are resulting in surface and groundwater pollution (Dahiya 2014).

In addition to the above paragraph, the increase in built-up areas is also giving arguments in favor of the development of Sponge Cities and similar concepts. Urban land cover will increase by 315% between 2000 and 2050 (Angel et al. 2011). The expansion of urban settlements, often occur at the expense of nature, causing fragmentation in the natural habitat, reducing ecosystem services, participating in the biodiversity crisis (Seto, Güneralp, and Hutyra 2012), and modifying the natural flow of water and impacting the level and quality of natural reservoirs (Wang et al. 2008).

Urbanization is also responsible for aggravated the effects of natural disasters. The overuse of concrete and sealed surfaces has increased urban heat island effects (Tan et al. 2010) and reduced water infiltration, increasing the risk of flooding (Depietri and McPhearson 2017). The impervious ground in addition to the lack of infrastructures have negative effects in terms of rainwater management, leading to flooding issues and other natural disasters. Adding to this the undersized water drainage network due to rapid expansion and you increase even more the vulnerability of cities and its inhabitants regarding flood risks (Chitwatkulsiri and Miyamoto 2023).

These elements and challenges cities around the world are facing are being exacerbated by climate change, causing more frequent and powerful hazards. As stated in the (IPCC-AR6 2023) climate change is not only characterized by more floods but also by more heat waves, more drought, more risks to health and food production as well as many other parameters. Hence, it is affecting to a certain extent a wide range of people living in urbanized regions but above all, it is impacting the ones directly dependent on the ecosystems like the local communities and indigenous people for instance. Flooding is a major issue affecting some regions around the world more than others, and raises many concerns for the economy but also the health and well-being of the population. Some regions and cities around the world are more at risk than others regarding flooding. Like the ones exposed to tropical storm, typhoon and monsoon (Torti 2012), as well as the population living along the coastline, exposed to sea level rise, storm surges and salinity intrusion, resulting in major impacts on the economy, the population and the well development of the country (Raitzer et al. 2016).

We have seen that climate change and urbanization are two of the biggest challenges facing cities around the world. As the population is expanding and cities as well, it is essential to develop innovative strategies and solutions to build more resilient, sustainable and livable cities, having less impact on the environment. It is important to identify and analyze these various factors in order to develop effective strategies and solutions to address the problem. Now that we understand the problems and challenges cities are facing, I will explain in the next section why there is a need to create a Sponge City Assessment Framework.

1.1.1 Drivers of this thesis

Climate change is already impacting many cities around the world and some organizations like the C40 have made it their central point of interest. The C40 cities organization is a global network comprised of 100 cities around the world aiming at collaborating to limit the global heating to 1.5°C, and build healthy, equitable and resilient communities. These cities, which are witnesses of the impact of climate change, are working together for scaling up climate action across many sectors. The CDP is another organization, a non-profit organization, working in collaboration with intergovernmental agencies, governments and associations in order to provide support to cities, companies, states and regions to measure and manage their risks and opportunities on climate change. The data they have collected shows the most exposed cities towards hazards and identifies the consequences as well as the strategy, barriers and enablers to answer these issues. After having a look at the data provided on their website (CDP 2018), we can realize that each corner of the world map is vulnerable to hazards. The score given to cities has been calculated by multiplying the number of risks reported by the severity. Cities around the world are not impacted in the same way, hazards are different according to the geography, the climate, the population and infrastructures. Although, among the most exposed cities towards hazards are found: Sidney (Oceania), Cape Town (Africa), Manilla (Asia), Rio de Janeiro (South America), Barcelona (Europe) and Miami (North America). Hence, no one is spared regarding climate change and cities must act to become resilient and work with Nature instead of against it (CDP 2018).

To highlight these facts, there is a need to investigate more in some of the examples mentioned earlier. We could notice from the example that cities affected by hazards are very different, one from the other. By their geography, the local climate as well as by their GDP and socio-economics challenges.

Cape Town in South Africa is one of them. The city is experiencing frequent heavy rainfall during the winter from May to September (Pharoah 2014). As a result, the study from (Ziervogel and Smit 2009) estimates that between 32,000 and 34,000 people were displaced each year due to flooding for the period from 2007 to 2009. In addition, to costly damages to property, roads and infrastructures flooding are causing (DiMP 2010), there is the threat to citizens, where the most vulnerable population towards these events appeared to be the poorer (Pharoah 2014). Indeed, residents of informal settlements in Cape Town are experiencing flooding. Due to urban sprawl, unplanned habitation developed on wetlands or other flood-prone areas (Pharoah 2014). Moreover, even when informal settlements are not located in flood-prone areas, it does not mean that the population is not vulnerable. Poorly designed dwellings constructed with inappropriate materials suggest a greater exposure regarding floods and other hazards compared to concrete and brick houses with drainage infrastructure (Pharoah 2014).

In Europe, Barcelona is one of the most affected cities by hazards. For the period from 1980 to 2017, economical damages were considerable (32.2 billion), where two-thirds of these damages costs are associated with flood impacts (Martínez-Gomariz et al. 2021). As a consequence of climate change and the rising temperatures altering the hydrological cycle, more frequent and intense events may occur resulting in higher damages costs and other threats to people and nature if nothing is done (European Environmental Agency 2016). Barcelona has a Mediterranean climate, experiencing heavy rainfalls of high intensities and flash flood events. Nevertheless, the reasons why rainfall is a problem in this city are multiple. The local rainfall pattern can often be characterized by 50% of the annual precipitation within two or three rainfall events (Martínez-Gomariz et al. 2021), on top of the old drainage infrastructures combining wastewater and rainwater, in most cases leading to overflow of the system and then flooding. Additional aggravating factors like the fact that the city is situated on a flat surface between mountains/hills and the sea. As well as the high rate of imperviousness (70%) of the ground guiding run-offs towards the low-lying areas of the city. These elements are causing critical flooding with significant economic damages, increasing the possible risk of service interruptions and other associated repercussions (Martínez-Gomariz et al. 2021). These components combined pushed the municipality to look into storm-water management with help of other solutions rather than the traditional one. Topics like Sustainable Urban Drainage Systems (SUDs) are being investigated by researchers and tested by the municipality (Nóblega Carriquiry, Sauri, and March 2020).

In Asia, due to the climate and the monsoon, many mega cities in India, China and Southeast Asia for instance are suffering from flooding and related issues. Manila and more precisely the greater Manila area is one of the hotspots. Its geographical position, situated in a tropical monsoon climate zone, is causing serious problems to the city. Experiencing perennial flooding due to the local climate as well as regular typhoons combined to its proximity to the coastline and the fact that the city is located at sea level results in frequent floods (Nga and Fukushi 2017). In addition to the elements associated with the geographical position of the city, other factors exacerbate the flooding situation. Indeed, the city's rapid urbanization with poor capacity from the river channels and infrastructures to evacuate the water as well the lack of maintenance, informal settlements, institutional and financial constraints are not helping with the context (JICA 2001). Having this information has a background allows, to understand challenges the city and the inhabitants are facing. The study from (Nga and Fukushi 2017), linked floodings to direct health issues with rising infectious risks according to the severity of the inundation. Among the population, children between 5 and 14 years-old are most vulnerable. However, more frequent and powerful events will affect a wider portion of the population. Unfortunately, issues in Manila and the Philippines are not only climate related. Undeniably, the country is also under the threat of earthquake, tsunami and volcanic eruptions, making Manila one of the least resilient cities in the world due to the combination of high hazards susceptibility, the high population density and the insufficient level of preparedness (Diola 2014).

We have seen with these few examples from around the world that every city needs to feel concern about climate change which is causing more powerful and frequent events at the four corners of the planet. Hazards can take many forms regarding the place you are living on earth. Areas around the tropics are more susceptible to experience monsoon, flash floods and heavy rainfall. Coastal cities are under the threat of sea-level rise and even European cities are vulnerable. Indeed, one fifth of European cities with over 100,000 inhabitants are very vulnerable to river floods according (European Environmental Agency 2016). To add more complexity to these issues, some factors worsen the situation. The under-sized or nonexistent infrastructures to deal with hazards on top of informal settlements for instance are increasing the vulnerability of the population, more specifically low-income groups. Vulnerability and resilience towards climate tarnish the image of a city, making it less attractive and influencing tourist activities leading to potentially less incomes in the local economy (Fitchett, Grant, and Hoogendoorn 2016).

1.1.2 Background of the Research Question

On top of the growing economy and the multiplier effects such as climate change, built-up environment, diversity of species and lack of infrastructures, the call for a solid urban water management is essential in the race towards sustainability. Based on the current situation, the emerging concept of Sponge City, which refers to a city that has been designed to absorb, store, and use rainwater to mitigate the impacts of floods, droughts, and other extreme weather events, could be a good point of departure for my research paper. This quite recent concept tackles the issues mentioned earlier, but it also the representation of a non-western point of view to deal with issues related to water in urban areas.

In recent years, the rise in urbanization and climate change have created significant challenges for many cities around the world, particularly in vulnerable regions and developing countries (Asian Development Bank 2009). Cities rapid expansion combined with inadequate infrastructures and a lack of effective disaster preparedness, had led to increased vulnerability to natural disasters such as flooding and landslides. In the field of sustainable urban development strategy, resilient and Sponge Cities have gained in popularity. This concept could be one of the solutions towards climate mitigation and adaptation.

The Chinese concept of Sponge City has been regulated and developed by the Chinese government (Xiang et al. 2018). Even if they recognize the possible implementation of their concept outside China, the available data regarding the construction and design guidelines or monitoring and assessment methodology are found in Chinese. Adding to this the unique way of financing these projects, which relies on three sources (Xiang et al. 2018). The central government is delivering a special subsidy for the selected pilot cities representing around 20% of the total investments. Then the local government contributes for 40% and the remaining 40% comes from non-governmental investments (Xiang et al. 2018). In this context, it makes it difficult to plan the implementation of sponge cities outside China. Moreover, initiatives like the "Global Sponge Cities Snapshot" (Arup 2023), using only a part of the concept in their assessment is creating more confusion in the comprehension of what Sponge Cities really are and what are the elements associated with it. The lack of clarity on the topic with relatively little information shared by the Chinese government in English in addition to inappropriate use of this term by other entities is creating a need. Indeed, this thesis aims to provide guidelines based on the Sponge city concept. The current need for our cities around the world to become resilient and reach the SDGs as quickly as possible requires more accurate and upgraded tools to help this process.

1.2 RESEARCH QUESTION

The implementation of Sponge City projects is relatively new (Xiang et al. 2018). Therefore, there is a need to investigate and develop different tools that can provide a standardized and systematic approach to evaluate the performances or the status of cities according to the Sponge City concept. This assessment framework does not aim to compare cities with each other and rank them. Instead it will provide to a wide range of cities, a simplified tool that does not require a lot of data, a tool which is able to guide municipalities towards a city that mitigate flood risks and climate change following the principles of a non-western point of view, the Sponge City Concept. Reducing the indicators to the most crucial ones will help reduce the cost to get the data and make it more accessible. This assessment framework is being seen as a first step towards "Resilient city" by tackling the most crucial challenge which is, vulnerability to floods, climate change as well as the biodiversity crisis and the loss of ecosystem services. Another interesting point, that is justifying the necessity of this work is the fact that at the moment, most of the concepts aiming at using natural solutions to mitigate the impacts of climate in cities are symbolizing a specific context. In fact, concepts like Sustainable Urban Drainages (SUDs) in the UK, Water Sensitive Urban Design (WSUD) in Australia and Low Impact Developments Urban Design (LIDUS) in New Zealand are all representing solutions adapted to western countries (He et al. 2019). Indeed, their perspective and the principles attached to these concepts are adapted to solve issues occurring in developed countries in the first place. Asian/Chinese Sponge City Concept is bringing a novel insight to deal with water in cities (Nguyen et al. 2019), promoting adaptation and acceptance of floods with a hybrid landscape evolving in accordance to the seasons.

In conclusion, the analysis of the current gaps in the research are leading to the following Research Question:

How can the Sponge City Assessment Framework be utilized to assess the effectiveness and impacts of various BGI interventions and strategies in cities?

In order to delve deeper into the main Research Question, this study has identified three sub-questions that will guide the reader throughout the report. These questions are integrated into the research design and will help to shed light on specific aspects of the larger investigation. By addressing these sub-questions, we gain a more comprehensive understanding of the overall topic and its relevance.

The first sub-question aims to explore how the General System Theory (GST) can be used as a theoretical framework to identify the key elements and components of the Sponge city concept. By applying the principles of System Theory, the study will delve into the relationships and interactions between the various components of the Sponge city framework, and how they contribute to achieving the overall objective of sustainable urban development.
SQ1: *By using the General System Theory which key elements and components of the Sponge city concept can be emphasized?*

The following sub-question will investigate available indexes focused on sustainable, resilient cities or similar topics and will identify the key indicators that should be included in the sponge city framework for assessing the effectiveness of a city in mitigating climate change. The second sub-question requires the elements discovered after answering the first sub-question.
SQ2: *What are the key indicators that should be included in the Sponge city framework for assessing the effectiveness of a city to mitigate climate and bring multiple co-benefits?*

Finally, the last sub-question will combine the elements found in the two previous sub-questions in order to develop the Sponge city assessment framework. The final part of the results will introduce each indicator, their grading systems, which data they need and the way of calculating them. Ultimately, the outcome of this thesis, the Sponge City Assessment Framework will be presented as a whole, expressing the representation of the concept.
SQ3: *How can the Sponge City Assessment Framework express the true representation of the Sponge City Concept?*

1.3 RESEARCH DESIGN

The research design of this study is based on a systematic literature review approach. To comprehensively investigate and evaluate the Sponge City Concept, a combination of scientific articles and gray literature will provide this thesis with diverse data. The research design includes three different analysis but connected to each other.

The first analysis aims to answer the first sub-question: *By using the General System Theory which key elements and components of the Sponge city concept can be emphasized?* The analysis will dive in more details into the sponge city concept, what it represents and its characteristics in order to help define the right indicators for the Sponge city assessment framework. Analysis 1 is based on official documentation delivered by the Chine Ministry of Housing and Urban-Rural Development (MHURD) and scientific articles gathered from the Web of Science.

The second analysis is directly integrating the findings from the previous analysis to build on it. This section seeks to answer the second sub-question: *What are the key indicators that should be included in the Sponge city framework for assessing the effectiveness of a city to mitigate* *climate and bring multiple co-benefits?* This part of the analysis will investigate the different existing indexes on sustainable cities by highlighting their strengths and weaknesses regarding the objectives of this thesis and the potential indicators that can be integrated or took as an inspiration into the Sponge City Assessment Framework.

Finally, the Analysis 3 will answer the last sub-question: *How can the Sponge City Assessment Framework express the true representation of the Sponge City Concept?* The last part of the analysis will combine the results coming from the two previous chapters in order to develop the Sponge city assessment framework. This section will also provide a description of each indicators in a sort of an handbook, describing the grading system as well as well the way of getting the data and the further information on calculations when needed.

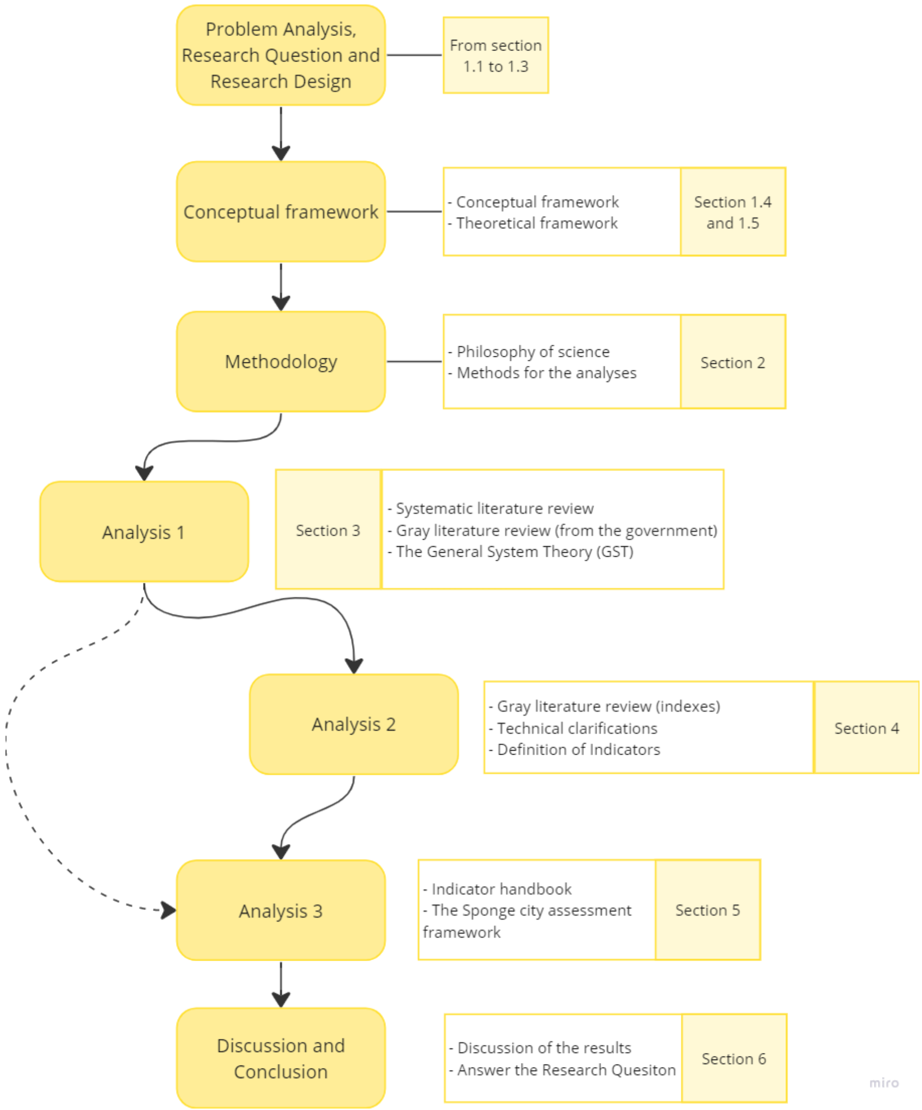


Figure 3: Research design for the realization of this thesis (figure from author)

1.4 CONCEPTUAL FRAMEWORK

Among the different concepts in Urban Water Management, the term Sponge City is relatively new and was presented for the first time in 2013 by the Chinese president Xi Jinping in response to the urban issues caused by urbanization and dramatic flood events, which caused huge losses of lives and properties (Xia et al. 2017). Consecutively, from the end of 2013 and the beginning of the 2014, the concept aiming in decreasing national flood risk, increasing water supply and improving water quality has been defined by the State council of China with the publishing of guidance for Sponge cities, which describes the construction and design for a range of urban infrastructure (Griffiths et al. 2020). This initiative by the Chinese governments in response of climate change has been inspired by other national concepts like the "Low Impact Development" (the USA), "Water Sensitive Urban Design" (Australia), "Sustainable Urban Drainage Systems" (the UK) and "Low Impact Urban Design & Development" (New Zealand) (Griffiths et al. 2020; Peng and Reilly 2021). These concepts as well as the differences with the Sponge City Concept will be further investigated later in the thesis. The long term goal aims a complete integration of the Sponge City concept in urban development, planning and construction management by 2030; with more than 80% of municipal areas able to recycle 70% of incident rainfall (Griffiths et al. 2020). In order to realize this plan a coalition of three ministries, the Ministry of Finance (MOF), the Ministry of Housing and Urban and Rural Development (MOHURD) and the Ministry of Water Resources (MWR) selected 16 pilot cities out of 130 candidates in first place. Another 14 cities were selected a year later in order to have a complete representation of the different landscape, climate conditions and hydrological issues you can find in China. In order to reach these objectives, the governments have allocated a budget for each of these cities, going from US$57 to US$85 million per year (for 3 years) according to the size of the city (Chan et al. 2018; Griffiths et al. 2020). Their performances are evaluated and their subsidy re-evaluated upward or downward in regards to the results (Griffiths et al. 2020). The 'sponge city concept' term has been defined by the Chinese governments on the General office of the state council's platform with the help of different documents like the 'Sponge City Technical Guidelines' and the 'Instructions on Promoting Sponge City Construction' for instance. However this document hasn't been translated directly into English by the government, that is why I will mention what has been highlighted by (Qiao, Liao, and Randrup 2020). A sponge city is described as "*a city which has the flexibility to adapt to environmental changes and natural hazards by absorbing, retaining, infiltrating and purifying water and by releasing and utilizing the stored water when it is needed*" as well as "*as an approach to urban development where urban planning and construction management take full advantage of the absorption, infiltration and retention functions of buildings, roadways, green spaces and aquatic and other ecosystems, to control stormwater runoff. Sponge City is described as a form of urban development that achieves natural storage, infiltration and purification*" (Qiao, Liao, and Randrup 2020, p4). Despite the multiple benefits the concept is designed for, the relatively new implementation still needs to be tested against heavy rainfall to be able to judge the effectiveness of the concept at a city scale.

The following section presents two case studies that illustrate the successful implementation of the sponge city concept. In both of these cases, due to rapid urbanization and the national policies, the city had to find a solution that provides multiple benefits. From these two cities, one of them, Haikou, a city with 2.3 million citizens is located in a sub-tropical climate and the other one, Nanchang, with a population of 6.2 million is situated in a more temperate area. Nevertheless, both of these cases are experiencing recurrent monsoon events, which is characterized by heavy rainfall causing potential damages in an urban area that is not adapted. Both case studies addressed the problem with a holistic answer with the help of nature-based solutions. The Chinese design institute, Turenscape, has realized these two projects. They have planned and designed 1000 ecological projects in China. These two cases address challenges of climate change and urbanization, while also providing a range of benefits such as improved biodiversity, social and cultural values and economic benefits (TURENSCAPE 2019; 2021).

Haikou, Hainan, CHINA

HAIKOU MEISHE RIVER GREENWAY AND FENGXIANG PARK

CONTINENT: Asia
CLIMATE: Tropical with monsoon events
POPULATION: 2.3 million
TYPE: Sponge city

CHALLENGES

GROWING POPULATION & URBANIZATION
In the past 4 decades, the population grew from 250,000 people to 2.3 million, disturbing the natural water system.

GREY INFRASTRUCTURE & GREY CONCRETE RIVER
Rapid growth led to over used of concrete, worsen effects of the monsoon, leading to concrete flood wall and concrete river

SEWAGE & SURFACE RUNOFFS POLLUTION
The Meishe River was for decades a sewage dump, highly polluted, impacting the image of the city.

After many years of water pollution affecting the Meishe river, "The mother river" in the local language. In 2016, with the arrival of the sponge city concept, Haikou's government decided to go from a grey infrastructure to a green and holistic solution. The project included the restoration of the river banks with the Fengxiang Park, 80 hectares in size and 13 kilometers long. The recovering mission encompassed the integration of an ecological infrastructure aiming to absorb the storm-water. The transformation of grey infrastructure into wetlands and natural river banks leaving some space for water and the integration of elevated paths to provide a pleasant waterfront access. Finally, the "terraced wetland park" designed as a water cleaning facilities cleaning the surface water runoffs and the sewage from the local urban villages that are currently not connected to the centralized treatment system.
This intervention is now attracting biodiversity and the citizens back on the river banks. This project claims the replicability of these nature-based solutions into other urban areas, especially in developing countries, where the surface water runoffs and sewage are polluting, rivers lakes and oceans (Turenscape, 2019).

Nanchang, Jiangxi, CHINA

Nanchang Fish Tail Park

CONTINENT: Asia
CLIMATE: Temperate with monsoon events
POPULATION: 6.2 million
TYPE: Sponge city

CHALLENGES

RAPID DEVELOPMENT & URBANIZATION
Rapid development on lakes and wetlands impacted the natural landscape and impacted its water regulated capacity

URBAN INUNDATION & FLOODING
The monsoon season has been a chronic challenge for the city, exacerbate by climate change and urbanization

SURFACE RUNOFFS POLLUTION
Surface water being polluted by urban runoffs affecting ecosystems and the residents

LAND USE
This case study is a former fish farm / dump site, polluted by coal ash, overuse of fish feed and urban runoffs

The transformation of this 55 hectares site from badly abused landscape into a holistic solution, aiming in regulating storm-water, provides habitats for wildlife and offer recreational possibilities for the local citizens allowing them to connect with nature and improve the quality of life. The first challenge was to transform a former dump site with polluted soil into a natural site combining water and forest providing the capacity to store 1 million cubic meters of storm- water inflow. The design is also adaptive, tree species have been selected for their resistance to survive fluctuating water levels and some of the boardwalk designed to still be used during a 20- year flood event and annual monsoon. Marshlands, forest and water are providing habitats for nature while elevated pathways and platforms are giving opportunities for the visitors to explore and finally, terraced constructed wetlands are designed to filter urban runoffs. This project is also part of the national policy on sponge cities, providing a replicable model for cities sharing common issues like monsoon and fast urbanization (Turenscape, 2021).

We have seen with these two cases, a part of the potential of the Sponge City. By having the same approach of restoring the natural landscape into multi-purposes areas, they are solving different problems. Indeed, for the first case, on top of the shift from concrete to green landscape, the project is providing recreational areas to the communities and solution to purify runoffs and sewage from the surroundings. The second case study looked into formerly polluted areas and transformed them into an urban park providing a solution to store storm water, provide ecosystems for biodiversity and recreational areas for the inhabitants. Together these two case studies are addressing different abilities of a Sponge City: reduce flood risks, reduce surface runoff pollution, treat sewage water, enhance or recover the natural landscape and provide recreational opportunities for people. These two examples are only representing a part of the concept, that it why this thesis seeks to investigate Sponge City in order to reveal the full scope of its abilities.

Given the multiple benefits of Sponge Cities and the national policy, many cities in China are now exploring the potential of this approach. However, to implement sponge cities effectively, it is necessary to develop an assessment framework that can evaluate the performance of the sponge city concept and guide decision-making. This is where the importance of a sponge city assessment framework comes in.

1.5 THEORETICAL FRAMEWORK

To help me during the realization of this thesis I chose to work with a system theory, namely, the General System Theory (GST). In order to understand the theory I have selected, it is relevant to understand its origins. The one I have picked is part of a larger group called Systems Theory, which was introduced for the first time in the 19th century by the English sociologist and philosopher, Herbert Spencer and the French social scientist Emile Durkheim. It was first inspired by Darwin's Theory of Evolution and where focusing on the society and social systems (Gibson 2016). Systems Theory is now seen as a group of theories that share a common focus on understanding systems as a whole rather than as a collection of individual parts. The study of systems as a whole, aiming to understand the interrelationships and interactions between different components of a system. Basically, Systems Theory can be found in various disciplines such as natural and ecological sciences, chemical and biological disciplines, sociology and psychology for instance. And the idea of Systems Theory is the fact that each system is based or connected to other concepts developed by other theories (Mele, Pels, and Polese 2010).

The General System Theory or GST is one of the key systems approaches. Defined by Ludwig von Bertalanffy in 1956, it is described by the author as a general approach that can be used and integrated into various sciences. The theory is not specific to a particular domain because its principles are expressed as a complex set of interacting elements, providing general principles valid to all systems (Von Bertalanffy 1968; Mele, Pels, and Polese 2010). Therefore, (Von Bertalanffy 1950) was describing his theory as an important regulative device in science, an important means of controlling and instigating the transfer of knowledge and principles from one field to another. In addition, the author highlighted the idea that the GST is a general science of "wholeness", where systems are either closed and open systems. Closed systems are systems isolated from the environment with no interaction while open systems are the ones interacting with their environments (Von Bertalanffy 1950; 1968).

In the case of the Sponge City Assessment Framework, the application of this theory will be helpful to understand the bonds between various systems and subsystems that are interacting with each other. Identifying the different systems could also help to manage and optimize the efficiency of sponge cities. By applying GST, we can also analyze how changes in one subsystem of the sponge city might affect the behavior of the entire system. The General System Theory should provide useful inputs for analyzing and improving the Sponge City Assessment Framework in this thesis and beyond.

Methodology

The methodology part is divided into different sub-chapters, starting by the philosophy of science the role of the ontology and epistemology in the research paper. It well then present the methods for Analysess 1, 2 and 3 describing for each of them, the collection methods, the analysis strategy and the limitations associated with it.

This thesis aims to understand and identify the different drivers of a sponge city in order to build more resilient cities. The starting point of projects in urban planning, begin with the research and observation of the social world, what is real (Ontology), what we know (Epistemology) and how we can find out (Methodology) (Farthing 2016). Therefore, the following section will describe which pathway thesis is on by interpreting the nature of reality, and the nature of knowledge.

The ontology is the philosophy of what is real, different concepts ensue from the ontology which can be categorized between objectivism and constructivism which can be respectively associated to positivism and interpretivism of the epistemology. On one side, objectivism and interpretivism is the action of dissociating our personal beliefs from the study and the importance of objectivity and evidence in the research (Al-Saadi 2014). It is a really scientific method, based on clear data collection and interpretation leaving no room for deduction, choice or freedom. On the other hand, constructivism and interpretivism are more subjective approaches, based on interpretation and the use of different senses (Al-Saadi 2014). While, the scientific approach objectivism and positivism are embodied, constructivism and interpretivism are more associated with social sciences, reflecting the researcher's perspective without being able to dissociate the research from the author. For this thesis the ontological and epistemology assumptions will try to describe elements such as, "what is sponge city" or "what are the components of a sponge city" in order to make an argumentation based on the different scientific literatures and indexes I could find with the help of the concept and the theory described in previous chapters. The analysis claimed to be scientific and so on, the approach will follow principles from objectivism and positivism. To be more precise, a more elaborated and recent approach called post-positivism, which in comparison to the traditional way of thinking argues that knowledge is generated by testing and allows that reality can be known approximately (Al-Saadi 2014). Moreover, we have to keep in mind that the true nature of knowledge could be altered by different elements (Farthing 2016). In my case it could be affected by the context of my studies, a Master's program on Cities and Sustainability based on problem analysis. My lack of experience in writing research papers in addition to my academic and professional background could let my interest in a topic as well as cultural values influence, to some extent, my way of perceiving the information, the same way, readers of this thesis will be influenced by their background and their interests.

2.1 METHODS: ANALYSIS 1

Analysis 1 is a combination of Grey literature by having a look at official documents released by the Chinese government and a Systematic Literature Review conducted with the help of Web of Science. Part 1 and 2 consists of official documents released by the Chinese Government. Part 3 and 4 are different relevant literature on Sponge cities. The approach used to perform this analysis is following the principle introduced by (Berrang-Ford, Pearce, and Ford 2015), a method that is being described in the following paragraph and with the help of the upcoming figure **(Figure 4)**.

On top of the systematic literature review of scientific articles, conducting gray literature reiview is a good way to investigate documents that can not be found with tools like the Web of Science (Paez 2017). Methodologies to achieve a gray literature are diverse. The strategies are: (1) searches in gray literature databases, (2) searches in clinical trial registers, (4) searches in conference proceedings and (4) searches with Google Scholar and Google (Paez 2017). The test realized at the early phases of the thesis showed some good results by using the last option, which is why this analysis will be based on the findings generated by Google Scholar and Google. The subsequent figure (Figure X) is describing the research method for the Analysis 2, following the principles introduced by (Berrang-Ford, Pearce, and Ford 2015). The literature search has been divided into different parts (four parts in total) and each of these parts are going through a two phase's process in order to keep only the relevant papers to review. Part 1 and 2 are looking into official documents and information released by the Chinese Government. The English version of the official website is very limited and does not allow you to look for information in English in the different libraries. That is why I had to use a simple method to prevent errors.

For the Part 1, on the Chinese Government official website (www.gov.cn), a free access to three libraries is provided. The "State Council Policy Library", the "National Regulatory Library" and the "Administrative Code Library". Knowing that the entire website and the different libraries are all in the Chinese, I used the Google Translate extension, which is translating the entire the web page. However, in the first place the research has to be done in Chinese in order to, in a second place, be able to translate the results. That is why, while investigating these different libraries, I used a simple term "Sponge City" translated into Chinese "海绵城市" to prevent errors. By applying this method to the "Administrative Code Library", (0) results came out of it. By applying this method to the "National Regulatory Library" (3) results came out of it, however, after reviewing them, the documents were focused on specific areas in China, on specific cities and where indicating their specificity regarding the national guidelines, that is why none of them have been retained. From the last library, "State Council Policy Library", (8) results came out of the research, after having a closer look at each of them, only (5) were retained for further review. The other documents were focusing on financial aspects of the Sponge City which is not the priority for this thesis. For Part 2, we know that all the official documentations on Sponge City are being delivered by the Ministry of Housing and Urban-Rural Development (MHURD), that is why I did further investigation on their official website directly (www.mohurd.gov.cn). By using the same method and the key word "Sponge City" (399) results came out, I had to filter the results by excluding the "News" in order to focus on official papers. After narrowing it down, (80) results came out of it, and by executing phase 2 consisting of reviewing the Title and the Description (Berrang-Ford, Pearce, and Ford 2015), the selection ended up with (7) documents. The inclusion criteria for these two parts consisted in documentation focusing on (1) Guidelines, (2) Standards, and (3) Updates on the planning, design and construction phases of a Sponge City, excluding irrelevant aspects for this thesis such as financing methods, selection process of the pilot cities for instance.

The Part.3 and 4 have been conducted with the help of Web of Science and limited to "Article" and "Review Article" excluding the other types of documents. During the process some key words like "Sponge city", "Sponge city concept" have been used but the results were not convincing enough and too broad, generating too many results.

Hence, in order to find the relevant documents that could lead to a satisfactory review, the following search was developed for Part 3 ((Title) "*Sponge city*" AND (Title) "*Analysis*"). Phase 1 finished, with (19) documents remaining, phase 2 began by selecting the relevant documents by reading Titles and Abstracts, (15) made it to this phase. A further review of the content led the selection to (6) papers that will be further investigated.

To provide additional and overcome the few quantity of relevant documents generated by the Part 3, the last Part was also conducted on Web of Science, focusing on "Article" and "Review Article". This time, the following search was used ((Title) "Sponge city" OR (Title) "Sponge cities"). Part 4 generated (255) results limited to (6) using the filter "highly cited paper". Phase 2 which consists of revealing the true meaning of the paper by having a look at the title, abstract and the content, conclusion led to the same number of research papers. Unlike the result from the Part 3, which analyzed what Sponge cities could accomplish, the Part 4 revealed papers focusing on the understanding, the opportunities and the implementation of the Sponge City concept, describing the general philosophy compared to similar concepts, which is also essential for the well development of the Analysis 1.

The aim of the Part 3 was to concentrate the results on the analyses made by different scholars, and in order to take a decision whether or no an article need to be kept, some criteria had to be define. Results were selected for inclusion based on three criteria: (1) Focus on the effects, (2) Focus on the multi-objectives it is offering, and (3) Focus on comparative analysis. However, some unexpected topic, which were not part of the criteria in a first place such as the social and environmental costs of the sponge cities, had to be included in the results.

Regarding the Part 4, inclusion criteria were defined, such as: (1) Articles on co-benefits, (2) Articles on performance and evaluation and (3)Articles on planning, design, implementation and construction.

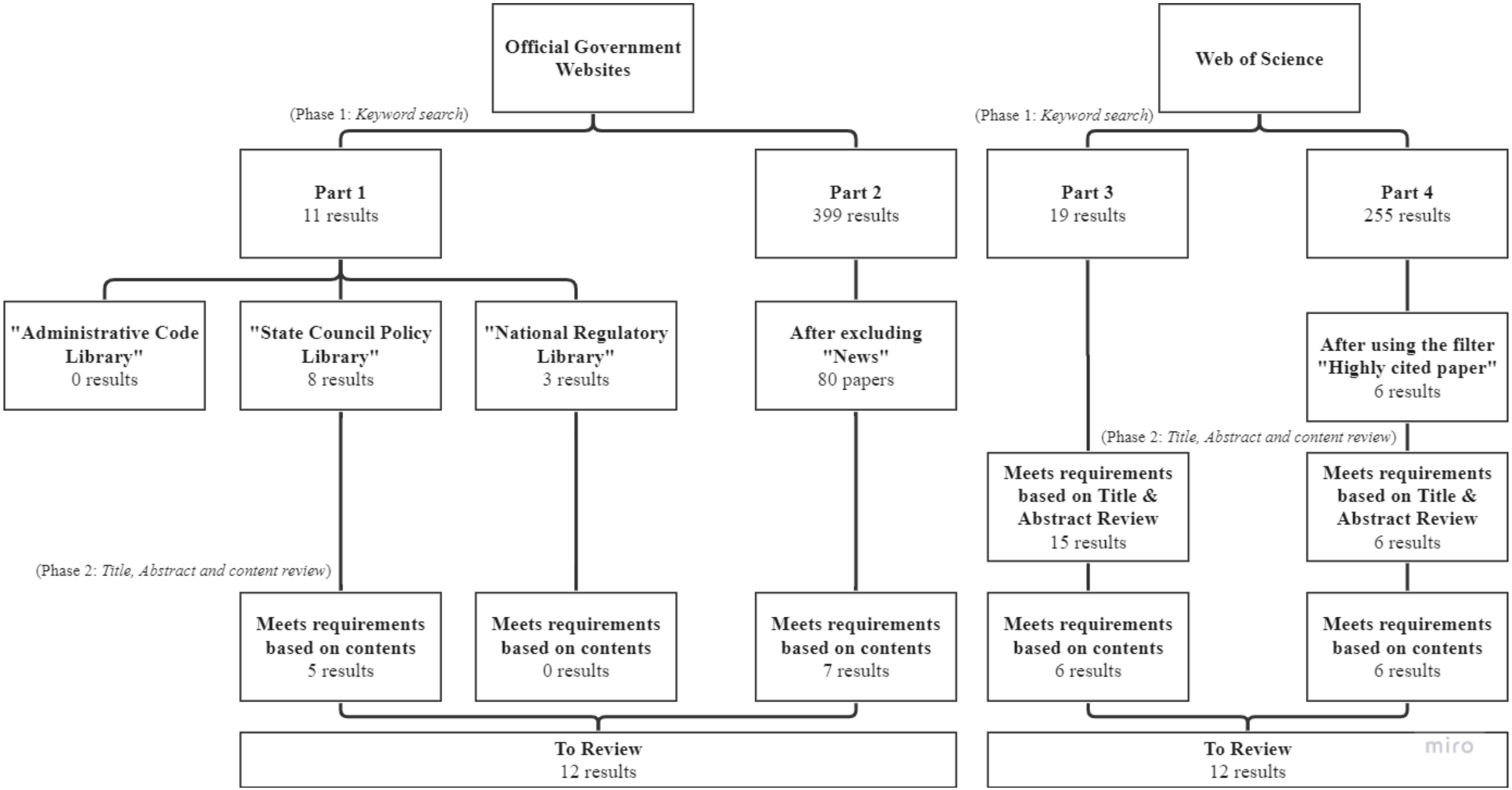


Figure 4: Literature search and selection process divided into two distinct sections, the process for the gray literature on the left side with the Part 1 & 2, and the process for the scientific articles with the Part 3 & 4.

2.1.1 Bibliography

Due to the relatively recent definition of the concept, none of the documents are preceding 2015. The Analysis 1 is divided in two distinct sections. First, you have the Part 1 & 2, which are the gray literatures, delivered by the Chinese government. It is a mix of official guidelines, standards for the construction, evaluation and the assessment intended for Chinese pilot cities and update documents characterized by "Notice". Secondly, the other section of this Analysis, represented by the Part 3 & 4 portray the systematic literature conducted with the Web of Science. Among the 12 documents selected from the systematic literature review (part 3 & part 4), the geographical coverage of the literature is primarily Asian (8), more specifically Chinese (for 7). Europe represented by (3) documents and Oceania (1). These numbers are highlighting a different angle and approach of climate mitigation which make it even more interesting. The majority of the academic knowledge on Blue/Green Infrastructure has been generated to fit with the requirements of the global North region and the western countries (Hamel and Tan 2022). Taking an Asian/Chinese angle to these climate related issues is necessary and probably beneficial to reduce cities' vulnerability towards climate in Asia but probably other places around the globe as well. These papers can also be divided into various categories according to the direction the authors took and the elements they wanted to highlight in their work. The majority of these papers (5) are investigating the multi-benefits Sponge Cities are offering, (3) of them are looking at the efficiency by evaluating the effects of the solution. In addition, (2) are exploring the drivers for the construction of such projects, for governments, investors, developers and users for instance. The last (2) documents are cost related analysis, examining the cost effectiveness and social cost of Sponge City construction. The details of these different papers used during this analysis are referenced in Annex **(Table 10)**.

2.1.2 Data Analysis Strategy

In order to define the true meaning of the Sponge city concept, this analysis will be divided into different parts. The first part of the Analysis 1 will be based on official documents delivered by the Chinese Ministry of Housing and Urban-Rural Development (MHURD) and relevant literature about Sponge Cities. This phase will help to define the true meaning of the concept and the differences it has with other similar approaches aiming at mitigating the effects of climate change by using natural solutions. After gathering the relevant data, with the help of the General System Theory (GST), the thesis will identify the different systems and subsystems of a Sponge City that will be needed for the rest of this paper, notably to guide the Analysis 2 and the realization of the Analysis 3. The application of this theory will make the understanding of the Sponge City Concept easier, as well as more comprehensive and structured for the readers and users. The knowledge acquired, thanks to the literature review conducted and the use of the GST will be materialized into different figures to characterize the different interactions and links between the components.

The main limitation of this analysis, which can be encountered in similar work having a look at specific topics embodied and associated with a country like China is the language barrier. Indeed, navigating and translating data from Chinese to English is time consuming and it is possible that, regarding the methods used, some relevant information shared by the Chinese Government have been missed. On top of this, the restricted access to scientific papers can also lead to gaps in my research.

2.2 METHODS: ANALYSIS 2

While the analysis 1 used a mixed-method of scientific articles and Gray Literature Review by using governmental websites and Web of Science, the Analysis 2 will take another pathway by looking at the “Gray literature” only. Indeed, the use of Web of Science provides an academic point of view on the researched topic, which is essential. However, the gray literature review will contribute to offer another perspective, representing the drivers and challenges encountered by the professional world. The idea with the analysis 2 is to have a look at the work and more particularly at the different indexes produced by the major engineering, consulting, planning companies as well as associations, NGOs and governments’ participation in the field. The selection will focus on related topics to Sponge Cities like water management, biodiversity, resiliency and similar terms that will be described later.

After testing keywords in both Google and Google Scholar, I chose to work with Google due to the fact that Google Scholar is more academic oriented. This method was given too many research papers, which is not the purpose of this analysis. In order to obtain satisfaction with the results, and try to have a holistic view of the sponge city as well as covering its different aspects, an array of keywords composition have been searched. Starting by the core of the topic with “Sponge City Index”, “Sustainable city Index” and “Resilient city Index”. To then, breaking it down to more specific terms such as: “Urban biodiversity Index”, “Urban water management Index”, and “Urban liveability Index”. All these terms are linked in two ways to each other. First, by the utilization of “Index” to generate results on assessment framework to take inspiration from their indicators. Secondly, with “city” or “urban” to keep a specific scope. The search targeted the first 10 results (equivalent to the first page) of each different part, which is equal to 60 links in total. The phase 2 permitted selecting the different links according to their titles and the small description, narrowing it down to (17) results. After reviewing the different links, the ones that were not respecting the different inclusion criteria, consisting of: (1) the availability of the document, (2) its origin, being non-academic delivered by a well-known company or institution, and (3) providing an index with defined indicators. This last phase filtered the documents to (6) results that will need to be further reviewed. The selection of indexes will allow to evaluate different aspects of the sustainability or resiliency of a city according to different angles, providing a wide range of indicators to pick from. The literature search and selection process is being described in the figure below **(Figure 5)**.

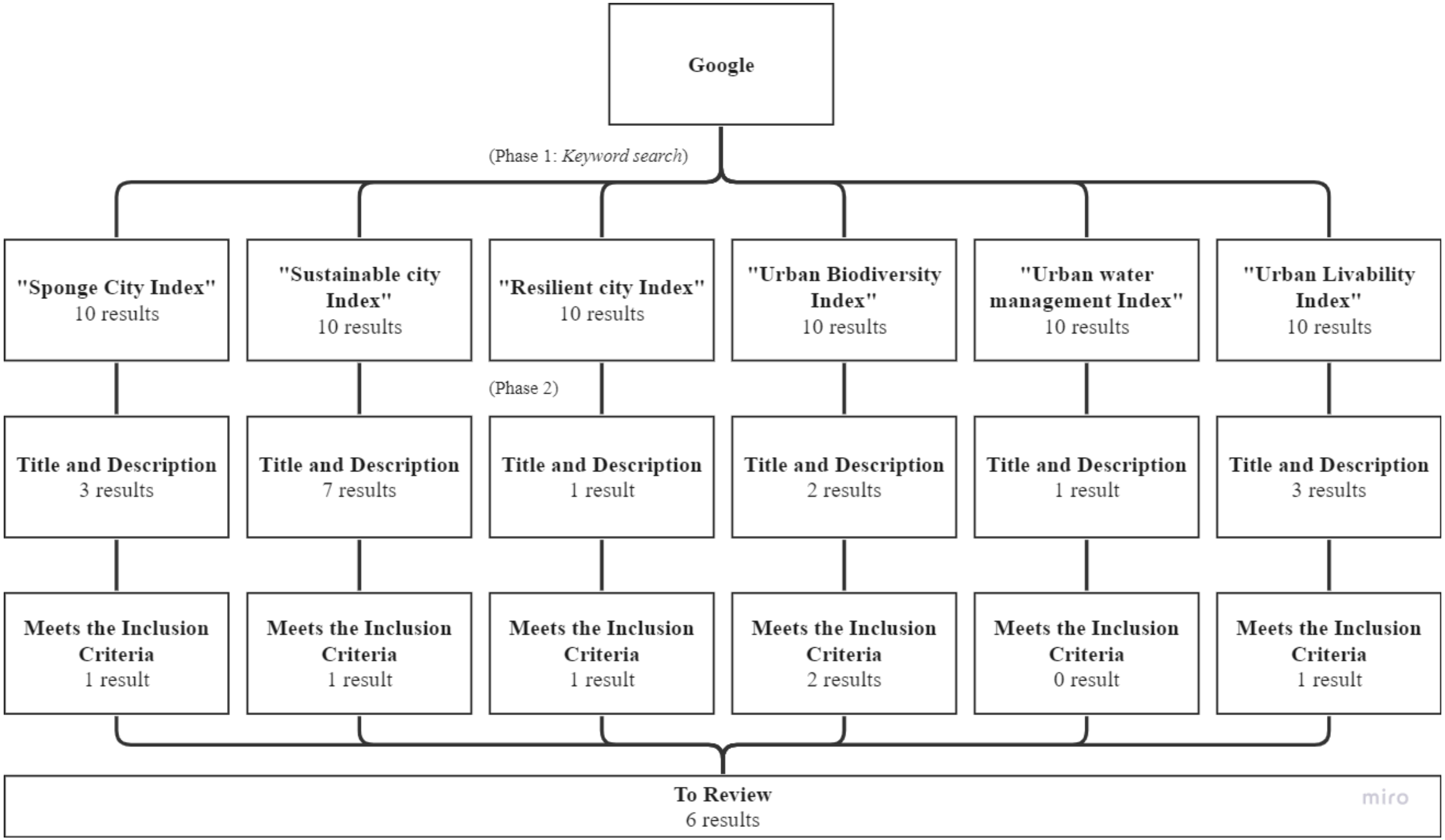


Figure 5: Literature search and selection process divided into several sections, each of them (6 in total) is representing a search

2.2.1 Bibliography

All the selected indexes are identified to be used in an urban environment and the great majority of them were delivered by well-known institutions or companies like the United Nations, Arup, the CBD, the European Environmental Agency, the Rockefeller Foundation or The Urban Taskforce, a non-profit organization representing Australia's most prominent property developers and equity financiers. These indexes are relatively recent, nine years ago for the oldest one. This parameter is important to make sure that the challenges and indicators addressed in those tools are still up to date and relevant to look into. In terms of geographical impact, half of them are intended to be applied in a specific region of the world and the other half, aims to be carried out around the different cities around the world. According to the type of indexes, they can be divided into two different categories. The ones that are looking into multiple dimensions (2 indexes). For instance, (The Rockefeller Foundation and Arup 2014) investigates four dimensions to assess the resiliency of a city, it is looking into "Health and Well-being", "Economy and Society", "Infrastructure and Environment", "Leadership and strategy". The (UNIDO 2017) are using the Sustainable Development Goals (SDGs) to evaluate the sustainability of cities. On the other side, the other indexes (4) are investigating one particular area (anthropocentric, biodiversity, sponginess). The details of these different papers used during this analysis are referenced in Annex **(Table 11)**.

2.2.2 Data Analysis Strategy

After defining the different systems and subsystems of a sponge city in the previous analysis, this chapter aspired to take inspiration from the indicators and grading system used in the selected indexes to apply them or take inspiration from, in order to realize a Sponge City Assessment Framework. Further investigations on the indexes will permit a comparison of their approach and identify the important elements as well as emphasised their strengths and weaknesses regarding of what a Sponge City is trying to achieve. Another element that could guide me into my work is the level of difficulty to find the data for one indicator. Indeed, since this thesis seeks to produce a simple Sponge City Assessment Framework that can be applied easily by municipalities around the world, the accessibility to the data will be a parameter taken into account for the selection of indicators.

The access to possible relevant indexes has, in rare cases, been compromised, avoiding having a closer look at the paper and so on excluding them from the results of the final selection.

2.3 METHODS: ANALYSIS 3

The analysis 3 aims to answer the last sub-question: How can the sponge city assessment framework help for decision making regarding the urban water management? It will combine the knowledge acquired with the two previous analyses. This final analysis will bring the final product, the Sponge City Assessment Framework. In addition, this section will also provide a handbook of the indicators comprised in this framework. Different sections such as a description of the indicator, the calculation method as well as the way of getting the data with some links to websites or which institutions to reach. This catalog is also providing the grading system with different level of points based on the performance of the studied city.

ANALYSIS 1

The introduction showed us that the effect of climate change will be experienced all around the planet. Some places more than others, due to their geophysical location or due to their level of preparedness for instance. Cities, with their density, are one of them. The change in land use, as a consequence of a growing population as well as the rapid urbanization and the natural development following this, made of cities, one of the main actors to climate change but also one of the most vulnerable places towards it. Urbanization transformed the natural landscape and diverted water flow lines to expand cities and respond to social and economical development. In the process, artificial methods to control water were implemented, replacing the natural infrastructure into canals, sewer systems and dams for instance (Scalenghe and Marsan 2009). However, this system has its limits, especially when the growing population in cities is combined with the under-sized infrastructure and the increase of more powerful and frequent events (Sim and Balamurugan 1991; Van der Bruggen, Borghgraef, and Vinckier 2010). To overcome these challenges, new concepts emerged since the end of the previous century, promoting the use of natural solutions. In addition to relieving the traditional system to prevent flooding in cities, these natural solutions are advocating many side benefits in terms of hydrology, but also for nature and people. The Analysis 1 which aims to answer the first sub-question: "*By using the General System Theory which key elements and components of the Sponge city concept can be emphasized?"* will in this chapter, start by introducing the different practices around the world to manage water, based on green and blue infrastructure. Another section will then have a closer look the central topic of this thesis, the Sponge City Concept, to then finish off by identifying the different Systems and subsystems of the Sponge City Concept with the help of the GST (General System Theory).

3.1 Urban Water Management Practices

This section aims to introduce the different practices to manage stormwater with the help of natural solutions. The concept of working with nature started in the 1970s with the Best Management Practices (BMPs) and was describing a structured approach to control stormwater pollution. Based on this, the Low Impact Development (LID) was introduced a few years later, followed by Sustainable Urban Drainage Systems (SUDs). Another concept, developed by the Australian government, the Water Sensitive Urban Design (WSUD) came out in the 1990s. These concepts, developed by developed countries in North America, Europe, Australia and New Zealand are still in the development stage and are being implemented at a small scale only (Fletcher et al. 2015; Nguyen et al. 2019; Xia et al. 2017). The most recent concept, the Sponge City Concept launched by China in 2014/2015, represents a new approach, which takes the side of the developing countries. These concepts might not be the only ones talking about sustainable urban water management practices, but they are representing the most cited terms identified from the systematic literature review.

Best Management Practices

The term "Best Management Practices" found its origins in North America in the 1970s and was referring to pollution prevention activities in Canada and the US (Fletcher et al. 2015; Xia et al. 2017). A few years later, BMP went from a method aiming at controlling plant site runoff, spillage, sludge or waste disposal to a concept that aims at answering a gap encountered in urban stormwater treatment at a national scale (Fletcher et al. 2015). The concept evolved and a more clear definition appeared, describing BMP as a technique, process, activity or structure to reduce the pollutant content of stormwater discharge and linked non-structural methods like prevention and good maintenance to structural deployment with bioretention systems and green infrastructure (Fletcher et al. 2015). Nowadays, both non-structural and structural BMPs are used worldwide and have inspired other concepts in North America but also in Europe, Australia and New Zealand (Fletcher et al. 2015; Xia et al. 2017).

Low Impact Development

Low Impact Development practices took inspiration from the BMPs. This concept, which uses or mimics natural processes to minimize the cost of stormwater management, has been adopted by the United States and New Zealand since the 1990s (Nguyen et al. 2019; Fletcher et al. 2015). This principle refers to practices aiming at preserving, restoring and creating green spaces in order to manage stormwater and provide habitat, flood protection, cleaner air and cleaner water. LID practices are characterized by the implementation at a local scale, providing a solution with a lower impact than the normal practice, located at or near the source of runoff (Fletcher et al. 2015). It is both intended for land development and land redevelopment. Today LID practices are being used in New Zealand and North America mainly, as a solution to reduce impacts of built areas and promote the natural movement of water (Fletcher et al. 2015).

Sustainable Urban Drainage Systems

In Europe, the UK has been the first to introduce the use of natural solutions to address stormwater pollution and flood hazards (Nguyen et al. 2019; Xia et al. 2017; Fletcher et al. 2015). At the beginning of the 1990s, the first guidelines on technical control options were published. In UK practice, SUDS are quite similar to the LID approach previously described. It consists of a range of technologies and techniques to drain stormwater and surface water by using sustainable solutions, replicating the natural flow of water (Fletcher et al. 2015). SUDS, use a sequence of techniques such as source control methods, pre-treatment steps with vegetation or filter trenches, retention systems and infiltration systems. Together, they are forming a management train that combines different solutions that deal with water quantity and water quality (Fletcher et al. 2015). Nowadays, SUDS are integrated in UK development projects, especially in Scotland, where it has been mandatory in most new development projects and written in the Scottish Water Environment and Water Services Act since 2003 (Fletcher et al. 2015).

Water Sensitive Urban Design

The term WSUD was first introduced in the 1990s in Australia but the project was initiated in the 21st century. This concept on top of using planning and design methods that aims to minimize the hydrological impacts of urban development on the surrounding environment, bring a wide range of benefits. WSUD is not only focusing on stormwater management control but targets also water quality improvements, water recycling and maximizing visual and recreational amenity so that cities become more sustainable, liveable and resilient (Nguyen et al. 2019; Xia et al. 2017; Fletcher et al. 2015). Today, the term WSUD crossed the borders of Australia and is being used in the UK and New Zealand and has inspired other concepts as well (Fletcher et al. 2015).

3.2 Defining a Sponge City and its Components

The Sponge City Concept is relatively new to the field, introduced for the first time by the Chinese government in 2013 (Y. Li and Kim 2022; She, Wei, and You 2021; Nguyen et al. 2019). The government launched a first batch of 16 urban districts in 2015 and a second one of 14 urban districts a year later, representing various landscape and climate conditions (Nguyen et al. 2019; Xia et al. 2017). With this concept, China’s ambition is to create a new kind of urban water management system adapted to a developing country like China with their local challenges (Nguyen et al. 2019; Xia et al. 2017). The national strategy is to combine LID with engineered systems (Q. Li et al. 2019) but the overall goal is to improve water absorption instead of the traditional rapid drainage approach (Y. Li and Kim 2022). Compared to the previous concepts presented earlier, Sponge Cities are covering a greater scope, addressing urban water problems and enhancing ecological conditions that can mitigate climate (Y. Li and Kim 2022). Today, Sponge Cities are still at an early stage, but the Chinese government has a vision and has already financed numerous pilot cities. The next section will have a closer look at all the different aspects of the Sponge City.

3.2.1 Why China needed this

From the 1970s until now, China has experienced rapid urbanization due to the movement of the rural inhabitants towards urban regions (Fan and Matsumoto 2020; Y. Li and Kim 2022; She, Wei, and You 2021; Nguyen et al. 2019), concentrating 90% of the population in East and Middle China giving rise to megalopolis cities whose population reached 10 million (Xia et al. 2017). This trend, in addition to the already particular climate most Chinese cities are experiencing during the monsoon season (Chan et al. 2018), facing more urban pluvial flooding (Y. Li and Kim 2022; She, Wei, and You 2021; Jiang, Zevenbergen, and Ma 2018; Nguyen et al. 2019). Indeed, the expansion of cities and the overuse of concrete, changed the land use from a natural landscape to urban land-use modifying the natural flow of water and the natural water cycle causing many issues in cities (Fan and Matsumoto 2020; Y. Li and Kim 2022). Rapid urbanization and urban sprawl led to the reduction of permeable surfaces, preventing water infiltration in order to evacuate stormwater and recharge the groundwater. It also reduced the landscape capacities to retain rainwater during a storm and increased the total water runoff, flood peak, flow rate and pollutant load which aggravate urban waterlogging and urban drainage systems (Fan and Matsumoto 2020; Y. Li and Kim 2022; She, Wei, and You 2021). However, the increase of impervious surfaces is not the only problem causing urban pluvial flooding. It is often that the drainage systems of the Chinese cities are not well designed for the capacity of their cities, many of these drainage systems are outdated and are operating in exceeding conditions for what they are initially designed for (Fan and Matsumoto 2020). Which is the trade-off of their fast development and the inability for the traditional engineered infrastructure to keep up with the growth rate of the urban centers. On top of these conditions, climate change may further increase risks of flooding due to more frequent and more powerful events, increasing the vulnerability of cities (Fan and Matsumoto 2020). During the last decade, many Chinese cities have experienced severe flooding causing major economical loss but above all, harmed mentally and physically the population. Causing great inconvenience to the life of urban residents restricted the development of the city and in the worst cases, causing the death of citizens during the more powerful events (Chen and Chen 2020; Fan and Matsumoto 2020). In terms of numbers, the collected data shows that out of the 654 Chinese cities studied, 641 are exposed to frequent floods (Jiang, Zevenbergen, and Ma 2018). Another study conducted by the Ministry of Housing and Urban-Rural Development (MHURD), in 351 Chinese surveyed cities over the period between 2008 and 2010, 62% suffered from urban pluvial flooding (Chen and Chen 2020; Jiang, Zevenbergen, and Ma 2018). These elements could also be linked with another study, which shows that over 90% of Chinese which have integrated an urban flooding mitigation strategy based on traditional infrastructure (i.g. floodgates, concrete infrastructure, pumping stations and stormwater pipe networks) are showing an incompatibility to accommodate unplanned urban expansion due to the fact that the principles mentioned before relies on rapid drainage to downstream outlets (Fan and Matsumoto 2020; Wang et al. 2022). These methods, relying on impervious urban land surfaces and engineered systems require material production and can have a heavy environmental impact as well (Fan and Matsumoto 2020). The need of the Chinese government to manage all the issues they are facing, called for the establishment of their own concept. Inspired by other international approaches, the Sponge City Concept aims to be adapted to the particularity of their climate and their cities. The numerous urban floods Chinese cities have experienced and are experiencing are resulting in several economic damages, affecting water quality and quantity of water supply. With the wasting of water resources by discharging the stormwater as wastewater is preventing the recharge of the groundwater on top of the over exploitation and over consumption exceeds the amount of local water resources leading to water shortage and water-scarce city (Wang et al. 2022; Jiang, Zevenbergen, and Ma 2018; Nguyen et al. 2019). To sum up, the Sponge city initiative has been pushed by the current situation their cities are in. Due to urban pluvial flood disaster, to urbanization, to urban development practices and patterns, to urban stormwater management and due to climate change (Jiang, Zevenbergen, and Ma 2018). Following this part, the following section will explain the principle of the Sponge City and on which components its philosophy is based on.

3.2.2 The philosophy behind this: living with the flood

The Chinese concept is clearly taking inspiration from the other water management concepts based on natural solutions like the LID, WSUS or SUDS for instance (Chen and Chen 2020; Fan and Matsumoto 2020; Lashford et al. 2019; Y. Li and Kim 2022; She, Wei, and You 2021; Chan et al. 2018; Nguyen et al. 2019). However, it brings its own parameters and guidelines adapted to their cities and their situation. The first requirement of this concept is to absorb and store 70% of the rainfall to be utilized locally when needed (MHURD 2015a; Lashford et al. 2019; Chan et al. 2018). To reach this point, the Sponge City Concept will rely on Green/Blue and Gray infrastructures, to be more precise, the philosophy behind this promotes the following principle: “Green first, then Green and Gray combination” (MHURD 2020b). On top this slogan, the following six key words: “Infiltration, Stagnation, Storage, Purification, Utilization and Discharge” are used as important principles, representing the core of the concept (Lashford et al. 2019; Y. Li and Kim 2022; Jiang, Zevenbergen, and Ma 2018). Moreover, because the concept is advocating multi-collaboration and multi-objective integration (MHURD 2022; Chan et al. 2018), it should protect the natural landscape (mountains, forests, rivers, lakes, grasslands…), maintain their services (Infiltration, stagnation, evaporation, and hydrological characteristics) to preserve or restore their abilities to absorb, purify and store water. By promoting the construction of Sponge Cities, it aims at (1) improving the quality of urban ecological environment, (1) preventing and mitigating the urban floods, (3) enhancing and providing high quality ecological infrastructures as well as (4) reinforcing the sense of happiness of the population (MHURD 2018; Y. Li and Kim 2022). In terms of multi-objectives, because the idea is to reduce flood risks in a first place but also reduce water shortage, urban heat island, improve ecological patterns and other side benefits. It necessitate the collaboration of different Ministries at the national level (Ministry of Housing and Urban-Rural Development, Ministry of Water Resources and Ministry of Finance) but also the collaboration of different entities (landscaper, architect, road planner, engineer, etc) (see **Figure 6**) (MHURD 2015a; 2020b; Chen and Chen 2020).

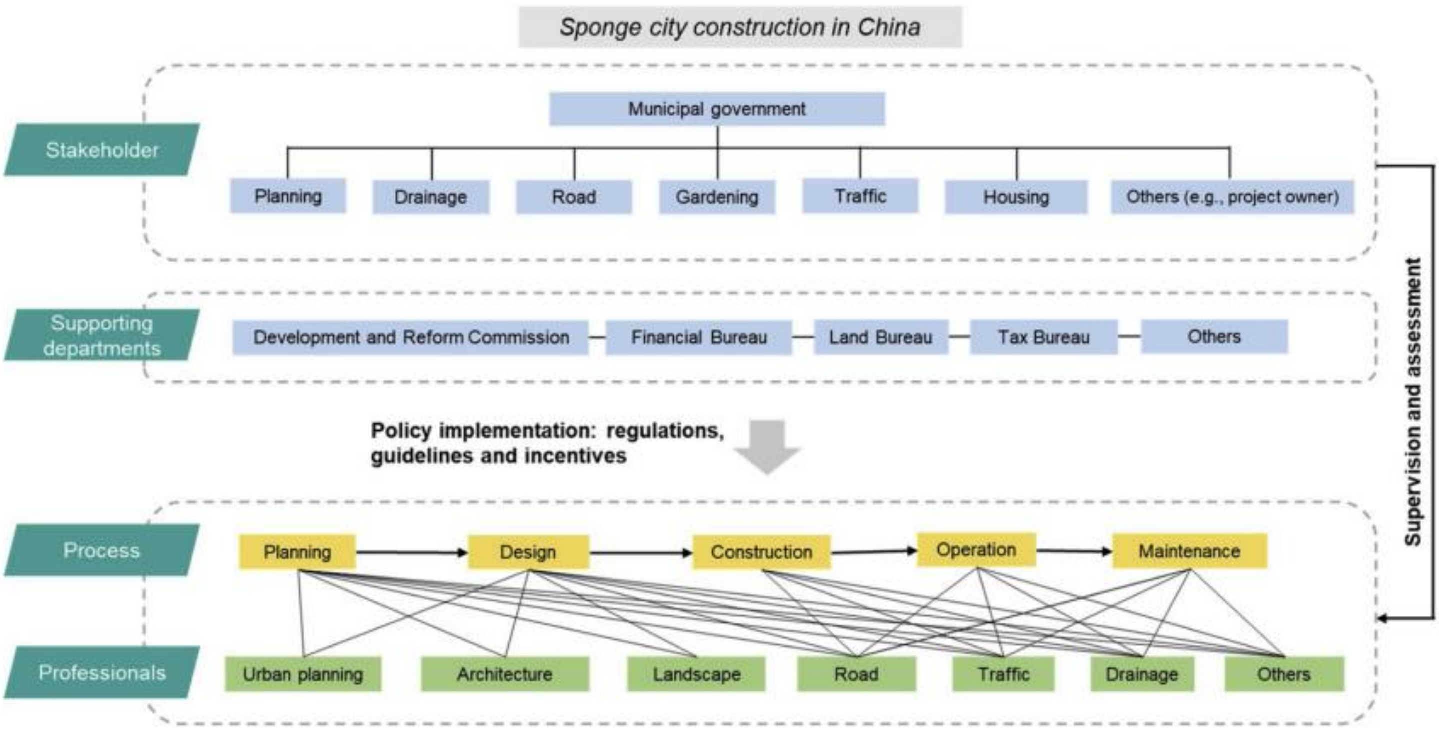


Figure 6: The inter-agency collaborations during the SPC construction from He et al. (2019)

Compared to the other concepts, the implementation is not only being implemented at a micro-scale, meaning the local scale with projects executed at strategic points. But also at a meso scale, by combining the micro scale projects and looking at larger river basins, watersheds (Nguyen et al. 2019). The name "Sponge City" is not anecdotal to describe this concept. Indeed, as we can see with the figures below (**Figure 7 and Figure 8**), the city is showing two different faces. On the figure 8, the photo is showing an urban park, which can be, used during the majority of the time in the dry season, and on the figure 7, the same park during the wet season (monsoon) after a major rain event, which flooded a good part of the area. The concept is promoting a hybrid landscape fulfilling multi-purposes, for Water, for Nature and for People. On top of accepting the flooding and leaving some areas in the city dedicated to store water for some time, we can see that they have also adapted to climate by creating elevated pathways and higher zones to still be able to use a portion of the park even after heavy rainfall.

Figure 8: Jinhua Yanweizhou Park during the dry season (Turenscape, 2014)

Figure 7: Jinhua Yanweizhou Park during the wet season or after a major rain event (Turenscape, 2014)

The philosophy behind the Sponge City gave a good overview of the concept and what is making it different from the other similar concepts but the last section will have a closer look at these differences. As a logical continuation of this section, the next ones will highlight the objectives the Sponge City is devoted to reach, in terms of Water, Nature and People.

3.2.3 Objectives: in terms of Water

The Chinese Government is referring to Sponge Cities to describe the role of buildings, roads, green spaces and water systems in absorbing, storing, purifying the stormwater and recycling the stormwater when needed through green infrastructure applications. By (1) controlling the urban flooding disasters, (2) enhancing the water quality in urban areas, (3) recycling stormwater and (4) create a pleasant city micro climate, the measures adopted will provide many benefits for the urban water circulation system, preserving or restoring ecological infrastructures and create a high-quality living (MHURD 2015a; Nguyen et al. 2019).
In terms of water, some objectives are clearly defined like the overall goal for a Sponge City, which is to absorb 70% of the rainfall in order to be stored and re-use locally when needed (MHURD 2015a) or green area rate in newly built and rebuilt areas (MHURD 2020b). However the Ministry of Housing and Urban-Rural Development is not only giving construction guidelines, they have also delivered other documents stating the objectives of their concept. The documentation selected with the help of the literature review highlighted the focus the government where making about creating demonstration work that adheres to the principle of simplicity, applicability and adapting the measure to the local conditions. The mentioned principles are aiming to solve urban waterlogging, rainwater collection and utilization, the treatment and purification of black odorous water as well as revealed the city from urban heat island effects and preserve nature (MHURD 2015a; 2021). One way to look at their interests when building a Sponge City is to have a look at what they are measuring. The "Sponge City Construction Performance Evaluation and Assessment" and other documents (MHURD 2016; 2015a; 2018), are insisting on Water ecology, Water Environment, Water Resources, Water Security. The following table **(Table 1)**, which has been adapted from the "Sponge City Construction Performance Evaluation and Assessment" document, is presenting the indicators related to water. This table is representing the Chinese government's interest in water-related parameters.

Table 1: A presentation of the important water-related parameters according to the Chinese government regarding the Sponge City objectives (Adapted from (MHURD 2015))

Category	**Indicators**
Water Ecology	• Total annual runoff control rate • Ecological shoreline restoration • Groundwater level • Urban heat island effect
Water Environment	• Water environment quality • Urban surface source pollution control
Water Resources	• Rainwater Resource Utilization • Leakage control of pipe network
Water Security	• Prevention and control of urban storm flooding • Safe Drinking Water

Because the Sponge City is a national project and is being implemented in many cities in China, representing different climates and topographies, the adaptability of the municipalities to the local conditions are essential to the development of the concept. The country is large and the national guidelines cannot be applicable for the entire country in terms of water objectives. For instance, water-scarce areas should give more consideration to rainwater collection and utilization, and the scale of the water storage and storage tanks should match the rainwater utilization capacity (MHURD 2022).

3.2.4 Objectives: in terms of Nature

The multi-objectives of this concept is also allowing multi-benefits. Flood risk management should not be seen as the main goal of the Sponge City but more as one of the objectives the concept is achieving. In fact, the concept is based on the understanding of nature to protect the city, giving Nature good conditions to thrive will provide better protection towards floodings. The Ministry of Housing and Urban-Rural Development are promoting conservation and ecological restoration of rivers and lakes, respecting the natural circulation and adapting the local infrastructures, according to the local conditions. Giving priority to the natural infrastructures and reasonably controlling development intensity (MHURD 2016). Regarding the design, the planning and the construction phases priority should be given to natural bodies of water, and make sure the natural vegetation and biodiversity remains untouched in the process of urban development. In the case of the restoration projects, biodiversity and the creation of natural habitats as well as the construction of shoreline and water bodies should not be oversimplified according to the (MHURD 2018). Moreover, it is stated that during the implementation, attention should be given to the surrounding environment, in particular during the excavation of the ground to avoid the destruction of natural habitats (MHURD 2020a).

In addition to these requirements, the government is providing more technical guidelines for the construction of a Sponge City. For instance, it is stated that the utilization of the area under the green space should not exceed 10% than the total area in order to maintain the normal condition and not affect seepage, stagnation and storage of the rainwater (MHURD 2020b). The guidelines are promoting the use of natural materials for embankments, natural soil slopes will be planted as much as possible, respecting the local constraints. Native plants will be able to consolidate the slopes and should cover 95% of the surface it minimum. The concept enforces the use of ecological revetment for the riverbanks, focusing on a natural transition between the water, the shoreline and the land. In addition, it is also mentioned that if the surroundings of the Green/Blue Infrastructures are adapted to provide recreational facilities such as walkways for instance, the infiltration rate of these covers should not be less than 90% (MHURD 2020b).

3.2.5 Objectives: in terms of People

In terms of objectives for the citizens, the guidelines are not promoting any numbers and indicators to reach. However, they are highlighting some principles. Advocating an harmonious development between people and nature, putting the construction of Sponge Cities as a key project for people's livelihood aiming at participating to the general happiness of the citizens by providing a pleasant ecosystem and enhancing water-related services (MHURD 2015b). Because the concept will focus on both newly built and rebuilt areas, communities are involved in scheme design and construction supervision to encourage adapted environment regarding flood risks, enhance biodiversity and participate in liveable communities and cities (MHURD 2022). Moreover, by doing it like this, by involving the population and setting up publicity materials, citizens and especially young people can understand the role of sponge cities, raise awareness on rainwater management, on the use of water and the benefits of the conservation of the natural landscape and its biodiversity for instance(MHURD 2020a).

3.3 How is it different from the other concepts

The concepts on urban water management, which have been presented earlier in *section 3.1* are sharing the same basis. All these concepts are using Green/Blue Infrastructure and natural solutions to deal with urban floods. However, some elements are different from one to another, the sponge city covers a greater scope and due to the scale of the project, at a national level, the government is providing more comprehensive guidelines on the direction cities will have to take and how to do it (Y. Li and Kim 2022; Nguyen et al. 2019). For instance, the central Chinese Governments set some targets to achieve, by 2030, more than 80% of urban built-up areas will meet the requirements such as absorbing and using locally 70% of rainfall with the help of green infrastructure mainly (MHURD 2015b). In addition, it has been said earlier that the philosophy of the Sponge City promotes "green first, then green and gray", utilizing both green infrastructures and engineered solutions into one hybrid control system (Chan et al. 2018). Nevertheless, as seen in the objectives, the guidelines are framed in a way to enforce green infrastructures in some situations like the planning of the riverbanks and the transition between land and water which has to respect the minimum green cover percentage and other elements. The dimension, the implementation of the Sponge City concept is going through at the moment is unmatched by the other concepts, which are still implemented at a very local scale. While other concepts are focusing on the micro-scale with the implementation of local projects (micro catchment scenario), the Sponge City long-term plan is to be implemented in three scales. On top of micro implementation, the combination of projects at this scale will be combines to manage water at a meso-scale (sub-catchment scenario), and at a macro-scale (catchment scenario). Integrating micro and meso-scale projects into a holistic system is permitting interactions within the catchment, between the micro catchments, and between the sub-catchments (Y. Li and Kim 2022; Nguyen et al. 2019; Zhai et al. 2021). The figure below (**Figure 9**) is illustrating mechanisms of inter-catchments coordination. A scenario that is occurring during rainfall events when the underground pipe network is saturated (Zhai et al. 2021).

As stated in the paper from Zhai et al. (2021), Green Infrastructure to manage storm water have mostly been implemented at a micro scale, even in Sponge Cities. The theoretical concept of the Sponge City described by the Chinese government is promoting the management of water at a larger scale (catchment scenario). At the moment, the vision from the central government on Sponge Cities is somehow different from the decision taken from the local governments, who are skeptical about the efficiency of Green/Blue Infrastructure to mitigate storm water at a larger scale (Zhai et al. 2021). From a theoretical point of view, the work realized by Zhai et al. (2021) on multi-scale watershed is providing an interpretation of what the Sponge City could aim for if the vision from the central government, which is the operation at a macro-scale is respected. The ambition the central government has for their concepts at a large scale is probably the biggest difference the Sponge City concept has with the other urban water management systems. And even if the work from Zhai et al. (2021) is providing a theoretical approach and an interpretation of the concept at a larger scale, their figure (**Figure 9**) and their paper allow to understand these interactions between the different scales.

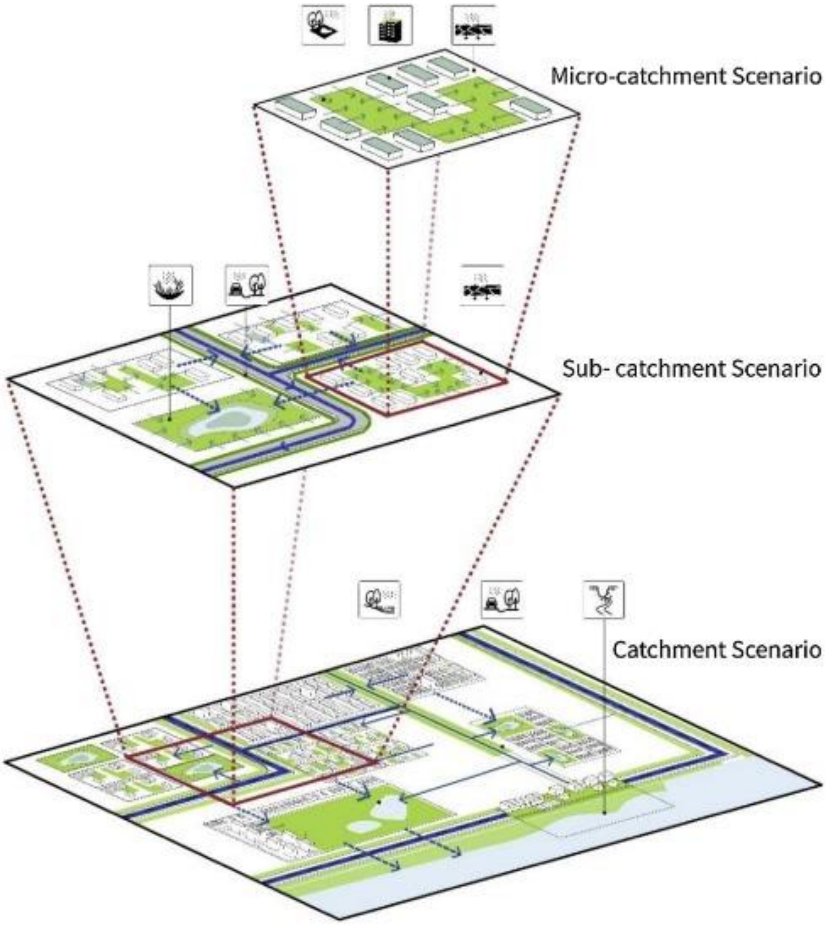


Figure 9: The typological illustration of the three mitigation scenarios covered by Sponge Cities when the other concepts are focusing on micro-scale implementation (Zhai et al. 2021)

3.4 Systems of the Sponge City concept

We have seen earlier in the report, with the analytical framework that (Von Bertalanffy 1950; 1968) describes the General Systems Theory (GST) with two types of systems, the open systems, the close systems. Open systems are the ones interacting with each other and with their environments when closed systems are the opposite. In the case of the Sponge City Concept, we have seen with the previous section (defining the different elements of the concept), that the concept is composed of various fields and requires the collaboration of different entities in order to perform and attain its goals. Indeed, the Sponge City is composed of open systems, which require interaction between the different systems and subsystems in order to solve one or many issues at the same time. In the first place, we will identify in this section the different systems based on the analysis performed earlier and the data gathered.

In order to apply the GST in a more comprehensive way and make it more visual, I will use an allegory supported by different figures. Sponge cities, its systems, subsystems, components and drivers can be associated with the development of a tree, from the seed to the leaves. The concept in itself, being the seed, needs two elements to thrive, the sun and water. The sun can be interpreted by the governance, policies and laws in favor of the concept and the water by the financing aspects. In the case of the Sponge City, the Government is the one who launched the project and set some guidelines for the cities to attain with deadlines to respect (Chen and Chen 2020). Financing, represented by water, is essential for the development of the concept. For the Sponge city, money is one of the challenges it has to face, the strategy China took is to combine financial sources (Nguyen et al. 2019). Indeed, the development of the concept demands first investments from the central government, expressed by subsidies to the selected pilot cities and potential adjustments (giving more or less) according to the advancement and the performances of the projects (MHURD 2015b). But it also required investments from the local governments and Private/Public investors (Nguyen et al. 2019).

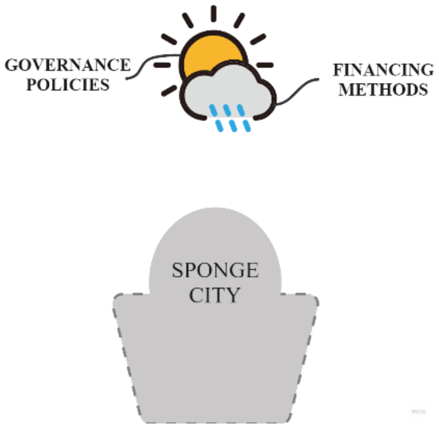


Figure 10: Illustration representing the parallel between the implementation of a Sponge city and the growth of a tree. Here, the early phase of the project is symbolized by a seed (figure from author).

To continue with the allegory, what makes the seed stronger is its roots, and as part of this concept, the roots or the drivers are giving power to justify the necessity of such urban water management. As seen in the *section 3.2.1*, in a Chinese context, the drivers are characterized by the rapid urbanization and the already complicated climate with heavy rainfall during the monsoon season. As well as land-use change by transforming the natural landscape into impervious surfaces modifying the water cycle, the already lack of infrastructure and the increase in more frequent and powerful events due to climate change. With the help of the adjacent figure (**Figure 11**), we can see that the systems (Nature, Water, People) are represented by the main branches of the tree and are connected to each other by the common core (the Sponge City). For the realization of the fig.11 and for the realization of the coming ones about the different subsystems and components. It is only a representation of the elements highlighted during the literature review and are here to have a better understanding of the principles of the Sponge City and the elements the concept is promoting. Each System is divided into subsystems, representing the specificity of this type of urban water management, but these elements will be presented in the next section.

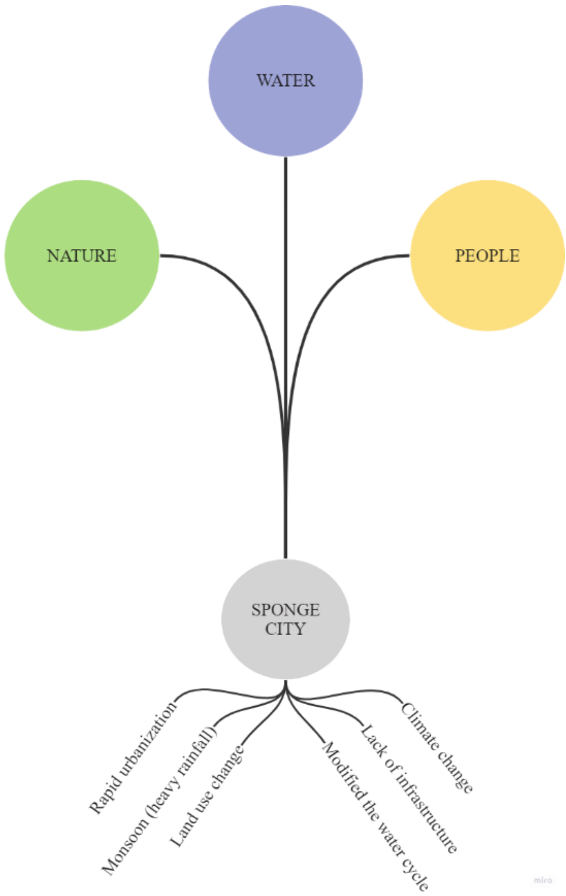


Figure 11: Illustration representing the parallel between the implementation of a Sponge city and the growth of a tree. Here, the roots are characterizing the drivers of the concept, what makes it stronger (figure from author).

3.5 Subsystems and components of the Sponge City concept

Before diving more in depth into each subsystem, the figure below (**Figure 12**), gives an overview of how the Sponge City is being described according to the data extracted during the literature review. Now that the full picture of the tree is being represented by the main branches (Nature, Water, People), the smaller branches represented by the subsystems and the leaves by the components. By representing the Sponge City system like this, as a tree, we can understand the importance of each branch and not only the Water or the People, because without one of this branch, it is not the Sponge City Concept anymore. This understanding as whole is giving importance to each components of the concept without prioritizing some of them in regards to the remaining ones.

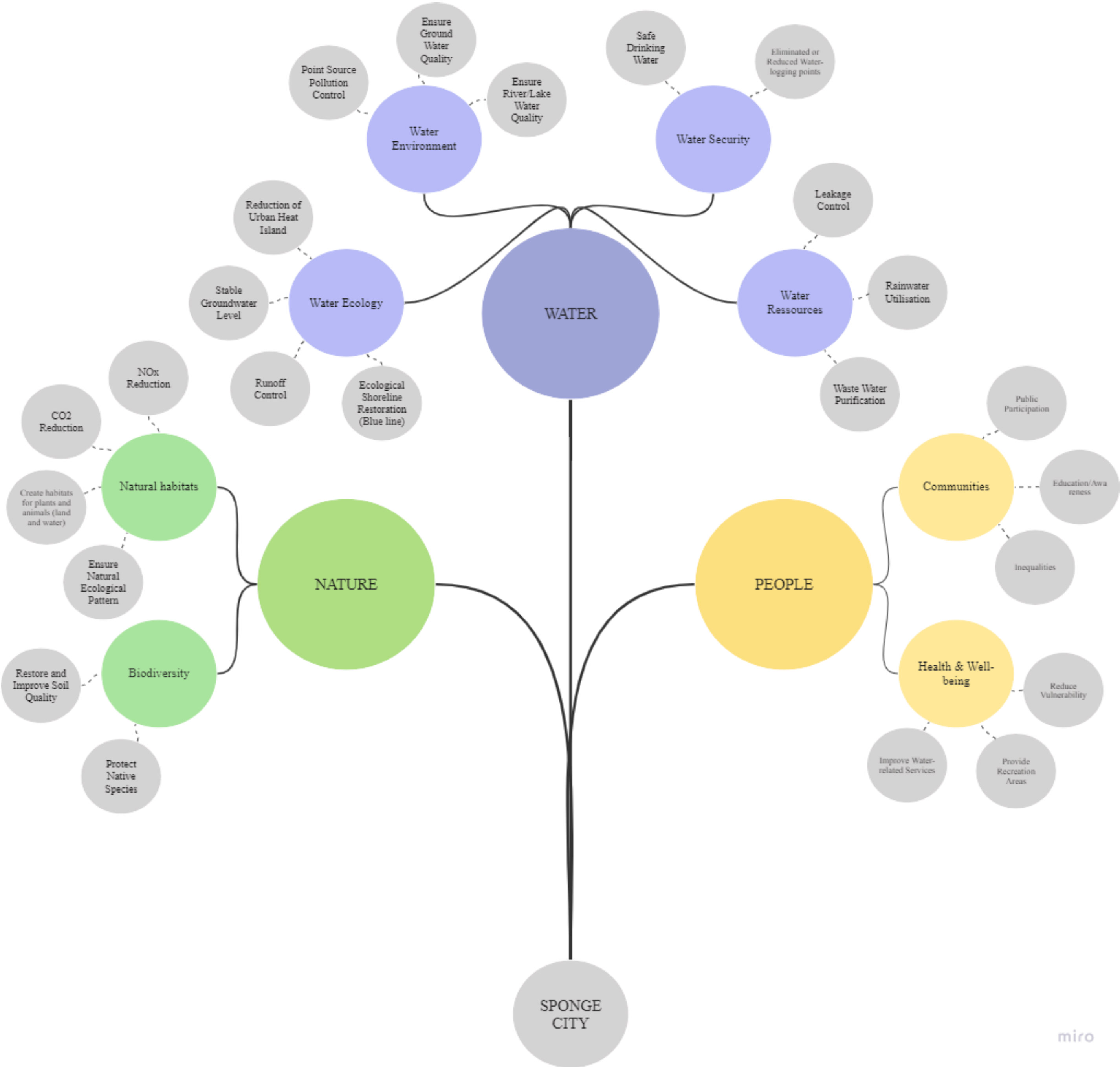


Figure 12: Illustration representing the concept as core, the systems as the main branches, the subsystems as the smaller branches and the components as the leaves (figure from author).

3.5.1 Close-up: Water

The Water systems, subsystems and components has mainly been inspired by the **table 1**, presented earlier in the *section 3.2.3*, which has been extracted from the "Sponge Construction Performance Evaluation and Assessment" (MHURD 2015a). In order to facilitate their assessment, the Ministry of Housing and Urban-Rural Development (MHURD) have divided the Water into four different categories: Water Ecology, Water Environment, Water Security and Waste Water Purification to make sure the infrastructure is ensuring the principles of Infiltration, Stagnation, Storage, Purification, Utilization and Discharge of rainwater (the six crucial keywords according to the MHURD). The concept is truly focused on trying to keep as much of the natural landscape. To protect the natural flow of water and reduce the risks of flooding. Their desire to preserve the ecological landscape is also characterized by another Chinese urban water management principle, the blue line delineation. The blue line is an important component of their planning techniques, seeking to provide an ecological buffer zone around the water bodies like rivers and lake, providing a protection to absorb the fluctuation of the water level (Lian et al. 2022). This planning principle has not been created for the implementation of Sponge Cities but has been integrated as a requirement from the Chinese Government.

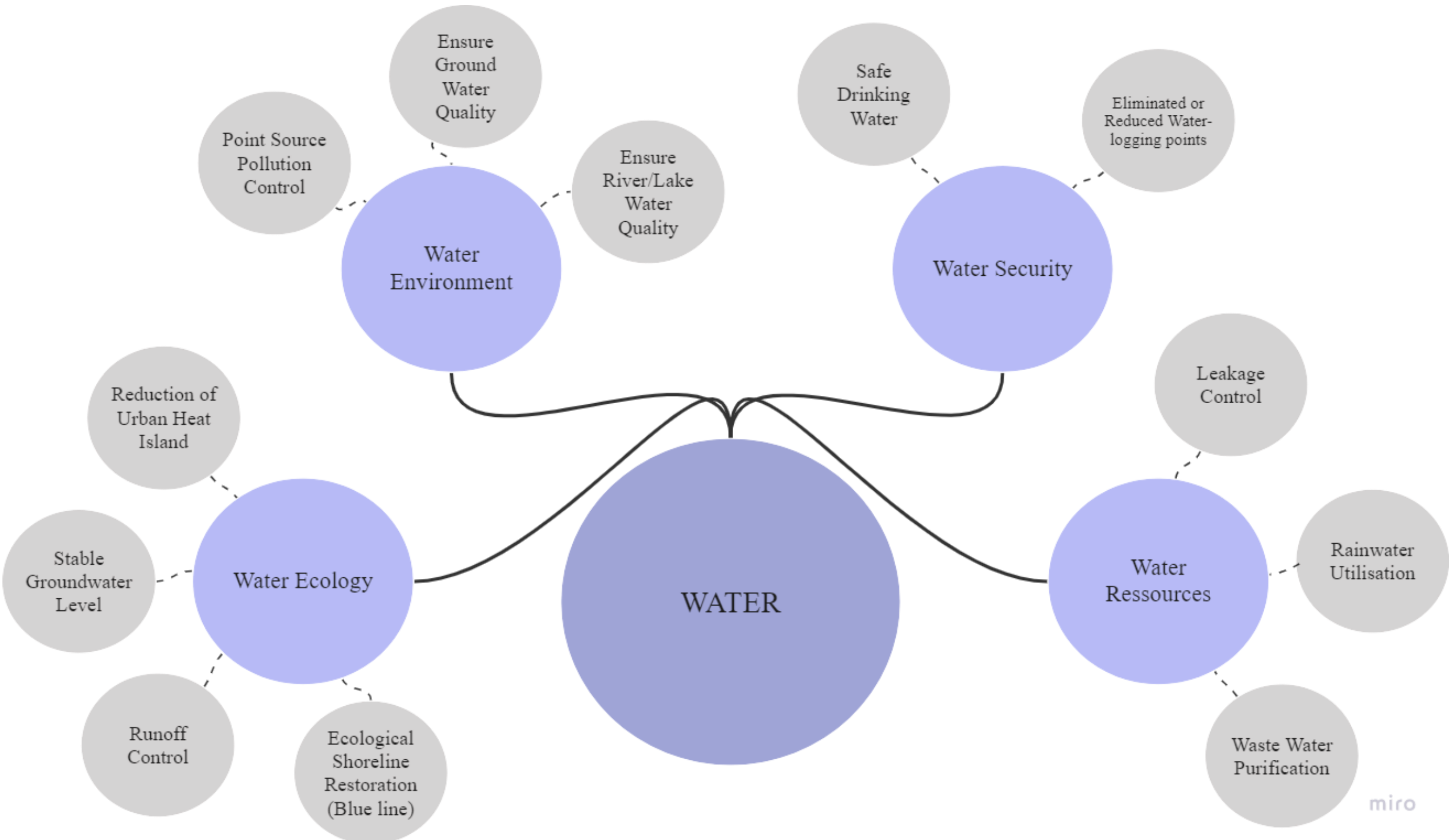


Figure 13: A closer look at the Water System, its systems and affiliated components (figure from author)

3.5.2 Close-up: Nature

The Nature system is being divided into two subsystems, “Natural Habitats” and “Biodiversity”. The Sponge City Concept relies on green and gray infrastructure but mostly on green (MHURD 2020b), preserving or restoring the natural habitats and potential habitats to help biodiversity thrive. We have also seen earlier in this Chapter that, in the guidelines, an emphasis has been put on the utilization of the native species of plants to stabilize the banks, filter the water (MHURD 2020b). The choice of using native plants instead of regular plants is highlighting the consideration the Chinese government is giving to the support of the local biodiversity and the conservation of species. They are demonstrating that the percentage of the city’s green cover is not the only important parameter to provide habitats but the quality of these green spaces need to be considered.

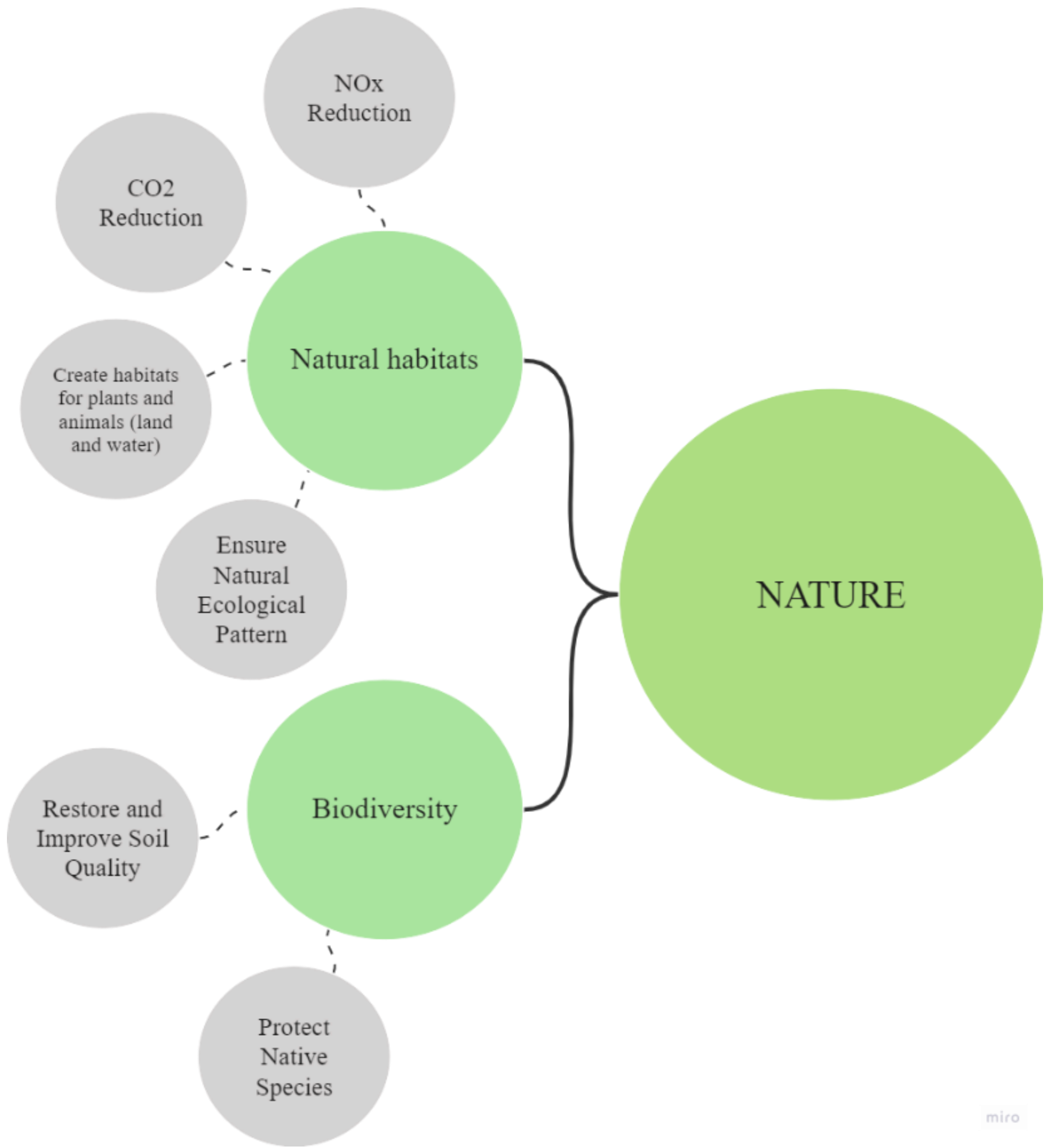


Figure 14: A closer look at the Nature System, its systems and affiliated components (figure from author)

3.5.3 Close-up: People

The People system is also being divided into two subsystems, "Communities" and "Health & Well-being". People are of course an important part of the Sponge City, the aim of this urban water management concept is indeed to reduce the risk and the cost of the urban flooding by having an holistic approach (Xia et al. 2017). In their paper, (Chen and Chen 2020), were mentioning a not sufficient involvement from the public. However in the "Notice of the General office of the MHURD on further clarifying relevant requirements for Sponge city construction" it is being strongly encouraged to involve communities and listen to their opinions during the scheme design and the supervision of the construction, especially when it is about the renovation of old communities (MHURD 2022; He et al. 2019). The willingness of the government to involve the citizens is also being characterized by raising awareness particularly with the younger generation but also all the citizens on the use of water and purposes of a concept such as the Sponge City (MHURD 2020b).

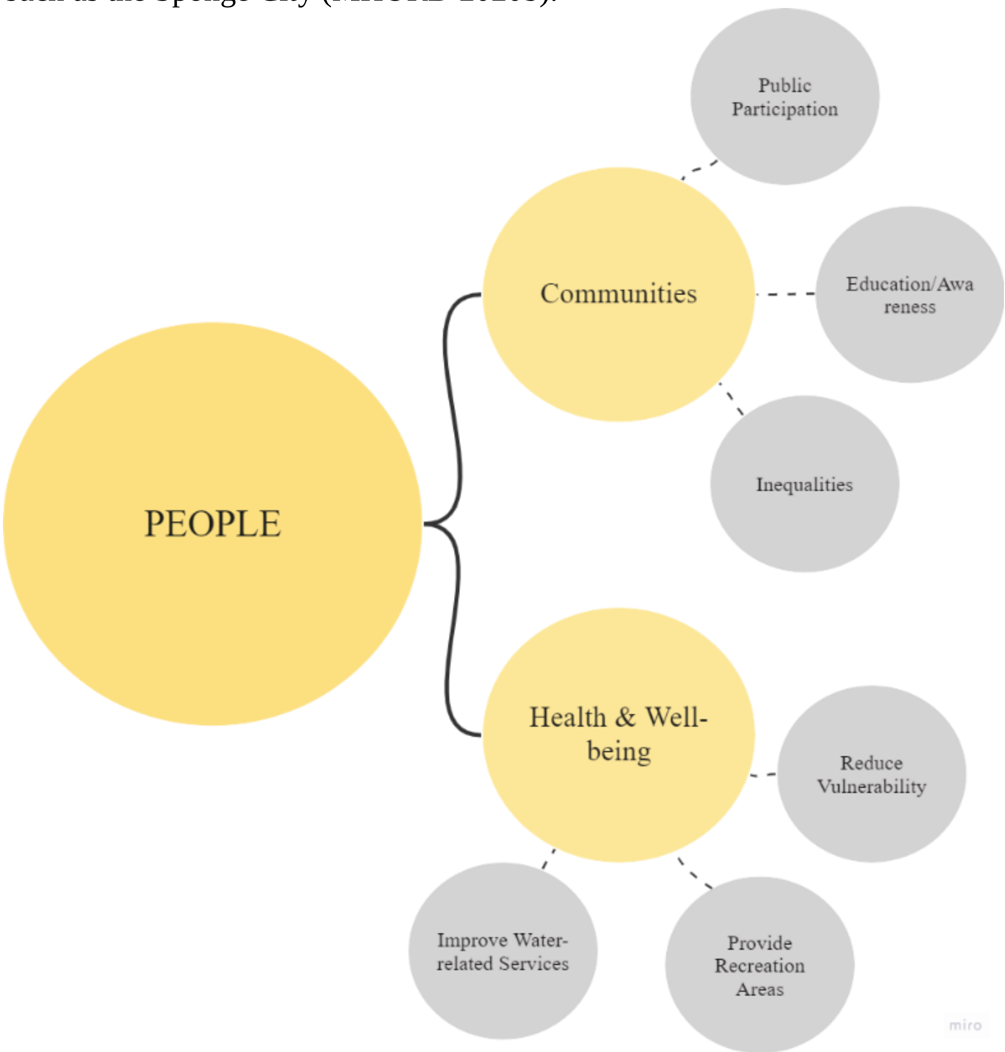


Figure 15: A closer look at the People System, its systems and affiliated components (figure from author)

3.5.4 Interaction between the components

By breaking the systems and subsystems into components, makes it easier to manage and by activating leverage points within these components, can lead to a cascade of additional changes in the entire system due to the interaction between the different components and the interaction among the subsystems (Wan Rosely and Voulvoulis 2023; Von Bertalanffy 1968). The analysis of various literature sources in the initial phase of this section (Analysis 1) has played a pivotal role in shaping the development of the comprehensive **Figure 16** presented below. It has provided valuable insights to describe the interconnectivity of the indicators, shedding light on the complex relationships and dependencies between different components. This Figure serves as a visual representation of these interactions, offering a holistic view of how modifications or interventions in one component can potentially impact other components, either positively or negatively. By mapping out these relationships, the **Figure 16** enhances our understanding of the complex systems operating within the Sponge City Assessment Framework. Moreover, the strategic use of color in the Figure provides additional clarity by categorizing the components based on the systems they belong to. This visual representation not only facilitates comprehension but also enables stakeholders to identify the systemic implications of their actions, fostering a more integrated and sustainable approach to urban development.

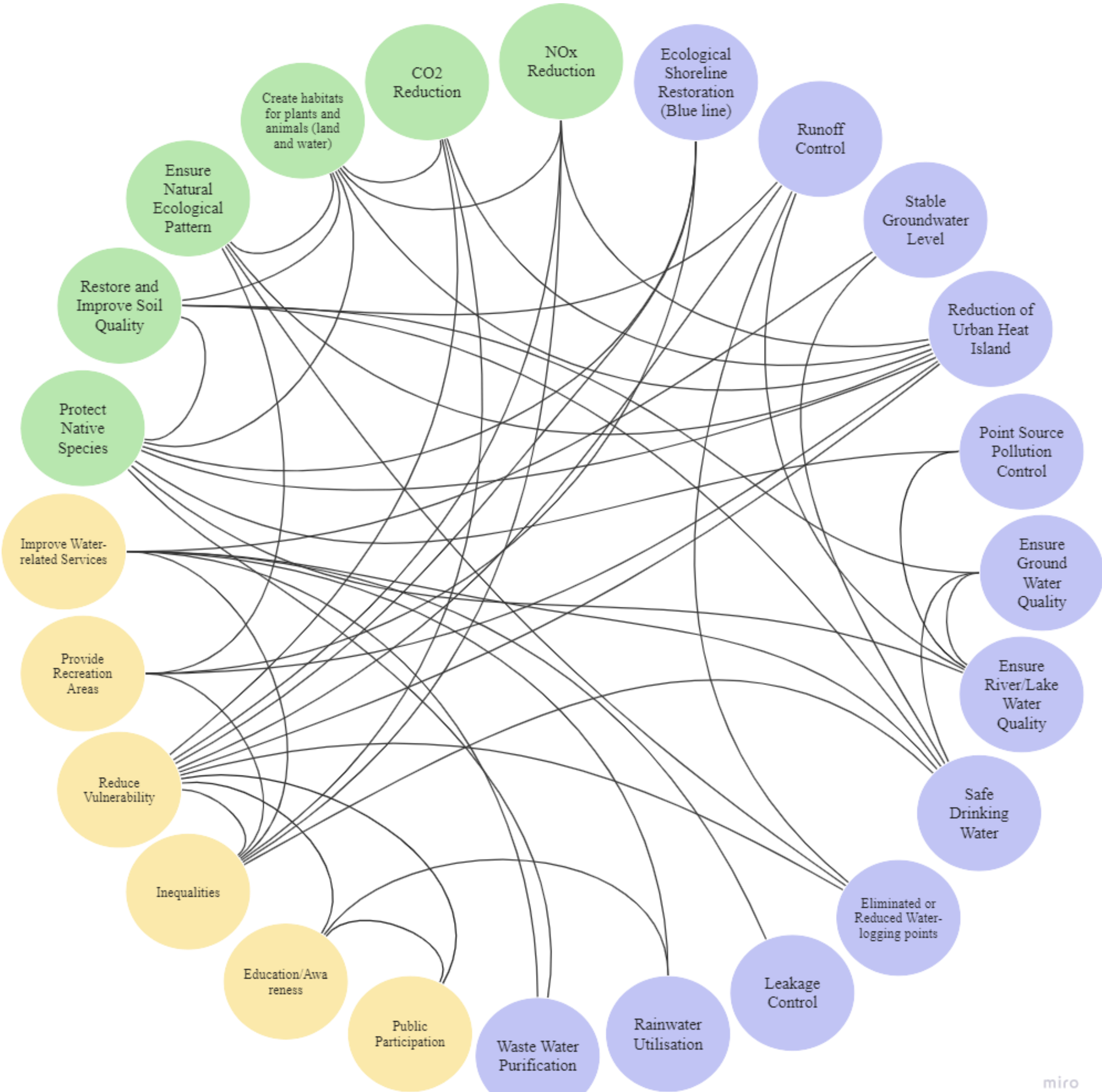


Figure 16: The Wheel of Components. Because the Subsystems and the components are interacting with each others, this figure illustrate the overall connection between them (from the author)

Based on the systematic literature review, the Analysis 1 gave a good overview of the other sustainable urban water management around the world, which are mainly coming and intended to Western countries in North America and Europe. Following this section, this thesis addressed the elements the Sponge City was focusing on and which way it was necessary for China to create a new concept on sustainable urban water management. The Asian/Chinese point of view on this topic is unprecedented if we are not including Singapore Which is an already developed country. This new eye on the field seeks to fit with the local Chinese context but could also be applied to similar developing countries facing the same challenges as China. In Southeast Asia for instance, which are in a situation similar to China, encountering urban expansion, growing population, land use change, lack of infrastructure, vulnerability to climate on top of climate change (Asian Development Bank 2009). Based on the data collected in the previous section and after having a clear understanding of the concept, the thesis investigates the interrelations of the concept with the help of the General System Theory (GST).

The objective of the Analysis 1 was to dive in more details into the Sponge City concept, finding out by what it is. The goal of this analysis was also to answer the first sub-question: *By using the General System Theory which key elements and components of the Sponge city concept can be emphasized*

With the help of the GST and the data collected, this chapter successfully identified the Systems, the SubSystems, the Components and their links. The use of visual representations with different figures assisted the words aiming for a clear and better comprehension.

However, the Analysis and understanding that this section made out of the concept, is simply based on the papers generated by the literature review. The combination of scientific papers and official documents from the Chinese governments helped to cover different angles. A subjective angle with official documents, giving guidelines at a national scale and can potentially differ from the reality and the specificity of each region or cities. And a more objective analysis provided by the scientific method of the research papers, sharing their analysis from an outside point of view. Associating these two parts gave both the official definition of the concept and the possibility to compare it with similar approaches. The Analysis 1 is limited to the gathered data.

The support from other documents, official or scientific could have slightly changed the understanding this thesis made out of the Systems, Subsystems and components. The findings resulting from this chapter are significant for the rest of the thesis, and will provide crucial information for the Analysis 2, as well as for the Analysis 3.

ANALYSIS 2

The Analysis 2, which is following and using the materials and the information collected by the Analysis 1, will have a look at different indexes on sustainable cities delivered by major companies or institutions. From the method, which has been described earlier in the report, six indexes came out. With the help of these components, this Chapter aims at answering the second sub-question: *"By using the General System Theory which key elements and components of the Sponge city concept can be emphasized?"*. In order to do this, this Chapter will be divided into two sections, the first section will start by presenting these different indexes and provide a constructive critique, identifying their strengths and weaknesses in relation to what this thesis seeks to achieve. And the second section will then identify the key elements of these indexes relevant for the Sponge City Assessment Framework like the way they have structured their index, similar indicators that are corresponding to this work and other relevant aspects. This section will be concluded by answering the second sub-question and will provide the reader with the result of the Analysis 2.

From the research method to find these indexes, two types are represented. The first type is the one having a specific interest about a field within a city, like urban biodiversity, urban liveability and sponginess of a city. The other types have a multi-objectives approach, assessing a concept, like the city's resiliency or city's sustainability.

4.1 The Global Sponge Cities Snapshot - Arup

The Global Sponge Cities Snapshot was released in 2023 by Arup to highlight the importance of understanding a city's natural ability to manage heavy rainfall (Arup 2023). Their survey ranked cities according to their natural absorbency or "sponginess". With the help of the digital mapping tool combined with machine learning they have developed, they are able to compile terrain data, green, blue and gray infrastructures to identify land use in cities' urban centers.

At the moment, their investigation is covering nine cities around the world: Auckland, Nairobi, Singapore, Mumbai, New York City, Montreal, Shanghai, London and Sydney. They have ranked the sponginess of these cities according to a framework.
This Index is only composed of one section made out of three indicators. The first indicator called, blue, green and gray infrastructure is using their digital mapping tool combined with machine learning to produce high quality land use assessment from satellite imagery. The second indicator is having a look at soil types and vegetation, with the help of the land use type of the first indicator associated with a general database indicating the composition of the soil within the region. And the last indicator is the water runoff potential, based on the soil type factor with the infiltration, they are calculating the runoff potential for 50mm of rain falling in one day.

Table 2: The table below is the representation of the different sections and indicators used by (Arup 2023) in The Global Sponge Cities Snapchot

Section	Indicators
City's natural absorbency	Blue, green, Gray infrastructure Soil Types and Vegetation The Water Runoff potential

The digital tool they have developed is providing an efficient map able to identify the amount of green, blue and gray infrastructure which then can be combined with the soil type and determine the runoff potential. The percentage given by this tool gives a good overview of the city's ability to absorb water, we can see with the ranking that cities with the highest percentage of green and blue cover are situated higher in the general ranking (Arup 2023). The use of quantitative data for their three indicators is a good point to prevent subjective assessments.
On the other hand, the fact that they are using the term "Sponge City" for their index is bringing confusion and is automatically associated with the Sponge City Concept. However, their index is only assessing 3 indicators which is too little to represent the true meaning of the Chinese concept. In addition, the database they used to determine the soil type looks quite general and could differ from the reality if samples were made directly on site. Moreover, their assessment is made based on a 50mm rain event for all the cities wherever their location on the planet. The non-consideration of the challenges faced locally is a major drawback when comparing the sponginess of a city. To bring more equity, they could have used the amount of rain corresponding to a 5 year event in the local context for instance.

To conclude, it looks like the techniques they are using for the first indicator is good to assess the land use type, however, it does not seem accessible for everyone. The second indicator is good to determine the infiltration rate however, the database they are using looks quite general and does not allow a lot of precision, however, for the purpose of creating a simple tool accessible by a lot of people, using this type of database could be a good alternative. Even if the approach is simple and limited to only a few indicators, the introduction of the term “sponginess” in an index permits a new approach and an example of how it could be done or not.

4.2 Singapore Index on Cities’ biodiversity

The Singapore Index on Cities’ Biodiversity was launched in 2008 by the Convention of Biological Diversity in collaboration with the UN environment programme and the ‘National Parks’ group (CBD 2021). The Singapore Index aims to help cities better understand how they could improve their biodiversity conservation efforts over time. This index helps cities to accomplish their biodiversity goals by assessing the city’s current biodiversity profile, by raising awareness and sensitizing the public and the citizens on the state of the local biodiversity. As well as acting as a portal for various academics, NGOs, schools and others to promote communication and collaboration through data collection and sharing mutual goals for instance (CBD 2021).

This index is dedicated to cities around the world but not only, because national and regional governments have been using it to develop their own local strategy plan. Also by city planners who used it as benchmarks for their master plan for example.
In terms of indicators, the index is composed of three sections, namely: “Native biodiversity in the city”, “Ecosystem services provided by biodiversity” and “Government and Management of biodiversity”. These sections are covered by 28 indicators (see **Table 3** below) with each of these indicators being worth 4 points. These indicators are providing a good overview of how to assess urban biodiversity. However, some indicators are quite precise and should not correspond to what the Sponge City Assessment Framework aims for.

Table 3: The table below is the representation of the different sections and indicators found in the Singapore Index on Cities’ Biodiversity (CBD 2021). None of the indicators has a weight, and they all worth the same (4 points).

Sections	Indicators
Native Biodiversity in the city (36 points)	Proportion of Natural Areas in the City Connectivity Measures or Ecological Networks to Counter Fragmentation Native Biodiversity in Built Up Areas (Bird Species) Change in Number of Vascular Plant Species Change in Number of Native Bird Species Change in Number of Native Arthropod Species Habitat Restoration Proportion of Protected Natural Areas Proportion of Invasive Alien Species
Ecosystems services provided by biodiversity (20 points)	Regulation of Quantity of Water Climate Regulation – Benefits of Trees and Greenery Recreational Services Health and Wellbeing – Proximity/Accessibility to Parks Food Security Resilience – Urban Agriculture
Government and Management of biodiversity (56 points)	Institutional Capacity Budget Allocated to Biodiversity Policies, Rules and Regulations – Existence of Local Biodiversity Strategy and Action Plan Status of Natural Capital Assessment in the City State of Green and Blue Space Management Plans in the City

Sections	Indicators
	Biodiversity Related Responses to Climate Change
	Policy and/or Incentives for Green Infrastructure as Nature-based Solutions
	Cross-sectoral and Inter-agency Collaborations
	Participation and Partnership: Existence of Formal or Informal Public Consultation Process Pertaining to Biodiversity Related Matters
	Participation and Partnership: Number of Agencies/Private Companies/ NGOs/Academic Institutions/International Organisations with which the City is Partnering in Biodiversity Activities, Projects and Programmes
	Number of Biodiversity Projects Implemented by the City Annually
	Education
	Awareness
	Community Science

The level of details of these indicators is also what makes this index strong, expressing the important elements in terms of urban biodiversity and what should be considered when assessing such a topic. In their report, each indicator is associated with the method of calculation as well as the grading system indicating the score of each value (between 1 to 5) as well as where to find or obtain this data. These components appeared to be quite useful and inspiring and could influence the final result of this thesis.
At first sight, unless the fact that some indicators are quite precise and so on not applicable for the future part of this thesis, this index provides a good tool to assess the state of the urban biodiversity in cities and what is being done for it.

The Singapore Index on Cities Biodiversity gives a good overview of how to assess urban biodiversity, some indicators appeared to be too precise. However, the Sponge City Assessment Framework could take inspiration from the grading system and the way each indicators is presented by providing a description, how to calculate it, where to get the data and the basis of scoring (CBD 2021).

4.3 The European Urban Biodiversity

The aim of the EUBI is to create a self assessment tool for urban areas. It is focusing on urban biodiversity, which they define as biological components comprising everything from singular organisms to larger forest for instance (Ruf et al. 2018).

This index, operating at a European scale is supporting ongoing project like MAES (Mapping Assessment of Ecosystems and their services) and 'EnRoute' (Enhancing Resilience of Urban Ecosystem through Green Infrastructure) project to give the opportunity to cities to gain information on biodiversity development in a European context using easily accessible and free data (Ruf et al. 2018).
The index has divided its assessment approach into two components in order to make full use of the European project, Copernicus. The first type of indicators are part of the "Core index", divided into eight indicators and are based on Copernicus products. These indicators are representing characteristics such as habitat availability, landscape heterogeneity, habitat connectivity and species density. The second type of indicators are part of the "Local index" and composed of four ancillary indicators depending on the data availability of each city (Ruf et al. 2018).

Table 4: The table below is the representation of the different sections and indicators found outlined by The European Urban Biodiversity (Ruf et al. 2018). The indicators are divided into two "sections" which are in reality, the mandatory indicators (Core Index) and the optional ones (Local Index). The data used for the Core Index is available for all European cities thanks to the Copernicus project. However, the data availability for the Local Index vary from city to city.

Sections	Indicators
Core index	C01 Proportion of permeable urban are
	C02 Proportion of protected area
	C03 Proportion of green areas
	C04 Proportion of blue areas
	C05 Length of ecotones
	C06 Art. 12 Species richness
	C07 Art. 17 Species richness
	C08 Art. 17 Habitat richness
Local Index	L01 Number of native species
	L02 Proportion of invasive alien species
	L03 Proportion of Natural Areas in the City
	L04 Access to urban green areas

The major strong point of this index is the ease to have access to the data due to the Copernicus programme. Similarly to the Singapore Index on Cities' Biodiversity, a clear description of each indicator is provided with the data source. Another element they are promoting is the use of grid cells to apply the index's score, breaking the city into smaller pieces (10ha hexagonal shape) which allow it to identify the weak points of the city (Ruf et al. 2018).
On the other hand, this index is built to be apply in the European context, making its application to cities outside Europe compromised. Moreover, the data gathered with the help of Copernicus is only available in Europe.

To conclude, this index is providing a simple assessment, less detailed compared to the Singapore Index, with data more accessible for European cities. Its affiliation with other European projects is giving even more credit to the information brought to the fore. In their report, the process they went trough is described, as well as the methodology to a gather the data for each indicators and the data source.

4.4 The City Resilience Framework

The City Resilience Index developed by Arup in 2015 supported by The Rockefeller Foundation is providing an evidence-based definition of urban resilience. Instead of comparing cities with each other, the CRI (City Resilience Index) aims at measuring the performance of cities over time. This tool will primarily be used by city governments or other interested organizations and individuals like universities and non-governmental organizations for instance. It is intended that the CRI process will also provide an understanding of the vulnerable groups who normally suffer more severely from the impacts of disruptions and failures (The Rockefeller Foundation and Arup 2014).

This index has been developed in collaboration with pilot cities around the world. The knowledge gained is now applied to numerous cities around the world of every type and scale. It will provide a common basis of measurement and assessment to facilitate dialogue and knowledge-sharing between cities (The Rockefeller Foundation and Arup 2014).
In terms of indicators, the CRI is divided into four dimensions, "Health and Wellbeing", "Economy and Society", "Infrastructure and Environment" and "Leadership and strategy". Each dimension is composed of three goals (12 in total), together the index comprises 52 indicators. The specificity of this index is the fact that each indicator is combining quantitative

and qualitative data. For the qualitative data, each question counts in average three questions (more or less according to the indicator), to help guide the answer on a scale from 1 to 5, the index gives an example of the best and worst case scenario. Regarding the quantitative data, they have identified quantitative metrics that can be used by cities as proxies for past and current performance in relation to the sub indicator. The data is then combined to obtain an indicator going from 1 to 5 (1=Very poor, Poor, Moderate, Good, 5=Excellent) (The Rockefeller Foundation and Arup 2014).

Table 5: The table represents the Categories, the Sections and the Indicators of the City Resilience Framework (The Rockefeller Foundation and Arup 2014). As seen above, each indicators are associated both quantitative and qualitative data. They are also associated with qualities (7 qualities in total) in order to provide a more complete measure of resilience according to (The Rockefeller Foundation and Arup 2014).

Category	Section	Indicators
Health and Well-being	Minimal human vulnerability	Safe and affordable housing Adequate affordable energy supply Inclusive access to safe drinking water Effective Sanitation Sufficient affordable food supply
	Diverse livelihoods and employment	Inclusive labour policies Relevant skills and training Local business development and innovation Supportive financing mechanisms Diverse protection of livelihoods following a shock
	Effective safeguards to human health and life	Robust public health systems Adequate access to quality healthcare Emergency medical care Effective emergency response services
Economy and society	Collective identity and community support	Local Community Support Cohesive communities Strong city-wide identity and culture Actively engaged citizens Actively engaged citizens Effective systems to deter crime Proactive corruption prevention Competent policing Accessible criminal and civil justice
	Sustainable economy	Well-managed public finances Comprehensive business continuity planning Diverse economic base Attractive business environment Strong integration with regional and global economies
Infrastructure and ecosystems	Reduced exposure & fragility	Comprehensive hazard and exposure mapping Appropriate codes, standards and enforcement Effectively managed protective ecosystems Robust protective infrastructure

Category	Section	Indicators
	Effective provision of critical services	Effective stewardship of ecosystems Flexible infrastructure Retained spare capacity Diligent maintenance and continuity Adequate continuity for critical assets and services
	Reliable mobility and communications	Diverse and affordable transport networks Effective transport operation & maintenance Reliable communications technology Secure technology networks
Leadership and strategy	Effective leadership and management	Appropriate government decision-making Effective co-ordination with other government bodies Proactive multi-stakeholder collaboration Comprehensive hazard monitoring and risk assessment Comprehensive government emergency management
	Empowered stakeholders	Adequate education for all Widespread community awareness and preparedness Effective mechanisms for communities to engage with government
	Integrated development planning	Comprehensive city monitoring and data management Consultative planning process Appropriate land use and zoning Robust planning approval process

The major strength of this Index is based on the way it is structured, with different dimensions and goals, allowing to understand which domain the city is performing well and which domain they are behind. In addition, the combination of the quantitative and qualitative data for each indicator permits to cover a lot and provide a strong assessment.
However, regarding the Sponge City Assessment Framework, what makes its strength is also its weakness. Indeed, the complexity of gathering the data can be quite a challenge. Moreover, the use of qualitative data and the Sponge City Assessment Framework is not compatible.It can provide too much fluctuation in the answers and can too much variations according to different perspectives.

To conclude, this index is particularly interesting in terms of structure, the way the different section are separated and presented, moreover the grading system (1-5 scale bar) ties up with the previous indexes which are using the same system and could influence the work done within this thesis. However, this index is focusing on the People aspect of the Resilient city, which is only a part of the Sponge City Concept, and is not focusing much on the ability cities have to mitigate climate with given solutions such as Green or Engineered Infrastructures. By no means the City Resilience Index is assessing elements the Sponge City Concept is trying to achieve, but it can still be used as an inspiration source for the development of a Sponge City Assessment Framework.

4.5 Sustainable City Indexing

The Sustainable City Indexing, developed in 2017, is the result of the efforts of the United Nations Industrial Development Organization (UNIDO), which had the desire to develop a framework of indices aligned with the SDGs. Their idea is to provide support to assess and compare cities to reveal their comparative advantages and disadvantages for the sake of smart, sustainable and inclusive urban and regional growth (UNIDO 2017).

This index is dedicated to all the United Nations member states, which adopted the 2030 Agenda for Sustainable Development. The current challenges cities around the world are facing regarding sustainability are in need of solutions (UNIDO 2017). By making a particular focus on the SDGs associated with cities, on top of the already existing work on the field. This index is providing a framework able to answer the following objectives: (1)To assess the city's current development situation; (2)To monitor urban and industrial development trends; (3)To identify urban risks and hazards; (4)To identify focus areas for further development (UNIDO 2017).
Based on their study, they have developed a framework of "inclusive and sustainable urban-industrial development indices" (UNIDO 2017). They have divided this framework into six key domains: "Infrastructure", "Industry and innovation", "Environment", "Governance", "Citizen development" and "Social equity". Each domain comprises three to four factors, for a total of 22 factors in total, factors which will further be developed into multiple indicators (UNIDO 2017).

Table 6:The Sustainable City Indexing presented the Key domains and Factors of their Index inspired by a list of European and Worldwide indexes as well as the challenges addressed in the SDGs (UNIDO 2017).

Key domains	**Factors**
Infrastructure	Mobility Water treatment Waste management ICT infrastructure
Industry and innovation	Green economy Innovation Competitiveness Industrial clusters
Environment	Energy efficiency Pollution control Nature condition
Governance	Public participation Urban strategy and planning Multi-level involvement and cooperation Political transparency
Citizen development	Safety and health Education Human capital Culture development
Social equity	Employment Housing Social cohesion

Regarding this index, what makes it interesting to look at is the fact that in order to arrive at these domains and indicators, they took inspiration from different index with different influences operating at different scales (China, Europe, Worldwide) and combined them to fit with the Sustainable Development Goals. Moreover, they are also taking into account the different links between the six domains in an urban system (UNIDO 2017).
However, the document they have released looks not ready for disclosure due to the fact that they have not defined the indicators and the grading system. Their plan to build these indicators is to have a look at the 232 indicators from the SDGs or to use the ISO 37120 indicators list (UNIDO 2017).

Because what the United Nations are representing makes it interesting and assures that the work is embodied within the current challenges cities are facing and align with the 2030 Agenda for Sustainable Development. The idea of the sustainable city and the different links its domains are highlighting makes it valuable enough to look at and take inspiration from.

4.6 Urban Living Index

The Urban Living Index is the result of the collaboration of Urban Taskforce Australia and McCrindle. This index is exploring the city of Sydney’s abilities to deal with a growing population, densification and all the challenges associated with it in order to assess the urban liveability of the different parts of the city.

The framework they have developed was showcased in a first place to answer the issues the city of Sydney is facing. However, the different measures they came up with could be applied to other cities seeking to define their liveability.
The Urban Living Index is composed of five categories: “Affordability”, “Community”, “Employability”, “Amenity” and “Accessibility”. Each of these categories is divided into four measures costing five points each. The index is assessing each suburb and identifying the strong and weak points of the city in regards to livability (Urban Taskforce 2023).

Table 7: It represent the Categories and the Indicators used in the Urban Living Index (Urban Taskforce 2023).

Categories	**Indicators**
Affordability (Financial)	Home cost Rental cost Rental population Household income
Community (Social)	Dynamic community Language diversity Volunteer work Workforce participation
Employability (Vocational)	Full time employment Higher education qualification Professionals Employing businesses
Amenity (Environmental)	Educational attendence Arts and recreation Restaurants and cafes Shopping

Categories	Indicators
Accessibility (Physical)	Access to work Population density Walking to work Transport sustainability

The data can be visualized as an interactive map outlining the strong and weak neighborhoods at a city scale according to each categories or as an overall result. Similarly to other indexes, the Urban Living Index is based on a 5 points scale bars, each of the category assigned with a color, facilitating the comprehension of the situation. The visual display associated with the data brings an efficient way to interpret the results.
In terms of indicators, not much could be taken out of it and integrated into the Sponge City Assessment Framework. In addition, the fact that it has been developed for a unique city could show some limitations in terms of adaptability, to get the data but also regarding the choice of the indicators, which can maybe not correspond to a city situated in a developing country who is not sharing the same philosophy and lifestyle principles.

Not a lot of indicators could correspond to what this thesis is aiming for, however, the grading system as well as the simplicity the data is presented make it inspiring. The data visualization, in the form of a map is interesting and deliver a clear assessment of the situation.

4.7 Defining the indicators for the Sponge City Assessment Framework

First of all, before defining the potential indicators that can be associated with the components, there is a need to integrate the potential technical guidelines provided by the government. Based on the documentation delivered by the Chinese Governments in my possession and providing technical guidelines for the implementation, design and construction of the Sponge City, some key elements have been extracted. Indeed, one of the documents retrieved from the Ministry of Housing and Urban-Rural Development called "Standard for subject plan and design of sponge city construction" is delivering these precisions. In fact, for the main majority, these details are concerning the Water system, covering the technical aspects of the urban water management. These specificities are being presented in the following table.

Table 8: Based on the Systems, Subsystems and Components highlighted in the Analysis 1, the specific requirements from the Chinese governments in terms of the efficiency a Sponge City needs to reach, are integrated in the column "Technical Clarifications". When the row corresponding to a component is not filled out, it means that none of the key elements extracted from the documents in my possession are giving further clarifications.

SYSTEMS	SUBSYSTEMS	COMPONENTS	TECHNICAL CLARIFICATIONS	SOURCE
WATER	Water Ecology	Ecological Shoreline Restoration (blue line)	Rivers should be able to absorb a 200 year event	(Griffiths et al. 2020)
		Runoff Control	Not less than 40% permeable surfaces in new areas	(Griffiths et al. 2020)
		Stable Groundwater Level	The annual average groundwater level remained stable or the decline rate is lower than before the construction at the same period of the year. This indicator is not evaluated in areas where the average annual rainfall exceeds 1000 mm	(MHURD 2020)

SYSTEMS	SUBSYSTEMS	COMPONENTS	TECHNICAL CLARIFICATIONS	SOURCE
		Reduction of Urban Heat Island	Green areas should not be lower than 30% for newly built and not lower than 25% for rebuilt areas	(MHURD 2020)
	Water Environment	Point Source Pollution Control	No direct discharge from rainwater pipe into river system. No direct discharge from combined system. Combined system should be treated to respect standard IV of water qulity before discharge into rivers and lakes.	(MHURD 2020)
		Ensure Ground Water Quality	Not lower than groundwater quality standard Class III	(MHURD 2020)
		Ensure River/Lake Water Quality	Not lower than IV	(MHURD 2020)
	Water Security	Safe Drinking Water	Level III of standard requirements	(MHURD 2020)
		Eliminated or Reduced Water-logging points	-	-
	Water Ressources	Leakage Control	Not higher than 12%	(MHURD 2020)
		Rainwater Utilisation	Recycle 70% of rainfall	(MHURD 2020)
		Waste Water Purification	Recycling rate not less than 20%	(MHURD 2020)
NATURE	Natural habitats	NOx Reduction	-	-
		CO2 Reduction	-	-
		Create habitats for plants and animals (land and water)	-	-
		Ensure Natural Ecological Pattern	-	-
	Biodiversity	Restore and Improve Soil Quality	-	-
		Protect Native Species	-	-
PEOPLE	Communities	Public Participation	-	-
		Education/Awareness	-	-
		Inequalities	-	-

SYSTEMS	SUBSYSTEMS	COMPONENTS	TECHNICAL CLARIFICATIONS	SOURCE
	Health & Well-being	Reduce Vulnerability	Cities should be able to resist to a 30y event	(Chan et al. 2018)
		Provide Recreation Areas	-	-
		Improve Water-related Services	-	-
		Improve Water-related Services	-	-

All these components presented earlier in the Analysis 1 and presented in another form in the table above are the representation of the Sponge City described by the Chinese government. To assess the status of a city regarding this idea requires setting up some indicators matching with mentioned components. The following section will present the associated to set up some indicators of these components. The technical requirements highlighted above will be taken into consideration and integrated within the assessment framework during the constitution of the indicators and the grading system.

After presenting the different indexes and extracting the indicators, this section aims at picking up all the relevant indicators that correspond to the components of the Sponge City highlighted previously with the help of the General System Theory. In first place, this section will have a look only at the indexes selected thanks to the gray literature review. In a second place, if some components are not covered by these indicators, it will be supplied by international organizations. The following table seeks to present the chosen indicators to represent the different components. The blue color is corresponding to the indicators extracted directly from the indexes presented earlier. The green is for the ones that have been directly extracted from other sources like the SDGs, United Nations or the Mori Memorial foundation. And the rest of the indicators took inspiration, either from the government's requirements directly or from other studies. It is necessary to precise that some sources are coming from the early phases of the project when different keywords (i.g. "urban water management", "sustainable city index" and similar terms) were tested on google scholar in order to outline the problematic of this thesis. It appear at this stage of the thesis that some of them contained useful information.

Table 9: Based on Components, a selection of indicators have been made and are presented below. The majority of the indicators associated with a source but for the remaining one, the indicators have been define based on the description made out of the components provided by the MHURD.

COMPONENTS	INDICATORS	SOURCE
Ecological Shoreline Restoration (blue line)	Assessment of the blue line delineation	-
Runoff Control	Percentage of permeable surfaces	(CBD 2021)
Stable Groundwater Level	Assessment of the groundwater level	-
Reduction of Urban Heat Island	Percentage of green cover	(CBD 2021)
Point Source Pollution Control	Percentage of separation of the infrastructures for wastewater and storm water collection	(Van Leeuwen et al. 2012)

COMPONENTS	INDICATORS	SOURCE
Ensure Ground Water Quality	Assessment of the ground water quality based on international standards	(Van Leeuwen et al. 2012)
Ensure River/Lake Water Quality	Assessment of the surface water quality based on international standards	(Van Leeuwen et al. 2012)
Safe Drinking Water	Percentage of the population using safely managed drinking-water services	(The Rockefeller Foundation and Arup 2014)
Eliminated or Reduced Water-logging points	Assessing the evolution of the water-logging points	-
Leakage Control	Percentage of the water loss in the distribution system	(Van Leeuwen et al. 2012)
Rainwater Utilisation	Percentage of the rainwater that is being re-use	-
Waste Water Purification	Percentage of safely treated domestic wastewater flows	(SDGs)
NOx Reduction	PM2.5 concentration	(IQ Air)
CO2 Reduction	Carbon capture capacity	-
Create habitats for plants and animals (land and water)	Percentage of habitat restored	(CBD 2021)
Ensure Natural Ecological Pattern	Ecological network	(CBD 2021)
Restore and Improve Soil Quality	Assessment of the soil quality based on international standards	-
Protect Native Species	Proportion of invasive alien species	(CBD 2021)
Public Participation Education/Awareness	Participation rate of youth and adults in formal and non-formal education and training in the previous 12 months	(SDGs)
Inequalities	Access to basic services	(SDGs)
Reduce Vulnerability	Capacity of the city to resist to rain events	-
Provide Recreation Areas	Recreational services	(CBD 2021)
Improve Water-related Services	Percentage of the population with access to improved sanitation	(The Rockefeller Foundation and Arup 2014)

The requirements provided by the Chinese Ministry of Housing and Urban-Rural Development (MHURD) have not been integrated directly as an indicator. Indeed, as long as it is possible, instead of using a Yes or No question like “Does the requirements on runoff control are met” which is providing only two possibilities. The choice made and inspired by the studied index, was to provide a more open question with multiple choices where the amount of points for one indicator would vary in accordance to the answer and provide a more precise assessment. All the specificity about the grading system and the integration of national requirements in the grade will be revealed in the next chapter.

In conclusion of the Analysis 2, this chapter started by analyzing the result from the gray literature review presented earlier in the report. The aim of this section was to present these different indexes and highlight the key elements, the strengths and the weaknesses. Assessing these frameworks was necessary for the continuation of this chapter in order to emphasize the choice of the future indicators, which will constitute the Sponge City Assessment Framework. Indeed, after having a look at the different requirements from the Chinese Ministry of Housing and Urban-Rural Development regarding the different components identified in the previous chapter with the help of the General System Theory, this section has associated the relevant indicators from various sources with these components. The majority of presented indicators have been transferred or inspired by already existing work, only a few of them have been created to fit specifically with the components.
The objective of Chapter 4 was to answer the second sub-research question: "*What are the key indicators that should be included in the Sponge city framework for assessing the effectiveness of a city to mitigate climate and bring multiple co-benefits?"*. Thanks to the gray literature review, which collected the right data necessary for the realization of this Chapter, the second sub research question has successfully been answered by investigating the Indexes selected earlier and by identifying the key indicators that should be included in the Sponge City Assessment Framework.

ANALYSIS 3

As a conclusion of the results this thesis generated, this section will combine the results from the Analysis 1 and the Analysis 2 in order to answer the third and last sub-question: "*How can the Sponge City Assessment Framework express the true representation of the Sponge City Concept?*". To do this, this section will first introduce the 23 indicators to then conclude on the final product of this thesis, the Sponge City Assessment Framework.

5.1 Sponge City Assessment Framework Handbook

As seen in the Analysis 2, each component is not associated with one specific indicator, in fact this section will present 23 indicators for 24 components identified. In addition, because the aim of this thesis is also to provide a simple assessment framework which can be used by as many cities around the world as possible, some indicators are sometimes sharing the same data. The process of selecting these indicators involved drawing inspiration from existing indexes while adapting and refining them to align with the objectives of this thesis. In some cases, only the grading scale was adopted, while in others, both the grading system and calculation methods were integrated. Furthermore, the 23 individual indicators are meticulously presented, accompanied by detailed descriptions that emphasize their significance within the context of the Sponge City Concept. Some indicators are supported by already available data which can be transferred into the grading without conversion but some need a quick calculation in order to be applicable and translated into a grade.
To enhance the usability and flexibility of the assessment framework, the grading system allows for varying levels of performance assessment for all indicators except one. This feature empowers cities to monitor their progress and track the evolution of their performance over time. Additionally, a level of difficulty to gather the required data has been assigned to each indicator, representing an estimation based on preliminary investigations conducted during the indicator development process. It is important to note that this estimation is subject to change as new information becomes available and further refinements are made.

The indicators are presented below, categorized according to the color code identified in the Analysis 1, where blue signifies water-related indicators, green represents nature-related indicators, and yellow pertains to indicators related to people. This comprehensive array of indicators and their associated grading systems forms the backbone of the Sponge City Assessment Framework, offering cities a robust and adaptable tool for evaluating their progress towards sustainable urban water management and resilience.

By expanding upon the above description, we can provide a more detailed explanation of the various aspects involved in the development and implementation of the indicators within the Sponge City Assessment Framework.

In certain instances, specific sections within the indicator catalog may remain empty, indicating that, within the designated time frame, no sufficient or satisfactory information was obtained to effectively address those particular sections of the indicator. This occurrence underscores the significance of comprehensive data collection and highlights the challenges associated with acquiring complete and reliable information in certain contexts. While the absence of information in certain sections may be disappointing, it also presents an opportunity for future research and data gathering endeavors. It highlights the need for targeted investigations and collaborations to bridge these information gaps and enrich the understanding of the evaluated indicators. By identifying these gaps, it becomes evident where further attention and resources are required to enhance the effectiveness and completeness of the assessment framework. It is crucial to acknowledge that the absence of information within specific sections of the catalog does not diminish the overall value and efficacy of the assessment framework. Rather, it serves as a reminder of the dynamic and evolving nature of urban water management and the ongoing challenges associated with data collection and analysis. Through ongoing research, collaboration, and data-sharing initiatives, the aim is to gradually fill these knowledge gaps and enhance the comprehensiveness and reliability of the assessment framework for the benefit of cities worldwide.

The delimitation between a simple and imprecise indicator is delicate, and can result in a misalignment with the original intentions of the assessment framework. The challenge is to find the right balance between simplicity and level of precision, as indicators that are too simplistic may fail to capture the original evaluated aspects, while overly precise indicators may become unreliable in real situation due to the level of difficulty to gather the necessary data. Therefore, careful consideration is required when selecting and defining indicators to ensure they align closely with the desired objectives and accurately reflect the intended dimensions of the assessment. And that is what the Analysis 3 have tried to do with the following catalog of indicators representing the components of the Sponge City.

Indicator 1

ASSESSMENT OF THE BLUE LINE DELINEATION

DESCRIPTION

This indicator is the only one to have a yes or no answer. Indeed, the blue line delineation can not be quantified on a scale from 0-4. Even if the rules regarding this concept can differ from city to city or province to province (Lian et al., 2022), the urban blue line refer to the protection of the water bodies, by creating a buffer zone around it. In a Sponge City context, the restoration and protection of ecological shorelines should meet the control requirements of the blue line (MHURD, 2020).

HOW TO CALCULATE IT

In a Sponge City context, the following requirements need to be respected: (1) Vegetation buffer on the waterside space, (2) Permeable pavement of the waterfront walkway should not be less than 70% (3) Natural embankment slope with native plants (green cover not less than 95% (4) Natural transition, water-shore-land.

LEVEL OF DIFFICULTY

Guidelines about the blue line delineation must be define by the local or national government beforehand, increasing the complexity of this indicator.

GRADING

Exceptionally this indicator can not represents an evolution based on different levels like the other indicators are doing. The urban blue line have either been respected or no, based on the local or national guidelines.

0 POINTS: Not meeting the requirements
4 POINTS: Meeting the requirements

WHERE TO GET THE DATA

Because the definition of the urban blue line can differ from area to area, other cities outside China will have to define their guidelines.

Indicator 2

PERCENTAGE OF PERMEABLE SURFACES

DESCRIPTION

Land use change and shift from a natural landscape with permeable surfaces to urban development led to the overuse of concrete and the modification of the natural flow of water. Urban development increased the impervious areas, which is increasing the water runoff and increasing the risks. This indicator aims at measuring the percentage of permeable surface area in a city.

HOW TO CALCULATE IT

(Total permeable area) ÷ (Total terrestrial area of the city) × 100%

WHERE TO GET THE DATA

Regarding European cities, the data can be found on Urban Atlas 2018 (Copernicus). Otherwise, possible source of data include government environmental agencies, city municipalities, satellite images, etc (CBD, 2021).

LEVEL OF DIFFICULTY

The data for European cities is accessible and free. Outside Europe, the status is unknown and probably depend from city to city.

GRADING

Regarding this indicator, the MHURD is requiring a minimum of 40%, equivalent to 2 points in the bellow scoring.

0 POINTS: <30%
1 POINTS: 30.0% - 39.9%
2 POINTS: 40.0% - 49.9%
3 POINTS: 50.0% - 59.9%
4 POINTS: >60%

SOURCE OF INSPIRATION

This indicator as well as the grading scale have been extracted from the indicator 10 of (CBD, 2021)

Indicator 3

ASSESSMENT OF THE GROUNDWATER LEVEL

DESCRIPTION

Groundwater is essential for our society and provides many opportunities for social, economic and environmental benefits. It contributes for almost 50% of the volume withdrawn for domestic use and for around 25% for irrigation. The groundwater level is becoming an even more important parameter with the challenges brought by climate change and urbanization, increasing water scarcity in cities and beyond (United Nations, 2022).

HOW TO CALCULATE IT

No calculation needed.

WHERE TO GET THE DATA

The data can be found on the World Resources Institute website (WRI, 2019) only at a global scale, however some local samplings will be necessary to assess this indicators, which is adding complexity.

LEVEL OF DIFFICULTY

- EASY
- MODERATE
- ▶ DIFFICULT

The current knowledge on the complexity of the samplings methods to assess this indicator do not permit to put the cursor to 'moderate' or 'easy'.

GRADING

According to the MHURD, the groundwater level should remain the same from one year to the next or the decline should be slowed down.

0 POINTS: >8 cm/year *(extremely high)*
1 POINTS: 4.1 - 8 cm/year *(high)*
2 POINTS: 2.1 - 4 cm/year *(medium-high)*
3 POINTS: 0.1 - 2 cm/year *(low-medium)*
4 POINTS: <0 cm/year *(low)*

SOURCE OF INSPIRATION

The grading scale took inspiration from the map p52, presented in the report from (United Nations, 2022).

Indicator 4

PERCENTAGE OF GREEN COVER

DESCRIPTION

In opposition to built up areas, trees and greenery are providing many benefits, especially in climate regulation (CBD, 2021). Briefly, they are filtering the air, increasing water infiltration and reducing the temperature in cities. It has been shown in studies that their presence our cities in essential to reduce phenomenon such as urban heat island (He et al., 2019).

HOW TO CALCULATE IT

(Tree canopy cover + green cover) ÷ (Total terrestrial area of the city) × 100%

WHERE TO GET THE DATA

Regarding European cities, the data can be found on Urban Atlas 2018 (Copernicus). Otherwise, city councils, parks departments, research institutions, universities, land cover maps and satellite images (CBD, 2021).

LEVEL OF DIFFICULTY

- ▶ EASY
- MODERATE
- DIFFICULT

The data for European cities is accessible and free. Outside Europe, the status is unknown and probably depend from city to city.

GRADING

The MHURD is requiring not less than 30% for newly built and not less than 25% of green areas for rebuilt zones. However the tree canopy is not comprised in their percentage.

0 POINTS: <10.0%
1 POINTS: 10.1% - 24.9%
2 POINTS: 25.0% - 39.9%
3 POINTS: 40.0% - 54.9%
4 POINTS: >55%

SOURCE OF INSPIRATION

This indicator as well as the grading scale have been extracted from the indicator 11 of (CBD, 2021)

Indicator 5

SEPARATION OF WASTEWATER AND STORM-WATER INFRASTRUCTURE

DESCRIPTION

Combined sewerage systems are including wastewater, storm water and other type of urban runoff. These types of infrastructure was originally designed to limit the costs but the population density and city expansion led to sewerage overflow and a source of pollution (United Nations, 2017). According to the United Nations (2017), combined sewerage should not be considered as an effective solution.

LEVEL OF DIFFICULTY

EASY
MODERATE
DIFFICULT

Further investigations need to be done in order to evaluate the level of difficulty to acquire this data.

HOW TO CALCULATE IT

No calculation needed.

GRADING

Combined or Separate systems should be based on the local challenges, however, in any case, rainwater or combined pipes should be directly discharge into lakes and rivers.

0 POINTS: <5.0%
1 POINTS: 5.1% - 35.0%
2 POINTS: 35.1% - 65.0%
3 POINTS: 65.1% - 99.9%
4 POINTS: 100%

WHERE TO GET THE DATA

Municipalities, city agencies, universities, companies, governments, etc.

SOURCE OF INSPIRATION

The grading scale is based on best case scenarios (NRMMC, 2004).

Indicator 6

ASSESSMENT OF THE GROUND WATER QUALITY

DESCRIPTION

The assessment of the groundwater quality can be done with the help of many parameters. However, in order to keep the assessment framework simple, this indicator is looking into Nitrate (NO3) pollution which is considered as the most ubiquitous non-point source contaminant of groundwater resources worldwide (World Water Quality, 2021).

LEVEL OF DIFFICULTY

EASY
MODERATE
DIFFICULT

The current knowledge on the complexity of the samplings methods to assess this indicator do not permit to put the cursor to 'moderate' or 'easy'.

HOW TO CALCULATE IT

No calculation are needed.

GRADING

Ground water quality should not be lower than standard III according to the MHURD, however, these standards have not been identified in this thesis.

0 POINTS: >45 mg/L
1 POINTS: 15.0 - 34.9 mg/L
2 POINTS: 5 - 14.9 mg/L
3 POINTS: 2.0 - 4.9 mg/L
4 POINTS: <1.9 mg/L

WHERE TO GET THE DATA

The data can be gathered online with the help of different database and studies made on the groundwater quality around the world. However this indicator will require local samplings to address correctly this indicator.

SOURCE OF INSPIRATION

The grading scale is based on international requirements (Karthikeyan et al., 2017).

Indicator 7

ASSESSMENT OF THE SURFACE WATER QUALITY

DESCRIPTION

The presence of clean surface water is essential to maintain a healthy ecosystem and support habitats and biodiversity. Traditionally, Human have damaged water quality trough agricultural and industrial waste as well as urbanization and alteration made to the natural landscape (European Environmental Agency, 2018). In terms of international guidelines, only the EEA is providing a framework across different countries, that it is why it has been chosen as basis.

HOW TO CALCULATE IT

No calculation needed.

WHERE TO GET THE DATA

The evaluation of rivers and lakes water quality is made according to different indicators which probably require local samples. Water bodies in Europe have already been evaluated, which the data can be visualized on EEA website.

SOURCE OF INSPIRATION

The grading scale took inspiration from the (European Environmental Agency, 2018).

LEVEL OF DIFFICULTY

The data and the status of water bodies in Europe have already been assessed but regarding outside these boundaries, the data availability is unknown.

GRADING

Surface water quality should not be lower than standard IV according to the MHURD, however, these standards have not been identified in this thesis.

0 POINTS: Bad
1 POINTS: Poor
2 POINTS: Moderate
3 POINTS: Good
4 POINTS: High

Indicator 8

POPULATION ACCESS TO SAFE DRINKING-WATER SERVICES

DESCRIPTION

To fit with the component "Safe drinking water", different indicators could have been chosen. Indeed, the World Health Organization (WHO) are providing different specific indicators. In this case, the % of the population using safely managed drinking-water related services have been chosen. It also has the advantage to be associated with SDG 6.1 and so on representing International requirements.

HOW TO CALCULATE IT

This indicator is based on already existing data.

WHERE TO GET THE DATA

The data can be gathered at a national scale on the World Health Organization platform. However, the local conditions need to be assess in order to correctly grade this indicator.

SOURCE OF INSPIRATION

This indicator took inspiration from the indicator 1.3 of the City Resiliency Index (The Rockefeller Foundation and Arup, 2014).

LEVEL OF DIFFICULTY

The level of difficulty to gather data at a local scale are for now unknown.

GRADING

The grading table is based on grid provided by the World Health Organization to classify the different countries (WHO, 2023).

0 POINTS: <24.9%
1 POINTS: 25.0 - 49.9%
2 POINTS: 50.0 - 74.9%
3 POINTS: 75.0% - 98.9%
4 POINTS: >99%

Indicator 9

ASSESSING THE EVOLUTION OF THE WATER-LOGGING POINTS

DESCRIPTION

The assessment of the water logging points is made in two phases, before and after hydro-logical modification. Not many guidelines are delivered by the MHURD on this topic and no indicators shown an interesting approach to tackle the component highlighted during the application of the General System Theory, that is why this indicator have been created to fit with the situation.

LEVEL OF DIFFICULTY

EASY
▶ MODERATE
DIFFICULT

Many uncertainties regarding the level of difficulty to gather data for this indicator.

HOW TO CALCULATE IT

[1-(Recent number of water logging points ÷ Previous number of water logging points)] ×100

GRADING

The MHURD simply required a reduction or a complete elimination of the water logging points.

0 POINTS: <25%
1 POINTS: 25.0% - 49.0%
2 POINTS: 50.0% - 74.9%
3 POINTS: 75.0% - 95.0%
4 POINTS: >95%

WHERE TO GET THE DATA

City agencies, municipalities, universities, companies, studies, etc.

SOURCE OF INSPIRATION

This indicator only used the requirements from the MHURD to define the grading scale.

Indicator 10

PERCENTAGE OF THE WATER LOSS IN THE DISTRIBUTION SYSTEM

DESCRIPTION

Indicator 10 is focusing on the leakage control. Some studies have evaluated the water loss in the distribution systems across continents but no international guidelines have been found. However, the SDGs are promoting responsible consumption, and taking care of the water leakage is moving into the same direction and participate to the achievement of the goals.

LEVEL OF DIFFICULTY

EASY
▶ MODERATE
DIFFICULT

This indicator does not require a lot of complex data however the mean to acquiring it is not known at the moment.

HOW TO CALCULATE IT

[1-(Water consumed ÷ Water produced)] ×100

GRADING

According to the MHURD, leakage should not exceeds 12%. The grading scale is based on the worst and best case scenario (Laspidou, 2014).

0 POINTS: >50.1%
1 POINTS: 25.1% - 50.0%
2 POINTS: 15.1% - 25.0%
3 POINTS: 5.1% - 15.0%
4 POINTS: <5.0%

WHERE TO GET THE DATA

The data can probably be found with the help of municipalities and water utility companies.

SOURCE OF INSPIRATION

This indicator has been inspired from the indicator 7 of The city Blueprints (Van Leeuwen et al. 2012).

Indicator 11

PERCENTAGE OF THE RAINWATER THAT IS BEING RE-USED

DESCRIPTION

Based on the information delivered by the MHURD, the importance of this indicator can vary according to the local conditions. It is recommended for cities experiencing water scarcity frequently to be more vigilant regarding this indicator. Harvesting rainwater can be made with the help of rainwater tanks or natural solutions such as lakes and other natural reservoirs.

LEVEL OF DIFFICULTY

EASY
▶ MODERATE
DIFFICULT

If the amount of harvesting capacities are not known by the municipality, more complex calculations will have to be conducted.

HOW TO CALCULATE IT

(Amount of rainwater stored ÷ Volume of rainfall) ×100

GRADING

The sponge city concept is based on the idea that cities should collect, store and re-use 70% of the rainfall. However, this number can vary based on local conditions.

0 POINTS: <29.9%
1 POINTS: 30.0% - 49.9%
2 POINTS: 50.0% - 69.9%
3 POINTS: 70.0% - 79.9%
4 POINTS: >80.0%

WHERE TO GET THE DATA

The percentage of the rainwater stored can be delivered by the municipalities and water agencies for instance. The percentage of harvested rainwater should be based on annual average even though, it has not been stated.

SOURCE OF INSPIRATION

The grading scale has been set up based on cities existing conditions.

Indicator 12

PROPORTION OF SAFELY TREATED DOMESTIC WASTEWATER

DESCRIPTION

Improved water quality is embodied as a strong requirement in the Sponge City Concept. Properly treating wastewater is also reducing pollution on the environment and risks of disease and contamination (SDGs). For this indicator, the Sponge City Assessment Framework chose to align with existing international guidelines, indeed, the sub-goal 6.3 of the SDGs targeted this issue. One limitation of this indicator is the fact that is looking only into domestic and not industrial wastewater.

LEVEL OF DIFFICULTY

EASY
▶ MODERATE
DIFFICULT

The data at a national scale can be retrieve easily, however the state at a city scale is unknown at the moment.

HOW TO CALCULATE IT

No calculation needed.

WHERE TO GET THE DATA

The data can be retrieve at a country scale on the World Health Organization's website or in reports from the United Nations focusing on the progress of the SDG indicator 6.3.1. However, the local conditions need to be assess in order to correctly grade this indicator.

GRADING

Guidelines on this indicator from the MHURD lack of precision and can not be apply in this context. The grid below is based on the data from the WHO.

0 POINTS: <14.9%
1 POINTS: 15.0% - 49.9%
2 POINTS: 50.0% - 74.49%
3 POINTS: 75.0% - 94.49%
4 POINTS: >95%

SOURCE OF INSPIRATION

This indicator took inspiration from the SDG 6.3.1 and the World Health Organization data platform.

Indicator 13

PM2.5 CONCENTRATION

DESCRIPTION

From the systematic literature review came out as component, the reduction of Nox, however in terms of air quality many parameters can be assess and choosing to measure one and not the others does not make much sense. However, this index seeks to stay simple. PM2.5 are known to be the most harmful air pollutant for humans but are also causing many disturbances on the natural environment. In fact, PM2.5 rate can be seen as the representation of air pollutants in general giving an idea of the situation.

HOW TO CALCULATE IT

No calculation is required.

WHERE TO GET THE DATA

The data for a lot of cities around the world can be retrieve online, on real time air quality data like IQAir.

LEVEL OF DIFFICULTY

EASY
MODERATE
DIFFICULT

The data for many cities around the world is free and accessible.

GRADING

The grid is based on international requirements. 4 points correspond to satisfactory levels according to WHO and 0 point correspond to more 7x higher.

0 POINTS: >35.1 ug/m3
1 POINTS: 15.1-35 ug/m3
2 POINTS: 10.1-15 ug/m3
3 POINTS: 5.1-10 ug/m3
4 POINTS: 0-5 ug/m3

SOURCE OF INSPIRATION

This indicator took inspiration from the IQair grid system which is following WHO requirements.

Indicator 14

CARBON CAPTURE CAPACITY

DESCRIPTION

As a way to emphasize to contribution of nature and the ecosystem services, the carbon capture capacity of a city can be used as an indicator. However, the lack of example among the literature gathered during this thesis, as well as the lack of time to conduct further research, this indicator will remain empty for now.

HOW TO CALCULATE IT

WHERE TO GET THE DATA

SOURCE OF INSPIRATION

LEVEL OF DIFFICULTY

EASY
MODERATE
DIFFICULT

GRADING

Indicator 15

PERCENTAGE OF HABITAT RESTORED

DESCRIPTION

This indicator is aligned with the UN Decade on Ecosystem Restoration from 2021-2030 (CBD,2021). Expansion and land use change in cities are leading to degradation of the natural habitats. This indicator would measure the city efforts to restore, enhanced or rehabilitate existing habitats to a level of good ecological functioning. These criteria should be defined by the city itself based on their objectives and the local situation.

HOW TO CALCULATE IT

(Area of habitat restored) ÷ (Area of original habitat that is degraded) × 100%

WHERE TO GET THE DATA

City agencies in charge of biodiversity, nature groups, NGOs, biodiversity centres, universities, etc (CBD, 2021). Moreover, this indicator is combining quantitative and qualitative data, and criteria needs to be define by the city beforehand.

LEVEL OF DIFFICULTY

- EASY
- ▶ MODERATE
- DIFFICULT

This indicator requires to first defined all the degraded habitats in the city in order to find out how much have been restored.

GRADING

The definition of whether an area recover good ecological functioning or no is based on qualitative data defined by the city.

0 POINTS: <20.0%
1 POINTS: 20.0% - 39.9%
2 POINTS: 40.0% - 59.9%
3 POINTS: 60.0% - 79.9%
4 POINTS: >80.0%

SOURCE OF INSPIRATION

This indicator as well as the grading scale have been extracted from the indicator 7 of (CBD, 2021)

Indicator 16

ECOLOGICAL NETWORK

DESCRIPTION

The MHURD is insisting on the fact to preserve as much as possible of the natural landscape in order to preserve the natural flow of water and prevent urban flooding. The indicator from the (CBD, 2021), aiming at measuring the ecological networks should be able to cover this challenge.

HOW TO CALCULATE IT

It is a 2 steps process, first the mesh size (EMS) then the coherence

EMS= $\frac{1}{A_{total}}(A_{G1}^2 + A_{G2}^2 + A_{Gn}^2)$ Coherence= $\frac{Effective\ Mesh\ Size}{A_{total}}$

• A_{total} is the total natural area • A_{G1} to A_{Gn} are the size of each patch

A_{G1} to A_{Gn} are the patches that are distinct from each other (100m minimum), for more information, check (CBD, 2021).

WHERE TO GET THE DATA

Regarding European cities, the data can be found on Urban Atlas 2018 (Copernicus). Otherwise, satellite images can be used in the computation of this indicator (CBD, 2021).

LEVEL OF DIFFICULTY

- ▶ EASY
- MODERATE
- DIFFICULT

The data for European cities is accessible and free. Outside Europe, the status is unknown and probably depend from city to city.

GRADING

The MHURD are highlighting the importance of this parameter, however no requirement have been mentioned.

0 POINTS: <20.0%
1 POINTS: 20.0% - 39.9%
2 POINTS: 40.0% - 59:9%
3 POINTS: 60.0% - 79.9%
4 POINTS: >79.0%

SOURCE OF INSPIRATION

This indicator as well as the grading scale have been extracted from the indicator 2 of (CBD, 2021).

Indicator 17

ASSESSMENT OF THE SOIL QUALITY

DESCRIPTION

The assessment of the soil quality is being monitored at an international scale with the World Soil Charter by the FAO (United Nations) but it gives an overall state of the soil at a global view, measuring various parameters. That is why, because this framework aims for simplicity and this indicator is part of the "Nature" system, the evaluation will be based on the amount of degraded habitat compare to the Total area of the city. As stated in their report (IPCC-AR5), land degradation affects the entire ecosystems.

HOW TO CALCULATE IT

(Area of original habitat that is degraded) ÷ (Total area of the city) × 100%

WHERE TO GET THE DATA

The data is re-used from a previous indicator (n°15).

SOURCE OF INSPIRATION

This indicator took inspiration from the SDG 15.3.1.

LEVEL OF DIFFICULTY

▶ EASY
MODERATE
DIFFICULT

The data can be re-used from the previous Indicator 15

GRADING

The result is representing the percentage of the city that is degraded and so on have an impact on the soil quality.

0 POINTS:
1 POINTS:
2 POINTS:
3 POINTS:
4 POINTS:

NOT DEFINE YET

Indicator 18

PROPORTION OF INVASIVE ALIEN SPECIES

DESCRIPTION

The MHURD did not provide any requirements in terms of invasive and native populations in the city. However, as seen earlier in the thesis, it is stated that the use of native species of plants to provide ecosystem services and at the same time habitats for the local species is essential. This indicator based on the Biodiversity Index (CBD, 2021) looks into the proportion of invasive alien species to evaluate the state of native species.

HOW TO CALCULATE IT

(Number of invasive alien species in a taxonomic group) ÷ (Total number of native species of the same taxonomic group + number of invasive alien species) × 100%

WHERE TO GET THE DATA

Possible source of data include government agencies in charge of biodiversity, municipalities, biodiversity centers, nature groups, universities... or public participation with already existing apps.

SOURCE OF INSPIRATION

This indicator as well as the grading scale have been extracted from the indicator 9 of (CBD, 2021).

LEVEL OF DIFFICULTY

EASY
▶ MODERATE
DIFFICULT

Further investigations need to be done to assess the data availability. It will probably different for each city.

GRADING

No specific goals in terms of number from the MHURD, the scoring range is based on the premise that the more invasive species, the more impacts on habitats and native species (CBD,2021).

0 POINTS: >30.0%
1 POINTS: 20.1% - 30.0%
2 POINTS: 11.1% - 20.0%
3 POINTS: 1.0% - 11.0%
4 POINTS: <1.0%

Indicator 19

PARTICIPATION RATE OF YOUTH AND ADULTS

DESCRIPTION

Participation of the public into Sponge City development is wish from the Chinese Government. It is seen by the MHURD as an occasion to sensitize the youth and adults on the use of water and raise awareness on the importance and significance of the a Sponge city. This indicator is looking into a given age range, *a* (15-24 yo), in a given time period, *t* (e.g. the year 2022).

LEVEL OF DIFFICULTY

EASY
▶ MODERATE
DIFFICULT

There is still a lot of uncertainty regarding the collection of data for this indicator.

HOW TO CALCULATE IT

To calculate the participation rate: $PR_a^t = \frac{P_a^t}{POP_a^t} \times 100$

- P_a^t is the number of people who participated, a is the age group and t the year
- POP_a^t is population in age group a and year t

GRADING

NOT DEFINE YET

0 POINTS:
1 POINTS:
2 POINTS:
3 POINTS:
4 POINTS:

WHERE TO GET THE DATA

Because this indicator have been extracted from the SDGs, data could be gather on the United Nations statistic's website.

SOURCE OF INSPIRATION

This indicator took inspiration from the indicator 4.3.1 of the SDGs.

Indicator 20

ACCESS TO BASIC SERVICES

DESCRIPTION

The sponge city concept aims also at providing an alternative to the the traditional system. As seen in one of the case study presented in the section 5.1.2, a part of the project was dedicated for water treatment. Indeed, they used this opportunity to connect the sewage from the surrounding areas which were not connected to the centralized treatment system. This type of actions is participating to the reduction of inequalities in the city.

LEVEL OF DIFFICULTY

EASY
▶ MODERATE
DIFFICULT

Data at a national scale can be gathered easily, however the state at a local scale is unknown at the moment.

HOW TO CALCULATE IT

(Population access to safe drinking water* + Population using safely managed sanitation services**) ÷ 2

GRADING

The grading table is based on grid provided by the World Health Organization to classify the different countries (WHO, 2023).

0 POINTS: <24.9%
1 POINTS: 25.0 - 49.9%
2 POINTS: 50.0 - 74.9%
3 POINTS: 75.0% - 98.9%
4 POINTS: >99%

WHERE TO GET THE DATA

*data used for Indicator 8

**The data can be gathered at a national scale on the World Health Organization platform. Investigations at a city scale could be necessary for this parameter.

SOURCE OF INSPIRATION

These parameters are taking inspiration from SDG 6.1 and SDG 6.2 and from The World Health Organization.

Indicator 21

CAPACITY OF THE CITY TO RESIST TO RAIN EVENTS

DESCRIPTION

As seen in the introduction of this thesis, hazards, depending of the severity have dramatic socio-economical impacts. The city's capacity to resist to major rain events is essential in order to preserve the city and protect the population. Based on the definition given by the MHURD, the city is considered able to resist to a rain event when runoff rate on road surfaces is not more than 15 cm and when the ground floor of residential, commercial and residential building is not flooded (Griffiths et al., 2020).

HOW TO CALCULATE IT

No calculation nedded.

WHERE TO GET THE DATA

The information regarding the capacity of the city to resist to major rain events can be found with the help of the municipality, studies, assessment from companies... or can be based on the effects of previous floods.

SOURCE OF INSPIRATION

The identification of levels was based on best scenarios (Chan et al., 2018).

LEVEL OF DIFFICULTY

- ▶ EASY
- MODERATE
- DIFFICULT

This indicator only requires a bit of research.

GRADING

According to the MHURD, a Sponge city should be able to resist to 30 year rainfall event for 24h. This number can vary according the size of the city.

0 POINTS: <5 year event
1 POINTS: 5 - 14 year event
2 POINTS: 15 - 29 year event
3 POINTS: 30 - 49 year event
4 POINTS: >50 year event

Indicator 22

RECREATIONAL SERVICES

DESCRIPTION

Because the sponge city is having a multi-purposes focus, their green infrastructures aims at reducing stormwater runoff, mitigate urban heat island, improve water quality, improve natural habitat and increase recreational areas. Measuring the amount of green spaces in relation to the number of inhabitants is essential. It will highlight the opportunity, people have to interact with nature and possibly provide benefit to their health.

HOW TO CALCULATE IT

Natural areas / 1000 persons

WHERE TO GET THE DATA

Natural areas or green cover can be re-used from the indicator 4.

SOURCE OF INSPIRATION

This indicator as well as the grading scale have been extracted from the indicator 12 of (CBD, 2021).

LEVEL OF DIFFICULTY

- ▶ EASY
- MODERATE
- DIFFICULT

This indicator require only few data. Moreover, the data has been re-used from a previous indicator which is facilitating the process.

GRADING

The scoring is based on the widely accepted standard of 0.9 ha of urban green space for 1000 persons (CBD, 2021).

0 POINTS: <0.1 ha/1000 persons
1 POINTS: 0.1 - 0.3 ha/1000 persons
2 POINTS: 0.4 - 0.6 ha/1000 persons
3 POINTS: 0.7 - 0.9 ha/1000 persons
4 POINTS: >0.9 ha/1000 persons

Indicator 23

POPULATION USING SAFELY MANAGED SANITATION SERVICES

DESCRIPTION

Similar to Indicator 8 seen earlier, to assess the component: "Improve water-related services", different indicators could have been chosen. Indeed, the World Health Organization (WHO) are providing different specific indicators. In this case, the % of the population using safely managed sanitation services have been chosen. It also has the advantage to be associated with SDG 6.1 and so on representing International requirements.

LEVEL OF DIFFICULTY

- ▶ EASY
- MODERATE
- DIFFICULT

This indicator does not require many resources, the data is free and available for the majority of countries around the world.

HOW TO CALCULATE IT

This indicator is based on already existing data.

WHERE TO GET THE DATA

The data can be gathered at a national scale on the World Health Organization platform. Investigations at a city scale may not be necessary for this indicator.

GRADING

The grading table is based on grid provided by the World Health Organization to classify the different countries (WHO, 2023).

0 POINTS: <24.9%
1 POINTS: 25.0 - 49.9%
2 POINTS: 50.0 - 74.9%
3 POINTS: 75.0% - 98.9%
4 POINTS: >99%

SOURCE OF INSPIRATION

This indicator took inspiration from the indicator 1.4 of the City Resiliency Index (The Rockefeller Foundation and Arup, 2014).

5.2 The Sponge City Assessment Framework

This subsection gives an overview of all the elements put together. Throughout this final Chapter of the Results section, the different elements highlighted during the Analysis 1 and 2 led to the final product of this thesis. The Systems and Subsystems resulting from the first Analysis provided this paper with all the components of the Sponge City Concept. Together with the help of the indicators, grading systems, structures and other aspects emphasized by the second Analysis led to a framework representing the key elements of the Sponge City Concept.
The culmination of this thesis is the development of the Sponge City Assessment framework, which represents a step forward in evaluating and promoting sustainable urban water management practices, in particular the Chinese concept. Through an extensive analysis of gray literature, scientific articles as well as indexes and their indicators, a comprehensive framework has been outlined. The framework incorporates multiple dimensions, characterized by the three Systems (Water, Nature and People) and the subsystems associated with it. By adopting this framework, cities will have a standardized tool to assess their progress regarding the principles of a Sponge City and to also identify areas for improvement. The framework not only emphasizes the quantity of water management measures but also focuses on the quality of implementation, ecological functionality, and co-benefits for communities. It can be utilizzed as a valuable guide for urban planners, policymakers, and stakeholders in their efforts to create resilient and livable cities that effectively manage water resources and mitigate the impacts of climate change. With the Sponge City Assessment framework, cities can proactively enhance their water management strategies, foster sustainable development, and contribute to a more resilient and environmentally friendly future.

SYSTEM	SUBSYSTEM		INDICATOR	GRADE				
WATER 48 points	WATER ECOLOGY	1	Assessment of the blue line delineation	0pt				4pts
		2	Percentage of permeable surfaces	0pt	1pt	2pts	3pts	4pts
		3	Assessment of the groundwater level	0pt	1pt	2pts	3pts	4pts
		4	Percentage of green cover	0pt	1pt	2pts	3pts	4pts
	WATER ENVIRONMENT	5	Separation of wastewater and storm-water infrastructure	0pt	1pt	2pts	3pts	4pts
		6	Assessment of the ground water quality	0pt	1pt	2pts	3pts	4pts
		7	Assessment of the surface water quality	0pt	1pt	2pts	3pts	4pts
	WATER SECURITY	8	Population access to safe drinking-water services	0pt	1pt	2pts	3pts	4pts
		9	Assessing the evolution of the water-logging points	0pt	1pt	2pts	3pts	4pts
	WATER RESOURCES	10	Percentage of the water loss in the distribution system	0pt	1pt	2pts	3pts	4pts
		11	Percentage of the rainwater that is being re-use	0pt	1pt	2pts	3pts	4pts
		12	Proportion of safely treated domestic wastewater	0pt	1pt	2pts	3pts	4pts
NATURE 24 points	NATURAL HABITATS	13	PM2.5 concentration	0pt	1pt	2pts	3pts	4pts
		14	CO2 emissions per capita	0pt	1pt	2pts	3pts	4pts
		15	Percentage of habitat restored	0pt	1pt	2pts	3pts	4pts
		16	Ecological network	0pt	1pt	2pts	3pts	4pts
	BIODIVERSITY	17	Assessment of the soil quality	0pt	1pt	2pts	3pts	4pts
		18	Proportion of invasive alien species	0pt	1pt	2pts	3pts	4pts
PEOPLE 20 points	COMMUNITIES	19	Participation rate of youth and adults	0pt	1pt	2pts	3pts	4pts
		20	Access to basic services	0pt	1pt	2pts	3pts	4pts
	HEALTH & WELL-BEING	21	Capacity of the city to resist to rain events	0pt	1pt	2pts	3pts	4pts
		22	Recreational services	0pt	1pt	2pts	3pts	4pts
		23	Population using safely managed sanitation services	0pt	1pt	2pts	3pts	4pts

Figure 17: The sponge City Assessment Framework (figure from the author)

DISCUSSION & CONCLUSION

The increase of the world population and the increase of the urban population can lead to additional pressure on the Water Supply system, the Waste Water and solid waste management systems (Sim and Balamurugan 1991). In many developing countries, water supply and sanitation in urbanized areas are facing many challenges such as the growing population, the lack of infrastructure and investments in infrastructures and limitations to natural resources (Van der Bruggen, Borghgraef, and Vinckier 2010). That is why developed countries and developing cities around the world are in need of solutions, which can tackle many issues at once. Sustainable Urban Water Management like the Sponge City Concept can be the solution to reduce the harmful effects of urbanization and climate change.

With the help of the sub-questions, this thesis developed an analysis divided into three parts. Analysis 1 started by defining the term “Sponge City” and the idea behind it by using the documents resulting from the literature review. Based on the knowledge acquired from this step, the General System Theory helped to identify the Systems, Subsystems and components of a Sponge City. The first analysis was also the occasion, based on the understanding of the concept gained during the literature review, to identify the links between the components. Once the systems, the subsystems and the components where identified, this data was used to identify the relevant indicators from a batch of indexes on sustainable cities selected beforehand. Analysis 2 was also the occasion to take inspiration from these indexes for their grading systems and the way they were structured. With now, a selection of indicators where each corresponding to one or two components highlighted in the previous phase, which then led to Analysis 3. The final part collected the data from the two previous phases to combine them in order to obtain the Sponge City Assessment Framework. During this final step, each indicator was presented one by one, giving a grading scale adapted for each of them based on existing indicators, on international guidelines or based on the current worst and best-case scenarios from cities around the world.

Overall, investigations conducted by this thesis highlighted the fact that the sponge city concept compared to similar Urban Water Management concepts are aiming to operate at larger scale, combining micro and meso scale projects. This thesis highlighted also that together, the different components of a sponge city are participating to provide multiple benefits and in some ways, they are all supporting each other. Impacts on one of the components might affect other components. The relation between the components emphasized in Analysis 1 can also provide a better understanding and identify the issues encountered if one of the indicators is low.

6.1 Interpretations

Even if the Sponge City Concept is being described by the MHURD as a solution combining green and gray infrastructures, their requirements are strongly focusing on green cover and giving room for rivers and water bodies by creating natural buffer zones around them. The protection or restoration of the natural water system is put forward in favor of green infrastructure while gray infrastructure like the sewage drainage network and pumps for instance need to be updated to provide minimum services to the inhabitants (Xia et al. 2017). The Sponge City Assessment Framework is also following these principles by integrating the technical requirements into the grading system.

The understanding of the Sponge City Concept represented by the final product of this thesis, the Sponge City Assessment Framework, aimed to be utilized as an evaluation and monitoring tool for cities to track changes. It can also be used to provide an understanding of a more specific situation, if the urbanization is affecting in good or bad some subsystems of the city or if the plan from the municipality to reduce Urban Heat Island is beneficial for native species and air quality for instance. Along those lines, the wheel of components (Figure 15), can also be used

as a handbook and provide solutions by having a look at the links between the components to understand by what the components are affected and which other components it is affecting.
In addition, knowing its origins from an Asian developing country (China) experiencing recurrent heavy rainfall with the monsoon season. Similar countries experiencing the same challenges could potentially fit well with the challenges addressed by Sponge Cities. Southeast Asian countries are some of them, the region, facing challenges such as income inequality, environmental degradation and political instability (Carroll 2020). As well as the large population (665 millions), and the geography, surrounded by water with a high concentration of population and economic activities in coastal areas makes these countries highly vulnerable (Asian Development Bank 2009) and in need of solutions to overcome the effects of climate change. Knowing that the geographical position of this region on the globe makes it particularly exposed to tropical storm, typhoon and monsoon (Torti 2012), flooding represents, the main threat and raises many concerns for the economy but also for the health and well-being of the population (Asian Development Bank 2019). Similar to China, rapid urbanization and rapid expansion led to higher demand on the water supply and sanitation services, putting pressure on the infrastructure resulting in an unreliable service for a part of the population. Increasing the stress on the environment and the threats of climate change (Asian Development Bank 2009). Poor governance is also a contributing factor to water-related issues in Southeast Asia. Weak governance combined with disaster risk worsen inequalities and poverty. Ineffective policy can lead to inadequate infrastructure and poor management and exacerbate water related issues (Asian Development Bank 2019).
As seen with the above example, urbanization and climate change are the major challenges faced by Southeast Asian cities. Hence, the work realized within this thesis could be particularly relevant in this type of region to emphasize the areas of improvements and the potential reasons related to the issues encountered.

6.2 Implications

Key elements have been identified regarding the implication of this work into the current context. The data contributes to a clearer understanding of a Sponge City. Indeed, as seen with the literature review of indexes on sustainable cities, one of them used the term Sponge City to assess only a small part of the concept, which is creating confusion to the uninformed public. In that sense, this work participates in the definition of the concept based on official data. In comparison with other concepts of sustainable Urban Water Management developed from a western point of view, this work participates in the democratization of an Asian/Chinese concept developed for developing countries. In addition, the fact that it is a relatively new concept, established recently only, on top of the few information delivered in English by the Chinese government, as well as the fact that the literature on Sponge Cities, are often focusing on one aspect of the sponge city but not describing the different components of a Sponge City. This thesis is bringing new insights to the field. By utilizing the General System Theory, the links between the different systems and components are bringed to the fore. This on top of the assessment framework are offering a uniformed methodology to cities around the world.
Moreover, another important point that needs to be highlighted in this thesis, is the fact that the technical requirements from the MHURD identified in Analysis 2 have been integrated in the grading system but the grading scale is not only based on this information. As a matter of fact, to facilitate the exportation of this work in another context than the Chinese one, the different levels of points have been aligned with international guidelines, with the SDGs and WHO requirements for instance to. Utilizing this strategy is also proposing a version 2.0 of the Sponge City Concept without denying the original concept.

6.3 Limitations

It is important to identify the limitations of this work in order to evaluate if it could have a significant impact on the findings. This discussion on the limitations is also relevant to determine the potential improvements on similar work.

The first limitation can be due to the systematic literature review conducted. To realize the analyses, the bibliography is combining scientific articles and gray literature, which is a good point, however, the scientific papers are limited to the documents found on the Web of Science. Moreover, even if some keyword combinations have been tested beforehand, the choice of these keywords is limiting the result of the searches. On the side of the gray literature, two points are important, the first one is the fact that the official documentation has been obtained after navigating through the MHURD's website and testing keywords. Because the website is only available in Chinese, moving around even with the automatic translation was not always easy and it is possible that additional relevant documentation were available at other places. The second point concerned the methods to gather indexes on sustainable cities. Indeed, the searches tested different keywords but focused only on the 10 first results of each search, potentially limiting the outcomes.

The second limitation identified concerned the possible lack of information regarding the "Where to get the data" section of the Analysis 3. Putting additional time to this thesis would allow deeper investigations and provide additional data. From this limitation is also linked the lack of precision for some indicators. With the desire to propose a catalog of indicators as much filled as possible, the "Where to get the data" section is giving links to data at a national scale when data at a city scale is preferable.

Another limitation is the fact that none of the indicators has a "weight", meaning even if some indicators could be considered as more important than others they are still worth the same for now. Only one index of the selected ones was presenting an example of an index with a weight associated with each indicator. In that sense, a dedicated methodology would have to be considered to define the importance of each indicator. The weight can also be adapted by the cities in order to fit with their local policy and what they want to achieve.

Finally, in regards to the specificity of each city around the world, of different size, different culture, experiencing different challenges and different climate, the Sponge City Assessment Framework could show some limitations. Indeed, the desire to create a simplified framework adaptable to different places around the world can be seen as a weak point, not addressing specific challenges.

Overall, as mentioned in the section 2.1 of this thesis, "Philosophy of science", this work followed the principles of post-positivism, which means that the outcomes produced are based on empirical data, representing one reality. In the case of this thesis, the reality is based on the selected documents from the systematic literature review. This precision is important in order to claim that the results of this paper are not wrong or right but are representing one reality, some adjustments could be made over time to sharpen the assessment framework and its indicators. Ultimately, these limitations are the witnesses of what can and cannot be concluded from this thesis.

6.4 Recommendations

The objectives this thesis set up at the beginning of the project have been fulfilled. The idea was to provide a ready to use tool. The Sponge City Assessment Framework with the catalog of indicators as well as the wheel of components are providing a strong base. However, there is still room for improvement. Starting by providing a more accurate way of getting the data for each indicator, which requires deeper investigations. These tools can also become the basis for future works, adapted to specific regions or nations around the world.

Interviewing some experts of the field could also be considered to evaluate the strengths and weaknesses of this work which could lead to adjustments.
As seen earlier, the Sponge City Concept is relatively new, and still in need to be investigated, notably the already existing projects. By having a look at case studies on Sponge Cities and case studies on other sustainable Urban Water Management like the WSUD or SUDs could lead to interesting observations in order to spot the real differences on concrete projects after implementation. It could lead as well to a uniformed guidelines, taking the best from all these concepts and making the collaboration between nations and cities on sustainable Urban Water Management easier.
In addition, it has not been highlighted in this thesis but the main drawback of the implementation are the financial aspects. And it is mostly due to the scale of the project, because the concept is taking the city as a whole, larger fundings is required (Nguyen et al. 2019). Some studies like the one from (Fan and Matsumoto 2020) are focusing on the financial aspects of the Sponge City, and conclude by saying that the concept is not only competitive from an economical point of view but from an environmental perspective as well. However, the current business model of the Chinese concept needs to be supported by almost 50% from private investors, and the high initial cost is holding back some of them (Nguyen et al. 2019). Hence, more research on the viability and the business model of Sponge Cities are needed, one possibility could be to look into the other side benefits it is bringing. The paper from the Indian banker Pavan Sukhdev and his colleagues is bringing to the fore the idea of putting a price on the value of Nature. By thinking differently, looking back at what nature is providing in many fields, and putting a value on the natural capital, investments having harmful effects on ecological systems could not be worth it anymore (Sukhdev, Wittmer, and Miller 2014). Sponge Cities which are promoting the use of green infrastructures and the use of native plants are enhancing the biodiversity and increasing the natural habitats. Making the parallel between the Chinese concept and the work from Sukhdev, Wittmer, and Miller (2014) could bring the another axis of research for the development of sponge cities.

In conclusion, this thesis aimed at answering several objectives characterized by the sub questions. This thesis aimed as well at answering the core of this research paper, the main research question: "*How can the Sponge City Assessment Framework be utilized to assess the effectiveness and impacts of various BGI interventions and strategies in cities?".*, This study first introduced the importance of innovative solution to deal with urban storm water. The current conditions our cities are in and the projections for the future are calling for the use of holistic solutions tackling many challenges at once. Throughout the different analysis, this thesis shaped different tools, like the Sponge City Assessment Framework, the catalog of indicators and the Wheel of components. These tools are providing valuable materials to evaluate the effectiveness and impacts of the Sponge City Concept. The methodology of this paper allowed through a comprehensive and systematic approach, to provide a structured methodology for assessing the performance of cities in implementing sustainable urban water management practices. The findings of this research have theoretically demonstrated that a Sponge City is not only associated with its ability to absorb water but so much more than that. The Sponge City Assessment Framework, is also seen as a mean for cities to gain insights into the effectiveness of their BGI interventions, identify areas for improvement, and make informed decisions regarding future urban planning and development. In addition, by employing the Sponge City Assessment Framework, cities can enhance their capacity to address the challenges of urbanization and climate change, promoting sustainable and resilient urban development. This framework serves as a valuable resource for city planners, policymakers, and decisionmakers to evaluate the effectiveness of their existing BGI interventions, identify gaps and opportunities, and implement targeted strategies for sustainable water management.

Overall, this research has demonstrated the importance of integrating nature-based solutions and sustainable water management practices in urban planning. The Sponge City Assessment Framework offers a practical and adaptable approach to assessing and improving the effectiveness of BGI interventions and strategies in cities. It provides tools towards the achievement of more resilient, sustainable, and livable urban environments, fostering harmony between human activities and the natural environment. Through its utilization, cities can move closer to their goals of becoming true sponge cities, capable of effectively managing water resources and mitigating the impacts of climate change. The concept as well as this thesis are participating in the race towards climate change and the achievement of the international guidelines like the Sustainable Development Goals for instance.

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APPENDIX

Table 10: Results from the systematic and gray literature review

Keywords	Citations
Part 1: Chinese Government's website - State Council Policy Library: *"海绵城市"*	**MHURD (2015)** 'Guiding Opinions of the General Office of the State Council on Promoting the Construction of Sponge Cities Government Information Disclosure Column' **MHURD (2016)** 'Notice of the Ministry of Housing and Urban-Rural Development on Printing and Distributing the Interim Provisions on the Preparation of Special Planning for Sponge Cities' **MHURD (2021)** 'Notice on Carrying out the Demonstration Work of Promoting Sponge City Construction in a Systematic and All-in-One Area Finance China Government Network' **MHURD (2022a)** 'Notice of the General Office of the Ministry of Housing and Urban-Rural Development on Further Clarifying Relevant Requirements for Sponge City Construction' **MHURD (2022b)** 'Notice on Carrying out the Second Batch of "14th Five-Year Plan" Systematically Promoting Sponge City Construction Demonstration Work Urban and Rural Construction (Including Housing) China Government Network'
Part 2: Chinese Ministry of Housing and Urban-Rural Development: *"海绵城市"*	**MHURD (2015)** 'Sponge City Construction Performance Evaluation and Assessment - Chinese Ministry of Housing and Urban-Rural Development' **MHURD (2016)** 'National Building Standard Design System for Urban Comprehensive Pipe Gallery and Sponge City Construction' **MHURD (2018a)** 'Assessment Standards for Sponge Cities' **MHURD (2018b)** 'Sponge City Construction Evaluation Standards' **MHURD (2020a)** 'Standard for Construction Acceptance and Operation Maintenance for Subject Construction of Sponge City - Chinese Ministry of Housing and Urban-Rural Development' **MHURD (2020b)** 'Standard for Sponge City Effect Monitoring - Chinese Ministry of Housing and Urban-Rural Development' **MHURD (2020c)** 'Standard for Subject Plan and Design of Sponge City Construction - Chinese Ministry of Housing and Urban-Rural Development'
Part 3: WoS: *"Sponge city, Analysis"*	**Chen, Yan, and Hongmei Chen (2020)** 'The Collective Strategies of Key Stakeholders in Sponge City Construction: A Tripartite Game Analysis of Governments, Developers, and Consumers' **Fan, Xuezhou, and Toru Matsumoto (2020)** 'Comparative Analysis on Urban Flood Countermeasures Based on Life Cycle Thinking: A Comparison between Enhancing of Drainage Capacity Project and Sponge City' **Lashford, Craig, Matteo Rubinato, Yanpeng Cai, Jingming Hou, Soroush Abolfathi, Stephen Coupe, Susanne Charlesworth, and Simon Tait (2019)** 'SuDS & Sponge Cities: A Comparative Analysis of the Implementation of Pluvial Flood Management in the UK and China'

Keywords	Citations
	Li, Yaoxue, and Youngmin Kim (2022) 'Analysis of Effects of Sponge City Projects Applying the Geodesign Framework' **She, Lin, Ming Wei, and Xue-yi You (2021)** 'Multi-Objective Layout Optimization for Sponge City by Annealing Algorithm and Its Environmental Benefits Analysis' **Wang, Mengjie, Xiaoyue Wang, Caihui Yi, and Xiaoyu Ge (2022)** 'Cost-Effectiveness Analysis of a Sponge City Construction Based on the Life Cycle Cost Theory - A Case Study of the Yanshan South Road Area of Qian'an City, China'
Part 4: WoS: *"Sponge city/cities"*	**Chan, Faith Ka Shun, James A. Griffiths, David Higgitt, Shuyang Xu, Fangfang Zhu, Yu-Ting Tang, Yuyao Xu, and Colin R. Thorne (2018)** '"Sponge City" in China—A Breakthrough of Planning and Flood Risk Management in the Urban Context' **He, Bao-Jie, Jin Zhu, Dong-Xue Zhao, Zhong-Hua Gou, Jin-Da Qi, and Junsong Wang (2019)** 'Co-Benefits Approach: Opportunities for Implementing Sponge City and Urban Heat Island Mitigation' **Jiang, Yong, Chris Zevenbergen, and Yongchi Ma (2018)** 'Urban Pluvial Flooding and Stormwater Management: A Contemporary Review of China's Challenges and "Sponge Cities" Strategy' **Li, Qian, Feng Wang, Yang Yu, Zhengce Huang, Mantao Li, and Yuntao Guan (2019)** 'Comprehensive Performance Evaluation of LID Practices for the Sponge City Construction: A Case Study in Guangxi, China' **Nguyen, Thu Thuy, Huu Hao Ngo, Wenshan Guo, Xiaochang C. Wang, Nanqi Ren, Guibai Li, Jie Ding, and Heng Liang (2019)** 'Implementation of a Specific Urban Water Management - Sponge City' **Xia, Jun, YongYong Zhang, LiHua Xiong, Shan He, LongFeng Wang, and ZhongBo Yu (2017)** 'Opportunities and Challenges of the Sponge City Construction Related to Urban Water Issues in China'

Table 11: Results from the gray literature review on Indexes

Key words	Citations
"Sponge city Index", "Sustainable city Index", "Resilient city Index", "Urban biodiversity Index", "Urban Water Management Index", "Urban Livability Index"	**Arup (2023)** 'Global Sponge Cities Snapshot - Arup' **CBD (2021)** '2021 Singapore Index on Cities' Biodiversity out Now' **Ruf, Karl, Mirko Gregor, McKenna Davis, Sandra Naumann, and Keighley McFarland (2018)** 'The European Urban Biodiversity Index (EUBI): A Composite Indicator for Biodiversity in Cities. ETC/BD Report to the EEA.' **The Rockfeller Foundation, and Arup (2014)** 'City Resilience Index' **UNIDO (2017)** 'Sustainable City Indexing: Towards the Creation of an Assessment Framework for Inclusive and Sustainable Urban-Industrial Development - Unieted Nations Industrial Development Organization' **Urban Taskforce (n.d)** 'Urban Living Index – Measuring the Urban Lifestyle of Your Suburb'