WATER MACHINE NETWORKING

DESIGNING A FUTURE-PROOF WATER NETWORK
FOR INTEGRAL URBAN DEVELOPMENT
IN SINT-OEDENRODE, THE NETHERLANDS

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MSc Thesis Landscape Architecture
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This publication is written as a final master thesis report landscape architecture by order of the chairgroup of Landscape Architecture at Wageningen University.

May 2017
Landscape Architecture Group

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PREFACE

Fascination with the relationship between the Dutch and water originated from some interesting projects in the Netherlands when I was looking into references for my Bachelor graduation design three years ago. Water has shaped the Dutch landscape, culture and lifestyle, distinguishing it from other countries. I choose a water-related topic for my master thesis due to my personal interest and knowing the IABR project 'Mosaic Brabant' by chance.

This thesis takes a parallel study with an in-process project in Sint-Oedenrode that test the design products of 'Mosaic Brabant' – water machines as the starting point. Considering the real-world problems in relation to water, history, culture, nature, and urban development, the study is extended to involve multi-disciplinary research and design. It aims to establish a future-proof water network by combining all the relevant elements into a system that serve the integral ambitions in Sint-Oedenrode through landscape approach.

I have enjoyed working on my quest for in-depth knowledge, thorough analysis and broader perspective as a young landscape architect. I would like to particularly thank Paul Roncken for his inspiring, motivating, critical and patient supervision during the whole thesis process. I would also like to thank Rudi van Etteger for his valuable input during the 'proposal' presentation and short-term supervision in Paul's absence. And I would like to thank Daniel Jauslin for his helpful comment on the 'green-light' exam. Moreover, I would like to thank Anne van Kuijk for her kindness of providing me with detailed information of Sint-Oedenrode and introducing me to other experts. Finally, I want to thank my families and friends for their support.

Xiao Chen, May 2017

SUMMARY

A provincial project 'Mosaic Brabant' creates six development mechanisms – water machines that act as new spatial bond to connect urban and nature of North Brabant to steer the interplay of all the different ambitions. To translate the regional principles into local proposals, Sint-Oedenrode intends to be a 'pioneer' as an experimental case to test the use of project results and integrated approach of 'Mosaic Brabant'. Together with a new discovered meaningful historical structure 'wallenstructuur', they form the starting point of the thesis. In addition, the changing climate has forced Sint-Oedenrode to take measures for unpredictable future, thus the topic is extended to develop an integrated system that involves all the relevant issues.

The study therefore begins with looking into the concepts of a sustainable water management and analyzing the water situations in Sint-Oedenrode, getting to know the historical structure and the method of integrating it through landscape approach, a complete understanding of water machines and investigating the requirements of urban development in Sint-Oedenrode. On the basis of the research conclusions, a cyclical design process is conducted which comprises two parts: an exploration of alternatives concerning with different concepts of water system as the possible solution and preliminary plan; followed by further detail design that is line with the characteristics and the goals of Sint-Oedenrode.

As a results, the thesis creates a new integrated water network by applying the regional development principles water machines, and the local existing historical structure 'wallenstructuur', into the specific context of Sint-Oedenrode in the Netherlands. It can not only deal with the high water problem in central urban areas even when subjected to extreme climate scenarios, but also add potential values to water system through various water machine functioning for integral ambitions, which includes historic, ecological and economic values. It finally provides more opportunities that contribute to urban development of Sint-Oedenrode in the future.

Key words:
water machines, historical structure, Sint-Oedenrode, high water problem, climate scenarios, potential values, urban development, network, integration

CONTENTS

1

INTRODUCTION

This chapter introduces the topic of this thesis starting from the personal fascination and a regional project, and announces the study area as Sint-Oedenrode. A preliminary introduction illustrates the context, the problem, and the purpose of this study.

1.1 Research context

1.1.1 Fascination: Dutch vs. Water

With a large part of land below the sea level, the Netherlands is probably the country that most vulnerable to flooding on the planet. Living on the edge of land, the Dutch struggle against water continually for centuries. Being well known for its expertise in water management, the nation has been busy with dike construction, land reclamations, polder drainage, canals and ditches extension. Various great projects can be found in different places of this country (e.g. figure 1.1-1.3), which have proved that water issues in the Netherlands are always complicated, also water distribution throughout the country is far from straightforward (Rijkswaterstaat 2011). Policy makers and experts keep developing long-term vision and exploring innovative solutions in response to complex water problems in the Netherlands, particularly it is exposed to a changing climate.

1.1.2 An undoubted fact: climate change

It is a global issue that climate has been changing and will continue to change. According to the data from the Royal Netherlands Meteorological Institute (KNMI), the average annual temperature in the Netherlands has increased over the last 100 years, and will keep increasing in the coming years. The situation in the Netherlands is worse than the rest of the world, it has warmed more than twice as fast as the average global temperature since the beginning of 20th century (figure 1.4).


Figure 1.1: Afsluitdijk (photo by author, 2015)


Figure 1.2: Sand motor (dezandmotor.nl 2016)


Figure 1.3: 'Room for the River' at Neder-Rhine (rws.nl 2016)

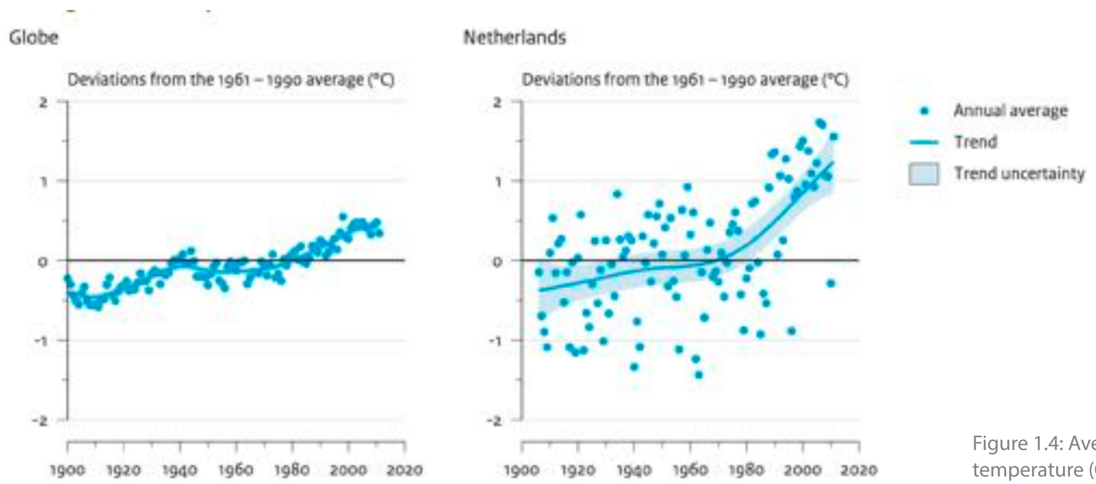

Figure 1.4: Average annual temperature (CBS et al. 2012)

The Intergovernmental Panel on Climate Change (IPCC) states that global warming results in a number of impacts to the hydrological cycle, including changes in precipitation patterns (IPCC 2007). Precipitation is directly influenced by changes in atmospheric circulation and increases in water vapor and evaporation associated with warmer temperature. As a result, an overall increase in precipitation is observed. In the Netherlands, annual precipitation is about 850mm in recent years, even reaches 900mm, which is more than 20% higher than a century ago when it was around 700mm (figure 1.5). This increase has occurred mainly in the winter (+26%), while the amount in the summer has changed by only 5% (KNMI 2006; KNMI 2011).

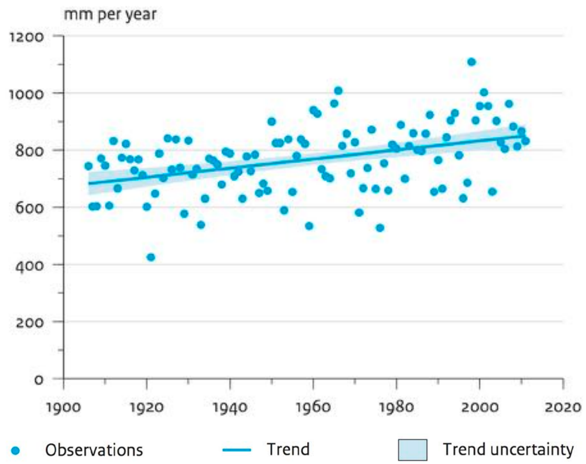

Figure 1.5: Precipitation in the Netherlands (KNMI 2011; CBS et al. 2012)

Heavy precipitation with more than 50mm per day can cause local flooding, restricted visibility and damage to buildings, agriculture and horticulture (PBL 2013). The frequency of this type of rainfall events in the Netherlands has increased as well since the last century (Van der Schrier et al., 2009; KNMI, 2011) (figure 1.6). Fortunately, despite the rising temperatures, there has been no visible trend in the average maximum precipitation deficit in the Netherlands, thus also in the occurrence of drought (KNMI, 2010, 2011; PCCC, 2011). However, it is predicted that extreme weather events such as heavy precipitation (floods), storms, heat waves and droughts become more frequent in the future, which are likely to result in economic losses (KNMI 2009; Verweij et al. 2010).

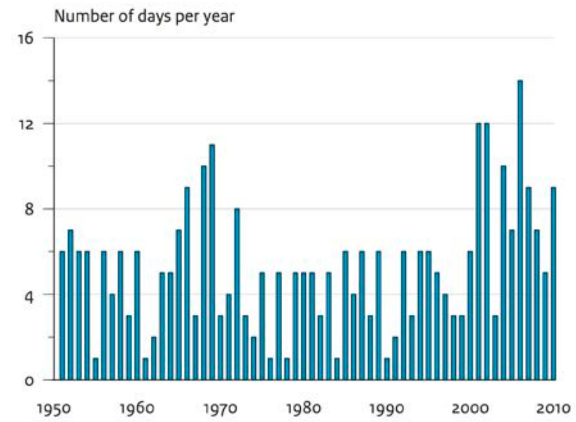

Figure 1.6: Days with 50 mm of precipitation or more in the Netherlands (KNMI, 2011)

1.1.3 Water management and landscape approach

With the trend of a warming globe, water management is facing challenges due to fast changing conditions and increasing uncertainties. To be well prepared for the unpredictable future, either a robust or a resilient solution could be effective. Robustness is actually an important design criterion in engineering, referring to the ability to maintain essential system characteristics when subjected to disturbances (Carlson and Doyle, 2002; Mens, 2015). Resilience of water is included in the development framework as one of the aims for the European Adaption to Climate Change (EU, 2009). As two popular and sustainable perspectives of water management strategy on dealing with extreme events, both of them are able to provide with high levels of protection.

In fact, water management has a long history in the Netherlands, which was already a part of life before the Common Era began (Rijkswaterstaat 2011). The Dutch are renowned for their integrated water management that balances various factors. It is becoming more apparent now that water management is not an independent issue, but needs social, economic and environmental coherence within it (Harrington et al. 2011). In many cases, the necessity of multi-disciplinary integration has been emphasized while discussing the challenges and opportunities associated with taking a landscape approach to water issues. In Dutch origin, *landschap* (landscape) meant to adapt natural and cultural processes to create new territory. As the word moved into English and other languages, it took on visual meaning as well (Steiner 2011). There is a "false dichotomy" held by many ecologists that landscape is either 'nature' or 'culture', and cannot be both (France 2007). However, landscape is in fact always a combination of natural and cultural elements forming the 'physiognomy' of the environment (Earth's surface) (Bogdanowski et al. 1976; Wlodarczyk 2009).

In the past decade or two, the functional value of landscape design structures a larger framework to synthesize natural and cultural expressions, regarding ecosystems and biodiversity as part of ambitions (Roncken et al. 2014). It is not a new concept. As early as 1969, McHarg put forward with his ideas about using ecology as a basis for landscape design and planning. Hough (1995) also searched for the potential of cities to be environmentally, economically and socially sustainable, thinking about the city as a part of the big wide natural world and designing with natural processes such as sunlight, wind, water, and seasons. The growing awareness of nurturing a rewarding environment where nature and urbanism co-exist calls for a more sustainable and practical strategy in the 21st century.

1.1.4 IABR-Project Atelier BrabantStad – 'Mosaic Brabant'

The topic of sixth International Architecture Biennale Rotterdam (IABR) in 2014 is URBAN BY NATURE, looking at the city on the scale of urban landscape, spatial configuration, nature and metabolism. One of the three project ateliers in the Netherlands which was realized at that time is IABR-Project Atelier BrabantStad. It was set up in 2013 by IABR in alliance with the Province of North Brabant, BrabantStad (the municipalities of 's-Hertogenbosch, Eindhoven, Tilburg, Breda, and Helmond) and four water boards of North Brabant. North Brabant (figure 1.7) is facing major ecologic and socio-economic challenges, but at the same time presents a huge opportunity with which it can be properly prepared for the future (Floris Alkemade Architect et al. 2014).

Figure 1.7: The province of North Brabant

Spatial planning in North Brabant has always been committed to strengthening and improving the urban environment, the green structure and the agricultural area as three separate worlds. As a result, spatial and economic cohesion are lacking: the ties between town and country slacken, and the cities pay most of the bill for maintaining the quality and safety of the water system. At present, it seems prudent to invest the linkage of these worlds rather than separate investment (Floris Alkemade Architect et al. 2014).

BrabantStad is in essence a dispersed city, an urban landscape. It is an extensive and flexible mosaic with different land use both in high and low densities (LOLA 2014). To make it to be a cohesive urban metabolism, Atelier in collaboration with local stakeholders, Architecture Workroom Brussels, LOLA Landscape Architects and Floris Alkemade Architect conduct research by design into the hidden strength of Brabant's urban tapestry, searching for the bond between urban and nature (three separate worlds) to steer the interplay of all the different ambitions and actors (IABR 2014). The specific spatial pattern characterizes the province of North Brabant. It is an urban carpet, a colorful mosaic of city neighborhoods, intensive agriculture, lanes, villages, industrial activities, stream valleys, nature reserves and canals (figure 1.8). To reactivate the urban carpet, the IABR-Project Atelier Brabantstad explored multilayered challenge, proved that the water system affects all economic and environmental interests, and can act as a catalyst for advancement to a future-proof Brabant. On this basis, the Atelier proposed six development mechanisms as model solutions (figure 1.9 & 1.10), and the program of innovative spatial planning is named 'Mosaic Brabant'. Ultimately, the aim is to create an accumulative development policy instead of a single extensive regional plan (Floris Alkemade Architect et al. 2014).

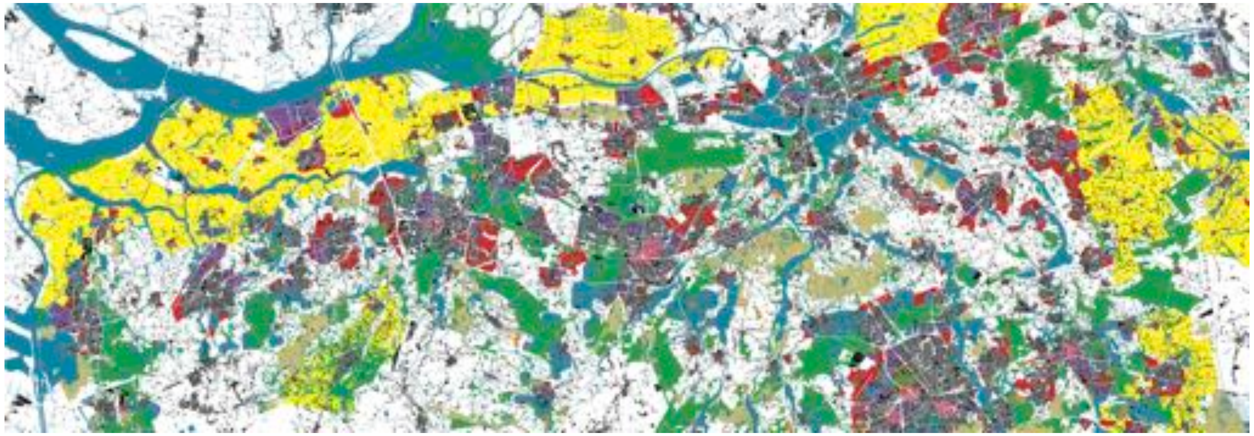

Figure 1.8: A 'Mosaic Brabant' with colorful urban landscape (IABR, 2014)

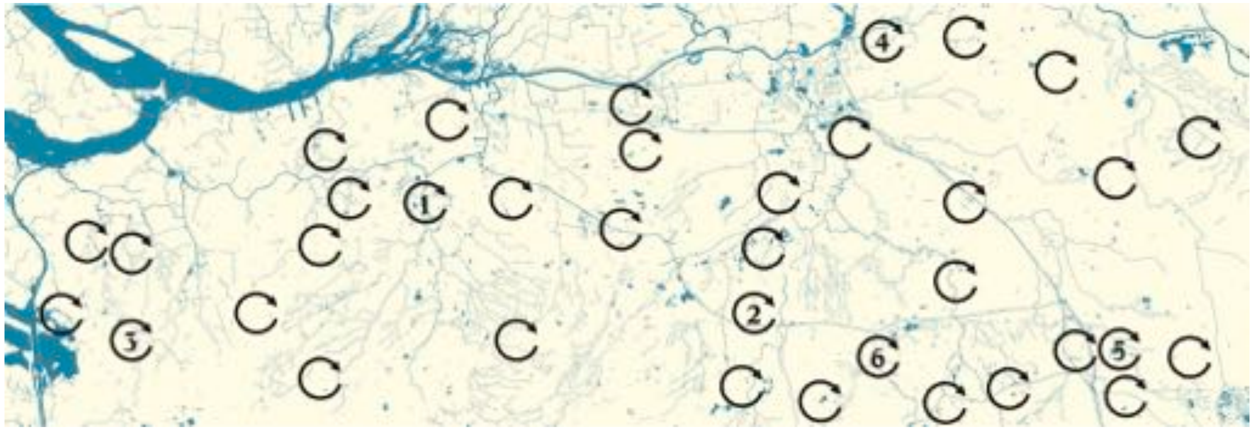

Figure 1.9: Six machines to reactivate the Brabant carpet landscape (IABR, 2014)

Figure 1.10: Diagram of six water machines (LOLA, 2015)

1.1.5 Program 'Mosaic Dommelvallei'

Now a number of locations work on the translation of regional development principles into local project proposals continues to concretize (IABR 2014). The Dommelvallei (Dommel valley) municipalities (between Eindhoven and 's-Hertogenbosch and ones connect with Dommel river) participate in this new spatial planning, launch the program 'Mosaic Dommelvallei' in which several 'pioneer' projects are being implemented as experimental cases to test the use of water machines and integrated approach of 'Mosaic Brabant'. They will serve as inspirations for new initiatives and other projects.

The thesis takes one of the leading projects that is taking place in Sint-Oedenrode (figure 1.11). On the basis of six water machines mentioned above, regional concept will be applied. Associated with the specific context and local features of Sint-Oedenrode, the thesis sets brand new ambitions.

Figure 1.11: Location of Sint-Oedenrode and Dommel river

1.2 The study area and problem introduction

1.2.1 The site: Sint-Oedenrode

Sint-Oedenrode (figure 1.12) is a municipality (merged into a new municipality 'Meierijstad' together with Schijndel and Veghel from 1st Janauary 2017) and a town in the province of North Brabant, located in the Meierij of 's-Hertogenbosch, covering an area of 6,494 hectares, of which 0.8% are lakes, ditches and other water bodies. It has a large part of natural area such as forests, parks, grassland and farmland, and lies as 'the green heart of the Meierij' between the cities 's-Hertogenbosch, Tilburg and Eindhoven (Gemeete Sint-Oedenrode 2016).

Sint-Oedenrode originated on the banks of the river Dommel around 500 AD, and developed from a historically booming center of culture and trade to a rural village as it is today. It keeps a green and bucolic image with a charming historic city center and a leisurely living environment. The Dommel is a tributary of the Meuse River that rises in north-eastern Belgium and flows into the southern part of the Netherlands, where it joins the Meuse close to 's-Hertogenbosch (Petelet-Giraud et al. 2009). It runs through the central urban area of Sint-Oedenrode (figure 1.13) and has shaped the main landscape of the town.

Figure 1.12: The municipality of Sint-Oedenrode (Kadaster, 2015)

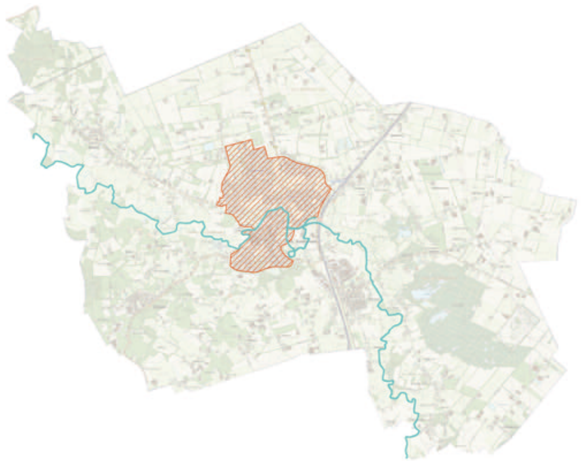

Figure 1.13: Dommel runs through the central urban area of Sint-Oedenrode (adapted from Kadaster, 2015)

1.2.2 Landscape development

The typical characteristics of Dommel valley landscape can be found in Sint-Oedenrode. Originally, it consisted of meadows, pastures and small landscape elements such as steep edges and pools, which was fairly open. While the higher, cultivated fields were more closed with a variety of gibbous fields, hawthorn hedges and wooden windbreaks (ELINGS 2016). Stream valleys are also characterized by having a floodplain, where is naturally subject to periodic flooding (Bridge 2009).

During the 18th century, accompanied by the birth of a new export industry – clog-making, many poplars were planted in some parts of Sint-Oedenrode where the soil was loamy. It then resulted in a new distinctive type of landscape called 'poplar-landscape', which existed from about 1750 to 2000 AD, contrasted with the landscape of the surrounding villages (Leenders 1998). In the twentieth century, most stream valleys were modified for agricultural purposes: fertilization to maximize yield, ditches that drain groundwater, stream water directly flows into the stream and dikes to control flooding (Bas et al. 1990; Pedroli and Borger 1990; Beumer 2009).

At present, the landscape of the area is still deeply influenced by the Dommel, which is clearly visible from the elevation map (figure 1.14). The valley landscape is in green / blue areas around the Dommel, the higher parts are yellow / orange where urban areas are located to prevent flooding as much as possible.

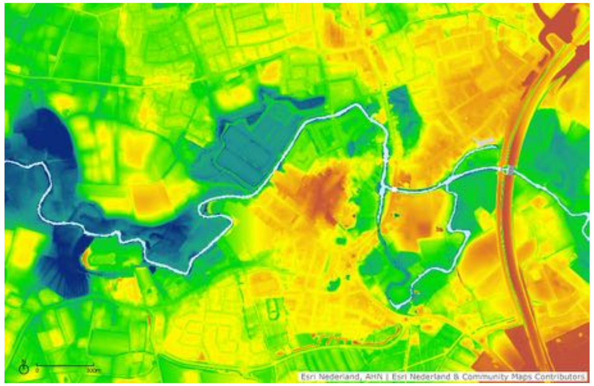

Figure 1.14: Elevation map of central Sint-Oedenrode (AHN, 2016)

1.2.3 Challenges for Sint-Oedenrode

With the trend of climate change, it is expected that Sint-Oedenrode will be hotter, drier and also wetter in 2050 (figure 1.15-1.17). The maps show the situations when the climate scenario* is supposed to be at the high peaks (climate scenario W+). In this case, the temperature in urban area will become higher, and the groundwater levels will change a lot in both dry and wet seasons. The thesis focuses on dealing with high water problem in Sint-Oedenrode. It has been proved that the increase in precipitation leads to higher river discharges and flooding risk (IPCC 2007; Bates et al. 2008; KNMI 2009; KNMI 2015). More and more frequent high-level water under the extreme weather conditions is beyond the capacity of the current drainage system.

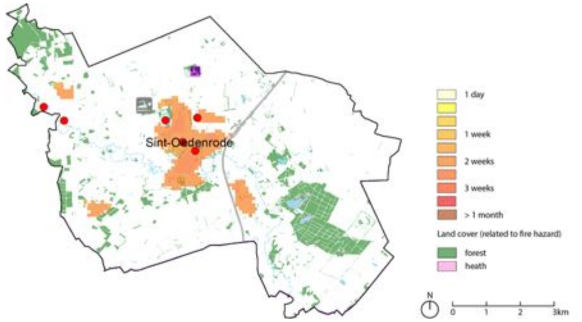

Figure 1.15: Number of nights that the temperature > 20 degrees, climate scenario W+ 2050 (Whaterschap De Dommel, 2015)

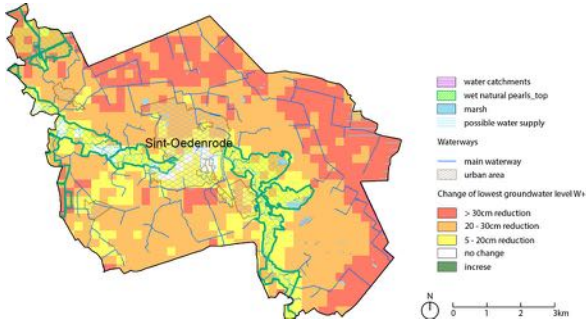

Figure 1.16: Change of lowest groundwater level, climate scenario W+ 2050 (Waterschap De Dommel, 2015)

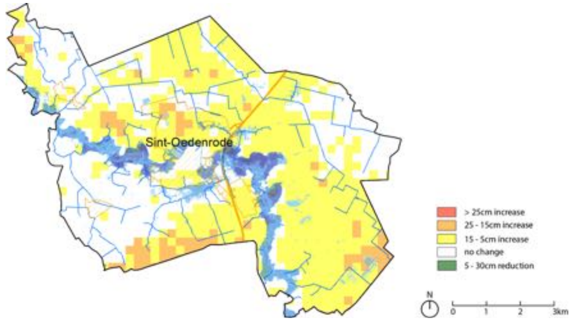

Figure 1.17: Change of highest groundwater level, climate scenario W+ 2050 (Waterschap De Dommel, 2015)

***Knowledge supplement:**
Climate scenarios for the Netherlands

Climate scenarios are intended as the calculations of possible future based on a series of coherent and plausible assumption. Each scenario is a projection, not a prediction (PBL 2013). In 2006, KNMI issued four scenarios for future climate in the Netherlands around 2050 and 2100. They differ in the amount of global warming or the degree of change in air circulation pattern above the Netherlands (figure 1.18) (Klein Tank and Lenderink 2009). Theses KNMI'06 scenarios offer a guide for evaluating the consequences of climate change and for developing options and strategies for climate adaptation (KNMI 2015).

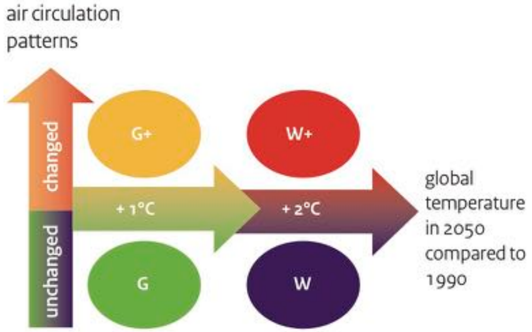

Figure 1.18: Climate scenarios (KNMI, 2006)

The pictures (figure 1.19-1.22) were taken within or around the urban area of Sint-Oedenrode after continuous raining, which show the unsatisfying situation that water cannot be drained in time. What about the result under even more serious condition? Earlier hydrological model calculations done by Royal Hoskoning in 2012 found that urban areas in Sint-Oedenrode are not sufficiently protected against flooding from the Dommel. The calculations assumed the climate scenario as W+ with a flood once per 100 years (T=100), and the result presented that some areas around the center of Sint-Oedenrode are prone to inundation (figure 1.23). Without any measures, both blue and yellow areas are inundated; while the yellow part can be protected by using the controlled water storage areas Dommeldal Eindhoven (a nature reserve) and Kleine Dommel (in upstream Dommel).

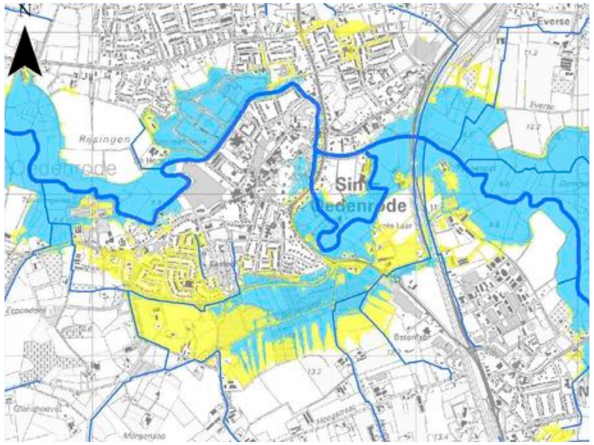

Figure 1.23: Hydrological model calculations, climate scenario W+ T=100 (Royal Haskoning, 2012)

Figure 1.19-1.22: Pictures taken in Sint-Oedenrode after raining

In summary, the current water system in Sint-Oedenrode is not strong enough to prevent flooding, especially when it comes to the extreme climate scenarios, which are very likely to happen in the near future. Water causes problems that need to be urgently solved, but also can be regarded as an opportunity, a starting point for spatial planning and urban development. Waterschap De Dommel has put forward five water issues as dry feet, sufficient water, clean water, natural water and beautiful water. They are connected to each other, and in fact involve many aspects and values.

1.2.4 Water as potential in Sint-Oedenrode

It is already clear that water is the hidden strength of North Brabant. Some documents also indicate that water is a great chance for Sint-Oedenrode / stream valleys. They help to shape parts of ambitions of this study.

In the end of 2015, Waterschap De Dommel formulated *Waterbeheerplan 2016-2021* for the middle Brabant region, and updated it at the beginning of 2016. It is a regional plan and includes different cities and towns, but they share the same hydrological unit: the stream valley. The plan aims at giving more values to water. A number of challenges and ambitions are explained in the document to deal with the complex water issues in this area and achieve sustainable water system. Besides, according to the *Collegeprogramma 2014-2018* from the municipality of Sint-Oedenrode, water is the key to "growth". It doesn't refer to extension of area or increasing number of inhabitants and companies, but means improving the quality of life and environment, enhancing both natural and cultural values somehow.

These additional values could be achieved by applying the regional development principles - water machines, and a particular local historical structure that was discovered by Harry van Kuijk in 2015. This structure is called 'wallenstructuur' in Dutch, located in the south and west of urban area. It formerly was drainage ditches with raised stretches of land as supposed, which offers an inspiration of spatial and hydrological vision for its future use, as well as historic value to the water structure.

1.2.5 Problem statement

Based on the challenges and opportunities introduced above, the core problem of this study is the possible high water problem in the urban area of Sint-Oedenrode in 2050 under the extreme climate scenarios W+. In addition to solve this main issue, catalytic interventions can be caused to provide opportunities for creating and strengthening the potential values in the area. Therefore, the problem of this study is actually more complex, which refers to an integral water network. In the case of Sint-Oedenrode, the integral parts could involve the living environment, spatial quality, business, agriculture, nature, recreation, economy, as well as a special historical element ('wallenstructuur'). Due to the presence of so many and diverse aspects, it is questionable to what level of detail the integral result will be predictable.

1.3 Purpose of the study

The main purpose of this thesis is to develop a new water network against high water problem, applying the provincial water machines and a particular historical structure ('wallenstructuur') through an integrated landscape approach in Sint-Oedenrode, adding potential values to water system and providing more opportunities for urban development, making a future-proof Sint-Oedenrode (figure 1.24). As an experimental project to test the water machines, the results of design assignment should also revisit the general principles of North Brabant, evaluating the effects and giving a feedback to the regional policy. It intends to see the utility of water machines and summarizes the lessons that can be learned to improve them.

From the landscape architectonic perspective, another objective is to get an insight into how landscape practice build a balance, an integration within the system. Sint-Oedenrode is in a large natural world and can be regarded as a component of a system. A wider context should be considered beyond the boundaries or scale of the project area (Corner 2006). 'Water' is a big issue in the Netherlands, full of dynamics and uncertainties. Through this study, it is expected to provide a new perspective on the adaptive and sustainable water network for integral ambitions of urban development not only in Sint-Oedenrode, but also in other places.

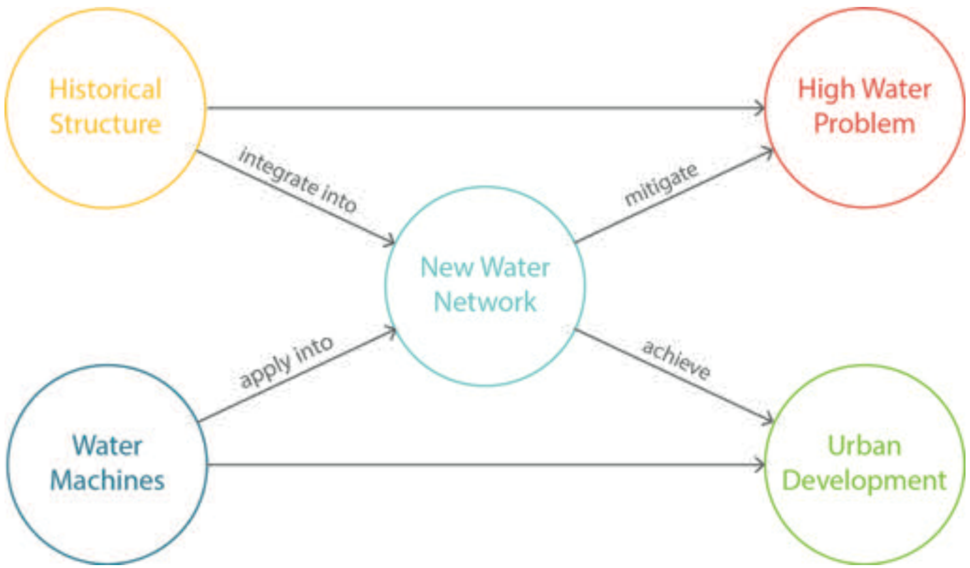

Figure 1.24: The framework of this thesis

1.4 Philosophical worldviews

Creswell (2014) put forward four philosophical worldviews that shape the approach to research – postpositivism, constructivism, transformative, and pragmatism.

In this study, pragmatic worldview is dominant, which is problem-oriented and concerned with approaches to understand the problem. It arises out of actions, situations, and consequences. There is a concern with applications—what works—and solutions to problem (Patton 1990; Creswell 2014). The research is based on the real world problem in Sint-Oedenrode, and occurs in social, political, historical and other contexts. Mixed methods will be applied for collecting and analyzing data, integrating knowledge of different fields and looking to 'what' and 'how' to research based on the intended consequences (Creswell 2014).

In addition, transformative worldview is also applied in this study because in the case of Sint-Oedenrode, the research needs to be intertwined with general principles of the regional development plan in the North Brabant. Differ from the constructivist stance which focuses on the experiences and interpretations of individuals or participants, transformative confront social issues and contain actions for reform, which goes far more than constructivism (Mertens 2010; Creswell 2014).

1.5 Outline

In the following pages, the complete content of research and design process will be elaborated and presented.

Chapter 2 elaborates on the research strategy. It first points out the knowledge gap that this thesis is going to fill, referring to which three research questions and one design questions are formulated. For each question, specific methods are introduced, together with the relationships and framework of 'research + design' process.

Chapter 3 answers the first research question by introducing and comparing the concept of 'robustness' and 'resilience', as well as an analysis of current water system of Sint-Oedenrode. Chapter 4 answers the second research question by describing and summarizing the characteristics of historical structure ('wallenstructuur'), and looks into several reference projects to extract qualitative elements that are valuable for integrating it into landscape design. Chapter 5 answers the third research question by researching on LOLA water machines, and summarizes the vision and actions of upcoming urban development in Sint-Oedenrode.

The results of all three chapters before contribute to design process, starting from chapter 6 – a clear translation into design strategy and exploration of alternatives from three perspectives. This chapter provides with several possible solutions with principle profiles, and potential water machines that can be applied in Sint-Oedenrode. The most suitable option is selected after an objective evaluation and is further developed in chapter 7 through a master plan, application of various water machines, descriptions and visualizations.

Finally, chapter 8 evaluates and reflects critically on this thesis through a discussion, recommendation and conclusion.

2

RESEARCH DESIGN

This chapter aims to formulate research and design questions for this study, and elaborates on the research methods that are used to answer these questions to accomplish the purpose as indicated in chapter one.

2.1 Knowledge gap

The knowledge gap of this study is related to the practice of a landscape design: there is a lack of experience in the application of water machines and the integration with a historical structure. The water machines are general principles that suit the spatial characteristics of North Brabant, while in this study, the idea is implemented in the specific context of Sint-Oedenrode. The context here is complex: not only in terms of its current water situations, culture, economy, development policy and ambitions, but also in terms of the fragments of historical structure ('wallenstructuur'). The original appearance and function of the structure still remains unclear, so the way to combine it with water system and water machines needs to be explored as well.

To close the knowledge gap, the interpretation of water machines is necessary, where can they be implemented for what purposes, how to modify them to make sense in Sint-Oedenrode; wherein the interpretation of Sint-Oedenrode is required, especially its demand of water in specific conditions, for nature, agriculture, living, recreation, public services etc. This also helps to determine the additional values that can be realized by the new network of water. Translating the results into spatial landscape design is the design assignment for the thesis. A link is going to be made between natural and cultural worlds through the design interventions.

2.2 Research and design questions

In order to fill the knowledge gap and achieve the purpose of this study, research and design questions are formulated. Each research question refers to important component that is included in the whole framework, and the design question assigns an integrated landscape design challenge based upon the results of research questions.

Research questions (RQ):

RQ1: What are the characteristics of either a robust or resilient water system (climate scenario W+, T100) in Sint-Oedenrode area?

RQ2: How can the local historical structure ('wallenstructuur') be integrated in an improved water network?

RQ3: Following the concept of 'water machines' (LOLA 2015), what type of machine would be applicable to fit the integrated landscape development in Sint-Oedenrode?

Design question (DQ):

How to combine specific types of 'water machine' (LOLA 2015) with the rehabilitation of (parts of) the historical structure ('wallenstructuur') and serve the integral urban development in Sint- Oedenrode?

2.3 Methodology

To answer the research questions, several steps will be processed in a combination of pragmatism and transformative worldviews as explained before. The study is associated with a concurrent mixed-methods because of the complexity of water system and its interrelationships to the nature and culture in the specific context in Sint-Oedenrode. Research and design are involved in the whole process: research for design to improve the quality and increase the reliability of the design products, research on design, and research through designing that design as a way to generate new ideas and questions, as well as exploring possibilities (Lenzholzer et al. 2013).

The study is highly influenced by the context in which the dynamic water system, historical structure, never practiced water machines and several development values are perceived. Therefore, all the research questions include a site-based part. RQ1 is solved by understanding robust / resilient water system [literature study] and analyzing water situation of Sint-Oedenrode on different conditions [interview + scenario study]. RQ 2 is answered by getting to know the historical structure ('wallenstructuur') [interview + Field survey] and studying experience from similar projects [Reference study]. RQ3 is settled by understanding water machines' concept designed by LOLA [Model study + interview] and reading relevant policies that concerned with urban development of Sint-Oedenrode [Document review]. And DQ is done by generating a design result of integrating all previous conclusions [field survey + design models + cyclical landscape design process]. The details are explained in the following.

Literature study

A literature study is conducted to have a theoretical understanding of the concept of 'robustness' and 'resilience', regarding their definitions, development, characteristics and applications, particularly in the field of water management. The literature is searched mainly through Wageningen UR Library Catalogue and Google Scholar. There are two steps to process: having a notion of them separately and then making a comparison of similarities and differences.

Semi-structured interviews

Due to complexity of the local context this study covers, interviews are one of the most important methods during the research process. The "interview" is a managed verbal exchange (Ritchie & Lewis 2003; Gillham 2000), which can be simply classified as 'unstructured', 'structured' and something in between, namely 'semi-structured'. Unlike the structured interviews that detailed questions are formulated beforehand (similar to type of questionnaire), semi-structured interviews are conducted with a fairly open framework (Davis Case et al. 1990). Not all questions are designed and prepared in advance. This allows both the interviewer and the interviewee to be flexible to probe for details or discuss issues (Davis Case et al. 1990).

Figure 2.1: Contact network

The reason of choosing semi-structured interviewing as research method is that specific quantitative and qualitative information is needed for this study. This kind of information cannot be obtained through internet or library (unpublished), even cannot be found in any existing writings. Certainly, it is also the most direct way to have a better understanding by talking to people involved even if information is acquired. The contact network (figure 2.1) shows people who are connected with this study. Some of them are interviewed face to face, some are reached by email or phone to provide with relevant materials. All the interviews are recorded and reorganized later, which offer useful information and inspirations but are not be regarded as scientific data.

Scenario study

A scenario study is coupled with climate scenarios for the first research question, which aims to obtain a holistic exploration of current and future water situations in Sint-Oedenrode under normal or extreme climate conditions based upon the analysis of Waterschap De Dommel. The scenario study is accompanied by interviewing with some water specialists, through which the improved and future-proof decisions can be proposed and made since various consequences are calculated and clearly predicted. The results provide an effective dependence for design strategy, which further forms an important input for the design models.

Field survey

As mentioned, the study is site-based, wherein a field survey is indispensable. Sint-Oedenrode is visited and investigated for several times during the research phase. For the second research question, a field survey helps to find out fragments of the structure and its spatial relationship with current water system, which gives a better impression in addition to the descriptions in words. Besides, field survey is also applied during the landscape design phase combined with map study, relying upon the principles of observation and analysis of field evidence of certain types and periods. For instance, land use, infrastructure, property, landscape features and so on.

Reference study

Reference study can be a source of practical information on potential solutions to difficult problems (Francis 2001). In this part for the second research question, a reference study aims to draw inspirations from existing functioning projects in the real-life context with relation to the keywords like historic preservation / cultural heritage / cultural landscape / landscape narratives / symbolic landscape. Qualitative elements that contribute to the design are extracted, particularity combined with the case of historical structure. Therefore, this method here takes account of the research result of 'wallenstructuur', considering its unique history and features.

Model study

A model study for the third research question focuses on an analysis of design products by LOLA Landscape Architects – water machines. Synthesizing the written materials and record of interview with the designer, it is not difficult to understand water machines completely, including their concepts, characteristics, functions, scales, applications, potential values, etc. The model study lays a foundation for new creation of additional water machines and their application in the specific context of Sint-Oedenrode.

Document rewiew

The third question consists of two separate parts, one is introduced above, the other is concerned with unique local context. Because of the site's peculiarity, a document review is conducted in order to go deep into local culture, nature, society, policy, etc. Some relevant documents / booklets about urban development in Sint-Oedenrode are collected from the municipality. They offer objective descriptions of current situation and ambitions for upcoming years, which gives a political basis and qualitative potentials that can be achieved by water machines.

Design models

Alternatives from various perspectives are explored as the possible design solutions of a new water network in order to solve high water problem in Sint-Oedenrode. Theses alternatives are created according to different characteristics of water system – either robust or resilient, as derived from the result of RQ1. The potential water machines are suggested in specific locations based on the result of RQ3 and different starting points. They are evaluated by a multi-criteria analysis that regards to various types of values – historic, ecological, economic, and feasibility of implementation. The evaluation emphasizes the strengthens and weakness of each alternative, involving both qualitative and quantitative analysis, but can never completely cover all the factors. Despite that a preferred alternative is selected as the initial plan for detail design process.

Cyclical design process

In the field of landscape architecture, design is considered the primary activity, which is surely involved in this study as a method, relating to 'research through designing' (Lenzholzer et al. 2013). It is in fact an interactive process and the pattern is cyclical rather than sequential (Filor 1994). This kind of cyclical design process is used to search for creative and rational design solution on the basis of research results (answers to RQ1, RQ2 and RQ3) in the form of sketching, modelling, brainstorming, additional analysis and testing. In this part, detailed design of water machines is generated as a further development of preferred alternative. Together with an integral planning, it shapes a brand new networking in the context of Sint-Oedenrode.

"Fundamental questions of design can be illuminated not by any attempt to make the process of designing 'scientific', but rather by subjecting the products of design scientific study" (Steadman 1979). Critical testing and reflection of design product is essential. It is important to see the initial concept as a first step, something which will change, often out of all recognition, as it is evaluated against scientific and qualitative criteria (Filor 1994). The design experiments on the application of water machines, which needs to be assessed – stepping backward and forwards as a vital ingredient in the process.

The relationship of research and design process, together with methods applied and expected results for each question is summarized in the diagram below (figure 2.2). It illustrates the structure of this study through a systematic steps and organization. In the following chapters, the results of research and products of design will be elaborated and presented.

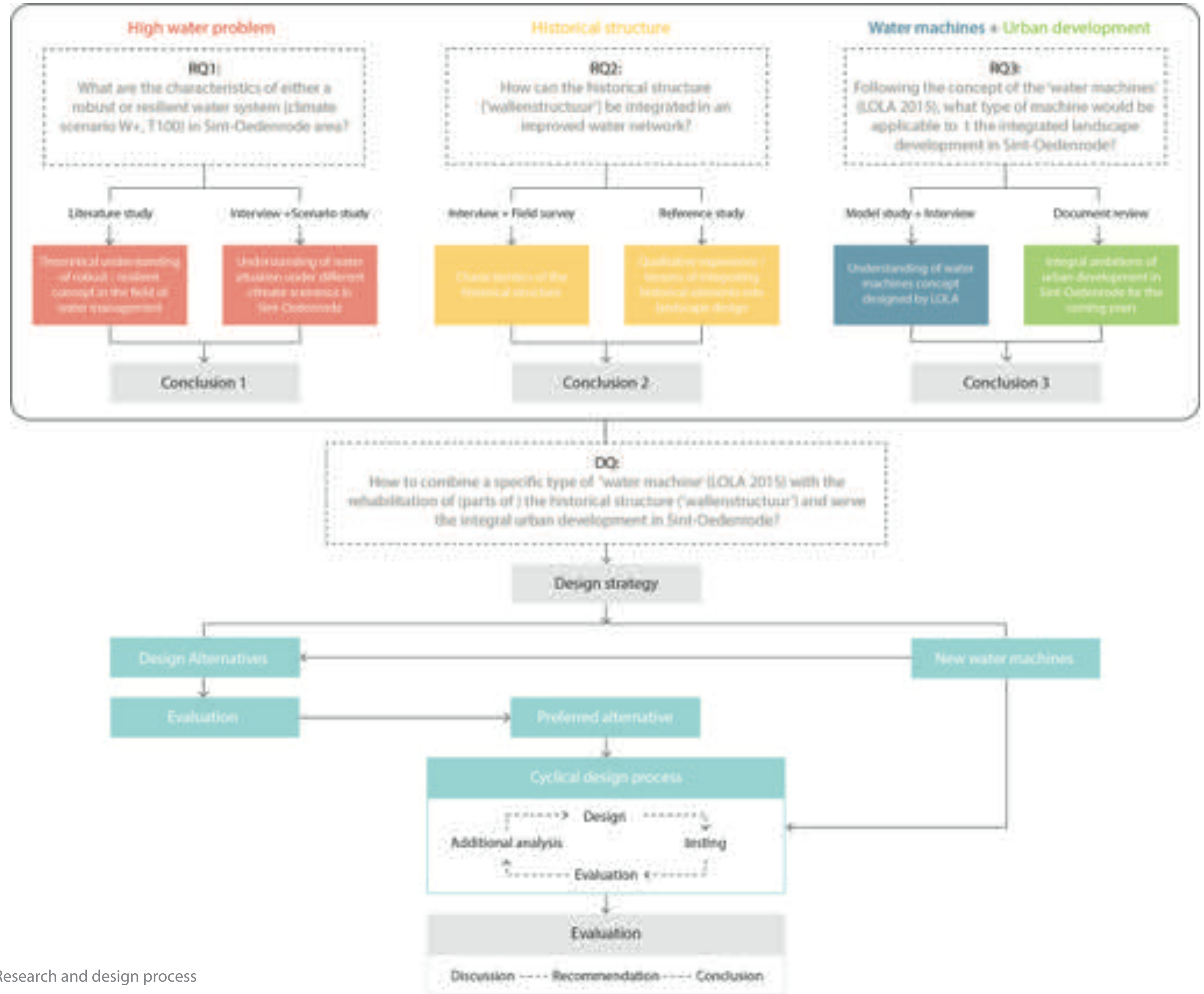

Figure 2.2: Research and design process

3

ROBUST WATER SYSTEM VS. RESILIENT WATER SYSTEM

This chapter aims to answer RQ1: *What are the characteristics of either a robust or resilient water system (climate scenario W+, T100) in Sint-Oedenrode area?*

3.1 Robustness

3.1.1 Definition

The word 'robust' originates from the Latin *robustus*, meaning 'strong' or 'hardy' (Mens et al. 2011). According to Merriam-Webster dictionary, it is explained as having strength, or showing vigorous health, or being strongly constructed, or being capable of performing without failure under a wide range of conditions.

In scientific literature, robustness is defined in various ways when involved in different fields, which can be roughly distinguish between system robustness and decision robustness (Mens et al. 2011). System robustness is common to see in engineering and biology, where it refers to the ability of systems to maintain desired system characteristics when subjected to disturbances (Carlson and Doyle 2002; Stelling et al. 2004; Jen 2005; Mens et al. 2011); while decision robustness is mostly used in policy analysis and economics as a criterion for making decisions under uncertainties (Rosenhead et al. 1972; Bankes 1993; Lempert et al. 2003; Ben-Haim 2006; Mens et al. 2011).

This thesis focuses on system robustness since it is discussed with regard to water system. To be more specific, how the concept of robustness makes sense and be operational for a water system when subjected to unpredictable extreme climate events (floods) is exploded.

3.1.2 Robust system: fail-safe

A robust system is considered as fail-safe system, meaning it is designed not to fail. This kind of system has high reliability, and the failure does not lead to catastrophic consequences, while the influence could be large. The concept of 'fail-safe' has been applied in many disciplines like mechanism, physics, electronics as a design criterion (Rutherford 1992; Mens 2015). In such control systems, safety is (or at least should be) an important design priority.

Historically, the implementation of sustainability focuses on achieving stability, practicing effective management and the control of change and growth, namely a 'fail-safe' mentality (Ahern 2011). In this thesis, a robust or fail-safe system is expressed in terms of sustainable water management, particularly in terms of flood risk management. It is already discussed by Merz et al. (2010), who suggested the possibility of controlled flooding.

3.1.3 Towards flood risk management

In fact, similar perspectives on system robustness can be found in many topics related to water issues such as robust water distribution networks (Yazdani and Jeffrey 2010; Cunha and Sousa 2010; Greco et al. 2012) and robust water resources management (Hashimoto et al. 1982; Watkins and McKinney 1997; Dessai and Hulme 2007). Among those definitions, the one focuses on flood risk management is the most aptly to be applied in this study. As put forwarded by Marjolein Mens, robustness can be considered as "a system characteristic that represents the ability of a system to remain functioning under different degrees of disturbances" (Mens et al. 2010; Mens et al. 2011).

A flood risk system comprises physical and socio-economic components: the physical elements (e.g. embankments and structures) control floods, and the socio-economic elements refer to people who live in the flood-prone area, economic values of land uses, financial situation of the area, and economic connections to other places (Mens 2015). It can be disturbed by extreme events like intensive rainfalls, flood waves in river catchments, and storm surges at sea. Climate variability results in such events with unacceptable consequences to the social, economic and environmental system. It is considered that a disaster may happen when the capacity to cope with impacts is exceeded that normal activities are severely disrupted (IPCC 2012). This is often related to the large-scale and irreversible nature of the impacts (Mens 2015).

A robust system towards flood risk management is able to remain functioning under a range of extreme climate events, even the consequences of failure are potential but still acceptable and manageable. To further explain, it has the system characteristics of resistance and sensitivity. Resistance is the ability to withstand disturbance, and sensitivity is the ability to limit the impacts of a disturbance (Mens et al.2010). This provides a clear conceptual framework for a 'robust water system'. In the case of Sint-Oedenrode, both robustness components can be quantified. The degree of resistance is indicated by the maximum water level that does not cause flooding from the Dommel river, while the sensitivity is indicated by the increase of flooding risk under the extreme climate conditions (climate scenario W+ 2050). In addition, the financial, social and technical state of the water system robustness are also important components that allow it keeping the original status from the impact of flooding.

3.2 Resilience

3.2.1 Definition

The term 'resilience' has a number of definitions that can be found in literature. Simply, it is explained as the ability to respond and recover from a disturbance (Begon et al. 1996), also known as 'engineering resilience' (Holling 1996), which stays closest to the Latin origin *resilire*: to jump back (Mens et al. 2011). Actually the resilience perspective was first emerged from a stream of ecology in the 1960s and early 1970s through studies of interacting populations (Folke 2006). The ecologist Holling introduced it as a property of system, which is "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling 1973). Afterwards it began to influence other fields outside ecology (Folke 2006).

Resilience is currently defined as "the capacity to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks" (Walker et al. 2004; Folke 2006). This definition indicates that resilience has evolved into a broader concept, which is now generally accepted and used in many disciplines. Folke (2006) makes a clear division of various perspectives on resilience into three: engineering resilience, ecological resilience and social-ecological resilience, among which social-ecological resilience provides the most suitable framework for this study.

3.2.2 Resilient system: safe-fail

A resilient system is known as safe-fail system, minimizing the probability of failure. This kind of system anticipates the failures and is designed strategically to allow failing (Steiner 2006). In this sense, a resilient system is fault-tolerant, which enables the system to continue its intended operation properly, or possibly at a reduced level, rather than completely failing (Johnson 1984). The term is most commonly used to describe computer systems, but has been introduced within the scope of other systems.

Recent thinking about change, disturbance, uncertainty and adaptability becomes fundamental to the emerging of resilience. The capacity of systems to reorganize and recover from change and disturbances – in other words, a 'safe-fail' system (Ahern 2011). This is considered as a new perspective of sustainability in terms of broad categories, also could be a key concept for sustainability of water management and flood risk management.

3.2.3 Towards flood risk management

The use of resilience in water management is derived from ecology as well. Similar to the concept of 'robustness', 'resilience' has also been applied in some water-related fields. Hashimoto et al. (1982) discussed this idea in the context of water management and stated that instead of trying to eliminate the possibility of reservoir failure, measures should be taken to make the consequences of failure acceptable.

As to flood risk management, De Bruijn (2014) stated that although resilience has several definitions in the context of water management, there is no clear definition for flood risk management yet. She distinguished between resilience and resistance as two flood risk management system characteristics that determine a system's response to disturbances. Resistance is the ability to withstand disturbances without responding, while resilience is the ability to recover from the response to disturbances (De Bruijn 2014; Mens 2015). To be more specific, the disturbances for a flood risk management system may cause floods, casualties, damage and/or socio-economic disruption. Therefore, the resilience of flood risk management systems can be defined as "the ease with which the system, consisting of the socio-economic and physical aspects of the flood-prone area and the river, recovers from floods" (De Bruijn 2014). In other words, in a resilient flood risk management system, floods may occur, but their impacts will be easily recovered from (De Bruijn 2014).

Besides, the broader concept of resilience on socio-ecological perspective has been applied in climate change adaptation as a way to deal with disturbing events (resulting from climate variability) and disturbing trends (resulting from climate change) (Wardekker et al. 2010; Linkov et al. 2014). In the case of Sint-Oedenrode, the disturbing events refer to the potential urban flooding from Dommel river, which is caused by the disturbing trends – the future climate scenario W+ in 2050. A resilient water system for Sint-Oedenrode is adaptive to any possible extreme events brought by climate change, recovering quickly from the flood impacts even if it suffers temporary failures. The system may shift into a different state but still maintains functionality.

3.2.4 Towards landscape design

Within the design disciplines, research has been already started to examine the theoretical framework of resilience and its usefulness for design in detail (Hill 2005; Lister 2007, Pickett 2004; Allan and Bryant 2011). As introduced in the first chapter, landscape is a combination of both nature and culture, which fits in socio-ecological perspective of resilience. This concept is more strategic than normative that must be explicitly based on, and informed by the environmental, ecological, social, and economic drivers and dynamics of a particular place, and must be integrated across a range of linked scales to be effective (Pickett et al. 2004). Moreover as stated above, resilience depends on being able to adapt to unprecedented and unexpected changes, which demands a new way of thinking about sustainability and future-proof solution (Ahern 2011).

When landscape is understood as a system that performs functions, network is the critical factor to support it to be operational. As Ahern (2011) pointed out, "complex networks build resilience capacity through redundant circuitry that maintains functional connectivity after network disturbances". Regarding to the landscape design for this thesis, the resilience concept can be a framework in developing an adaptive water system in Sint-Oedenrode through a complex networking to deal with the uncertainties of climate change in the future. The network here can be related to not only the dynamic hydrological processes, but also natural, cultural, environmental, socio-economic issues.

3.3 Comparison

Literature compares the concept of robustness with resilience in ecological and socio-ecological context (Mens 2015). In socio-ecological systems, a robust or resilient system is achieved to deal with uncertainties and makes the system persistent or sustainable instead of trying to control external disturbances (Folke 2006; De Bruijn 2014). Some consider robustness as being equal to resilience. Indeed, they are comparable, but not identical.

As introduced, both of robustness and resilience can be regarded as system characteristics that keep the system's functioning when subjected to disturbances. Robustness is to some extent similar to the concept of resistance and fail-safe, which ensures the system not suffering failure by withstanding all different degrees of disturbances without any reaction. It is strong and stable to keep the original state with high reliability. On the contrary, resilience is somehow fail-safe, which is not only about being robust to disturbance, but also about the opportunities that disturbance opens up in terms of the recombination of evolved structures and processes, the renewal of the system (Folke 2006). In this sense, resilience provides adaptive capacity (Smit and Wandel 2006) that allows for continuous development.

Furthermore, the comparison between robustness and resilience needs to determine a specific system and a specific type of disturbance (Mens 2015; Carpenter et al. 2001). In this thesis, the system

		Robustness	Resilience
In general	Definition of word	Perform strong / hardy without failure	Recover quickly from / adjust to change
As a system property	Nature	System characteristic	System characteristic
	Reaction to disturbances	Withstand disturbance	Respond to disturbances
	Consequence	Remain functioning Keep the original state	Remain functioning Shift into another state
	Performance	Fail-safe	Safe-fail
	Narrow down		
Define a specific system and disturbance	System = Improved water system in Sint-Oedenrode (climate scenario W+, T=100)	Prevent flooding, and still keep the original state	Prevent flooding, and can adapt to any possible changes in the future
	Disturbance = extreme climate event - flood		

Table 3.1: Summary of comparasion between 'robust' and 'resilient' concepts

is concerned with an improved water system in the area of Sint-Oedenrode, and the disturbance refers to a temporary extreme event – 100-year flooding that results from climate variability under scenario W+ around 2050. In this context, a 'robust water system' can be simply understood as an extra strong body, being able to withstand a grave risk of flooding without changing to another status; while a 'resilient water system' is capable of adapting to any possible events that may happen in the future, which allows changing but remains functioning. The result of comparison between these two concepts is summarized in table 3.1.

3.4 Analysis of high water problem in Sint-Oedenrode

3.4.1 Introduction of the Dommel flow

The Dommel river is one of the most important components in Sint-Oedenrode and runs through the center of the town. A larger scale of Dommel valley area is shown in figure 3.1, from which it is not difficult to see the elevation decreases in downstream direction, and the area around the Dommel is much lower than the surroundings with a height difference of about 1.5 to 2.5 meters, where floods are liable to happen.

The Dommel flow rate within Sint-Oedenrode is primarily determined by the upstream portion from Eindhoven, and partly by the stream Ekkersrijt as well as a number of smaller waterways (figure 3.2). As stated in chapter 1, earlier hydrological model calculations have already pointed out that urban areas in Sint-Oedenrode are not sufficiently protected against flooding from the Dommel. The core mission of Waterschap De Dommel is to ensure the residents to keep their feet dry (Waterschap De Dommel 2016). In 2015, they conduct a new research to further investigate the inundation areas in Sint-Oedenrode and give suggestions for protection. The built-up areas circled by dark lines (figure 3.1) are the main focus of this analysis due to the existence of buildings and key infrastructures.

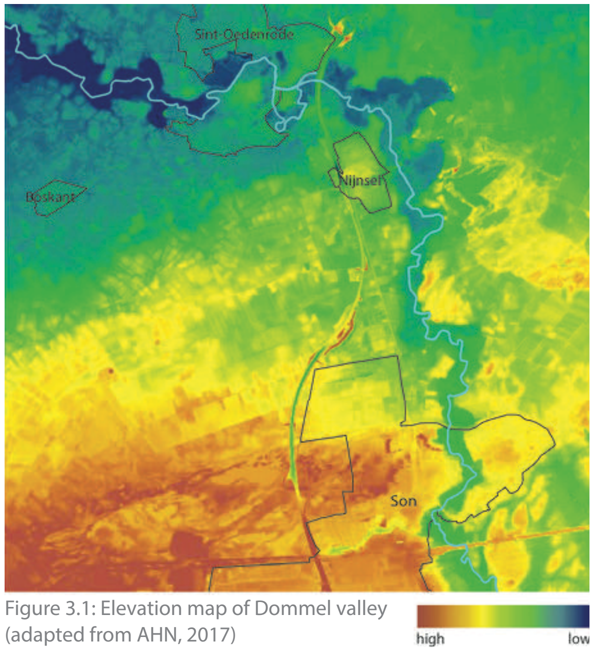

Figure 3.1: Elevation map of Dommel valley (adapted from AHN, 2017)

Figure 3.2: Inflows of the Dommel

The data source of this section is based upon a report of Waterschap De Dommel (2015) about protection of Sint-Oedenrode and Son against high water from the Dommel. In the following the concrete processes, methods and conclusions will be explained.

3.4.2 Scenarios and MHW

In this research, four scenarios are considered by Waterschap De Dommel, concerning different climate scenarios (either current climate scenario H 2015 or extreme climate scenario W+ 2050) and different flow rate by Eindhoven (either 2.8m^3/s or 10.8m^3/s). They are:

Scenario 1: T100H 2.8m^3/s
Scenario 2: T100H 10.8m^3/s
Scenario 3: T100W+ 2.8m^3/s
Scenario 4: T100W+ 10.8m^3/s

The former two scenarios concerned with current climate aim at making a clear image of current bottlenecks along Dommel, which are also used to define MHW*. The latter two intend to provide a view of the situation in 2050. The problem is enlarged in these cases that does not need to be resolved immediately, but is good to take preventive measures in advance.

MHWs in central urban area of Sint-Oedenrode are calculated for each scenario (figure 3.3), and some specific locations are marked (figure 3.4). It is obvious that lines of Scenario 2 and Scenario 3 lie in between. The difference between Scenario 1 and Scenario 4 at both point A and point D (motorway A50) is 13cm, while at point C the difference is only 9cm. The consequence means that the probability of occurrence of flood under four scenarios is quite similar from each other, and the maximum difference of MHW is between scenario 1 and scenario 4. Following water expert's advice, only scenario 1 and 4 will be analyzed for this study.

***Knowledge supplement:**
MHW = normative high water level

MHW is an abbreviation of Mean High Water (normative high water level) as the average of all high water levels observed over a period of several years. It determines the locally required height of the flood defense (Van Eijsbergen et al. 2008).

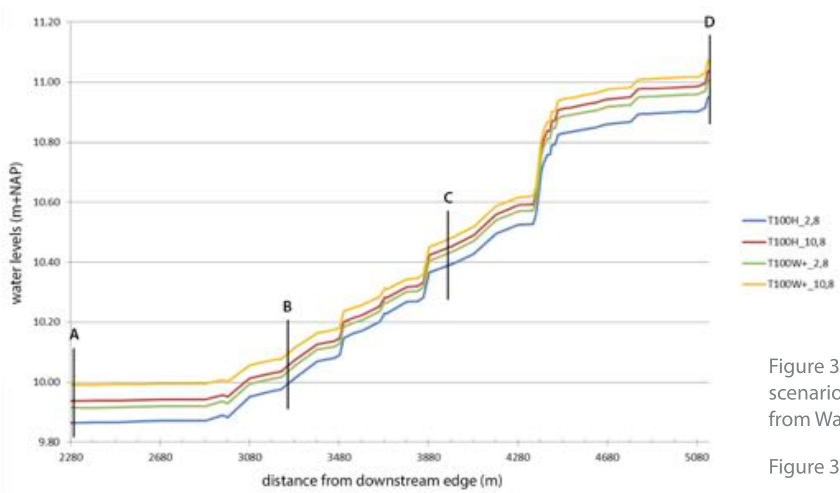

Figure 3.3: (left) MHW for the four scenarios in Sint-Oedenrode (adapted from Waterschap De Dommel 2015)

Figure 3.4: (right) Corresponding locations

3.4.3 Potential bottlenecks

Based on the calculated MHW, the potential bottlenecks are determined along the Dommel within the urban area of Sint-Oedenrode where the extrapolated MHW through GIS are below this level. They indicate the locations that inundation occurs under specific scenarios (Scenario 1 and Scenario 4), some places along the Dommel even reach a depth of more than 1.5 meters. Circled on the map (figure 3.5 & 3.6), the results of bottlenecks show that there is only a little difference between Scenario 1 and Scenario 4, the maximum difference of water levels is 14cm. Among these inundation areas in central Sint-Oedenrode, some pose a threat to the existing buildings.

In order to determine the measures to be taken, further discussions are proceeded through zooming in on these positions and analyzing the construction of current regional flood defenses. For Scenario 1, the detailed analysis designates less sites as final bottlenecks which depends on the flooding risk to facades of houses or important buildings (figure 3.7). And through the calculation, it is found that the current defenses can not meet the requirements of their positions to prevent flooding with a T100 situation. As to Scenario 4, final bottlenecks are not determined, but it is obvious that measures should be taken to either strengthen the current defense system or seek for other alternative solutions to cope with extreme climate events.

Figure 3.5: Potential inundation areas under Scenario 1 (adapted from Waterschap De Dommel 2015)

Figure 3.7: Final bottlenecks under Scenario 1 (adapted from Waterschap De Dommel 2015)

Figure 3.6: Potential inundation areas under Scenario 4 (adapted from Waterschap De Dommel 2015)

3.4.4 Two optional solutions

Waterschap De Dommel put forward two options for solving the high water problem in Sint-Oedenrode: sectoral technical approach or integral mosaic solution (figure 3.8). The former one includes adjustment of the existing infrastructure and construction of new ones at a number of locations, which is only implemented at the central urban area of Sint-Oedenrode (marked by green line). Guided by accurately calculated design principles based on climate scenario W+, this measure is definite to be effective and has a positive impact on the increase of MHWs with an affordable budget in a relatively short term. It can meet the requirements of provincial commission, reduces flooding during heavy precipitation and guarantees the safety of water.

The latter measure is presented in yellow and red lines, which is consist of two options: bypass in north or south of Dommel. Both of them make significant influence on the MHWs in Sint-Oedenrode. The northern plan is more feasible with shorter route and less interjunctions with current infrastructures, while the southern one is more economical and has smaller impacts on the environment. It is planed in a lager scale around the urban area of Sint-Oedenrode with almost more than seven times investment. Nevertheless, it can not only solve the high water problem, but also gets positive feedback with local development opportunities such as housing, business, nature, agriculture and recreation (refer to water machines by LOLA though they are not determined yet). In addition to developmental values, this solution is potential to combine with historical structure and aims at a sustainable water management.

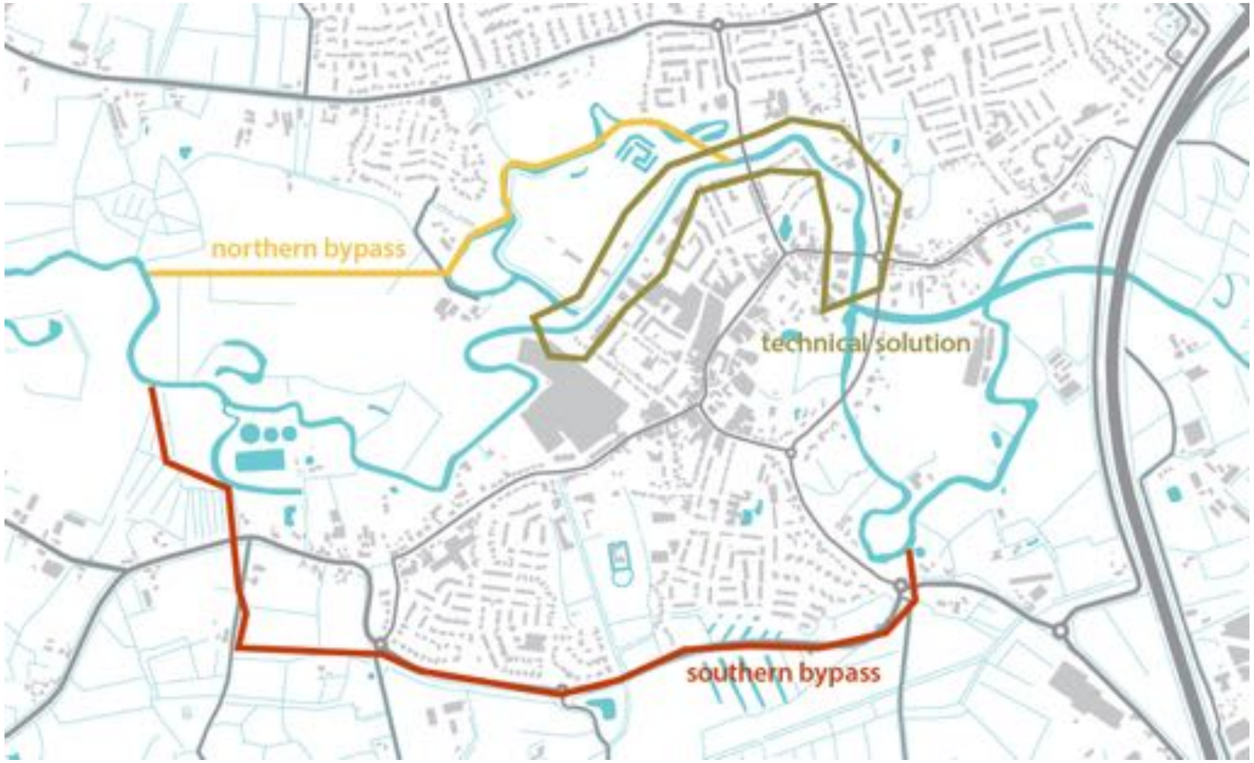

Figure 3.8: Optional solutions of high water problem in Sint-Oedenrode by water board (adapted from Waterschap De Dommel 2015)

As known from the introduction, it is clear that the integral mosaic solution (northern or southern bypass) is what this study is going to research and design further. It intends to bring more benefits to Sint-Oedenrode as a chance for development through both engineering and landscape approach instead of focusing on solving only one major problem. The specific measures of final plan will be decided after more analysis of relevant issues through exploring two other research questions.

3.5 Conclusion

The literature study of 'robustness' and 'resilience' provides clear definitions and concepts of these two words. They are both generally accepted as a system property in many disciplines, and is considered as the ability to retain essentially the same system characteristics when subjected to disturbances. But they perform differently: 'a robust system' is never failed, which withstands the disturbances and always keeps the original state; while 'a resilient system' allows to fail, which adapts to disturbances with a shift to another state if necessary.

When applied in water system of Sint-Oedenrode, the concepts of system 'robustness' and 'resilience' are still effective, as explained in section 3.3. To be more specific, the system here refers to the new water system with implementation of one proposed solution (either northern bypass or southern bypass), which is either robust or resilient towards a healthy and sustainable development. The disturbance refers to the high water problem, which results in different degrees of inundation and poses a threat to existing buildings and infrastructures around the Dommel river in the central urban area of Sint-Oedenrode. The calculation has proved that this can happen even under current climate scenario with the Dommel flow rate 2.8m^3/s, not to speak of climate scenario W+ with a higher flow rate 10.8m^3/s.

According to the theoretical understanding of system 'robustness' and 'resilience', and combined with analysis of high water problem in Sint-Oedenrode, together with optional solutions, the first research question (RQ1) "What are the characteristics of either a robust or resilient water system (climate scenario W+, T100) in Sint-Oedenrode area?" can be concluded and answered as:

A robust water system in Sint-Oedenrode means a combination of the current water system and a constructed bypass, which can withstand the possible high water problem from the Dommel in central urban area with a T100 situation under climate scenario W+ without any changes of its function, structure, status and the way of working. A resilient water system also represents a combination of the current water system and a constructed bypass, which is able to be adaptive when the high water problem of T100 condition under climate scenario W+ exceeds the capacity of system without influencing its function, but may lead to the change of its appearance, state, feedbacks and working mode. However, the situation is temporary that it is easy to quickly recover from these changes. In this sense, either a robust or resilient water system can be the solution to Sint-Oedenrode.

4

HISTORICAL STRUCTURE AND ITS INTEGRATION

This chapter aims to answer RQ2: *How can the local historical structure ('wallenstructuur') be integrated in an improved water network?*

4.1 A historical structure in Sint-Oedenrode

4.1.1 Discovery

Sint-Oedenrode is well known for its great historic and archaeological values. In 2015, Harry van Kuijk highlighted a particular historical structure in the south and west of Sint-Oedenrode (figure 4.1-4.3) in his pamphlet "*Landweer in Sint-Oedenrode, aangelegd in de 13e eeuw?*". It was an engineering work built by humans that can date back to the Middle Ages about 13th century, and had been maintained for a long time until 19th century. The structure was supposed to be consisted of drainage ditches and raised stretches of land, even with a sluice in specific position. Together with the Dommel river, it formerly provided a good line of defense for Oude Vrijheid (Old Liberty – the urban area).

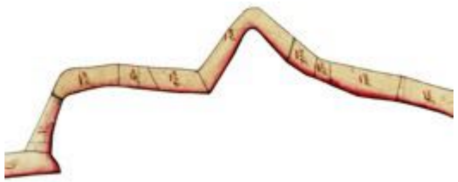

Figure 4.1: Detial 'landweer' (Harry van Kuijk 2015)

Unfortunately, little archival materials were preserved. Till now there are no clear descriptions or drawings about it, and nobody knows what it exactly looked like. Nevertheless, Harry van Kuijk still recorded some recognizable fragments of the structure in Sint-Oedenrode by photographs, and with the help of local, they are found in field study (figure 4.4-4.11).

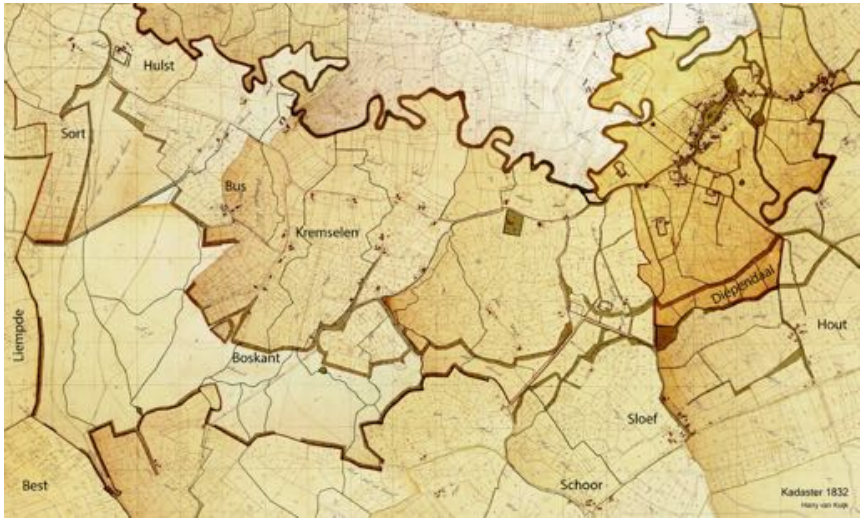

Figure 4.2: Historical structure in the south and west of Sint-Oedenrode (Harry van Kuijk 2015)

Figure 4.3: Structure in aerial map and fragments' positions (adapted from Harry van Kuijk 2015)

Figure 4.4: Old sluice in the Hapert (Harry van Kuijk 2015)


Figure 4.5: (top by Harry van Kuijk 2015 / bottom by author 2016)


Figure 4.6: (photo by author 2016)


Figure 4.7: (photo by author 2016)


Figure 4.8: (top by Harry van Kuijk 2015 / botton by author 2016)


Figure 4.9: (photo by Harry van Kuijk 2015)


Figure 4.10: (photo by author 2016)


Figure 4.11: (photo by author 2016)

4.1.2 'landweer' vs. 'wallenstructuur'

Harry van Kuijk considered this historical structure as 'landweer', a Dutch term that represents a kind of defense structure for rural areas that were mostly built in the 14^{th} and 15^{th} century. While through the interview (Aug 2016) with Jos Cuijpers who is doing research on this old structure of Sint-Oedenrode, the judgment of 'landweer' is denied by him. He compares the structure with the landweer in surrounding areas within the province of North Brabant, and the results show that they are different from each other.

North Brabant is one of the regions in the Netherlands where a large number of landweer were built to mark the territorial boundaries and defend cities, villages, fields or pastures. According to Cuijpers, landweer was always several kilometers long and in straight line. The basic structure of a landweer usually had a central rampart, flanked by wide deep ditches (figure 4.12). Hedges was often planted on the central or outermost ramparts, consisting of trees for solidity and bushes to prevent the military moving through. Apart from ramparts, ditches and hedges, ancient people also filled the fields with stumbling holes or wooden poles, which has been found in various places in the Netherlands. However, the original form of both the ramparts and ditches, from which the landweer were built up can no longer be read out in existing structure because of erosion for centuries (Cuijpers 2013; Brokamp 2007).

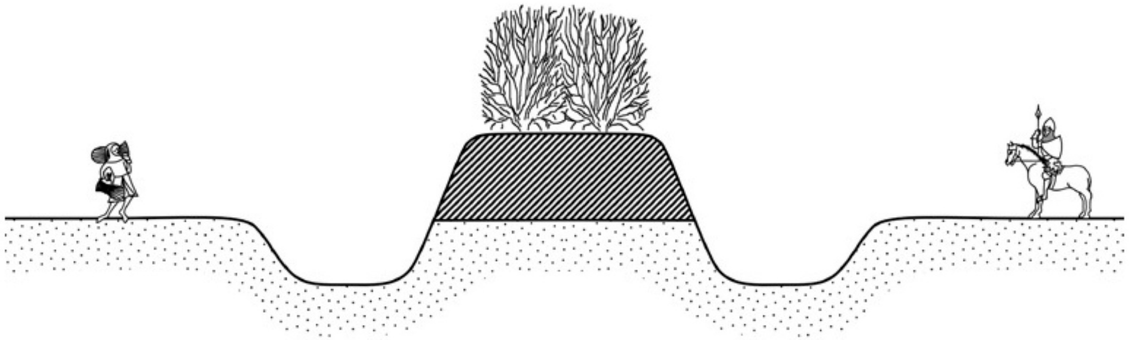

Figure 4.12: The basic structure of landweer (Brokamp 2012)

owever, the structure in Sint-Oedenrode was not as same as a landweer used to look like. One reason is that this historical structure was along the border of communal land but not straight as landweer, which can be obviously seen in the map (see figure 4.2 or 4.3). Besides, researchers didn't find any high points like the ramparts, instead, most of the structure were quite low. Therefore, it is now called 'wallenstructuur' in Dutch, describing a structure of raised land with drainage ditches.

4.1.3 Function

The original function of this historical structure still remains unclear. There are four assumptions now:

i. The structure acted as a landweer to protect rural areas against itinerant army. As explained in the last section, although it didn't match the landweer that were excavated elsewhere in North Brabant, researchers found that the southern part of the structure could theoretically function as a landweer.

ii. The structure was a retention for the storage of water (figure 4.13). Surrounding a pretty large but lower area where water from the Dommel was easy to be collected, it was possibly used to store water during the high water period. It is known that watermills in Brabant cannot reach the maximum production due to a lack of water storage, thus the structure could be a collective system to be responsible for the provision for watermills as a very special infrastructure until 19th century. However, there is no similar / parallel structure to be found in Brabant.

Figure 4.13: The structure is possible to function as water retention for strorage (Harry van Kuijk 2015)

Figure 4.14: The structure fromed a dividing line between wild land and adjacent fields (Harry van Kuijk 2015)

iii. The structure was used for the irrigation in grasslands and pasture. According to the medieval texts, water-meadows (*vloeiweide* in Dutch) were built in Brabant, representing an area of grassland subject to controlled irrigation to increase agricultural productivity. They were usually irrigated artificially in the winter with water from nutrient-rich river. To achieve this form of technique, facilities such as dikes, sluices and drainage ditches were required (Baaijen et al. 2011; Bleumink 2014). The structure was probably one of these facilities. But the waterways in the area didn't resemble the water-meadow system, and a large part was covered with forests, which contradict the supposition. Thereby it needs to be further explored and analyzed.

iv. The structure could prevent livestock from coming out of the fields. A lot of embankments were constructed with dense shrubs and low trees (coppice) in many locations to avoid livestock getting out of fields at harvest time. As supposed, the structure formed a dividing line between wild land and adjacent fields (figure 4.15), which was likely to serve for farms. Within North Brabant, such kind of structure between two types of land can still be found in many place as a strong regional feature.

Research is still proceeding to look for more written references to investigate the real purpose of constructing the structure and its original functions, it could come upon another possibility, or may have a combination of several functions.

4.1.4 Relation to the study

The discovery of this remarkable structure intrigues experts from different disciplines, such as archaeologist, local historian, landscape architect, as well as relevant staff from the municipality of Sint-Oedenrode. They are curious about for what purpose the structure was built, how it worked, and whether it was related to the water system, etc. Although these questions are difficult to answer in a short time, the structure still constitutes an inspiration for the landscape improvement. The experts not only aim to clarify the function of this interesting historical structure, but also intend to give a spatial and hydrological vision for the future use of the structure in Sint-Oedenrode.

This thesis takes a parallel study to the project. As introduced in the first chapter, the study explores a way to combine the historical structure into a new water network through an integrated landscape approach, developing possibilities to make it function again as a solution to high water problem of Sint-Oedernode and an additional value for urban development. Thus the knowledge of this old structure is necessary though it is not visible any more.

4.2 Inspirations from practical designed historic landscapes

During the past few decades, the concept of historic preservation has grown beyond protecting a single building or urban district to include the historic landscape that provides the setting and context for a property as well as much larger landscapes that have regional and national significance (ASLA 2016). Historic landscapes vary in size, range from designed to vernacular, rural to urban, and agricultural to industrial spaces.

In the following part, several practical landscape design projects with relation to historic preservation and rehabilitation are selected and analyzed to find out how the historical elements are reused and integrated into contemporary landscape design. Qualitative elements that contribute to restore the unique history, memory and former features are extracted and further explained. The results can provide a better understanding of combining historical structure with current spatial settings and inspirations of integrating it into the design of new water network in Sint-Oedenrode through landscape approach.

4.2.1 Stronghold Grebbeberg

Location: Grebbeberg, Rhenen, The Netherlands
Designer: Michael van Gessel
Realization: 2005

This stronghold overlooking the Lower Rhine dates from the Merovingian Period (481-751) when the Frankish dynasty ruled France. In the 17th century, a King's Table was erected on a clearing in the woods, surrounded by twelve linden trees to commemorate a visit by the Winter King of Bohemia. The World War II left its mark with a cemetery for fallen soldiers of the Dutch Army who fought the German invasion. The place is rife with history (Van Gessel 2011).

Archeological past of the Dutch landscape calls for a recuperation plan of these historical remains, for which Michael set the concept of the design as "make nature and manmade history visible again". As the 18th century English author and landscape architect Joseph Spence said: "What is, is the great guide as to what ought to be." Designed on such a place filled with history, almost nothing was invented, the result is predominantly a resurrection of what was already there (Van Gessel 2011). To interpret this design, it is important to know several distinctive landscape approach and elements that are applied.

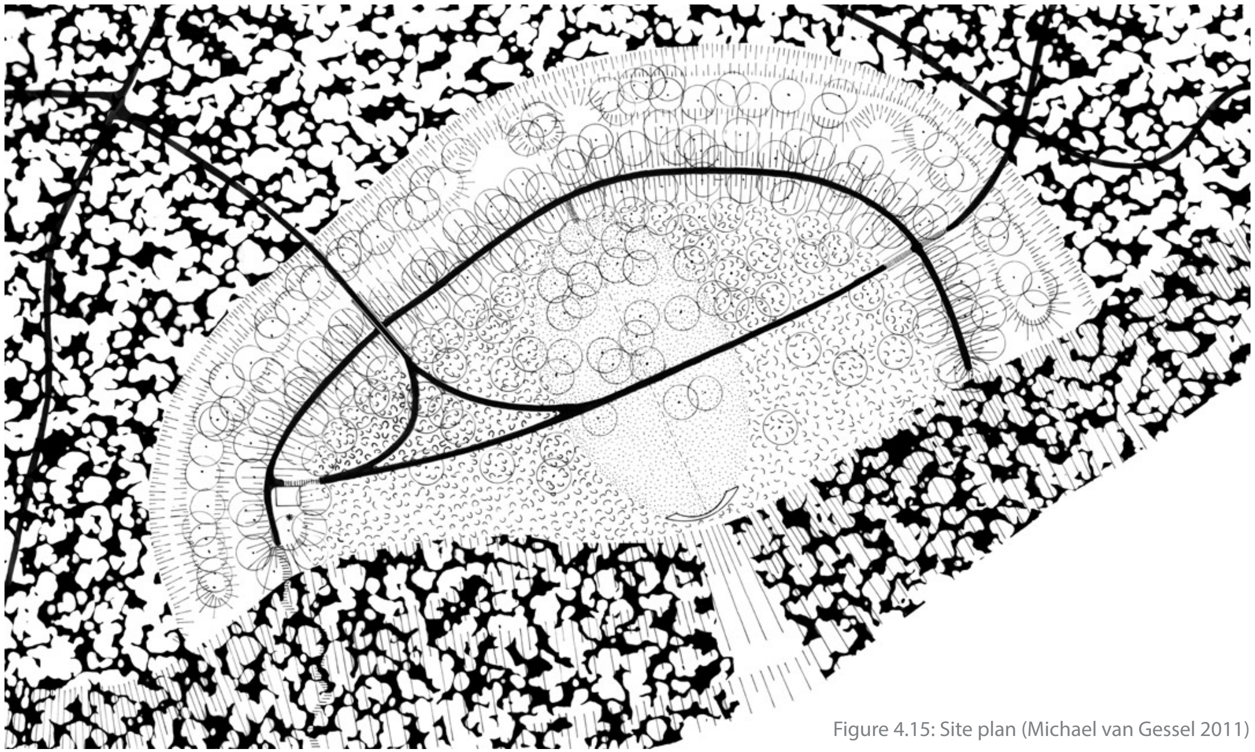

Figure 4.15: Site plan (Michael van Gessel 2011)

Clear-out

The overgrown stretch of woodland at the edge of the steep was cleared out to restore the view of the surrounding landscape and the ancient ring wall that defining the stronghold. Instead, oaks, beeches and other deciduous trees reemerged and occupied the space where there are royal ferns (figure 4.16 & 4.17) (Van Gessel 2011). Accompanied by such a mature forest as a cloak, the place becomes an oasis of peace and tranquility.

Path

The design makes the path more visible, which crosses the ring wall at two spots (figure 4.15). One is an incision through rampart (figure 4.18); the other is a notch that is dramatized by lining it with corten steel plates, showing the exact cross section of the wall (Van Gessel 2011). Here steel stairs slightly raised over the slope (see figure 4.16), forming a changeover of the materials. Following the stairs, corten steel is implemented in many landscape interventions on the top of the hill (52meters high).

Look-out

A panorama platform is created over the edge of the plateau in line with one of the ends of the rampart, which is also a corten steel structure. Towering above the treetops, it is extremely breathtaking when standing there and enjoying a picturesque and wonderful view of the Rhine river landscape (figure 4.19 & 4.20).

Figure 4.16: The overgrown woodland at the edge of the steep was cleared out (Michael van Gessel 2011)

Figure 4.17: Oaks, beeches and other deciduous trees, together with ferns form a dense forest (Michael van Gessel 2011)

Figure 4.18: Path with an incision through rampart (Michael van Gessel 2011)

Figure 4.19: The panorama platform (Michael van Gessel 2011)

Figure 4.20: The panorama platform (Rosanne Schrijver 2015)

Figure 4.21: The crescent-shaped wooden bench (Rosanne Schrijver 2015)

Bench

Making fully use of the shade of the surrounding trees, a wooden bench is designed in an oversized crescent (figure 4.21), which fits perfectly into the area with wooded setting. It provides a restful place for having a view over the reclaimed river delta and the pure nature just around. Situated in the axis of the oval-shaped clearing (see figure 4.15), the bench connects the plateau with the landscape below (Van Gessel 2011).

4.2.2 Green Road Works

Location: Utrecht, The Netherlands
Designer: REDscape Landscape and Urbanism
Realization: 2015
Area: 10 ha

The Green Road Works is a former defensive trench and bunker system dating from 1918, and now it is designed as part of a large military park for nature and recreation (figure 4.22). The park is commissioned by the Dutch Forestry Commission and Linieland, of which the landscape belongs to the "Lek-acces" – a complex of forts, works and bunker systems that was built to defend the river against invasion from the east (REDscape 2015).

During the period of 1945 to 2010, most of the trench system was removed. Complex had become unrecognizable, overgrown and inaccessible

(REDscape 2015). Well known for its unique military history, the site calls for a redevelopment to recur the historical situation and tell the story of the past. The design aims to re-establish the relationship between the original trench system and its surrounding landscape, for which partial restoration of its sections are proposed by REDscape. In the following, vital actions that were taken to contribute to this design are explained separately.

Excavating bunkers

The unique feature for this place is the range and variety of bunkers that distributed throughout the site (REDscape 2015). Therefore, they are unearthed to present the original appearance of the military defenses (figure 4.23). A collection of 36 bunkers are preserved, telling the story of the military past in World War I and World War II. The reinstatement of these bunkers makes them visible again that form a distinctive landscape in the park.

Strengthening nature and ecology

The nature and ecology of the site are strengthened by developing fresh water habitats for amphibians and tree cover for nesting owls, as well as open grassland for foraging birdlife. Four new ecological zones are constructed, providing space to a variety of flora and fauna. Some of he bunkers are also included as the habitats for bats. In addition, fruit trees that are unique for this region are retained during construction, serving as camouflage for the defensive works (figure 4.24) (REDscape 2015).

Planning routes

Aiming to be a new destination for both locals and tourists in the New Dutch Waterline (a water-based defence line), recreational routes are planned in the park. They are mostly hidden between raised structures with a relatively closed space (figure 4.25-4.27), which enable the visitors to experience the original intention of the military defences. As connection, a bridge with fencing in black steel is designed at the entrance of the park (figure 4.28).

Figure 4.24: Landscape with ecological values (REDscape 2015)

Figure 4.22: Bird view of Green Road Works (REDscape 2015)

Figure 4.23: Bunkers are unearthed (REDscape 2015)

Figure 4.25: Paths are hidden in raised structures (REDscape 2015)

4.2.3 Qualitative elements and inspirations

Location

Both reference projects are constructed on the original sites that are rife with history. Undoubtedly, this is the most basic, direct and simplest way to evoke memories of the past. As Michael states, the idea is not about inventing something new, but about reviving what was already there. Situated in historic sites, preserved relics can be better integrated into surroundings compared with a man-made imitation, though the conditions have changed over time.

Structure

Here the structure refers to the engineering system, infrastructure and artificial constructions, such as the ring walls of stronghold and the defensive military works. Preservation and reconstruction of these unique structures distinguish them from other types of landscape and establish a strong sense of the particular identity. Through landscape approach, these structures can be aesthetically attractive with soft skin instead of undisguised hard engineering works.

Material

The use of material in landscape architecture is based upon an understanding of their characteristics, for example, what they are, in what way they were used, and what they can do to support human activities. Applied in historical sites, material plays an important role that it should be integrated and at the same time it should have functionality. The implementation of corten steel and wooden bench by Michael is an appropriate representative: they are plain but fit perfectly into the surroundings with practical functions that offer a better landscape experience.

Vegetation

Vegetation is in fact one of the natural materials that is commonly used in landscape design. It concerns internal characteristics including shapes, colors, scale, texture; and external factors like climate, seasons, territoriality. From two reference projects, the application of previous plants for the stronghold and the retention of local fruit trees for defensive works contribute to complement and reinforcement of the existing structures and elements, as well as help to create a sense of place, evoke feelings and capture a mood. In addition, rich vegetation increases ecological values.

Function

Functionalism is an essential principle for landscape design whatever themes the project is related to. A special aspect of historic landscape is that the function

Figure 4.26: Paths are hidden in raised structures (REDscape 2015)

Figure 4.27: Paths are hidden in raised structures (REDscape 2015)

Figure 4.28: Bridge in black steel at the entrance (REDscape 2015)

may refer to original or current, certainly could be both. The restoration of the first purpose is the most direct and obvious way to present the historical usage of an element / structure / place; however, in most situations, new functions are required for people, animals, production, maintenance, etc. Stronghold is not used for stronghold anymore, but a heritage for visiting, thus panorama platform and bench are added. Defensive trench and bunker system are open for flora and fauna; recreational routes are planed for the whole military park to attract tourists.

4.3 Conclusion

The historical structure ('wallenstructuur') in Sint-Oedenrode is newly discovered in 2015, and there exist little information and existing writings about it. With the aid of semi-structured interviews and field survey, it has become clear that the structure was an engineering work dating from 13th century, located in the south and west of Sint-Oedenrode. It comprised drainage ditches and raised stretches of land, and has sluice at the junction with the Dommel. Now only a few fragments are still there but not easily recognizable. In the Middle Ages, it was probably used as defensive structure, water retention, part of irrigation system or fence for farms. The cross-section and its relationship with local water system are still under investigation, but the potential of its future usage for multiple purposes causes an exploration of integration to the new plan through landscape design approach.

Inspired from two practical designed historic landscape "Stronghold Grebbeberg" and "Green Road Works", five qualitative elements that promote the integration of historical structure with current spatial settings are extracted as location, structure, material, vegetation and function. Combining these factors with the characteristics of historical structure ('wallenstructuur') and the specific context of Sint-Oedenrode area, different interpretation and application are developed depending on the implications that derived from reference projects. Thereby the second research question (RQ2) "How can the local historical structure ('wallenstructuur') be integrated in an improved water network?" can be concluded and answered as:

The landscape design of integrating the historical structure ('wallenstructuur') with a new planned water network can be realized through five aspects:

- Location. The historical structure is situated in the south and west of Sint-Oedenrode, part of which is not far away from the central urban area. It is possible to be reconstructed on the original site either in large or in small scales on the basis of current land use conditions and properties.

- Structure. The 'wallenstructuur' is no longer available, thus the exact cross-section becomes a mystery. By imagi-nation and imitation of similar engineering constructions like 'landweer', a nearly true but more attractive appear-ance of 'wallenstructuur' can be restored with aesthetically landscape processing.

- Material. The selection of material is based on the specific design of rehabilitated 'wallenstructuur' and its positions, its surroundings, its functions. For example, wood is an appropriate material if the structure aims to present an old-fashioned style in a forest, but concrete is more suitable in the water due to management and maintenance.

- Vegetation. The selection of vegetation can focus on previous plants and unique regional species, revealing local culture and feature. The principle not only fits the historical structure, but also fits other planning within the site. Besides, vegetation as natural material may cooperate with other materials, which calls for a consideration of coordination.

- Function. The original function of the historical structure remains unclear, but several assumptions have been put forwarded. On the one hand, these assumptions provide alternatives to resume first purpose of 'wallenstructure'; on the other hand, they offer inspirations for its spatial and hydrological use for now. Since the functionalism is highlighted in landscape design, it is necessary to develop new functions that cater for the needs in practice.

"What is, is the great guide as to what ought to be."

5

WATER MACHINES AND THEIR APPLICATION

This chapter aims to answer RQ3: *Following the concept of 'water machines' (LOLA 2015), what type of machine would be applicable to fit the integrated landscape development in Sint-Oedenrode?*

5.1 Water machines by LOLA

5.1.1 What are water machines?

As stated in chapter 1, water is the hidden strength of North Brabant, which makes spatial and economic development of the region going. Therefore, six water machines were devised as the model solutions of the project 'Mosaic Brabant' by the Dutch landscape architecture firm 'LOLA Landscape Architects', providing new links within different aspects and indicating the programs that North Brabant can develop in the future. They guarantee the water quality and reduce water demands. With a new economic structure in regard to high-quality living, multifunctional agriculture, scenic recreation and innovative enterprise connected to the water challenge, the strategy is accumulative and concerns with so-called local intertwining (IABR 2014; Floris Alkemade Architect et al. 2014).

5.1.2 How do they work?

Water machines act as the inspiring regional design strategy (IABR 2014; Floris Alkemade Architect et al. 2014). The concepts of these machines are clear, as well as the way they work and where to be applied. For the purpose of both spatial and economic development, water machines are related to industry, agriculture, recreation and living environment (LOLA 2015). In the following the detailed content of six water machines are introduced through diagrams, maps and explanations (figure 5.1-5.12).

<u>**Machine 1**</u>

Redevelop the outdated industrial areas around public water systems to combat urban heat stress and create a healthy urban environment for emerging economies.

① Many of North Brabant's industrial estates are obsolete or underutilized.
② Industry pumps up large quantities of ground water annually, for which taxes are paid.
③ Money that can be used to build a collective system of water storage and purification.
④ A constructed wetland with a wide, urban profile that doubles as an air corridor against heat stress.
⑤ This landscape intervention also creates an attractive and urban work environment.
⑥ The purified water can be used to counter dehydration or fed back into the system of canals.
⑦ Or it can be recovered for industrial objectives.

Figure 5.1: Diagram of water machine 1 (LOLA 2015)

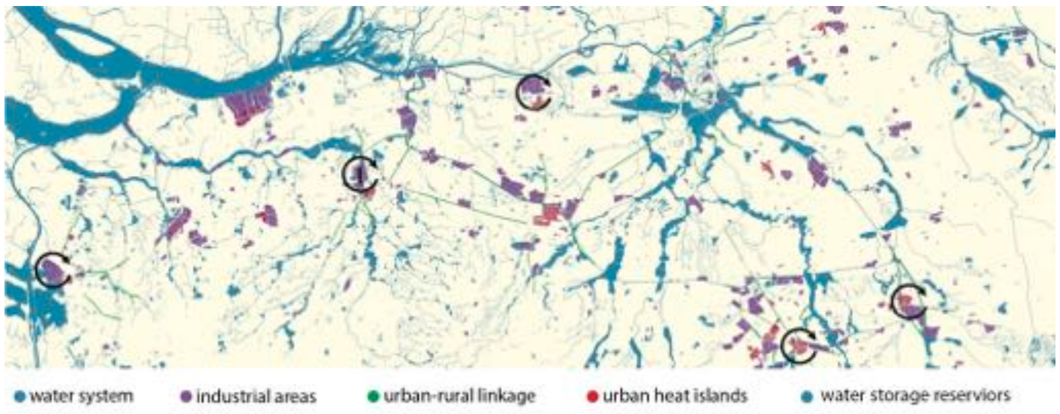

Figure 5.2: Locations of applying machine 1 in BrabantStad (LOLA 2015)

Machine 2

Support the transition to a more sustainable crop production to increase both the profitability of farms and the quality of the landscape, as well as instigate the slow infiltration of water into the soil in order to counteract the acidification of natural landscapes.

① We stimulate the specific switch to more sustainable crops with higher returns.

② Sustainable agriculture also uses less ground water.

③ This can be achieved by investing in a collective irrigation system.

④ An irrigation system that makes use of the eutrophic canal water of North Brabant.

⑤ The supply of surplus manure also contributes to a productive arboriculture sector.

⑥ Floriculture and tree nurseries filter the eutrophic canal water before it is absorbed into the soil.

⑦ That way we counter the dehydration of our nature reserves by feeding the aquifers and the underground water flows.

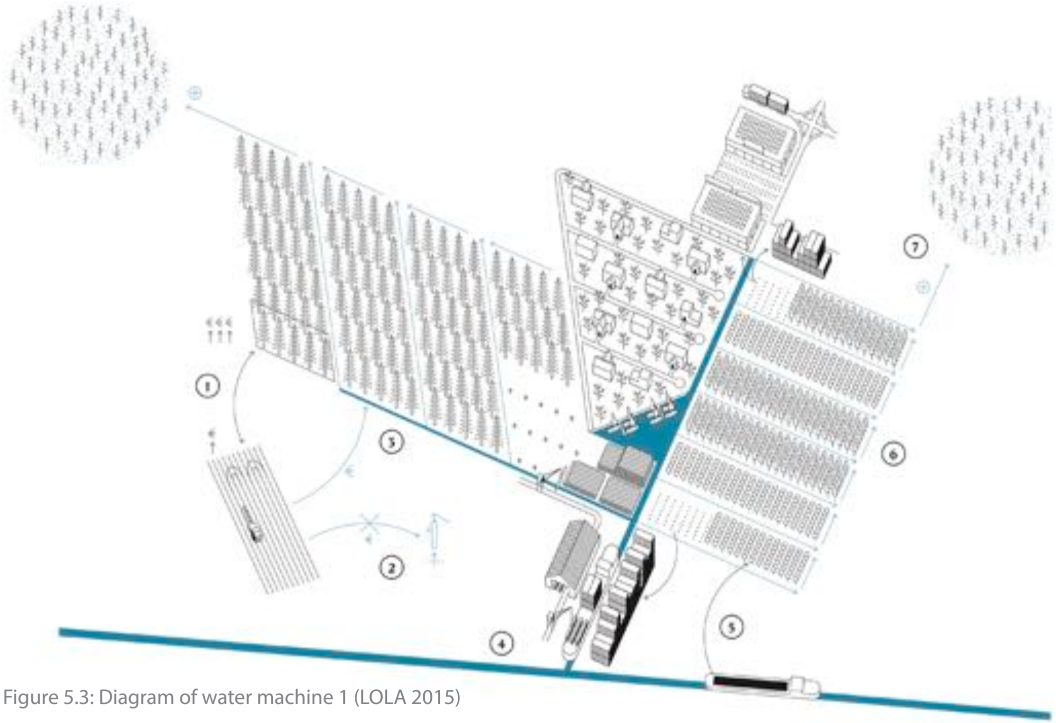

Figure 5.3: Diagram of water machine 1 (LOLA 2015)

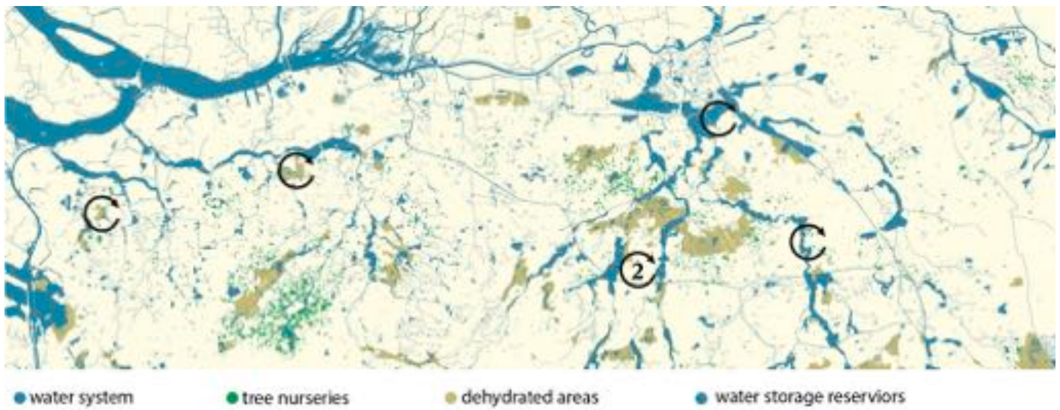

Figure 5.4: Locations of applying machine 1 in BrabantStad (LOLA 2015)

Machine 3

Redirect the Brabant waterways through recreational areas to create a tourist and leisure network and slow down drainage, which contribute to the fresh water balance of North Brabant.

① Tourism and recreation are not yet making complete use of the potential that the water has to offer.

② By linking recreation and water a high-quality recreational landscape is created.

③ A recreational landscape that can anticipate trends like agritourism.

④ The historical bocage landscape is thus reinstated.
⑤ By redirecting the watercourses through recreational areas, drainage is slowed down.

⑥ It contributes to the conservation of the supply of fresh water in North Brabant.

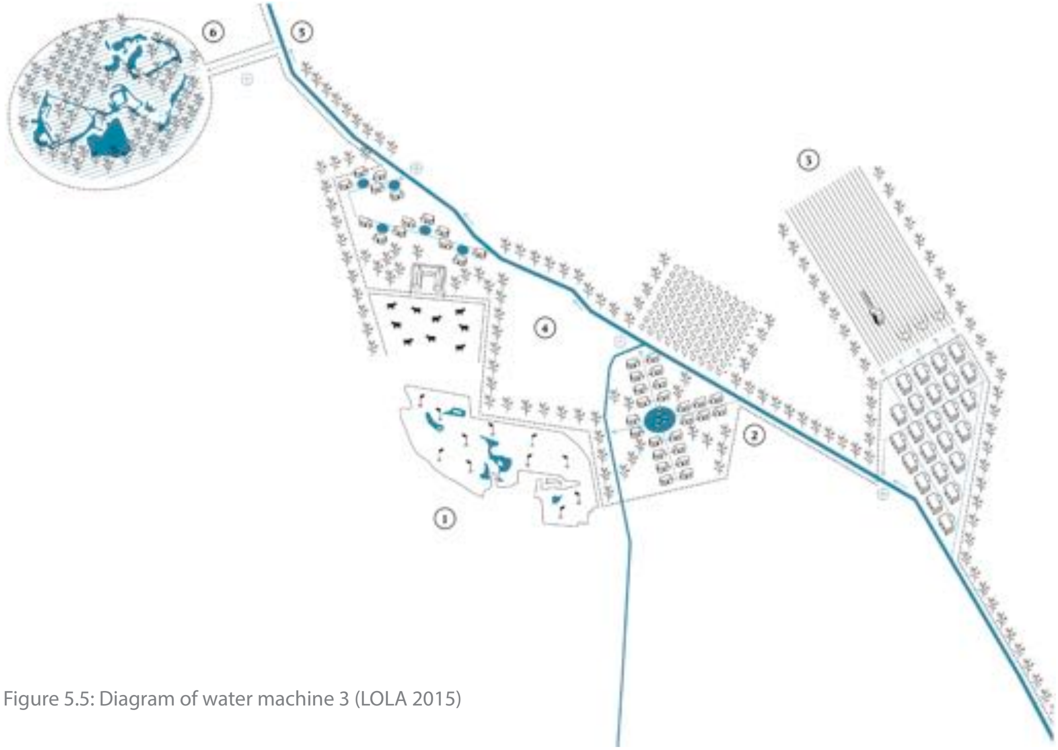

Figure 5.5: Diagram of water machine 3 (LOLA 2015)

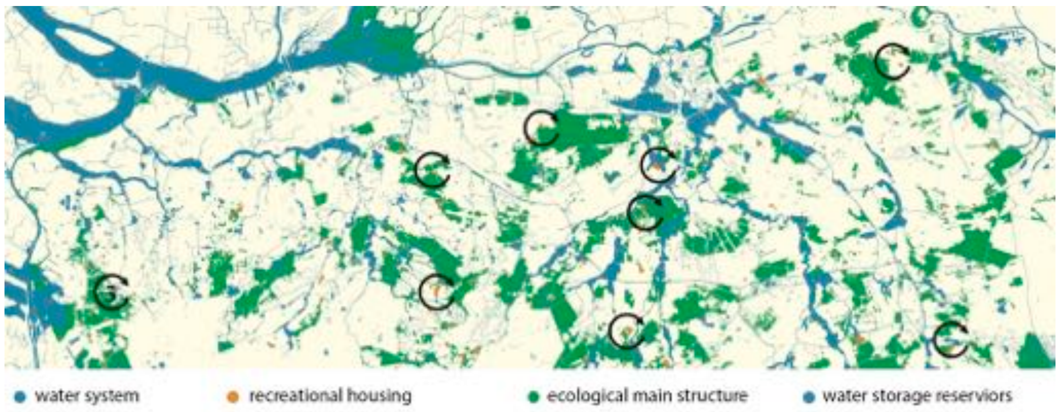

Figure 5.6: Locations of applying machine 3 in BrabantStad (LOLA 2015)

Machine 4

Seize the opportunities created by the expansion of intensive cattle farming, reorganize crop production and integrate landscape-bound public services such as water purification to make agriculture in North Brabant sustainable.

① Many farms in the catchment areas of the Brabant water network are focused on an increase in scale.

② Collective water treatment ensures that a part of the agricultural waste water can be used for irrigation.

③ Through the collaboration between various farms large-scale water purification becomes feasible.

④ Collective manure processing, renewable energy, and better mobility also become viable options.

⑤ The necessary scale permits arable land to be used as a nuisance buffer for intensive cattle breeding.

⑥ This organization around collective amenities also offers possibilities for recreational use.

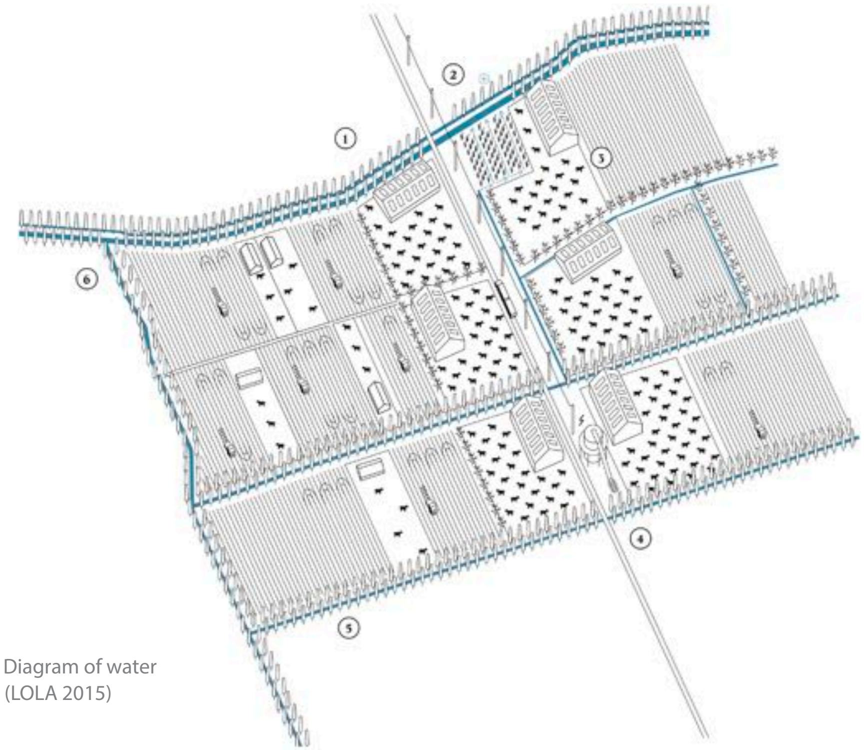

Figure 5.7: Diagram of water machine 4 (LOLA 2015)

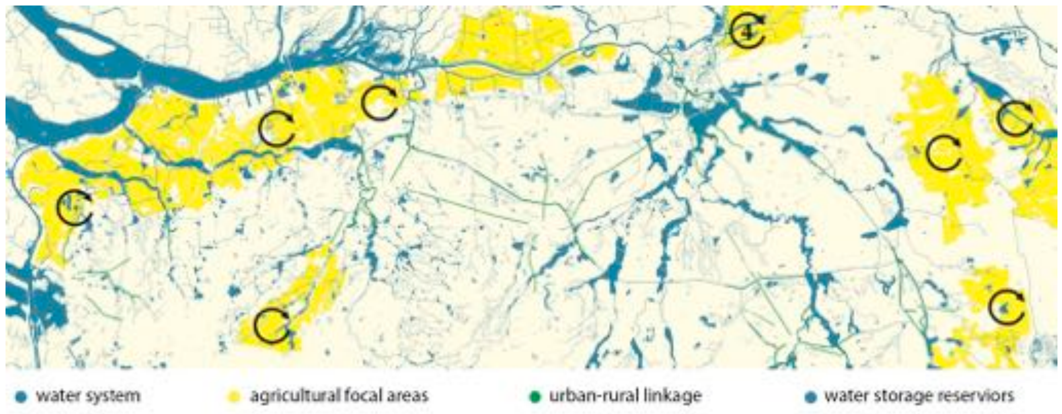

Figure 5.8: Locations of applying machine 4 in BrabantStad (LOLA 2015)

Machine 5

Construct infiltration areas that also provide unique residential landscapes to create an alternative to planned suburban residential expansions and develop a new aspect of sandy, wet landscapes.

① The residential expansion areas are often a threat to the remaining open space in the suburbs.

② In order to obtain a robust water system, the water should be retained where possible upstream.

③ Infiltration areas, made by building dams, form a unique part of the wet sand landscape.

④ An attractive landscape, linked to high-quality suburban living.

⑤ And to small-scale agricultural areas in the suburbs that provide short-chain food production.

⑥ With an advantageous side effect: the instigation of the ground water flow.

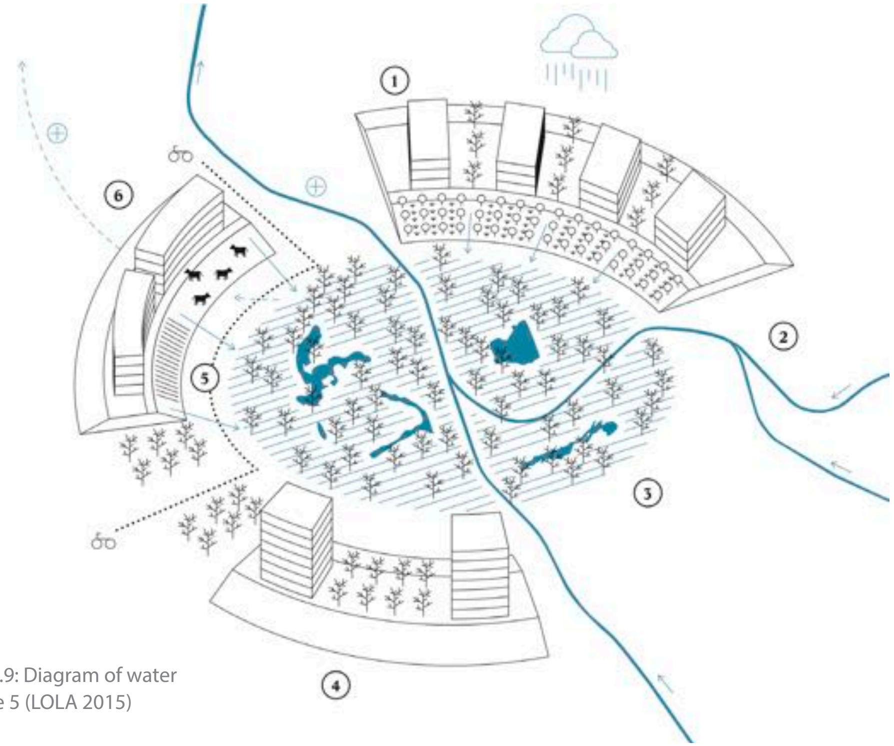

Figure 5.9: Diagram of water machine 5 (LOLA 2015)

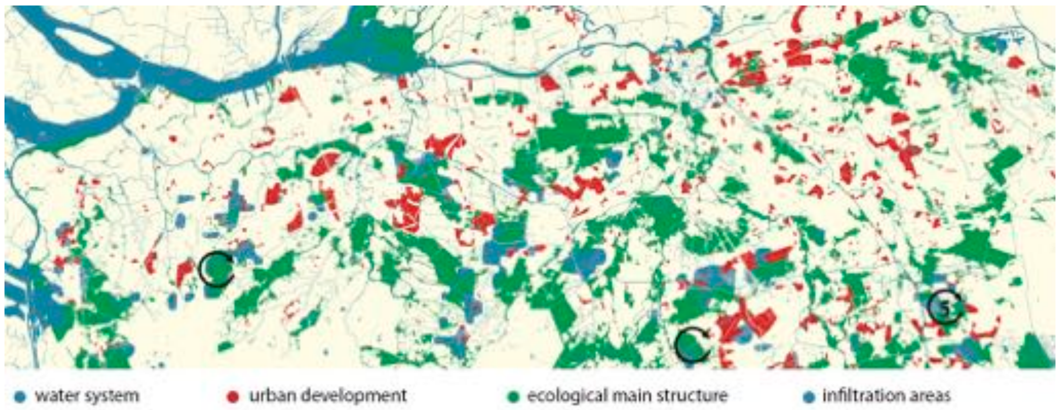

Figure 5.10: Locations of applying machine 5 in BrabantStad (LOLA 2015)

Machine 6

Redesign the profile of the boulevards that connect the innovative industry on the edge of town to facilities in the city center creates huge linear 'wadis' where new construction projects with a separate sewer system can take root.

① North Brabant is an innovative region that develops industrial estates in top locations adjacent to highways.

② Large boulevards connect the landscape, industrial estates, and the city center, and guarantee urban amenities in the vicinity.

③ By rewarding the profiles of these boulevards, enormous linear 'wadis' are created that store water.

④ At the same time we can develop a separate sewer system that discharges rainwater.

⑤ The 'wadis' are also green corridors that ensure a healthy urban climate.

⑥ And they create conditions for interesting locations in which the many knowledge workers can live and work.

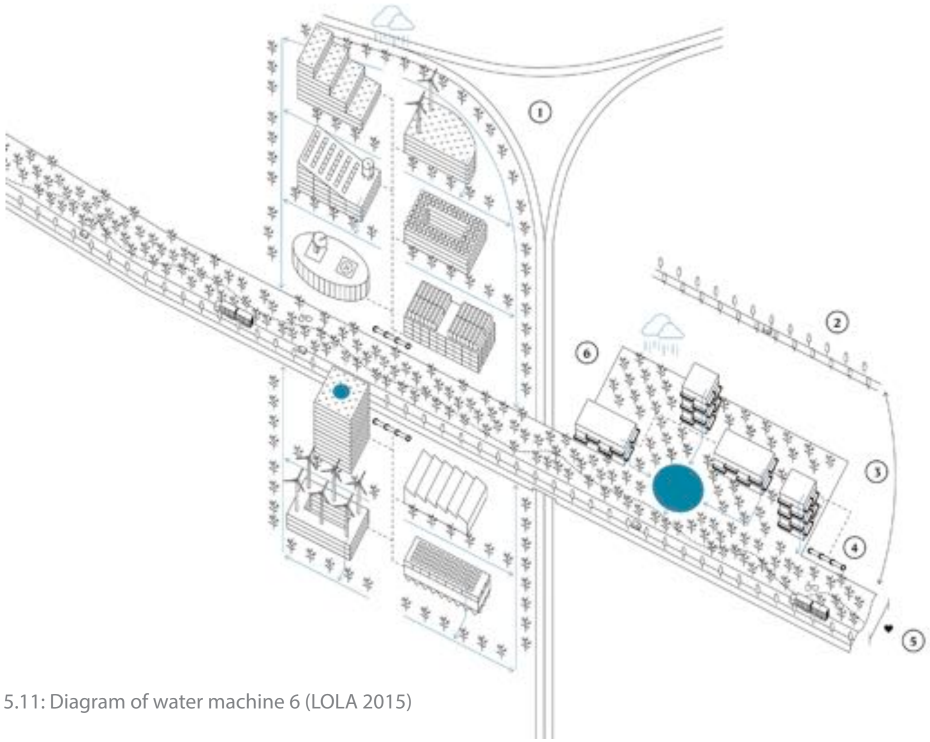

Figure 5.11: Diagram of water machine 6 (LOLA 2015)

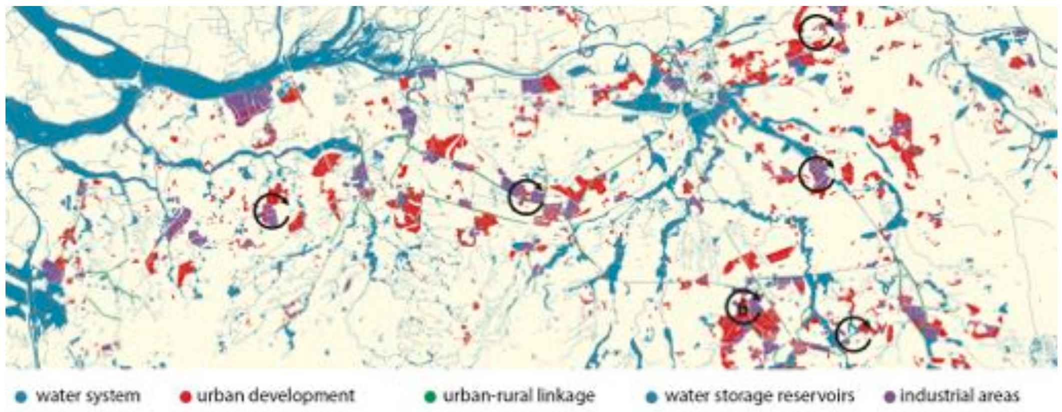

Figure 5.12: Locations of applying machine 6 in BrabantStad (LOLA 2015)

5.1.3 Summary of characteristics

The characteristics of all the proposed water machines are concluded in the table 5.1, combining the model study of design products, and the interview with LOLA landscape architect Cees van der Veeken. The result contains 4 aspects – application, ideas, effects and feature to clearly explain six model solutions, not only to deal with water issues in North Brabant, but also to serve as catalyst for spatial and economic developments.

	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5	Machine 6
Application	Run-down industrial areas	Agriculture and bio-industry areas	Recreational areas	Large-scale agriculture fields	Residential expansion areas	Large infrastructure between urban and industrial estates
Ideas	• Redevelop outdated industrial area • Collective system of water storage and purification • Wetland	• Sustainable productions • Collective irrigation system • Make use of eutrophic canal water	• Redirect waterways	• Collective water treatment • Collective manure processing	• Infiltration areas • Small-scale agricultural areas	• Create green structure 'wadi' • Separate sewer system
Effects	• Reduce water demand • Relieve heat stress • Attractive work environment	• Increase profitability • Slow down infiltration • Mitigate dehydration of nature reserves	• Promote tourism and recreation • Slow down drainage • Balance fresh water	• Reuse agricultural waste water • Renewable energy • Multifunctional agriculture	• Slow down water • Unique residential landscape • Short-chain food production	• Store water • Healthy urban climate • Attractive work and living environment
Feature	Reflect the image of city-rural connection	Investment of water system is combined with bio-industry (tree nurseries)	Act as secondary systems	Large but sustainable with shorter food chain and self-management	Natural areas in urban context	Linear 'wadis' in urban-industry connection

Table 5.1: Characteristics of six water machines by LOLA

5.2 Urban development in Sint-Oedenrode

The municipal council of Sint-Oedenrode insists on open and active policy-making process. With the involvement of 100 local participants discussing on specific issues concerned with their own life, the municipality is wiser and more democratic to make strategic vision for the future development. This section is mainly referred to a municipal document *"De Rooi(s)e draad versterkt"* (figure 5.13) edited in 2012, which evaluated the results on the basis of original vision 2005, made a description of situation at that moment in 2012, and formulated new trends and developments for 2020-2030.

5.2.1 The image of Sint-Oedenrode

With a large part of natural area and Dommel river running through the historic center (figure 5.14-5.17), Sint-Oedenrode has unique characteristics that can be key qualities of its future. The document *"De Rooi(s)e draad versterkt"* (Gemeente Sint-Oedenroce 2012) describes an image: "whether you are in the rural area or urban area of Sint-Oedenrode, you can experience nature and culture nearby." This ambition does not ever change during the past decade.

To strengthen the identity of Sint-Oedenrode as a green, beautiful village where people are enjoyable to live, work and stay, three major themes were formulated in the document: 1) Housing and livability, 2) Vital rural area, 3) Economy and spatial development. They cover all social, spatial and economic aspects.

Figure 5.13: Municipal document *'De Rooi(s)e draad versterkt'*

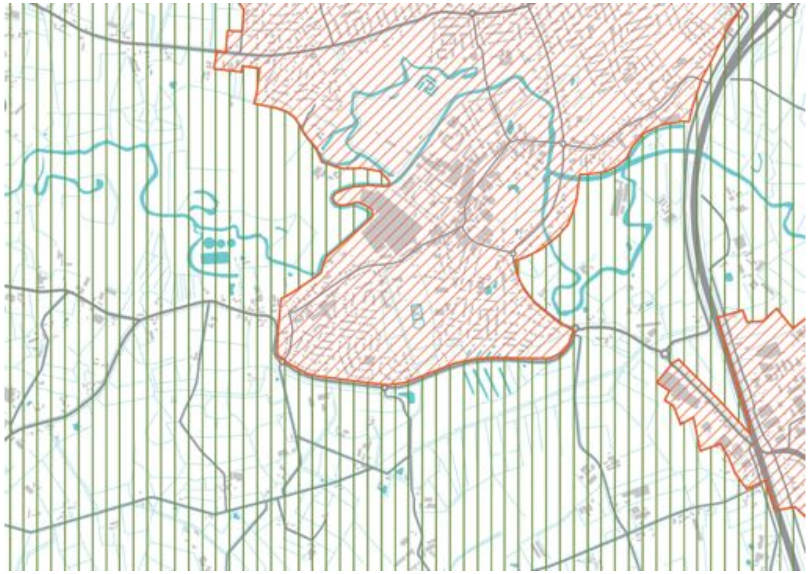

Figure 5.14: Urban and rural areas

Figure 5.15: Notable places in central urban area

Figure 5.16: Saint Martin Church square

Figure 5.17: Henkenshage Castle

5.2.2 Upcoming development (policy)

Vision and actions for 2020-2030

The strategic vision was developed logically by process-oriented discussions among more than one hundred participants. For the upcoming years, Sint-Oedenrode is still aiming to be an attractive municipality with high quality environment for living, working and staying, which needs the cooperation among the government, citizens, civil society and business.

It is crucial to translate the vision to implementation. Therefore, a number of actions were proposed to achieve new ambitions. The table 5.2 lists some relative details of three themes and appropriate actions. These actions are extracted and summarized by author and do not strictly belong to one theme, but overlap each other to some degree.

Themes	Actions
Improve quality of life (most important issue)	• Multifunctional facilities for people of all ages (education, healthcare, childcare, art, culture, sport, meeting spaces, etc.) • Good quality of landscape and nature • Provide an affordable life
Connect urban and rural area (characteristic of Sint-Oedenrode)	• Stick to the green image as a rural municipality (enhance landscape experience and historical recognition) • Renewal of agricultural sector (cooperation of farmers and other potential users, participation of stakeholders) • Develop green space to be valuable for recreation, tourism and other services
Develop the economy (ensure Sint-Oedenrode remains vital and autonomous)	• Develop new business (eg. make use of vacant agricultural buildings) • Develop tourism (improve quality of public space, open green space) • Develop retailing (high quality of shopping and catering business, webshops) • Adequate supply of employment to attract young people • Hold the concept of 'sustainability' as a guiding principle

Table 5.2: Details of proposed actions for upcoming development in Sint-Oedenrode

Spatial planning - Province of North Brabant

In 2014, North Brabant formulated a provincial policy called "*Verordening ruimte 2014*" as the guiding regulation for spatial planning in different regions within the province. It deployed the municipalities to take actions to achieve the goals that were put forward and be responsible for the translation and realization. A zoning plan was made for the central area of Sint-Oedenrode regarding to water, agriculture, nature and landscape, culture, and urban development (figure 5.18-5.22).

5.2.3 Relation to the study

The policy of local government is accord with the purpose of this thesis. Due to the policy is also subject to change, the municipality of Sint-Oedenrode intends to simplify these complicated provincial regulations by merging various issues into an integrated planning, which regards the high water problem as a starting point. Associated with either robust or resilient structure, with the aid of water machines, it is possible to realize water-related functions and achieve part of ambitions of urban development in Sint-Oedenrode.

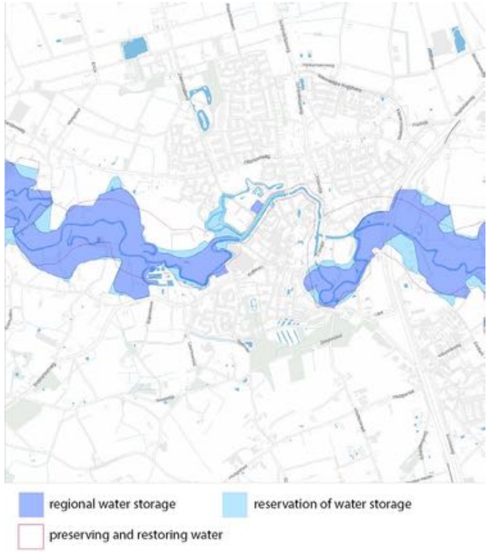

Figure 5.18: Water (Province Noord-Brabant 2014)

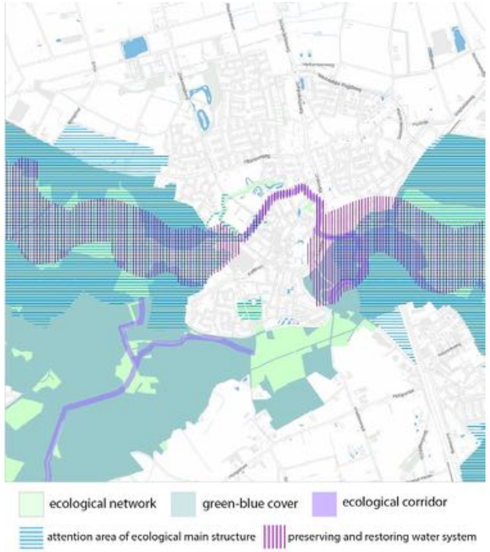

Figure 5.20: Nature and landscape (Province Noord-Brabant 2014)

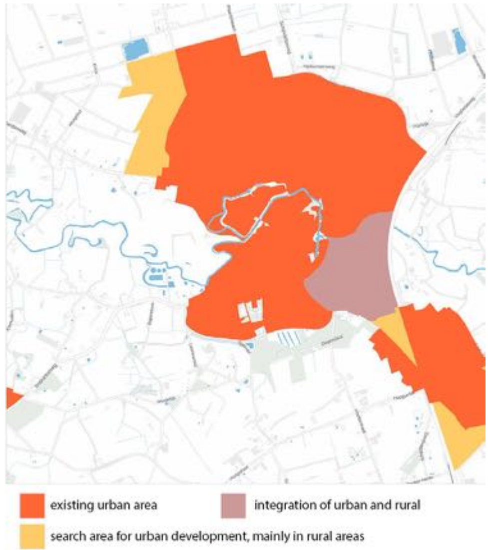

Figure 5.22: Urban development (Province Noord-Brabant 2014)

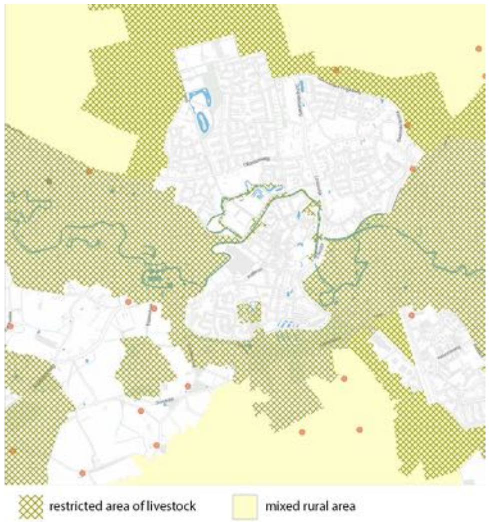

Figure 5.19: Agricultural development (Province Noord-Brabant 2014)

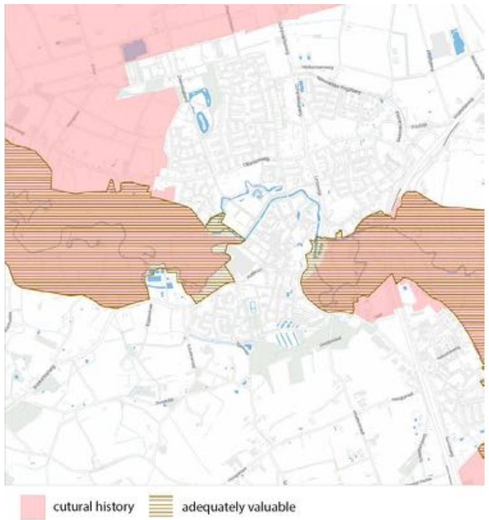

Figure 5.21: Cultural history (Province Noord-Brabant 2014)

5.3 Conclusion

The analysis of water machines leads to a complete understanding of their characteristics as summarized in table 5.1, by synthesizing the IABR booklet *"Reweaving the Urban Carpet"* and record of interview with the LOLA landscape architect. They are created to be applicable for different types of land – industrial, bio-industrial, recreational, large-scale agricultural, residential, large infrastructure; and for multiple purposes. The main idea is to guarantee the water quality and reduce water demands in BrabantStad, in the meantime a new economic structure is connected to the water system that additional values can be achieved through these machines.

As experimental site of water machines, Sint-Oedenrode is inquired to know what it really needs. By reviewing relevant municipal documents which includes the ambitions and policies for upcoming years' development, it is clear that Sint-Oedernode aims to create an attractive urban-rural connected village to strengthen its identity, and improve the quality of environment for living, working and staying.

Combining two separate investigations, the third research question (RQ3) "Following the concept of 'water machines' (LOLA 2015), what type of machine would be applicable to fit the integrated landscape development in Sint-Oedenrode?" can be concluded and answered as:

Water machines are devised to fit in the Brabant's situations, not perfectly in the unique context of Sint-Oederode. Machines can be used in the site by adapting a bit to help add values to water system and achieve the ambitions of urban development (figure 5.23).

Sint-Oederode has a large mixed rural area with various types of land, which are potential to be developed. Both water machine 2 and 4 are related to agricultural sector that can make it more effective and profitable as well as promote agritourism. Machine 3 and 5 concern with high-quality living environment by providing more green space and amenities for recreational use and healthy production. Machine 6 itself is a large green infrastructure that is already existing in the west of central urban area – RWZI, a sewage treatment plant. Since the project site doesn't have run-down industrial area, machine 1 is excluded for the study.

In addition, Sint-Oedernode is well known for its historic values, wherein other water machines are required to enhance historical recognition. While the water machines by LOLA are more conceptual rather than practical, further exploration and design should be done to make more detailed and applicable machines in the specific context of Sint-Oedenrode.

Besides, for integrated development ambitions in regard to closer urban-rural connection, higher spatial quality and better landscape experience, Sint-Oedenrode calls for an integral planning to combine all the water machines and particular landscape design.

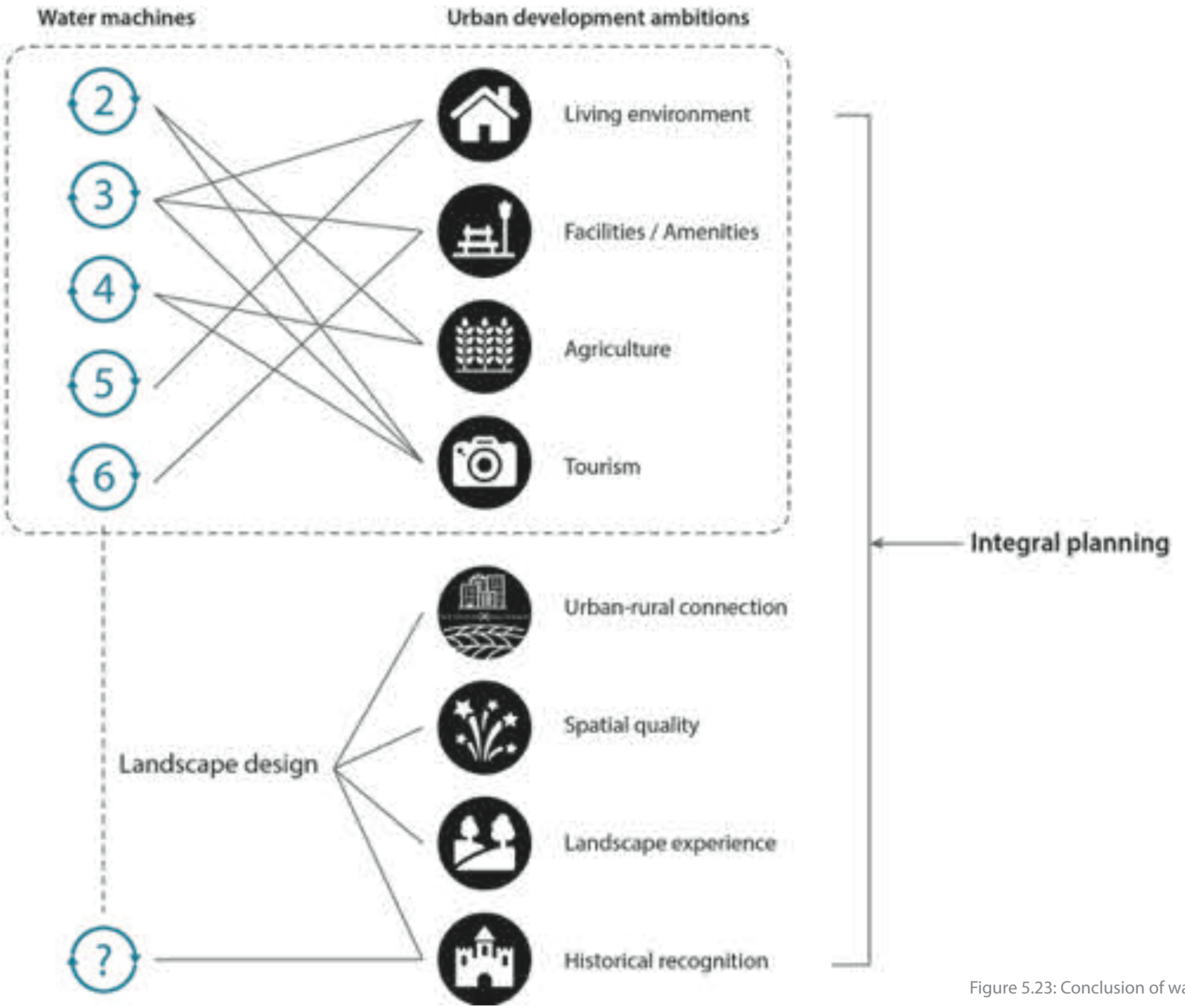

Figure 5.23: Conclusion of water machines and urban development

6

DESIGN: EXPLORATION OF POSSIBILITIES

This chapter elaborates on the design strategy based on the results of previous three chapters, explores new water machines and design alternatives as possible solutions to Sint-Oedenrode from different perspectives.

6.1 Design strategy

Design strategy refers to the conceptual underpinning for creative work, providing the integrated and holistic planning, as a field of theory and practice (Stone 2013). By synthesizing the input of previous analysis and conclusions, the design strategy is developed as a transition from research framework to design process (figure 6.1). It includes five determinant steps to reach a design product, and five main components of this study. The decisions for each step are framed with rectangles and the interplays between these components are indicated by curved arrows.

The action to be taken concerns with the final outcome of the new water network, and the selection of 'constructing a bypass' is derived from the conclusion of first research question (RQ1). Since the study intends to bring more benefits to Sint-Oedenrode as a chance for development, bypass would be a wiser choice. The location to implement the bypass is decided by the location of historical structure ('wallenstructuur'), which partly overlap with each other. This leads to more potential landscape interventions in spatial respect. And the methods to integrate 'wallenstructuur' into the new water network are from the conclusion of the second research question (RQ2) as well. Only three qualitative elements are shown in the diagram, but the design tries to explore and use as many methods as possible. The decision of application of water machines are made in the conclusion of the third research question (RQ3) that based on the LOLA design, additional machines are needed to fit in the unique context of Sin-Oedenrode. Ultimately, the design product should be a practical future-proof solution to high water problem by achieving an either robust or resilient water system (also from RQ1), and meantime provides more opportunities for urban development.

In summary, a robust or resilient new water network will be developed, consisting of the current water system and a southern bypass with an integration part of historical structure, attached by water machines of both LOLA design and new creation. Therefore, alternatives of possible bypass route are going to be explored with suggestion of water machines' application, before which site analysis and new creation of additional machines should be done first.

6.2 Site analysis and implications

Site analysis is conducted in a large scale for the south and west of Sint-Oedenrode that the whole historical structure is all-inclusive. It helps to figure out the situations and conditions of project area with more detailed information, and supports to generate practical design alternatives.

Land use

The south and west of Sint-Oederonde is covered with a large part of rural area, as mentioned in chapter 5. The map analysis makes a precise image of the current land use, compromising forests, tree nurseries, grasslands, poplar plantations, fruit farms and arable lands (figure 6.2). This is helpful to pick a suitable position for applying water machines: grasslands are potential for water machine 3 to create more recreational area; poplar plantations and fruit farms belong to bio-industry which fit water machine 2; arable lands are related to agriculture that is possible to apply machine 4; while there is not proper water machine for forests still. As the experimental site, the mixed rural area has high potential to examine the effects of water machines.

Land property

Due to the limited available information, the analysis of land property is concentrated in the south of central urban area (figure 6.3). It aims to make the design alternatives more feasible by taking the stakeholders into consideration. Combined with land use map, it can be seen that some forests and grasslands are

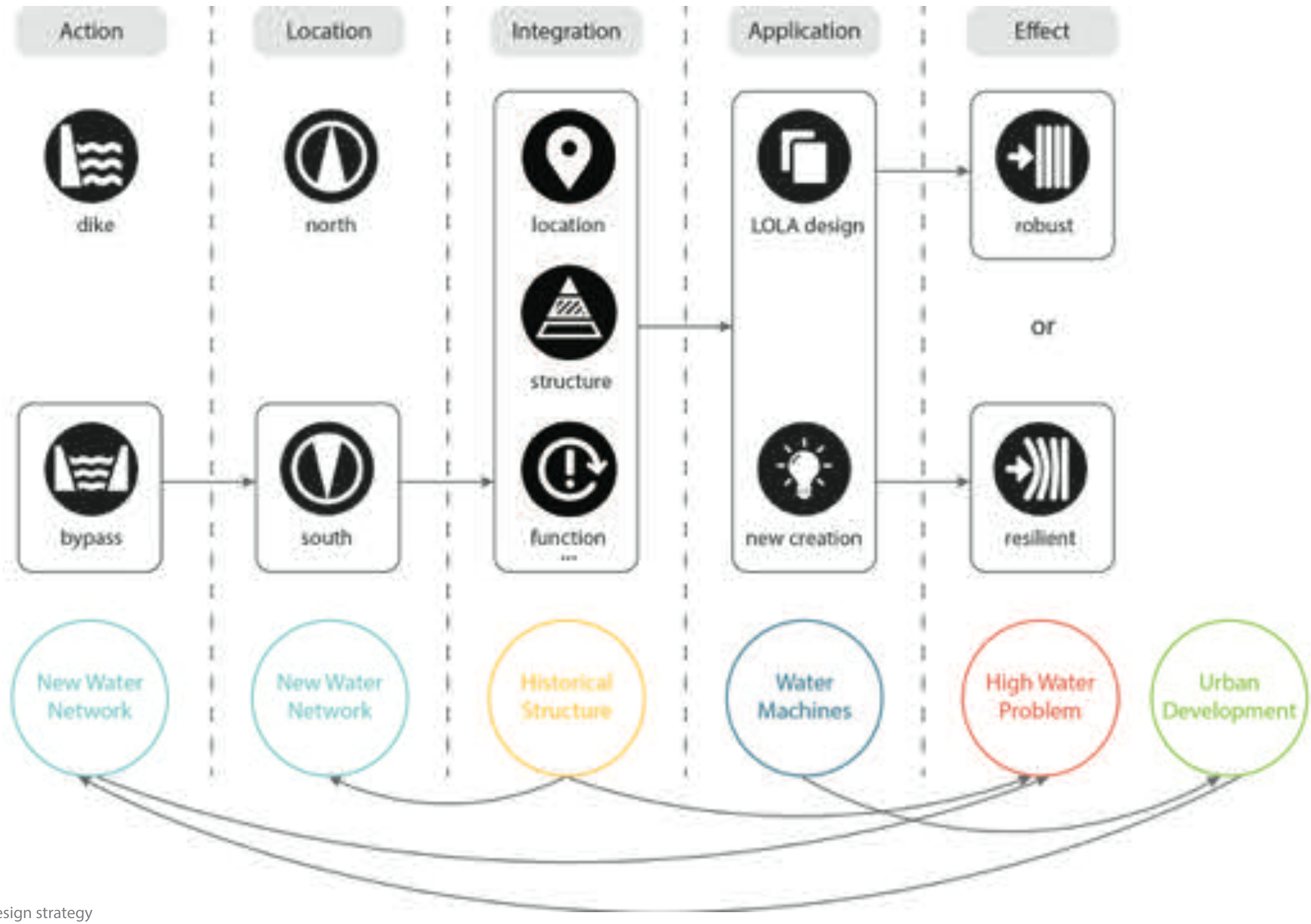

Figure 6.1: Design strategy

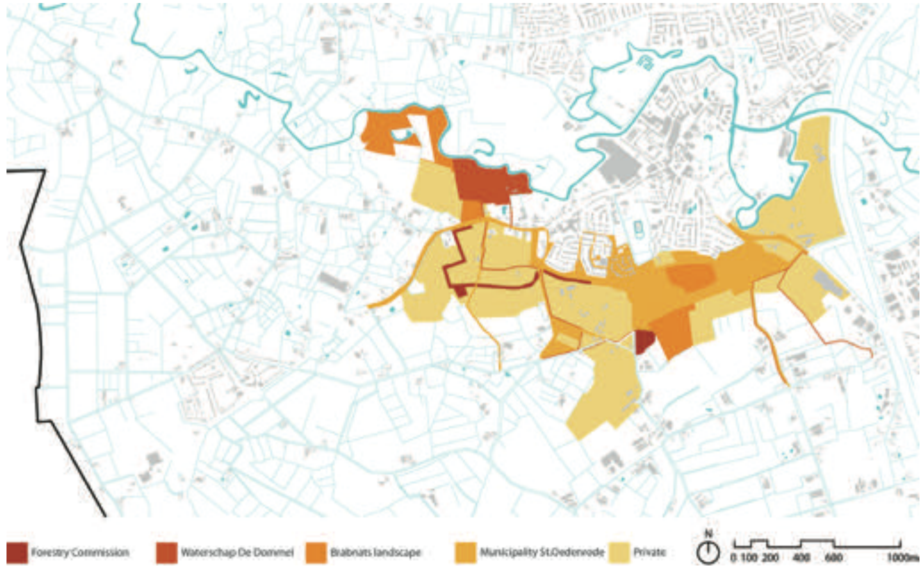

Figure 6.2: (left top) Land use in the south and west of Sint-Oedenrode

Figure 6.3: (right top) Land property in the south of Sint-Oedenrode

Figure 6.4: (left bottom) Instracture (road system) in the south and west of Sint-Oedenrode

attached to the government organizations, which are highly workable to be developed as public space; while almost all the arable lands are private, which need more attention to be paid.

Infrastructure (road system)

There exist many transportation infrastructures within the project area (figure 6.4). The largest one is the motorway A50 at the eastern side, connecting Sint-Oedenrode with other cities. Secondary (regional) roads and local roads are the main components throughout the whole site, so do other unmetalled roads and pedestrian paths certainly. Obviously, the bypass crosses a few roads, either simple one with ample space or complicated one with crossings, which have an influence on budget and feasibility.

Waterways

From the background map of all three figures, it is clear to see a number of waterways are located within the project area which have connections with the Dommel. They mainly consist of farmland ditches that could drain water from the raised strip of fields. One trick for the design of bypass is that the route could partly follow the existing waterways, being more practical and reliable.

6.3 New water machines

Three new water machines are created as additional 'model solutions' that particularly suit the context of Sint-Oedenrode (figure 6.5). Two of them lay special emphasis on historical structure ('wallenstructuur'), the other one focuses on the local natural resources and landscape features. All the three water machines complement and cooperate with LOLA designs to add values to water system, mitigating the high water problem and contributing to spatial and economic development.

In this part, the conceptual ideas of water machines are introduced with simple diagrams. The detailed designs of their applications in Sint-Oedenrode are specified in the next chapter, inclusive of positions, values can be achieved, qualitative elements used for integration and visualizations.

Machine A

Rebuilding the sluice gate in the location where it was not only makes it function again for controlling the flow of water flexibly, discharging excessive water of Dommel when subjected to extreme climate event, but also acts as a memory of old structure that brings historic significance.

Machine B

Restoring and redecorating the 'wallenstructuur' to serve as a part of new water network creates a special landscape monument, increases the visibility of functionality it used to have, which will provide opportunities for recreational and educational use as well as tourism development.

Machine C

Constructing the bypasses through existing forest will take advantages of rich natural resources for water storage and water purification, also fulfills natural areas' potential for recreation and meanwhile represents unique local landscape features.

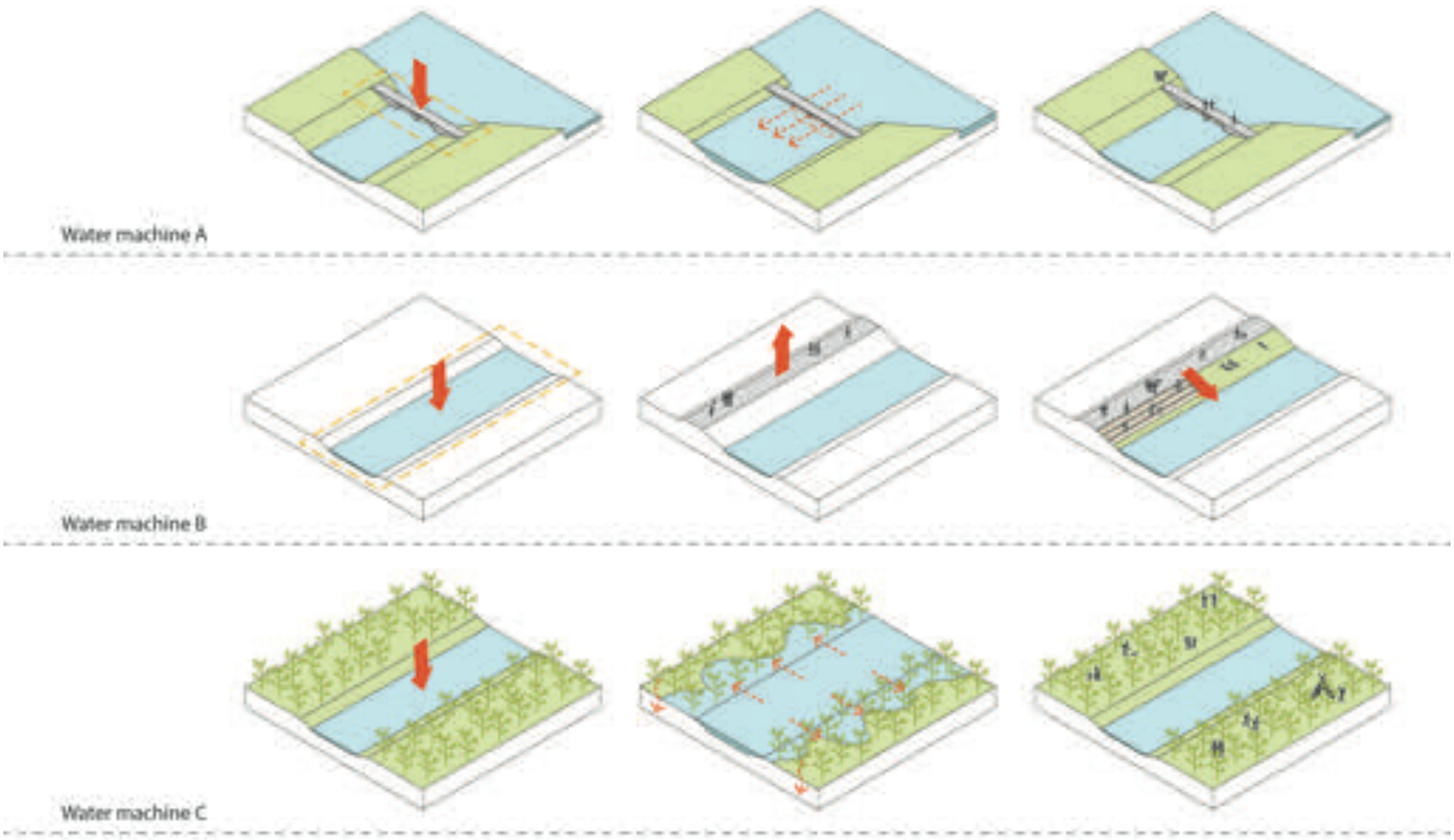

Figure 6.5: Conceptual diagram of three new water machines for Sint-Oedenrode

6.4 Design models

From various starting points, three models are developed as possible design solutions to Sint-Oedenrode. Each model has one to two alternatives that are either robust or resilient. For each alternative, a bypass is designed with principle profiles, as well as several potential water machines along it. The route of bypass mainly depends on different starting points, while the water machines accord with current land use along the bypass.

6.4.1 Model 1: Water board solution

This model is the southern bypass developed by the water board as a reference design. It provides the principle profile that can help to inspire more alternatives and decide different profiles with regard to creative solutions.

<u>**Alternative 1-1 (robust)**</u>

This bypass is designed as a robust solution to all the potential bottlenecks mentioned in chapter 3. It branches off from the Dommel in southeastern urban area and lies along the south of Zuidelijke Randweg (southern ring road), going further to the west and then connects to the Dommel again near RWZI Sint-Oedenrode (figure 6.6). The total length of this bypass is about 2.75km, and almost the whole one follows the existing waterways. To ensure it function robustly to respond to extreme climate events, the bypass needs a considerably larger profile with a 10m-wide bottom and a slope of 1:2 (figure 6.7).

Figure 6.6: Alternative 1-1 (adapted from Waterschap De Dommel 2015, water machines are suggested by author)

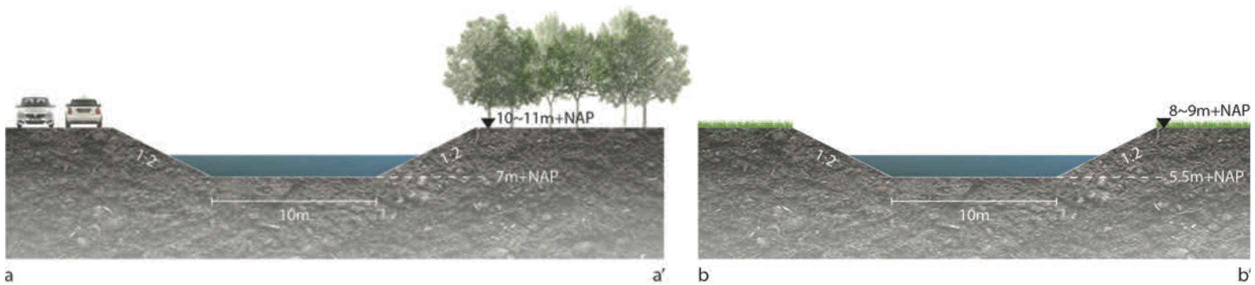

Figure 6.7: Principle profiles for alternative 1-1 (data from Waterschap De Dommel 2015)

6.4.2 Model 2: Historical pattern context

This model is dominated by the trace of 'wallenstructuur' in order to make it function again as a special meaningful structure. The reinstatement of 'wallenstrutuur' is accompanied by the creation of new bypass routes on the basis of current situation.

Alternative 2-1 (robust)

This bypass simply follows the original trace of the historical structure (figure 6.8), which is also a robust solution because of the designed wide profiles – two times of water board's plan (figure 6.9). It connects the Dommel only at the position of old sluice gate, and forms a large circle in the south and west of Sint-Oedenrode (border of municipality is indicated by dark line). The total length of this bypass is approximately 18.10km that is much longer than alternative 1-1, allowing more landscape interventions caused by water machines as suggested.

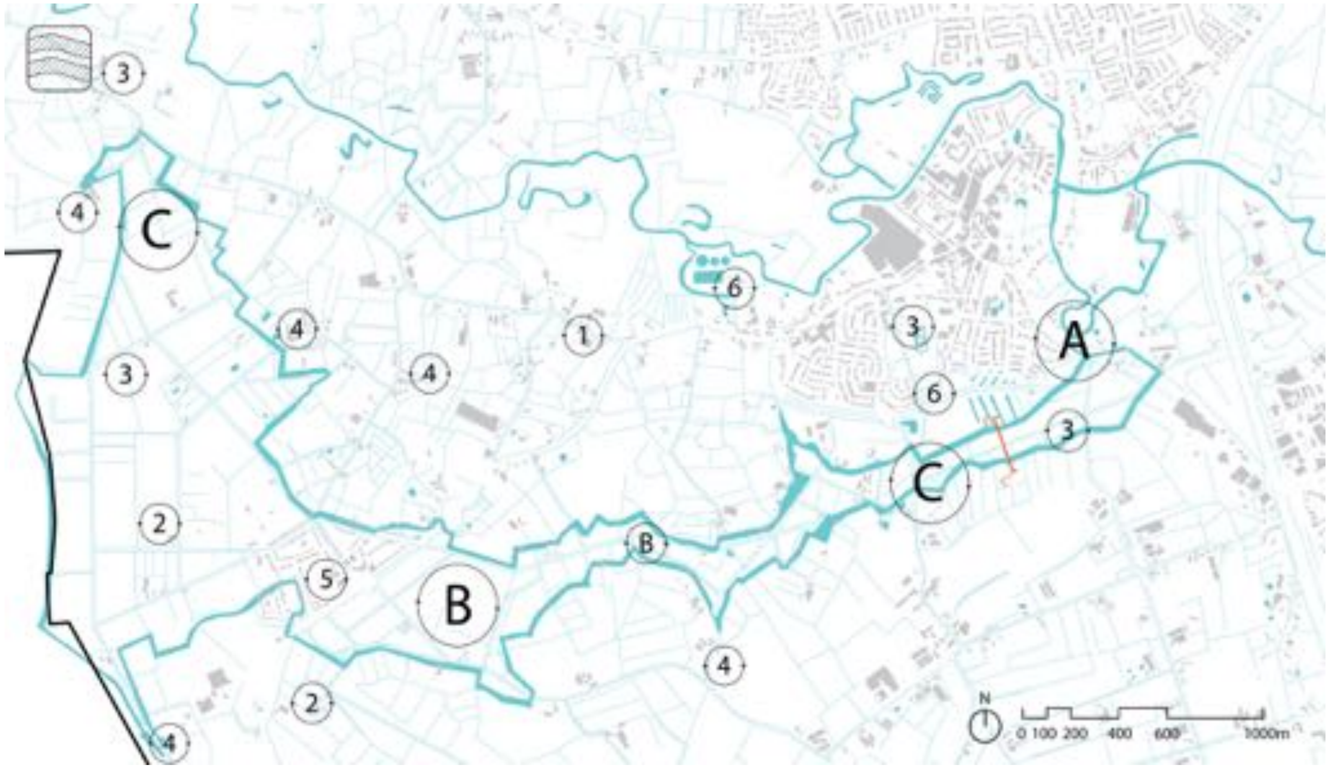

Figure 6.8: Alternative 2-1 (water machines are suggested by Floris Alkemade)

Figure 6.9: Principle profile for alternative 2-1

Alternative 2-2 (resilient)

This alternative is in fact a combination of alternative 1-1 and 2-1 with a total length of 6.7km (figure 6.10). In the former part starting from its connection with the Dommel, there are two bypasses that follow the trace of 'wallenstructuur', with the bottoms of 5.5m wide and slopes of 1:3. The design of this profile adheres to the principle of remaining the equivalent flow capacity to water board solution (figure 6.11). In the latter part, it overlaps with alternative 1-1 and keeps the same cross section of a 10m-wide bottom and slopes of 1:2 (figure 6.12). However, it's a resilient solution because the former part allows excessive water coming out of the bypass without influencing the surroundings, which also slows down the water and reduces the pressure for the latter part.

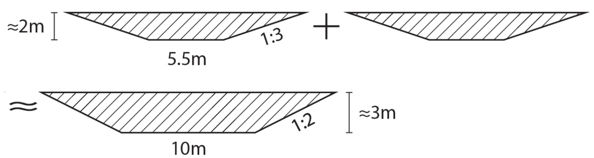

Figure 6.11: Comparison of two profiles

Figure 6.10: Alternative 2-2

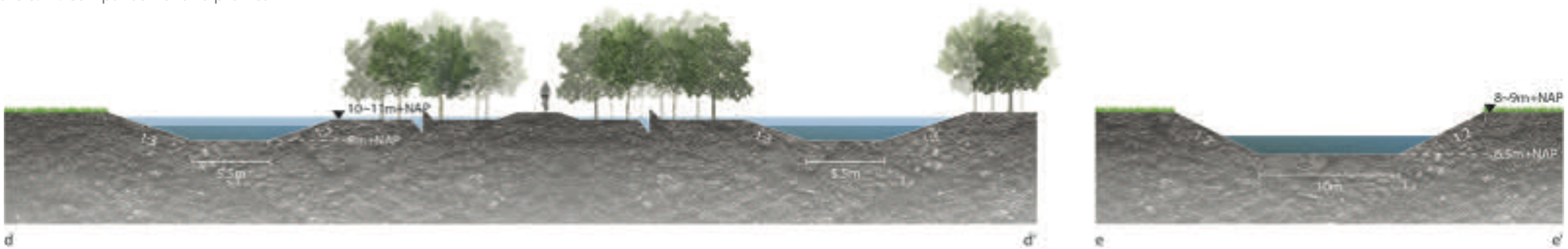

Figure 6.12: Principle profiles for alternative 2-2

6.4.2 Model 3: Water machine context

This model intends to maximize the effects of water machines, thus the process of designing alternatives is almost opposite to model 1 and model 2. It begins with searching out the locations that can develop multi-functional water machines, and then a route by which they can be well connected is conceived. Although some previous alternatives also have high potentials to apply water machines, this model aims to make more efficient efforts in a proper scale.

Alternative 3-1 (robust)

This bypass is designed as a robust solution, which has the same profile with water board solution (figure 6.14). It branches off the Dommel also from the location of original sluice gate, and goes through the forests, grasslands, agricultural fields, and tree nurseries, finally converges into the Dommel near RWZI Sint-Oedenrode (figure 6.13). Most of the route follows the existing waterways, and the total length is around 3.47km, along which more than ten places are appropriate to develop various water machines.

Figure 6.13: Alternative 3-1

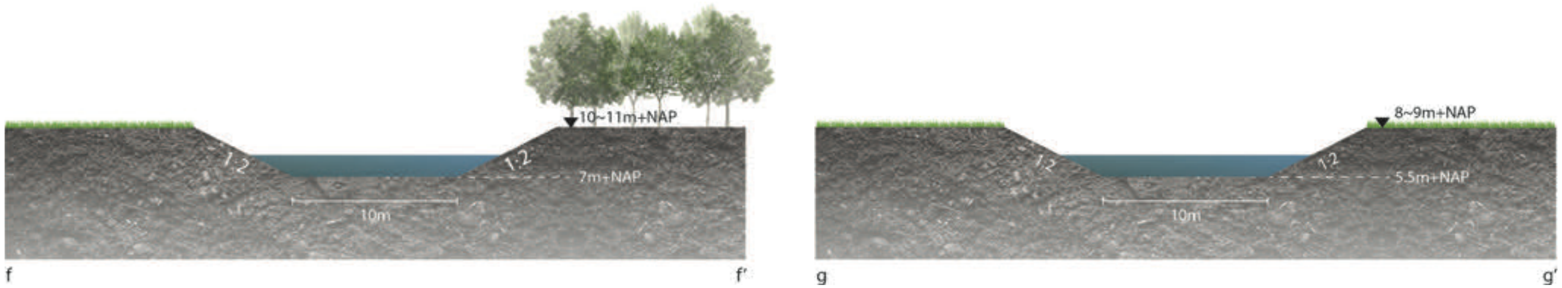

Figure 6.14: Principle profiles for alternative 3-1

Alternative 3-2 (resilient)

This alternative has two separate bypasses the whole way with a total length about 6.64km (figure 6.15). The northern one starts from the old sluice gate, lies along the north of Zuidelijke Randweg that is close to residential area, then continues a bit further and changes direction flowing into the Dommel again just beside RWZI SInt-Oedenrode. The southern one branches off the Dommel from more eastern part in an agricultural field, goes through different types of land by following the existing waterways in most situation. They together form a big circulation in the mixed rural area, providing more possibilities to use water machines and lead to landscape interventions. As a resilient solution, the profile of bypass is designed with a narrower bottom and more gentle slopes compared to water board's plan (figure 6.16). The former part of two bypasses has the huge capacity that water is allowed to overflow the structure into the forest and grassland in between, which actually has a greater impact on discharging water under extreme climate scenario.

Figure 6.15: Alternative 3-2

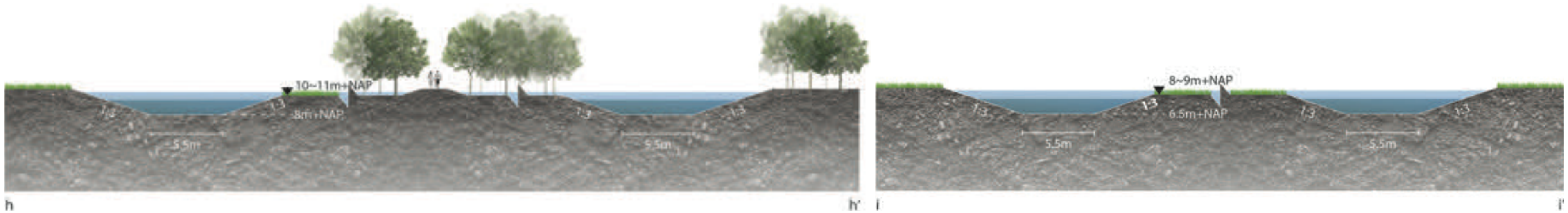

Figure 6.16: Principle profiles for alternative 3-2

6.5 Evaluation

In this section, the alternatives as described above are evaluated. According to the reference design (alternative 1-1), as calculated by water board, all the alternatives have significant impact on MHWs in Sint-Oedenrode that can count as effective solutions to the potential bottlenecks under scenario 4 (100W+ 10.8m^3/s). Therefore, the evaluation focuses on the additional values that they can bring to Sint-Oedenrode, which are divided into three categories: historic value, ecological value and economic value. For each category, several criteria are formulated, either qualitative or quantitative, regarding to both effects of water machines and ambitions of urban development. The feasibility of implementation is also listed as an important item to weigh the benefits against the operation. All the alternatives are graded by five levels for each criterion, and ultimately the alternative 3-2 stands out as the preferred design for further development (figure 6.17).

6.5.1 Historic value

Reinstatement of historical 'wallenstructuur'

This criterion is indicated by the degree of the use of 'wallenstructuur'. Obviously, two alternatives of design model 2 which emphasize on historical pattern context have higher marks than others, because they completely or partly follow the trace of original structure. Both alternatives of model 3 also partly overlap with it, and take the old sluice gate into consideration. Only the alternative 1-1 doesn't pay attention to this point.

Opportunities for Experiential design

This criterion is an advanced procedure on the basis of last one and refers to the application of water machines A and B. The alternative 2-1 is not the best one because it is designed in a super wide range that is too far away from the central urban area to access. And despite of water machines, design with other historical elements are also possible, thus alternative 1-1 still has chance.

6.5.2 Ecological value

Diversity of nature and landscape

The assessment of this criterion depends on the types of nature and landscape that the bypass going through. According to the map (figure 6.18), numbers are counted for each alternative in the table 6.1.

Ecosystem services

The ecosystem service is a complicated concept, here we only discuss about its contributions in local scale. Based on the site condition, the main ecosystem services are derived from forest and agro-ecosystems. Goods and services from forest that can be directly used are forest products, genetic information, recreation and tourism; the indirect goods and services are regulation of rainfall, flood and water yield regulation, control of soil erosion, carbon storage and health (Newcome et al. 2005). Agro-ecosystems provide direct goods and services such as plants, livestock, food, visual amenity of agricultural landscapes; and indirect ones are pest and disease control, soil processes, pollination, nutrient cycling, water quality and quantity, carbon storage and genetic diversity (Newcome et al. 2005).

Combining the forest and agricultural fields with bypass and landscape development along it, some water-related and landscape-related ecosystem services can be better used by Sint-Oedenrode. Both alternative 2-1 and 3-2 involve more forests and agricultural fields that can offer ecosystem services than other alternatives. The water board solution suggests the bypass next to the infrastructure instead of going through the mixed rural area so that it has less opportunity to obtain goods and services.

6.5.3 Economic value

This part is more quantitative but will be evaluated qualitatively by looking into the application of different water machines.

Efficiency of water use

This criterion can be extended as the potential of water storage and purification, the application of collective irrigation system, and the possibility of reducing water demand, which can be indicated by the water machines 2, 4, 6, and C. As suggested before, alternative 3-2 is the most effective plan with

Category	Criteria	Alternative 1-1	Alternative 2-1	Alternative 2-2	Alternative 3-1	Alternative 3-2
Historic value	Reinstatement of historical 'wallenstructuur'	[illegible]	++	+	+-	+-
	Opportunities for Experiential design (narrative / education / recreation)	[illegible]	+	++	+-	+
Ecological value	Diversity of nature and landscape	[illegible]	+	+	+	++
	Ecosystem services (local)	[illegible]	++	+	+-	++
Economic value	Efficiency of water use	+-	+-	+	+	++
	Sustainable / productive agriculture	[illegible]	+	+	+-	++
	Potential for tourism	[illegible]	+	+	+-	++
Feasibility of implementation	Budget	++	[illegible]	+-	+	+-
	Consideration and use of existing situation	++	[illegible]	[illegible]	+	+-
	Control and maintenance	+	[illegible]	+-	+-	+
Summary	Values / feasibility	[illegible]	[illegible]	+/+-	+-/+	++/+

Figure 6.17: Evaluation of design alternatives

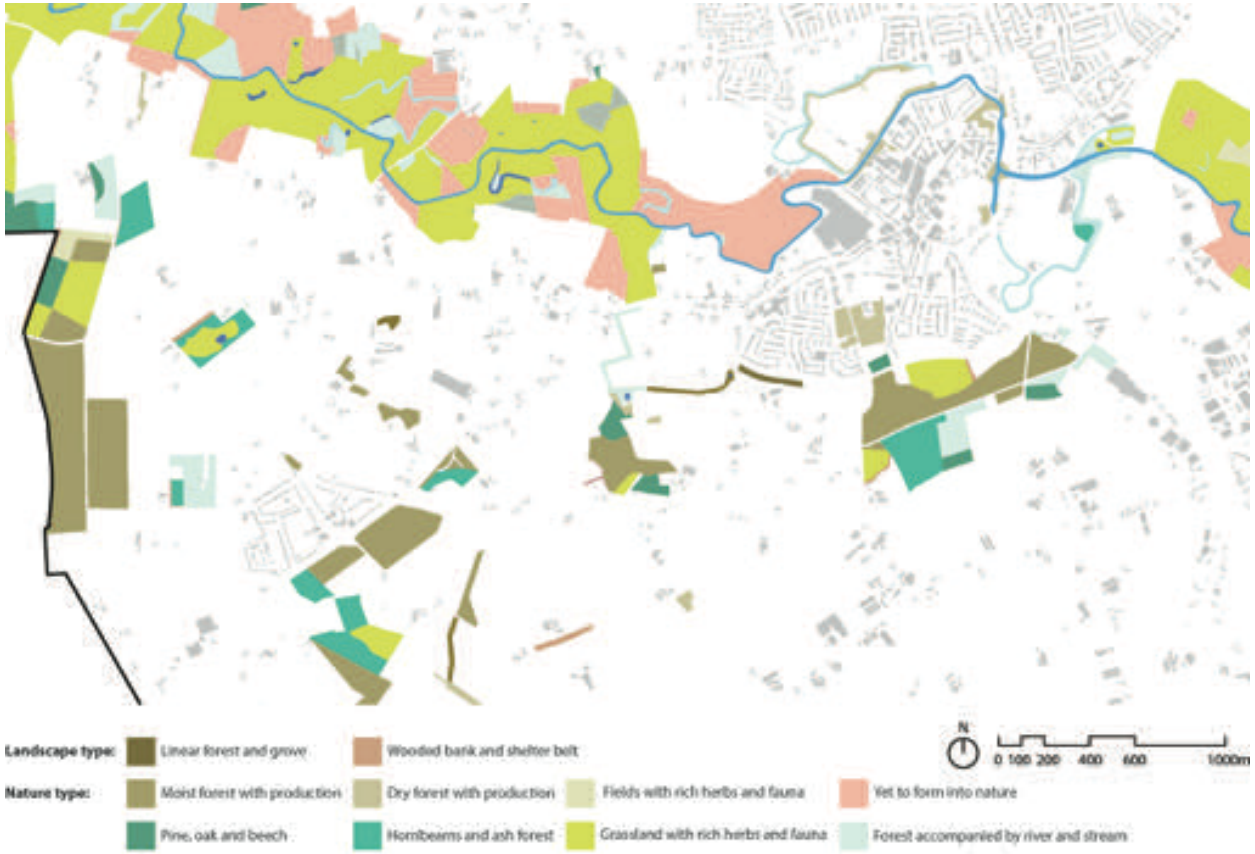

Figure 6.18: Landscape and nature types in Sint-Oedenrode (adapted from Nature Management Plan by Province Noord-Brabant 2016)

	Alternative 1-1	Alternative 2-1	Alternative 2-2	Alternative 3-1	Alternative 3-2
Types of nature and landscape	5 types	7 types	7 types	7 types	8 types

Table 6.1: Statistical result of nature and landscape types for design alternatives

maximum machines within a proper range, followed by 3-1 and 2-2

Sustainable/productive agriculture

This criterion is extracted from one of the ambitions of urban development that to revive the agricultural sector in Sint-Oedenrode, fortunately we have corresponding water machines 2 and 4. It is not difficult to conclude that alternative 3-2 has more potentiality to realize a sustainable agriculture with the aid of machines, so do alternative 2-2 and 2-1.

Potential for tourism

This criterion also refers to the policy for upcoming development in Sint-Oedenrode, which intends to develop tourism by improving the quality of public space and increasing the number of open green area. Application of water machine 3 for recreational areas is the right action to realize this ambition, and a combination of culture and nature is also attractive for tourists, which concerns with machine A, B and C. Thereby both model 2 and 3 are potential for tourism, among which alternative 3-2 is graded relatively higher level because it supports harmonious development rather than focuses on one aspect.

6.5.4 Feasibility of implementation

Budget

The budget of each alternative cannot estimated in this study, but is simply indicated by the length of bypasses and their interjunctions with big infrastructures. As introduced in the description, alternative 2-1 has the longest bypass that reaches 18.10km, while water board solution 1-1 is the shortest as 2.75km. Alternative 2-2 and 3-2 are almost the same with a length of about 6.70km.

All the bypasses cross a few transportation infrastructures which can be divided into two types: quite simple one with ample space, or more complicated one with crossings. To be operational, the interjunctions with different types of infrastructure are simply counted together (figure 6.19-6.23). The result shows that the longest one has the most crossings definitely, followed by alternative 2-2 and 3-2 with nearly half of 2-1, and two smaller-scale robust solutions have the least crossings.

	Alternative 1-1	Alternative 2-1	Alternative 2-2	Alternative 3-1	Alternative 3-2
Length	2.75km	18.10km	6.70km	3.47km	6.64km
Interjunctions	6	24	11	6	11

Table 6.2: Statistical result of the length of bypass and interjunctions with infrastructures for each alternative

Figure 6.19: Interjunctions with infrastructure (Alternative 1-1)

Figure 6.20: Interjunctions with infrastructure (Alternative 2-1)

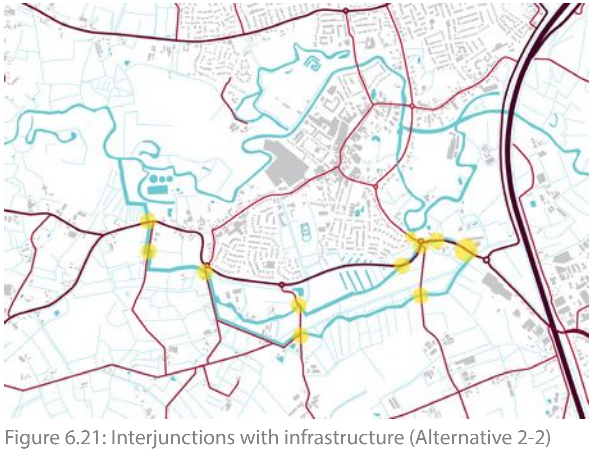

Figure 6.21: Interjunctions with infrastructure (Alternative 2-2)

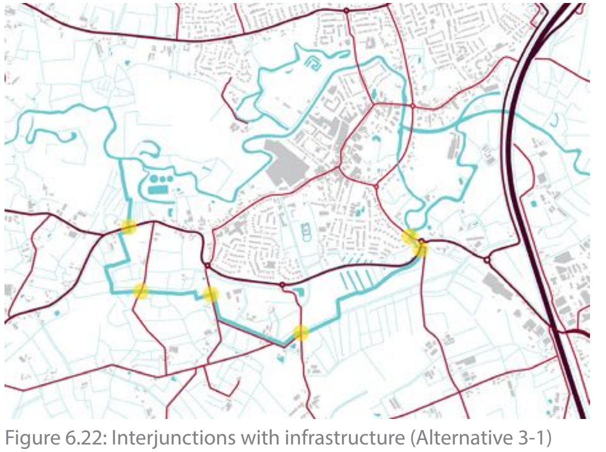

Figure 6.22: Interjunctions with infrastructure (Alternative 3-1)

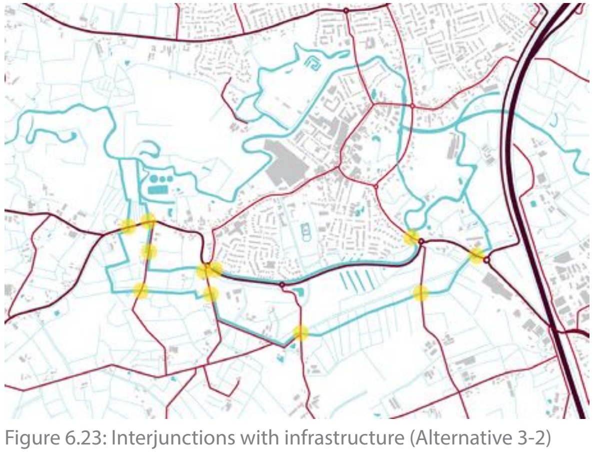

Figure 6.23: Interjunctions with infrastructure (Alternative 3-2)

The quantitative result is concluded in the table 6.2, and it is obvious to see that the number of interjunctions is directly proportional to the length of bypass.

Consideration and use of existing situation

The assessment of this criterion is decided by looking into the restriction of private property and use of existing waterways. Almost the whole bypass proposed by water board follows the existing ways and goes through the land that attached to the government organizations. Alternative 3-1 as a similar robust solution, also has small impact on private land and current water situation. However, alternative 2-1doesn't consider the current condition too much and could lead to significant influence because a large area is involved.

Control and maintenance

Here the evaluation of 'control' means assessing the degree of difficulty to keep the bypass well functioning, which can be indicated by the variety of interventions. With more interventions, the alternative is more difficult to be controlled. And 'maintenance' depends on the system features that robust systems should be managed well to keep the initial status all the time, while resilient systems are more flexible and self-sustaining that can adapt to any changes themselves. Each alternative is evaluated qualitatively in the table 6.3, and the total result is the final mark for this criterion.

6.5.5 Summary

All the criteria assessed above are summarized as values and feasibility. From the last row of evaluation result, characteristics of each alternative are distinctive. The water board solution (alternative 1-1) is the most viable one but won't bring too many additional values to water system; alternative 2-1 which completely follows the historical pattern is valuable but unrealistic; alternative 2-2 that partly use the trace of 'wallenstructuur' balances quite well, but still weak in feasibility compared to others; the model of water machine context gives weight to different factors in a practical way by considering both sides, while alternative 3-2 could achieve better effects.

For further landscape development, it is clear to see the weakness of alternative 3-2 is that it is not historic referred, and doesn't pay too much attention on budget and private property. The latter one cannot be improved if two bypasses are constructed as the key intervention for Sint-Oedenrode, but the historic value is possible to be enhanced through integral planning and landscape design, which will be done in the next chapter.

	Alternative 1-1	Alternative 2-1	Alternative 2-2	Alternative 3-1	Alternative 3-2
Control	++	--	+-	+	+-
Maintenance	+-	--	+	+-	++

Table 6.3: Qualitative evaluation of control and maintenance for each alternative

7

DETAIL DESIGN: WATER MACHINE NETWORKING

This chapter further develops the design product of chapter six and aims to answer DQ: *How to combine a specific type of 'water machine' (LOLA 2015) with the rehabilitation of (parts of) the historical structure ('wallenstructuur') and serve the integral urban development in Sint- Oedenrode?*

7.1 Master plan

This master plan integrates the design of bypass and various water machines into the case of Sint-Oedenrode to strengthen its water system responding to high water problem and facilitate the process of urban development for upcoming years (figure 7.1). The design can be decoded by a multi-layer analysis which reflects the current situations and changes to be made. It consists of four recognizable layers: water system, land & facilities, buildings and road system (figure 7.2). They show a strong coherency and close cooperation, and seamlessly integrated into the site as a whole.

The new plan starts with the improvement of preferred alternative by searching for more valuable route of bypass. The northern one close to residential area is changed to follow the existing waterways along the trace of 'wallenstructuur' within the forest. On the one hand, this adds historic value to water system by providing the chance for experiential design; on the other hand, it forms a more resilient system that guarantees excessive water against threatening the buildings. The improved bypass is called machine S, representing a 'super' new water network in 'Sint-Oederode' together with the Dommel.

The design doesn't change current land use considering the land property, but redefines some land for new ambitions. For example, three plots of grassland are designated for recreational use, and a piece of agricultural field is set for growing flowers. In accordance with these small changes and the conceptual water machines, multifunctional facilities are designed for diverse purposes such as meeting, water treatment, culture, education, which also respond to the action for improving quality of life proposed by the municipality.

Implemented in the mixed rural area, the master plan doesn't make an issue of buildings. Only three buildings are constructed and one is modified to better serve the integral ambitions of Sint-Oedenrode. They are distributed in different spots of project area that together assemble a well-equipped service network.

The existing road system cannot meet the requirements of the new plan, thus a more complete transportation network is designed, especially for cyclists and pedestrain. The new road system not only keeps close ties with different spots within the project area, making all the places accessible; but also leads to the big infrastructures that connect Sint-Oedenrode and other cities, offering convenient links for visitors. These new planned paths provide multiple possibilities for people to move and experience different types of water machines and local landscape.

All the layers collaborate together to facilitate the interactions between nature and culture, as one of the features that Sint-Oedenrode intends to maintain; for which the water machines make huge contributions although they are not obviously visible in the master plan due to the scales and forms. They are actually hidden in the different fields that establish a network and have already been integrated into the site context.

Figure 7.1: Master plan

ursery
Farmland
Grassland
Flower field
N
0
100
300
500m

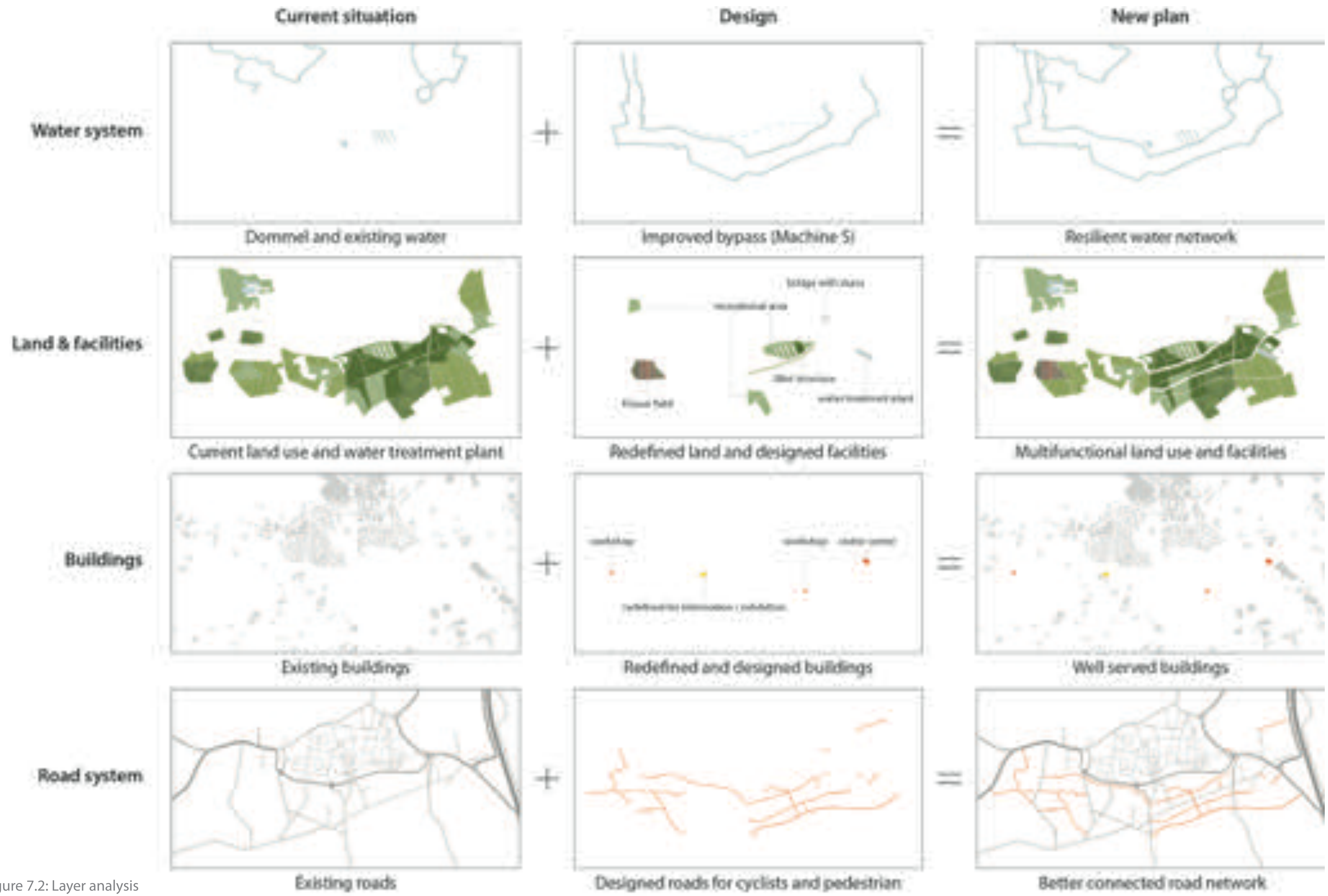

Figure 7.2: Layer analysis

7.2 Water machine networking

7.2.1 Application

The water machines are applied all over the south of central urban area that vary in size from small to large (figure 7.3), and range from natural to cultural, recreational to educational, historical to contemporary. Together they form a new networking in Sint-Oedenrode that all the components in this system are functioning themselves, but also collaborate with each other and complement to the improved bypass – machine S.

In the following, all the applied water machines are named and elaborated individually to emphasize their identities and characteristics. The new proposed water machines are further designed to be practical in the particular places; the LOLA water machines are modified and specified for the unique context of Sint-Oedenrode. Some machines are used in more than one locations, from which only one representative point is selected for detail design.

Figure 7.3: Application of water machines

7.2.2 Machine A – 'Sluice bridge'

Water machine A is related to an old sluice gate that connects bypass to the Dommel. The concept is to rebuild it in the original location to control the flow of water, and also to work as a part of historical structure that adds value to Sint-Oedenrode. Therefore, the design considers five qualitative elements that are extracted from reference projects (see chapter 4) and uses four as the theoretical basis for detailing.

Location

The sluice gate is planned in the location where an old sluice used to be, connecting to the Dommel (figure 7.4). This is an action of restoring rather than inventing that helps evoke memories of the past in a direct and simple way. Now it is designed as a junction between the Dommel and one bypass.

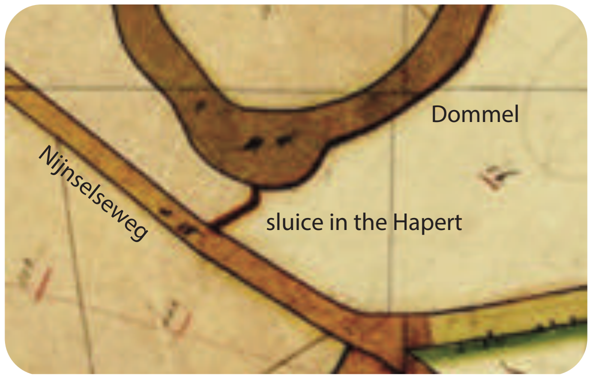

Figure 7.4: Location of old sluice

Basic function

A sluice gate should have its basic function – to control the water levels and flow rates in rivers and canals (figure 7.5). In normal times, the sluice is semi-open that allows a certain quantity of water flowing from the Dommel into bypass; when the water level is at high peaks, the sluice is totally open to discharge the excessive water (figure 7.6).

Material

A sluice gate is traditionally made of wood (figure 7.5), but the concrete one is more long-lasting and easy to be maintained (figure 7.7). To preserve a traditional appearance and historical feeling, a wooden bridge is design on top of it (figure 7.8). Up to this point a 'sluice bridge' is beginning to take shape.

New function

With the design of platforms and benches, the bridge is not aiming for transportation, but a place, an attraction that people can stay to know the history and the function of old sluice gate (figure 7.9). This also contributes to increase economic value by developing tourism, and provide opportunities to promote social communication.


Figure 7.5: Image of an old sluice


Figure 7.7:Material of concrete and wood

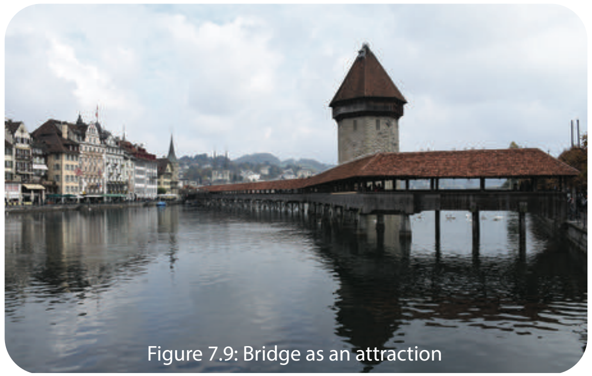
Figure 7.9: Bridge as an attraction

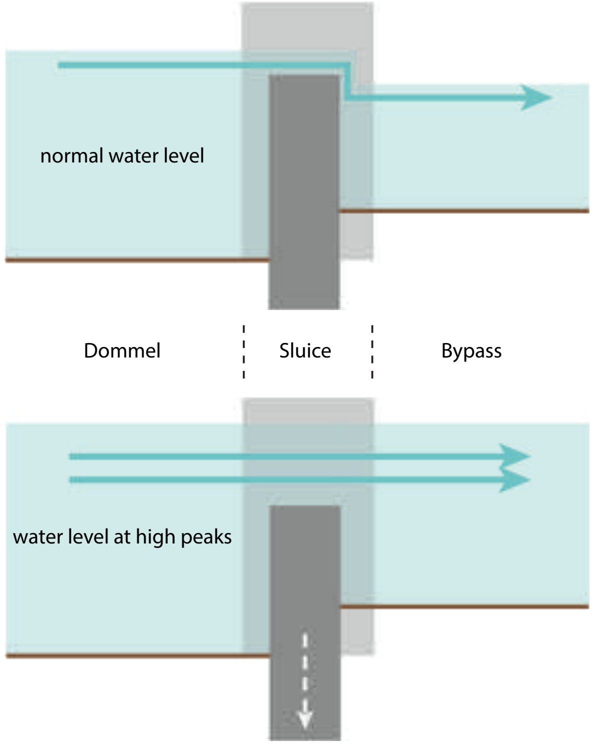

Figure 7.6: Profile of sluice to control water levels


Figure 7.8: Image of an old wooden bridge (dasgrondwerken.nl)

Figure 7.10: Visulization of water machine A – 'sluice bridge'

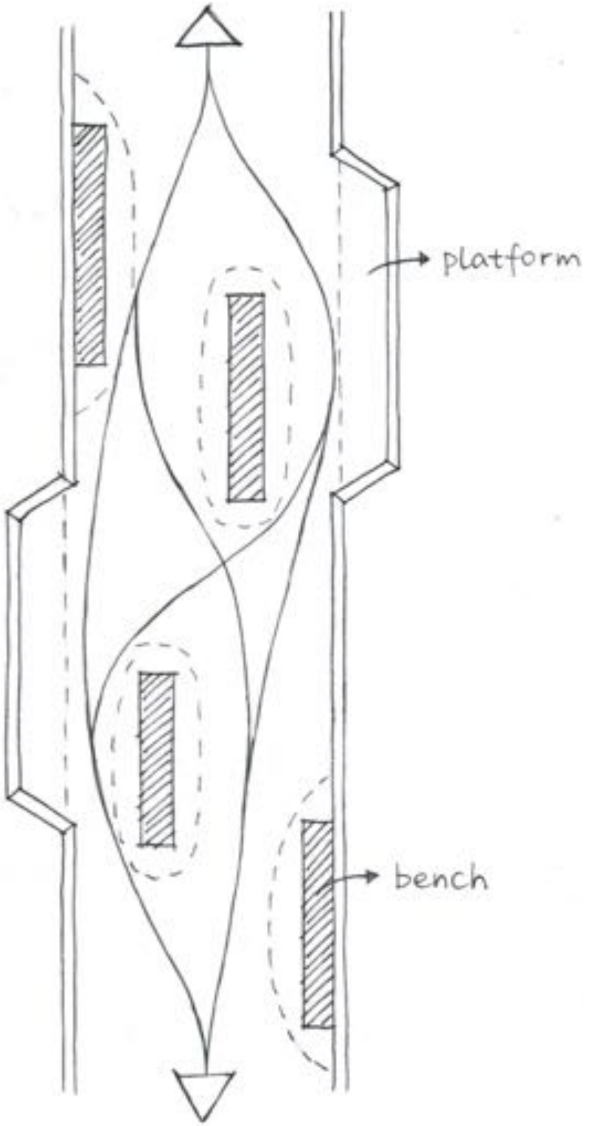

Figure 7.11: Analysis of pedestrian flow

The 'sluice bridge' is 4 meters wide and approximately 16 meters long crossing over the connection of Dommel and bypass, which has sufficient space for both locals and tourists to stay, move, and do some activities (figure 7.10). There are four benches and two platforms that offer stopover points to do various activities like reading, chatting, resting, photographying and enjoying the landscape around. Combining these spots with multiple possibilities of movement (figure 7.11), the 'sluice bridge' creates an attractive meeting place that not only tells the history, but also fulfills part of Sint-Oedenrode's ambition.

There are four junctions of the Dommel and two bypasses, each has a sluice gate to control water, whereas the special design of a 'sluice bridge' is only at the location where an old sluice was (as marked on figure 7.3). This water machine brings both historic value and economic value to Sint-Oedenrode as bonuses.

Historic value Economic value

7.2.3 Machine B – 'Regain wallenstructuur'

The concept of water machine B is to restore the 'wallenstructuur' to serve as a part of new water network. It is designed as a combination of bypass (machine S) and a 'dike' structure, which increases the visibility of the historical structure and landscape features, meanwhile places additional values on the site. The design is also inspired by four qualitative elements extracted in chapter 4.

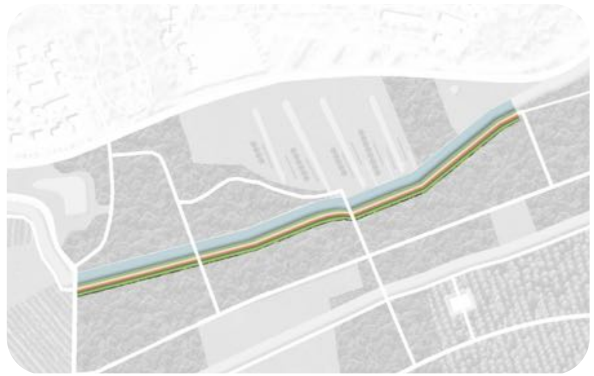

Figure 7.12: Location of machine B

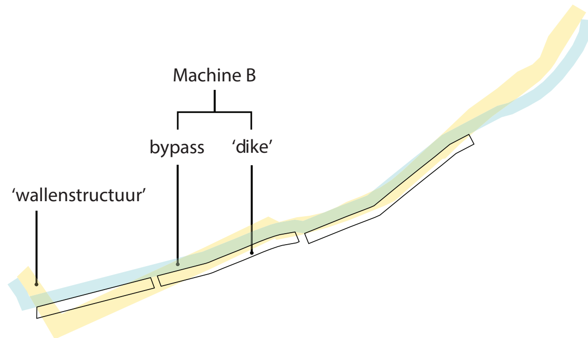

Figure 7.13: Machine B follows the trace of 'wallenstructuur'

Location

Machine B follows a small part of the original trace of 'wallenstrucuur' going through the forest (figure 7.12 & 7.13). On the one hand, the location as the historical site has the memorial and educational meaning; on the other hand, it is in the forest that has the good condition for experiential development.

Structure

As time goes on, the original landscape becomes unrecognizable (figure 7.14 & 7.15). The design of water machine B imitates the original supposed structure that delivers the history in an impressive way (figure 7.16). Although the cross section of 'wallenstrucuur' still remains unclear, the design to some extent resumes one of the first purposes that retains water by the raised land, and also represents a type of unique local 'roois' landscape.


Figure 7.15: Current situation

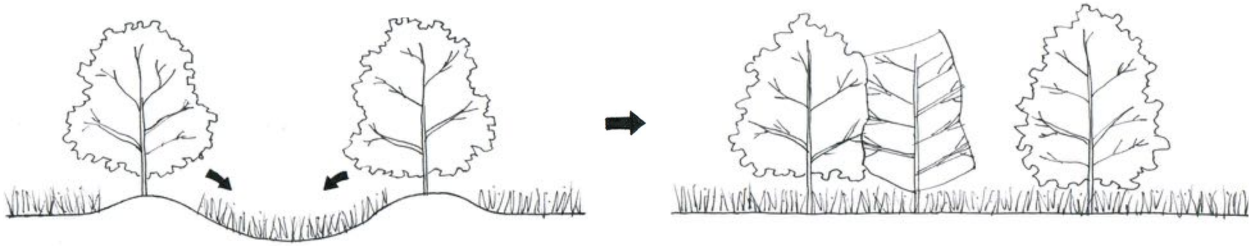
Figure 7.14: The land changes over time

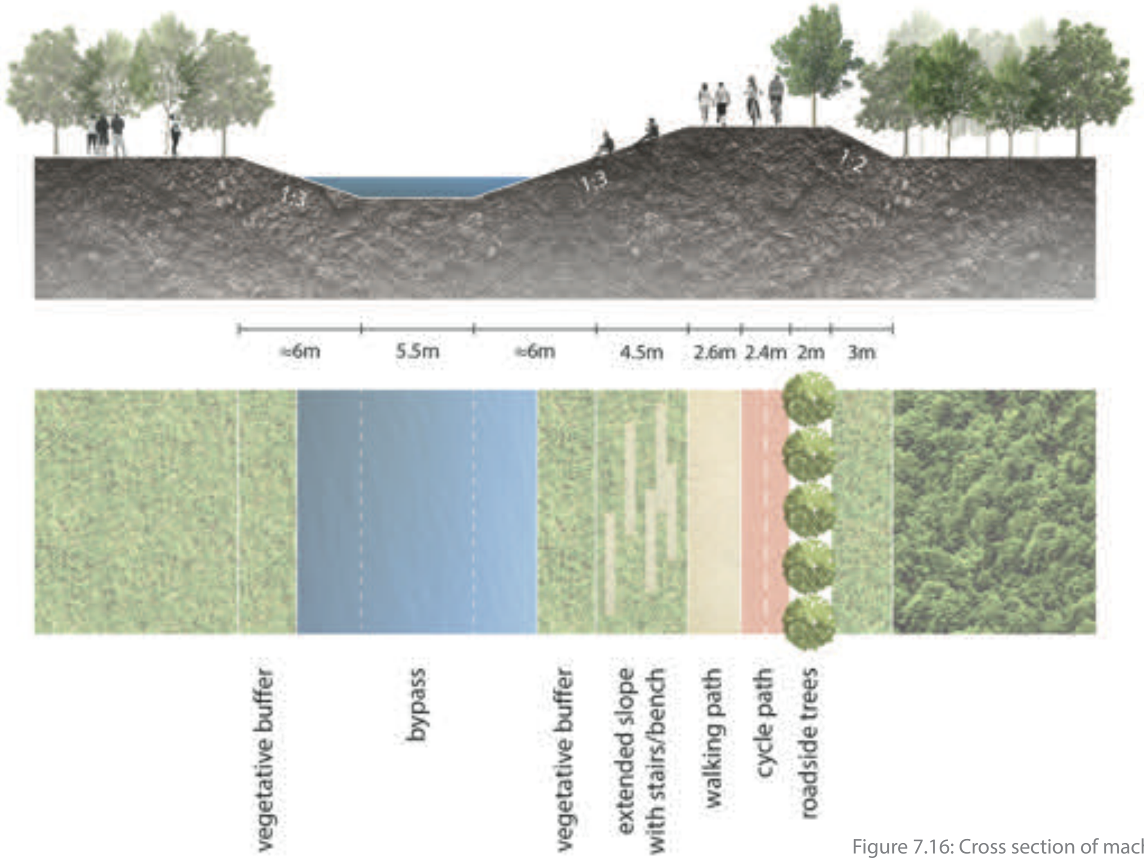

Figure 7.16: Cross section of machine B

Vegetation / Material

According to Jos Cuijpers' research, the structure was likely to be the communal ground that was used for for planting trees (coppice) to get firewood / timber (figure 7.17) and prevent shifting sands since about 1400 (Cuijpers 2016). Therefore, the design plants a row of trees on the one side of dike, among which some wooden art installations are inserted to recur this history. Moreover, instead of hard slopes, vegetative buffers are implemented that can better integrate into the surroundings.

Function

A 2.6m-wide walking path and a 2.4m-wide cycle path are designed on the 'dike', making it quite convenient and accessible for visitors. Soft slope is extended facing to water, together with some stairs / benches on it . Apart from the historic meaning and function of bypass, machine B is constructed for brand new purposes that provides multiple space and facilities for various leisure activities: walking or cycling on the dike to appreciate the scenery and installation art; lying on the slope or sitting on the benches to enjoy the sunshine and have a nice view of the other side of bypass (figure 7.18).

Figure 7.17: Image of coppice and timber

Figure 7.18: Various activities on the dike

In summary, since the 'wallenstructuur' remains many questionable points, the design of water machine B reinterprets the historical element by means of explicit explanation with a similar structure comprised of a 'dike' and partial bypass located in where the 'wallenstructuur' used to be, but is not a true 'wallenstructuur'. The top of this 'dike' structure is 7 meters wide, with pedestrian and bicycle lanes, a row of trees and wooden art installation (figure 7.19 & 7.20). As a water machine, it helps drain water from Dommel through bypass; in this sense, machine B can also be regarded as an attachment of machine S. However, as indicated by its name, machine B is the most significant design that 'regain the wallenstructuur', which contributes to adding historic value to Sint-Oedenrode. As introduced before, many activities can be done here, and they are not influenced by the water levels even when the climate scenario reaches an extreme point. Depending on the unique characteristics of both historical structure and attractive leisure space combined in one spot, the place is also potential to add economic value by developing tourism.

Historic value

Economic value

Figure 7.19: Visulization of water machine B – 'Regain wallenstructuur'

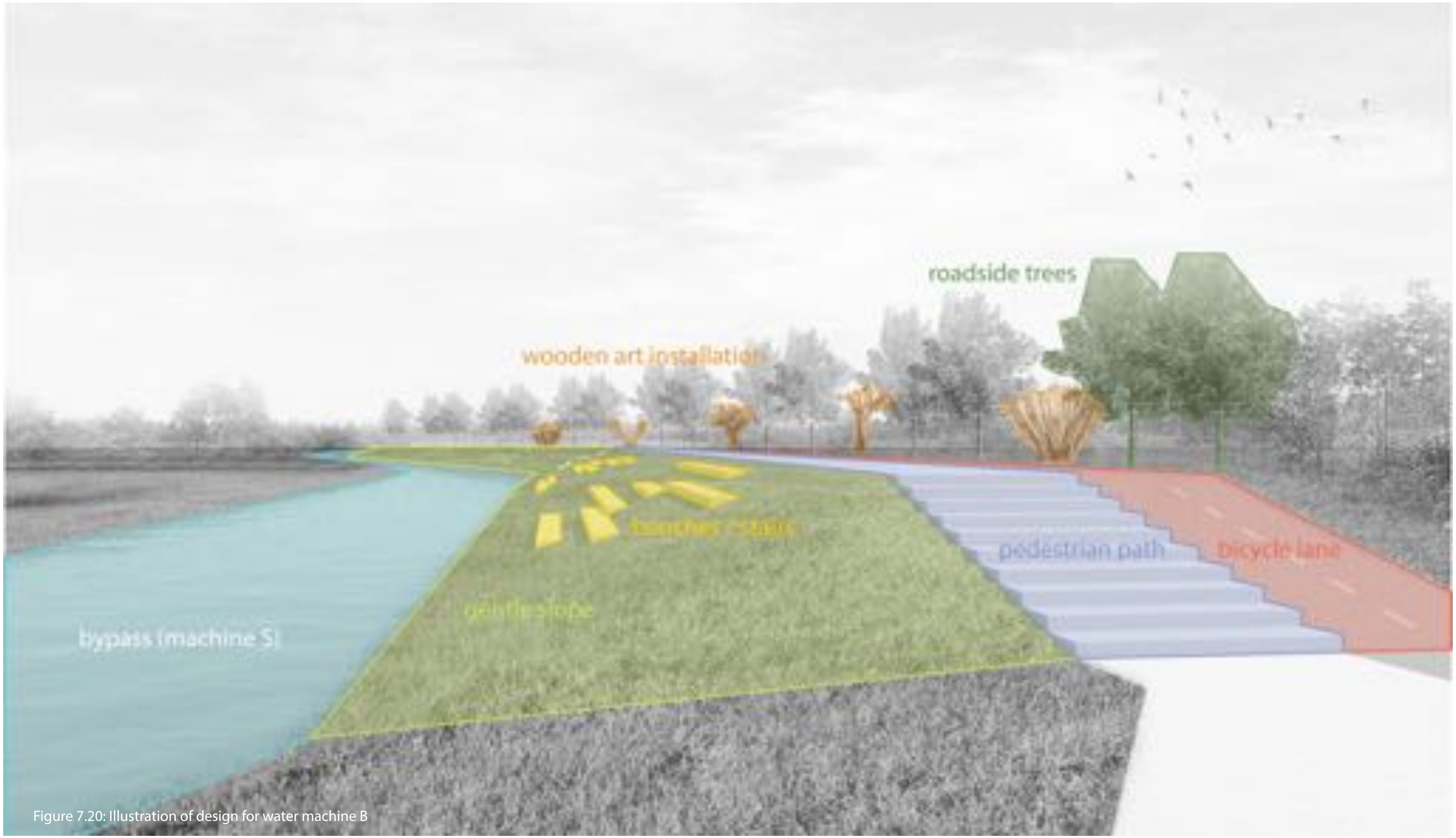

Figure 7.20: Illustration of design for water machine B

7.2.4 Machine C – 'Forest as conserver'

The concept of water machine C is to construct the bypass through the existing forest, taking advantages of natural resources for water storage and water purification, as well as develop potentials for recreational use. Thereby, the machine C in fact comprises part of bypass and the forest long it, which involves a large area (figure 7.21).

Figure 7.21: Location of machine C

Figure 7.22: Visualization of water machine C in normal time

It has already been proved that forest makes effects on water conservation (Schwab et al. 1981; Troeh et al. 1980; Chang 2006; Kittredge 1948), and this ability depends on the type of soil and the type of vegetation. Soils can process and hold considerable amount of water. From the interview, it is known that in this forest clay soil is the main composition, which has a very high water-holding capacity and poor water drainage ability. As a consequence, the south forest of Sint-Oedenrode is very suitable to be the 'conserver' for water, especially when the high water problem is beyond the capacity of machine S (figure 7.22 & 7.23). In this sense, forest is the body of 'water machine'.

Forest as a natural resource provides ecosystem services as explained in chapter 6. The function of water conservation is one of the services, and recreation and tourism can be another form of services. With criss-cross paths throughout the forest (figure 7.21), the place is very accessible for different kinds of activities for people of all ages (figure

Figure 7.23: Visualization of water machine C under extreme climate scenario

Figure 7.24: Icons of potential activities in the forest

7.24). Moreover, the forest presents the distinctive local landscape features with indigenous plants. In conclusion, water machine C contributes to both ecological and economic values.

Ecological value   Economic value

7.2.5 Machine 2 – 'Bio-industrial filter'

The water machine 2 is designed to apply in agriculture and bio-industry areas to slow down the infiltration of water and solve the dehydration of nature reserves by using and processing canal water. Sint-Oedenrode has many tree nurseries that are affiliated to "Van Den Berk" – one of the largest nurseries among Europe; the company also has experience of cultivating sustainable products that coincides with the idea of this water machine. So the potential to apply machine 2 is very high in Sint-Oedenrode, and within the project area the locations of tree nurseries are marked in figure 7.25. They are adjacent to the bypass, wherein making use of canal water is easy to be operated.

To further explain how water machine 2 works, the principle process is visualized (figure 7.26). The bypass water is eutrophic, and tree nursery could be a purification system; when the water comes out of this system and goes into other types of nature, it is already filtered. This process not only saves water for arboriculture sector, ensures the water to be filtered before absorbed into the soil; but also prevents the aridification of natural landscape by feeding the aquifers and underground water flows. In this sense, a tree nursery as a 'natural filter' is the water machine (figure 7.27). With diverse plants and ecosystem services, high efficiency of water use and sustainable products, the water machine benefits Sin-Oedenrode by adding ecological value and economic value.

Figure 7.25: Application areas of machine 2

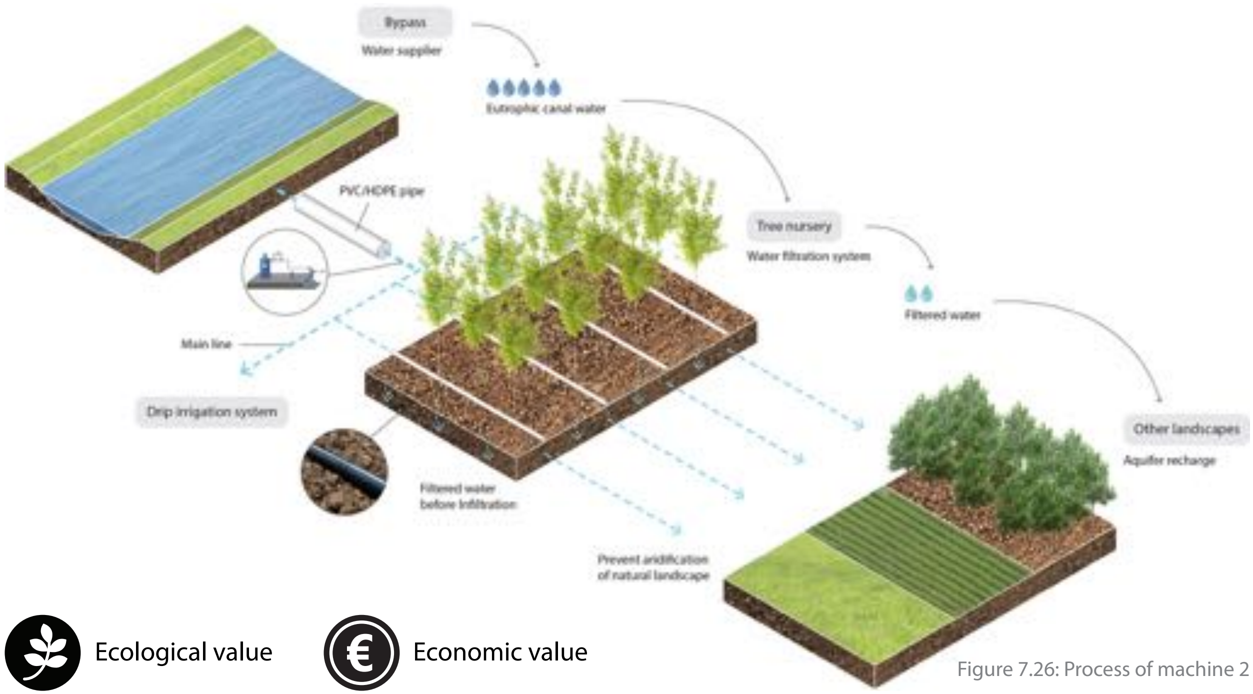

Figure 7.26: Process of machine 2

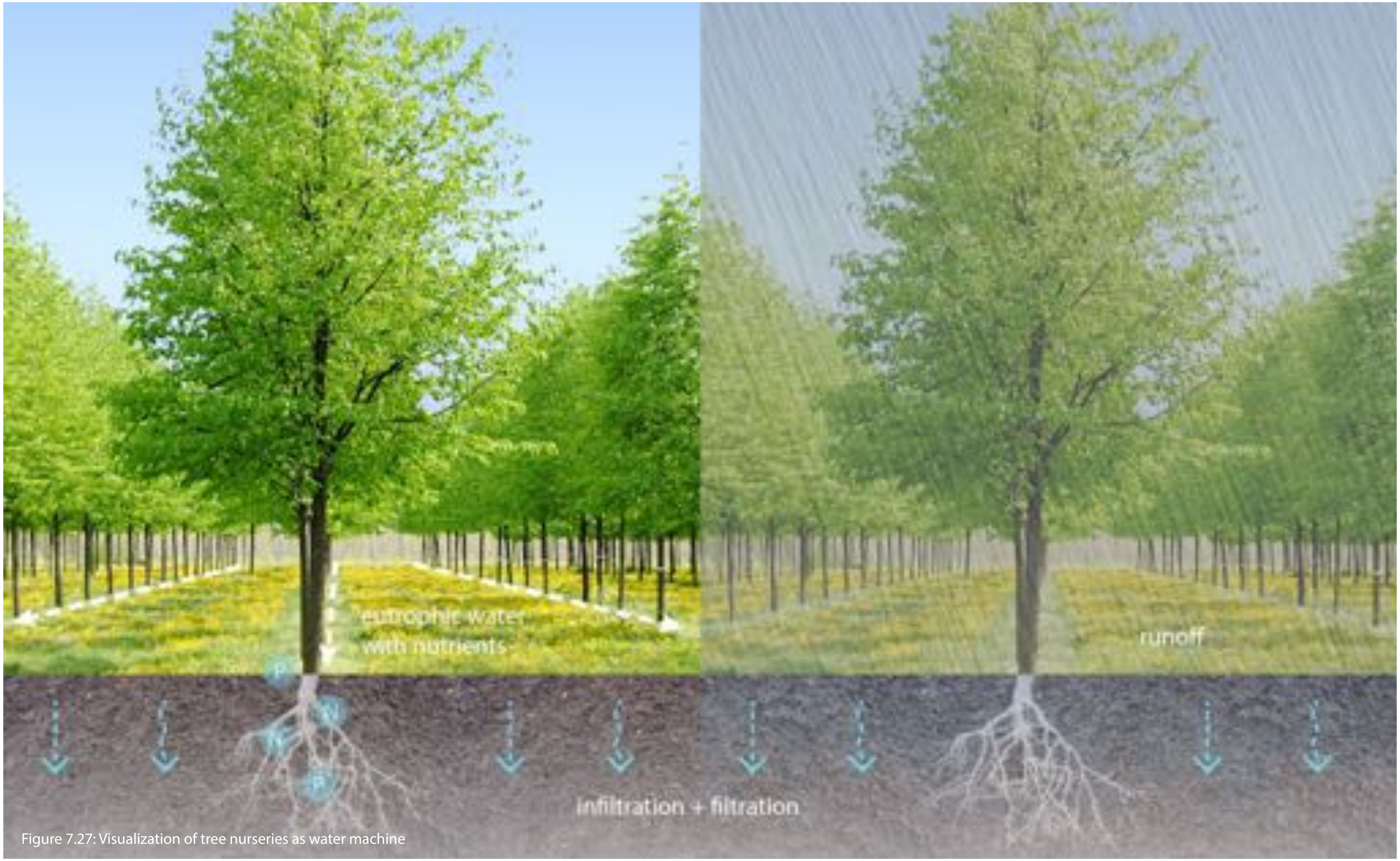

Figure 7.27: Visualization of tree nurseries as water machine

Figure 7.28: A workshop is designed in the tree nursery

Figure 7.29: Visualization of the workshop and outdoor activities

Figure 7.30: Various workshops

The detail design picks one of the tree nurseries, which is located at the south of forest (figure 7.28). A wooden house with a roof terrace is planned in it, where various indoor activities can be carried out on the ground floor and a nice view of tree nursery can be enjoyed from the roof (figure 7.29). This architecture can be the information center that introduces the story of tree nurseries and water machines, and can be used for workshops in regard to arts, woodcrafting and paintings that have close context with tree nursery's culture (figure 7.30). The outdoor activities such as plant observation and identification are also potential to be done. All these activities provide an opportunity for visitors to have an exploration and an in-depth understanding of tree nurseries and water machines, which has both recreational and educational functions.

7.2.6 Machine 3 – 'Natural amusement park'

The concept of water machine 3 is to redirect waterways through recreational area to slow down the drainage as well as creates a high-quality recreational landscape. As introduced in the master plan, three plots of grassland are redefined for recreational use within project area (figure 7.31), which meet the requirements: [1] they are next to the bypass; [2] they are not far away from the urban area (better to be within walking distance); [3] they have enough green space to develop. From this point of view, grassland is a suitable choice as a 'natural amusement park' that has potential to be improved valuable to recreation, tourism and other services. The purpose of applying water machine 3 also corresponds with political urban development ambition.

The detail design selects one spot as representative, which is close to residential area and has the best basic condition. It covers an area of more than 44,000m^2, and has several ditches in the site that are not sufficiently used for any purposes. However, by connecting to the bypass, they can slow down the drainage; and by adding some simple facilities, they can be an excellent place for recreation. The design uses the linear elements to better integrate the shape and position of ditches: wooden benches, small ditches, rows of trees, and stepping tones in water (figure 7.32). On the basis of existing condition, they together create a dynamic and high-quality environment for recreational use (figure 7.33-7.36).

Figure 7.31: Application areas of machine 3

Ecological value

Economic value

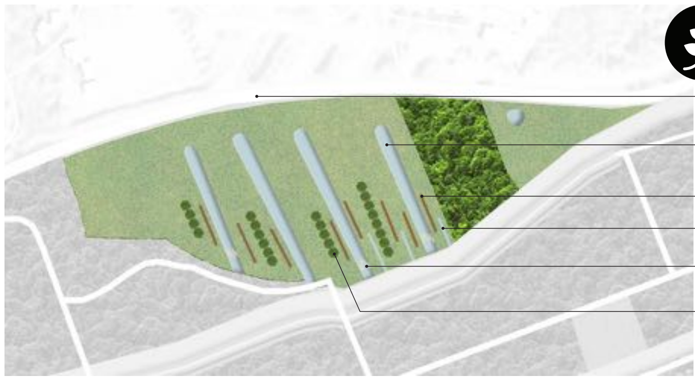

Figure 7.32: The design of recreational area

Figure 7.33: Visulization of various activities in recreational area

Figure 7.34: Visulization of stepping stones and various activities

Figure 7.35: Scene of stepping stones at high water level

Figure 7.36: Visulization of recreational area from the perspective of Zuidelijke Randweg

7.2.7 Machine 4 – 'Collective water purifier'

Water machine 4 is devised to apply in intensive cattle farming and large-scale agriculture fields, through the collaboration of which collective water treatment and collective manure processing can be realized. According to the map of agricultural development, there is a large restricted area for livestock in the rural part of Sint-Oedenrode. Therefore, the concept machine 4 is modified to better fit in the situation of Sint-Oedenrode that it is only implemented in agricultural fields, and focuses on collective water purification (figure 7.37).

The principle process of water machine 4 is illustrated in the diagram (figure 7.38). The water treatment plant is constructed in the southeast to make use of the eutrophic bypass water and part of agricultural waste water, through which the purified water can be used for irrigation in arable land. The statistical result shows that irrigation accounts for an important part of water use in agriculture and horticulture (CBS 2016), this water machine helps to save water and makes agriculture in Sint-Oedenorde sustainable, wherein the cooperation of large-scale farms is a prerequisite for this process.

Figure 7.37: Application areas of machine 4

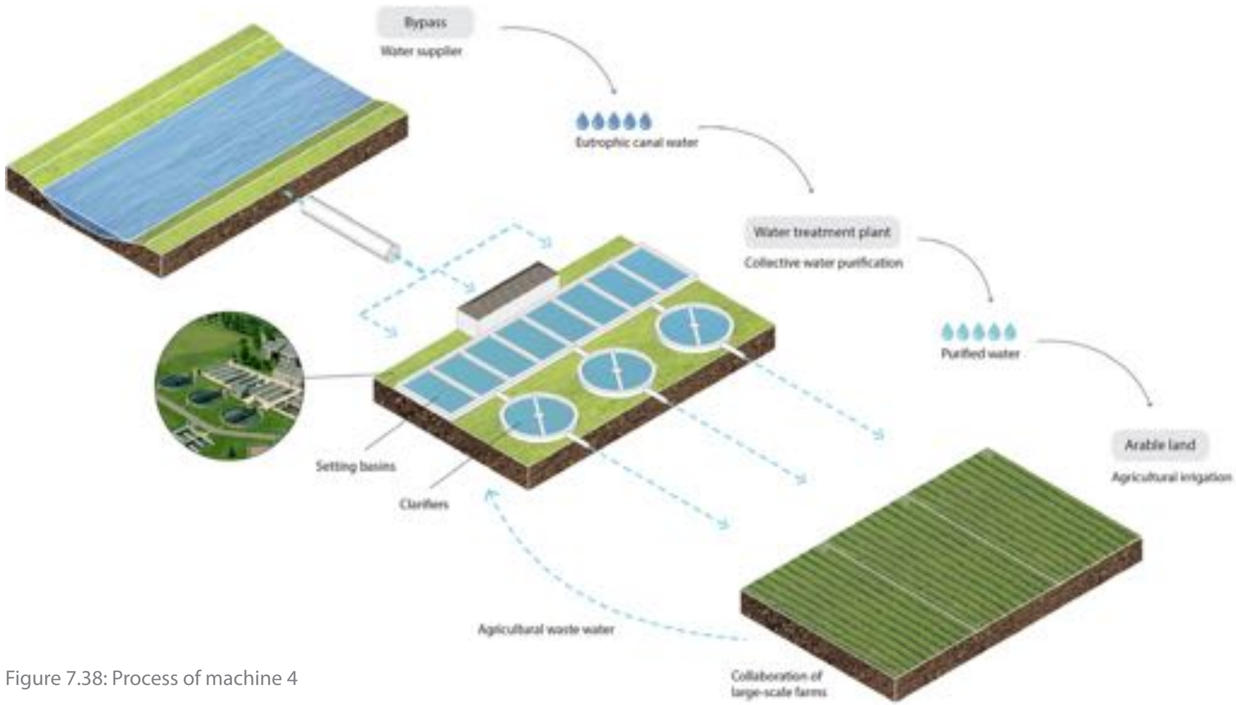

Figure 7.38: Process of machine 4

Figure 7.39: Visulization of farmland and flower field

Agriculture is a very important part of Sint-Oedenrode's landscape that concerns with both economy and cultural heritage. A piece of farmland is designated to plant indigenous flowers such as *"Caltha palustris"*, *"Papaver dubium"*, and *"Centaurea cyanus"* (figure 7.40); together with farms, they contribute to the scenic beauty and rural character that make Sint-Oedenrode such a desirable place to live and visit (figure 7.39). Because of the different types of landscape, many agro-ecosystem goods and services, economizing on water, productive agriculture and potential for tourism, water machine 4 is considerably beneficial to Sint-Oedenrode that brings both ecological and economic values.

Ecological value

Economic value

Caltha palustris *Papaver dubium* *Centaurea cyanus*

Figure 7.40: Indigenous flowers of Sint-Oedenrode

7.2.8 Machine 6 – 'Sewage treatment plant'

The water machine 6 is an existing big infrastructure located in the west of urban area (figure 7.41-7.43). It is a sewage treatment plant called RWZI Sint-Oedenrode since 1958, which has a capacity of 90,000 units and can process about 3,800m^3 sewage per hour now. It is responsible for 75 percent of sewage treatment for the cities of Best, Oirschot and Sint-Oedenrode. The purified sewage flows into the Dommel alongside the plant (Waterschap De Dommel 2010). This machine is purely related to economic value.

Figure 7.41: Location of RWZI Sint-Oedenrode

Economic value

Figure 7.42: RWZI Sint-Oedenrode (siebeswart.nl 2010)

Figure 7.43: RWZI Sint-Oedenrode (dommel.nl 2016)

7.2.9 Visitor center

A visitor center is planned at the southeast of project area near the motorway A50 as the main entrance of this site (figure 7.44). It faces the water treatment plant (machine 4) and is surrounded by a small forest. To make all the new designed constructions as a whole, its architectural form and style are similar to the workshop as well as the 'sluice bridge'. By using the material of wood and glass, the building has a warm appearance and the landscape can penetrate into it (figure 7.46).

The visitor center is 50 meters long and 30 meters wide, comprising three floors and a roof terrace (figure 7.45). As its name suggests, it is used for exhibition, information and offering different kinds of services on the first floor and second floor. For instance, it could organize an exhibition about the history and culture of Sint-Oedenrode; it could also provide visitors with detailed information of this program and the concept of water machines. The third floor is designed as offices for management of water treatment plant and the whole project area. Besides, visitors can have a visual experience over the water treatment plant and the further landscapes from the roof terrace.

Figure 7.44: Location of visitor center

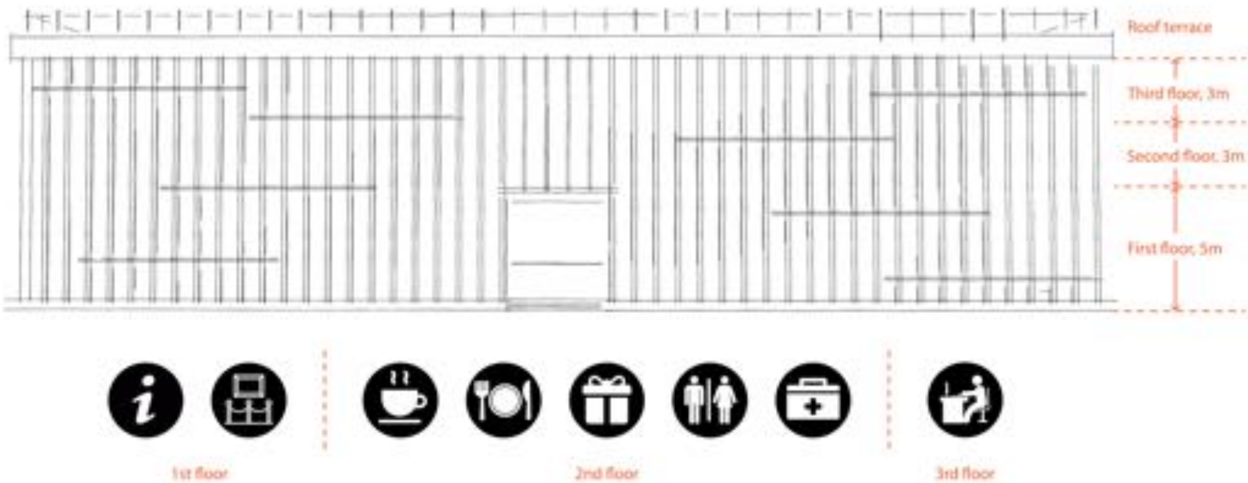

Figure 7.45: Functional zoning of the building

Figure 7.46: Visulization of visitor center

7.2.10 Accessibility

"The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation of specialized design." This is the definition of universal design by an American landscape architect Ronald L. Mace. It is landscape architects' responsibility to embrace the challenge of providing beautifully accessible landscapes and sites.

In this project, different routes are planned throughout the whole area, forming a seamless traffic network, and the accesses to the site are indicated by the arrows (figure 7.47-7.50). The car routes are the currently existing situation that include a motorway (A50), a regional road running east to west, and several local roads that connect sites to the regional way. More bicycle and pedestrian routes are added, making all the water machines and local landscapes accessible for people to visit, to experience, to enjoy in different ways. Furthermore, the bypass is allowed for canoeing with relatively lower flow rates than the Dommel, and many stops are designated along the bypass where people can choose to start, or finish, or exchange to another one.

Relying on these routes, some ambitions for urban development of Sint-Oedenrode can be implemented. For example, agritourism is possible with bicycle and pedestrian routes going through farmland and tree nurseries; the relationship between urban and rural areas becomes intimate that residents have more access to high-quality nature and landscape, as well as history and culture.

Figure 7.47: Car routes

Figure 7.48: Bicycle routes

Figure 7.49: Pedestrian routes

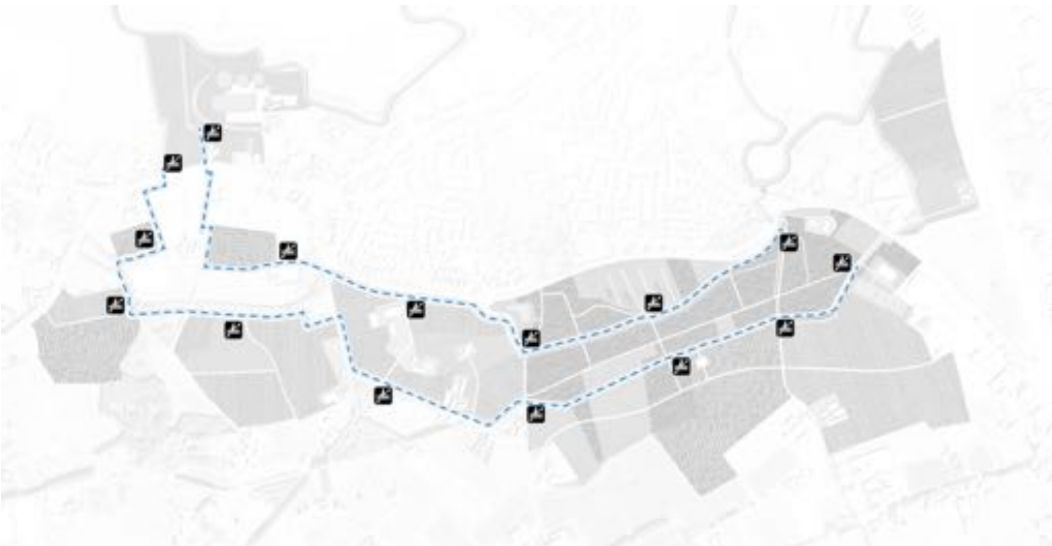

Figure 7.50: Canoe routes and stops

7.3 Design conclusion

On the basis of elaboration and visualizations of design products, the design question (DQ): “How to combine a specific type of ‘water machine’ (LOLA 2015) with the rehabilitation of (parts of) the historical structure (‘wallenstructuur’) and serve the integral urban development in Sint- Oedenrode?” can be concluded and answered as:

The design creates a water machine networking in the south of Sint-Oedenrode, which consists of a primary machine S – bypass and a number of other water machines along it. The bypass plays the leading role in taking precautions against high water problem in the urban area caused by extreme climate scenarios W+ in the future; while various water machines, either new designed or taken from regional models are improved to better fit the context of Sint-Oedenrode to serve the integral urban development ambitions, which involve historic, ecological and economic values.

The water machines are distributed all over the project area according to the current land use, functioning separately for the specific purposes, but have both internal and external coherence. Inherently, the idea of these machines is originated from the real-world problems concerned with water, and they are all facilitated by water; spatially, they are all connected to bypass, and are tied by different routes. As a result, a new network is beginning to take shape: one large intervention by water machine S running through east to west, accompanied by several water machines of different sizes and aims around to stir up catalytic advancement for a future-proof Sint-Oedenrode (figure 7.51). They together form a healthy and resilient water system that in normal times, each attends to their own duties to either surface or underground water; while during occasional high water situation or even extreme climate event, the upper bypass and water machines retain the water, which slow down the flow rate and reduce the pressure for latter part (figure 7.52).

To sum up, an integrated system motivated by the strength of water is introduced to Sint-Oedenrode, including historical structure, nature reserves, bio-industry, recreation, agriculture, water treatment, tourism. Landscape architecture here provides not only appealing scenery and high spatial quality, but also diverse products and services for better landscape experience, as well as cultural and historical recognition, and function as a water centered infrastructural intervention.

Figure 7.51: A water machine netwoking is integrated in Sint-Oedenrode

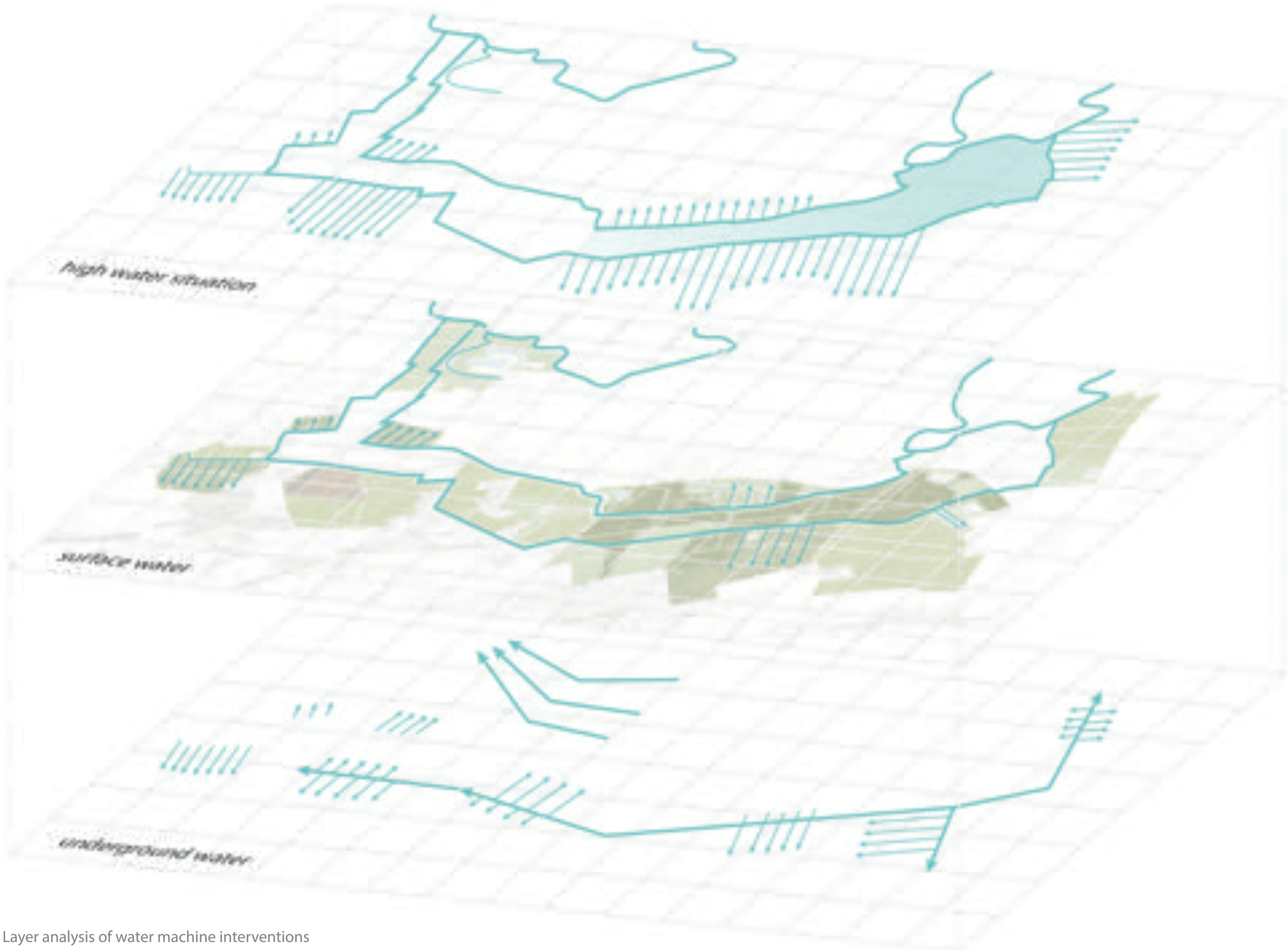

Figure 7.52: Layer analysis of water machine interventions

8

EVALUATION

This chapter aims to examine the thesis by reflecting on the research and design process, discussing the implications and limitations. Also, the recommendations are proposed and the main conclusions are outlined in the end.

8.1 Discussion

8.1.1 Significance

The study originates from a provincial project 'Mosaic Brabant', which creates six development mechanisms called "water machines" as an accumulative development policy instead of a single extensive regional plan. The principles should be concretized, Sint-Oedenrode as an experimental case is one of the representative municipalities in the province of North Brabant, where the spatial pattern of urban landscape is dispersed like a colorful carpet. Opportunities that water can bring exist alongside the challenges from it. The study attempts to utilize these machines as catalyst together with a special historical structure, to develop an integrated water network to prepare Sint-Oedenrode for the uncertain and unpredictable future. On the one hand, it is problem oriented that aims to mitigate the high water problem in the urban area; on the other hand, it probes potentials of water machines to facilitate spatial connection and urban development.

Theoretically, the study explores and compares robust and resilient system towards a T100 situation under climate scenario W+, which broadens outlook on coping with extreme climate events. And a research on landscape approach of integrating 'wallenstructuur' into the design supplement existing literature and the results have proven to be useful tools to initiate an abstract design direction. From a practical point of view, the design products can be an alternative or reference for the in-process parallel study of the water board, municipality and relevant landscape architecture firm. By testing the use of water machines in the context of Sint-Oedenrode, the study also provides inspiring and applicable outcomes for other comparable municipalities within the province of North Brabant.

8.1.2 Reflections on research process

The research part is conducted aiming to giving answers to the formulated questions by carrying out specific methods corresponded with each research question in sequence.

For the first research question, a literature study on robust and resilient system lays a theoretical foundation for the exploration of possible solutions in later stage. By reviewing their definitions and concepts towards flood risk management, combined with the analysis of current water system situation in Sint-Oedenrode, the conclusion is more concentrated on describing different performances of robust system and resilient system, where the result of water analysis is not completely used. This results from: 1) the qualitative research question; 2) the analysis takes the conclusion of water board instead of complicated data processing; 3) some data (e.g. potential bottlenecks) is visualized and used for the design part (e.g. evaluation), not contributes to the answer to the first research question.

For the second research question, the historical structure is explored. During this process, I knew that unfortunately, the discoverer of this structure Harry van Kuijk passed away and left his research halfway. As mentioned, till now little archival materials about this structure were preserved, all the data that presented in this study comes from the interviews and informal text, which are not strictly scientific. Besides, the current outcome is not completed and may be overturned afterwards that also leads to the quality of further development to be imaginative and unsure. However, the qualitative elements that extracted from two reference projects provide me with essential evidence and inspirations for integration of historical elements as practical tool and design language.

For the third research question, a model study offers me with comprehensive insight regarding the water machines by LOLA and basis for new creation of machines specially for Sint-Oedenrode. While the only obtained document of policy for urban development was edited in 2012, five years ago. During this period, many things have changed and the ambitions for upcoming development may have achieved, or may have been removed considering the current situation. Although the conclusion is not up to date, these ambitions as reference can still be part of the purposes of this study that only have a minor impact on the design products, because the principal goals are always beneficial to a future-proof Sint-Oedenrode.

In summary, limitations exist in the research process, but the results still turn out to be theoretical basis, inspiring implications and fundamental idea for design process.

8.1.3 Reflections on design process

The design process consists of two parts: exploration of possible routes for bypass and detail design for master plan and each water machine. This makes the final products more reasonable and reliable by comparing a number of parallel plans through an evaluation involving multiple perspectives.

Alternatives are created from different starting points. To definite their property as either robust or resilient, only the flow capacity of each principle profile is simply calculated. This can result in errors caused by the thickness of bottom, thickness of edge with vegetation, and other factors. Besides, the determination of system's property pays attention to the phenomenon from a landscape architect's point of view, which is not scientifically proved to be effective. In addition, the evaluation of each alternative can never be completely objective, neither can the criteria fully cover all the relevant aspects. This challenges the validity of the assessment that forms the main limitation on the results of this study. However, the design process can not and is not necessary be one-hundred percent scientific objectivity.

The further development of all the water machines tries to find the most proper way to fit them into the context of Sint-Oedenrode. It is impossible to cover the full complexity of Sint-Oedenrode due to the large amount of variables and restrictions in time and resources. The study selects some water machines to have an in-depth design, this not means other machines are not applicable or not fit Sint-Oedenrode. Since the project area is limited in the south of central urban area, and the study emphasizes on dealing with high water problem and promoting urban development, the concepts and applications of water machines could differ from the original principle of water machines by LOLA. What's more, there is a limitation on testing these machines quantitatively, especially some of them are devised to apply in large-scale area and concern with the quantity of water. For example, the water machine 4 'collective water purifier' aims to purify canal water and agricultural waste water for irrigation, wherein the size of water treatment plant is not defined, the cost of piping and how large the farmland area it can serve for remain unknown in this study. Therefore, the real effects of water machines are hardly to be measured.

To sum up, the design process not only provides an alternative to solve the water problem, but also gives a model, an example for the application of water machines as water's opportunity. It still has room for improvement to include more scientific support and experts' suggestions.

8.2 Recommendation

8.2.1 Considering for a long-term vision

The study explores the robust and resilient system towards flood risk management and water situation of Sint-Oedenrode more qualitatively rather than quantitatively due to the limited knowledge of engineering. I would recommend the relevant stakeholders to use the results of this thesis as a reference solution to Sint-Oedenrode to take both robust and resilient alternatives into consideration, and further assess them scientifically from a long-term perspective before decision making.

8.2.2 Discovering more historic value

The study focuses on a particular historical structure located in south and west of Sint-Oedenrode, and finds out several qualitative elements as inspiring methods to integrate it into the current landscape. Sint-Oedenrode is well known for its great historic and archaeological values, I recommend that more historical elements can be discovered and developed to strengthen the identity of Sint-Oedenrode that culture coexist with nature in both urban and rural area. To achieve this ambition, further research can be conducted on excavating more qualitative elements that contribute to integration.

8.2.3 Developing featured water machines

As regional model solutions, the water machines have to be continuously applied in different municipalities within the province of North Brabant. Through the text case of Sint-Oedenrode, it has been proved that the LOLA water machines are applicable in different types of land, but should pay attention to the local situation, demands of people and municipality, size and location of land. Furthermore, I would recommend that every city to create featured water machines to present its unique characteristics of history, culture, nature, customs, etc.

8.3 Conslusion

The purpose of this study is to develop a new water network against high water problem by integrating the water machines and a particular historical structure ('wallenstrucuur') in Sint-Oedenrode, adding potential values to water system that provide more opportunities for urban development. This is achieved by exploring the formulated research questions and utilizing their results to generate design products. In the following, all the conclusions of previous chapters and answers to research and design questions are stated.

RQ1: What are the characteristics of either a robust or resilient water system (climate scenario W+, T100) in Sint-Oedenrode area?"

A robust water system in Sint-Oedenrode means a combination of the current water system and a constructed bypass, which can withstand the possible high water problem from the Dommel in central urban area with a T100 situation under climate scenario W+ without any changes of its function, structure, status and the way of working. A resilient water system also represents a combination of the current water system and a constructed bypass, which is able to be adaptive when the high water problem of T100 condition under climate scenario W+ exceeds the capacity of system without influencing its function, but may lead to the change of its appearance, state, feedbacks and working mode. However, the situation is temporary that it is easy to quickly recover from these changes.

In this sense, either a robust or resilient water system can be the solution to Sint-Oedenrode.

RQ2: How can the local historical structure ('wallenstructuur') be integrated in an improved water network?

The landscape design of integrating the historical structure ('wallenstructuur') with a new planned water network can be realized through five aspects:

- Location. The historical structure is situated in the south and west of Sint-Oedenrode, part of which is not far away from the central urban area. It is possible to be reconstructed on the original site either in large or in small scales on the basis of current land use conditions and properties.
- Structure. The 'wallenstructuur' is no longer available, thus the exact cross-section becomes a mystery. By imagi-nation and imitation of similar engineering constructions like 'landweer', a nearly true but more attractive appear-ance of 'wallenstructuur' can be restored with aesthetically landscape processing.
- Material. The selection of material is based on the specific design of rehabilitated 'wallenstructuur' and its positions, its surroundings, its functions. For example, wood is an appropriate material if the structure aims to present an old-fashioned style in a forest, but concrete is more suitable in the water due to management and maintenance.

- Vegetation. The selection of vegetation can focus on previous plants and unique regional species, revealing local culture and feature. The principle not only fits the historical structure, but also fits other planning within the site. Besides, vegetation as natural material may cooperate with other materials, which calls for a consideration of coordination.
- Function. The original function of the historical structure remains unclear, but several assumptions have been put forwarded. On the one hand, these assumptions provide alternatives to resume first purpose of 'wallenstructure'; on the other hand, they offer inspirations for its spatial and hydrological use for now. Since the functionalism is highlighted in landscape design, it is necessary to develop new functions that cater for the needs in practice.

RQ3: Following the concept of 'water machines' (LOLA 2015), what type of machine would be applicable to fit the integrated landscape development in Sint-Oedenrode?

Sint-Oederode has a large mixed rural area with various types of land, which are potential to be developed. Both water machine 2 and 4 are related to agricultural sector that can make it more effective and profitable as well as promote agritourism. Machine 3 and 5 concern with high-quality living environment by providing more green space and amenities for recreational use and healthy production. Machine 6 itself is a large green infrastructure that is already existing in the west of central urban area – RWZI, a sewage treatment plant. Since the project site doesn't have run-down industrial area, machine 1 is excluded for the study.

In addition, Sint-Oedernode is well known for its historic values, wherein other water machines are required to enhance historical recognition. While the water machines by LOLA are more conceptual rather than practical, further exploration and design should be done to make more detailed and applicable machines in the specific context of Sint-Oedenrode.

DQ: How to combine a specific type of 'water machine' (LOLA 2015) with the rehabilitation of (parts of) the historical structure ('wallenstructuur') and serve the integral urban development in Sint- Oedenrode?

The design creates a water machine networking in the south of Sint-Oedenrode, which consists of a primary machine S – bypass and a number of other water machines along it. The bypass plays the leading role in taking precautions against high water problem in the urban area caused by extreme climate scenarios W+ in the future; while various water machines, either new designed or taken from regional models are improved to better fit the context of Sint-Oedenrode to serve the integral urban development ambitions, which involve historic, ecological and economic values.

The water machines are distributed all over the project area according to the current land use, functioning separately for the specific purposes, but have both internal and external coherence. Inherently, the idea of these machines is originated from the real-world problems concerned with water, and they are all facilitated by water; spatially, they are all connected to bypass, and are tied by different routes. As a result, a new network is beginning to take shape: one large intervention by water machine S running through east to west, accompanied by several water machines of different sizes and aims around to stir up catalytic advancement for a future-proof Sint-Oedenrode. They together form a healthy and resilient water system.

In conclusion, an integrated system motivated by the strength of water is introduced to Sint-Oedenrode, including historical structure, nature reserves, bio-industry, recreation, agriculture, water treatment, tourism. Landscape architecture here provides not only appealing scenery and high spatial quality, but also diverse products and services for better landscape experience, as well as cultural and historical recognition, and function as a water centered infrastructural intervention.

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APPENDIX

During the thesis process, many semi-structured interviews are conducted. Here listed some prepared questions, which not include all the content.

Interview with Cees van der Veeken (Designer of water machines) 14-06-2016:

1. What are the concepts of water machines?
2. In which locations of North Brabant will they be applied? How did you select locations?
3. What are the scales and levels of these water machines?
4. Why they are devised? What are the main purpose?
5. How they can be implemented since the design result is quite general and conceptual?
6. How did you evaluate design product?
7. How did you develop these machines (decide different specific aspects)?
8. Any suggestions of using / modifying / realizing these water machines?

Interview with Jos Cuijpers (Researcher of historical structure) 04-08-2016:

1. Are there any fragments of historical structure still?
2. What are the components / structure of historical structure?
3. What is the history?
4. What is the function?
5. What is the relationship with Dommel?
6. What is the significance?
7. What are the spatial and hydrological vision for the future use? How can it contribute to Sin-Oedenrode?

Interview with Leonie van Beek (Landscape architecture for parallel project) 12-08-2016:

1. Can you describe your project?
2. How did you decide the route of bypass? Do you have any criteria?
3. In your report, you mentioned 'wallenstructuur' but there is no further development, why? Is it possible to reuse it?
4. Do you make use of water machines in your design? How do you apply them?
5. I see some analysis of climate scenarios, how did you make scenario development?
6. How do you evaluate your alternatives (from what aspects)?

Interview with Karin van der Hoeven (Water specialist in Whaterschap De Dommel) (she didn't respond but provided several water board's reports)

1. How robust the water system is now in SInt-Oedenrode?
2. What is the capacity of current water system?
3. What is the historical events of water system in Sint-Oedenrode?
4. Is there any predicted flooding risk in Sint-Oedenrode? What is the policy / strategy / plan to prevent it?
5. Can you offer some information with technical data (precipitation, flow rate, climate scenarios, etc.)?
6. Any suggestions of aspects / keywords that should be explored for the study?

Interview with Roel Dijksma (Water specialist in Wagneningen University) 19-09-2016:

1. Terminology in the water board's report.
2. Any reference project do you recommend?