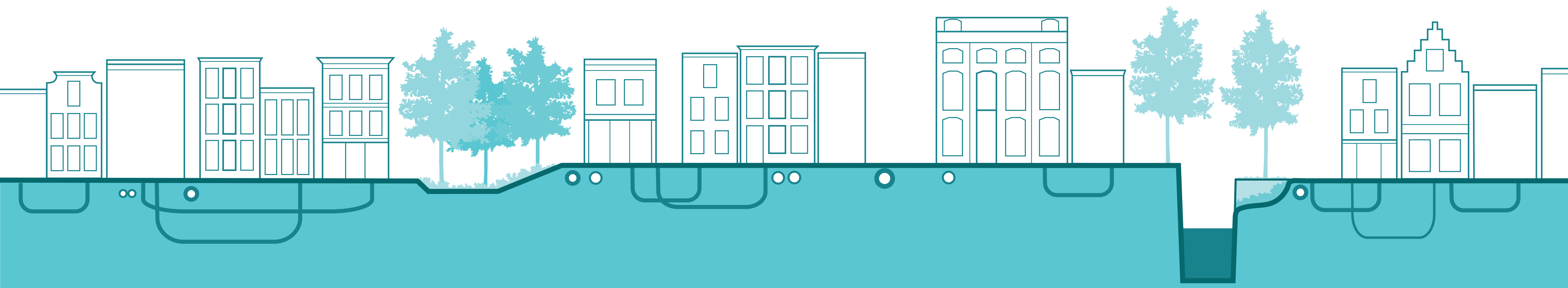
Waterproof Gouda

The creation of new spatial pathways to connect climate sustainability with monumental preservation



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July 2018

Preface

This report covers the graduation project 'Waterproof Gouda: the creation of new spatial pathways to connect climate sustainability with monumental preservation', which is a master's thesis in the Faculty of Architecture, Urbanism and Building Sciences, specifically in the Urbanism track at the TU Delft.

Motivation
I developed an interest in water management and future-oriented, climate sustainable projects during my study at this faculty. Especially, the ability of urbanism to combine adaptive capacity with new public facilities is something I try to apply in my projects.

My first contact with the city and municipality of Gouda was during a very short two-month internship a few years ago with two other students (Chu, van Loenen & Garcia, 2015). During this time, I was struck by the municipality's enthusiasm for this project and their perseverance in trying to solve the seemingly impossible issues present in Gouda. Though this internship originally focused on other subjects, it quickly morphed into a project which attempted to visualize possible integrated designs for Gouda in an attempt to look at the issues from a different perspective.

Though the internship was brief, it motivated me to focus my graduation project on this city and find out how urbanists can help connect issues that are seemingly unrelated on paper in a spatial manner, trying to promote integration and synergies in complex issues.

Acknowledgements
I would like to thank everyone from the TU Delft who has been helping me refine this project into something more doable, my mentors Fransje Hooimeijer, Inge Bobbink, and Frans van de Ven, as well as Arie Romein for helping me refine my thesis layout. I would also like to thank the people at the municipality of Gouda, and specifically Arianne Fijan, for their willingness to help me gather information, organize two workshops and connect me to relevant stakeholders. I am also very grateful from the help I got from Hans Suijs, for letting me use his water model to test my design and Jeroen van Leuken for helping me organize one of the workshops in Gouda.

This thesis was improved through various edits to the text and calculations by Fransje Hooimeijer, Frans van de Ven, Arianne Fijan, Inge van Andel and Diane Butterman.

Lastly, I am thankful for all the other participants of these workshops, my proof-readers for helping me make this thesis better, and everyone who has listened to me talk about this project at length.

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1. Summary

This thesis is the culmination of all the research done during the graduation process at the TU Delft with the goal to develop one (out of many) possible solution for the various climate and subsidence related water issues the city of Gouda has to cope with. This was done as an alternative strategy to the plan the municipality is developing with several other stakeholders at this moment in time.

This is done by researching the optimal balance between spatial improvements and required technical adapations for the problems present within the city. One other major consideration is the effect of climate change. These elements must be integrated while preserving the spatial characteristics and values of the city itself.

In order to create a design that includes all these factors, an exhaustive study was done, which can be split up roughly into I. a study of the problem field, II. a literature analysis of the theories and methodology behind this project. III. an analysis of the various layers of the city and the creation and testing of various research interventions. V. three design strategies, four street profiles and one integrated design.

This project consists of many different analyses, studies and tests done in order to create a comprehensive overview of the interconnecting systems of this historical city centre. Two main perspectives can be found in these analyses. The first evaluates the existing spatial city to discover the values and vulnerabilities from the perspective of a planner and urban designer.

The other analyses, such as the research interventions, were developed to find the perspective of the stakeholders and local inhabitants.

While the city centre functions as a singular system, there are many different spatial characteristics to be found throughout the area.

A risk analysis was set up, in order to maintain this variability and to find the appropriate measures for each street. This framework balances potential probles, social and historical values, and innovative potential.

Three interlocking strategies were developed for the city centre, each of which reacts to different problems present in the area. These pathways focus on large scale changes to the social and physical network of parts of the city. Guidelines for materialisation were developed to maintain cohesion across pathways, but care is taken to make sure the variability of the street profile is maintained.

The strategies each characterise and help develop different parts of the identity of Gouda. This ranges from enhancement of the monumental areas through new connections with the active social centres of the city, to a protective strategy which combines innovative water storage techniques with preservation of the historical character, to an innovative strategy that focuses on one of Gouda’s historic characteristics: a constantly innovating and unique water system.

Within each of these pathways, careful consideration is given to the balance of existing technical solutions in the cith with these new innovations, and how each of these adaptations interacts with the existing spatial and monumental identity of the city.

However, the main strength of these pathways is how they will intersect and combine to create a cohesive strategy while integrating these various identityes. In order to create this cohesion, special attention is given to places where these strategies intersect. Through these new pathways, Gouda will become an innovative, multi-faceted city, throughout which runs a single continuing identity.

2. Introduction

2.1. Introduction topic

The Netherlands has a long tradition and worldwide reputation for hydrological engineering, urban water management and flood control. This mastery of water management and drainage allowed them to build cities in places which were not naturally suited for any type of urban expansion, using dikes, pumps and polders to construct the landscape around the cities according to their own requirements (Hooimeijer, 2014).

Gouda is one such city. The highly advantageous location next to a major trading river allowed this city to expand from a group of agricultural buildings into a flourishing city, which expanded out on land that had already begun to subside quickly (Denslagen, 2001). In order to keep the city above water, a long line of interventions, detailed in Chapter 3, were tried, tested and replaced for progressively more extreme measures when the degenerating situation made the previous one unsuitable. In modern times, this continuing deterioration, with the urban system battling to keep the city sustainable against more extreme weather situations is starting to call for alternative measures. The municipality of Gouda is currently going through a progress to study and come up with logical solutions for this problem.

2.2. Goal

The objective of this study is to research the possibilities for a water sustainable Gouda for the next 50 years (and beyond), using mostly spatial interventions and decentralized storage, while maintaining the historical character of the city. While the municipality and other parties are currently going through a long process, which involves the creation of an advisory plan for adaptations to make Gouda more climate and flood-sustainable, many of these interventions will be technological in nature (A. Fijan, personal communication, 16 may 2018).

This project will take a parallel path, using spatial interventions as the main solutions, in which technical solutions will only be utilized when no other natural or spatial options are possible. This is done to find a balance between technical and spatial interventions to create a future proof water system and provide an alternative vision.

2.3. Problem Field

The existing water system has a long history, characterized by many different types of water management (Chapter 3), all designed to keep the city safe and liveable. This ranges from early farm settlements with standard polder water management, to drainage canals, windmills, sluices, sewers and eventually electrical pumps (Denslagen, 2001).

Nowadays, many of these interventions are still visible in the spatial structure of the city, and some are still in use as part of the water system. The water system is strictly managed, and water is transported through the canals and sewers, and then discharged quickly when the system is under pressure (Tamboer, 2007). While this system works, space for improvement in the existing system is limited.

The water level is kept at a standardized height, but ongoing subsidence, caused by the weight of the city (Willemse, 2017) is slowly bringing the surface closer to this level. While it is an option to mechanically lower the water level in (some parts of the city), and the municipality is studying the feasability of this option (A. Fijan, personal communication, may 17, 2018), it is not considered as a solution in this project. The problem here is that, at the latest estimate, there are approximately 447 houses built on wooden foundations (Willemse, 2017). Lowering the water level will bring these foundations into contact with oxygen, which will lead to bacterial decay (Klaassen, 2015).

At the same time, a clear growth in precipitation levels is being measured (KNMI, 2018). This increasing rain is putting more pressure on the existing system. This leaves the city with a shrinking amount of space for water storage.

The city of Gouda and other stakeholders have already been working to find a solution for these problems. Their focus has been on gathering the information and data, in order to make a responsible decision. Now, the project has moved on to the creation of an advisory plan using the data from this research. (A. Fijan, personal communication, April 12, 2017; May 16, 2018) Several reports from this study will be used, but the main objective of this thesis is to create a new vision using a parallel path, with spatial interventions rather than technical. Hopefully this will inspire new directions of thought that can be integrated with the solution-focused goal of the municipality.

2.4. Thesis structure

This thesis is split into five parts, each with a different focus. Gouda has a complex spatial structure, with a long history that is still highly influential in today's situation, which also happens to be dealing with a water issue that is highly relevant for the rest of the Netherlands and other coastal areas. Because of this, the first part of the thesis defines the scope of the project within the larger context of the physical situation of the city, the problem itself, as well as in the academic discourse. This will include the introduction, problem field and research questions.

The second group of chapters structures the research question of the thesis into the defined project, using the theoretical framework, the relevance and the methodology. The third part contains the research done for this project, including spatial (analysis), social (workshops) and technical (testing the efficacy) data.

The following set of chapters shows the results, which includes the design, conclusions and reflections. The fifth part includes the reflection and literature study. The other addendums, such as the literature study done for the theoretical framework, large schematics and workshop results are gathered in a separate booklet.

I. SCOPE

Introduction
Problem field
Relevance
Research questions

3. Problem field

3.1. Scope

3.1.1. Spatial scope

The broad vulnerabilities and problems of Gouda – low-lying city versus climate change – are not that uncommon in South-Holland. However, a more focused analysis will show that the small details and characteristics of all these areas, cities and neighbourhoods each have their unique mix of additional factors and spatial characteristics, which will influence the problem. Therefore, all of these situations will require their own unique approach and solution, yet these approaches must also be measurable, comparable and realistic, in order to succeed.

Within the city of Gouda, many neighbourhoods are dealing with subsidence related flooding issues (Hoogheemraadschap van Rijnland, 2018). Yet, these issues are almost incomparable, because the spatial characteristics are different. The neighbourhoods surrounding the city centre were all built after 1900, and the type and material of which these foundations consist are well known, and often are the less troublesome concrete and pile foundations instead of the shallow wooden foundations of the city centre (Van Winsen, van Velzen, van Dasselaar & van der Mark, 2015). Though subsidence is a problem, the issue in these areas is the growing gap between the subsiding land and the steady houses. Even though ground levels in the outer neighbourhoods are a lot lower than in the inner city, there is actually more water storage, because in comparison the ground water level is also lower.

The inner city developed over a period of 900 years and during this long span of time, various types of buildings and foundations were used (Van Winsen et al., 2015). Because they were built so long ago, many of these buildings are now monuments, which need to be be protected from (damaging) adaptations. Meanwhile, the distance between the ground water level and the surface, also known as the freeboard, is much shorter, which brings additional problems. Due to this difference in character and problems between the neighbourhoods, the scope of this project is limited to the city centre of Gouda.

3.1.2. Climatological scope

The other main issue that is confronted in this thesis is climate change, which consists of large changes in temperature, wind, precipitation and biodiversity, amongst others (KNMI, 2015). It will cause widespread changes. And yet, exact numbers do not exist. Because flooding and water management are currently the biggest issues present in Gouda, increased precipitation will be the main factor when considering climate change and its related uncertainty in the future.

There are many uncertain elements in Gouda, from the type of foundation to the requirements of the stakeholders. In this thesis, stakeholder aspirations are only used as a way to prioritize the means by which these goals will be fulfilled. The main research question defines the goal of this project: how can a climate sustainable Gouda be created for (at least) the next 50 years, while maintaining the character of the city? By defining a goal, the importance and influence of stakeholder uncertainty is limited, while maintaining the uncertainty about the future (which ties into the goal) and what actions must be taken to bridge the gap between the current and desired situation. These two types of uncertainty form the major barrier that must be overcome throughout the project.

At the same time as this study, there is a large research project going on, which asks the same question this project does: *'What is a robust perspective for a historical inner city with subsidence?'* by the municipality, Rijkswaterstaat, Hoogheemraadschap van Rijnland, Deltares, Province of South-Holland and Wareco (Kennisprogramma KWB, 2017a). This study concerns many of the same issues as this thesis, but while the research done by the municipality will be acknowledged throughout the thesis, and several reports form this municipal study will be used, the municipality will most likely focus on more technological solutions. For this reason, this project chose a parallel path, and will not discuss the results from the Municipality's study.

3.2. Development of the city

The city of Gouda was built on the peat area covering parts of Holland and Utrecht, in which the Hollandsche IJssel is the largest river, connecting to many smaller peat rivers, of which the Gouwe was one. The earth beneath the city consists of a thick layer of peat, covered by clay deposited by these rivers (Van Winsen et al., 2015). The earliest archaeological remains from Gouda dates from around 1100 (RAAP, 2017), with the first evidence of reclamation dating from before 1050 (Denslagen, 2001).
At the time, it was given out to settlers for use as farmland, due to the large amounts of fertile peat soil (Abels, 2005). Eventually a settlement started to grow around the crossing of the large river the IJssel, and the small peat river, the Gouwe. This peat, while good farmland, quickly started to subside. This caused farmes to use the Gouwe as a drainage system (RAAP, 2017).

The reason this settlement could grow into a large city was the presence of the sailing route on the IJssel. In 1244, a canal was dug between the old run of the Gouwe and the Oude Rijn (Figure 3.1). This not only improved the water situation, but also helped Gouda grow into the central city on one of the biggest trade routes in the country (Denslagen, 2001). Gouda was considered as one of the major 'Dutch Harbour Cities' which developed in the 13th and 14th century (Van Winsen et al., 2015)

This inner river route connected Amsterdam to Vlaanderen and other southern countries, which allowed them to trade on the relatively safe rivers, without having to brave the dangers of the North Sea. Around 1250, the harbour was dug (Denslagen, 2001).

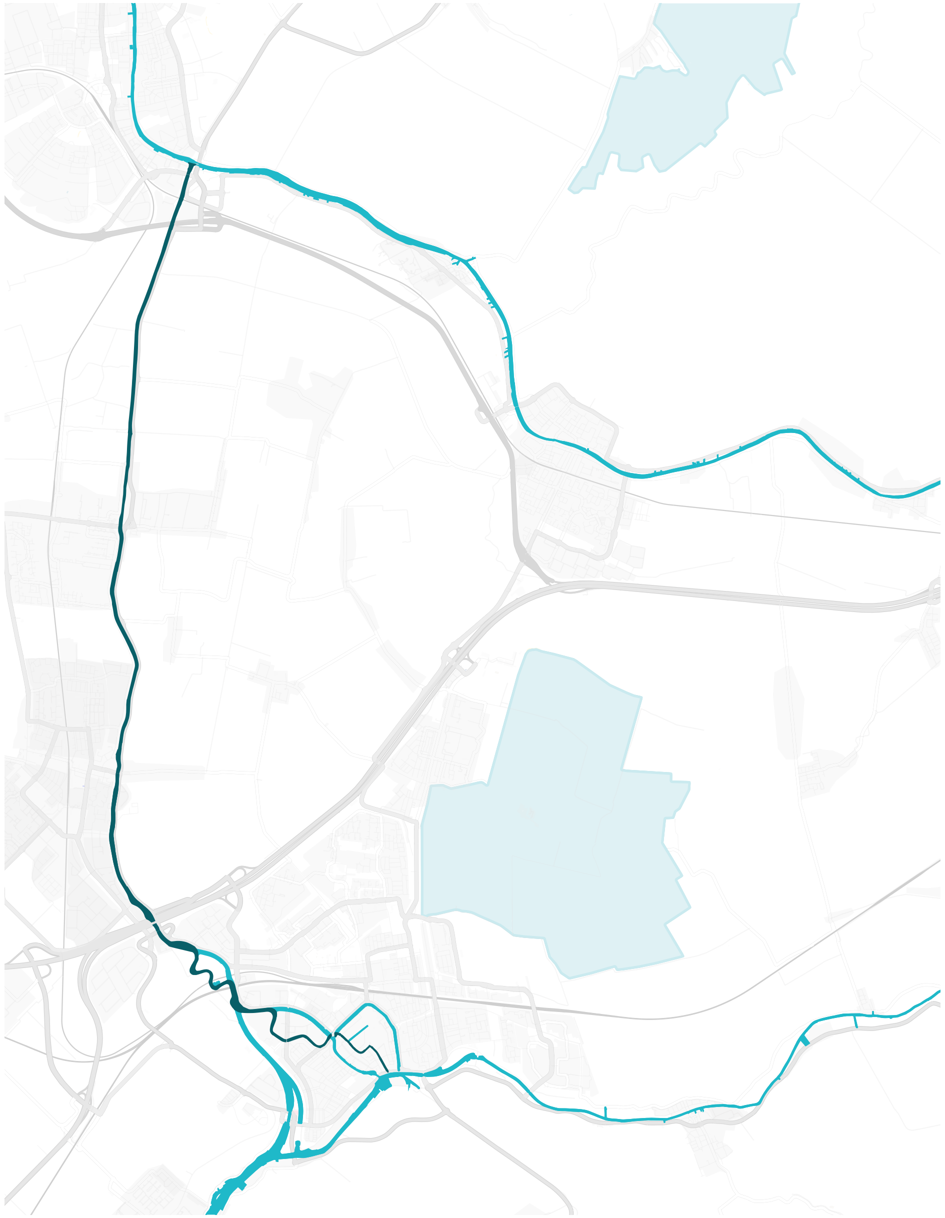


Figure 3.1. Image of the connection between the Hollandsche IJssel and the Oude Rijn (OpenStreetMap, 2018)

From 1300 on, Gouda became a trade city. This favourable situation drew new inhabitants, and by 1400, there were over 900 houses, and between 4500-5000 inhabitants. In another 150 years, the number of houses doubled again, and Gouda had become the 6th biggest city of the Netherlands (Denslagen, 2001). The harbour kept growing, and the city profited heavily from both inner and external trade. With over 10.000 boats working around Gouda, the city made a tidy profit. However, this was not their only means of prosperity.

Gouda had some other methods of profit as well throughout the centuries independent from external trade. One example was the brewing of beer, using the trade routes to reach a large international market, all the way to Brabant and Vlaanderen (Denslagen, 2001). However, the success of this trade was largely dependent on the quality of the soil, and subsidence and competition eventually made this trade unsuccessful. A successor was the sale of the peat that had now become unsuitable for the growing of beer grains. In 1530, the addition of new technology (in the shape of a net-shaped mesh on the end of a long pole), allowed farmers to remove the peat even below waterlevel. The sale of this peat shifted the market centre of the city from the Gouwe to the Turfmarkt. Other trades were the sale of pottery and pipes, as well as several other trades that drew their success from both the availability of the IJssel as a trade route, as well as a source of fresh, clean water.

Even with the occasional heavy setback and shrinkage of the city, from the diminishing of the beer trade, to two catastrophic city fires in 1361 and especially in 1438, during which only a few houses were spared (Denslagen, 2001), to several plague epidemics between 1573 and 1575 (Abels, 2005), Gouda in the 17th century was a successful city with nearly 4000 houses and 20.000 inhabitants (Denslagen, 2001)

Gouda was highly dependent on the availability of trading partners for its financial success, and this international market was not to last. Wars and other international developments in the 18th and 19th century set trade restrictions on import and export, leading to a population exodus. Local trades in Gouda were simply not capable of sustaining a large city population by themselves. Their success and growth was dependant on clients from the trading routes they fortunately happened to be a part of (Denslagen, 2001).

And while the industrial revolution caused swift development in surrounding countries it did not reach Gouda until the second half of the 19th century (Denslagen, 2001), and in the meanwhile the city (and the Netherlands) became poorer. In the middle of the 18th century, the situation was severe enough that many historical buildings and structures were demolished to combat the surplus of houses and spare the upkeep (Abels, 2005). All of this left Gouda without an obvious autonomous source of income; the subsidence and high water level had long started to degrade the quality of the urban land (Denslagen, 2001).

3.3. Development of the water dynamics

The original subsidence problem, over the centuries, interacted with other local problems such as the settling foundations, flooding and pollution to eventually create the modern situation. These problems have had a long time to develop, as from its earliest existence, Gouda was dealing with many water and subsidence related issues. These problems can be divided into three main phases, which can be seen in figure 3.2. This image shows the three main problem factors, as well as their basic influence on each other.

The first phase discusses the early development and growth of Gouda between 1100 and 1500. In the second phase, between 1500-1900, Gouda had shrunk back to a smaller town. Several of the techniques developed in the earlier phase were maintained or improved, but this was not a period of great innovation. The third phase, which continues up to modern times, includes the switch to much more mechanical types of water management, and the development of the sewers, all of which shaped the city Gouda is today.

It turns out that these phases match up almost perfectly to earlier developed state of water phases (Van der Ham, cited by Hooimeijer, 2014). The only exception is the start date for the third phase, which had a delay of a century, possibly due to the economic problems in Gouda in the 19th century.

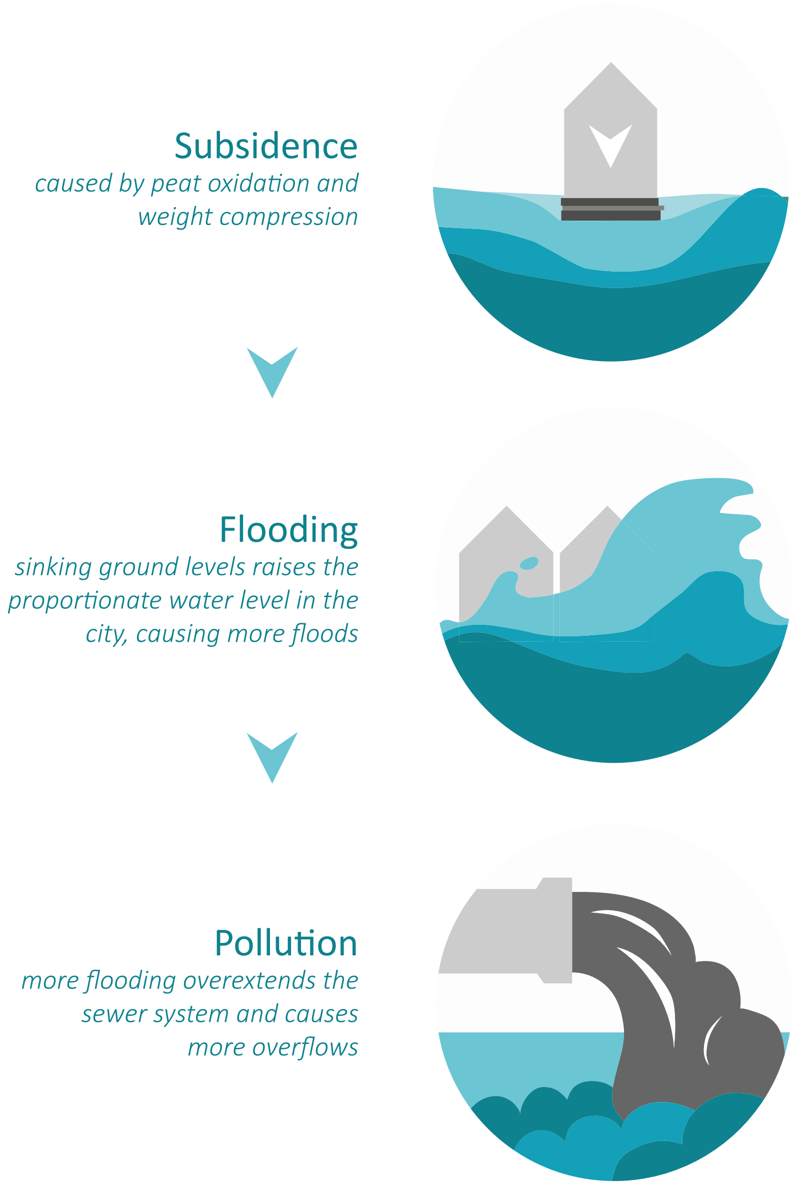


Figure 3.2. Problems and consequences in the city centre

3.3.1. 1100-1500: Phase I: Growth and experimentation

As this chapter described earlier, the land around the town started subsiding very early on. From 1250 settlers drained the water using control locks at low tide. This eventually stopped working, and drainage strategies evolved into digging long canals to lower lying waterways, which worked with relative success until about 1450 (RAAP, 2017) (figure 3.2, time period I).

The harbour in Gouda itself was dug around 1250, and Dark Sluice (Donkere Sluis) is another historical element, as mentions of its existence are found as early as 1301. This was the connection between the harbour and the Gouwe. The development of the rest of the medieval city centre occurred between 1250 and 1350, quickly developing into the shape and size of the modern-day centre (Van Winsen et al., 2015). But the harbour remained the heart of the city. Every single ship that wanted to trade with Amsterdam or Vlaanderen from either side passed by this harbour.

It was the route that connected North and South Holland with each other and with other countries. Eventually it was so popular that other sluices were constructed as back-up. One of these is the Mallegatsluice, which was built around 1400, and in use when the Dark Sluice was filled to capacity (Denslagen, 2001).

This was when the river Gouwe was the main source of trade, but also of fresh water. In this period there were many businesses located within the borders of Gouda that required a lot of fresh water. In order to facilitate this need for clean water, there were three large pipes allowing more water into the city. Two of these spanned from the harbour, to the Molenstraat and to the Spieringstraat. The third directly connected the IJssel and the Peperstraat, in a very advanced system for the time. The large amount of people produced a lot of pollution, which made it necessary to regularly empty the water of the inner-city system into the IJssel using the harbour sluice during low tide (Denslagen, 2001).

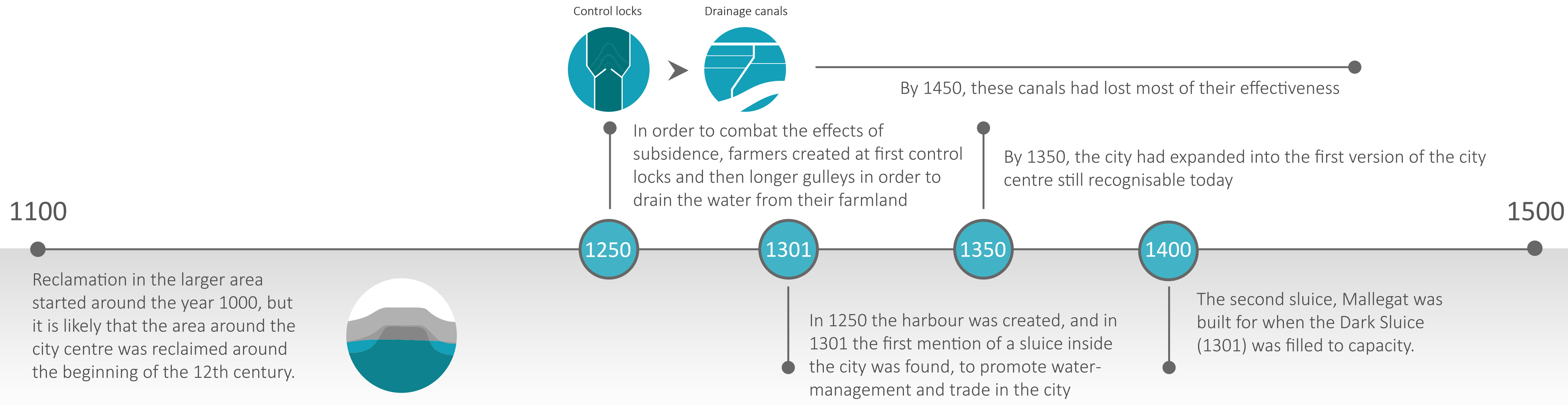


Figure 3.3. Development water phase I (Denslagen, 2001; RAAP, 2017; Willemse, 2017; van Dasselaar, 2013; Abels, 2005)

3.3.2. 1500-1900: Phase II – Maintenance

Around 1500 the era of breweries was over, and the citizens switched to peat farming. The subsidence and high groundwater level of the land made conventional farming too difficult, making peat farming a good alternative (Denslagen, 2001). It was during this phase that they switched to windmill powered pumps (RAAP, 2017) to help lower the water level. Much later, these windmills themselves would be replaced by mechanically powered pumps.

Meanwhile, the subsidence in the city itself also continued, though here the cause was not the oxygenation of peat, but instead the weight of the city which compressed the peat layer (Willemse, 2017). There had been several city fires, after which the rubble was used to even out the ground in some areas of the city (Van Dasselaar, 2013). This raised those areas for a period, but the heavier weight probably influenced the speed of the subsidence.

Water from the IJssel was not only a source of trade, but also the source of most of the drinking water in the city, as well as the place people dumped their waste. It was forbidden to leave garbage on the street, and other disposal methods were not always available. Clean water from the tidal river refreshed the water in the city and took away refuse. Eventually, after more years of subsidence the city had sunk so much that during high tide, sludgy water from the IJssel started flowing into Gouda (Denslagen, 2001).

But there were other things happening too. While Gouda was attempting to deal with their water management, the Netherlands went to war. During this period of time, the Eighty Years' War was fought. In 1576 the order was given by William of Orange, to reserve the use of the Mallegatsluice and the Turfsingel for warships only. Smaller ships could pass by but only with written permission. This allowed the Gouwe to remain the centre of the trade, though the river was more difficult to navigate than the canal (Abels, 2005).

Figure 3.4. Development water phase II (Denslagen, 2001; RAAP, 2017; Willemse, 2017; van Dasselaar, 2013; Abels, 2005)

Around 1615 the Harbour sluice was built to keep the sludgy river water out. At that time, the low tide was still low enough that filthy water could discharge into the IJssel. The water management went on this way until the early 1770s. Then the citizens of Gouda decided to turn the waterflow around, and instead use the high level of the IJssel to flush this water through the entire inner-city system (Denslagen, 2001)

To facilitate this, they built a unique sluice in 1778 (Denslagen, 2001). This was a so-called cross sluice, for the shape of the doors (Figure 3.3). They developed a system called 'schuren', or scrubbing. During high tide they would close the second sluice, and allow water through the first, trapping a much higher level in that part of the river.

The unique configuration of the doors, and the way they opened, as can be seen in figure 3.3, allowed the water to rush out quickly and scrub all the accumulated refuse from the canals. Even in this early period, this would cause flooding through all the lower areas of the city. Town criers would walk through the streets to announce the scrubbing, to give citizens time to prepare and block their entryway with sandbags (Denslagen, 2001).

The large height difference in water levels that forced Gouda to re-organize their water system in 1778 also made it difficult for trade pass through the harbour. Fortunately, the Mallegatsluice was replaced with a bigger sluice in 1763, and then opened to all in 1795 (Denslagen, 2001).

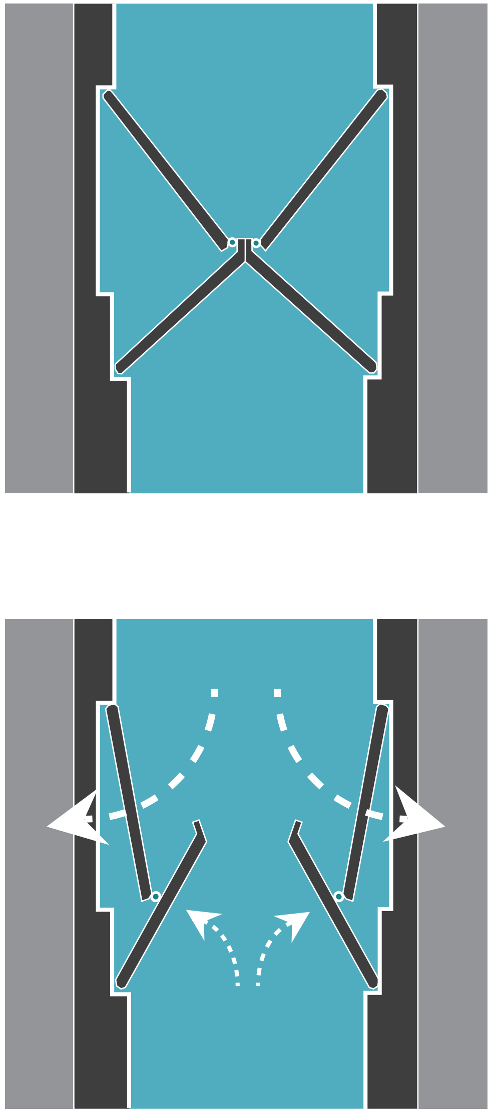


Figure 3.5. Dark Sluice schematic (Denslagen, 2001)

3.3.3.1900-current day: Phase III - Technical solutions

The Mallegatsluice remained one of the busiest water locks of the Netherlands until 1936. This was the year in which the new canal, the Gouwekanaal was completed, with the Julianasluice controlling it. It was wider and deeper, allowing for much larger ships, than the Mallegatsluice, and was a lot faster. From this moment on, Gouda lost its place as a centre for trade, and turned into more of a sail-by city. Still, the Mallegatsluice was renovated in 1939. By this point in time, the city had stopped using windmills, and had moved on to pumps powered by electricity, the first one of which was built in 1960, next to the Mallegatsluice (Abels, 2005).

This pump was placed partially due to the horrible smell of the canals on warm summer days (Abels, 2005), which the scrubbing of the inner city did not succeed in removing. This strategy was halted in the same year as the pump was built (1960) due to flooding. Fortunately, by that time most people had long stopped discarding their refuse into the surface water.

After a cholera outbreak and a report showing the dire quality problems of the water in the late 19th century, the city had started to build sewers (Denslagen, 2001). The surface water system still needed regular cleaning, and it was not until the mid-2000s that all houses were connected to the sewer system (Tamboer, 2007).

It became obvious very quickly one pump was not sufficient to either clean the water system or to stop the area from flooding during high water levels. The discharge of water from the canals onto the IJssel also caused a lot of pollution to the river itself. In 1970, two emergency pumps were added. In 1976 it was decided to build a waste water treatment facility just outside the city, and to simply treat all the polluted water there. Two other pumps, Mallegat and Hanepraai (placed in 1986) move other excess water out of the area during an emergency (Denslagen, 2001).

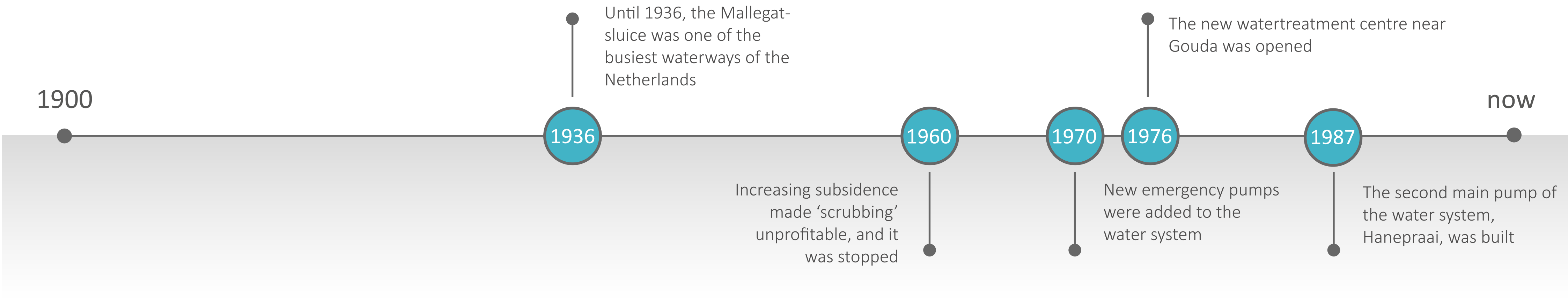


Figure 3.6. Development water phase III (Denslagen, 2001; RAAP, 2017; Willemse, 2017; van Dasselaar, 2013; Abels, 2005)

3.4. Water system 2000-2010s

3.4.1. Status

All these developments have led to the water system that existed at the beginning of the 21st century. This system can be split up into two types of surface water: the outer ring, the *singels*, which are wider and deeper, and the inner canals, which are a lot smaller and shallower.

Increasing modernisation led to a very constant and cohesive water level throughout the inner city, which is maintained at-0.70 m NAP. This is a different water level from the rest of the Gouwe, which forms part of the separate water system surrounding the city, and strives for a level of-0.60 m NAP (Tamboer, 2007). This system is allowed to have more variability (Hoogheemraadschap van Rijnland, 2009), while this waas not allowed in the inner-city system, due to its issues with flooding in lower areas of the town if the water level rises (Tamboer, 2007) and oxygen exposure to wooden foundations if the water levels go down (Willemse, 2017; Klaassen, 2015)

This meant no natural and open connections were possible, and interaction between the water subsystems had to be controlled. This is especially important as the connection with the boezem is not unique. The city centre was connected to five other polder systems and neighbourhoods: Reeuwijk, Spruit, Korte Akkeren, Kadebuurt, Kort Haarlem and Willens. These systems all have water levels that fluctuate between-1.90 and-2.30 m NAP, further complicating water interaction between subsystems of the whole city (Tamboer, 2007; Hoogheemraadschap van Rijnland, 2009).

Interaction between these systems was necessary, as the main outlets for the city's water system are located within the inner city: Hanepraai and Mallegat, which pump water out of the system into the Hollandsche IJssel (Tamboer, 2007). This water exchange was at times an advantage, helping to balance out the water levels in the inner city. On the other hand, water shortages or surpluses from other neighbourhoods had to travel through the inner-city system.

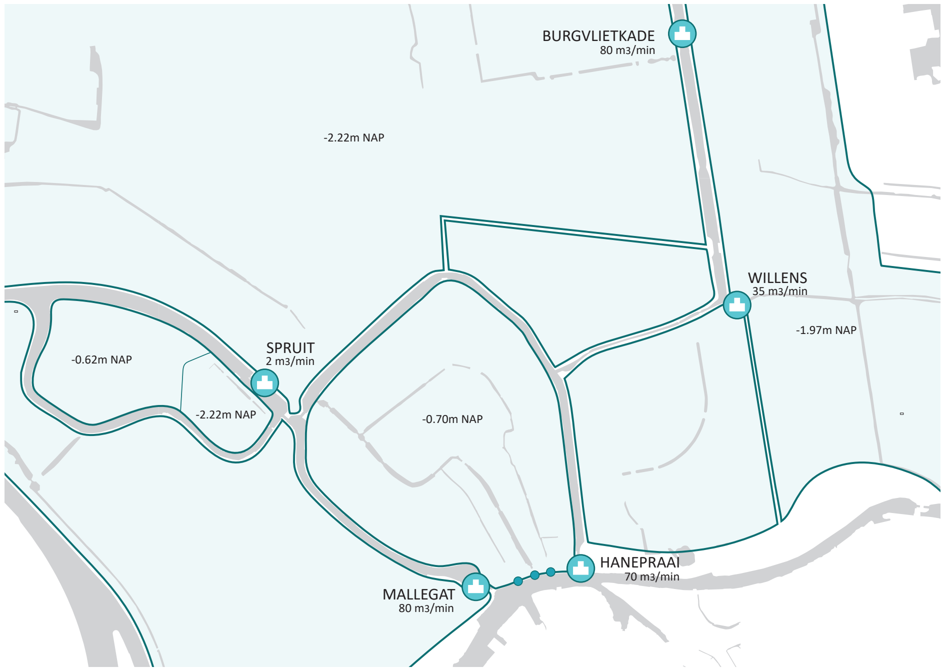


Figure 3.7. Watersystem in the beginning of 21st century (Tamboer, 2007)

3.4.2. Extreme weather: Flooding and Drought

During dry periods, water was be led in through the Kock van Leeuwensluis in order to maintain the water level. This wasn't limited to just the water needed for the inner city, but instead involved large amounts of water, as the water level of the Reeuwijkse Plassen, a large body of water just northeast of Gouda was maintained with this same system (Hoogheemraadschap van Rijnland, 2009).

Other inlets, such as the Hollandsche IJssel, the Oostvolmolenduiker and the Westvolmolenduiker, are also inlets, but their use seems to have been primarily to improve the water quality of the city system. During a single year, the total volume of water let in (over the course of on average 30 events) through these three inlets is slightly more than the total volume of surface water in the entire inner-city system (Tamboer, 2007).

These methods also worked the other way around. During periods of high precipitation, areas without enough water capacity discharge the excess through the inner-city system. In 2007, three of the surrounding neighbourhoods, Spruit, Willens (east) and Reeuwijk managed their water levels by discharging water through the inner city. When the water level reaches -0.68m, the first pump starts. At -0.67, the second pump goes online. In emergencies other, more extreme ways of discharging the water were possible (Tamboer, 2007).

Through the entire 21st century, changes and improvements have been made to decrease the vulnerabilities of this system through added pumps, new connections and limits on the amount of water that was allowed to flow through this system (Gemeente Gouda, 2012).

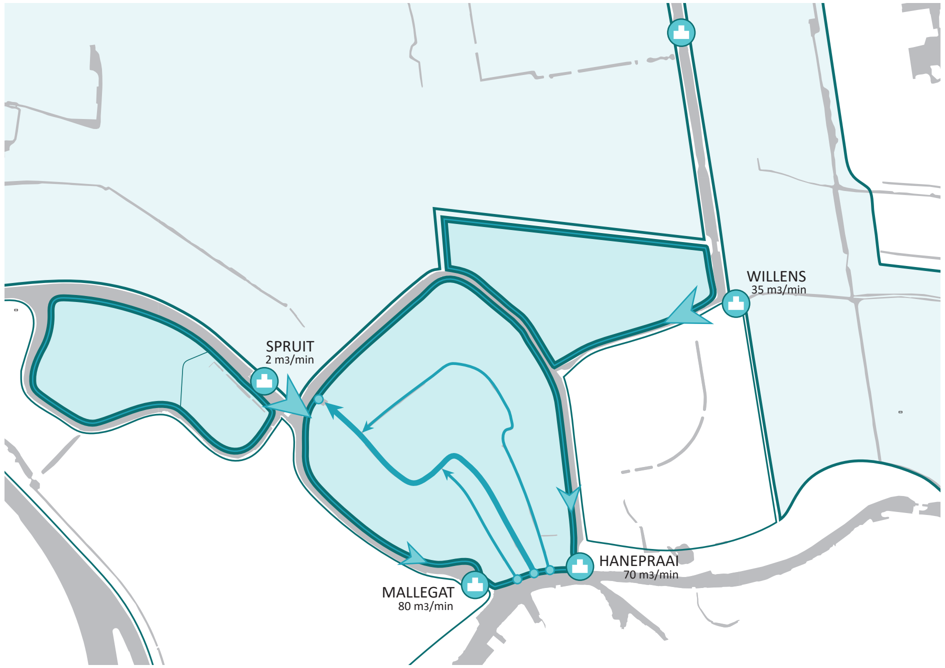


Figure 3.8. Watersystem: flooding in the beginning of the 21st century (Tamboer, 2007; Hoogheemraadschap van Rijnland, 2007)

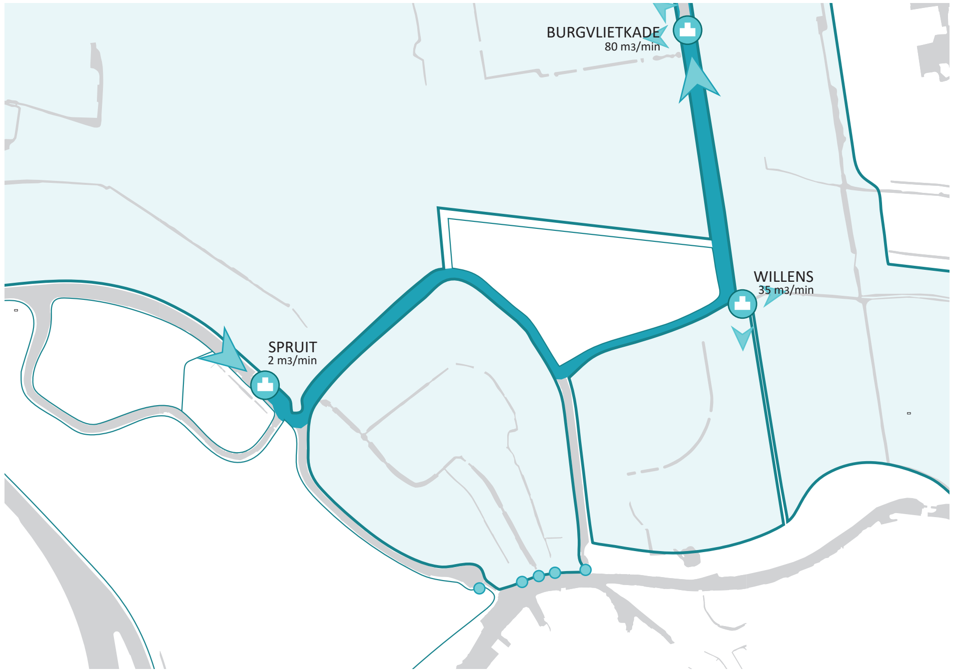


Figure 3.9. Watersystem: drought in the beginning of the 21st century (Tamboer, 2007; Hoogheemraadschap van Rijnland, 2007)

Interestingly, the burden these connected regions used to place on the water system was minimal. The capacity of the two pumps (Hanepraai and Mallegat) is so great that the capacity that remains for the city centre was still thrice the minimum level set by the relevant authorities in order to maintain water security in urban areas (Tamboer, 2007)

And yet, there are still complaints of water issues in the city centre. This suggests that the problem might be in the management and discharge of precipitation from the streets to the singels. The lack of waterflow within the inner-city system is a known problem, and potential improvements were researched in the waterplan (Gemeente Gouda, 2012).

3.4.3. Water quality

The slow speed of the waterflow becomes especially obvious when discussing the water quality of the system. Water moves around the city in extreme situations, however, the studies of the inner-city system show that this is not an even process. With the high capacity of the two pumps (Hanepraai and Mallegat, the waterways that surround the centre (the singels) were cleared out once a week (Tamboer, 2007).

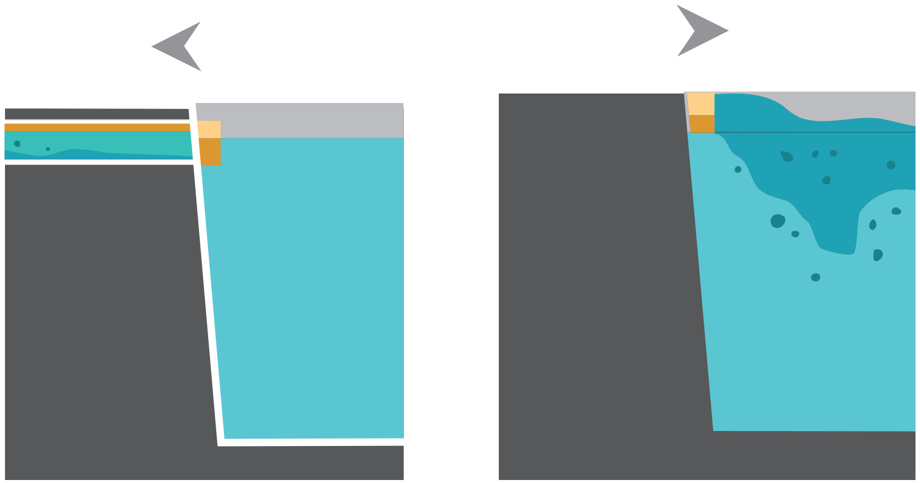


 Figure 3.10. Intermixing and overflow sewers (Tamboer, 2007)

This is a contrast to the canals that are threaded throughout the centre. The water here is shallower, and the total area of water is smaller, yet measurements show it took about a month for the water in this system to refresh itself completely. This is an important element in the discussion of water issues in the city centre, as there are occurrences of intermixing of the sewer and surface water.

Unfortunately, this situation not easily fixable, as again, subsidence plays a role here. Due to the low location and high water levels (figure 3.5), all the overflows of the sewer system, which are placed there for emergencies, are constantly submerged. This means sewer water is flowing into the surface water, up to 50.000 m^3 per year, but it also means that clean surface water is flowing into the sewers and getting polluted (figure 3.6 and 3.7). The total amounted for up to 450.000-500.000 m^3 per year (Tamboer, 2007).

This results in intermixing of clean surface water and sewer water during periods outside of heavy precipitation. To minimize this, the waterlevel in the sewers is kept slightly lower than the groundwater level (A. Fijan, personal communication, june 26, 2018).

Figure 3.11. Subsidence-damaged sewers (based on image shown during interview with A. Fijan, personal communication, may 2015)

The sewers were built on end bearing pile foundations, while many of the old houses were not and subside along with the surface. With something as inflexible as sewer pipes, this naturally means many of the connections have broken (image 3.4, based on images shown during interview with A. Fijan, personal communication, May 2015). This has caused a lot of damage to the sewers, which allows for intermixing of the ground and sewer water.

However, Gouda has turned these leaks into an integrated and important component of their water management strategy. These sewers are used as extra storage space. This unique sewer system is normally partially filled with water (lowering the capacity of the sewer system), but by draining them, new storage is created within the soil for precipitation (Tamboer, 2007; A.Fijan, personal communication, May 2015). Replacing the sewer with a non-leaking system will mean a decrease of the water storage in the city.

Both the management and the consequences of this high and stable water level cost a lot of time and money, and the high water levels result in a lot of polluted water that must be send out for treatment. At first glance, the easiest solution in response to subsidence and more precipitation would be to lower the water levels further down.

Unfortunately, there are several factors at play in Gouda which add complications to this solution. Analysis of the area has shown that in the period between 1903 and 1944, 447 buildings were constructed with wooden foundations, a large percentage of which are houses. (Willemse, 2017).

These old foundations must remain submerged at all times in order to remain sound. Lower water levels will allow oxygen to reach the poles, and unfortunately, damp, oxygenated environments are the perfect location for wood degrading fungi (Klaassen, 2015). Any solution that involves a change of the water level must include a solution for these foundations.

3.5. Conclusions

The water system has since adapted to be less vulnerable to extreme weather events by the addition of new waterways and pumps. However, this research shows that a large cause behind many of the current issues in the water system is the disconnect between the spatial inner-city canals, and the technical water management system that surrounds it (the singels and pumps).
While added capacity is an easy solution for more extreme precipitation events, its positive effect would be limited by the interaction between these two subsystems in the inner city. A possible method of improving this would be by storing surface water locally (and separately from the groundwater) and providing safe paths for water discharge, until it reaches the pumps. The new discharge paths in the design would limit danger to the inner city. This also catches and stores the precipitation before it enters the sewers, which lowers the pressure that is put on this system.

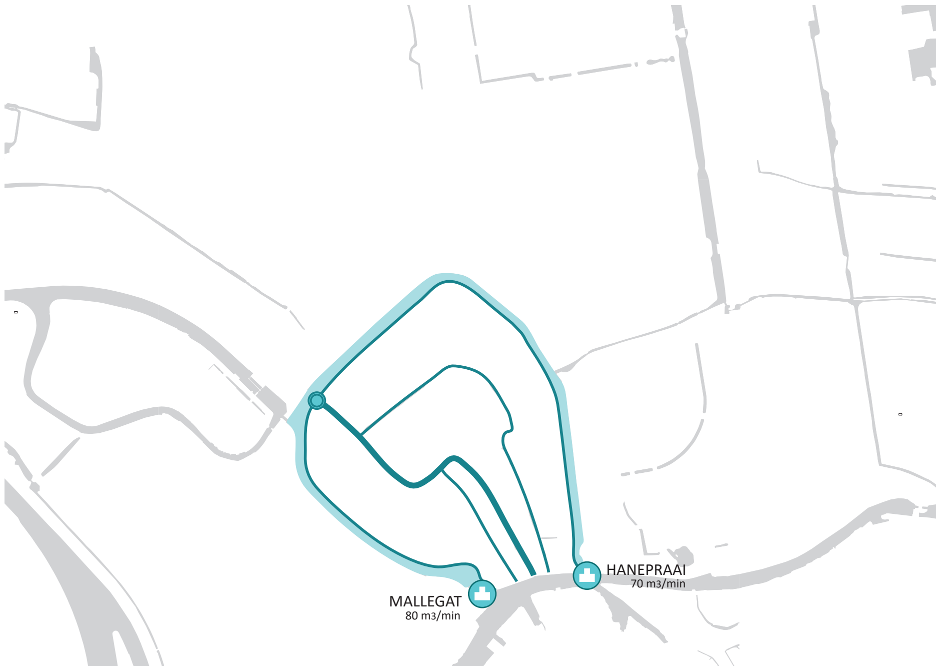


Figure 3.12. Canal connections in the inner city (Tamboer, 2007; Gemeente Gouda, 2012)

4. Research Questions

4.1. Introduction

Within the current situation, if no new actions are undertaken, the continuing subsidence and climate change problems will very likely result in a series of consecutively more extreme problems within the city centre, which will cause irreversible damage to the monumental buildings, as well as the character of the city.

Fortunately, the municipality is very aware, and is researching the technical possibilities for adaptation within the city. However, many of the considered solutions are technical in nature, without inherent spatial aspects. While it is very likely that the issues in Gouda can be solved in this manner, the result will be a maintained and mostly unchanged city centre.

Looked at through one lens, this can sound very advantageous, as it protects the historical and monumental nature of the city. From another perspective, strict maintenance of the *historical* image of the city causes Gouda to lose some of its *historic* character.

While these terms sound similar, linguistically they are distinct, and thus they are used very differently throughout this thesis. While a '*historical*' city concerns itself with its past, a '*historic*' city defines a place where significant, renowned and often groundbreaking events happened.

The historic character marks itself not by the age of its buildings, but by a centuries-long constant trend of innovative water management in reaction to changing circumstances.

Gouda was a city that constantly innovated and adapted, improving its water management system over the centuries. This should not be left outwhen considering those aspects of the city that must be protected at all costs.

Centuries later, a lot of care should be taken with changes to the spatial layout of the city, as it has gained both monumental and historical value, but the innovative spirit of Gouda should also be maintained.

Thus, this thesis attempts to find the fine balance between on one hand, innovatie spatial changes that improve the city and guard against climate change, and on the other hand the protection of the monumental city centre.

What balance of spatial interventions and technical solutions is needed to retain Gouda's historic character while enhancing the city's ability to withstand climate change-enhanced disasters?

4.3. Sub-research questions

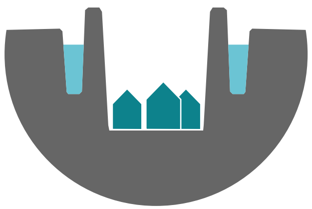
4.3.1. Sub-research question 1: History and disaster development

How is the water system connected to the historical development to the city, and does this (monumental) connection help or hinder the potential for adaptation?

4.3.1.1. Operational questions

In order to gather the data to answer the sub-research question, several operational questions were developed:

- what role did the water system have in the development of Gouda?
- how did the sewer system develop?
- what sort of (social/physical) space does the water system take in the city centre?
- what historical (water) elements are present in the current day?
- how has the city shaped itself around these elements?
- what areas of the water system and city cannot or should not be changed?



4.3.2. Sub-research question 2: The Water system and vulnerability to disasters

In what ways do the current water management and the urban system increase the vulnerability to climate change related disaster?

4.3.2.1. *Operational questions*

In order to gather the data to answer the sub-research question, several operational questions were developed:

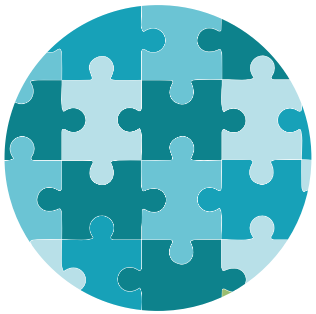
- what are the key structures of the water system?
- how does water flow through all of the various water systems?
- what is the influence of rainwater on all the water flows?
- what areas are at risk for pluvial/fluvial flooding?
- where is damage most likely?
- which areas are most vulnerable?
- how has the subsidence added to the vulnerability?
- what areas are at risk for pollution?
- what effective storage solutions are currently in the city?

4.3.3. Sub-research question 3: Uncertainty

What project and design strategies are available to deal with the uncertainty that is present due to the combination of drainage, subsidence and climate change?

4.3.3.1. *Operational questions*
In order to gather the data to answer the sub-research question, several operational questions were developed:

- what is uncertainty?
- what types of uncertainty of uncertainty exist?
- what types of uncertainty are relevant to this project?
- what sort of supporting method should be used here to engage with uncertainty?
- how effective are these strategies, and what types of uncertainty do they cover?
- what method is used to integrate the various types of uncertainty in this project?
- what certainty/uncertainty is there about subsidence?
- what certainty/uncertainty is there about climate change?
- what climate scenario can be expected?
- what are the wishes of the various stakeholders?



II. STRUCTURE

Theoretical framework
Methodology
Relevance

5. Theoretical framework

5.1. Introduction

This chapter defines several of the important terms that shape this project and its goals. These definitions are placed in the context of the larger academic discussion of this subject, and explores what methods are being constructed to solve the problems attached to these definitions. Many of the solutions to an issue that is threatening a city will actively damage another important factor of the city. For example, the easiest solution to the reduction of the water storage (which is lowering the ground water level) would be expensive and could result in damage to the foundations, which would lead to construction problems and would be detrimental to the historic character. On the other hand, the potential floods caused by inaction will also do harm

The monumental status of the city makes it preferable to do as little as possible, but due to the many uncertainties concerning climate change and other future factors, no one really knows to what extend the city should be adapted, or how. Technological solutions are an option, but they are also expensive (in creation and upkeep), non-adaptable, and do not bring any other advantages to the city. This does not fit well with the goal of long-term sustainability in an uncertain climate, and solutions like this are only used as a last resort.

In order to attempt to detangle all these factors, it is important to first understand the issues. This chapter argues why some of methods are better suited to the project in Gouda than others, and what position this research takes within the larger academic discussion. In order to do this, the following chapter will define what types of climate change will be considered in this project, what uncertainties are attached to this, as well as what types of uncertainty is present in the city. It is discussed why uncertainty is so difficult to deal with, but also why uncertainty-insensitive strategies are not an option in this case. The methodology is explained, and how it integrates uncertainty and flexibility in a structured approach. The last factor of some importance is the monumental value of the city. The last paragraph describes its effects on this project.

5.2 Climate change

Climate change has slowly risen in importance in the field of urbanism to become a key development issue (Chu, Anguelovski & Roberts, 2017). Dessai, Lu & Risbey (2005) define it further as natural and human induced fluctuations of the climate. These fluctuations have driven several naysayers to argue that the weather fluctuates naturally all the time. However, while weather and climate might seem interchangeable, and deal with the same factors, NASA (2017) specifically defines climate as atmospheric and weather behaviour over long periods of time. In order to work with such long-term prospects, KNMI (2015) has made several scenarios, predictions of future rainfall, temperature, and other climatic factors based on current knowledge.

The majority of the effects of climate change that will be considered in this study concern increased precipitation and flooding. Statistics show that the likelihood of more extreme precipitation events is increasing (KNMI, 2018). The likelihood of a 4 degree increase in temperature because of global warming is becoming more likely (Stafford Smith et al., 2011). Higher temperatures allow more moisture in the atmosphere, and a definite correlation between moisture and precipitation intensity has been found. This higher intensity increases the change of extreme precipitation events (From 20 mm every 5 years to this same amount every 2.5 years) (KNMI, 2018).

5.3. Uncertainty

Uncertainty, in its most general sense, is present in every planning project. Abbott (2005) defines it as 'any element that is either unknown or cannot be known'. Since humans are not omniscient, it follows that uncertainty is nearly always present. Nevertheless, not all types of uncertainty are problematic and the occasional occurrence of extreme, chaotic uncertainty should not prevent urban planners and designers from managing the other types (Stafford Smith et al, 2011).

A definition that is more applicable within this research is that uncertainty is the "complement of knowledge, the gap between what is known and what needs to be known to make correct decisions" (Mack, cited by Abbott, 2005). Christensen (1985) was one of the first to define this term, stating that uncertainty occurs if either the means or ends of a project are unknown. The first occurs when there are no known solutions to an issue. The second type is also often called stakeholder uncertainty. In this situation, there is no agreement about the final goal of a project, either due to conflicting interests, or a lack of knowledge about the future.

To many planners, climate change represents added uncertainty about the future (Hallegatte 2009). One of the more troublesome parts is the long time scale over which this uncertainty will occur, which increases all the possible directions in which the future can divert. These many variables make uncertainty difficult to comprehend. Even with (imperfect) climate models, understanding of these issues is limited (Stafford Smith et al., 2011).

5.3.1. Cognitive Barriers

One of the earlier researchers to study uncertainty, Christensen (1985) already defined one of the major problems of uncertainty as the lack of desire of many planners to integrate this complex issue into their project, instead choosing to work with premature solutions or goals. Another historical practice involves engineered interventions to try and limit the inherent instability and uncertainty that comes with urban equilibriums (Folke, 2006).

It seems illogical that even though planners are aware that integrated uncertainty is a vital part of effective adaptation plans, a large percentage of plans still do not actually address it in any way beyond this acknowledgement (Woodruff, 2016).

This is more understandable if the difficulty humans have in comprehending uncertainty is taken into account. Accepting an unknown and uncertain future is difficult and often anxiety-inducing (Hamilton, Sturt & Kasser, 2009), considering the strong human tendency is to make judgements based on historical facts, even when this data is no longer accurate (Stafford Smith et al., 2011).
It cannot be assumed that people will react to the existence of uncertainty with a structured coping strategy. Hamilton et al.(2009) have studied this and found three major coping strategies for planners who do not wish to engage with uncertainty. The first is denial, which suppresses facts, maladaptive coping strategies second, which twists facts to suit the planners' desires. The third is adapting coping strategies, in which planners accept both the facts and the anxiety it often brings.

This issue is not made simpler by the fact that there is still no real scientific agreement on how uncertainty should be integrated into projects (Van der Pol, van Ierland and Gabbert, 2017), which only adds to the cognitive difficulty (Stafford Smith et al., 2011).

5.3.2. General Strategies

At this moment, there are various available strategies that support planners in dealing with uncertainty, suited to different situations (Hallegatte, Shah, Lempert, Brown & Gill, 2012). Unfortunately, research shows that while many projects take steps to 'become aware of uncertainties', only a percentage of these makes plans to integrate it (Woodruff, 2016).
One common way uncertainty is studied in projects is through consideration of multiple scenarios (each visualizing a plausible future), which helps define the range of the uncertainty (Woodruff, 2016). However, it is frequently assumed that these futures are accurate, and planners then develop an optimal plan using the 'most likely future' (Haasnoot et al., 2013).

5.3.3. Insensitive strategies

The creation of climate insensitive plans that provide acceptable results regardless of climate change is one of the currently preferred strategies for many urban centres (Woodruff, 2016), and there are arguments to be made for this. One method to this is that the creation of a strategy capable of covering most scenarios that have a high probability of coming to pass (McInerney, Lempert & Keller, 2012). For many urban centres, this is a more effective cost-risk situation. The certain argument states that climate change is so unpredictable that climate models and scenarios are untrustworthy (Hallegatte, 2009). Because of this, robust plans should be developed that will work in all possible futures.
In either case, solutions are insensitive to the actual climate change uncertainties. The method that Dessai & Hulme (2007) define as 'insensitive to climate change uncertainties' is called robustness. These interventions will achieve their goal even if uncertainty creates a different future than was originally expected. Van Veelen, Stone & Jeuken (2015) affirm this, stating that robustness is the ability to (successfully) encompass a wide range of futures.
Interventions that work on this principle are safety margins (using higher figures than current data would require) (Hallegatte, 2009), redundancy (having multiple available options) and buffering (locations with the ability to absorb disturbances, such as flooding) (Wardekker et al., 2010).

5.3.4. Sensitive Strategies

While many of the insensitive strategies will work with the simple goal of 'controlling climate change effects', they often do not take into account the existing built environment in which they are placed. For example, while evacuation plans and warning systems are an important element to protect the inhabitants from climate change (Kartez & Lindell, 1987), one of the stated goals of this project is to protect the historical character of buildings of the city centre. Such options focus on short-term plans, but the serious situation and lack of space in the city centre means a long-term strategy that integrates short-term solutions is required, in order to establish Gouda's protection from water in the future.

The current issues in the city centre require interventions on the short term, but uncertainty on the long term must be considered as well. An earlier paragraph described the cognitive difficulty of taking into account uncertainty, but fortunately, there are solutions. One of the most important elements of a coping strategy for uncertainty is a systematic approach that will help categorize and make use of the available data. Such a stepwise approach can take away some of the difficulty of comprehending uncertainty and turn it into a simpler decision process (Stafford Smith et al., 2011). The lack of space in the city centre does not allow for redundancy or over dimensioned interventions, which means the strategy requires an intermixing of long and short-term interventions. Adaptability should be built in and be done on a timely scale.

Adaptability is defined by Folke (2006) as the capacity of a system to remain stable by adjusting to internal dynamics and external changes.
Rauws & De Roo (2016) dispute this and say that this leads to isolated and self-reliant systems. They argue that the creation of urban adaptivity should be done by combining them with social values and pre-existing agreements. Their definition, which will be used in this thesis, is that adaptive planning involves two steps. First, development conditions must be generated with regard to the future spatial configuration, and at the same time it must engage actors who can help steer adaptability.
Second, these conditions should be organized in such a way that during development, socially preferred trajectories are prioritized. This fits with the Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013) that will be discussed later in this chapter. By re-evaluating and re-prioritizing decisions and plans, the preferences of the stakeholders and inhabitants are incorporated into the project.

5.3.5. Strategy requirements
The spatial situation in Gouda, as well as the stated project goal, make uncertainty-insensitive strategies unsuitable, for several reasons.
The water system in Gouda is highly managed, and already stretched very thin. Interventions on the short term are needed. Series of disconnected short-term interventions in sequence are not an option, as the lack of space in the city centre does not have the space for multiple separated interventions. This is also why redundancy and safety margins are not an option either. Interventions must be suitable in the short term for current problems yet remain relevant and useable in the long term when climate change becomes more obvious.

Soft actions are not an option either, as the monumental city centre must be protected. This also requires timely action, with adaptation and expansion of interventions taking place before disaster strikes. Last, the complex situation and many different (opposing) needs require a structured approach.

5.3.6. Dynamic Adaptive Policy Pathways
There are several strategies which incorporate all these required elements, but the method that is used in this study is Dynamic Adaptive Policy Pathways (DAPP). This method was first developed in 2013, out of a combination of two other methods, and is part of a paradigm that dynamic adaptive plans are the only way to address deep uncertainty (Haasnoot et al., 2013).

The strategy is a very structured approach (see figure 6.1), that combines 'strategic future visioning' and adaptive planning techniques into a project (Merrie et al., 2014). It does this by combining sequences of interventions in pathways with assigned tipping points for when one single intervention no longer suffices with a structured approach which includes monitoring strategies for these tipping points (Haasnoot et al., 2013).

One major advantage of these sequenced interventions is that they are not dependant on the probability the future if any given scenario will come to pass (Gersonius, Ashley, Jeuken, Pathinara & Zevenbergen, 2015). The scenarios are used to test how successful an intervention will be in a given situation (Haasnoot et al., 2013).

This approach sets up sequential decision points in order to progress towards an adaptive future, rather than defining a final goal at the start (Maru, Stafford Smith, Sparrow, Pinho & Dube, 2014; Zeff, Herman, Reed & Characklis, 2016; Watkiss, Hunt, Blyth & Dyzinsky, 2015). The result is that when future predictions turn out to be false, neither the interventions nor the pathway has to be changed. The tipping point of the intervention is compared to the new future, and development along the pathway is sped up or slowed down in reaction (Klijn, Kreibisch, de Moel & Penning-Rowsell, 2013).

However, these tipping points must be implemented and set correctly. The model cannot do this, so this strategy requires stakeholders to define acceptable risk threshold levels (Gersonius et al., 2015). And while Haasnoot et al. (2013) note that some lead up time is required before new interventions can be implemented, no implementation schedule is proposed (Huskova, Matrosov, Harou, Kasprzyk & Lambert, 2016).

These same researchers also note that this approach is 'computationally intensive'. The model must be detailed enough to incorporate all of the relevant factors, yet it must be fast enough so that a large number of scenarios can be analysed in a reasonable amount of time (Haasnoot et al., 2013). This will result in a simplification of the system, especially within the underlying network of values, knowledge and institutions (Wise et al., 2014). Planners must remain aware of the simplification and limitations of the model approach throughout the process (Zeff, Herman, Reed & Characklis, 2016; Jurgilevich, Räsänen, Groundstroem & Juhola, 2017).

Several other articles propose improvements, such as toolkits and new models which makes the model DAPP requires less resource intensive. This makes it easier to run all the various scenarios (Haasnoot et al., 2014; Kwakkel, 2017; Kwakkel, Haasnoot & Walker, 2015).

Other researchers add methods to avoid illogical pathways and propose a minimum gain level before pathway switches are accepted, in order to avoid waste (Manocha & Babovic, 2017). Another study further defines warnings for future situations in which a project might fail (Groves et al., 2015).

Case studies in which DAPP is applied show that this strategy is quite popular with large scale projects (Van Slobbe, Werners, Riquelme-Solar, Bölscher & van Vliet, 2016). Woodruff (2016) states that such projects have both resources, a clear goal and consensus amongst stakeholders.

The lack of this on smaller, local scales makes uncertainty management tools less effective. Nevertheless, a recent case study (Lawrence & Haasnoot, 2017) shows that planners on local scales can be engaged using the DAPP methodand show that practical application (even in the format of a game) will quickly cause stakeholders and politicians to apply the Dynamic Adaptive Policy Pathways method, and even apply it beyond this original scope.

5.4. Monumental heritage

Like many European cities, Gouda has a characteristic historic centre, which includes a lot of cultural heritage (Gandini, Garmendia & San Mateos, 2017). This heritage is important for many different reasons; as well as their important historical function, monumental centres also form a source of identity for many of the communities who live there, and in an interesting way, cultural diversity increases the resilience of social systems in tying the community together. They're also responsible for a large part of the tourism, and the economic advantages that come with that (Jigyasu, 2013; Gandini et al., 2017).

These historic centres are threatened by many factors, from urbanization to unsustainable tourism (Jigyasu, 2013). But a new danger that has come to the forefront of many new research studies is climate change.

Historic buildings were designed for specific local climates (UNESCO World Heritage Centre, 2007), and they are generally sensitive to changing physical circumstances (Phillips, 2015). These circumstances vary from e.g. higher moisture levels (Jigyasu, 2013) to the possibility that several heritage sites will be inundated by rising sea levels (Ezcurra & Rivera-Collazo, 2017). When the World Heritage Centre studied the impact of climate change on heritage sites in 2005, 72% of responders stated this influence was visible (Jigyasu, 2013).

As a result, several studies proposing risk assessment frameworks have been written (Romão, Paupério, & Pereira, 2016; Fatorić, & Seekamp, 2018; Forino, MacKee & von Medin, 2016; Wang, 2015).

It is stated by Fatorić & Seekamp (2018) that managers of cultural heritage sites often left to prioritize heritage under their purview without any support, leaving them open to criticisms about this later. Fatorić & Seekamp also propose a transparent progress that measures the historical significance and the use potential of a building, according to several other factors. Heritage preservation can then be prioritized according to the vulnerability and the value of the buildings, and no longer according to which heritage site will bring the largest economic returns.

A similar framework, which has the capacity to (preliminary) assess a large number of heritage assets according to the probability of disaster, the consequences (vulnerability), the loss of value and the capacity to recover after, fits in well with this line of research (Romão et al., 2016). A paper by another researcher, Wang (2015) instead promotes the creation of a risk map to protect cultural heritage values, based on the likeliness of damage to irreplaceable cultural characteristics to flooding. These risk assessments can form a wide network of tools with which a planner can protect heritage from climate change (Forino et al., 2016).

6. Methodology

6.1. Introduction

The problem scope of the project consists of both a very complex location and a lot of uncertainty. So the methodology required a strategy or framework to work through all this data, and test various scenarios in a very methodical way. Various methods were considered, and in the end the project settled on the Dynamic Adaptive Policy Pathways method (Haasnoot et al., 2013). This chapter goes through the methodology step by step and clarifies what activities were undertaken.

6.3. Used methodology: Dynamic Adaptive Policy Pathways

Dynamic Adaptive Policy Pathways is a very methodical approach, working through different steps, which results in a series of interventions for which the effectiveness is known, which can be laid out in various configurations over different pathways along a time scale (Maru et al., 2014). The project can then move forward or sideways at varying speed, depending on the situation.

DAPP is by itself a combination of two other methods: Adaptation pathways and Adaptive Policymaking. The first approach involves the analysis of a wide variety of scenarios in which several interventions are tested and assigned a tipping point, based on the moment in which an intervention will no longer be sufficient to fulfil the requirements of the location. This alerts the planner that a specific intervention no longer fulfils the requirements needed for the situation. Based on these results, the interventions are connected in a large web-like strategy, so the project can switch over to another track after a tipping point has been reached (Haasnoot et al., 2013).

The second, adaptive policymaking, divides the methodology into structured steps. This guides planners through an iterative process, moving from spatial analysis to a temporary design, to interviews, to a technical analysis which leads back to the design.

At various points monitoring and improvement strategies are placed in vulnerable locations (Haasnoot et al., 2013). While this method eventually creates a full pathway map, not all the steps will be taken. Steps are occasionally moved to a different location, based on the needs of the model, which will be explained in a later chapter. The strategy used in this thesis consists only of the first five steps, the last of which, instead of an adaptation pathway map, will be a design in which some pathways are incorporated.

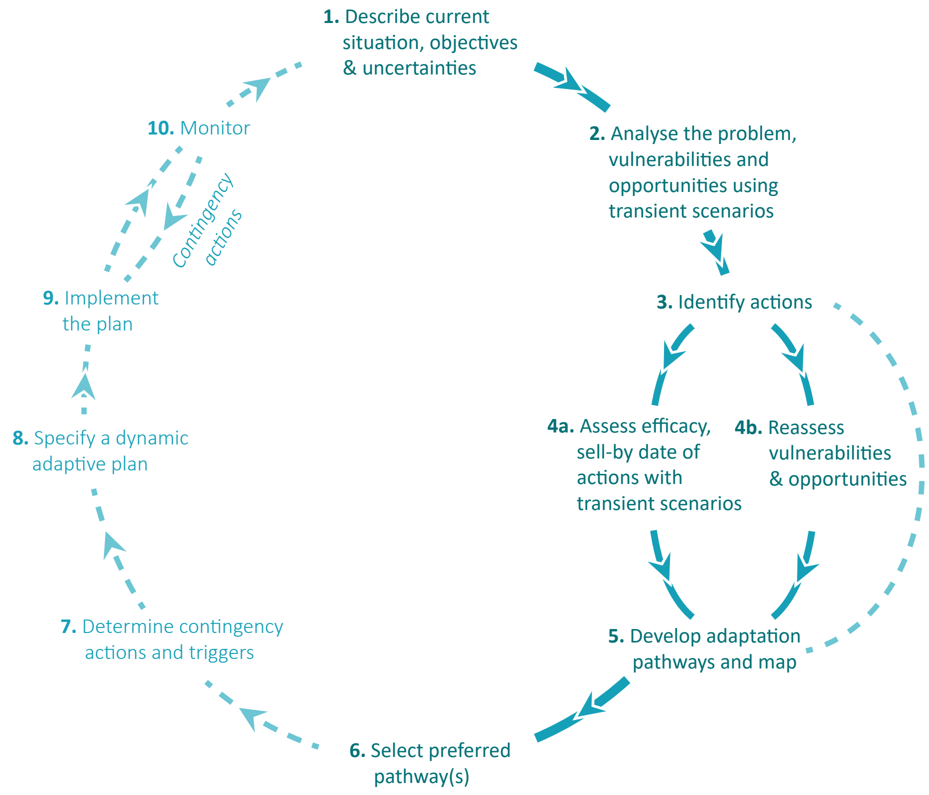


Figure 6.1. Dynamic adaptive policy pathways (Haasnoot, et al, 2013.)

6.3.1. Step 1: Describe the current problem

The first step in any design process, thus in this methodology as well, is to analyse the study area. This involves learning the characteristics and the constraints of the area, as well as the goal of the study, and what the definition of success will be (Haasnoot et al., 2013).
In order to understand the field, a literature analysis was carried out, describing the development of the water system, and the historical importance of the area. This basis helped to define the goal for this project.

6.3.2. Step 2: Analyse the situation

A spatial analysis maps out the characteristics, opportunities and present problems in the area. This analysis (Chapter 8) consists of two main elements, spread out over several categories. Each category first analyses the value of existing elements, and then maps out how these elements will fare when they encounter extreme climate situations. This situation is a future scenario based on a series of potential precipitation levels which will be defined within the analysis. Within each analysis category, the situations were compared, and vulnerabilities were mapped out.

6.3.3. Step 3: Identify actions

After the analysis mapped out the vulnerabilities in the city centre, the next step is to organize a series of possible actions that can be taken to curtail the existing issues. This is done through the creation of a variety of design interventions (chapter 9. One of the stated goals in this project was to use green-blue interventions to create a sustainable city, and to move away from technical solutions wherever possible.

However, this type of designs is susceptible to several problems. First, the green and blue elements are often difficult to separate when analysing. Normally, this would not be a major problem, but a major step of this methodology involves measuring the effectiveness of each intervention in order to find the area in which specific interventions are effective (Haasnoot et al., 2013).

The effectiveness must be calculated in order to create an optimal balance of space and water storage, and so the practical applicability of green-blue interventions in these situations can not be denied.

The different character green and blue interventions could bring to the city was demonstrated by the creation of two extreme scenarios, each displaying a situation where one option was carried out throughout the city.

In order to create a wide variety of data on a smaller scale, interventions were created based on these scenarios. These were then split up into categories, and half of each category involved much more extreme options. The categories themselves involved building adaptation, street adaptation, as well as two categories in which green and blue options were completely separated from each other

6.3.4. Step 4. Evaluate the actions

The next question was to consider what sort of influence these interventions will have on the predicted future situation. Was it efficient enough to remove or reduce a specified vulnerability, and what other benefits does it bring to the city (Haasnoot et al., 2013)? Research has shown that a transparent framework to support the arguments and choices behind a decision is important, especially when it concerns changes and potential damage to monumental heritage (Fatorić, & Seekamp, 2018).

Therefore, these interventions tested were in various ways, to assess the different strengths and weaknesses of the design, often with a phase of iterative design between. This step had three main phases: preferred pathway selection, testing the efficacy of the interventions, and reflection on this new data.

6.3.4.1. Step 4a: Selecting preferred pathways

This is the first time the thesis process steps away from the structure and order laid out by the DAPP method. One important stated goal is to maintain the essence of Gouda. Research by Van Raak (2004) has shown that priorities for protected areas differ quite a lot across locations. Because of this, step 6, Selecting Preferred Pathways, was brought forward. This was done in the early testing phase so interventions that did not fit with the character of Gouda could be screened out.

This prioritization was done by means of two workshops in which people (first a group of 19 citizens, second a group of 7 experts working around Gouda) were asked to prioritize each of these interventions and substantiate their arguments. These workshops started with a short presentation, in which the basic idea was explained. After that, the participants were split into groups, assigned either the blue or the green scenario, and were set four tasks. Each of these tasks involved the evaluation of a type of intervention, starting with the extreme scenarios on the scale of the inner city, to typologies and the actual interventions in the street, to an ensemble; a potential design in which these interventions were incorporated.

This led to an active discussion, and a wide variety of results, which will be explained in chapter 10. These results let to a few new potential ensembles, as well as a clear prioritization list for the interventions.

6.3.4.2. Step 4b: Assessing efficacy

While one stated goal was the creation of interventions that would protect and enhance the historical character of the city, the main goal was to protect the city itself from climate change damage. In DAPP, this is done through a model, testing the scenarios, and identifying the sell-by-date (also known as date on which the adaptation tipping point occurs) (Haasnoot et al., 2013).

The original plan was to use a technical model (Suijs, 2016) to measure the efficacy of every intervention, and Hans Suijs, the creator of this model, provided a lot of help and, and helped run several tests. Unfortunately, results of these tests showed that the scale for which this model was built did not provide the type of information needed to test the efficacy of the interventions.

Instead, the calculations to test the efficiency was done by hand, calculating the water storage for each intervention in one street, the Hoogstraat en Kleiweg. More details on these calculations are in chapter 11.

6.3.4.3. Step 4c: Re-evaluation

Both the workshop and the technical study provided a lot of new data, and allowed for a reprioritization of the interventions, as well as the issues. For example, one of the main conclusions of the first workshop was that the monumental buildings must be preserved. At the same time, the second workshop and the efficacy testing both proved that green interventions were more effective than water, but the characterisation of Gouda as a water city is important as well.

Eventually, the design was split up into three approaches, each of which has different goals, tipping points and preferences, splitting the pathways. The first of these, 'Strengthen and Enhance' focuses specifically on those areas with a strong historical character and very little threat from climate change. Interestingly, active city life has moved away from these locations to many of the areas that fall under the second approach.

The next one, 'Protect and Improve', concerns areas with a high historical value, but which also deal with a high climate change threat. In order to preserve the monumental heritage, green(-blue) interventions are mixed with technological solutions when necessary.

The last path 'Renew and Innovate' covers those areas without monumental value, which are also under a high climate change threat. This path will focus on new, adaptive and circular solutions for water, turning Gouda into a landmark city for water management. Due to the lower historical value, demolition and construction of new buildings are an option here, and they are written into the design as a possibility on a longer scale.

6.3.5. Step 5: developing an adaptation pathways and map

By now, a collection of interventions has been tested through various methods, and it is time to go the next step. In DAPP, this is one of the cornerstones, the adaptive pathway. As mentioned before, this study will approach this step in a different way. Instead of linking the scenarios in a web, a design for each path is created, showing how these interventions can interlock, and where space is left for added interventions later in the pathway. All three pathways interventions will cross and connect to create a sustainable city centre.

The final goal of this project was to create a design that integrated all the information from the earlier steps, so activities placed in later steps are not integrated within the design discussed in this thesis.

The step that follows after the creation of the design strategy within the methodology involves the creation of specific contingency triggers. Gouda already has an active monitoring system that can be appropriated in this design to help measure the practical efficacy of the design interventions, using tipping points created from the data calculated in step 4b. Furthermore, the strategies, street profiles and designs are created in such a way that extra additions to add to the water storage remain possible. All steps after this one concern actual implementation of the plan, and thus fall outside of the scope of this project.

7. Relevance

7.1. Scientific relevance

Consequences of climate disasters are now making themselves known throughout the world. These disasters range from hurricanes (Rosenzweig & Solecki, 2014) to local extreme precipitation (KNMI, 2018). Regardless of scale, these events show that extreme weather events are becoming more common. And as a result of this cities have to adapt to new circumstances.

Uncertainty has long been an element of planning, though not a particularly popular one. Ever since the term started appearing in the literature with any regularity, planners have preferred avoiding it. Sometimes even by prematurely pretending they have all the factors even in situations where this is false (Christensen, 1985). This made it preferable to use designs which covered all problems in most situations, also known as climate insensitive designs (Hallegatte, 2009). These interventions used evacuation strategies or robust design to develop plans in cities/urban centres where there was still space to integrate the adaptability into the fabric of the city and many planners have done excellent research on a variety of methods that can assimilate these robust designs into the urban project (e.g. Copenhagen's over dimensioned sewer systems) (Hallegatte, 2009).

However, these solutions work best when adaptation to the urban fabric is possible. In many of the historical, dense city centres, this space is not available, and the monumental status makes large adaptations difficult. This requires them to use a different type of strategy to deal with climate uncertainty. These cities have to work with climate adaptability instead. The lack of available space in historic centres requires a different approach. Interventions must be as minimal as possible, must interlock with each other, as no space can be wasted on inefficient actions.

Fortunately, there are also strategies to deal with this. The method that is applied in this thesis is Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013). This method has been applied in a limited capacity, mostly in large scale projects, though case studies have been done in a local scale project to test the applicability of this strategy (Lawrence & Haasnoot, 2017), and at least one case study has been done in a local scale project to test the suitability of this strategy there. This project will provide insight into the applicability of the method on a small local scale, with many conflicting problems and stakeholders, without a lot of space for interventions, to see if this can generate a new path forward.

7.2. Societal relevance

Many cities in the Netherlands are dealing with water various water issues, such as due to high groundwater, subsidence or not enough water storage (Coalitie: Stevige Stad op Slappe Bodem, 2017). These issues are part of living in a delta, and show up around the world, as seen in figure 7.2 (connecting delta cities, n.d.; Deltares, 2015).

Gouda experiences many of these issues, and while the current water system functions, a changing climate, with new quantities of precipitation will change this situation. Both Gouda and other groups have realized this, and the municipality is being proactive in combating the issue. After a long research trajectory, researching the exact spatial situation and the city has now moved on to the creation of advisory plans (A. Fijan, personal communication, may 16, 2018). Many of the considered directions involve technical solutions to regain a sustainable water management level. As supporting elements of this study, there are several coalitions and actions that take part in the study. On a national level, several actions are being undertaken. There is a knowledge program to inform stakeholders about research and methods to prevent more subsidence, and how this issue is connected to water and climate change (Kennisprogramma KWB, 2017b).

At the same time, at least two conferences have been held surrounding this subject. The first was Heel Holland Zakt in 2016 and Nationaal Congres Veen-bodemdaling in 2017 (Platform Slappe Bodem, 2017). These were organized the organisation 'Platform Slappe Bodem (Platform Weak Soil). Gouda is part of this coalition. This coalition has many other participants, which can be seen in figure 7.1. (Platform slappe bodem, n.d.).

Locally, there is a yearly water conference plus a historical organisation (Historische Vereniging die Goude, 2017). These people are very aware of the issue and try to figure out solutions on a local level.

Gouda is required to do something in the coming few years, and their reports show both awareness and actions. However, as a government institute, they must include all stakeholder, economic and spatial constraints in a long and formal project.

This project, as a design project, can choose to move past some of these constraints for the moment, by using urbanism as a transdisciplinary tool to visualize the different stakeholders' positions. While spatial adaptations are necessary in order to safeguard the city, this project attempts to shape them in such a way that they will connect to the historical character to the city, and add to the overall value, using alternative solutions and green-blue interventions. This will hopefully open new pathways and serve as future inspiration.

Figure 7.1. Cities involved in Platform Weak Soil (Platform slappe bodem, n.d.)

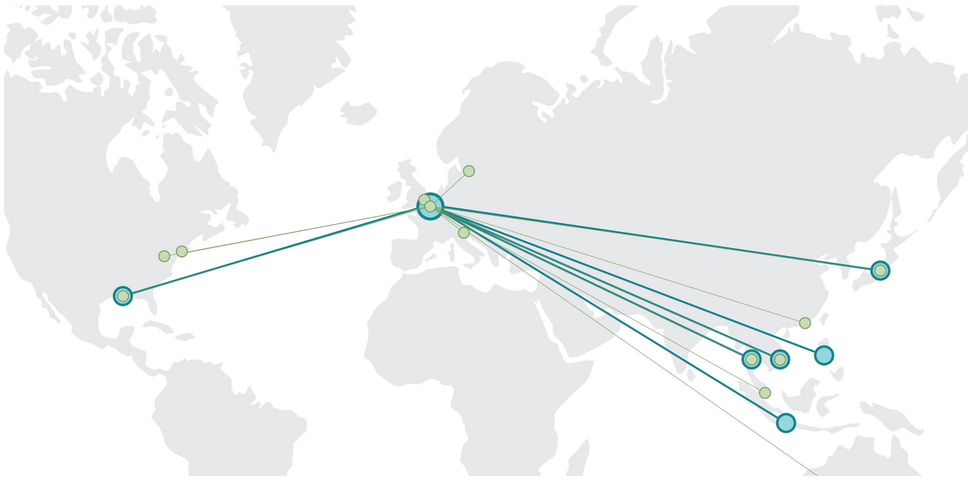


Figure 7.2. Delta cities dealing with subsidence around the world
Blue: Sinking cities (Deltares, 2015)
Green: CDC cities (connecting delta cities, n.d.)

6.3. Ethical substantiation

Gouda is a small city, but with many stakeholders, which all have different priorities and goals, complicating matters. However, the vulnerability of certain areas and the many buildings in the inner city to flooding is something is a problem that concerns all. The easiest and fasted solution to this issue would be to lower the groundwater to be more in line with the water level of the surrounding areas (-0.72 m in the city centre vs-2.30 m in the outer areas (Hoogheemraadschap van Rijnland, 2007).

Unfortunately, the subsidence in the system cannot be halted through any method, and even for solutions like lower water levels, the retainability has not been confirmed for very long spans of time. The subsidence occurs through the pressure the weight of the city puts on the peat layer. Lowered water levels might increase this weight, which could very well lead to faster subsidence without the water's carrying capacity (F. van de Ven, personal communication, spring 2017).

Another problem with the lowering of the water is that there are around 450 buildings in Gouda with foundations made of wooden poles, and a significant number of them will be houses, which require either new foundations, or some form of protection against the wood-damaging fungi that will increase as a result of the lower water levels (Klaassen, 2015)
If the municipality decides that a lowering of the water level is the most sustainable option, they must also find a solution for the protection of wooden foundations, either through replacement or other methods. This is an incredibly complex project and decision to make, either way.

It would be an incredibly heavy burden to put on the inhabitants of these houses, but the cost would not be insignificant for the municipality either. Other options, such as raising the houses across the city would be incredibly expensive and are not an acceptable option (A. Fijan, personal communication, April 12, 2017).

This project suggests another approach which involves the creation of extra water storage, located entirely in the public areas. This will move the problem away from the issue of public and private burdens, but the wishes of the inhabitants must remain an important consideration. The goal of this project is to adapt the city to safeguard it for the future, but the value this city has for the inhabitants must be maintained all throughout the transition.

III. Research

Analysis
Research interventions
Workshops: testing social adaptability
Model: testing efficacy interventions

8. Analysis

8.1. Introduction

One of the stated goals of this project is to create a climate sustainable situation for the city centre, even when accounting for climate change. Following the Dynamic Adaptive Policy Pathways method, the first two steps of the methodology consist of a description of the study area and the problem analysis (Haasnoot et al., 2013).

This analysis is built up out of four categories, in which the spatial layout of the city, the subsurface, the streets and the buildings are all analysed. This will shed light on both the advantages, unique characteristics and valueable elements, as well as the potential vulnerabilities. These problems are then compared to an extreme future situation, in order to identify high-risk areas, which will function as prime sites for opportunities in the design phase (Haasnoot et al., 2013)

8.2. Future scenarios

A starting point for future scenarios are the KNMI predictions. Current numbers state that once every ten years a precipitation occurs that will consist of 50 mm of water in 24 hours (KNMI, 2014). Even the worst scenario, does not show more than a 55% increase (including uncertainty) in precipitation (KNMI, 2015), resulting in 77.5 mm per 24 hours.

Yet, the period at which this project looks is longer than those 10 years, and history has already proven to us that these predictions are not absolute. In 2011, KNMI station Herwijnen measured 94 mm of rain within one hour, causing massive damage to nearby structures and systems. (KNMI, 2018)

All analysis maps use a base created with data from an OpenTopo (2017) map. Sources for the specific analyses will be mentioned on the relevant page.

Images taken by the author are given a figure number and the date

A year before that, in 2010 in Hupsel, 160 mm of precipitation fell over the course of a day (Stichting RIONED, 2018). Taking these numbers into account, the Hoogheemraadschap of Rijnland, which is responsible for a large part of the water management in Gouda, uses 100 mm per 2 hours of precipitation as an 'extreme case' measurement. According to the KNMI data, such a rainfall should occur less than once every 100 years. In fact, data from the precipitation at Herwijnen showed that even a 79 mm rainful is not likely to occur more than once every 1000 years (KNMI, 2018)

In order to create an overview of the efficacy of the interventions, a variety of precipitation scenarios is used, each with a different likelihood of appearance. The first of these is 10 mm/hour. This is quite common, occurring about twice a year somewhere in the Netherlands. The second is 25 mm/hour, which is very similar to a 27 mm/hour rainfall, something that happens around once every 10 years (KNMI, 2014). For more extreme calculations, 55 mm/hour is used, which is a variation on the 100 mm/2 hours precipitation. The last of these is used as the most extreme case scenario.

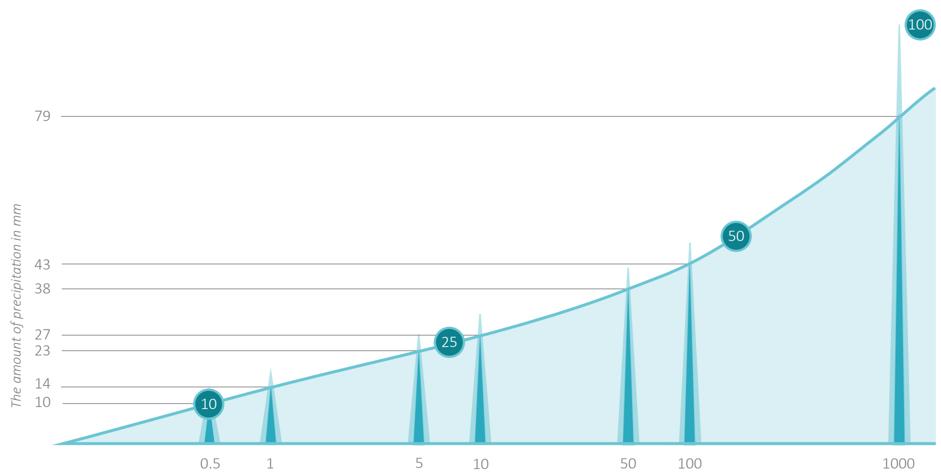


Figure 8.1. Precipitation occurence (KNMI, 2018; KNMI, 2014)

8.3. Natural analysis

The shape of Gouda as it is today is irrevocably intertwined with the land on which it developed. The shape of the canals was derived from the characteristics of the area, as well as the capabilities of the water system.

8.3.1. Historical development

The city started in 1100 as a loosely connected group of farms and a rural estate (RAAP, 2017), and it was its profitable position near a trade route that allowed it to grow into a larger city by 1350 (Denslagen, 2001). This expansion happened in circular rings around the pre-existing rural estate.

The recurrent canals in his expansion were regulated by the wetness of the soil, and the drainage requirements. The area that surrounds this small centre were marked by the long lines of the polder created by those earliest settlements (RAAP, 2017).

This physical shape remained unchanged for a long period of time, until the newly laid railway station in the 19th century cut through the polder landscape. This new connection promoted city growth in that direction (Rijkswaterstaat, 1882; RAAP, 2017). In the 20th century, the city started expanding into other directions, breaking up the long lines.

At the same time, modernisation and new technologies led to simplification and streamlining of the existing water system. First, the meandering route of the Gouwe outside the city was streamlined, and when this was not sufficient, a new canal was dug outside the city, bypassing the centre. Inside the city centre, new water management techniques, sanitation and pumps led to the removal of many of the smaller canals halfway through the 20th century (Denslagen, 2001; RAAP, 2017).

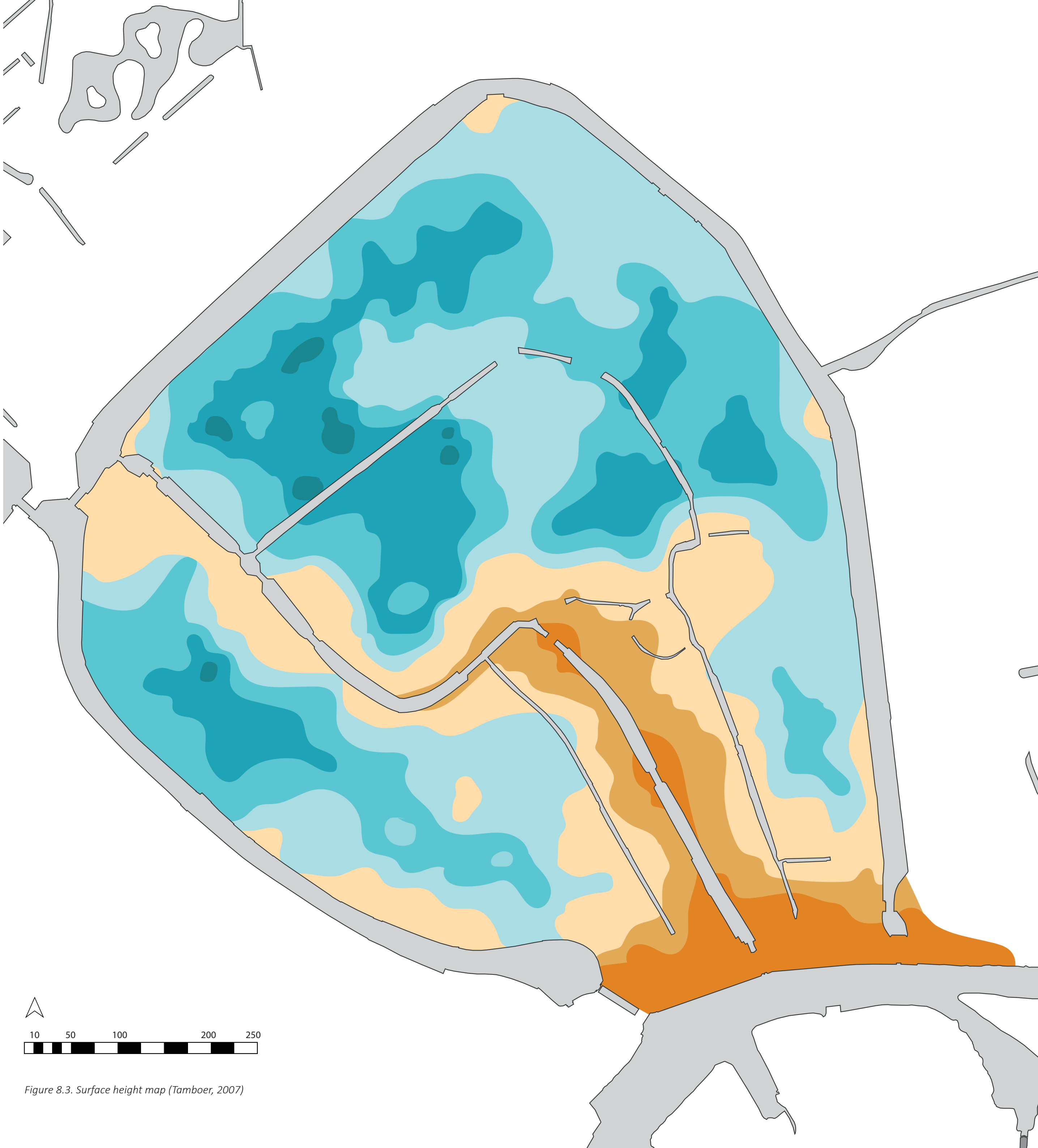
This resulted in a varied water landscape in Gouda. This ranged from the long sweeping lines of the new canals to the simplified water system inside the centre, the neighbourhood scale waterways which still vaguely follow the polder lines, to even areas where all of the surface water was removed.

Figure 8.2. The spatial (water) structure in 1100-1500, 1500-1900 and 1900 - now (Rijkswaterstaat, 1882; RAAP, 2017)

8.3.2. Flooding

This map shows the general ground level in comparison to the NAP (Normaal Amsterdams Peil), which shows the large height differences within the city centre when comparing levels at the outer areas to the Gouwe.

This higher level around the river is caused by clay deposits from the river (Van Winsen et al., 2015), which left the streets next to the Gouwe less sensitive to the subsidence (caused by compressed peat) that has lowered the ground level throughout the rest of the city (Willemse, 2017).



- -0.6 - -0.5 m
- -0.5 - -0.4 m
- -0.4 - -0.2 m
- -0.2 - 0 m
- 0 - 1.0 m
- 1.0 - 2.0 m
- 2.0 - 3.0 m

Figure 8.3. Surface height map (Tamboer, 2007)

8.4. Subsurface analysis

Since the characteristics of the landscape were so decisive in the shaping of the city, the subsurface layer, the connective tissue between this first, natural layer and the city itself, the subsurface layer, is heavily influenced by the characteristics of the ground, and in turn influenced the city. In this thesis, a focus is laid on the sensitivity of the foundations to water ground levels, as well as the possibilities of water storage within in the freeboard or in the vegetation.

8.4.1. Foundation research

There are a lot of knowledge gaps around the foundations in the city centre. A comprehensive report was released by Willemse (2017) gathered and laid out most of the available data. But even this study mentions that due to financial and other constraints, actual field research by earlier studies into the foundations was done through sampling of a few buildings.

The report built a logical case through historical research, traditional foundations and building ages. No comprehensive field research cataloguing the exact foundations beneath all the houses in the city has ever been done. Much of the data in this chapter is based on this report from Willemse (2017), combined with interviews (A. Fijan, personal communication, April 12, 2017) and spatial research, and are assumptions based on this information.

8.4.2.1 *Op staal* (shallow foundations)

Explanation foundation

The name for this foundation 'op staal', comes from the word stal or estal, and means 'stable surface, standing or resting on' (Haslinghuis & Janse, 2005). It is the Dutch word for shallow foundations that are built on the surface without bearing piles. It gains its loadbearing capacity directly from the stability of the ground, sometimes by placing the loadbearing walls directly on the surface, and sometimes distributing it around more evenly through a grid of horizontally placed beams.

Both of these variations can be found in the city centre. The first, also known as 'cold' constructions, have the loadbearing walls directly placed on the ground. This is the case for some of the oldest buildings in the city centre. Slightly newer buildings are standing on top of a grid of horizontal wooden beams. One other variant of this method is very common in Gouda, which consists of newer buildings built directly on the floors and foundations of the old buildings (Van Winsen et al., 2015), or on occasion even on debris (Willemse, 2017)

General timeline

For a long time, with a few exceptions, these variations of shallow and slab foundations were the standard type of foundation in Gouda. It remained in general use all the way up to 1902, after which it was only used for building plots too small and cramped for the machines needed to drive the wooden poles into the soil. After this period, this foundation type fell out favour in use for new buildings (Willemse, 2017).

Slab foundations create a few problems. In Gouda, the most important issue is that this foundation is built directly on the top layer of soil and is not connected to the load bearing layers of soil further down underground. And with the ongoing subsidence in the city centre (Van Winsen et al., 2015), this brings the buildings closer to the ground water with every passing year.

In many situations with subsidence, raising the street is a relatively effective option, even if it doesn't engage with the reason for this subsidence. However, it requires the houses to remain on the same level as before. As the floors of the houses sink lower, raising the street becomes infeasible.

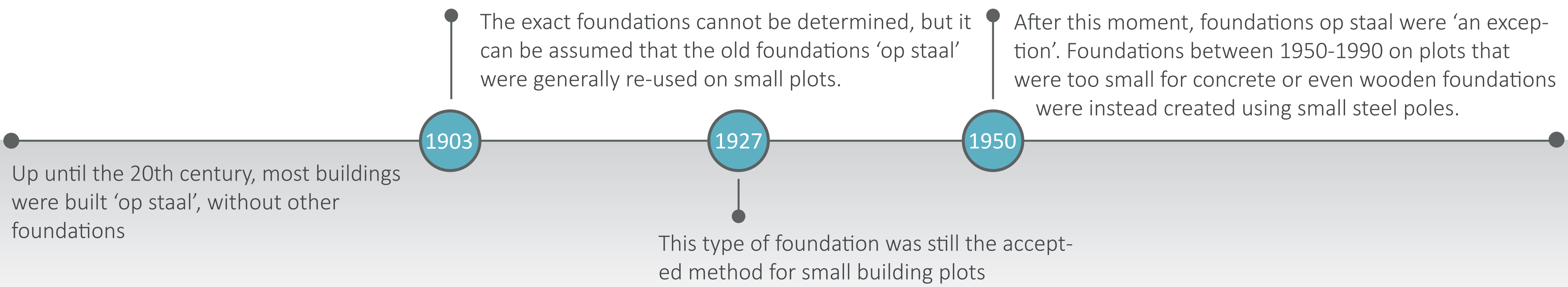
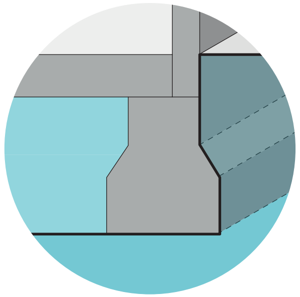
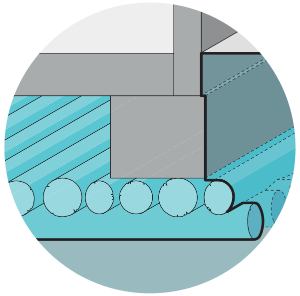


Figure 8.4. Timeline: shallow foundations (van Winsen et al., 2015; Willemse, 2017)





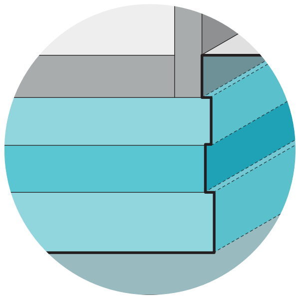


Figure 8.5. Foundation - directly on sand (based on Stenvert & van Tussenbroek, 2007)

Figure 8.6. Foundation - wooden grid (based on Stenvert & van Tussenbroek, 2007)

Figure 8.7. Foundation - on old foundations(Van Winsen et al., 2015)

Legend map

- This colour shows all houses constructed before 1900. As foundations ‘op staal’ were most common then, it is a reasonable assumption to say most of these buildings will have that foundation.
- The dark blue shows all of the smaller buildings constructed between 1900 and 1944. This layer does not consist exclusively of foundations ‘op staal’, instead showing a combination of this type with wooden pole foundations. It is likely that several of the smaller buildings in this layer do have foundations ‘op staal’.

Figure 8.8. Potential building on shallow foundations (before 1900)(waag, 2015; Kadaster, 2018)

8.4.2.2. *Op kleef* (Friction pile foundations)

Explanation foundation

Starting from the 15th century, several of the larger buildings, started to be built using a foundation that is called ‘op kleef’. In English this foundation type is generally called ‘friction pile foundations’. It consists of a lot of smaller poles under a grid. This provides a stable foundation for a building through a combination of friction resistance between the pole and the ground and the point resistance of the many poles (Understand Building Construction, 2017)

There are two important variations of this type of foundation. The first involves normal wooden poles, with an embedment depth of up to 5 metres. The second type also consists of many wooden poles, however these poles have a pointed end, and are called slieten. This second type depends more on friction resistance than the first variant (Stenvert & van Tussenbroek, 2007).

This method works best in locations with a lot of peat, as its friction resistance, or ‘stickiness’ is a lot higher than sand or even clay (Willemse, 2017).

General timeline

After 1600, this method was used on occasion for several of the more important and heavier buildings in the city centre, though not many of these buildings still exist, and end bearing pile foundations were more common (Willemse, 2017).

However, in the period between 1950 and 1990, when foundations ‘op staal’ were no longer used, but end bearing piles were not yet possible for cramped building spaces, an alternative similar to friction piles was used. These constructions made use of a foundation consisting of small steel piles, driven into the ground. By 1990, technology had advanced enough that concrete poles were the standard foundation used for every new building in the city (Willemse, 2017).

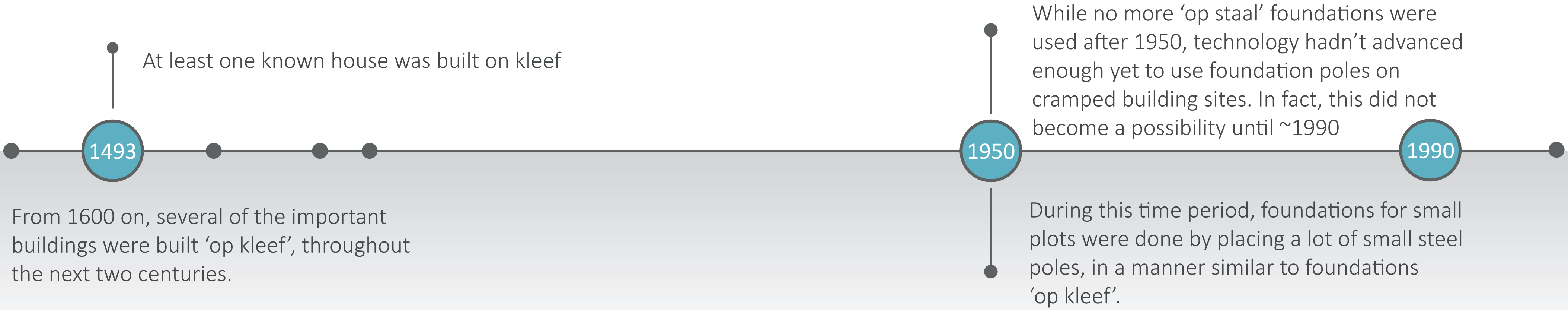
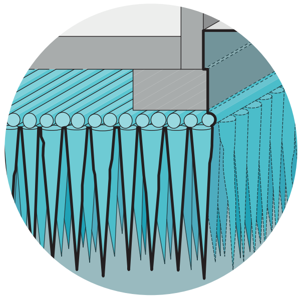


Figure 8.9. Timeline: friction pile foundations (Willemse, 2017)



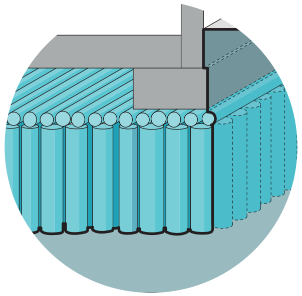


Figure 8.10. Foundation op kleef (based on Stenvert & van Tussenbroek, 2007)

Figure 8.11. Foundation op kleef (Willemse, 2017)

Legend map

- This colour shows the one known building built 'op kleef' in the city

- This layer shows all the buildings constructed between 1945 and 1990. It is probable that several of the more cramped building plots have foundations made of small steel poles.

Figure 8.12. Timeline: potential buildings on friction piles (1945 and 1990) (wagg, 2015; Kadaster, 2018)

8.4.2.3. *Op stuit* (end bearing pile foundation)

Explanation foundation

This last type of foundation consists of long piles beneath a building that reach down to a foundational layer of sand (10-13 metres below NAP in Gouda) (van Dasselaar, 2013; Willemse, 2017). In modern times, these piles are commonly concrete. In the beginning of the 20th century, they were often wood, with an intermediate phase where wooden poles were used in combination with a concrete head. This foundation type is the current standard in the city centre, but made entirely of concrete (Willemse, 2017)

General timeline

In the city centre, there are a few older buildings with foundations, but it was not until the 20th century that this method started being used for houses. In between 1903 and 1950, roughly 447 buildings were constructed on wooden foundations.

While not all of these were houses, a majority of them was (Willemse, 2017). This is a lot higher than earlier assumptions. After 1950, wooden foundations were still used in combination with a concrete head at the top. This method was in use up until 1990. Afterwards, all buildings were constructed with a completely concrete foundation (Willemse, 2017).

This high number of wooden foundations can be problematic, as the material must be submerged at all times. Lowered groundwater levels result in increased oxygen levels, which provides an ideal environment for wood degrading fungi (Klaassen, 2015). As the groundwater level in Gouda is highly managed, accidental fluctuation in water level is unlikely. However, the slow subsidence is slowly bringing the set ground water level closer to the surface. If this level is artificially lowered, it could potentially damage all houses built on wooden foundations.

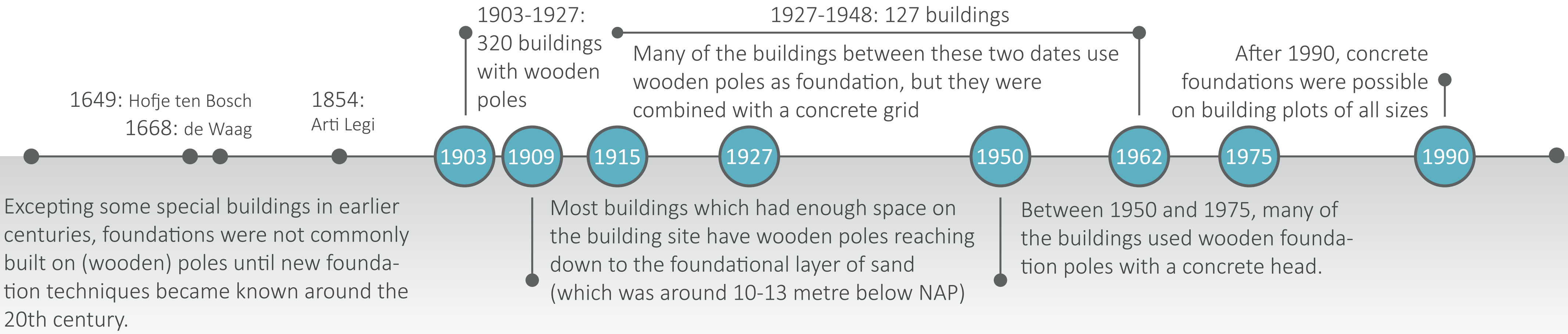
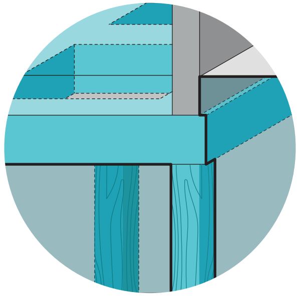
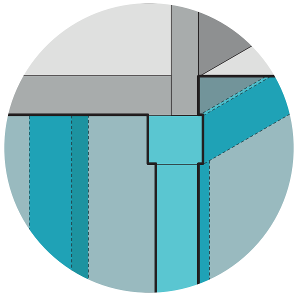


Figure 8.13. Timeline: friction pile foundations (Willemse, 2017)





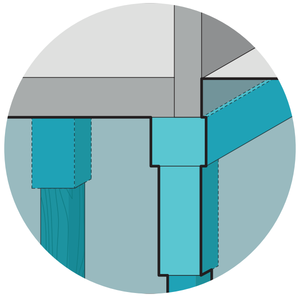


Figure 8.14. Foundation on wooden grid and piles (based on Stenvert & van Tussenbroek, 2007)

Figure 8.15. Foundation with concrete piles (Willemse, 2017)

Figure 8.16. Foundation with wooden piles and concrete head (Willemse, 2017)

Legend map

- All buildings in this layer were built after 1990 and have concrete end bearing pile foundations
- These buildings were constructed between 1945 and 1989 and are likely to have wooden foundations with concrete heads, excepting the smallest building plots.
- This layer consists of specific buildings for which it is known that they have end bearing piles. All others are built between 1900 and 1944, and contains most buildings with wooden foundations, as well as a number of buildings 'op staal', on smaller plots.

Figure 8.17. Timeline: Potential buildings on end bearing pile foundations (1945-1989 and after 1990) (waag, 2015; Kadaster, 2018)

8.4.3. Technical profile

Figure 8.18. shows a technical map of the city, which shows the buildings, the vegetation and the location of technical sections shown in this subchapter. These technical profiles show the different layers of various soil types, providing clarity about the soil foundations on which the city is built.

The main section (figure 8.20) shows elements of the city that were vital in shaping the current spatial structure, yet are no longer visible in current times. This ranges from centuries-old (natural) structures, such as the old river gully as well as the drained canal at Raam that was filled in last century. Clearly visible also is the is the high groundwater level and the lack of foundations beneath many of the buildings.

Figure 8.19. shows the Nonnenwater. Originally part of the canal that connected the Gouwe and the outer canal (singel), this canal was drained and filled in in 1960 (RAAP, 2017), though the space left by this water remains visible in the spatial structure of the street. Underground, it becomes even more obvious, showing the canal walls as well as the sewer that replaced this surface water. The soil is built up out of layer of various types of sand, clay and peat, with a small layer of debris in the southern side.

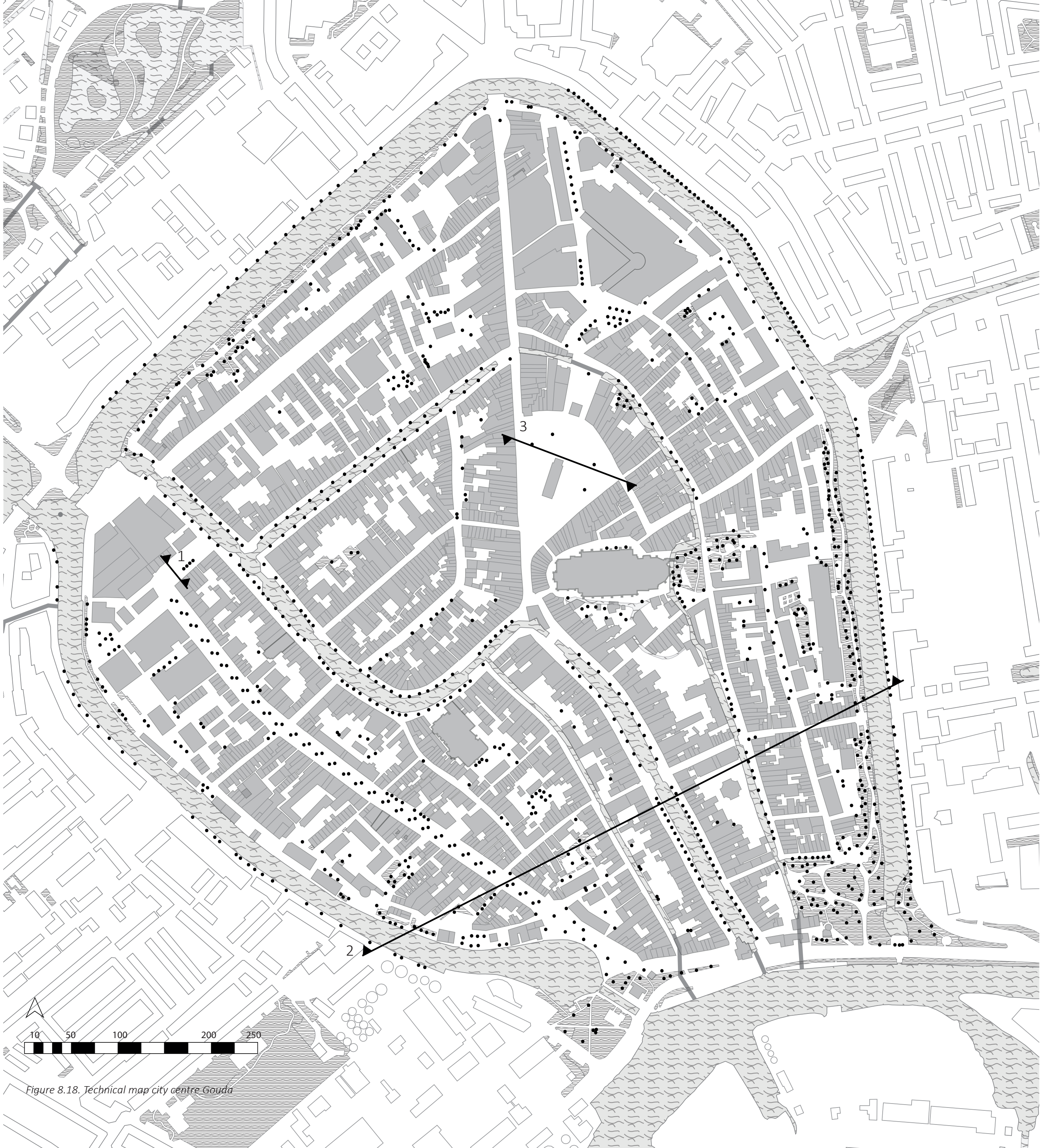


Figure 8.18. Technical map city centre Gouda

Layers	*Sections*	*Map*
People	Humans	
Buildings	Section (large) Section (small) Frontal view (small)	Footprint (centre) Footprint (outside)
Public space	Open soil Grass Low medium vegetation High vetegation	Trees Green (major) Green (minor)
Infrastructure	Road Permeable pavement Asphalt	Roads Public transport
Civil constructions	Sewers (concrete) Foundations (op staal) Foundations (poles) Canal filling	Pumps
Water	Surface water Groundwater Aquifer	Water (centre) Water (major) Water (minor) Culverts Polders
Soil	Sand (upper layer) Sand (lower layer) Clay Peat Debris	*Technical maps and sections based on work by Hooimeijer, Lafleur, Dobbelsteen & Yap (2017)*

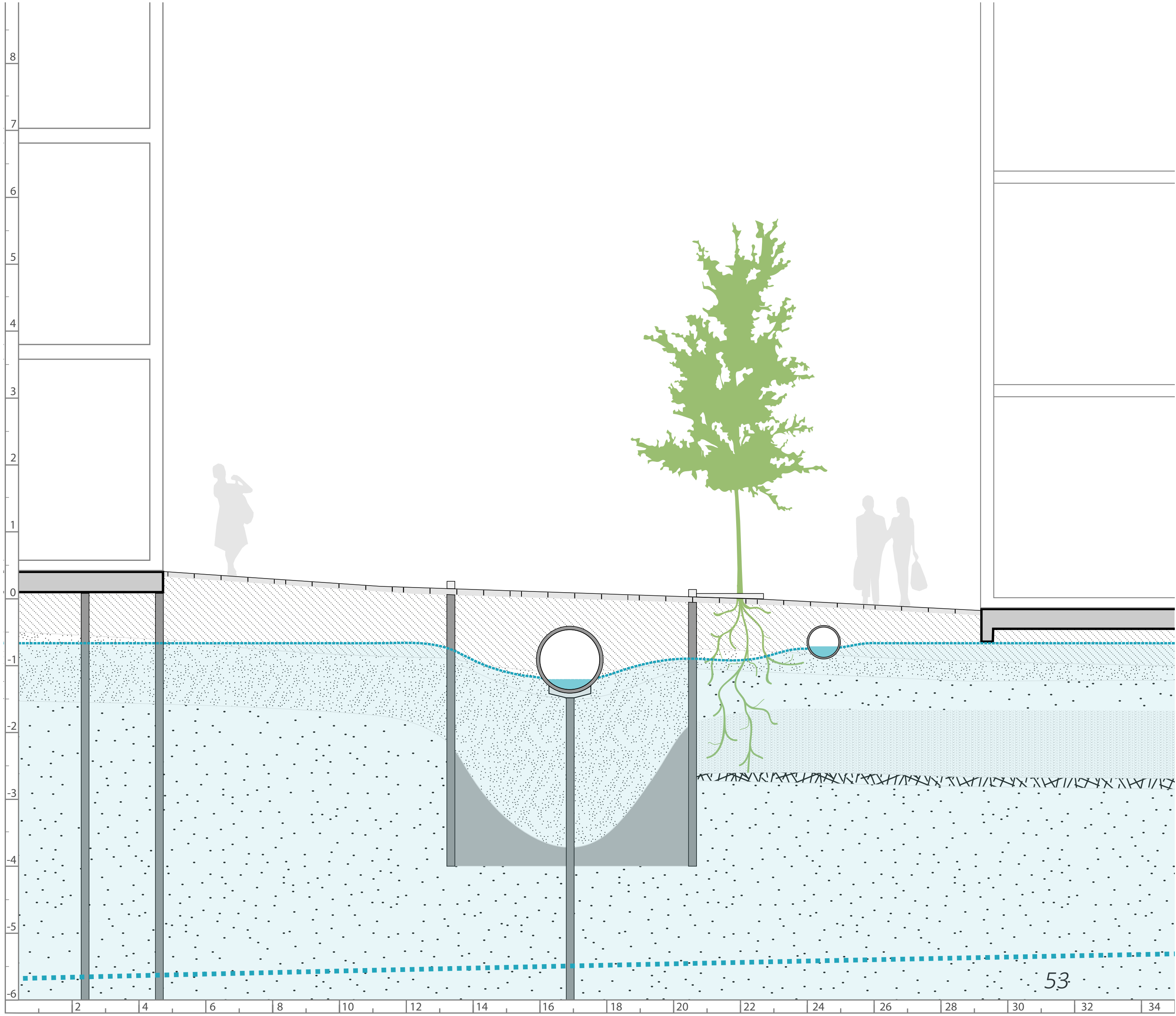


Figure 8.19. Section Nonnenwater

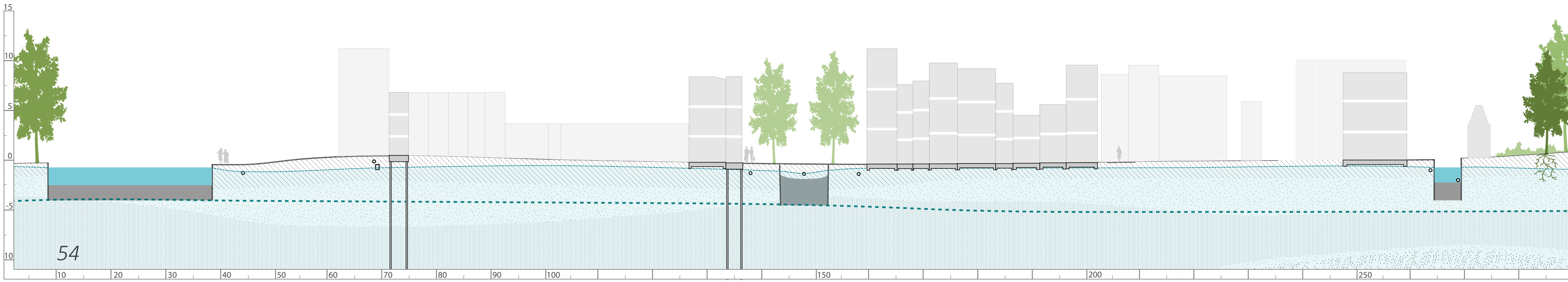
8.4.3.2. City section

Research by Willemse (2017) has already shown that around 450 buildings within the city centre have wooden foundations, but an even larger number, mostly consisting of the older buildings have shallow or even no foundations.

While no comprehensive research has been done into the foundation type of every building, chapter 8.4.2. shows how the existing data can be extrapolated into a map with likely foundation types. This same data is used for this section, and the lack of load bearing pile foundations is immediately obvious. The majority of the foundations in the image are shallow, which makes them vulnerable subsidence and consequently to flooding in specific locations.

It also shows the buildings next to the Gouwe, which, while lacking pile foundations, are in less danger of flooding and subsidence due to the clay layer that was long ago deposited by the river (Van Winsen et al., 2015).

And while the freeboard and amount of dry soil is larger in those areas next to this central river, in other areas the ground water level is very high, and even the small effect of sewers and is insufficient.



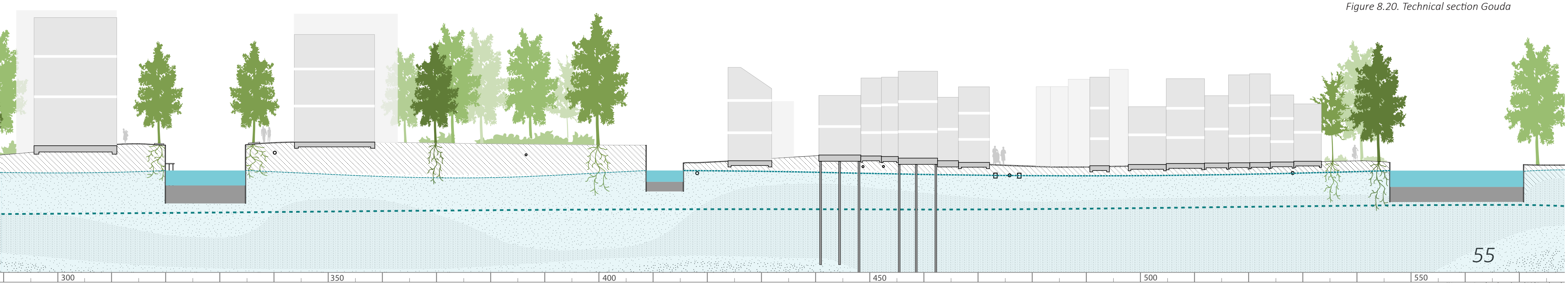
Another factor that influences the groundwater level is the amount of trees in the area. While not clearly shown on this scale, measurements by Wareco (2018) show a marked difference in waterlevel in backyards with higher levels of vegetation, especially in the winter months.

Throughout this section, many of the canals in the city centre can be seen, but this profile also shows one example of the closed off canals that were filled in during the 20th century (RAAP, 2017). This particular example, Raam was filled in in the 1960s, and replaced with parking places.

Within these underground remains, a sewer replaces the watertransport function of the original canal (Gemeente Gouda, 2018a). On one hand, this sewer is definitely more hygienic, as during the time this canal was filled in, many of the local sewer connections to the houses would likely still have discharged their refuse into the surface water (Denslagen, 2001; Tamboer, 2007).

On the other hand, the spatial advantages of surface water is gone, and the flexibility to adapt the water system definitely lessened.

Figure 8.20. Technical section Gouda



8.4.3.3. Market

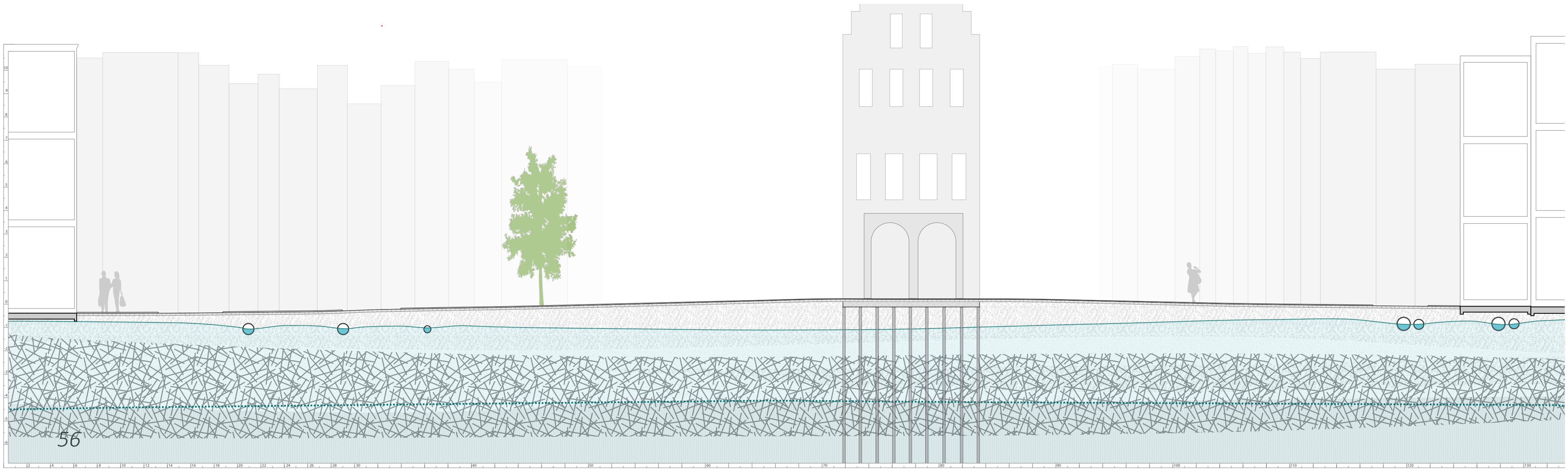
In 1438, there was a fire in the city that was so catastrophic that the old city, almost entirely built out of wood and thatch burned down in its entirety. This disaster, which left only a few houses standing, caused the city officials to think carefully about fire safety.
One of the developments was a move towards stone buildings, which will be visitied in more detail in chapter 8.6. Another was the rebuilding of the town hall (Denslagen, 2001; Abels, 2005).

As a preventative measure, it was placed in the middle of a large square, with no buildings around it, to prevent this disaster from reoccuring.

The area on which the new town hall and market were built was low-lying and marshy, and the citizens had to spend some time carting debris to this area to level it out (Denslagen, 2001). This layer of is clearly visible in the technical profile.

Over the centuries, the original foundations caused uneven subsidence in the town hall, and so the 1947 renovation started with the replacement of these foundations with new concrete pile foundations that rest directly on the sand layer. (Denslagen, 2001)

Figure 8.21. Section Market



8.4.4. Sewer overflows
This map shows a general overview of the main sewer lines in the city centre, as well as the overflows that can discharge onto the surface water. This can be a problem, as was explained in chapter 3, especially in lower-lying areas (Tamboer, 2007).

A noticeable increase in the number of sewers (3) within one street profile can be found in the Nieuwe Haven and Raam, the locations of two of the major canals which were removed in the last century. Likely these new canals were added to the sewer system in addition to the sewer lines that were laid at the end of the 18th century (Denslagen, 2001)

Figure 8.22. General overview sewer system and overflows (Gemeente Gouda, 2018a; Hoogheemraadschap van Rijnland, 2007)

8.4.5 Green

8.4.5.1. Trees

The trees in the city centre can be divided into several categories. The most recogniseable of these are probably the structured lines next to many of the (former) canals. The main structure here consists of a double row of linden trees which follows the Gouwe (Gemeente Gouda, 2018b), with the secondary structure following the Nieuwe Haven and Raam.

Throughout the rest of the city there are many other trees, both owned by particulars and the municipality, some of which have monumental status (Gemeente Gouda, 2018a).

Many of these municipality owned monumental trees are located in the southern green areas, and next to the church.

Figure 8.23. Trees structures in the city centre (Gemeente Gouda, 2018a)

8.4.5.2. Green areas

This map shows the green areas in the public areas of city centre.

While there are green spaces in the backyards, it still becomes obvious very quickly that the most of the green spaces in the city centre consist of two parks in the southern area, narrow green spaces next to the singels, and a small park next to the church.

Figure 8.24. Green surfaces (Gemeente Gouda, 2018a)

8.4.5.3. Green storage

Green spaces can be a very effective storage space during levels of high precipitation. However, most of this storage is located in the subsurface, through infiltration. In order for these interventions to be effective, the freeboard must be large enough that there is enough dry ground in which this precipitation can be stored.

This map shows one of the highest areas in the city centre, in which the green is colour-coded according to the average ground level.

When this knowledge is compared with the height level map, it becomes clear that green in other areas will be much less effective in local water storage.

The numbers used in this legend are based on the stated groundwater level: -0.7m (Tamboer, 2007). In reality, it is likely that the water level is a bit higher through capillary effects, which lowers the potential storage.

- 3.7 - 2.7 m of potential storage
- 2.7 - 1.7 m of potential storage
- 1.7 - 0.7 m of potential storage
- 0.7 - 0.5 m of potential storage

Figure 8.25. Height differences in green areas (Tamboer, 2007, Gemeente Gouda, 2018a)

8.5. Street analysis

Built directly on top of the technical subsurface are the streets of the city, and many of their characteristics can often be derived from this technical subsurface. This part of the analysis studies the streets and their characteristic shapes, and how these profiles add to the vulnerabilities and potential for flooding within the city.

8.5.1. Street profiles

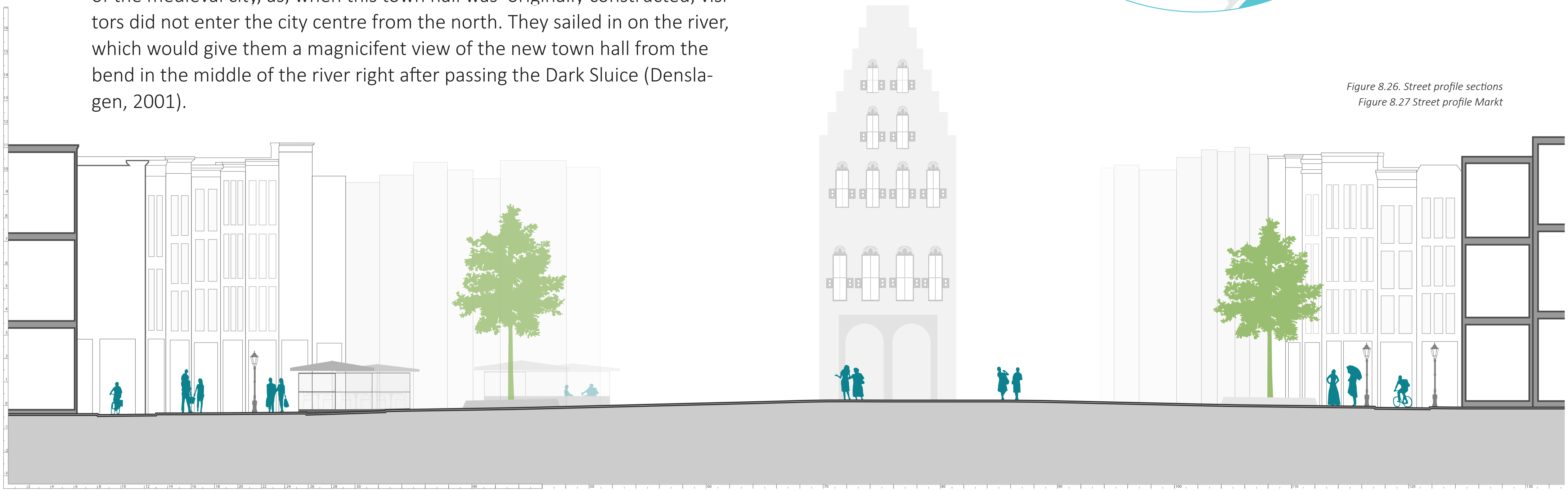
8.5.1.1 Market section

In modern times, many people enter the city centre from the direction of the train station, located north of the city centre. This is the view those visitors will see when they enter the marketsquare. Next to the buildings on either side there are small terraces and walking paths for shoppers, but most of the space is empty and reserved for the market.

Interestingly, all these visitors look at the back of the town hall. This is a relic of the medieval city, as, when this town hall was originally constructed, visitors did not enter the city centre from the north. They sailed in on the river, which would give them a magnicifent view of the new town hall from the bend in the middle of the river right after passing the Dark Sluice (Denslagen, 2001).

Figure 8.26. Street profile sections

Figure 8.27 Street profile Markt



8.5.1.2. Symmetrical street profiles

The market is a unique location in the city centre, but there are many recurrent street typologies throughout the city centre. One of the most important ones, historically, is the symmetrical structure of the streets in which the canals are integrated. These used to be the central market places of the city, and a street on both sides (in contrast to the asymmetrical street profiles) allowed for more and easier trade.

This profile shows a section of the Gouwe, and the Oost and Westhaven, but this profile continues all the way throughout the city, and can be found in the Turfmarkt as well. It is also still recognisable in some former canal streets, such as the Nonnenwater and Raam.

The removal of these canals actually left them with an unnaturally wide street profile, and the problematic consequences, as well as the potential this gives, are discussed later in this thesis.

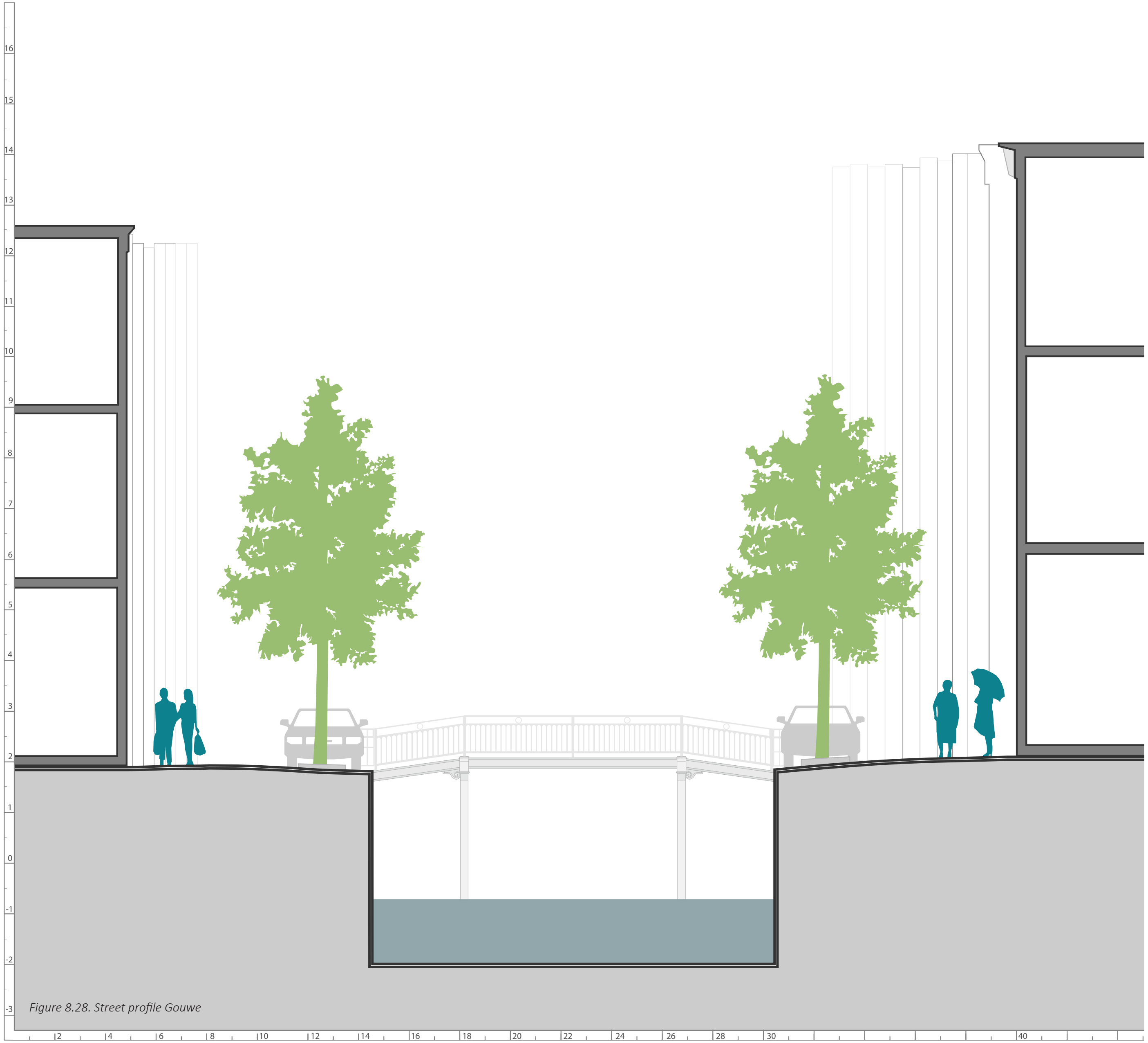


Figure 8.28. Street profile Gouwe

8.5.1.3. Asymmetrical street profiles

While this thesis talks a lot about the Gouwe, and the symmetrical street structure, it is not the traditional profile of the streets.

In the oldest parts of the city, many of the street profiles were asymmetrical, in part because of the many different small businesses in the city centre that used this water (Denslagen, 2001)

These streets had a house on one side, and a business on the back of the plot on the other side, and some of the modern facades on the back of these plots still state what type of business this used to be.

Interestingly, this typology was so common that symmetrical street profiles were 'doubled', and part of the street that follows the Gouwe is actually named for this effect (Denslagen, 2001).

Currently, the Spieringstraat, Peperstraat and Zeugstraat are the only ones that still have this historicallly important profile, though the businesses are gone. The private plot on one side of the canal gives them a more private character.

Figure 8.29. Street profile Peperstraat

8.5.1.4. Alleys

Not all the streets in a city can have the large, monumental profiles that are often characteristic for the most central and important streets in the city.

On the whole Gouda is a very dense city, and many of the common streets have a very narrow profile, with no clear separation of pavement and road. While this could potentially lead to claustrophobic situations, an important element to consider is that many front facades look out at these streets.

The profile is occassionally filled in with small public spaces for and maintained by the local inhabitants, which gives these alleys a homely character.

Figure 8.30. Street profile Lange Dwarsstraat

8.5.2. Streets

8.5.2.1. Valuable roads

In chapter 8.3 some of the important landscape structures and lines that run through the city are analysed, as well as their development throughout the centuries.

Noticeably, some lines were prominent from the earliest settlements in the area, and are still visible today.

These roads have historical value, but they are also the paths that connect most directly from the central point of the city outwards to the large road outside the city. This makes them excellent evacuation routes in emergency situations, and this factor will be influential on the later design.

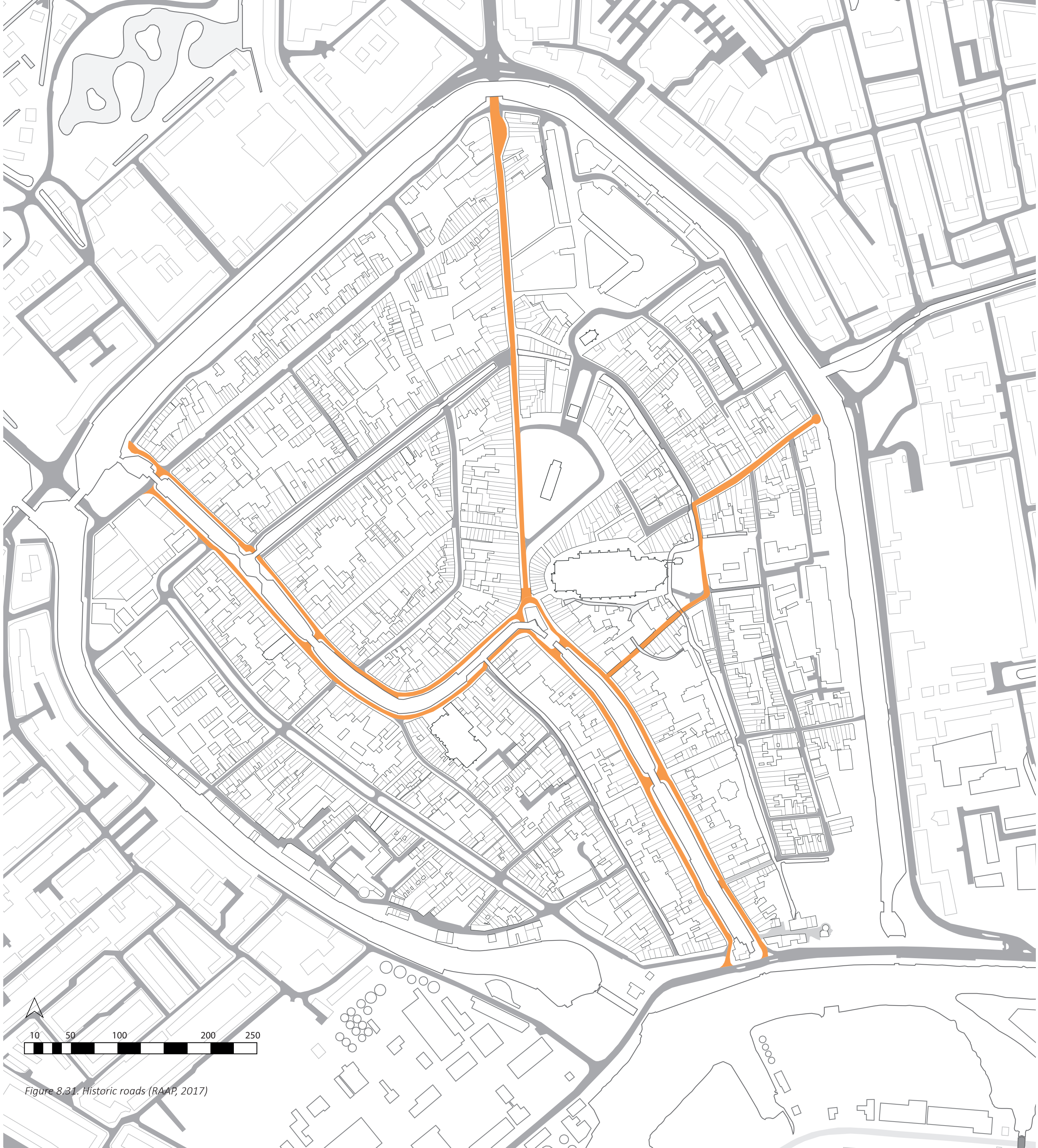


Figure 8.31. Historic roads (RAAP, 2017)

8.5.2.2. Pavements

An element that has been mentioned in passing during chapter 8.5.1 (Street profiles), is the lack of pavements in many of the streets. While a distinction is made between pavements and roads through the type of paving present in the city, this is not reflected in any height differences.

It contributes to the historical street profile, but it can be very disadvantageous for water storage. These raised pavements would form a natural barrier, that Gouda so far has had to do without. Only some newer areas of the city have pavements.

Figure 8.32. Pavements

- Pavements
- No height difference
- No pavements

8.5.3. Flooding

8.5.3.1. Water

The technical profile and height maps have already shown how small the freeboard is in specific areas of Gouda, and this analysis shows how much of a problem this can be during extreme precipitation effects.

This maps shows an analysis by the Hoogheemraadschap van Rijnland (2018) who created a flooding scenario during a 100 mm/2 hours precipitation event. Flooding occurs through most of the entire inner city, but the lower lying areas are nearly entirely submerged.

Figure 8.33. Flooding problems (Hoogheemraadschap van Rijnland (2018)

8.5.3.2. Flooded roads

The flood map showed that many of the lower lying areas would be submerged during extreme precipitation effects, and this has important consequences.

This level of flooding makes many of the roads inaccessible. During times of disaster, passable roads are a vital component, both for evacuations as well as emergency traffic.

The map shows the status of the roads during this extreme precipitation event as calculated by the Hoogheemraadschap of Rijnland, and makes it clear that the historical evacuation routes described in chapter 8.5.2.1. are not actually useable in the current situation.

Figure 8.34. Flooded roads (Hoogheemraadschap van Rijnland, 2018)

- Inaccessible roads
- Only emergency traffic
- Accessible roads

8.6. Building analysis

While urbanism more commonly focuses on the street level design rather than the buildings, the facades form an important element in the vision of the street that the designer wants to create, specifically when considering the experience of the users on eye level.

Throughout the various stages of the project, from the analysis to the workshops, the importance of these facades as a highly valued part of the street kept coming to the forefront. The varied exteriors tell part of the story of Gouda and are strongly connected to both the history as well as the innotative spirit of the city.

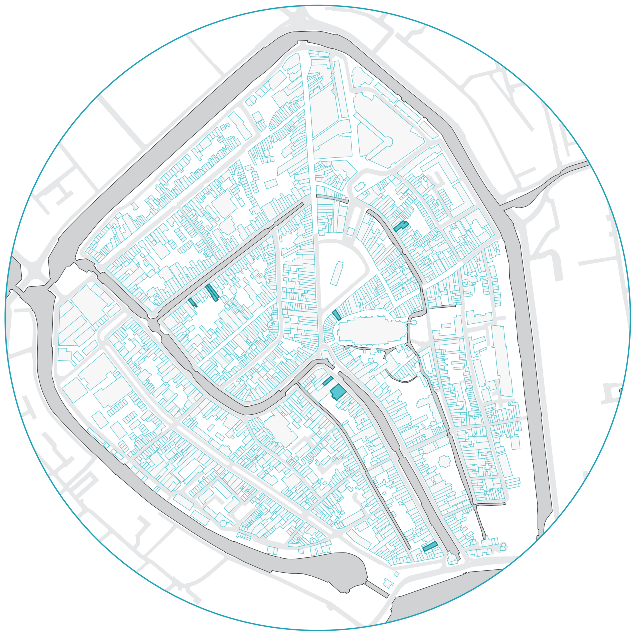


Figure 8.35. Locations of the facades analysed in this chapter

8.6.1. Monumental analysis

Throughout the centuries, the buildings in the city have changed often, sometimes through demolishing, but often through renovation. Historical data shows that smaller houses were merged into larger ones and facades were renovated to better fit the times (Denslagen, 2001), in this same sort of innovative spirit that marks the water system development.

This left Gouda with an eclectic mix of buildings and building facades, but study does show a general narrative trend in the development of the built environment of the city.

Like many medieval cities, many of the houses in Gouda were constructed from wood and thatched roofs, until a fire rushed through the city in 1438, and nearly burned down every house. From then on, fire safety became rather more important, and rewards were given to inhabitants who renovated their house with less flammable materials (Denslagen, 2001).

Eventually, over the course of the 16^{th} century, the wooden construction was replaced by stone materials. Interestingly, the facade was often still made out of wood, as it was so easily adaptable to the changing needs, and allowed for larger windows and more light. The lower part of the facade could be moved, and turned into a shopfront whenever necessary, allowing for multifunctional use (Denslagen, 2001).

All the pictures in this analysis were taken by the author.

8.6.1.2. Middle ages to the late 17th century

The use of natural types of stone cut in blocks, such as e.g. granite or marble, was not really practiced in Gouda. Eventually in the 16th and 17th century, the major building material used for the facades shifted from wood to clay bricks (Denslagen, 2001)

This trend towards renovation that brought the houses in with popular trends at the time made it so that only a few buildings have kept their medieval facade, though more of these buildings might be hidden beneath newer exteriors (Denslagen, 2001).

Westhaven 65 is one of these medieval facades, built in 1515, and recogniseable by the horizontal decorative bands across the facade (Denslagen, 2001). The stone has a very weathered look, especially in comparison to some of the other monumental buildings in the street.

The second facade shows a style that was popular in Gouda for quite a while: the crow-stepped gable. They were prevalent throughout the city until the style fell out of fashion in the 18th century. When these buildings were renovated, many of the gables were entirely or partially removed, and only a few remain in the city today (Denslagen, 2001). Zeugstraat 64 is a good example of one of these.

Figure 8.36. Westhaven 65. June 16th, 2018
Medieval facade

Figure 8.37 Westhaven 64. June 16th, 2018
Crow-stepped gable

8.6.1.3. Clock gables and simple constructions

When the crow-stepped gable fell out of popularity in the late 17th century, the clock gable stepped in to fill the gap, which can be seen in Turfmarkt 107, built in 1735. While this type of facade often lends itself to extravagant decorations, such facades in Gouda were often made out of brick, and decoration was limited and subtle (Denslagen, 2001).

But along with these other styles, there was a great preference for houses with simple straight lines and a flat facade in a classical style. These days a majority of the monumental buildings has this type of facade. Decoration, if present, was kept subtle (Denslagen, 2001). A good example of this style is Turfmarkt 69.

Figure 8.38 Turfmarkt 107. June 16th, 2018
Clock gable (1735)

Figure 8.39. Turfmarkt 69. June 16th, 2018
Classical gable (1644)

8.6.1.3. Symmetries

Within these straight facades, several types emerged. In this period, many smaller houses were merged to form larger buildings, with a new facade, often symmetrical and consisting of three to five bays (Denslagen, 2001)

Falling back to classical style ideals, symmetry was highly desired in these designs, but construction-wise, it was much easier to place the entrance on either the left or right side.

To disguise this, extra attention was paid to the central bay of the houses with the addition of extra decoration (Denslagen, 2001).

Not all of these buildings were symmetrical, and several buildings with four bays can be found within the city centre, standing out from amongst the others (Denslagen, 2001). One such example is Westhaven 12, built in 1762. This building emphasizes its asymmetrical lines with extravagant decoration.

Throughout the city, many asymmetrical facades with two bays can be seen as well, but these smaller houses often have less decoration, and stand out less.

Figure 8.40. Westhaven 8. June 16th, 2018
'Symmetrical' facade (1897)

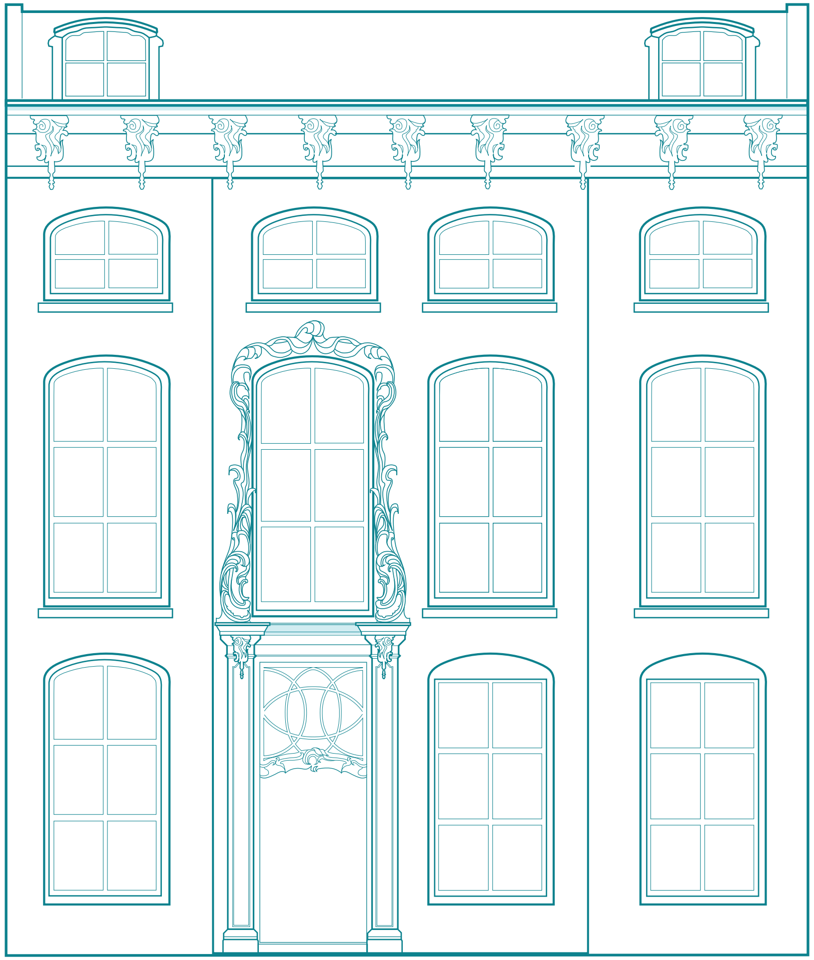


Figure 8.41. Westhaven 12. June 16th, 2018
Asymmetrical facade (1762)

8.6.1.3. Sober and Simple

Many of these houses were built and renovated during Gouda's golden age. Trade was flourishing, and the city had money to spare. But in the 19th century, this had all gone (see chapter 3.2) (Denslagen, 2001).

The city was very poor, and almost no new buildings were constructed. Houses were renovated or demolished. These serious financial circumstances were reflected in the facades of the houses (Denslagen, 2001).

Building exteriors were constructed with plaster, or brick, and very simple decorations were created with the material of the buildings (Denslagen, 2001).

Figure 8.42. Markt 2. June 16th, 2018.
Simple brick facade (1890)

Figure 8.43. Turfmarkt 71. June 16th, 2018.
Simple facade (1900)

8.6.2. Monuments

This map shows all the monuments present in the inner city, of which there are many, with the amount increasing the closer one gets to the centre of the city.

Traditionally, the outer edges were reserved for the industrial functions of the city (Denslagen, 2001), while the the inner city contained the historical houses, municipal and religious centres that are still mostly present in today’s city centre.

Even though the industry is gone, their historical remains can be seen in the difference in building age and monumental status in the city.

Figure 8.44. Monuments city centre (Gemeente Gouda, 2018a)

National monuments

Municipal monuments

8.6.3. Flooding

Unfortunately, these monumental buildings are now in danger. Chapter 8.4. showed that many of these old monumental buildings were not built on steady pile foundations, but often on shallow foundations. This makes them sensitive to subsidence, and over the centuries they slowly sunk along with the rest of the city centre.

These low floor levels makes them particular prone to flooding, especially in the 100 mm/2 hours scenario that the Hoogheemraadschap van Rijnland (2018) uses as their extreme precipitation scenario.

Strong risk
Average risk
Low risk

Figure 8.45. Flooding risk houses (Hoogheemraadschap van Rijnland, 2018)

8.6.4. Endangered monuments

The modelled consequences of extreme precipitation (Hoogheemraadschap van Rijnland, 2018) paint a bleak picture. A combination of these two maps shows the high risk to several of these monuments.

The high value that is placed upon these monuments, especially by the inhabitants, turns this issue into one of the main factors that influence the design.

High risk
Average risk
High risk

Figure 8.46. Flood risk monuments (Hoogheemraadschap van Rijnland, 2018; Gemeente Gouda, 2018a)

8.7. Important conclusions

The potential problems in the city centre must be taken seriously. While the precipitation event that is used throughout this analysis of 100 mm/2 hours (Hoogheemraadschap van Rijnland, 2018) is an extreme case, the likelihood of occurance increases with escalation of climate change effects.

A combined map shows how the flood risk in the city interacts with the monumental buildings, as well as the green spaces within the city centre. Specifically, it shows that many of the monumental buildings are vulnerable to flooding, and so are the evacuation routes, while any potential absorbent capacity in the form of green spaces is located well away from the issues.

In order to create an adaptable city that is still recognisably Gouda, it is important to find out what elements must be maintained, and where change is possible. In order to gain a comprehensive overview of this situation, the opinion of local stakeholders is sought in chapter 10. In chapter 5, the theoretical framework states that one of the requirements of such a task is the formulation of a risk analysis which, in this case, compares the value of the buildings (social and economical) verses the danger. Included as a factor within this analysis is the ease of adaptation. This is done in the design vision in chapter 12.

The original map is not available at this time for online publication

Instead, these images show a representation of a possible street in the city centre, and do not reflect any actual location. The three schematics each show one of the three results of the risk analysis.

1. No flooding and no monumental buildings at risk (monumental buildings not at risk are represented by a bold line)

2. Monuments at risk of flooding

3. Risk of flooding in areas without a lot of monumental buildings

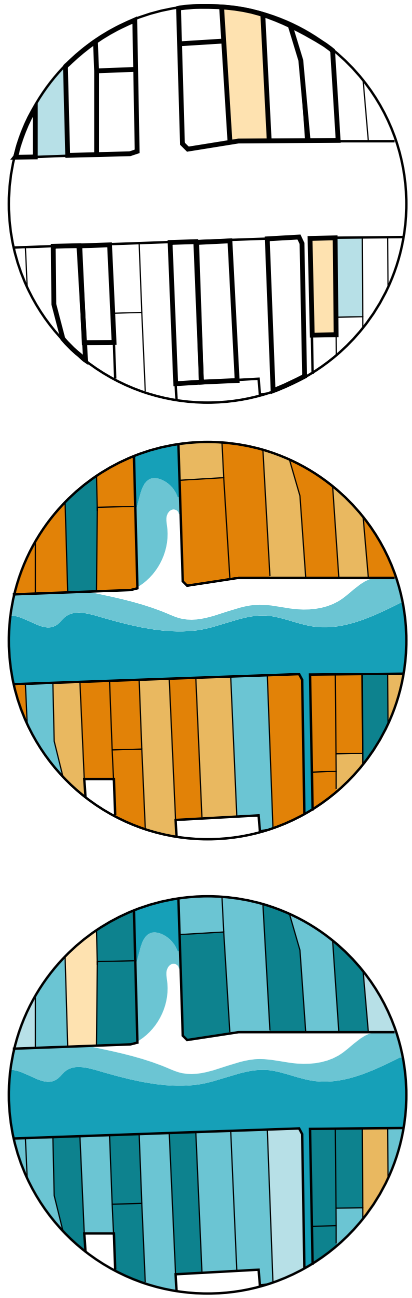


Figure 8.47. Combined problems

9. Research interventions

9.1. Introduction

Scenario making is often a helpful tool to study uncertainty when creating a robust design which will endure through (nearly) all expected futures (Hallegatte, 2009).

Robust interventions do not suit the priorities of this project, so instead Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013), to develop climate sensitive adaptations. This is possible by testing all the interventions and assigning them a tipping point. These represent the highest level of precipitation and flooding each particular intervention is capable of mitigating before it fails, in which case damage results (Haasnoot et al., 2013). This is done by calculating their maximum capacity for climate adaptability in comparison to set objectives.

The interventions are developed on several scales, in order to meet the three main objectives for this study: *design research, social research* and t*echnical research*. These objectives are represented by two steps within the DAPP methodology (the creation and testing of specific actions). At the same time, these steps help evolve the project towards the final design.

The scale of the interventions varies from a city-wide design to small adaptations on the street level. They also represent the first concept sketches of the eventual strategies that will be developed. They are an interesting tool to analyse various road patterns, building configurations, neighbourhood borders and social places within the city.

The second objective is the social suitability. One of the most important aims of this project is to create an improved situation for the inhabitants which protects their property and living situation from climate change-enhanced flooding. This project focuses on the use of spatial interventions over technical solutions because of the potential added benefits. While many designs bring relief from the flooding and precipitation problems, careful consideration is needed to develop a strategy that maintains the essence of the city even through spatial adaptation.

The last objective is to test the technical efficacy of these interventions. The choice for spatial interventions for a project whose major objective is to add water capacity for extreme precipitation events, quickly narrowed down the focus of this project onto green-blue interventions.

The interventions were created to interact and work in conjunction. Combined designs yield an increased amount of water capacity. However, this adds to the complexity of testing the efficacy of such interventions in comparison to preset objectives. To create clarity, two extreme scenarios were developed each focusing exclusively on one aspect of green-blue design, from which all further research interventions were built.

These research interventions were developed on multiple scales, in order to create a complete portfolio of possibilities, and to be able to gather as much data as possible for all three objectives. The main target here was to make sure this design series provided a guideline throughout the workshops.

The research design materials consist of three scales: scenario, typology and the interventions, as well as a fourth category (ensembles) that represents the potential results that could be reached simply through strict adherence to these interventions. The scenario-scale serves as an introduction to the concept, the typology hones in on the specific preferences citizens have about the size and ratio of the streets and buildings.

The interventions tranlated the ideas from these earlier scales into practice, and developed them into measurable, realistic design elements that could be used for the calculations. For the workshop, these interventions served as a physical representation of the street on eye level, and as building blocks for the ensembles, visualizing potential futures.

All these objectives and scales resulted in a large portfolio of many different design options, which were presented during the workshop, and used throughout chapter 11. The specific designs can be found in the addendum booklet to this thesis.

9.2. Scenarios

The largest scale research interventions are also the most extreme, and least realistic, in part because of what they had to accomplish. When looking at the three objective categories (design, social, technical), this scale is not actually relevant to all. Nevertheless, it provides an interesting study for the project objectives, showing the potential range of options for the final design, as well as the effect the choice for a specific type of spatial intervention had on the final results.

These dramatic, city-wide scenarios are not useful for the technical efficacy, which requires specific interventions and measurements in order to carry out the the calcations.

The main objective for this step was to define a starting point for the workshops, and to set the tone for this entire exercise. The extreme level of these scenarios was to provide a shock, and to help participants let go of any preconceived notions they might hold, and to immerse themselves into this entirely different series of solutions.

At the same time it was interesting to see during the workshop what elements the stakeholders objected to, if one scenario was much more objectionable than others, and what arguments were given to substantiate this.

While each scenario focuses exclusively on either green or blue interventions, they are developed through different methods, in order to gain more detailed information about the specific wishes of the inhabitants.

Figure 9.1. Extreme scenario: blue
Figure 9.2. Extreme scenario: green

9.2.1. Blue Scenario

The blue scenario focuses on the addition of large amounts of water by doubling the surface area of the singels. In order to create this large body of water, the outer ring of houses, which the analysis shows has less monumental value, was demolished. To maintain the same number of buildings, new, innovative floating houses can be built, and a public waterfront can be developed.

This scenario stores water through quick discharge of precipitation, using a series of open gutters or other surface water flows in the inner city to these singels, where the extra precipitation can be stored until the existing water system is able to process it.

9.2.2. Green Scenario

While the blue scenario buys out private plots to develop a large new urban water front on which new developments are built and sold, the green scenario takes a different path and uses exclusively municipal land.

This means no buildings are demolished in the realisation of the scenario but the character and use of all public streets will change drastically. Public areas, including the streets, markets, parks, parking places are turned into a large scale urban park. The addition of so much soft surface also changes the way transport works throughout the city, and even what methods of transport are possible in the inner city. And while the blue scenario only creates major changes through a small part of the city, the green scenario affects the character and image of the entire city centre.

 Figure 9.3. Map extreme scenario: blue

Figure 9.4. Map extreme scenario: green

9.3. Typologies

9.3.1. Blue typology

The typologies carry on the ideas of the extreme scenarios, but focus this on street level. The analysis shows that many different street profiles and building types are present throughout the city, evolved throughout the history of Gouda. The choice for the blue scenario was heavily influenced by the difference in style and age of the buildings on the city centre's borders versus those present in the middle, but are those actually less valued by the inhabitants than, for example, the monumental canal houses?

The typologies in the blue scenario creates a portfolio of options for innovative building and street designs on the newly created waterfront. This includes experiments with orientation, size and density, as well as the profile and useability of the waterfront of the singels. Different options ranged from a large monumental profile that mimicked the Gouwe and harbour within the centre, to small dense streets oriented on the housing typology within the city centre.

This allows the participants to point out their scruples and preferences in more detail. If all new options are rejected, a possible conclusion is that the objection is centred on the removal of existing buildings.

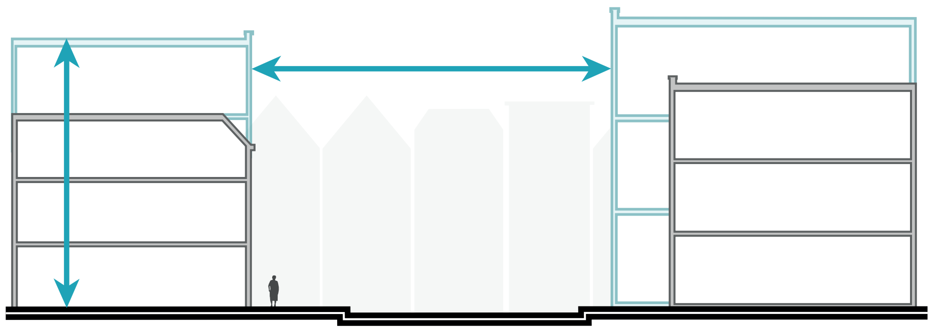


Figure 9.5. Schematic: Typology blue

9.3.2. Green typology

While the blue example specifically consideres changes to the building blocks and orientation, this typology instead focuses on adding detail to the street profiles. Gouda has many and varied profiles, from large canals to small alleys, but some of the new typologies are more common, while others are as of yety unknown within the city centre.

One common example is the double row of trees that marks so many of the monumental streets, while any form of private front yard is completely absent. This last option generated interesting possibilities, as in various places within of the city centre, citizens have created small pockets of green public space in front of their houses. These are maintained by the inhabitants, and function as small semi-private gathering places.

This study could also give interesting results about variations in green according to the street profile. While narrower streets naturally result in a smaller intervention, there are other ways to downscale this, from trees to small shrubs that might provide insight in the way inhabitants wish to actually use these streets.

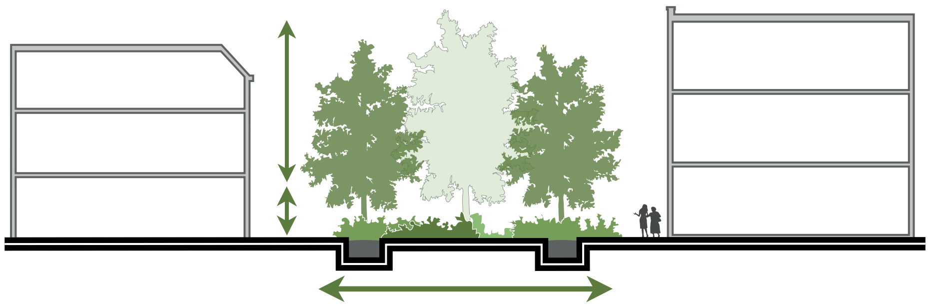


Figure 9.6. Schematic: Typology green

9.4. Interventions

The interventions are the largest, and most imporant group of research designs, and in order to be as multifunctional as possible, they have been produced as a series of street profiles. For the workshops, this shows how realistic designs can be developed from the idea that the extreme scenario concept brought forward. In the workshop, the longest section by far involved the rating of these interventions according to personal preference and suitability for the city. The goal is to start a discussion about the applicability of not only these specific profiles, but also about the larger concept of spatial changes to the city, and most importantly, what parts of the city could be adapted before its character and image was no longer recogniseable.

For the design objective, these early concepts were created to compare and test a large variety of design possibilities within the existing city structure and scale. The use of a realistic street profile was important, as these interventions are used in the calculation of the technical efficacy. By placing them in a realistic street profile, a comparison of the required space and the newly created storage can be made.

This chapter discusses some of the categories used to segment the interventions into easily comparable elements, gives the name of the intervention, and numbers them. A complete overview of the research interverntions can be found in the addendum booklet.

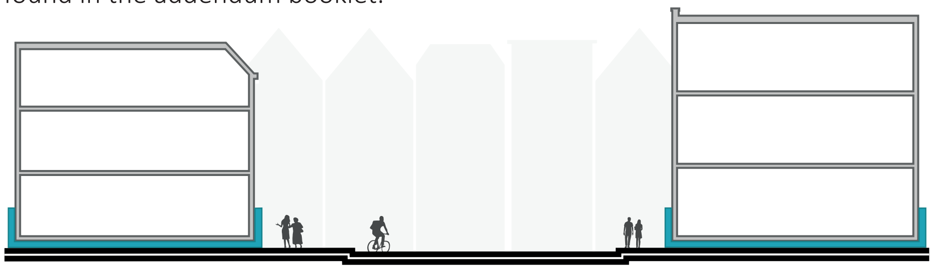


 Figure 9.7. Schematic: Normal interventions

9.4.1. Normal and Extreme interventions

The main drive behind the development of these interventions was for use during the workshop. In order to create contrast and provoke strong reactions, the interventions were developed in two levels of intensity. This forms a sort of axis that ranks these designs from subtle changes that take up little space within the street profile, to extreme situations which will completely alter the function and use of these streets.

For example, a gutter will only add a small drain to the street profile, but raising the houses to several metres above street level adds new public space, which will be filled in with new activities and walkways, making the street nearly unrecogniseable.

Within these intensities financial concerns are not taken into account. Interventions such as the barriers, would involve large scale underground renovation, in order to waterproof the foundations of the buildings. Such adaptations will cost a lot of money. Above ground, however, the final result will be a small barrier near the bottom of the houses' facades, and is thus placed amongth the normal interventions.

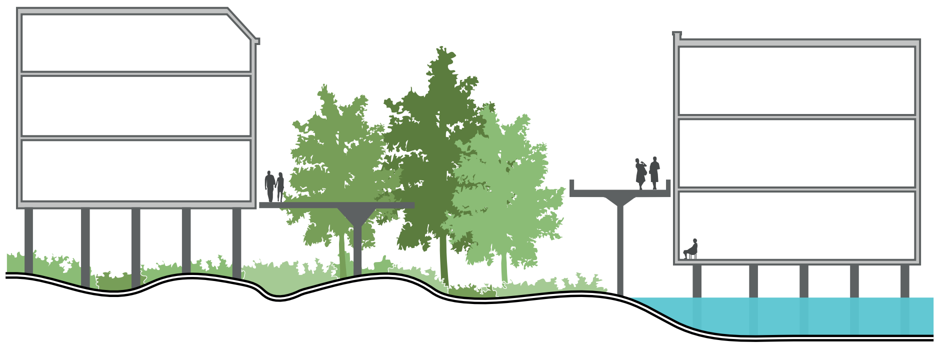


Figure 9.8. Schematic: Extreme interventions

9.4.2. Intervention categories

In order to get a comprehensive overview for the design goal and to test the technical efficacy, a large variety of interventions had to be created. However, for the workshops, this would raise the risk of chaos, because it would be too complicated to ask the participants to rank a group of 13 parallel interventions (not including the typology profiles, which look similar at first glance).

In order to add coherence, four categories were defined (buildings, streets, blue and green), and each workshop group received interventions for two of these: the two general categories and either the blue or green one, depending on which scenario they were developing.

Each intervention was designed from the perspective of one of these categories, which again provides contrast, and allows for interesting discussions during the workshops. Participants might dislike one or two interventions in each category, or they might dislike every intervention that adapts the related element of the street profile, such as the buildings, or the green spaces. This will generate interesting insight into the priorities of the local stakeholders on several levels.

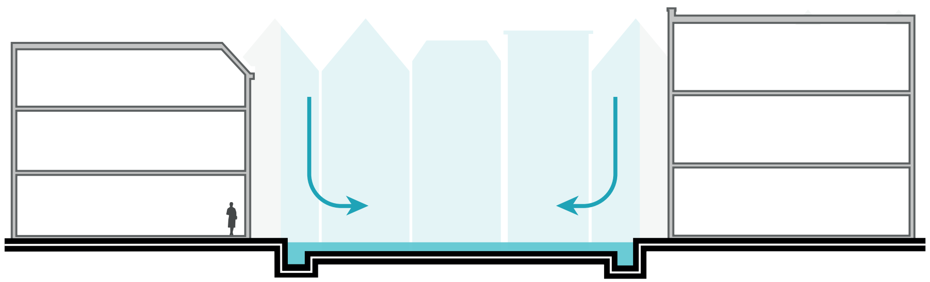


Figure 9.9. Schematic: Building interventions

9.4.2.1. Category 1: Building interventions

A significant portion of the analysis was spend discussing the importance and value of the buildings in the city, but at the same time it became clear how vulnerable these locations are to flooding. As a reaction to this, the building category was developed.
The focus of this intervention is the creation of designs that bar the precipitation-caused flooding to reach the monumental buildings. Interventions in this category include barriers (1), gutters (2), a green variation of the gutters, in the form of a green ditch (3), raising the level of the houses (4) and the creation of floating (5) or amphibious housing (6).

9.4.2.2. Category 2: Street interventions

The other general intervention focuses on the creation of storage in the streets to guide the water away from the vulnerable houses. While the end result of both interventions is roughly similar, the design options used to achieve this goal is different. The important aspect of the street intervention is the creation of local water storage, such as the permeable streets (7) or the infiltration boxes (8).

The extreme intervention in this category is an exception. The raised streets (9) were developed not because they create so much extra water storage, but to prompt participants of the workshop to think about completely different design options for the city streets.

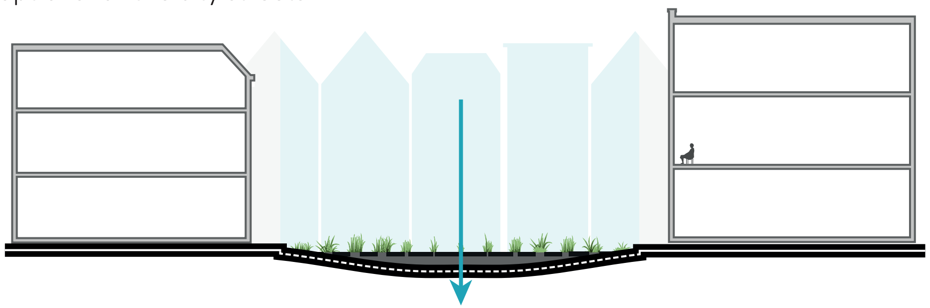


Figure 9.10. Schematic: Street interventions

9.4.2.3. Category 3: Water interventions

This group is the first of the water-based interventions, and is only handed out to the group of participants in the workshops who are working on the blue scenario. Both interventions in this category create of new surface water and localized water storage within the streets.

One of them focuses heavily on historical precedence, through the re-apparance of canals (11) in the street profile. While once a majority of the streets in the city had such canals, many of these were filled in and replaced by parking places during the 20th century (Denslagen, 2001). Bringing back these canals would reconnect the city to part of this historical heritage.

The other intervention in this category focuses instead on the development of modern, varied street heights (10) to create different zones and store water locally. This less extreme variant can be its own intervention, or it can be used as a step up towards the re-opening of the canals, if this second option is preferred.

An important distinction between the two interventions is the connection to the groundwater. The canals are connected to this system, but the varied street heights are not, and are thus in this situation more similar to the gutter intervention, which centres on the transport of precipitation to the outer singels.

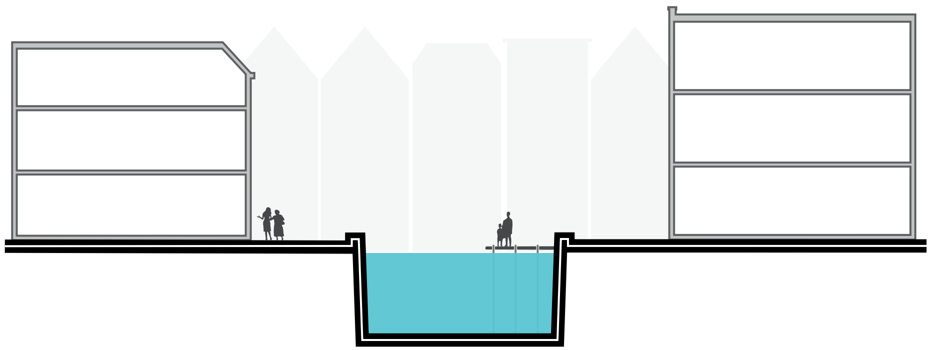


Figure 9.11. Schematic: Water interventions

9.4.2.4. Category 4: Green interventions

This is the other scenario-specific intervention, and it presents various methods of adding green space to the existing street profiles within the city. While Gouda has prominent tree structures throughout the centre, actual open ground can only be found in a few locations here. .

The normal and extreme intervention in this category compare these two green ideals. The first expands upon the existing tree structures in the city centre, adding extra rows to help encompass the living space and add interception storage (12).

The second, extreme design transforms the entire street, turning them into a long and interconnected wilderness (13) of parks and green spaces over and across which the inhabitants move. This creates a varying and seasonally changing street profile that adds new public spaces, playgrounds, and promotes more biodiversity, as well as many other benefits.

Figure 9.12. Schematic: Green interventions

9.5. Ensembles

These research designs are an early study into the possiblities of added water storage using spatial green-blue interventions. It examines how closely the shape of the pre-made interventions should be adhered to, and what combination of interventions works well together, and which interventions are redundant or conflicting.

However, for the workshops, these ensembles formed the conclusion of the exercise and thought experiment presented at the time: is it possible to use this extreme scenario and these standardized interventions to create a design that protects, adheres and even adds to the existing character of the city?

Opinions on the way these interventions were merged into a scenario could also provide a lot of new and interesting information. The opinion of the urbanist on how these interventions would look put together into a design might differ quite a bit from how an inhabitant would look at this.

One of the purposes of the workshops was to bring together stakeholders from other fields to see if there are disconnects in communication and opinion that can be discovered in the way these ensembles were drawn.

The ensembles were developed on the assumption that the stakeholders would have less experience with design. In this case, the ensembles show how an extreme idea develops into a realistic plan.
While the interventions still showed relatively generic street profiles, the last step was designed for the Nonnenwater, the street on which the two workshops focused.

To follow the theme of the workshop, a total of four ensembles were created, two of which adhere to the blue scenario while the other two focus on the green scenario. The first ensemble a group receives combines several of the most subtle and small interventions to create a new blue or green space, while the second ensemble creates a transformative experience according to the designated scenario.

9.5.1. Normal & Blue

For this particular ensemble, barriers, permeable streets and varied street heights were combined. It becomes immediately obvious that not all of these interventions are needed. The varied street heights form a natural barrier into which the water can be stored .There is a built-in gutter, as well as permeable surfaces, which are capable of both infiltrating and locally storing precipitation. In this particular ensemble, the gutter is used as a support system for the other water management interventions, as chapter 11 will show, its efficacy is mostly in its capacity to discharge water relatively quickly. This makes it a great connective element between larger interventions.

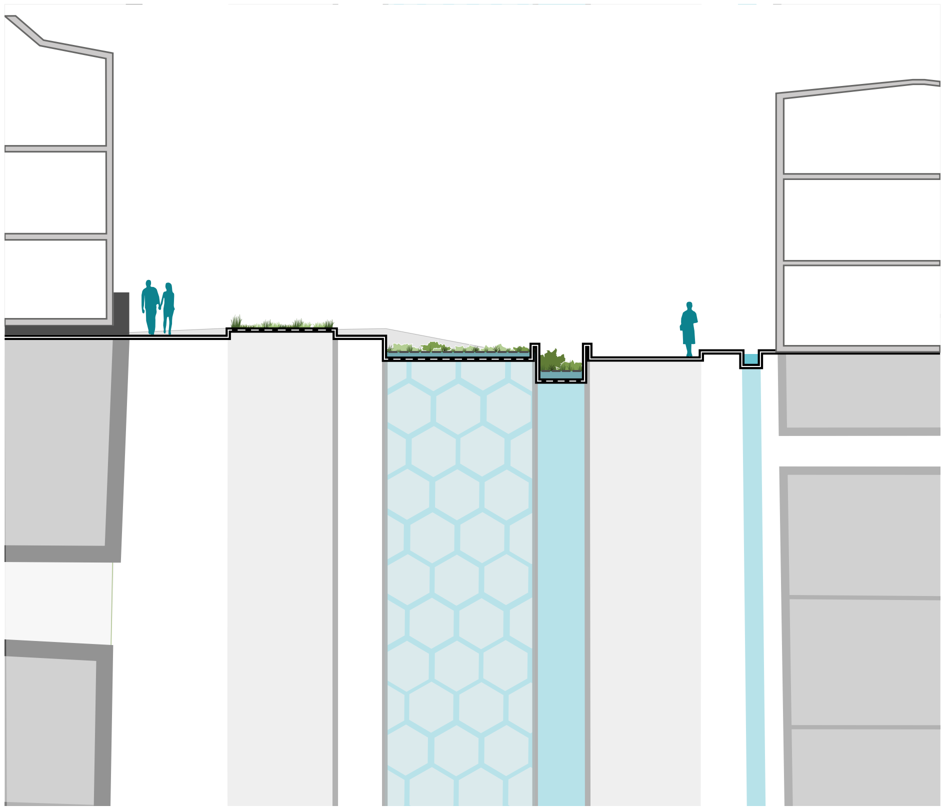


 Figure 9.13. Section ensemble blue - normal

Because the street in which for which this ensemble is designed used to be a canal before it was filled in around 1960 (RAAP, 2017), the street profile is very wide, with an empty space in the middle. In this ensemble, the space is filled up with the new water intervention. The small slope of the street itself is used to catch precipitation and guide it on its way to integrated local storage or gutter. While parking is no longer possible on this location, the centre of the street remains open and is useable as a public space.

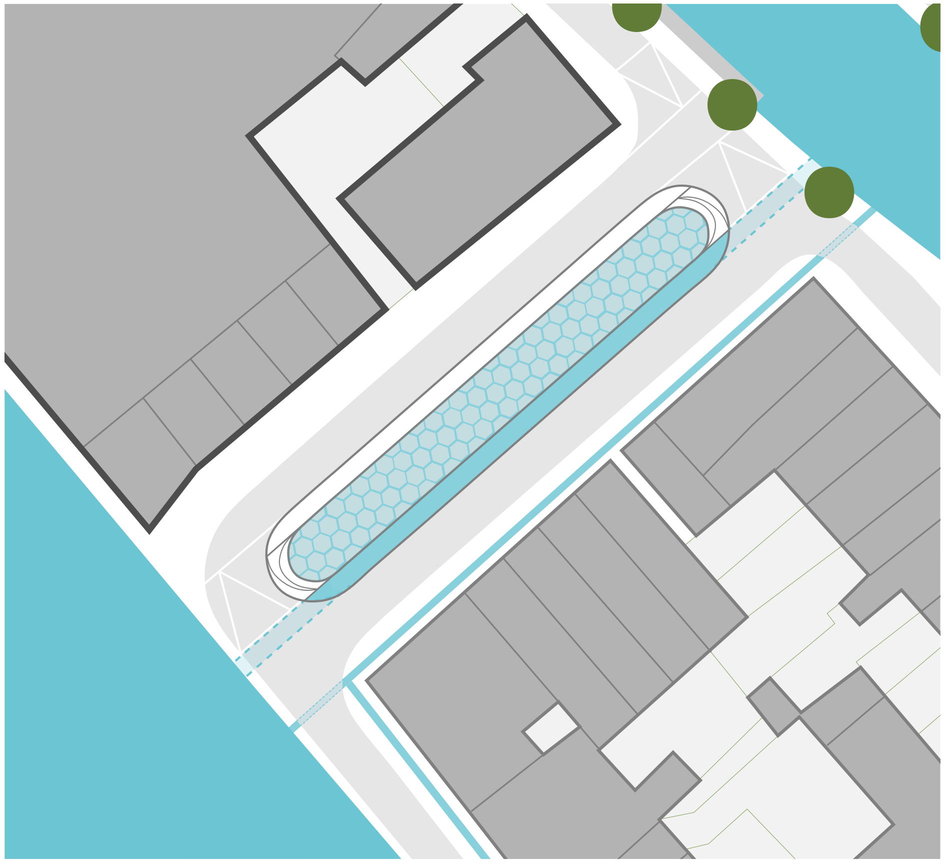


Figure 9.14. Ensemble blue - normal

9.5.2. Extreme & Blue

The removal of the canal in 1960 (RAAP, 2017), left the profile of this street slightly out of scale, with a large and empty middle space. The only logical option in an extreme scenario is to re-open the canal and connect the Gouwe and the singels.

In addition to this, both the streets and the living space are raised to a higher level, to prevent any damage in case of floods. This creates an intermixing of a low water-based public space, as well as a higher level public space with dry roads and social spaces.

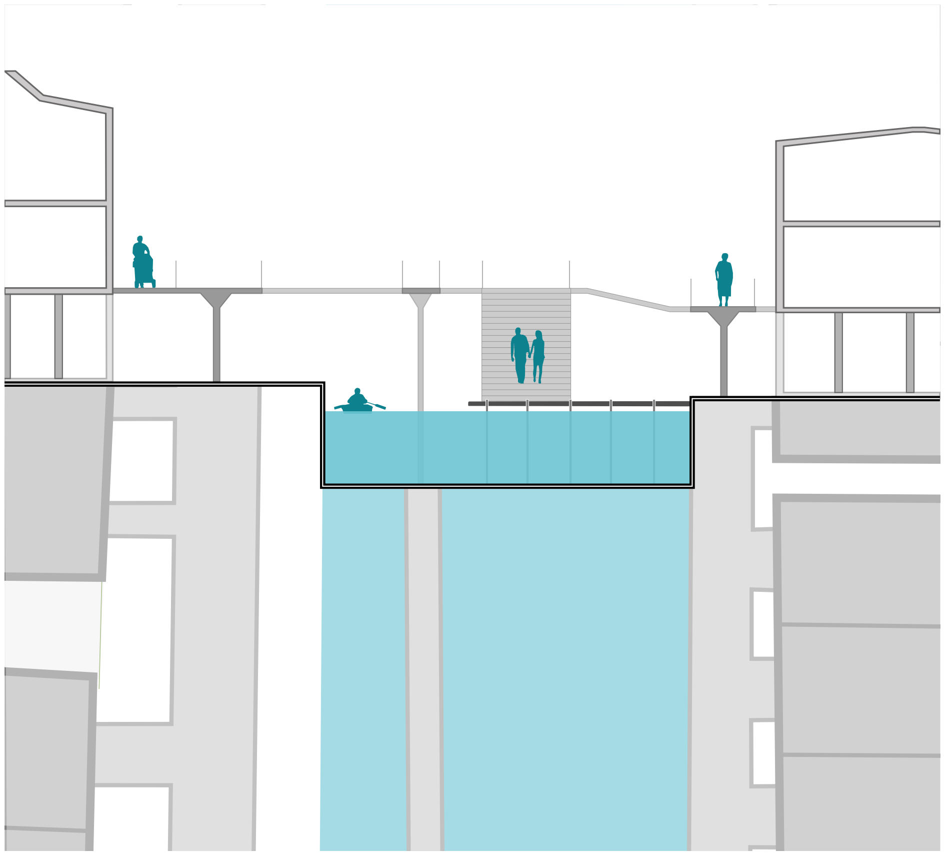


Figure 9.15. Section ensemble blue - extreme

Figure 9.16. Ensemble blue - extreme

9.5.3. Normal & Green

In this ensemble, no real changes are made to the main design of the public space. The addition of permeable pavement and ditches at either side of the old canal space will prevent water from flowing into the houses, and the creation of new green might make the centre of the street a more enclosed and useable space. This does involve the removal of several parking spots throughout the street, and lowers the carrying capacity of the road, which closes this space off for heavier vehicles.

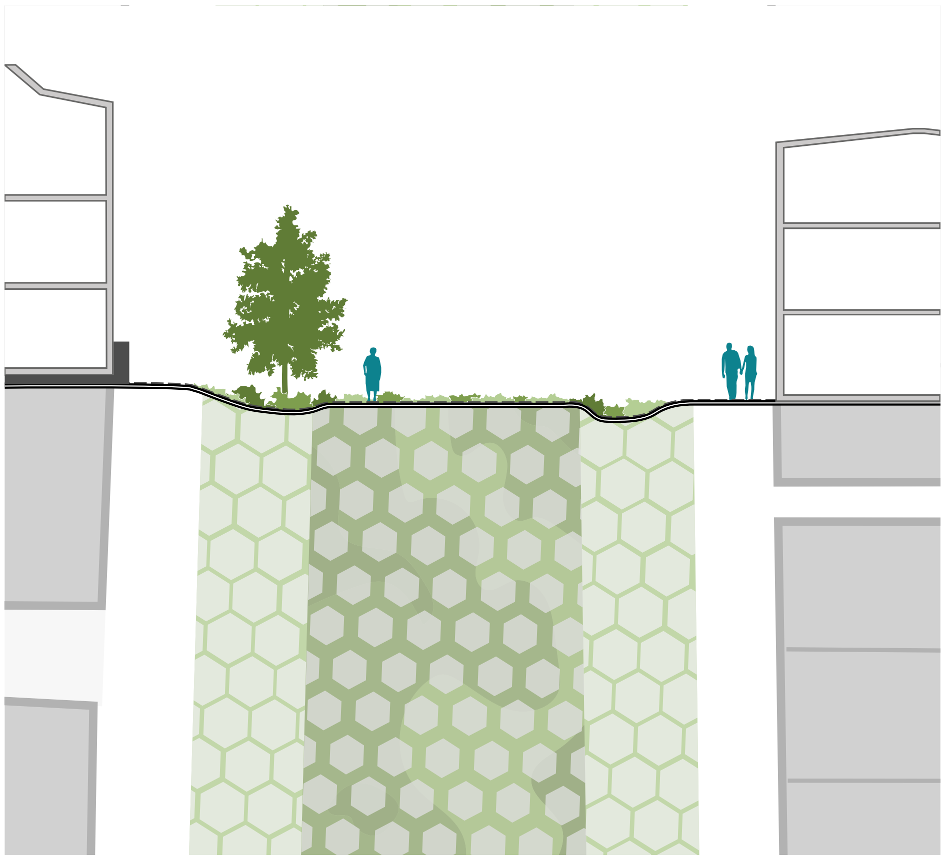


Figure 9.17. Section ensemble green - normal

Figure 9.18. Ensemble green - normal

9.5.4. Extreme & Green

This situation transforms all of the public space into a green park with small height variation. Pathways run through it, weaving through the trees, occasionally connecting to the houses. Depressions in the ground form natural storage places or ditches, which discharge precipitation water. While this creates a lot of new public space and water storage, there are some accessibility issues that have to be sorted out. Such an intervention, especially if a variety of greenery is used, will also cost a lot of time and effort in maintenance.

With the clear demarcation of public and private space in this situation, there is no guarantee that the inhabitants will or even if they should maintain the area. If this intervention is used throughout the whole city, costs for the maintenance will become a heavier financial burden for the municipality.

Figure 9.19. Section ensemble green - extreme

Figure 9.20. Ensemble green - extreme

10. Workshops

One of the most important phases in within this design study is the evaluation and testing of the newly created interventions. This is the critical element on which the entire design hinges. New designs can be sustainable and innovative, but if they do not match the spatial characteristics of the monumental city, important historical value is lost.

Cities have to be, as Haasnoot et al. (2013) say, not only physically robust (capable of withstanding climate change effects), but also socially robust. Because of the essential nature of this particular step, it was brought forward through the process.

Some of the designs posit major physical changes to the spatial characteristic of the city, influencing and other systems in turn. The inhabitants must be able to live in and adapt to these interventions before the city centre can function successfully.

The goal is to find the balance between the essence of the city centre, and the creation of new climate adaptations. Because of this importance, this particular step was moved forward form the original DAPP (Haasnoot et al., 2013) method, in order to integrate this prioritization into the design. This required interaction with stakeholders in the city, and a method to compare the designed interventions to each other, and to a set of inner priorities.

This interaction was found by setting up two workshops. One was held on January 16th, and included 19 participants, mostly inhabitants of the city. The second workshop was held on March 20th, and involved 7 participants, from the municipality or other companies that maintain the water system in Gouda.

10.1. Workshop set up

To set up this workshop, the problem field was simplified slightly to a simple interaction between two factors: 1. The rising water levels and 2. The subsiding city. The participants are divided into groups, each of which will discuss one scenario, either green or blue. The work itself is split up into four main steps. Each of these steps discusses a different scale of the project and moves from extreme to more realistic.

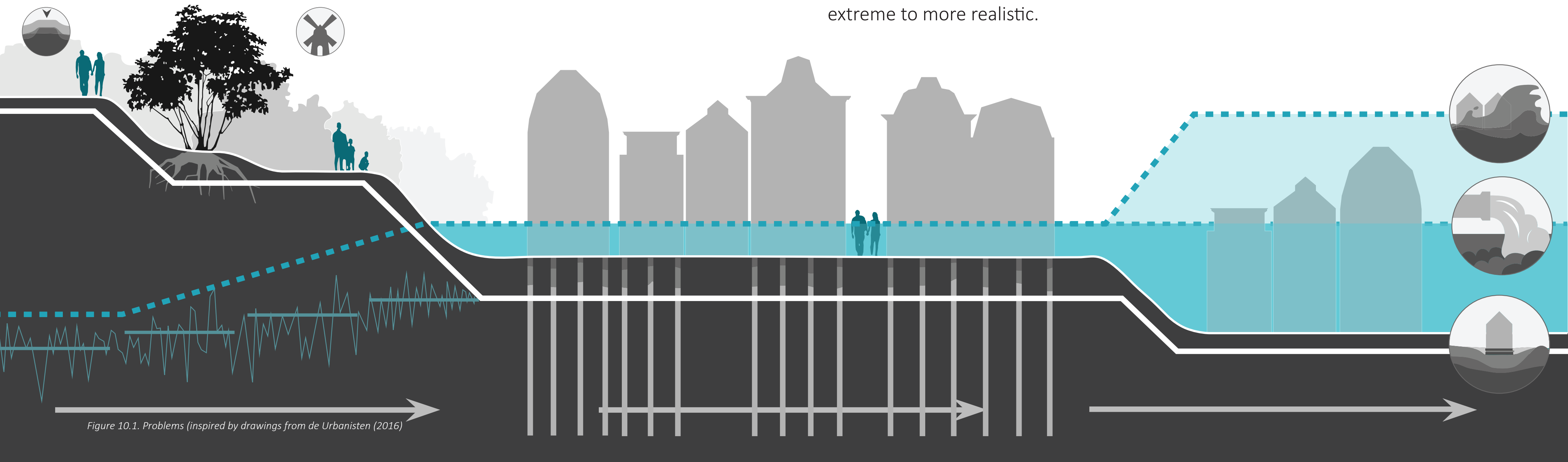


Figure 10.1. Problems (inspired by drawings from de Urbanisten (2016)

Step one discusses the scenario and creates a SWOT analysis in which advantages and disadvantages are discussed. This step helps define the scenarios, and to create a surrounding in which the next steps can take place

The following step analyses the actual interventions. The group receives a series of designs, with categories of buildings, streets and either green or blue. They are then asked to order these interventions from preferred to least desired, and to give arguments for these decisions. If no interventions suit, there is the possibility to create a new intervention.

Step three stays on the same scale, but analyses the new typologies created for the extreme scenarios. Blue groups discuss building construction and the scale and configuration of city blocks, while green participants comment on the various possibilities for added green in the street sections. These typologies help define the characteristic street, from building height to the street and pavement ratios.

The last part discusses the ensembles. In order to provide the participants with some examples for a final design, four ensembles were created, two for each group. They were then asked to comment and discuss whether such combinations are logical conclusions from the created interventions.

If the interventions from which they were built are desirable, but the final result is not, something new can be learned about the spatial character of the city. Participants were asked to design their on additions in such situations.

Small difficulties occurred when instructions for the workshop steps were open to accidental misinterpretation. These instructions told participants to order their preferred designs on the labelled lines on the handout. This created a certain prioritization list, one of which is shown in image 10.2.1, but the arguments behind decisions on this list suggested that this order might not accurately represent all the participants' actual preferences. Changes to the instruction were made to avoid this situation during the second workshop.

An important point to mention is that while some interesting patterns of preference showed up through this workshop, and interesting points were made, the workshop was only held with a limited group of people (29 in total), and results might be simply coincidence or not only representative of a part of the population of Gouda.

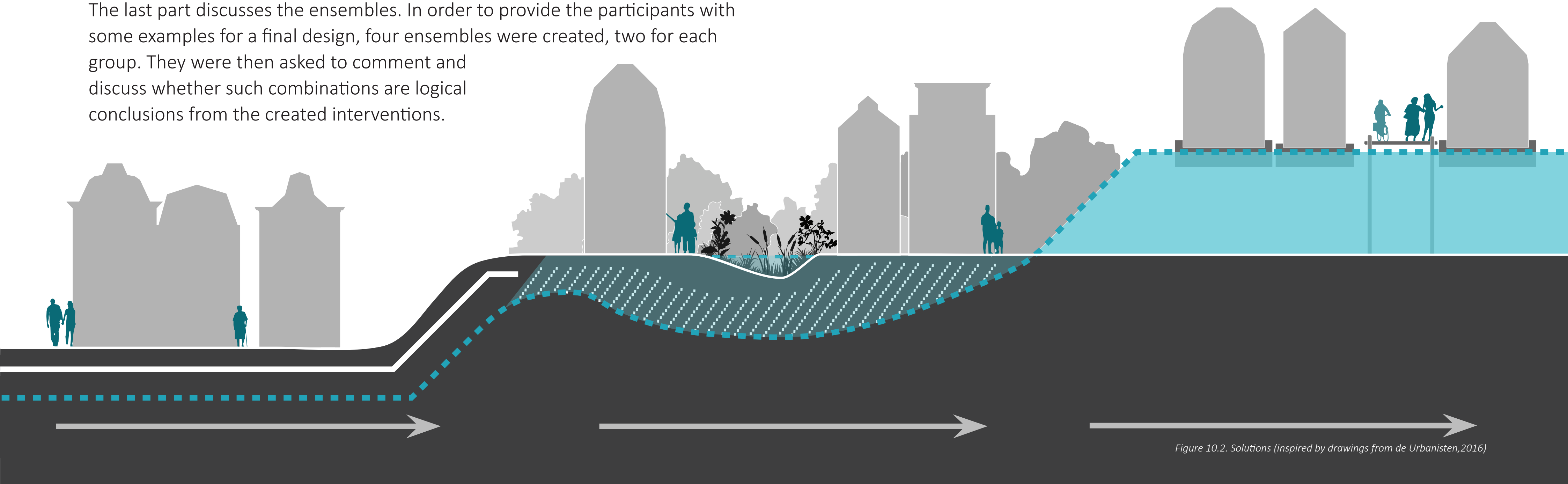


Figure 10.2. Solutions (inspired by drawings from de Urbanisten,2016)

10.2. Workshop 1

This first workshop was held on the 16th of January, 2018, with 19 participants, most of which were inhabitants who were reached through their involvement with local water initiatives in the city. The other few were municipality workers who came to give their perspective on these interventions.

10.2.1. Preferred interventions

The most important step of this workshop was the second, in which the participants studied and organized the various design interventions from most to least favourite. Some interesting discussion emerged here, which resulted in an agreement of purpose, if not of execution.

10.2.1.1. Building interventions

Overall, for the building interventions, the extreme versions were nearly universally rejected for fear that such interventions would damage the building stock of the city, and that they were unrealistic and unnecessarily destructive. Interestingly enough, this opinion was maintained even in one of the water scenario groups, where the participants were supposed to work from the assumption that a percentage of houses had already been demolished, though it is likely that this was miscommunicated.

This preference was carried over across three groups, which showed very similar results: a general preference for gutters and green ditches. Interestingly, one group put forward the barriers as the best solution for this workshop. The results of the last group of this workshop presented results which were nearly directly opposite. Coincidentally, the group with the opposite results was the only one in this particular group of workshop participants who named themselves a planner, and their results were a lot closer to what I (as the designer of the workshop) would have chosen to prioritize. This might suggest a disconnect in communication between the planner and the inhabitant – the intervention could have hidden advantages that are not immediately obvious – or it could be part of a disconnect between what planners think the city wants, and what the inhabitants desire for their city to be.

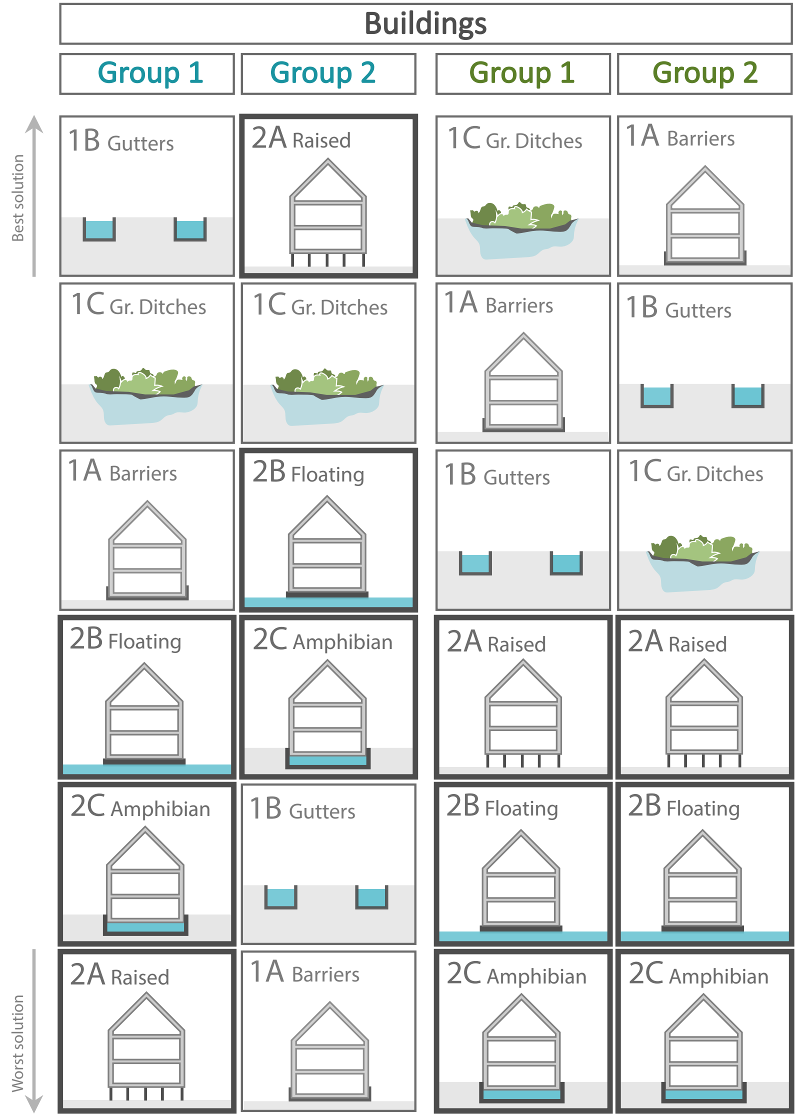


Figure 10.3. Results building interventions workshop 1

Interestingly, this group (group 2: water) chose the raised houses as their first priority as this would protect the historical character of the city while stabilizing the subsidence of the houses. Barriers would be low-quality (look cheap) and damage these monumental buildings. Group 2: green instead argued that these raised houses would destroy the cityscape.

Both of these arguments are correct in their own way. While raised houses would protect the existing façade from water damage, the image of the street at eye level would be irrevocably changed. Such an intervention would lower the monumental value of the city at ground level. Instead, the barriers will protect the facades at eye height, while changing or even damaging them physically.

From these discussion it could be concluded that the main priority for the stakeholders is to protect these monumental buildings. Interventions that adapt the houses are very contestable. This might make it more prudent to prioritize actions that do not involve adaptations to the houses without very strong arguments for it, and very little other available options. The intervention which was received with the most positive reaction overall was the green ditches. Such an intervention was often named as a no-regret adaptation.

10.2.1.2. Street interventions

The street interventions engendered fewer opposed actions. In fact, the two water groups and two green groups were in agreement amongst themselves, though not with each other. The water groups both preferred the creation of raised streets, stating that this intervention could create a climate-proof, dynamic environment, which provided many new possibilities. However, the green groups disagreed, noting that while this intervention could potentially be useful in certain locations (the Turfmarkt) it would not be realistic to carry it out on a larger scale.

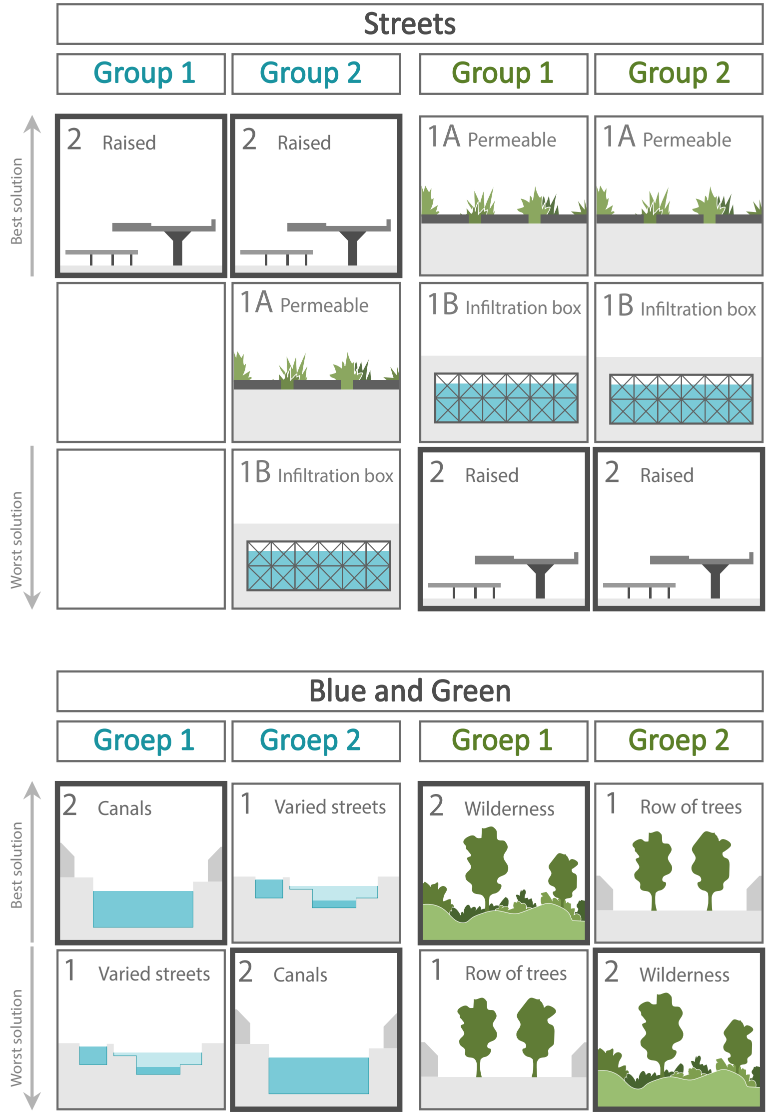


Figure 10.4. Results streets and blue/green interventions workshop 1

They preferred permeable streets for the green character, but infiltration boxes for their fast increase of the water storage available. The general preference of these two groups seemed to be for a combination of these two interventions. This would combine a controlled amount of green on top of the infiltration boxes with the added storage they bring. Spatially, this would result in a streetscape very similar to the green ditches which proved popular in the last chapter.

10.2.1.3. Green & Water interventions

These are the results with the fewest common elements from which a general preference could be concluded. However, study of the arguments for these choices showed some common ground. For the water scenario, a clear difference in status and style could be found between the two interventions. Canals are part of the historic system of the city centre, while the varied street heights are much more of a modern intervention.

In the historic city centre, the canals win, though one group states the varied street heights could be a good intermediary option before the canals are completed.

At the same time, the green interventions were received with surprising (even to the participants) enthusiasm. For more enclosed streets, the wilderness intervention would add public space and water storage to the area, but for more public streets with higher levels of traffic, the row of trees seemed more suitable. A preferred outcome for these two groups would be a balanced mix of the two.

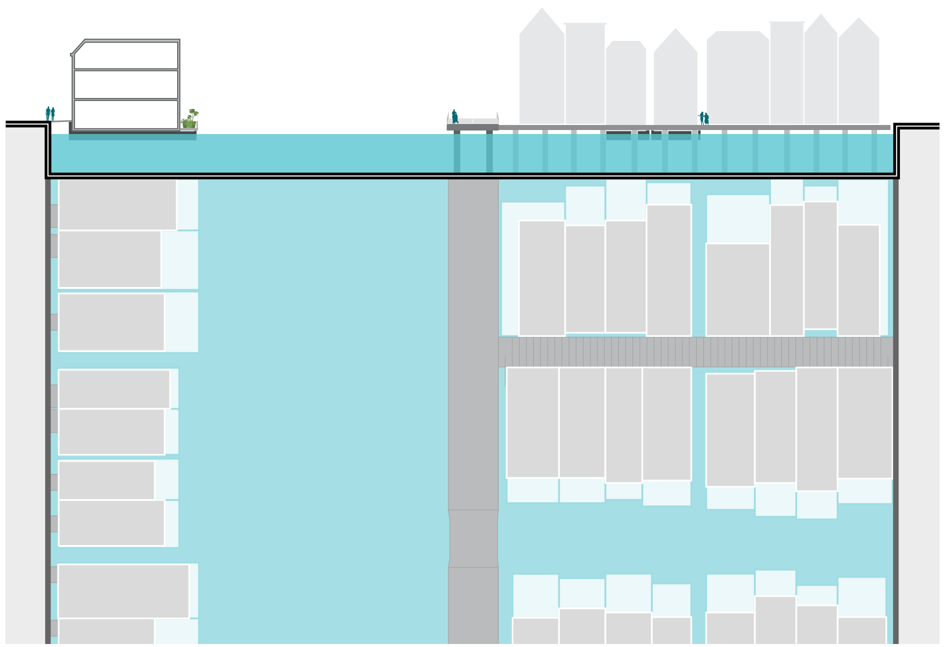


Figure 10.5. Results workshop 1: new typology

10.2.2. New designs

During this workshop, participants were given room to comment and criticize the interventions in order to 1. Find their flaws, and 2. Find out which interventions fit best within the city centre of Gouda. They were also asked to adapt or even draw new interventions, if they found that none of the designs suited their ideas.

Two of the groups designed their own intervention for the Nonnenwater street. The first of these suggested water stairs. More easily created than a full canal, this intervention follows the natural slope of the street to transport water to the outer canals during rainfall.

As the city is quite a bit higher near the Gouwe than it is near the outer singels, in order to make this intervention workable, the level of the entire stairs was lowered. To create a dynamic system, more variations were created within the stairs, to promote waterflow through this intervention during a larger part of the year. Even with these additions, a pump is probably still required in order to keep water flowing.

This can easily be combined with some sort of filtration system to raise water quality in the city.

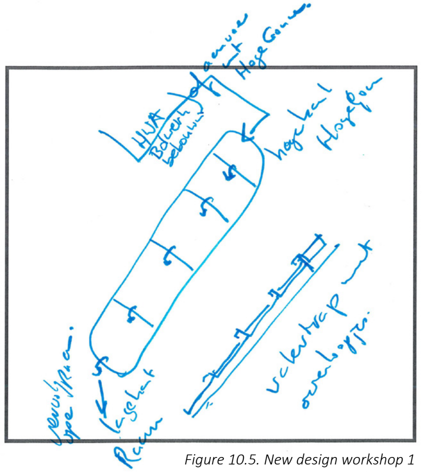


Figure 10.5. New design workshop 1
(See Addendum, chapter E.5.1., pg. 63)

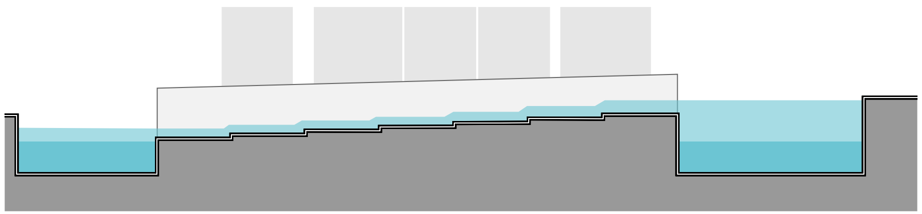


Figure 10.6.. Results workshop 1: Water stairs ensemble

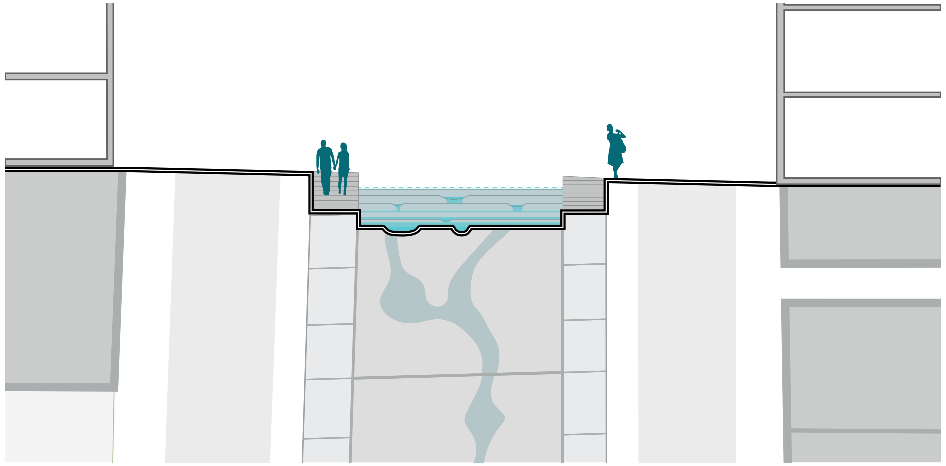


Figure 10.7. Results workshop 1: Water stairs section

Figure 10.8. Results workshop 1: Water stairs map

The second intervention wanted to prioritize the old waterfront quality of the Nonnenwater, by changing around the water and street in the design. In this ensemble, location of the streets and water are switched around, and houses on either side open up directly onto a canal, with only a small pavement for easy entrance. These canals make it possible for water recreation to travel through the street again, and the centre of the street becomes a central meeting ground for the inhabitants.

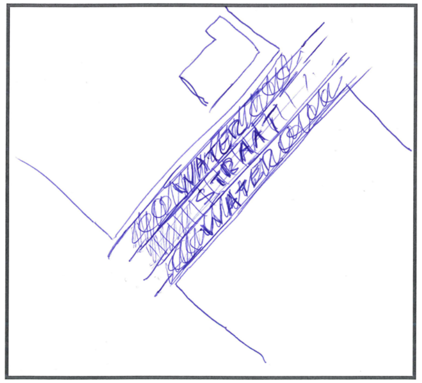


Figure 10.9. New design workshop 1
(See Addendum, chapter E.5.1., pg. 67)

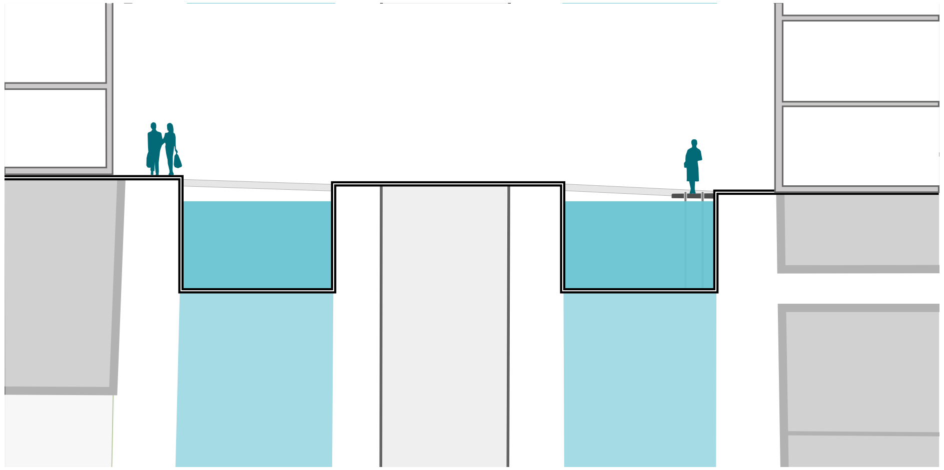


Figure 10.10. Results workshop 1: Switch street and canal section

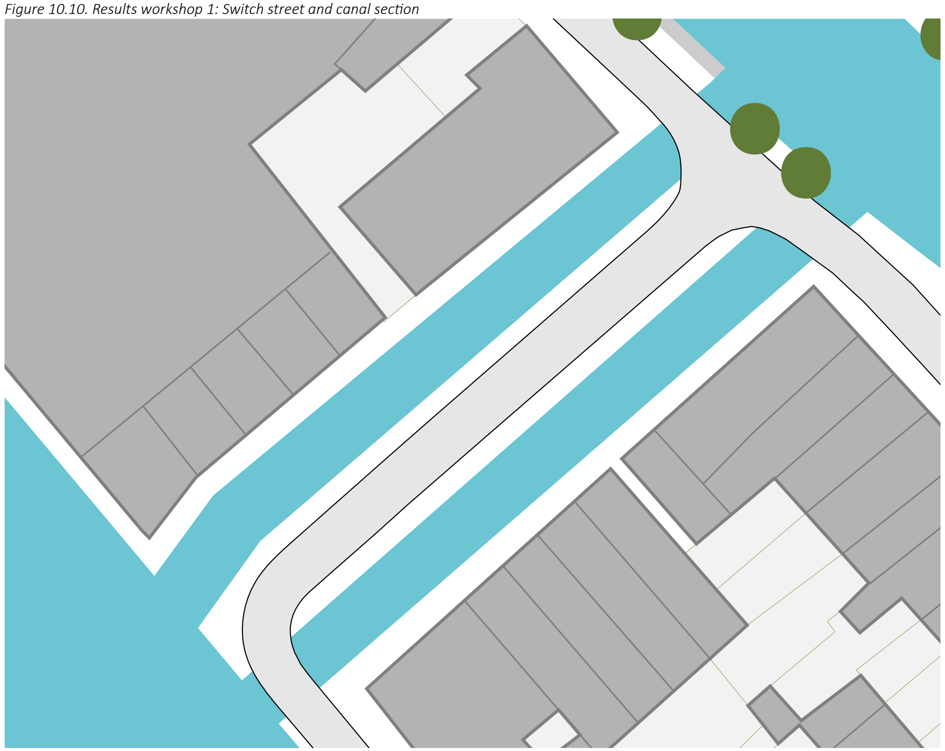


Figure 10.11. Results workshop 1: Switch street and canal map

10.2.3. Important conclusions

For the inhabitants of the city, the buildings are the most important element that must be maintained in order to preserve the essence of the city's identity. This does not just mean the facades, but it also includes the dense city structure and the small side streets and the varied housing types and heights.
Other elements include small walking paths throughout the city or the parks, and the preservation of the water route around the city.

10.3. Workshop 2
The second workshop was held on the 20th of March, 2018. The seven participants were a mix of municipality workers and people from the Hoogheemraadschap of Rijnland, Deltares and the TU Delft, each with a different expertise

10.3.2. Preferred interventions
Within the water group there was an immediate discussion starting from step 1 about the extreme scenario on which the interventions are based. One of the participants was worried about the potential consequences of removing part of the city edge, stating that the organism of the city might not function correctly afterwards. In this situation, improvement should always be prioritized over replacement.

10.3.2.1. Building interventions
A small example of the differing priorities between stakeholders that were mentioned as a problem early in this thesis was shown in this workshop. One participant focused on preservation of the building stock using physical barriers, similar to the inhabitants in workshop one. The other two participants were more focused on the efficient discharge of water, prioritizing the ditches and gutter interventions.

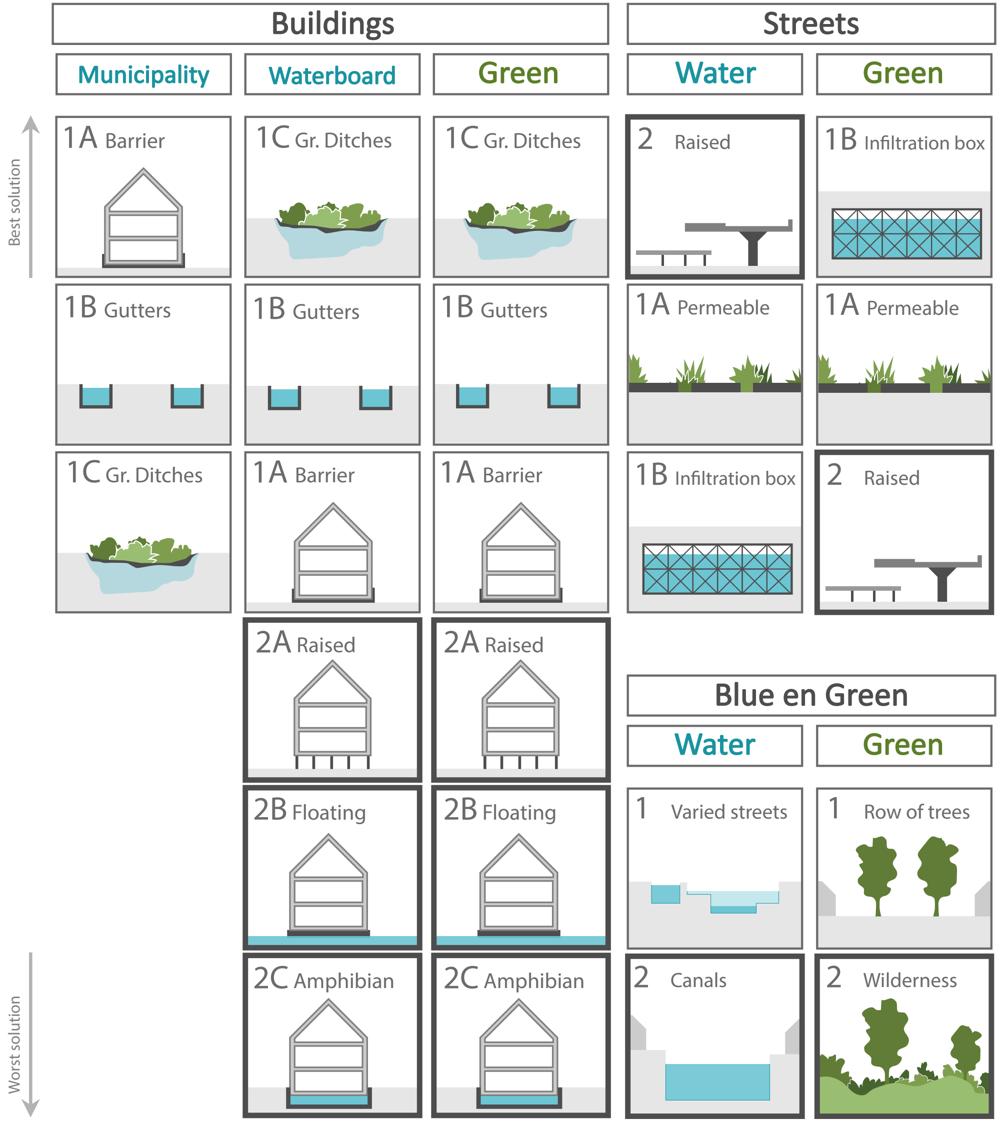


Figure 10.12. Results interventions workshop 2

In this particular workshop, the priority list created by the green workshop group happened to be the exact same as the water scenario, choosing relatively small spatial interventions in the street over adaptation to the buildings, though it did note that while such interventions are possible in certain streets, there are streets in the city centre that are so narrow that even mid-sized interventions would take up too much space.

10.3.2.2. Street interventions

Unlike the building interventions, opinions on the street interventions were more varied. The blue workshop group built on the extreme situation set by their
scenario, and chose raised streets as their preferred intervention, arguing that this added new qualities to the city, and pointed out that in an extreme scenario, extreme measures can be taken. This does mean that, as this scenario will not be carried out in reality, a more subtle and measured version of the raised streets should be developed to better suit the character of the city.

The green workshop group had a less extreme scenario, and their interventions were correspondingly less extreme. Permeable streets were a no-regret measure and should be added throughout the city. But for water storage capacity the decision was made to use infiltration boxes. Placement of these boxes should be just before the houses, in a role similar to the gutter and ditch interventions, to protect houses from flooding.

10.3.2.3. Blue and Green interventions

Earlier in the blue group's discussion, an interesting point had been raised: open surface water in Gouda does not create a lot of storage, especially not in comparison to the horizontal surface it takes up. This is because in the lowest areas of the city, the surface and water level are extremely close. This minimal difference sets the limits for the maximum amount of storage open surface water can provide. Any millimetre above that will cause flooding.

Interventions with green, which are capable of storing water in the vegetation, or interventions that are not connected to the groundwater work a lot better in this situation. Because of this argument, preference in the water group went to varied street heights, as it was capable of more water storage. Another important argument was the promotion of dynamic street use in the city.

The green interventions chosen by the second group were very similar to conclusions from the earlier group. Wilderness interventions, which function as a new park structure in the city, would be great for streets that do not form part of the major traffic patterns and dead-end streets. Other streets would be better served by the addition of new trees.

10.3.1. New designs
While the first workshop yielded some new designs in the ensemble step (4), here the design process started during the first step of the practical work. It was discussed how the removal of buildings in the city centre could damage the functioning of this centre, after which the group brainstormed a method to expand the water storage without damaging the city centre.

The canal was expanded outwards to connect to an old military canal, reinstating an old spatial element of the city centre. With the existing road now placed right in the middle of the water, this pathway can be downsized, and will form the central access for the neighbourhood, right according to the preferred building typology chosen by the group, which shows a central road with smaller private side streets.

10.3.3. Important results
In this workshop, an extreme scenario gave the participants the option to use extreme options, and to test potential new dynamic options for Gouda. However, this does mean that in less extreme situations, such interventions will have to be comparatively toned down in order to match the overall adaptions. In the group with the less extreme scenario (green), interventions were subtler as their scenario left them with less 'adaptation space' to work with.

For both scenarios, there is still an overall preference trend for interventions that protect the houses and which do not require adaptation to the houses themselves. In fact, large changes to houses or building blocks could be dangerous, as this could unbalance existing spatial systems in the city. While no adaption is not a feasible option, constructions that remove parts of the existing building stock should be done with subtlety and careful planning.

Figure 10.13. Current situation - blue scenario workshop - monumentally sustainable blue scenario

11. Efficacy interventions

Large parts of this thesis focus on the physical character of Gouda, important historical elements, and how new design elements can be measured and adapted to fit within this long existing spatial situation.

However, it is important to keep in mind that these new adaptations must adhere to other requirements as well. The main research question asks what balance of interventions is required to protect Gouda from climate change-enhanced disaster, and in order to find an equilibrium, the conditions on both sides must be known.

Naturally, climate change is an uncertain element, and though specifics are unknown, potential trends have been extrapolated based on changing circumstances. Chapter 8.2 discusses a few of these trends, and focuses in on a specific level of precipitation, 100 mm/2 hours, which is used by the Hoogheemraadschap van Rijnland (2018) in their climate atlas to determine the bottlenecks in the system.

On the other hand, this chapter discusses the specific effectiveness of the interventions created in chapter 9. The original strategy to find this information was through the use of an existing watermodel, created by Hans Suijs (2016). However, when discussions eventually led to early tests, it turned out that there was a mismatch in scales. The model created a comprehensive view of the watersystem of the entire inner city, while this thesis needed specific details of the consequences brought by heavy precipitation in distinct streets.

As the effectiveness of green-blue interventions can occassionally be nebulous, the scale of the interventions had to be specifically relatable to the actual effect brought by this design. Furthermore, all these interventions had to be internally comparable, in order to find the most effective solution for the existing spatial situation. Instead of the watermodel, two streets (Hoogstraat and Kleiweg) were designated as the testing site. Measurements and estimates of the length, width, elevation, freeboard, and soil profile eventually led to a series of calculations.

Not all interventions created in chapter 9 are appraised in this chapter, as some examples, e.g. floating houses or raised streets, are specifically designed to suit very extreme situations. This chapter focuses on interventions that adapt the existing situation, and their capacity to raise the total water storage.

The calculations and data used can be found in the addendum booklet.

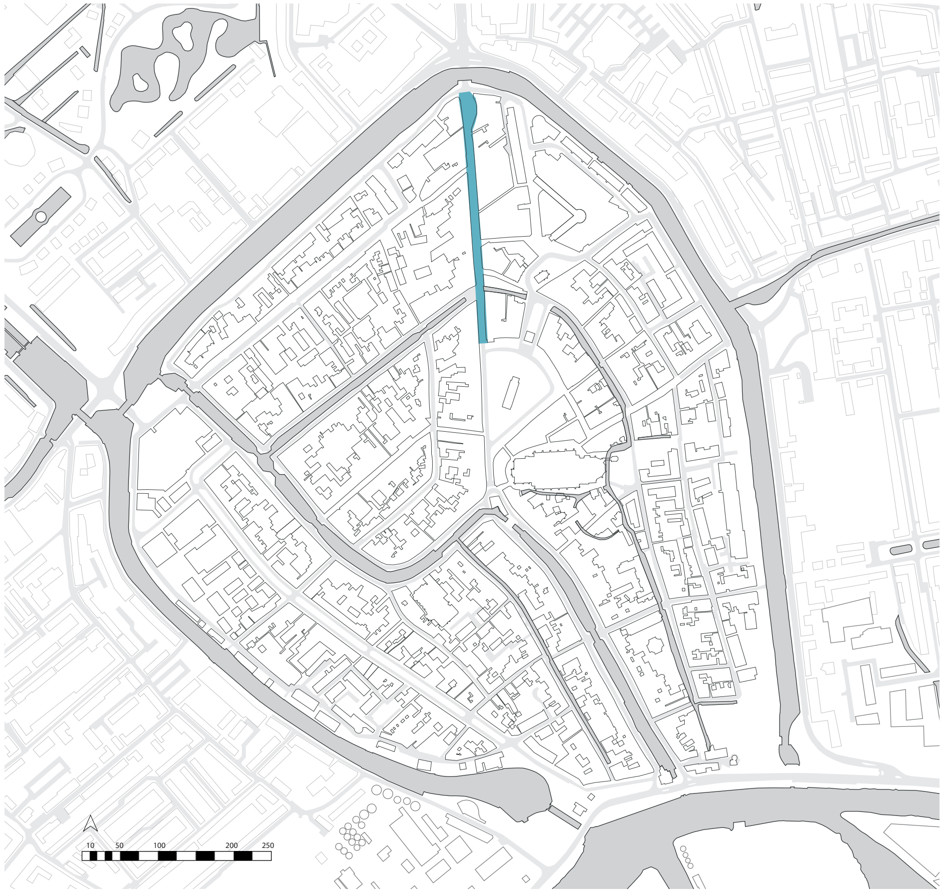


Figure 11.1. Hoogstraat and Kleiweg

Gouda currently uses their existing sewer system to catch and discharge rainwater. While these sewers were designed for fast water transport throughout the city, they were tailored to handle a predetermined amount of water, as household water use can easily be predicted (Waternet, n.d.)

Climate change distorts these predictions, and revision and renovation of the urban sewer system would be both expensive, and low in spatial benefits. There are two options to integrate existing systems with new spatial interventions. In the first, local water storage options are created in the streets which discharge onto the surface water after the event. Existing rainwater sewers will be used to catch and discharge only the precipitation that falls on the rooftops. Storm drains will be disconnected from this sewer system. Wastewater sewers will still function independently.

In the more severe situation, all rainwater pipes are decoupled from the sewer system. Only the wastewater sewers are retained to handle household water.

This chapter tests the effectiveness of the designed interventions in either situation. The calculations split the interventions up into different combinations of four water storage methods.

11.1. Storage methods

11.1.1. Interception storage

Rooftops are not the only barrier that stops precipitation from flowing down to the street and adding to the water storage burden that is accumulating there. Any barrier between the clouds and the ground can serve as temporary water retainer. One example that is commonly found in both urban and rural areas are trees (Gerrits, 2008).

The crown of the tree, while not solid, consists of many layers of small leaves, each capable of holding a small amount of precipitation. Several interventions test the capacity of this foliage to support the watersystem.

11.1.2. Infiltration

The second natural option, infiltration, occurs when rainwater drains through the surface and is absorbed into the soil and eventually reaches the groundwater. While much more common in rural areas, in cities the large amount of impervious road surfaces makes this solution less effective. Interventions such as ‘permeable roads’ test the increase in water storage when this type of paving is added to the local street profile.

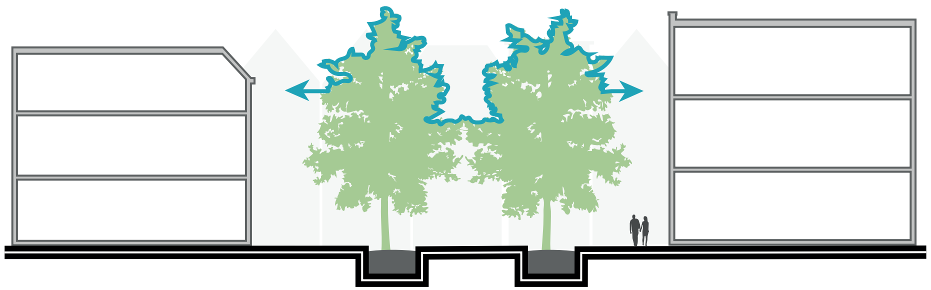


Figure 11.2. Schematic: Interception storage

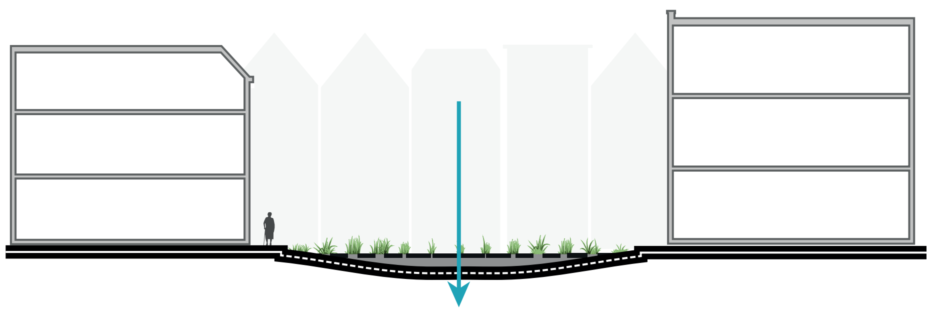


Figure 11.3. Schematic: Infiltration storage

11.1.3. Local water storage

While in many situations infiltration is a very useful method of water storage, chapter 8.4.3. (technical profile), shows that the actual freeboard, also known as the amount of dry soil in between the ground water level and the surface is smaller in Gouda than in many other cities, due to centuries of subsidence (Willemse, 2017). A comparison between the surface level as seen in chapter 8.3.2 and the regulated groundwater level of -0.7 m NAP (Tamboer, 2007) shows that the effectiveness of infiltration varies throughout the city centre.

A similar type of intervention that is not influenced by the groundwater level is local water storage. In this case, water is accumulated in the streets, but this is done in pre-designed basins which are disconnected from the groundwater. While this allows for more water storage in lower lying areas, some other method must be included for the discharge of this water.

11.1.4. Discharge

One such intervention is the discharge capacity. While similar in look to the local water storage, in practice it functions like surface-level sewers. A series of gutters transports water throughout the city centre from storage places to the singels, from where the pumps Hanepraai and Mallegat (Tamboer, 2007) drain it into the Hollandsche IJssel.

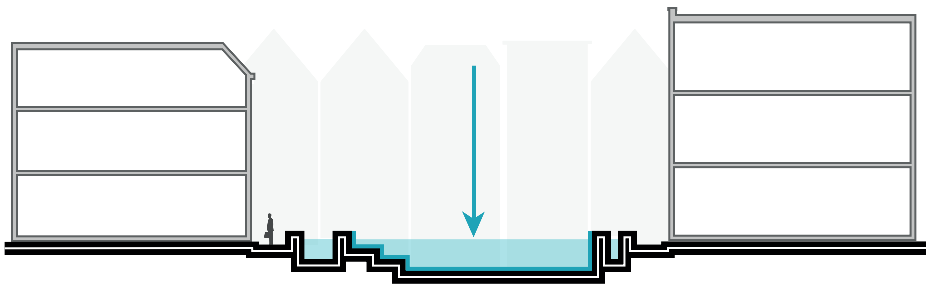


Figure 11.4. Schematic: local storage

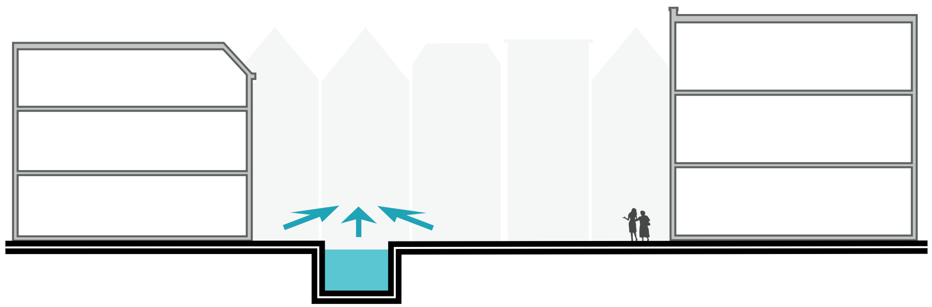


Figure 11.5. Schematic: discharge capacity

11.2 Results

11.2.1. Results situation 1: Streets

This particular set of calculations is named after the streets, as the dimensions of the streets are used as a limiting factor. In this situation, both the wastewater sewers and rainwater sewers are kept as active, functioning parts of the water system. The major change is that the the storm drains on the street are decoupled, instead trusting in the capacity of the new interventions to store the precipitation.

The graph shows the results per intervention for all four of the precipitation intensities that were calculated in chapter C. of the addendum booklet. Immediately obvious is the effectiveness of larger scale water solutions over either smaller, or green interventions. Interestingly, the wilderness (13) is not at all effective compared to its large-scale transformative effect on the street.

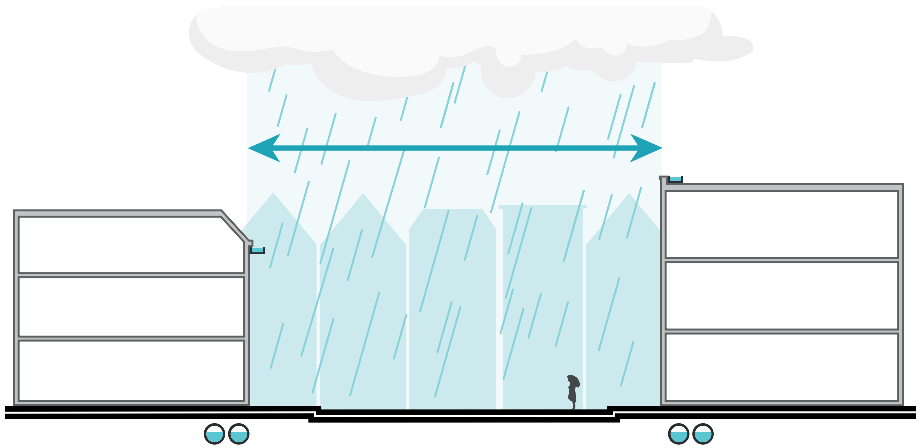
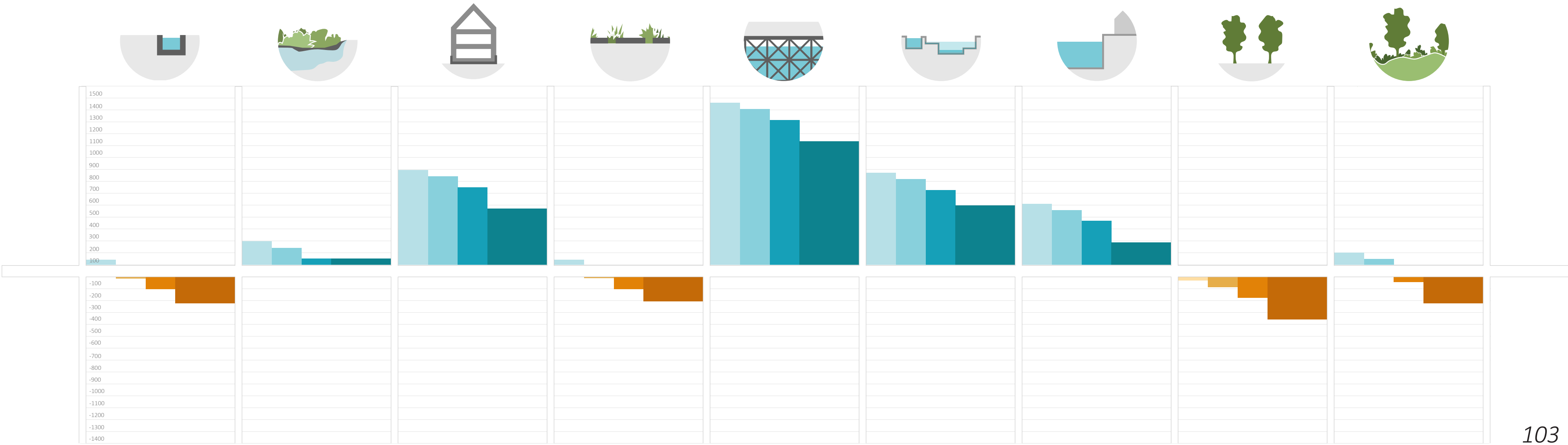


Figure 11.6. Smaller area

Figure 11.7. Graph effectiveness interventions 1



11.2.2. Results situation 2: Disconnect

In the second scenario, the entire rainwater sewer system has been disconnected, and the city must depend on the new interventions to store this increased amount of water, which now also includes water that has flowed down from the rooftops.

The results show the decreased effectiveness of this situation. In the last bar of each intervention, the situation in the most extreme, 100 mm/2 hours precipitation event can be seen. Only the infiltration boxes, which create a large underground open water storage, are sufficient. Interestingly, the barrier intervention, which proposes the same solution, except above ground, does not suffice, but this is due to the chosen parameters, and will be discussed in the conclusion. Other solutions involving infiltration and water discharge are not enough. The two water interventions, varied street heights (10) and canals (11) both fail in the most extreme precipitation intensity. But where option 10 can be increased without compromising the function of the street, this cannot be said for the canals.

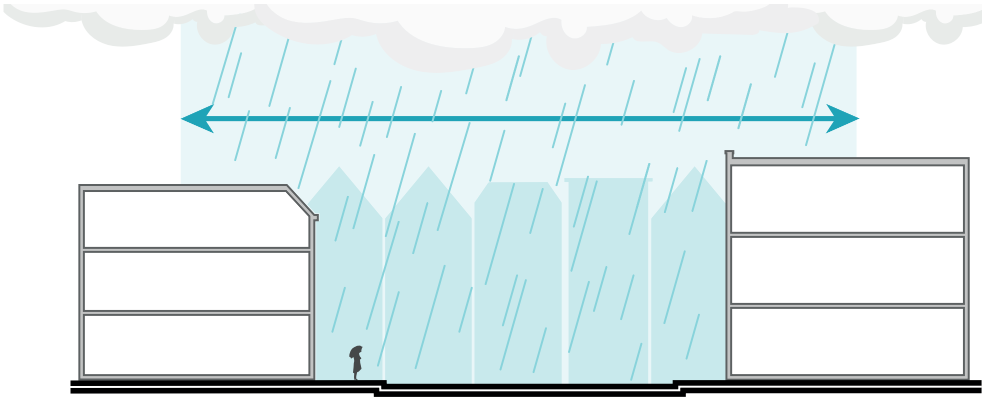
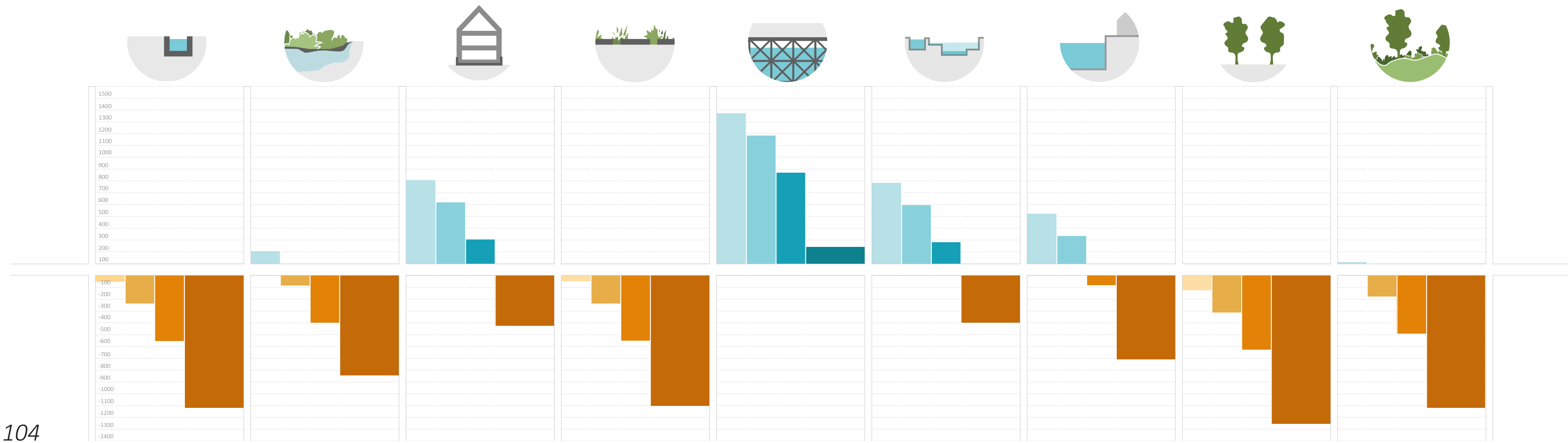


Figure 11.8. Larger area

Figure 11.9. Graph effectiveness interventions 2



11.3. Space versus results

The comparisons made in the previous graphs are not entirely without bias. The amount of water storage has been calculated per intervention, but the amount of space it physically takes up has not been considered. A comparison of these two factors per intervention can shed light on the actual efficacy across scales. In the following text, the results for scenario 2 (chapter 11.2.2) during a 100 mm/2 hours storm have been used.

11.3.1. Intervention 1: Gutters

storage-to-surface ratio: 5.5

A gutter is typically limited in size. Such interventions are not supposed to take up much space, and as such, cannot store as much water. But these graphs shows that for its size, the gutter is quite an effective method to retain water and opens the potential for merging this intervention with another (e.g. varied street heights, option 10) to apply this on a larger scale, gaining the benefits of both.

11.3.2. Intervention 2: Green ditches

storage-to-surface ratio: 2.4

This intervention is very similar in function to the gutters, but trades fast discharge for infiltration, interception, and more green space in the streets. Though capable of storing more water than the gutters, this is due to scale, not efficacy.

11.3.3. Intervention 3: Barriers

storage-to-surface ratio: 0.67

Spatially one of the least invasive interventios, this adaptation makes the entire street capable of accumulating water. While the amount of storage is not sufficient for heavy precipitation, it can be incread by raising the barriers. However this will create a trade-off between preservation of the facades and protection of the buildings.

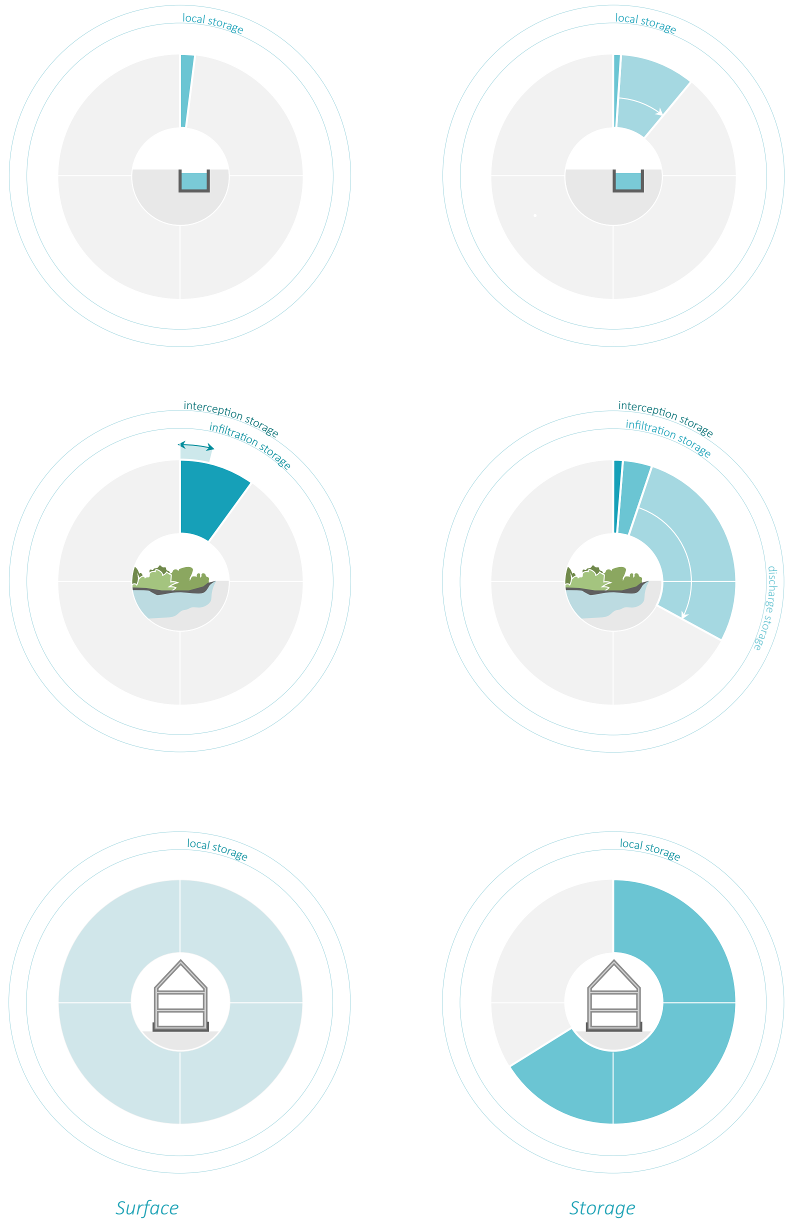


Figure 11.10. Efficacy interventions in comparison to surface area (intervention 1,2 & 3)

11.3.4. Intervention 7: Permeable streets

storage-to-surface ratio: 0.37

This intervention, while extensive, is not really spatially intensive. So while it covers the entire street, this only partially influences the function of the street. The effectiveness of this particular design is highly influenced by both the free-board under the street, as well as the type of paving used. In the addendum booklet, this intervention has been calculated twice, once to test the effective-ness with a relatively enclosed paving type (clinker bricks), and a second time with a more open structure (grass pavement), which might prevent heavier vehicles from using this street. The graph shows the effects for the more open permeability, as that is more realistic for an actual 'open pavement' typology.

11.3.5. Intervention 8: Infiltration boxes

storage-to-surface ratio: 1.09

By far the most effective intervention, it also happens to be the least visible. Through placement of water infiltration boxes under the road surface, fast local water storage is created.

11.3.6. Intervention 10: Varied street heights

storage-to-surface ratio: 0.81

Varied street heights are, by name, varied, and it is easy to do them a disservice by assuming the absolute efficacy of this intervention just by looking at the cal-cultion for a specific type. Both the width and the depth of this intervention are highly variable, with the potential to add permeable pavement, green ditches, gutters and other infiltration or water discharge methods.

As an intervention, it is adaptable to the specific streets, and in more vulnerable areas it should be possible to create a street profile capable of storing all of the local precipitation.

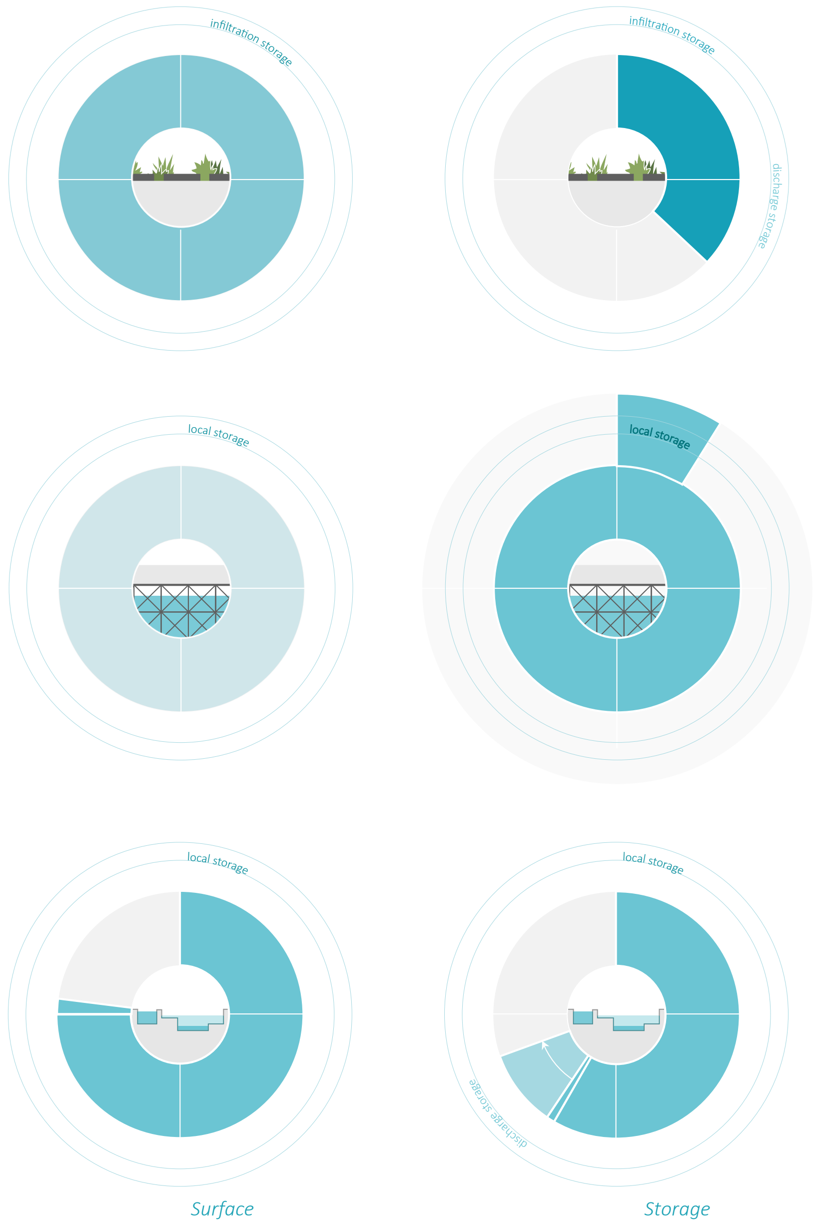


Figure 11.11. Efficacy interventions in comparison to surface area (Intervention 7, 8 & 10)

11.3.7. Intervention 11:Canals

storage-to-surface ratio: 1.09

While this is categorized under local storage, in practice the efficacy of this intervention is highly dependent on the same factors as the infiltration method. The canals will be part of the ground and surface water network, and in lower-lying areas, less water storage will be possible. In the Hoogstraat and Kleiweg, the surface to storage ratio is positive, but unlike in the previously discussed option 10, an increase of surface will make the actual streets unuseable.

11.3.8. Intervention 12: Row of trees

storage-to-surface ratio: 0.27

Though trees are a large visual presence within a street, they take up surprisingly little space near ground level, which is why their surface area is so low. Unfortunately, as detailed in the addendum booklet, the efficacy of the interception is for all intents and purposes, zero, and most of the water storage in this intervention is gained from the small open spaces near the base of the trees.

11.3.9. Intervention 13: Wilderness

storage-to-surface ratio: 0.14

The most extreme and alternative intervention, this design takes up a lot of space and creates a completely new environment. Unfortunately, this is not a solution that adds a lot of water storage. The inefficacy of the interception makes infiltration the most effective factor in these calculations, but it is both slow and highly dependent on the pre-existing water situation.

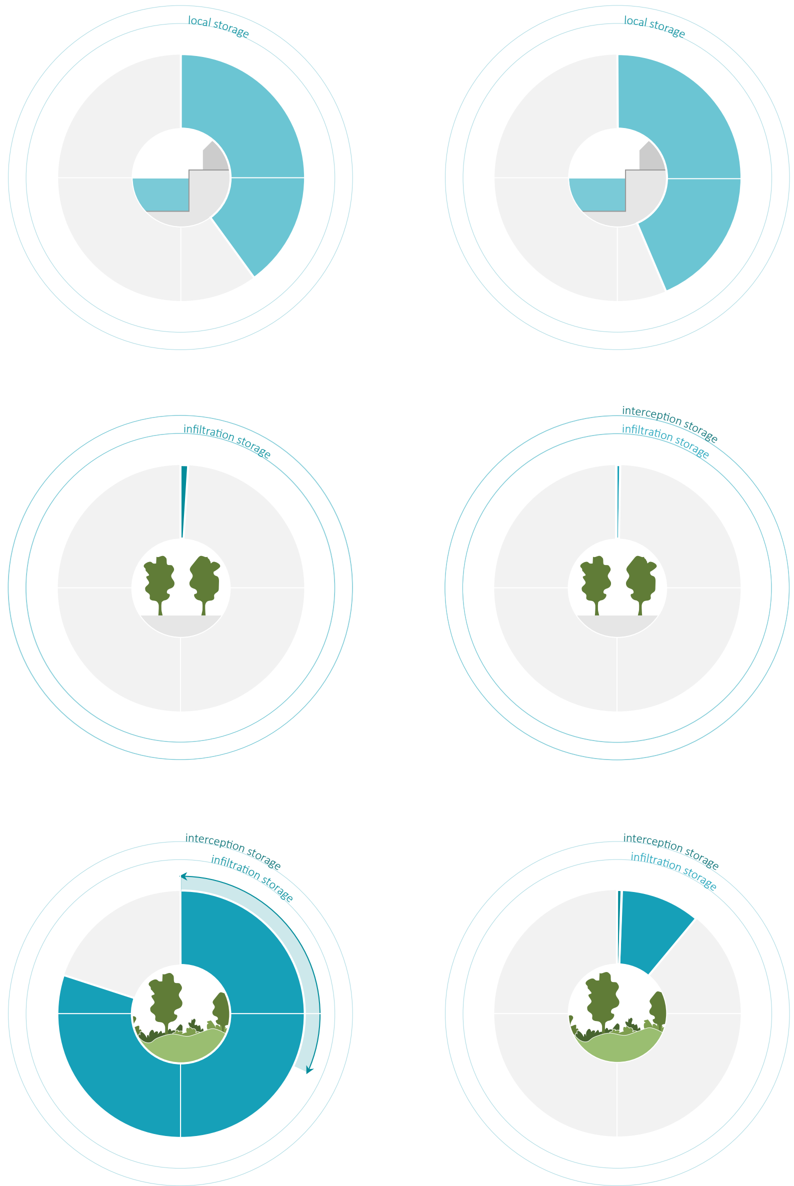


Figure 11.12. Efficacy interventions in comparison to surface area (Intervention 11, 12 & 13)

11.4. Conclusions

11.4.1. Variability interventions

This variability has come up in the discussion of various interventions. While some thought has gone into the size and scale of the interventions to make sure they suit both the design as well as the street profile, the choice was still relatively arbitrary.

While it is not possible to scale up some interventions without endangering the functionality of the street (e.g. 11: canals), and it is unreasonable to scale down some interventions (8: infiltration boxes), there is still a lot of variation possible.

This was done on purpose, to accommodate the large variaty of street profiles present across the city (chapter 8.5.1.). But within a single street, certain interventions provide various levels of intensity. One example is intervention 10, the various street heights, or 7: permeable streets. Differences in design will influence the eventual efficacy of these interventions.

11.4.2. Limits calculations

While the calculations give an interesting comparison of the potential efficacy of various types of interventions, this chapter has already mentioned the differences in scale, the potential variability and the distinct physical street profiles and situations throughout the city.

Furthermore, many of these calculations are based on assumptions and formulas, rather than actual measurements, and this should be taken into account. Last, these calcultions can suffer from a limited scope. For instance, 12 and 13, (rows of trees and the wilderness), might seem completely unsuited to any water management project, but this is because the calculations limit themselves to the usefulness of such interventions during heavy precipitation.

Green has many more advantages to offer to a city, even outside promotion of biodiversity and the creation of pleasant green spaces. Chapter 8.4.3.2. City section discusses the influence of green elements in creating a lower (and less prone to flooding) groundwater level, opening possibilities for other water storage interventions. The results should never be seen in a vacuum, but always as part of an integrated and complex story.

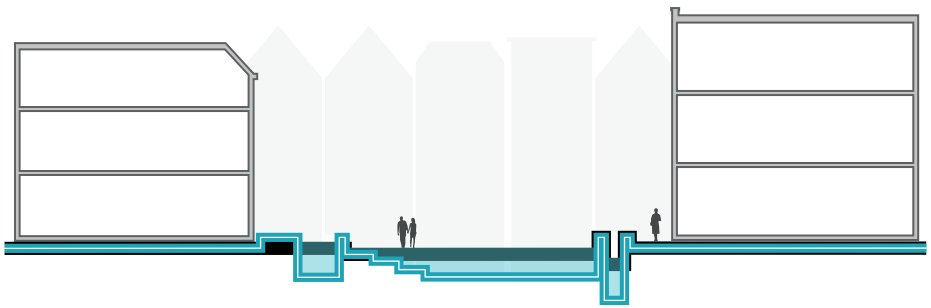


Figure 11.13. Schematic:variation interventions

Figure 11.14. Schematic: effect of vegetation on the groundwater level

IV. Results

Design
Conclusion
Reflection

12. Design vision

12.1. Concept

During the workshops, one participant commented that the city functions as a single organism, and that rough culling of any area, no matter how unimportant it seemed, could result in irreversible damage to the entire system.

Yet, trends shown in the analysis suggest that adaptations to the city could very well soon become a necessity. But in order to develop this with care, the creation of the strategies was approached the same way the restoration of a damaged and living organism would be.

In this particular metaphor, the city centre of Gouda can be compared to a very specific tree; namely a pollarded or a knotted willow, or as it is known in the Netherlands, a *knotwilg*.

Pollarding is an ancient pruning system, which involves cutting off the branches after the tree gains a specific height (RHS, n.d.). These trees are a common feature of the Dutch landscape. And they do have several advantages: They remain smaller, live longer, and at the same time, the young, thin branches at the top of the tree were historically used for weaving or other purposes (Voorhorst, 2004).

However, once this process is started, it must be continued. If maintenance on these trees is stopped, the continued growth of the branches will cause the tree to become so top-heavy tearing can occur (Voorhorst, 2004). The situation Gouda is in at the moment can be compared to this tree.

Somewhere, during the past, Gouda's innovative attitude was crippled by the economic situation in the 18th and 19th century (Denslagen, 2001). This resulted in a focus on maintenance of the existing elements instead of development. And the problem here is that, just like the *knotwilg*, a simple maintenance of the existing situations translates into an eventual decline of the health of the organism. So the new design vision centres on strategies that encourage and support Gouda to grow in a future-sustainable direction, while monitoring which locations are in potential need of pruning.

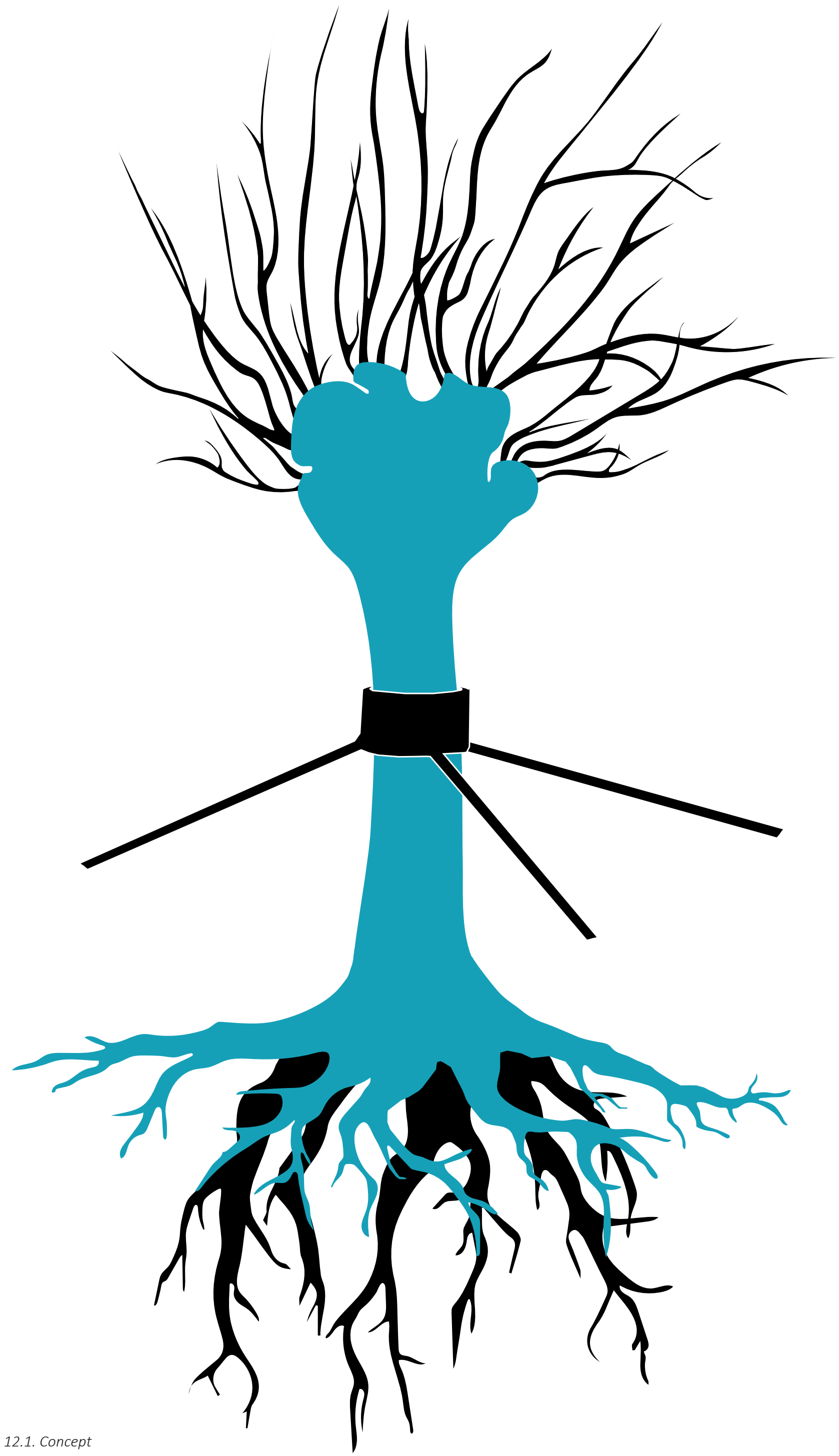


Figure 12.1. Concept

12.2. Three Pathways

In this project, the approach of the three pathways are all inspired by this concept, and each of them adds different supportive element to this living organism. Pruning must only be done when no other options are possible.

In chapter 5, the theoretical framework states that in order to create a future-proof heritage site, a risk analysis is needed. This consisted of a comparison between the value of the buildings versus the local danger. Another relevant factor was the ease of specific adaptations.

The pathways are divided as follows:
Many of the most important historical buildings were traditionally built on higher soil, which means that their current flood risk is low. When these high-value buildings are combined with low-risk streets they fall under the *enhance and protect* strategy.

Those monumental areas that do suffer from high flood risk instead fall under the *protect and improve* strategy, which focuses on the creation of innovative water storage with a historical character.

The last of the three encompasses those areas which do not include many monumental buildings, but which still suffer from the flood risks in the lower lying areas. The goal here is to *renew and innovate.*

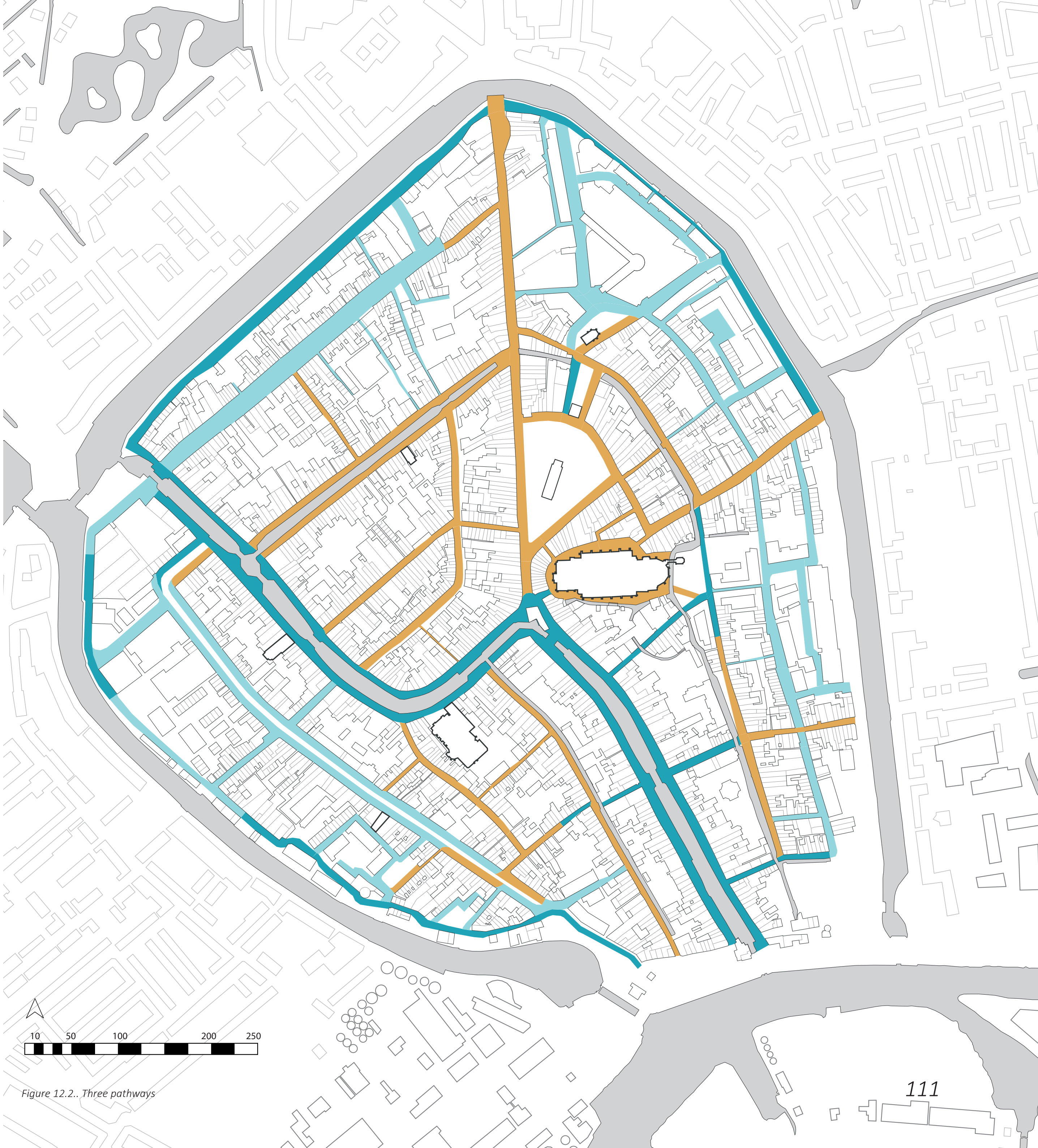


Figure 12.2.. Three pathways

13. Strategies

13.1. Strengthen and Enhance

13.1.1. Concept

When the different strategies are approached from the concept of Gouda as a living organism, this particular pathway represents the roots of the city.

The historical analyses go into detail about the monumental value of the Gouwe and how all activities centre around it, even influencing the direction in which the city hall was built.

While this is still visible in the layout of the buildings in this area as well as in the monumental profile, the active centre of the city has moved northwards (EduGIS, 2018), as new developments led to increasing traffic in that direction (see chapter 3). As a consequence, these historical roots are not really active in the current spatial structure of the city.

Figure 13.1. Pathway I: Strengthen and Enhance

Areas were allocated to this strategy in part because of their high monumental value, but another factor was that they are not vulnerable to flooding. As important buildings, they were constructed on top of the clay deposits from the Gouwe, which did not suvbside along with the rest of the city (Willemse, 2017).

This means that unlike the other two strategies, *Strengthen and Enhance* will not create any new water storage. Instead, interventions are designed to increase the spatial proximity to the water to help restore the historical connection. In the inner part of the city centre, this is done because the higher surface level has created a disconnect between the street and the river.

Near the singels, which is the outer water system, the design focuses on the creation of a basis from which the singels can be reconnected to the inner water system. In combination with the other strategies this will eventually increase and improve system flows throughout the city centre.

But in the first stage of the project this base consists only of identifiable, key functions in specific spaces within these areas. This gives potential users something to focus on, and makes the entire area more useable.

Figure 13.2. Pathway I: Strengthen and Enhance (axonometric projection)

13.1.2. Interventions

A variety of places are thus created within the city centre, each bringing something new to the area.

Intervention A and B each represent one aspect of the designs created for the Gouwe, to be explained in more detail in the next chapter. They both comprise the creation of a small public spaces in a sublevel between the surface and the water, but their general character and materialisation is different. This is to reference the innate differences between the two sides of the Gouwe, while still combining to form a strong symmetrical street profile.

Intervention C and D are two other major additions in this strategy. Both the Museumharbour (C) and the Bandstand (D) in the Houtmansplantsoen exist, but the area around them will be redesigned to add other functions that will increase the useability of these areas.

Finally, intervention E mainly concerns the improvement of the walkway around the outer singel. Attention must be paid to the monumental (and military) nature of these elements, to create a pleasant outer space. At the same time, these additions lay the groundwork for improved connections added in the later strategies.

Figure 13.3. Pathway I: Specific locations

Compared to the other strategies this first pathway is unique in that water storage and safety are not main requirements. In response to this, there are two levels of intensity: First, the specific locations where a small area is adapted to create new functions and to define a distinct space. The original street is long and symmetrical, and has no places people are naturally drawn to which can be used as a social centres. The interventions will create this. As multiple spaces are created along the street, this can increase general street life, but also adds more functions, which attracts other visitors. The stepwise development of this can be seen in figure 13.4.

At the same time, there are also larger lines of green or blue drawn throughout the strategy. This is done in part to connect these new intensive locations, but also to help guide precipitation through the city.

While there is no risk of flooding in this strategy, the precipitation likely flows down to lower areas, where it can create problems, making these guiding elements a necessity.

13.1.3. Materialisation

Because this strategy is is located in the most monumental and oldest streets in the city, the materialisation must remain true to this character. Many of the existing materials, such as the traditional bricks and the cobbles will be re-used, and plant-life must suit the formal character of the street.

When water gutters are created, this is mostly done through shaping of stones, which match the existing pavement. These are built directly into the street. Benches are made from stone or the same cast iron that decorates so many of the bridges and fences in this area.

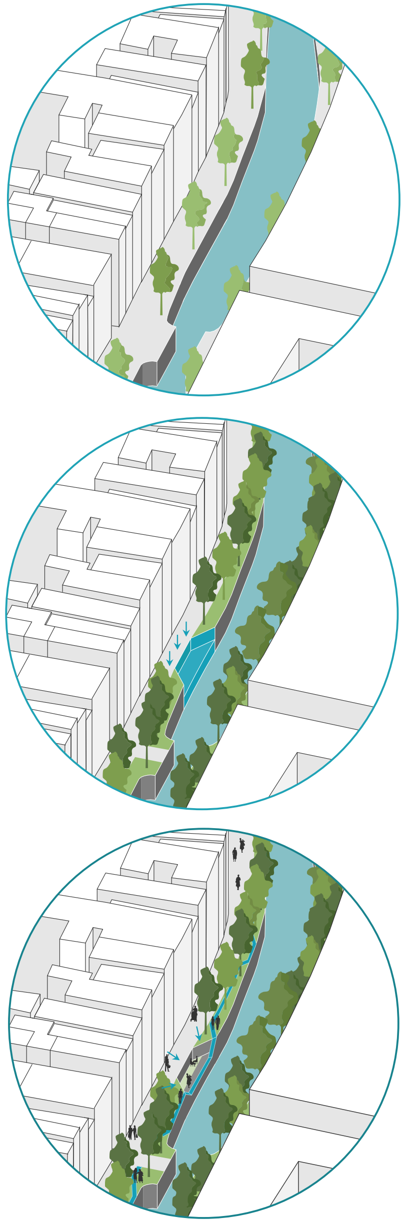


Figure 13.4. Pathway I: Stepwise approach

13.2. Protect and Innovate

13.2.1. Concept

This particular strategy is where the water problems really start coming into play. While these streets are often just as monumental as the ones discussed in chapter 13.1., they were built in lower-lying areas vulnerable to subsidence, and this increases the potential for flooding.

At the same time, these areas encompass the current social sentre of the city, which makes it double as important. This strategy focuses on the creation of supportive elements for the current social and monumental core of the city centre.

A requirement of the adaptations is that they increase the robustness of the street, to prevent damage from flooding.

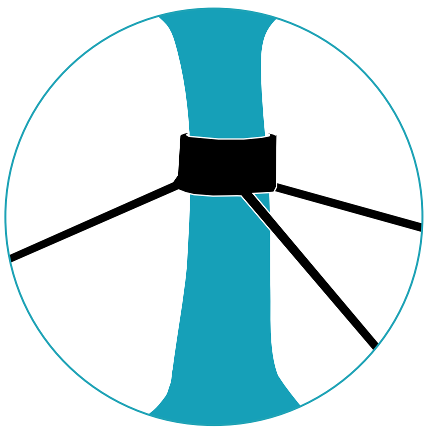


Figure 13.5. Pathway II: Protect and Improve

Unlike the *Strengthen and Enhance* strategy, areas in this particular pathway are very vulnerable to flooding. Due to the expansion of Gouda in concentric circles (RAAP, 2017), these areas lie very close to the city heart, the river, but outside of the non-subsiding clay deposits.

The water problems made actual storage measures a necessity. Chapter 11 discussed what types of interventions freed up the most storage space. The most effective options in this regard turned out to be solutions which created open water storage that is not directly connected to the groundwater system.

At the same time, several of the roads have to remain open for emergency traffic. These requirements led to the decision to focus on the redesigns of entire street profiles in this strategy.

Figure 13.6. Pathway II: Protect and Improve (axonometric projection)

13.2.2. Interventions

Because the risk analysis categorizes all the streets in only three pathways, there is a lot of natural variation within a single strategy. This means that the intensity of the intervention will vary depending on need and function. Some of the most important locations are described here.

First, intervention A shows the Turfmarkt, a which was a very important historical market. Currently it is one of the lowest lying areas in the city, and the difference between the ground and surface level is almost non-existent. Because of the drastic circumstances, a technical solution is inavoidable. A new street profile is created, in which both the houses and the street are raised by more than a metre.

Intervention B shows the two roads that border the shopping centre, and which will also serve as important emergency routes. At the same time, a green space is sectioned off, and designated for water storage.

Intervention C and D focus on the market square. At present, there is no clear water hierarchy for precipitation discharge. In the redesign, in addition to new gutters, the more vulnerable side (D) is buffered with infiltration storage, while the other area (C) is limited to permeable pavement, to keep the market function.

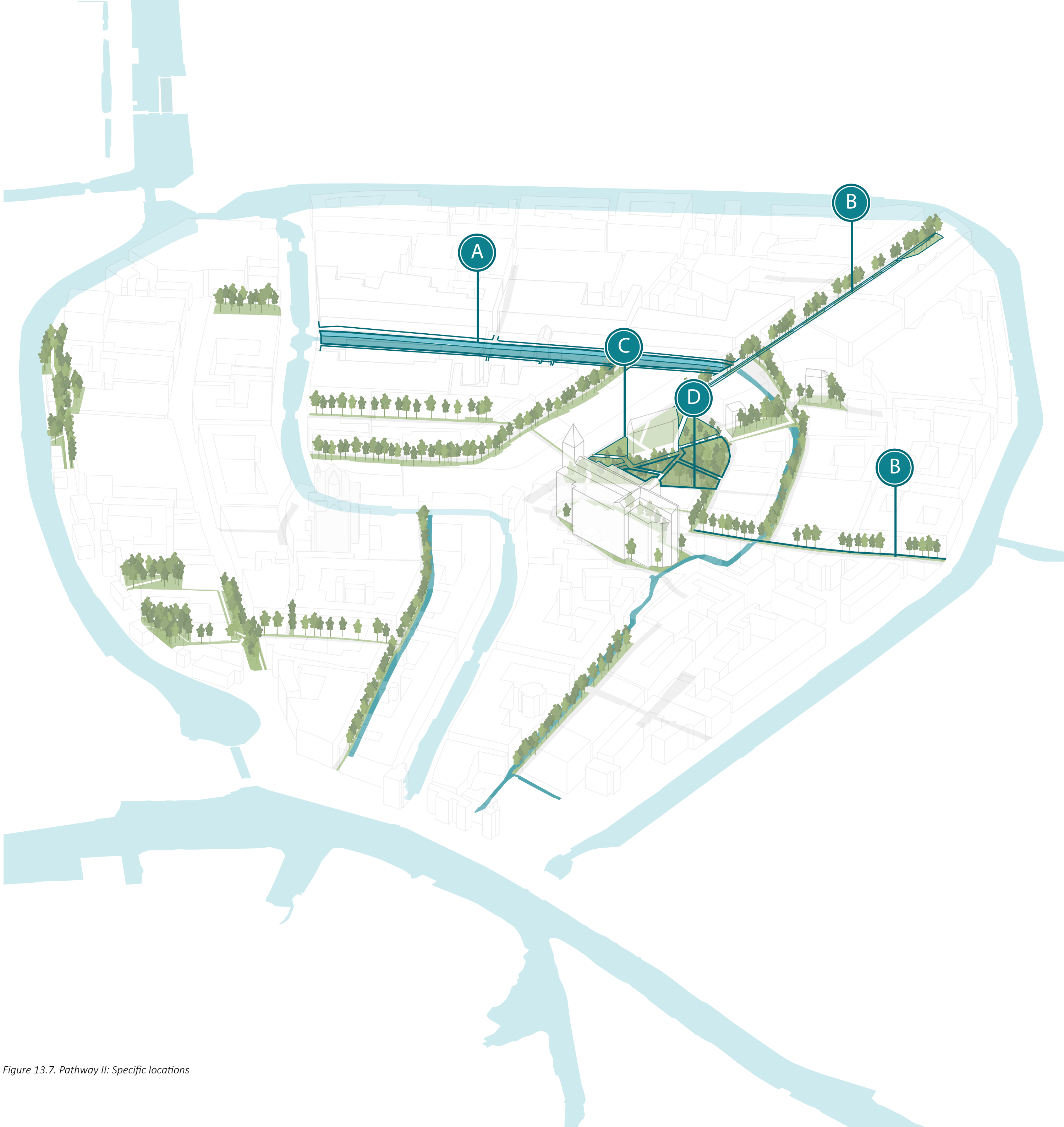


Figure 13.7. Pathway II: Specific locations

Figure 13.8, shows stepwise how the redesign of the street (B) profiles combine water storage with public space.

Half of the street remains open for use by emergency traffic. While this provides only enough space to travel in one direction, the current design of the street does not allow many cars, and its new function as an emergency and evacuation route does also not encourage high levels of traffic.

The other half of the street profile can be used as a large storage space during precipitation, and as a combination of public square and park at other times. The remaining pavement is slanted at a slight angle to promote water discharge.

13.2. 3. Materialisation

Just like the first strategy, the streets in this pathway have high historical value, and the design must hew as closely as possible to the existing space, even though this intervention includes several quite modern spatial water adaptations. This combination references the innovative spirit of Gouda, which has for centuries cheerfully used existing materials to built something more closely to their liking, as was described in chapter 8.6.1. (Denslagen, 2001)

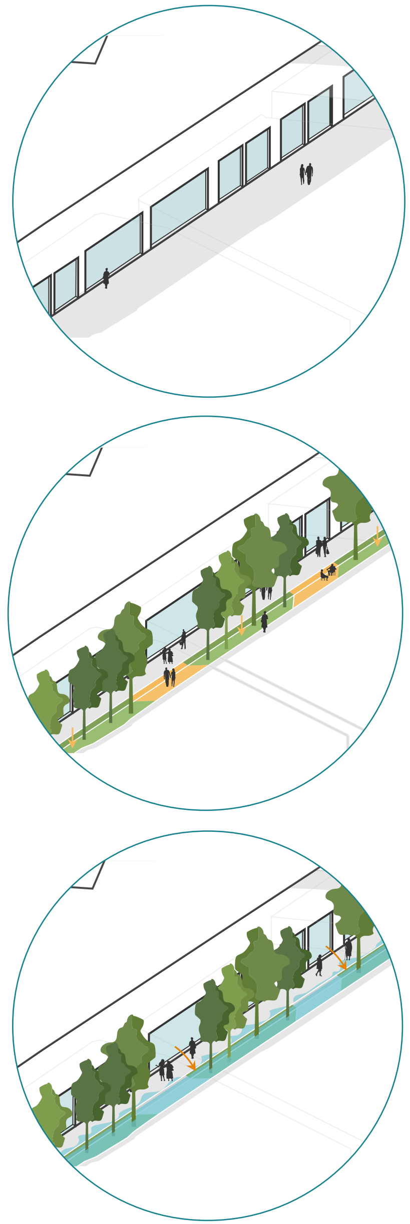


Figure 13.8. Pathway II: Stepwise approach

13.3.1. Renew and innovate

13.3.1. Concept

Even in a historical city like Gouda, not all buildings have monumental status. In fact, many of the houses in the outer ring were built during the 20th century or afterwards. This strategy concerns those areas with newer constructions, which are also vulnerable to flooding.

To go back to the concept for the strategies, this third one represents the new growth of the tree.

A knotted willow is famous for its characteristic, thin branches, which are cut down for maintenance regularly. This can be seen negatively, but it means these areas are where new growth occurs, where new ideas can be tested and improved or replaced.

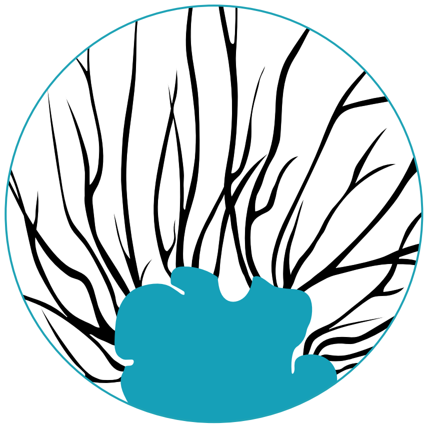


Figure 13.9. Pathway III: Renew and Innovate

This does not involve widespread demolishing, but it does mean that careful attention will be paid to the status of new developments. This means interventions will be monitored to analyse which ones will suffice in the changing climate, and thus help guide the future path of the city, with prunings only when absolutely necessary.

This strategy does not focus on the historical value of the city, but on the historic tendency of self-improvement, which gave Gouda its reputation as an important water city (Denslagen, 2001).

By centring the importance of new growth in this strategy, the area can function as a living lab where different types of storage and filtration options can be tested.

The first strategy created new connections to the water, and the second strategy focused on adding water storage and buffering existing, vulnerable streets. In comparison, this third strategy takes a look at possible adapatations to the water system, in order to improve both the quality and the quantity of water during all weather events.

Figure 13.10. Pathway III: Renew and Innovate (axonometric projection)

13.3.2. Interventions

Improved water quality and quantity require the addition of a new and interconnecting water system between the inner canals and the outer singels. Throughout the city, various methods to pump and filtrate the water can be tested. In case of ineffectiveness, the intervention can be adapted or integrated into a larger design to make it functional.

Therefore, the main goal of this strategy is the creation of new waterflows throughout the city. The most important aspect of this is movement. Water will be pumped through these canals and through decentralized filtration systems. This will improve the water quality and quantity in the city.

This is very reminiscent of a stopped practice in the city, 'schuren', or translated, scrubbing. (Denslagen, 2001). Chapter 3 explains the beginning and eventual end of this practice as subsidence continued to change the environment.

The exact method cannot come back, but the spirit can be maintained, using a more modern materialisation and techniques.

The locations in figure 13.11 show various testing sides, as well as the direction of the waterflow.

Figure 13.11. Pathway III: Specific locations

An early design example of this technique in this project are the water stairs in the Nonnenwater, created as a way of showing alternatives to the old canals (figure 10.7-10.8).

The main function of the new water system is to transport and clean water throughout the city centre (step 2 of figure 13.12), but at the same time, gutters have been laid down to connect the *Renew and Innovate* strategy to the outer singels, and to help support the vast discharge of water during moments of heavy precipitation.

13.3.3. Materialisation

Unlike the other two strategies, the goal here is not to focus on enhancement and protection of the existing value in the city, but to create new areas of significance.

And so materialisation for this area will be much more modern. While this image is important, it is vital to make sure the materials are in scale with the existing city, which is often small and detailed.

At the same time, Gouda is already known for its clean lines and minimal decoration, from the houses to the streets. By focusing on the more modern detailing, while keeping the scale of materialisation of the first two strategies, the different areas will weave in and out through each other, bringing together a monumental city with modern innovations.

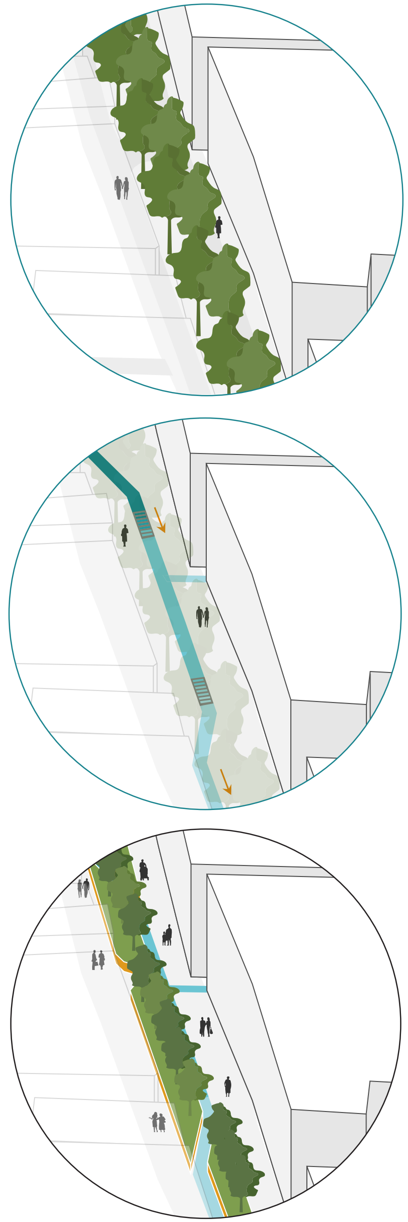


Figure 13.12. Pathway III: Stepwise approach

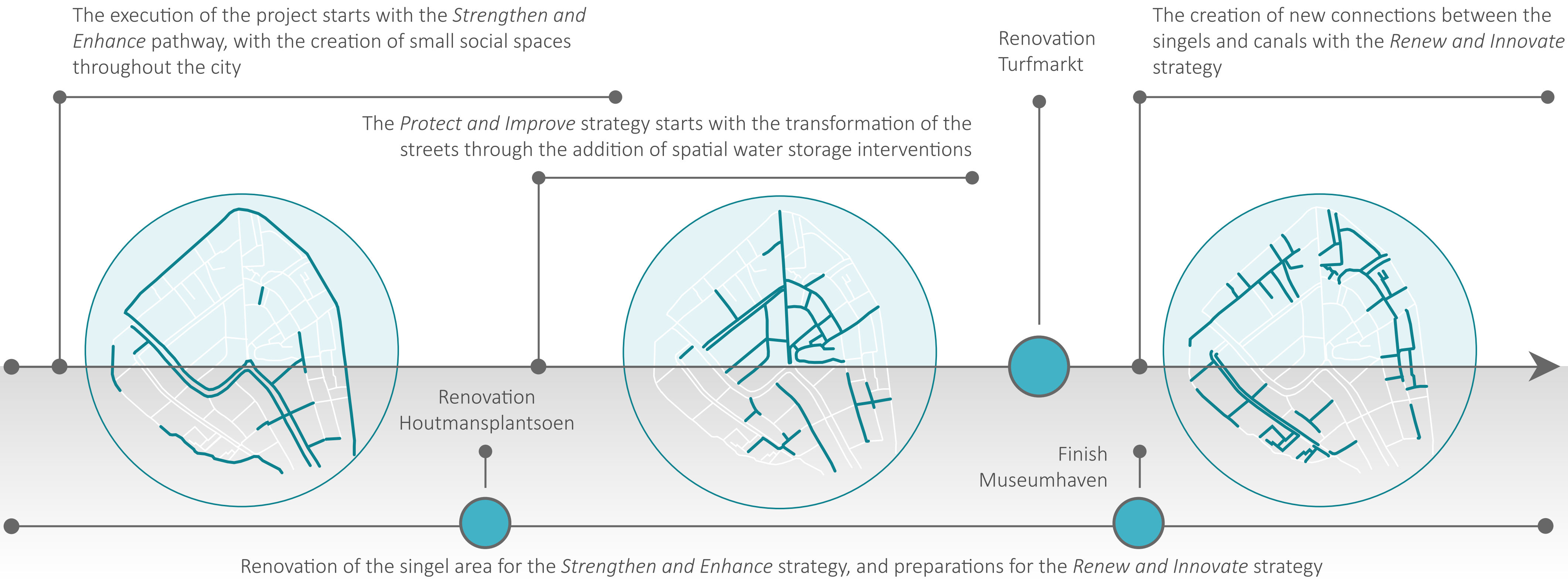
13.4. Timeline

At various points throughout the thesis, the problem of the disconnect between the inner and outer watersystems within the city centre was discussed. This is an important point to consider within the strategy, and is why two parallel, but interactive timelines have been developed. The first point in both locations is to strengthen the historical core of the city, and to create new functions in these spaces. This will serve two goals. First, it will enhance the connection of the inhabitants to the history of the city, and secondly, they will serve as replacement spaces for the streets adapted in the second strategy.

At the same time, renovations to the outer singel system are ongoing, and a renovation of the Bandstand in the Houtmansplantsoen creates interesting public spaces outside of the social centre of the city.

The second strategy is much more invasive, changing many of the street profiles throughout the city and ending with the large adaptation of the Turfmarkt, raising the entire street. On the other side of the city, small adaptations have been made to the singel route, ending in a renovation of the Museumharbour, finishing the outer circle.

Now that the groundwork is finished, and because of the slow progress of such a large intervention, the new adaptations have shown their effectiveness in storing precipitation. This means the third strategy can start developing, connecting the inner and outer water system, and testing new methods for sustainable pumping and filtration. As innovation is a constant, never-ending progress, no end-date is given for these strategies, nor should there be.



13.5. Combined strategies

One of the important factors that went into the creation of the strategies is that they had to interact and support each other, in order to successfully adapt the entire city.

Simultaneously, the varied and unique character of the city had to remain recogniseable. Therefore, while all strategies focus on adaptation of specific aspects of the city, attention has been paid to make sure elements that make up the character of the city remain.

When people walk from one side of the city to the other, a variety of materialisations, street profiles and interventions will greet them, but all of them will still be quintessentially Gouda.

Figure 13.13. Combined strategies

14. Street profiles

14.1. Introduction

While the previous chapter discussed the implementation of the strategies from a larger scale, at several points the importance of the careful design on eye level is referenced when talking about connective elements, or the way people move through cities.

The core of this design is about how these new interventions change the experience of the city, for the people who exist within it. The strategies can talk about newly created spaces or vertical connections, but this does not show how the spaces will change around eye level.

in order to stress the importance of this, four street profiles have been developed to show how the ideals of the strategies will interact with the existing street to create new spaces.

These street profiles include the new design for the Oost & Westhaven, which surround the Gouwe and are part of the *Strengthen and Enhance* strategy. As these particular interventions form the starting point for the application of the project, extra attention has been paid to the design.

The two examples for the *Protect and Improve* are the Kleiweg and the Turfmarkt. The Kleiweg is an important route both historically and in modern times, and is representative of changes made by this strategy.

The Turfmarkt is different. Throughout the history of the city, this particular street has at times been even more important than the Gouwe, as the location for the trade of peat, one of Gouda's major export products, as described in chapter 3.

It is also the image that often accompanies a discussion of the water issues in Gouda. The originally low street has sunk even further over the centuries until the difference between the water and surface level is minimal. Because this street is so important, an extreme intervention is planned to protect it from further water damage.

The last strategy, *Renew and Innovate*, focuses on newer areas, and the street used here is the Raam. While this street has existed in the city since the early phases of development (chapter 8.3.1.), its canal was filled in in the 20th century, and new houses were built.

This leaves Raam with a wide street profile perfect for a living lab with innovative new designs.

14.2. The Gouwe

This design is located at the heart of both the city and the project, and will create a starting point for the rest of the strategies.

The Gouwe is a very characteristic canal profile found in many cities, with a monumental history and a strong linear character, emphasized by the symmetrical lines and tall trees, which creates a sense of momentum.

The city grew around this small peat river, which developed from a natural stream into a vibrant market (Denslagen, 2001), and then eventually to a quiet street.

One noticeable detail of this profile is the height difference between the street and the surface of the water, which is much lower. This has disconnected the experience of the Gouwe from the street for people who move across it. The interventions here were designed to combat both problems.

Figure 14.1. Gouwe. june 16th, 2018

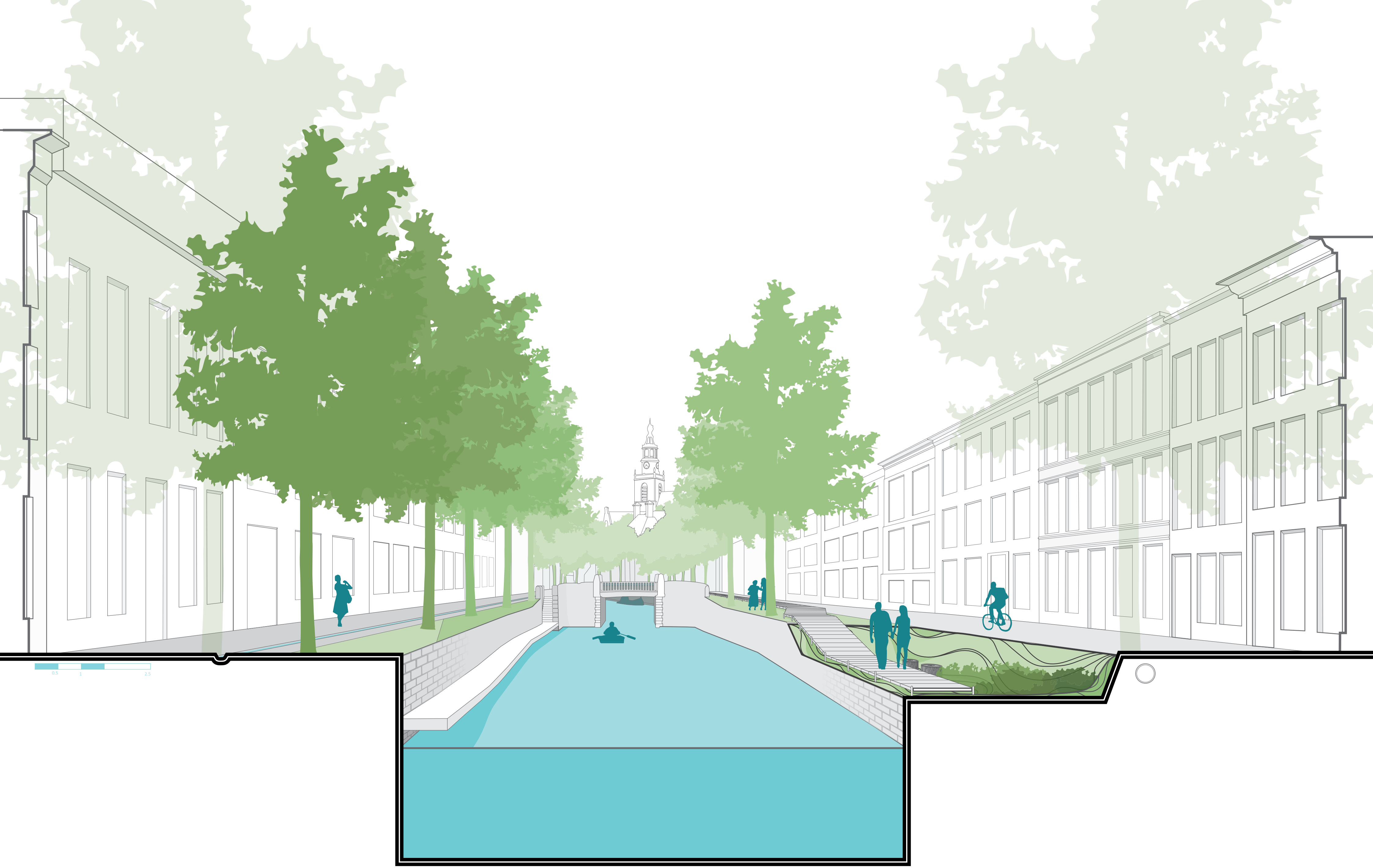


Figure 14.2 Gouwe (3D section)

In order to stay true to both its historical and its current character, new life and movement will be added to this street by the strategic placement of small public parks and functions in various locations. While these spaces can also act as terraces for restaurants or other functions, the spacing and scale of the parklets have been designed to attract enough people to create more active and varied street activities, while not filling up the street profile.

This placement creates a meandering shape that references the natural course of the river, which has been paved over and smoothed out across the centuries. This design attempts to remember these natural formations.

Vertically, the parklets were lowered to a level in between the street and the river, to create a closer connection to the water that shaped the streets. As the sides of the Gouwe are different heights, this means the parklets will be at different heights as well. The natural origins of the river means that while it gives off a very symmetrical image, actual symmetry is not present. This is very reminiscint of many of the building profiles discussed in chapter 8.6.1.).

Interventions have been designed for both sides of the river, using a very similar concept and structure. This helps shape this symmetrical line. However, when the eye moves towards the materialisation and design of the newly created space, large differences can be found.

14.2.1. Low Gouwe & Oosthaven

The Gouwe on the lower side (east), has a very natural, green image, fitted in the sculpted space. Because this intervention is a reference to the old peat river, but not a restoration of the original structure, the intervention remains surrounded by the existing quay. This is filled in with a sloping green space that smoothes out the harsher lines, and fills it with plants commonly found on riverbanks. Diagonal lines are used in both interventions to break up the flow of the street and create places where people will naturally gather.

Figure 14.3 Gouwe (map: natural side)

The walkway is located slightly above the green parklet, which keeps the visitor separated from this space. They can drift around or over it, reminiscing about the changing city. However, people can also move off the walkway and step into the space, and experience a little of this old peat river, in a pocket park, filled with benches and tables shaped to fit within this natural space.

14.2.1. Westhaven & High Gouwe

At the same time, the west and higher side of the river has a much more urban look, referencing the streets' history as a major harbour. Unlike the lower Gouwe, which focused on the creation of an experience for the inhabitants, this intervenion has more practical use. This could be a park, or it can be a neighbourhood social space for the evenings, or even the seating area of a restaurant. As there are several of these spaces throughout the street, actual application of these elements will vary.

This results in a much more formal look, which is represented by the vegetation, as well as the harsher lines and diagonals that can be found in this parklet. Unlike the lower Gouwe, green elements took the shape of the existing tree structures, formal flowerbeds and permeable pavement. The construction of the city, its streets as well as its buildings, is often characterized by long, simple lines and brickwork. Interestingly, this habit spans from the early ages of the city centre all the way to the 19th century. This means the careful materialisation does a lot of work in deliniating and assigning function to the spaces.

In the centre there are several pavement types used to represent specific typologies, and the simple adaptation of these patterns helps to create distinct spaces. A herringbone pattern is found on all the streets in the city, and is used to represent movement. At the same time, cobblestones are placed to deliniate locastions where people gather for social occasions. A difference in density of the cobblestones is added to define the intensity of use.

While flooding is not a major issue, gutters are still added to the street profile, to prevent potential damage in lower areas, while also creating more visibility for waterflows in the city.

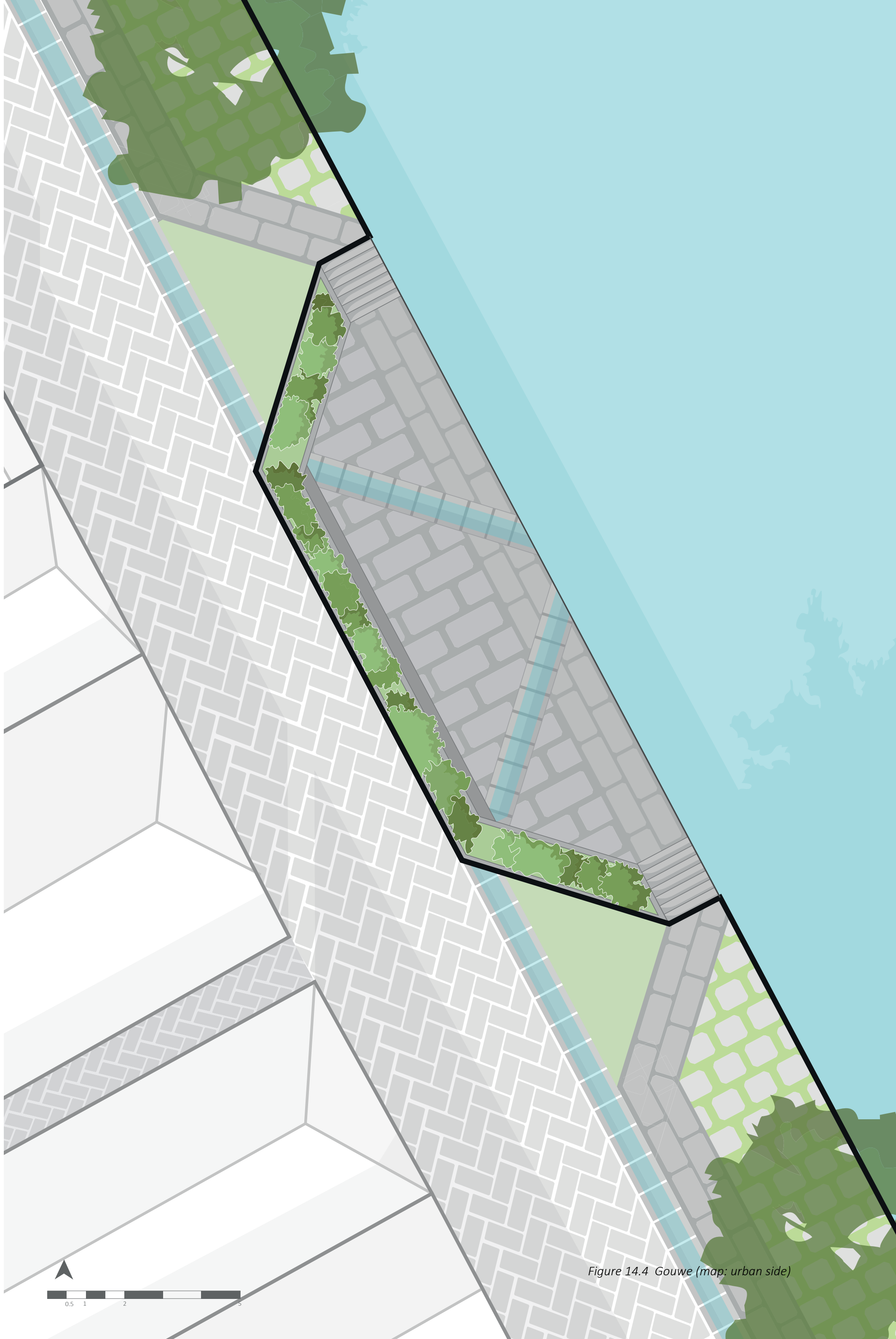


Figure 14.4 Gouwe (map: urban side)

Figure 14.5 Walkway (Flood Plain Boardwalk, n.d.) - Plants (FLORON, 2017) - Seats (How to Make, n.d.)

Figure 14.6 Gouwe (elevation: natural side)

Figure 14.7 Fence (Alloy Foundry, n.d.) - Brickwork. June 16th, 2018. - Gutters (Pötz & Bleuzé, 2012)

Figure 14.8 Gouwe (elevation: urban side)

14.3. Kleiweg & Hoogstraat

Though this particular road has been visible in the spatial structure of the city since the beginning, as can be seen in chapter 8.3.1., it is also the modern entrance to the city centre directly from the new town hall and the station. People walk through a long shopping lane that forms one edge of the social centre of Gouda, eventually opening up to the market square, and from there on directly to the geographical centre of the city.

Long and relatively narrow and fringed by monumental buildings, this street was built in one of the lower-lying areas, and thus has to cope with flooding. Within this busy shopping street, the design has to combine walkways for the inhabitants with enough space for the water storage.

Figure 14.9. Kleiweg. June 16th, 2018

Figure 14.10 Kleiweg (3D section)

14.3. Kleiweg & Hoogstraat

Water storage and shopping routes are not the only aspects that must be considered. The fact that this road directly connects the central point of the city with major roads outside it, is the reason behind the added requirement that this road must remain useable as an evacuation route.

This led to the creation of two distinct, multifunctional zones (movement and meandering) within the street, stretching onward in long lines, again evoking the idea of symmetry without acutally applying it. The movement zone includes both the evacuation route and part of the shopping walkway, and remains mostly unchanged. On one side of the street, this road is large enough to allow cars to pass, while the other side only has a small path for pedestrians.

The major change in the street profile is the integration of an entire meandering section. This combines more intensely green areas with places filled with permeable pavement. This variation is set up in such a way that it creates a zig-zag pattern that allows visitors to cross to the shops on the other side of the street without breaking up their progress.

These half-paved areas are ideal places for benches and waste containers, where people can take a break and rest. However they are also very practical as potential seating spaces for restaurants. At the moment, most catering businesses are found either on the market square or at the end of the street, where there is space for seating. This adaptation will allow for a more even mix of public activities in the street, which also leaves the street active for longer in the evening when the shops have closed.

An important distinction between the movement and the meandering section is the height difference. Because chapter 11 proofed the efficacy of water storage solutions that were not directly connected to the groundwater, this area was transformed into a large functional green ditch (as defined in chapter 9).

This intervention was chosen over less spatially intensive options (such as infiltration boxes). The lower area will create an enclosed feel and more intimate social spaces, something lacking in the current street. At the same time, a similar lower area already exists at the end of the street. This new zone is thus not a completely new idea, but simply an expansion of a pre-existing element.

While the vegetation will help with infiltration and interception, the actual useability of these interventions has proved limited. So in this design, they instead help define intimate spaces, add to the biodiversity and create a cooling effect in summer. A gutter runs through the zone, connecting the green and paved elements, and providing a method of water discharge after precipitation.

Materialisation for this street profile is quite simple, as it hews as closely as possible to the existing situation. This is done to balance out the spatial changes. The herringbone pattern is used on the higher surface areas, but a small adaptation is made for the lower zone. As these lower paved areas move diagonally across the street, instead of a herringbone pattern, a simple paved structure is used to represent the direction of the space. These bricks are also more open, allowing for more infiltration.

Care is taken to use smaller, narrower trees (such as birches) with a tall trunk to make sure visibility is not impeded in any way. Linden trees are also found, as this particular species is used to frame the Gouwe. As both roads function as evacuation routes, this long linear element makes them easy to follow.

Figure 14.11 Linden tree (bomengids, n.d.) - Birch (Kunev, n.d.)

14.4. Turfmarkt
As described in chapter 14.1., the Turfmarkt is commonly used to represent the water issues in the city centre. Once the site of the peat market in the city (Denslagen, 2001), currently it is a quiet street.

The ground level is so low compared to the surface of the water that it seems as if image 14.12. was taken in the middle of a flood situation.

While it is not immediately critical, the water issue is still a major problem. And it is one that is very difficult to solve with spatial interventions. Which means radical actions must be taken.

Figure 14.12. Turfmarkt. June 16th, 2018

Figure 14.13 Turfmarkt (3D section)

Green-blue interventions in this project rely on a certain amount of freeboard space beneath the surface level, which can be reinterpreted as storage space.

The Turfmarkt has no space into which this can be done. This makes most types of infiltration, local storage or water discharge unuseable. One remaining option involves the creation of barriers to protect the houses, something that can already been seen occassionally throughout this area.

But for such an historically important street, this is a low-quality solution. And so, uniquely in this project, the Turfmarkt is supported by technical solutions. The entire street and houses are lifted by 1.5 metres, solving the flooding problems.

However, this simple action would remove some of the historical identity of the street. The Turfmarkt's most famous characteristic its proximity to water. This separation goes against aspects of the of the combined strategy, which concerns itself with preserving the water connection.

And so, the design had to find a balance between higher and lower levels. And while the Turfmarkt and the Gouwe both belong to strategies that focus on maintenance of the old materialisation and image, they still had to be clearly distinct streets.

As a result, the decision was made to raise the street to a higher level, but, in order to maintain this historical characteristic, a section on the north side of the street was designed as a dynamic movement between the upper and lower areas of the street, using a series of stairs.

This provides a link to the newly added interventions in the Gouwe, as well as the old water situation. The lower section on the north side can be used as a public square or as semi-private front yards, or even as a terrace for the shops in the easternmost part of the street. Also, a dock is added to this section to create a multi-level gradient between the water and the street, and to add recreational water functions.

A disadvantage of this new water zone is the halving of the available parking space. This means inhabitants from both sides of the street must park on the south side. This is reserved for inhabitants with the highest need, while the other residents use the car park 250 metres away.

However, this is in line with the reduction of the parking spaces in other interventions, where cars are often replaced with green-blue designs. Though options are made available for people who require the availability of a car, the promotion of existing car pars as well as parking outside of the city centre will be promoted.

Because this is such a radical change to the street profile, the existing pavement (see figure 14.11 for an example) is recycled for the new intervention, to maintain familiarity. For those areas that remain on the original level, the current trees are kept as a reminder of the previous situation. In the higher levels, larger varieties of trees can now flourish.

Figure 14.11 standard pavement Gouda. june 16th, 2018. - existing trees. june 16th, 2018.

14.5. Raam

A common thread can be found throughout the first three street profiles in their goal to protect the monumentally valuable elements of the location, from the buildings to the canals themselves.

This contrasts with Raam, which is not defined by its historical elements, but by the lack of one. Once the location of one of the large canals in the city, in the 1960s (RAAP, 2017), the water in this street was drained and filled in with pavement and parking spots.

Further renovations and new construction on the west side of the city centre has left this street with an odd mix of old buildings, new constructions and the empty impression of the old canal in the middle.

Figure 14.14 Raam. June 16th, 2018

Figure 14.15 Raam (3D section)

This situation has left the street profile of Raam with interesting inbalance of width and height, which is also visible in some other places in the city centre, such as Nonnenwater and Nieuwehaven.

From a design perspective, this opens up a lot of opportunities. The goal of the Renew and Innovate strategy is to reconnect the inner and outer system, which is the network that was lost when the canals were removed.

Thus, a new waterway and filtration system is proposed, to increase the water connection throughout the city which will simultaneously improve the water quality.

This involves the creation of new green-blue spaces where this filtration can occur. In Raam, the design of this route was highly influenced by the slanted angle of the parking spaces, which is very distinct from streets with a similar profile.

This angle led to the introduction of a meandering route of the waterway, which delineates the area into different smaller zones. The original street profile was nearly completely symmetrical, except for the angle of the cars, but the new design changes this. The waterway moves from side to side within the centre area of the street along hard angles.

The shape of the waterway creates half-enclosed zones, which can be filled in according to the goal of the design. On one side, the current parking structure is maintained, but on the other side the roadway is removed and replaced by a bicycle path and an unpredictable walkway that moves according to the function and design of the space it passes. Car traffic is limited to one side of the street.

The progress of the waterway can be seen in figure 15.1. Across this route various filtration systems have been placed, and the water must pass through this before it moves on. Solar powered pumps are used in combination with gravity to move water around the city.

The third strategy's identity as a testing lab is responsible for the planned creation of variety of decentralized filtration designs. This particular option combines faster waterway (supported by pumps) with very localized helophyte filters (Pötz & Bleuzé, 2012). While these filters work quite well, the natural process takes around three days to complete (Huizinga, 2014).

At the beginning of the waterway, sieves and filters are used to help strain out larger sources of pollution and waste in the surface water, and larger helophyte filters start the filtration process. After this point, new sources of pollution are limited, which resulted in the use of a much smaller filter (see fig. 15.1). This allows the living lab to test if both quality and speed are sufficient, or if there are bottlenecks in the system.

While the main focus is on filtration and movement of water within the inner city system, the waterways connect to the outer singels as well. During periods of high precipitation, water can quickly flow out of the inner system to these new streets. The designated spaces on one side of the street help to store excess water until it can be discharged into the canals.

Though the choice for the shape of the new waterway was inspired in part by the existing angle of the cars, the strong angles were added to show that this waterway was not formed naturally. This concept can also be found in other street profiles.

The actual design of this profile laid some limits on the materialisation possibilities. The waterway had to be sturdy, and securely disconnected from the groundwater. Interaction between these two would slow down the waterflow. This led to the choice for a ditch made of concrete. In order to waterproof it as much as possible, and to create clean lines, larger elements were used.

As this ditch is the major design focus, its materialisation influenced the rest. The pavement of the walkway and re-done street had to suit both the waterway as well as the rest of the city. This was done by matching the city on the scale of the pavement, while using lighter concrete bricks to create contrast with the city and connection with the new waterway.

Further detailing is not actively applied throughout the area. Decoration mostly comes from the vegetation, which uses a variety of plant life that suits the natural (polder) landscape of the underlying structure. The use of this element is a factor in all the strategies, especially in the area near the singels.

As many as possible of the existing trees are kept in the new situation, but different species and variants are also used throughout the street.

Figure 14.16   Waterway (Dresen Landscaping, n.d.) - concrete pavement (ImproveNet, 2018) - helophyte filters (Pötz & Bleuzé, 2012)

15. Design

In the previous chapter, several designs for new street profiles were created to show how the goals of the three pathway strategies would influence the image of the city.

Within these streets, the spaces taken up by the new spatial interventions were often multifunctional, and interactive with other elements for public use. Since spatial interventions take up more room than technical solutions, the new elements were selected specifically to give new benefits to the city.

These spaces, parklets, seating areas and walkways can be seen throughout the various profiles, but the level of detail often remained low, At the same time, possibilities for realisation are discussed in the text and located in the images by the use of a few design elements

One of the important aspects of the city is the incredible variability and differences in character that exist within its borders. Several public spaces were even shaped by the residents to suit their own needs, which is what made them successful. This level of interaction is also needed to develop the realization of these spaces.

During the implementation of the project, the people involved will have to work very closely together with the inhabitants to find out what matches both the location and the stakeholders. Image 15.1 for instance, shows three very different options, and the effect they have on the street profile.

As a supplement addition to the various street profiles, a complete design, including a much higher level of detail was created for the Nonnenwater. This was feasible because the workshops, which were about this area and involved stakeholders from this street gave insight into their wishes.

Figure 15.1 Different design options Raam

15.1. Nonnenwater

One short workshop, including only a few inhabitants as well as participants from other locations, is of course not enough to have a comprehensive overview of all the various stakeholder desires.

This design thus does not attempt to develop a perfect solution, but observations from the first workshop (chapter 10) were used as factors. This location functions as the culmination of the three strategies and the various pathways in its ability to create water storage and to protect the city while also adding to the functionality and liveability of the street profile.

Figure 15.2 Nonnenwater. June 16th, 2018

Figure 15.3 Nonnenwater (map)

The street profile is very similar to the Raam, but unlike that street, where the former location of the former canal is filled with cars, this space has remained empty. This wide, open area can look empty and vacant, but it is also a unique open space, especially within such a dense city centre. The preservation of this open feeling was important to maintain the character of the street even through a complete redesign.

In order to provide smaller spaces within this street without disrupting the open feeling, the logical alternative is to create them by going downward, Re-using the vertical space formerly occupied by the canal.

Because of the varied water and safety requirements within this street, and the proximity to the *Strengthen and Enhance* strategy and the Gouwe, a different streetprofile was created for each side of the now recessed square.

Figure 15.4 Nonnenwater (section)

Looking from north to south there is a hard edge, but the lower structure prevents visual barriers, allowing inhabitants to look out to the other side. The materialisation and structure of this side is very clean and simple, based on the smooth, heavy lines that shape many of the old elements in Gouda, from the Gouwe itself to public elements at the Museumharbour.

Other elements are the addition of a grass field on the upper level, as well as a gutter that runs along the Nonnenwater to the Raam and catches precipitation flowing down from the road, which is stil in use by cars. The materialisation of this gutter is similar to those described in figure 14.7, at least on one side. On the other, the natural slope of the area forms the edge of this storage space.

The southern, green side slopes downward to encourage precipitation to flow down to the lower area, rather than into the houses. This gradient is reminiscent of the newly developed waterside near the singels, and vegetation mostly consists of reeds low shrubberies and other riverbank plants.

However, the use of vegetation that would naturally occur in a polder landscape does not mean that this has to be monotone. Traditionally, many flowering plants have flourished in these landscapes (Huizinga, 2014), and they will be used to create colour and variety. This will result in an interesting spatial composition, but it will also provide variety throughout the seasons. Examples of used plants are carnations, begiona, chrysanthemums or wallflowers (figure 15.5).

Trees in this area are high and narrow, to avoid blocking the view. Birches are preferred, as their light bark helps them blend in further.

There is only one exception to this arboreal rule. On the corner where Nonnenwater turns into Raam, a large weeping willow draws the eye. Located on a small hill within the recessed square, this tree is the centrepoint of the intervention. Benches surround it, located so that the tree and the higher ground block the morning and evening sun, while still being able to enjoy the sunny afternoon.

Just like the wall they rest against, these benches are simple in shape and material. The pavement beneath it is the exact same material that is currently used in the Nonnenwater, but relocated. On the higher level, one road remains accessible for car traffic, though it is discouraged. On the other side of the street, the walkway from intervention 14.5 transitions into the pavement that continues around the corner to the Hoge Gouwe.

This area is the endpoint of the *Renew and Innovate* strategy, and this means a waterflow must be included within the design. In order to prevent trash or fallen leaves from clogging this system, a roster is placed just below the water level, which also adds to the safety when using this space.

Overall, the height difference creates clearly delineated and functional spaces that can easily be used by inhabitants. The trees help to break up the vertical emptiness without blocking too much of the view and maintaining social cohesion across the square.

Figure 15.5 Wallflowers (Silver Falls Seed Company, 2018) - Royal Fern (Appeltern, n.d.)

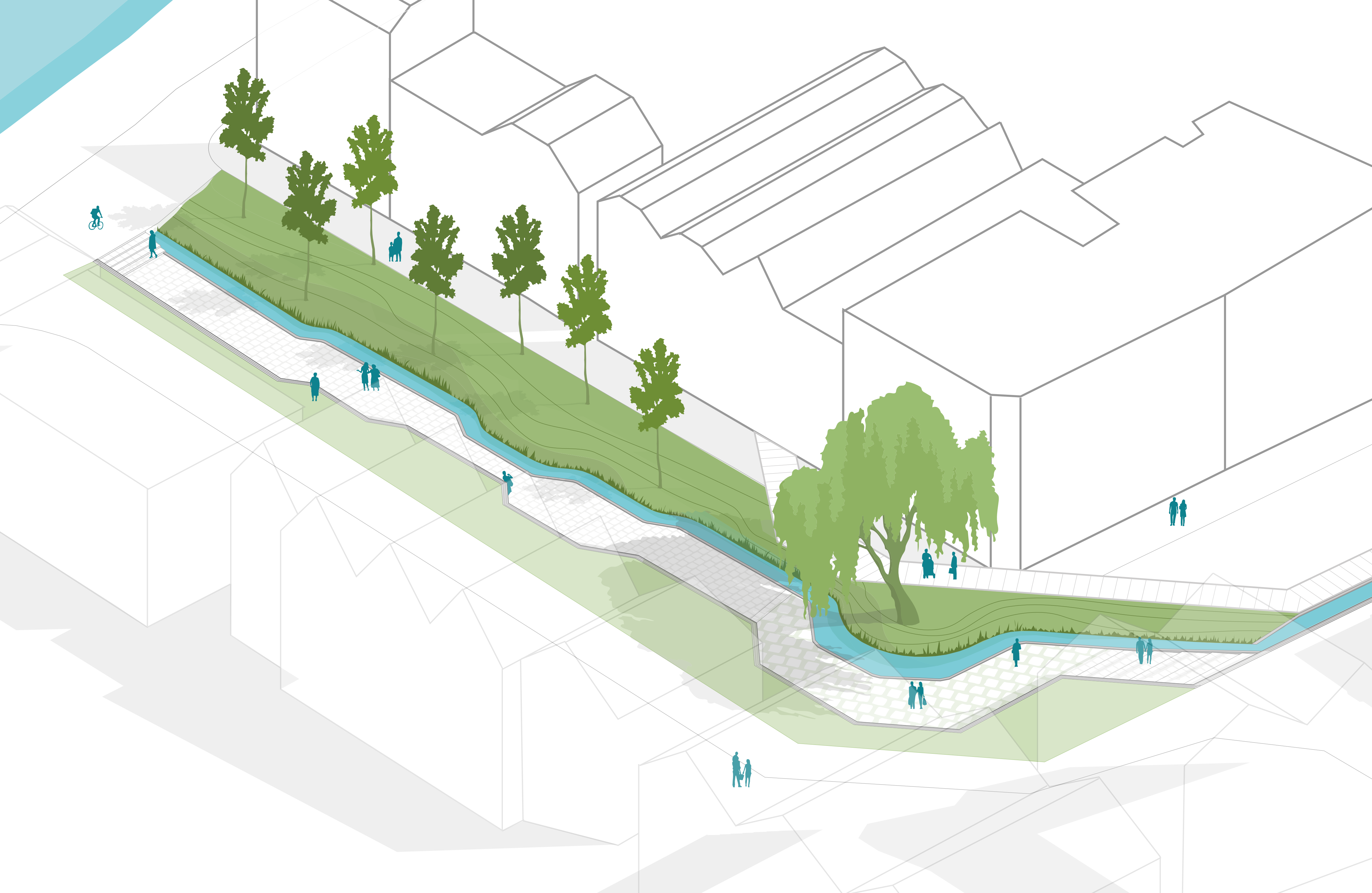


Figure 15.6. Nonnenwater (3D)

16. Conclusions

The goal of this study was to answer one important question, which can be paraphrased as 'Is it possible to use spatial interventions to protect Gouda from flooding caused by climate change? And if this is technically achievable, is it also possible to integrate these large new elements within the existing structure of the city?' This is to provide a parallel path to the study underway in the Municipality of Gouda, which researches possible (technical) solutions for the same problem.

16.1. Capability spatial elements
The answer to the first question, in a technical sense, is yes, up to a certain level. This project has shown that the technical efficacy of spatial interventions is high enough to counteract the extreme levels of precipitation the Hoogheemraadschap van Rijnland (2018) uses in their research. In order to study the likelihood of this situation, potential future scenarios were examined. This was combined with a methodology that calculated the efficacy limits of the interventions.

However, these results show that spatial interventions are only an sufficient as an alternative for technical solutions added as a result of the ongoing municipal investigation.

The existing sewer system must remain available for use as rainwater discharge, as the newly designed spatial storage will not be adequate throughout the entire inner city. This results in additional renovation costs, as the city would have to spend money on both systems, but, at the same time, this does create an opportunity to analyse the integrative potential of these two elements per street.

16.2. Integration
The next question was to find out how such spatial designs could be interspersed within the existing city. As a consequence, a large part of the process, this project consisted of a lot of analyses, calculations and workshops to study the city, with the development of the design running as a background process. For the last stage, these two priorities were switched around.

All the data was synthesized into the final design presented in the final phase. Notably, no more calculations were done on the eventually resulting designs, in order to avoid detracting from the creative process. The knowledge from the efficacy calculated in the earlier phase was used as base information.

16.3. Balance of technical and spatial design
Even if the research proved that the potential of a Gouda without any technical interventions was achievable, this still not be the final conclusion drawn in this thesis. Gouda's history is built on the new and innovative technical solutions used for water management through the centuries.

But these early technical interventions connected to the landscape in ways that the current solutions no longer have. This project attempts to bring back this balance to the city. Technical solutions are there to support the existence of spatial elements. This can be seen in the way the various strategies work together to reinforce the city centre.

The new Gouda will have integrated technical and spatial water systems which work together to set Gouda on the stage as a climate proof city that combines innovation with historical value.

V. Other

Reflection
References

17. Reflection

The goal of this study was to find a balance of interventions Gouda can apply to remain sustainable in a changed climate. The vulnerability of Gouda to climate change is heavily intertwined with its location.

The city originated around a small peat river, lying in the middle of a large delta. Subsiding peat levels (Denslagen, 2001) and rising precipitation (KNMI, 2018), requires intervention.

The Delta interventions studio focuses on the balance of urbanisation, port-development, environmental qualities and flood defence, amongst other things. These factors are important issues in Gouda's adaptation to climate sustainability.

And Gouda is not the only city in this situation. These problems stem from the physical qualities of the land on which the cities are built, as well as historic Dutch building traditions, which all suffer from global climate change. With extreme weather events occurring more often (KNMI, 2018), cities become anxious about how to protect their monumental heritage during disasters when this same heritage often means large changes are forbidden.

This situation requires a solution, but Gouda's complex water system, with its many conflicting elements, as well as the many uncertainties present stopped this project in its tracks in an early phase.

Instead of progressing through the research to come to a design, research started to move sideways, spiralling into side paths. Several explored methodologies supported the project with specific issues, but none of them provided a structured approach, and it led to a lower quality, chaotic result.

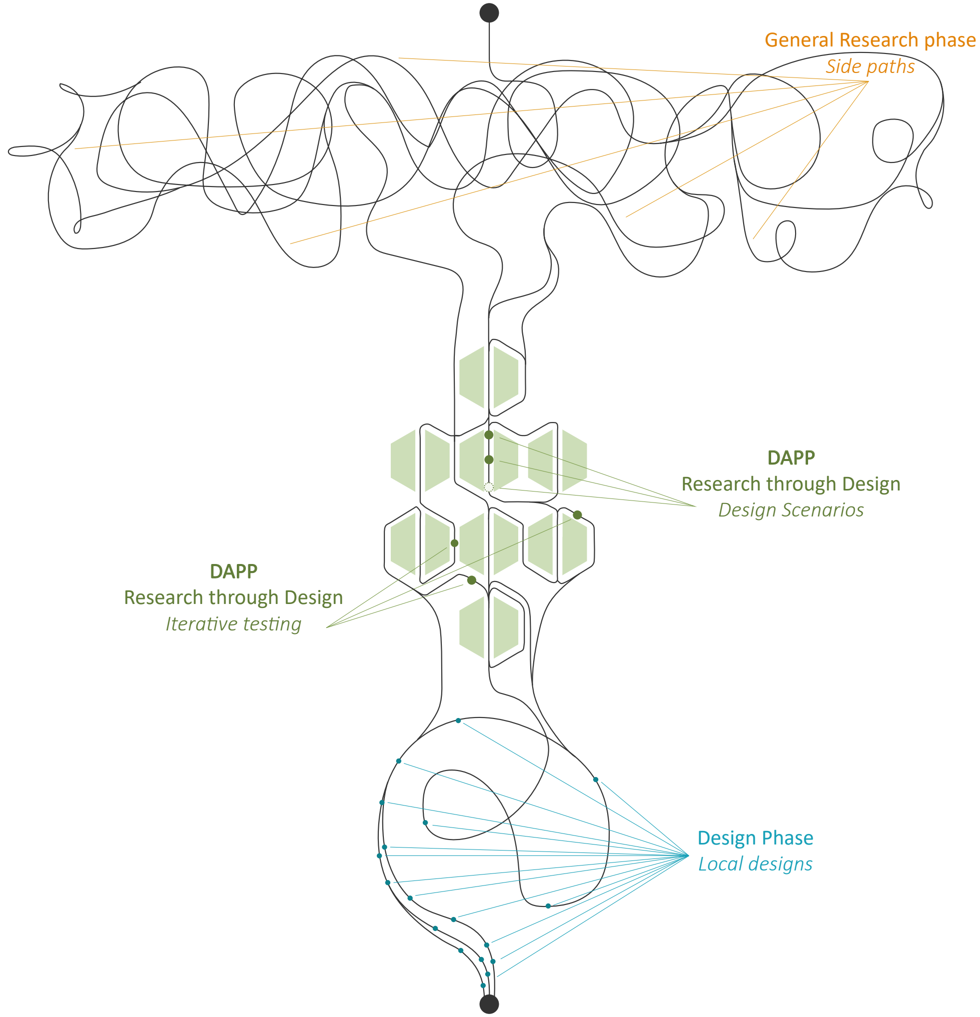


Figure 17.1. Structure of the research project

This asked for a more structured methodology, with a step-by-step progress that could be adapted for the specific situation in every phase. The chosen method (Dynamic Adaptive Policy Pathways) (Haasnoot et al., 2013) included all of this, as well as a supportive strategy for uncertainty.

This progress involved iterative steps of analysis and design. It started with a general analysis, which developed into the creation of several interventions, which were used for research through design. These interventions consequently were tested and prioritized using technical (calculations) and social (workshops) methods.

One other disadvantage was that, due to the relatively late entrance of this approach into the project, the design phases did not always match up to the graduation program.

Using DAPP helped to structure this project, the overall planning as well as the decisions that had to be made at various points. The iterative elements then allowed me to look back at my project and tweak elements. This methodology covers climate uncertainty, and allows for some measure of stakeholder uncertainty, but there are some uncertainties in Gouda that are not taken into account, e.g. the lack of available knowledge of the foundations and sewers.

There were some mismatches between this study and the methodology, but the project needed a clear structure in order to move forward. Fortunately, the framework layout left enough space to adapt elements and steps to interlink more closely with the requirements for Gouda. One major example of an adaptation is the fact that this study results in a design with integrated pathway elements, instead of a planning approach.

Overall, the integration of uncertainty, climate change, cultural heritage, technological and spatial interventions will provide a plan different from what Gouda planned, but it aims to be a different way forward to integrate tradition and the future.

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