adaptive architecture
and flood permitting cities

urban flooding as incentive for incremental positive change

the case of Brederode in Antwerp, Belgium

Sophie Leemans

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Master in Architecture 2018 - 2019
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"The city of tomorrow, created by architects of today, is built on what we have inherited from yesterday."

(Permanent exhibition 'Modern Utopias' in Centre Pompidou Malaga, 2019)

This dissertation marks the end of five years of intense studies including many encounters with inspiring people who I can't possibly thank all individually. Nevertheless, special thanks go to...

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Fig. 0.1. The Sea of Ice (Caspar David Friedrich, 1823)

Abstract

Humans have always had a strong connection with water. However, how we position ourselves towards nature and its elements has changed over time: the human lifestyle evolved from nomadic hunting (obeying nature's system) to living in sedentary settlements (bending nature's system). Especially after the Industrial Revolution, this started disrupting many natural processes of which we only found out the consequences decades later. Due to its global and relatively slow character, the exact consequences of **climate change** are difficult to predict and the issue is often seen as too big or complex. We need a global mentality shift instigated by local interventions to provide an answer to these changes.

This master dissertation focuses on the topic of **water**, as we are and will be experiencing an increase in extreme weather events and a rise in sea level as a consequence of climate change. The deltas of rivers are one of the most densely populated areas. Due to their delicate position in relation to water, they (will) experience flooding first and foremost. This puts millions of people and their homes at risk. In the first place, I tried to develop a strategy on how to deal with water different from the main discourse today. Instead of seeing it as something to get rid of as fast as possible, considering it as a catalyst for incremental positive redevelopment of an urban area.

Since dense urban areas don't have leftover space for large engineered protection structures I propose to implement a **network of relatively small-scale architectural interventions** in the existing dense urban fabric. Niche space offers opportunities to redevelop a complete neighbourhood through incremental change with small investment shares and a high engagement rate from the inhabitants.

To test this strategy, I developed a proposal for a case study, which could also be considered a pilot project. In the context of Flanders the Antwerp region shows to be an interesting area due to its location within the Rhine-Meuse-Scheldt delta, which is one of the two **largest risk zones** for flooding in the world. Within the city the highly densified neighbourhood Brederode shows large vulnerability and therefore offers to be a relevant case study to implement my proposal.

The network is based on four ways of dealing with large amounts of water: infiltrate locally (1), pump to connect (2), buffer temporarily (3) and protect the weakest areas (4). These four strategies are spatially implemented based on flooding maps and in the first place want to provide an answer to water coming from above (rainfall) and below (insufficient sewerage). Additionally, the network also provides resilience to river flooding. However, since the Sigma Plan mainly focuses on the latter, this became a secondary point of attention.

Each strategy has accompanying spatial interventions on multiple scales. Due to the limited predictability of the occurrence and intensity of certain weather situations the proposed network has to be **adaptive** in order to increase the neighbourhood's resilience. This network wants to allow water where it naturally wants to flow, temporarily retain it and let the unused infiltrate in a staggered manner. As such it wants to showcase the opportunities and positive effects of allowing water near our habitats (again). In this way, urban flooding becomes an incentive for incremental **positive change**.

This master dissertation is based on the personal design interest (topics) and design strategies (approaches) that I detected through an analysis of my previous projects.

Methodology

This master dissertation was generated in the studio "Graduating through portfolio" / "Afstuderen via portfolio" led by Arnaud Hendrickx and Nel Janssens in collaboration with Filip Mattens and Sam Dieltjens. This studio gave me the freedom to develop my own master dissertation topic and research question. Here, instead of considering the master dissertation as an all-round showcase of the students abilities, the aspiration is rather to develop a project that fits into the students' portfolio. In this way, it bridges the gap between the architectural education and the student's future practice.

The starting point was to observe my own work (both design projects and written papers) of the past four years to explore and understand my personal view on architecture. I isolated specific aspects that I found in a selection of previous projects which formed clusters based on similarity or contrast. This covered both graphical expressions as physically invisible themes and design strategies. This series of different clusters of aspects formed a list of what we called "patents" which were specifically linked to my personal architectural practice. Visual and textual material substantiating the following patents is shown in a separate portfolio booklet.

utopian realism
future optimism / power of architecture / glocal problem solving /
social relevance / design the city of tomorrow today

transdisciplinary master planning
urgency of a larger context / integration of different scales / timeline design
testing professional domain boundaries / participatory development

activating collective space
space belonging to everyone and no-one / tension between public and private /
power to the people / guerrilla architecture / use of niche space

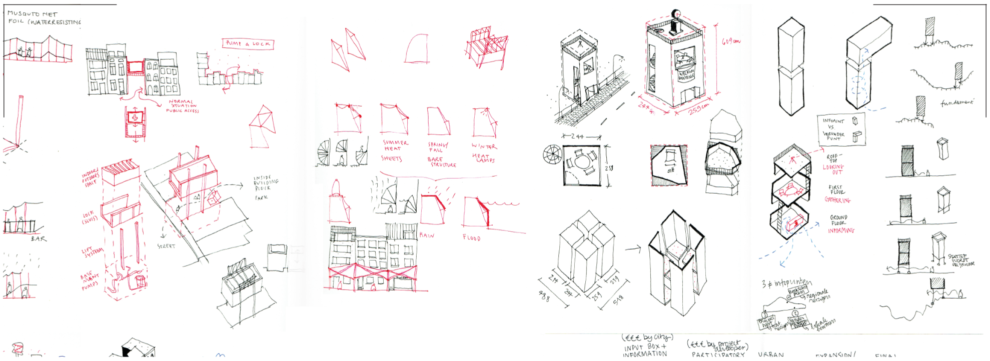
ephemeral interventions
small scale / tactical urbanism / pavilions /
temporary architecture / mobitecture

adaptive architecture
climate resilience / flexibility / universal applicability /
long term sustainability / scenario and case design

the sketch as primary design tool
visual production of incoming information / mapping with basic means / quick idea
development / communication to stakeholders and outsiders

Besides this rather methodological approach I also had a specific topic interest when starting this analysis. During my Erasmus exchange at Chalmers University of Technology in Gothenburg I developed a six-week design project based on the probability of future flooding at Kvillepiren, a former industrial port site. At the same time, I wrote a paper on the challenges and strategies for design professions for a sustainable future. The eagerness to elaborate on the flooding design project in combination with my raising awareness of climate change and its architectural challenges made it an obvious topic for this personal master dissertation.

The step by step analytical construction of a patent portfolio in combination with the personal interest in urban flooding led to the idea of a case study of a specific relevant area to crossbreed the larger issue with my personal design strategies.



portfolio

sophie leemans

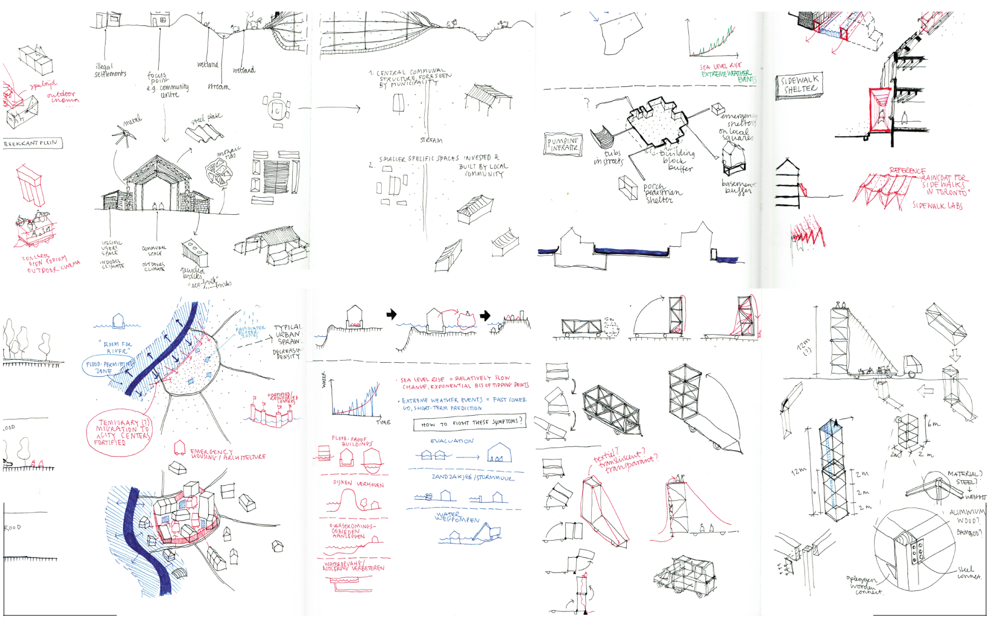


Fig. 0.2. Cover page of developed portfolio (Sophie Leemans, 2019)

Introduction

Human settlements have always had a strong connection with water. Even the earliest human migrations and settlements were deeply influenced by where humans could or could not pass over land. Traditionally, cities were built near a river or sea to have direct access to water as a basic need and to be able to connect the city to the rest of the region or the world. That is shown in the fact that 8 out of the 10 largest cities in the world are located by the coast (UN-Oceans, 2016).

Water seems to be an omnipresent and infinite source on our planet. While land makes up for about 29% of the earth's surface, water covers the remaining 71%. Together with air, water could be considered as one of the largest commons on Earth. Even though these sources seem to belong to everyone and no one at the same time, large companies or structures found ways to privatize them. Think of drinking water in bottles, or of countries "buying" clean air from others, to make up for their excessive polluted air quota.

However, the attraction water has on humans is not only one of necessity, but also one of **leisure**. Look at the crowded beaches and other recreational areas near water bodies on a sunny day in Belgium, for example. Water landscapes have always been a popular subject for painters, especially during Romanticism and Impressionism. Besides the depiction of leisure, a landscape painting could also be a metaphor for the mysticism of nature and the greatness of the universe, showing a human borderline experience.

The post-war zeitgeist of the 60s and 70s was steeped in **future optimism** and made architects dream of modern utopias, including living on or under water as a solution for the rapid urbanization. Offices like Archigram and Superstudio imagined a reality where everything could be infinitely designed and redesigned at the stroke of a pen.

But the relation between humans and water is also contradictory. Living near water means living with water and all its consequences like temporary accumulation of big water volumes. Before humans started mutating natural flooding areas, coasts and river banks were often reshaped by temporary floods. Due to the extensive dredging operations and the building of dikes and large controlling infrastructure, many natural flooding processes were disrupted. As a result of **climate change**, pressure on these engineered solutions will increase. The global sea level is rising and extreme weather events will occur more frequently, leaving large urban areas flooded.

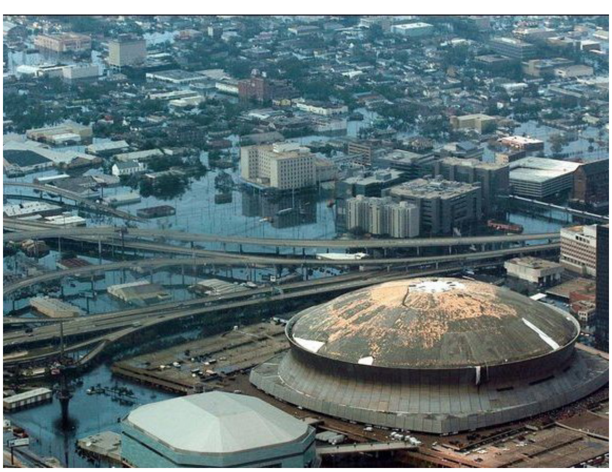
In a world where governments are seriously considering relocating entire capitals because they are sinking away it is important to reflect on both the cause and consequences of our changing climate. The obvious question we need to ask ourselves today is how architects can rethink todays cities in relation to future urban flooding scenarios in retrospective of these three key views on water (leisure, future optimism and climate change), as we can only learn from the past to design the future. As a graduating architecture student anno 2019 I feel this is one of the biggest challenges my generation will deal with since we could be the last ones to turn the tide.

Friedrichs paintings often convey layers of meaning from religion, a mysticism of nature and politics. This early Romantic painting depicts a young man watching over a landscape covered in a thick layer of fog. He seems to be captivated in the experience of a peak, impressed by the greatness of nature.

Fig. 0.3. Wanderer above the Sea of Fog (Caspar David Friedrich, 1818)

Superstudio is known for pushing their work to the radicality of the absurd. This collage was part of a collection published around the time UNESCO started the conservation of heritage. Through collages they wanted to criticize the absolute preservation of architecture.

Fig. 0.4. Rescue of Italian historic centres, Florence (Superstudio, 1972)



In August 2005, hurricane Katrina caused 1.833 deaths and 153 billion dollars of damage. Fatal engineering flaws in the flood protection system of New Orleans resulted in 80% of the city being flooded at a level of several meters. The Louisiana Superdome served as "shelter of last resort" for 9.500 people.

Fig. 0.5. New Orleans and the damaged Superdome (Vincent Laforet/Pool, 2005)

Global structures and challenges

Climate change is a problem that transcends the borders of countries and cities. Therefore, it is important to frame it in a larger context.

The scientific discovery of climate change started in the 19th century, when the greenhouse effect was first identified. During the 1960s, the warming effect of carbon dioxide was scientifically adopted. It became clear that human activities were polluting and changing the earth's climate (Flanders Environment Agency, 2019). Because climate change is influenced by global natural processes there was a need for a global structure. In 1988 the Intergovernmental Panel on Climate Change (**IPCC**) was established to provide policymakers with regular evaluation reports on the state of knowledge about climate change. Until today, the IPCC assessments form the most important scientific input for climate negotiations. The IPCC has multiple working groups that don't only do research on the scientific evolution of climate change, but also publish reports on how to deal with its consequences like "Managing the risks of Extreme Events and Disasters to Advance Climate Change Adaptation" in 2012. IPCC reports have revealed many different consequences of climate change for life on earth, including melting ice and rising sea levels, more extreme weather, risks for human health and wildlife and costs for society and economy. These consequences (will) have a big impact on migration flows, defining where life on earth will still be possible for humans.

Another global initiative is the 2030 Agenda for Sustainable Development, adopted by all **United Nations** members in 2015, which provides a blueprint for peace and prosperity for people and the planet through the establishment of 17 Sustainable Development Goals. The UN also holds yearly conferences (COP) to assess progress on climate change and this has resulted in concrete alliances like the Kyoto Protocol and the Paris Agreement. The United Nations are an acknowledged source of information, seen the fact that many national funding bodies consider the Sustainable Development Goals as a benchmark to approve funding for scientific research (Leemans, 2017).

These overarching initiatives have both the advantage and disadvantage of operating on a global scale. This means that it is impossible for them to have direct impact on a local scale. Their goals and reports often stay on a policy-making level. And even there it seems to be a long and laborious process to make sure all registered countries and partners actually ratify the promises they have made.

In 1958 (!), director Frank Capra explains the basics of climate change and warns for its catastrophic consequences. He points out that the melting of the ice caps could result in an inland sea in the Mississippi valley, leaving large urban areas permanently flooded.

Fig. 1.1. Climate Change 1958: The Bell Telephone Science Hour (Frank Capra, 1958)

Besides the political debate, also the architecture and building industry deals both with many causes and consequences of climate change. Today, around 55 percent of the world's population is living in an urban area or city. According to the "Population Division" report from the UN's Department of Economic and Social Affairs this will be two thirds by 2050. It is estimated that many of the world's large cities are vulnerable to rising sea levels and climate change, with millions of people being exposed to extreme weather (Aerts et al, 2009).

Increasing flooding in urban areas is a direct result of climate change. It is expressed by a **rise in sea level** (volume change of a water mass at changing temperatures, exchange of water mass with melting land ice and changing storage of water on land) and more **extreme weather conditions** (wet winters and dry summers with intense storms). Recent research shows that in case we don't cut carbon pollution we could reach a 4°C warming with a sea level rise of nearly 2 meters this century (Strauss, Kulp & Levermann, 2016).

Often the challenges offered by climate change are seen as too big and impossible to solve. However, for an effective approach of the climate change issue, it seems necessary to me to have a combination of top down and bottom up initiatives combined with an interdisciplinary approach. Climate change and its consequences is not something that occurs in only one aspect of society, nor does it only happen in specific regions or countries. It is a common problem and responsibility of every person living on our planet. This implies a global **mentality shift** on all levels, from nation leaders to "common" citizens.

Since we already warmed the planet more than 1°C, we will inevitably experience serious consequences regarding flooding. It is therefore important to take these disaster scenarios seriously and start to design possible ways to cope with these consequences. This offers particular **architectural challenges**, we have to be aware of the fact that many public spaces and buildings and their users will be threatened by vast amounts of water. Interdisciplinary teams could design the right solution how to deal with water for specific cases. However, there should be an overarching transdisciplinary strategy (involving academics and non-academics) on how to approach them.

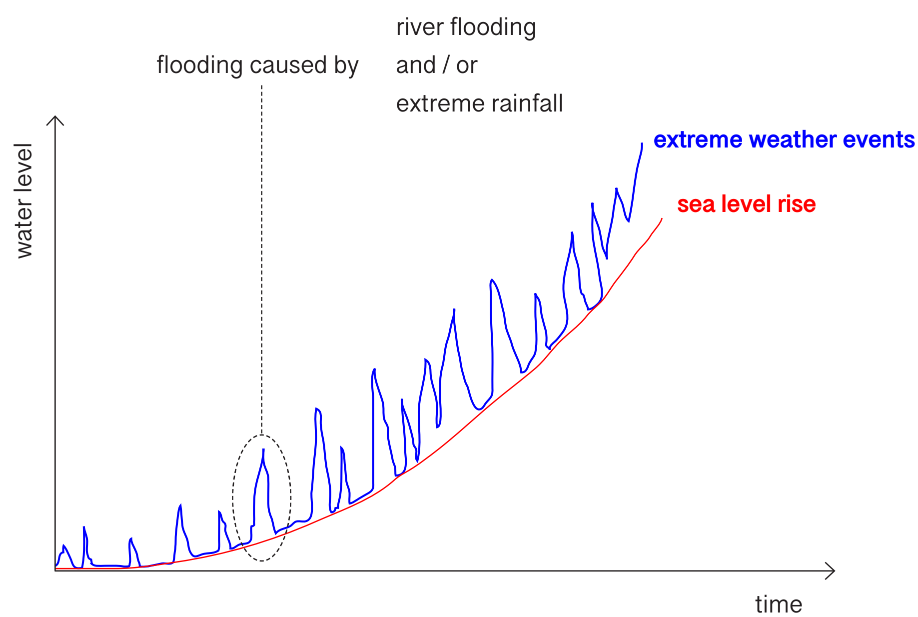


Fig. 1.2. Water disturbance evolution as a result of climate change (Sophie Leemans, 2019)

Vulnerability of river deltas

The deltas of rivers are usually highly fertile and thus some of the most densely populated areas. Because of their delicate position in relation to the sea, river delta cities will experience the effects of sea level rise and extreme weather conditions first and foremost.

The Rhine–Meuse–Scheldt delta is one of the two **largest risk zones** for flooding in the world. It is situated on the border of The Netherlands and Belgium, and these countries are also the two most vulnerable European countries for flooding as a result of rising sea levels: more than 85% of the coastal area lies below 5 meters above sea level. In Flanders, about 15% of the surface (coastal zone and Scheldt polders) is situated less than 5 meters above the average sea level.

In the past, this region has dealt with multiple serious floods. It is clear that flooding has direct impact on architecture and urban planning and vice versa. As a result of climate change, both the frequency and intensity of flooding will increase. Urban areas will be exposed to water permanently and/or during specific moments. Flood-preventing artificial structures like dikes actually enhance the long-term risk of flooding (Temmerman & Kirwan, 2015).

It seems that a **flood-permitting policy** with specific interventions on multiple scales could be a long-term sustainable strategy in contrast to end-of-the-pipe solutions mentioned above. I therefore advocate for a combination between flood-regulating infrastructure and small-scale adaptive architecture for resilient urban environments rather than investing everything in expensive large infrastructure that possibly won't protect us beyond a certain point. Through searching for specific spatial qualities of such small(er)-scale adaptive architecture architects can support the positive change towards flood permitting urban environments.

Fig. 1.3. World map of largest river deltas (Sophie Leemans, 2019)

References for flood resilience

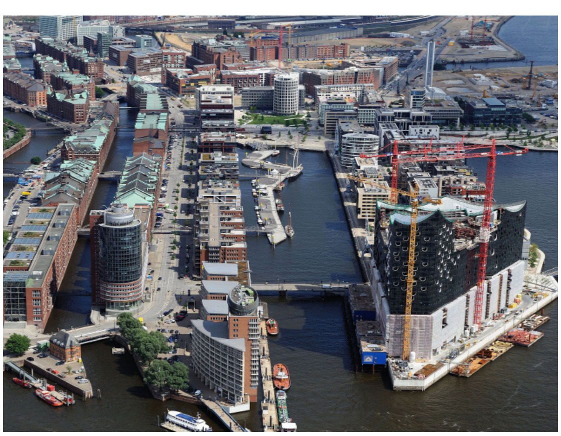
According to the institution of Civil Engineers, designers have three options: **retreat** (get away), **defend** (infrastructural protection) or **attack** (build on water) (Institution of Civil Engineers [ICE], 2010). Each of these strategies pose specific challenges for architectural interventions. Depending on the specific actor / situation one strategy might be more favoured than the other. Each spatial intervention has impact on the cultural context and vice versa. Therefore I consider the level of these architectural interventions of utmost importance to enable inhabitants to positively and qualitatively appropriate their flood environment.

Bangladesh lives at the pace of water flows: during rain season one fourth of the surface is flooded. But the country is also heavily endangered by the sea level rise. Due to coastal erosion, every day houses disappear into the water. Families have to dismantle and relocate their house in order to escape flooding

Fig. 1.4. Home for the moment (Bendiksen, 2011)

Mont-Saint-Michel is a tidal island in Normandy. Due to the alternation of ebb and flow the island is only accessible at certain times. During some days each month the island is only accessible by boat. It could be considered as a primitive version of a flood resilient settlement through defence.

Fig. 1.5. Mont-Saint-Michel, Normandy, France (Comite Regional de Tourisme de Normandie, 2018)



HafenCity is a new neighbourhood for the city of Hamburg, expanding its existing city area by 40%. It is entirely built on water and made floodproof by allowing certain areas to flood during heavy rainfall. The first ideas around this project arose in the 90s. The project is expected to be completed around 2030.

Fig. 1.6. Aerial view on HafenCity Hamburg (HafenCity Hamburg GmbH, 2016)

Historical flooding events

Because of Flanders' vulnerable position in relation to the sea, flooding is one of the natural risks it is subjected to. Since the start of the registrations in 1833 the amount of rainfall is significantly increasing (Flanders Environment Agency, 2019). But the region of Flanders has always dealt with flooding, even long before official meteorological measurements.

For example the island **Testerep**, on which the original Ostend was built, was completely washed away by a storm in 1394. The salt marsh and swallow area at the Belgian coastline even is the etymological source of the name of "Vlaanderen". The primordial Germanic "flaumaz" means "flooded land", which is exactly what the coastal area was: a piece of land that was flooded twice a day by the sea.

The most well-known flood in the Netherlands and Flanders region in our recent history is the North Sea Flood ("Watersnoodramp") of **1953**. A combination of storm surge and high

1953

Fig. 2.1. A dike breaks in Den Bommel, South-Holland as a consequence of the storm (Beeldarchief Rijkswaterstaat, 1953)

1976

The dike of a small tidal river of the Rupel breaks and causes a severe flood in the Dender Valley and Ruisbroek. The village was caught by surprise by a water level up to 3 meters. After this devastating flood the Belgian government decides to develop the Sigma Plan to improve the Flemish river bank protection.

Fig. 2.2. Ruisbroek (Vlaams-Nederlandse Scheldecommissie, 1976)

tide causes dikes to break at several locations across both countries and caused a water level of 5,6 meters above sea level. With a total of 2.551 deaths (of which 1.836 in The Netherlands alone) it was the main incentive for the reinforcement of flood protection in The Netherlands. This meant the start of the famous Delta Works: a series of engineered water protection infrastructure taking multiple decennia to construct. The Belgian government started a similar program called the Sigma Plan after the flooding in Ruisbroek in 1976.

The Flanders Environment Agency (2019) claims on their website that the amount of rainfall could mount to **+38% during winters in 2100**. It won't rain more often but when it does it will be bigger amounts, resulting in more frequent and larger river floods. At the same time, summer storms will become more severe and more frequent, causing an increase in urban flooding and more erosion and mudflows. The high-impact scenario shows that the probability of flooding in Flanders can increase by a factor of 5 to 10.

We can conclude that everything between severe rainfall and extreme storms will become more common, which requires a flexible infrastructural but moreover architectural design being able to adapt to and (socio-spatially) embrace a wide range of weather events.

2013

On November 13th, the channel Brussels-Charleroi is unable to handle the water coming from the Zenne and over tops the existing dikes. Especially the Dender Valley dealt with a lot of flooding. In Overboelaere a complete neighbourhood floods, leaving all houses with severe damage.

Fig. 2.3. A complete neighbourhood in Overboelaere, Geraardsbergen is flooded (Panorama, 2013)

During the so-called "Sinterklaasstorm" the highest water level in Belgium and the Netherlands was measured since the storm of 1953. In Antwerp this was 7,24 meters above mean sea level. The storm hit most of Northern Europe, causing floods in more than 10 countries.

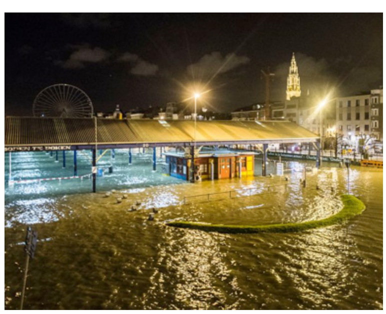


Fig. 2.4. The Scheldt Quays flood while the defence wall behind protects the inner city (De Scheirder, 2013)

2018

During the Eleanor storm of January 3rd, the polders of Kruibeke served as controlled flooding area for the first time. This infrastructural implementation is part of the Sigma plan and should reduce the chance of a flooding in Antwerp and its surroundings from once in 70 years to once in 350 years.

Fig. 2.5. The Kruibeke polders, Flanders' the largest controlled flooding area (Sigma Plan, 2018)

Flanders’ special spatial context

Flanders is known for its **chaotic spatial structure**. This is a legacy of lacking spatial planning in the past. The first law on urban development came into effect in 1962. However, these rules were very vague, and generally not applied on local level. Only in 1997 the first Spatial Structure Plan Flanders was implemented. That basically means that before that time, everyone was allowed to build wherever there was road infrastructure. It is difficult to make up for these spatial planning mistakes of the past, as a study at KU Leuven showed that while in 1976 only 7% of Flanders' space was occupied by built environment, this number already increased to 18% in 2000. A possible scenario showed that that could become 30 - 50% by 2050 (Poelmans, 2010, p. 136). However, it is important to keep in mind that Flanders is one of the most densely populated regions and therefore inevitably struggles with housing a relatively large population on a limited surface.

An important contributing factor to urban flooding is the **domination of hard surfaces**. Based on data from 2015 it is estimated that 16% of the total area in Flanders is covered with non-permeable material (Statistics Flanders, 2019). This means that the rainfall on those surfaces cannot infiltrate in the soil and has to be disposed through sewerage. The degree of hardening is the highest in and around large cities like Antwerp and Brussels.

The decrees about water management date from even more recent years, the first one from 2003. As a result, approximately **36.000 to 56.000 buildings are located in flooding areas** today, the Flemish Environment Agency claims in the documentary "Verdronken Vlaanderen" (Panorama, 2013). Another 24.000 building lots are ready to be built upon in those areas. Prohibiting building here would mean lots of financial compensation for the owner, paid by the government. In the past, there has been much ambiguity about flood sensitivity among buyers, because there was no obligation to inform them before closing the deal. These inhabitants now frequently deal with floods (sometimes up to once a year), damaging their property and decreasing its value.

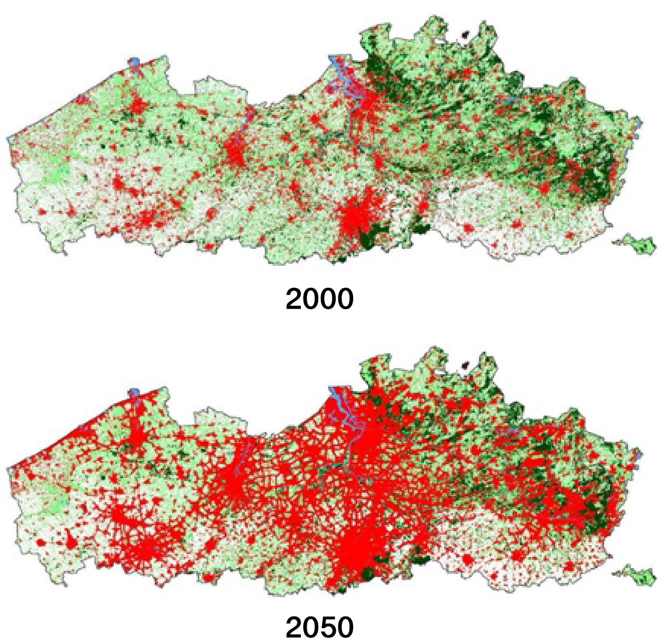


Fig. 2.6. Evolution of land coverage in Flanders (Poelmans, 2010)

Sigma Plan

After the flood of Ruisbroek in 1976 the federal government launched the Sigma Plan, in reference of the Dutch Delta Plan. The plan aims to protect Flanders from flooding coming from the Scheldt and its tributaries, but also wants to reinforce the surrounding nature. In 2005 the plan was updated according to new scientific insights on the topic. In 2030 the implementation of the plan should be completed. The Sigma Plan is a collection of relatively **large infrastructure works**, like the construction of sturdier and higher levees and a chain of natural flood control areas in the river valleys.

In Antwerp for example, the **Scheldt Quays** are being renovated and improved by WIT architects over a length of 5 kilometers because of their former poor condition. These quays play a crucial role in the river flood resilience of the city, as they become submerged in case of a storm tide. Besides the stabilizing of teh quay wall, both the water barrier (the current concrete wall is 1,35 meters high and was built in the 1970s) will be elevated and the public space will be improved. Also the possibility of letting the polders of Kruibeke flood in case of a local water level rise should spare the urban area of Antwerp of river flooding.

The incentive of the Sigma Plan is (like the Delta Plan) to protect the built environment from rising water levels. The infrastructure that is (re)built and improved should function as a shield protecting inhabitants from flooding. This fits in the above mentioned **defend** logic and strategy that governments often opt for (p. 15). However, it does not incorporate a scenario where in case of a severe storm the infrastructure might not be resilient enough (the dikes in 1953 broke because they simply weren't prepared for the large amount of water). Besides that, large volumes of rainfall could cause urban flooding because hard surfaces and limited sewerage capacity make it impossible for the water to be evacuated fast enough.

This implies that the infrastructural network of the Sigma Plan is in need of an accompanying **urban network of relatively small interventions** to handle the range of flooding possibilities coming from above (rainfall) and below (insufficient sewerage).

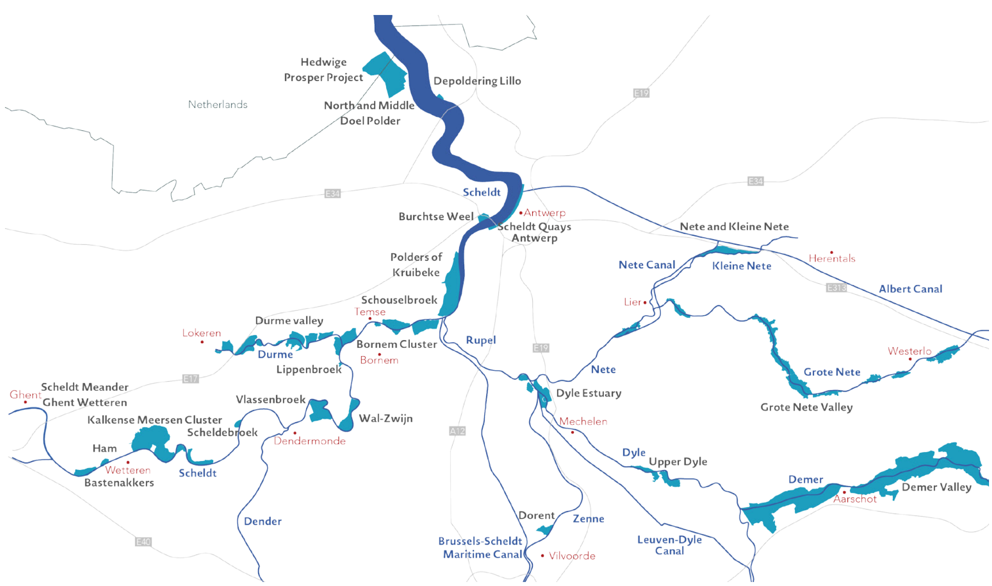


Fig. 2.7. Overview of the Sigma Plan projects (Sigma Plan, 2019)

Antwerp and water: happily ever after?

It has become clear that the city of Antwerp is located in a **vulnerable** position concerning water. Because of the limited predictability regarding future urban flooding, it is necessary for Antwerp to improve its resilience to water. Both the city and the federal government are already making efforts to do this. However, their incentive in urban environments is based on a defense strategy for river flooding in particular: construction of walls, reinforcement of quays etc.

Studies have shown that flood-preventing engineered structures like dikes enhance the long-term risk of flooding because they disrupt the natural processes of tidal inundation (Temmerman & Kirwan, 2015). On top of that, not only the risk of flooding from rivers will increase but also flooding from above (rainfall) and below (insufficient sewerage). This is why I would like to propose a **flood permitting policy** as incentive for my design approach. I will elaborate on what this implies more concrete further on in this dissertation. Let us first take a look at what kind of water and volumes we can expect.

Scientific models give us an idea of what areas within Antwerp will suffer the most from the consequences of the sea level rise and flooding caused by extreme weather events. Since flooding will occur more frequently and more intense as a result of climate change this means that maps that show us a case of a flood with a **probability of once in 1000 years today**, will be **tomorrows maps for a probability of once in 100 years** and so on. These predictability terms often lead to misunderstanding of the actual risk. It could seem as a "100-year flood" implies a flood that occurs only once in 100 years. However this means the flood can happen each year with a 0,1% chance.

According to maps of the Flanders Environment Agency that take the sea level rise and the increasing extreme weather events into account, several areas in Antwerp are located in high risk zones. Keeping in mind the challenges of urban flooding we find the highly urbanized neighbourhood **Brederode** as the most fit for a case study in this master dissertation. Its direct flooding vulnerability is due to a combination of a high number of hard surfaces, an insufficiently dimensioned sewerage system and local height differences (Van Havere, 2018).

How can we as designers rethink neighbourhoods like Brederode in a way that they are flood resilient without having to build a wall around them?

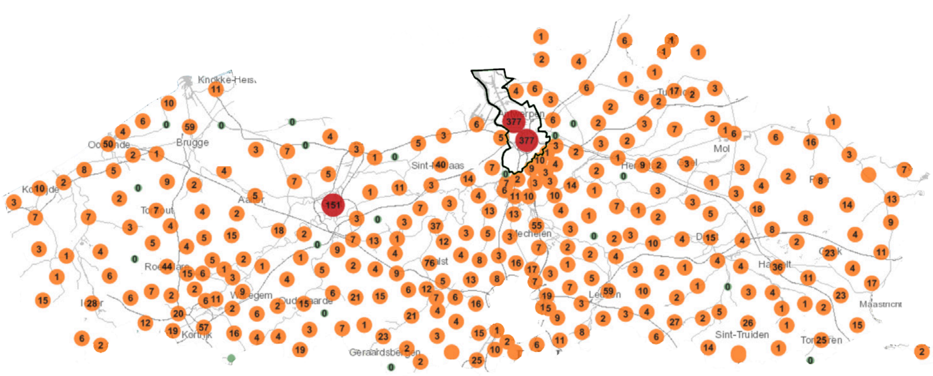
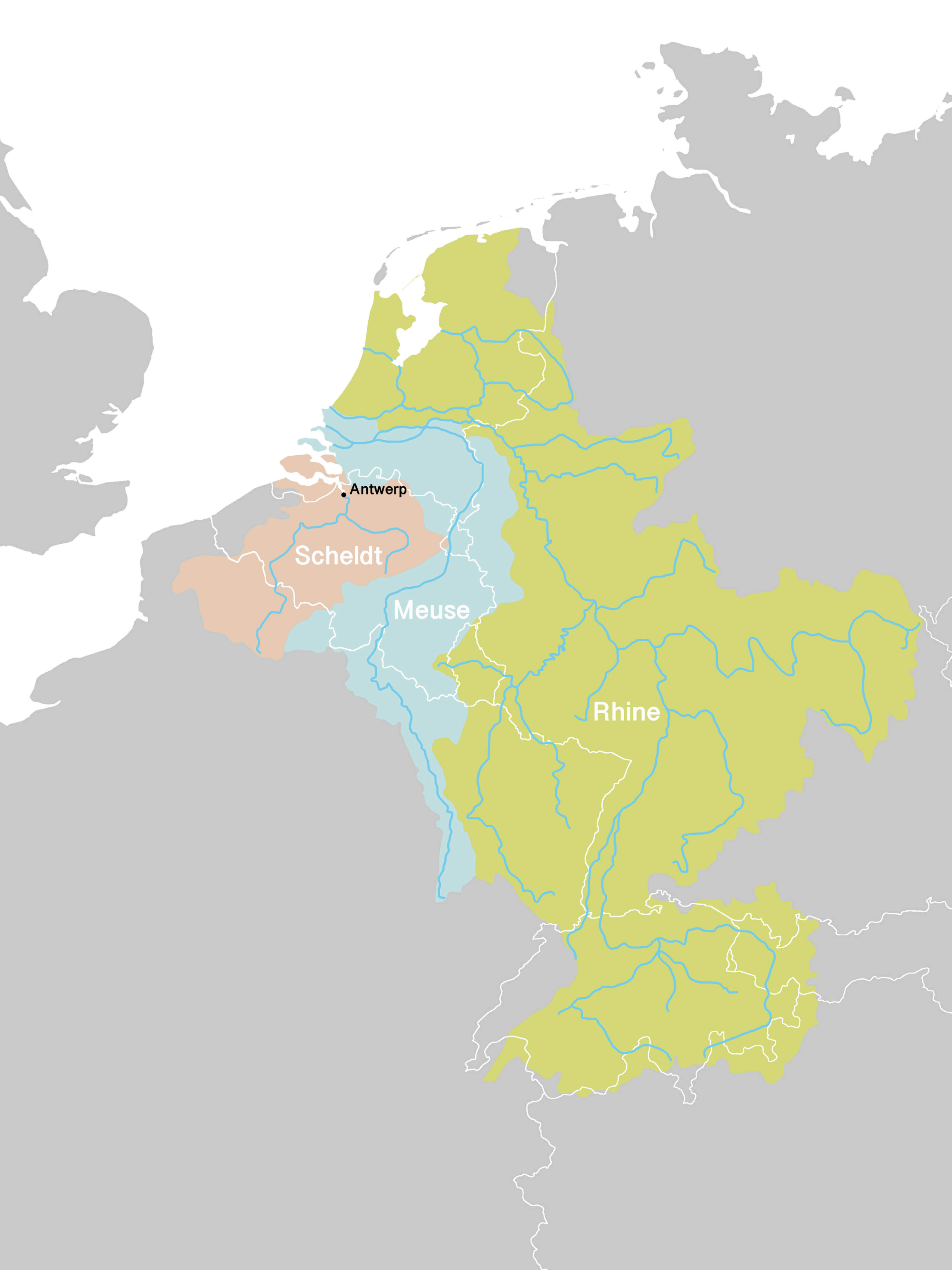


Fig. 3.1. Hazardous floodable (> 70 cm) vulnerable institutions (day-care, education, hospital, nursing facilities) in the high impact 2100 scenario (Flanders Environment Agency, 2019)

Fig. 3.2. Rhine-Meuse-Scheldt river basin and delta (Sophie Leemans, 2019) ▷


Antwerp
Scheldt
Meuse
Rhine

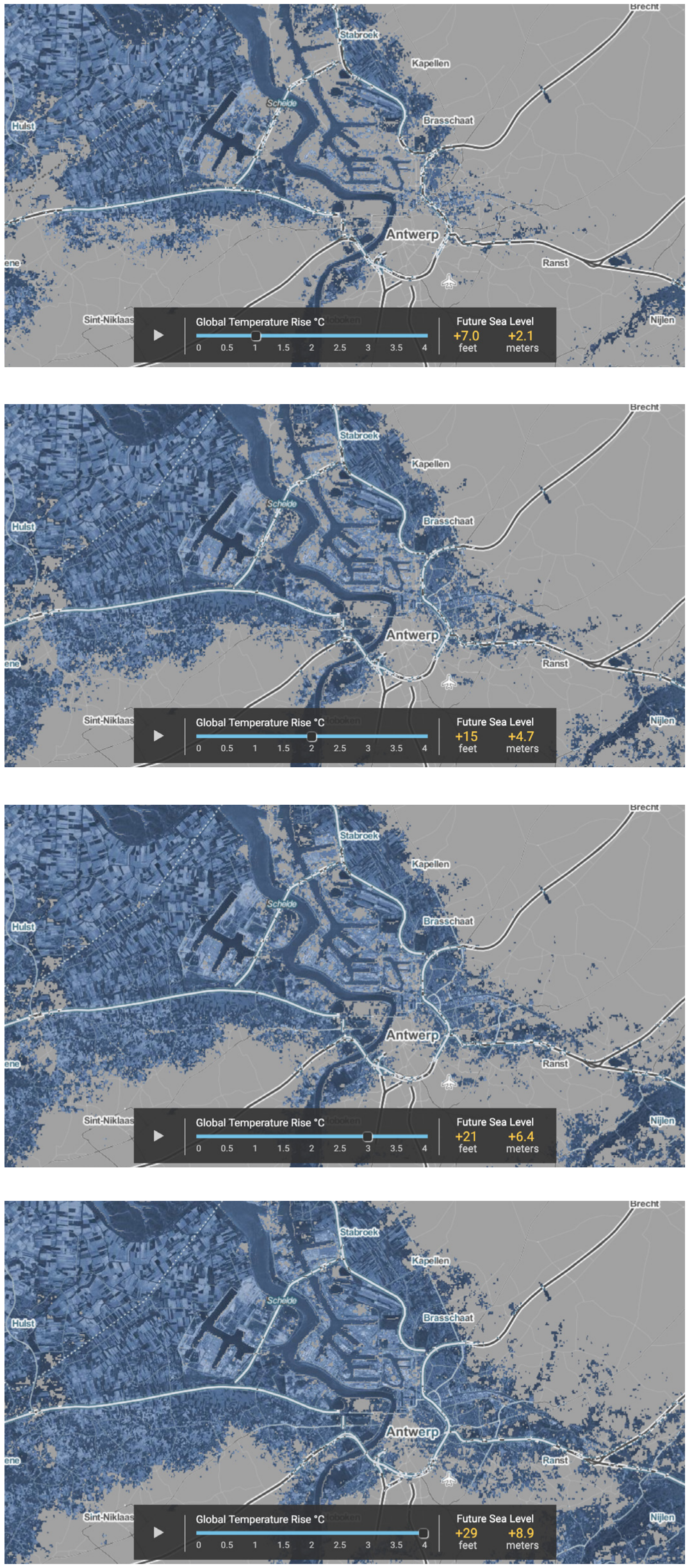


Fig. 3.3. Permanent flooding scenarios for Antwerp caused by sea level rise for a global temperature rise of 1°C, 2°C, 3°C and 4°C (Climate Central, 2019)

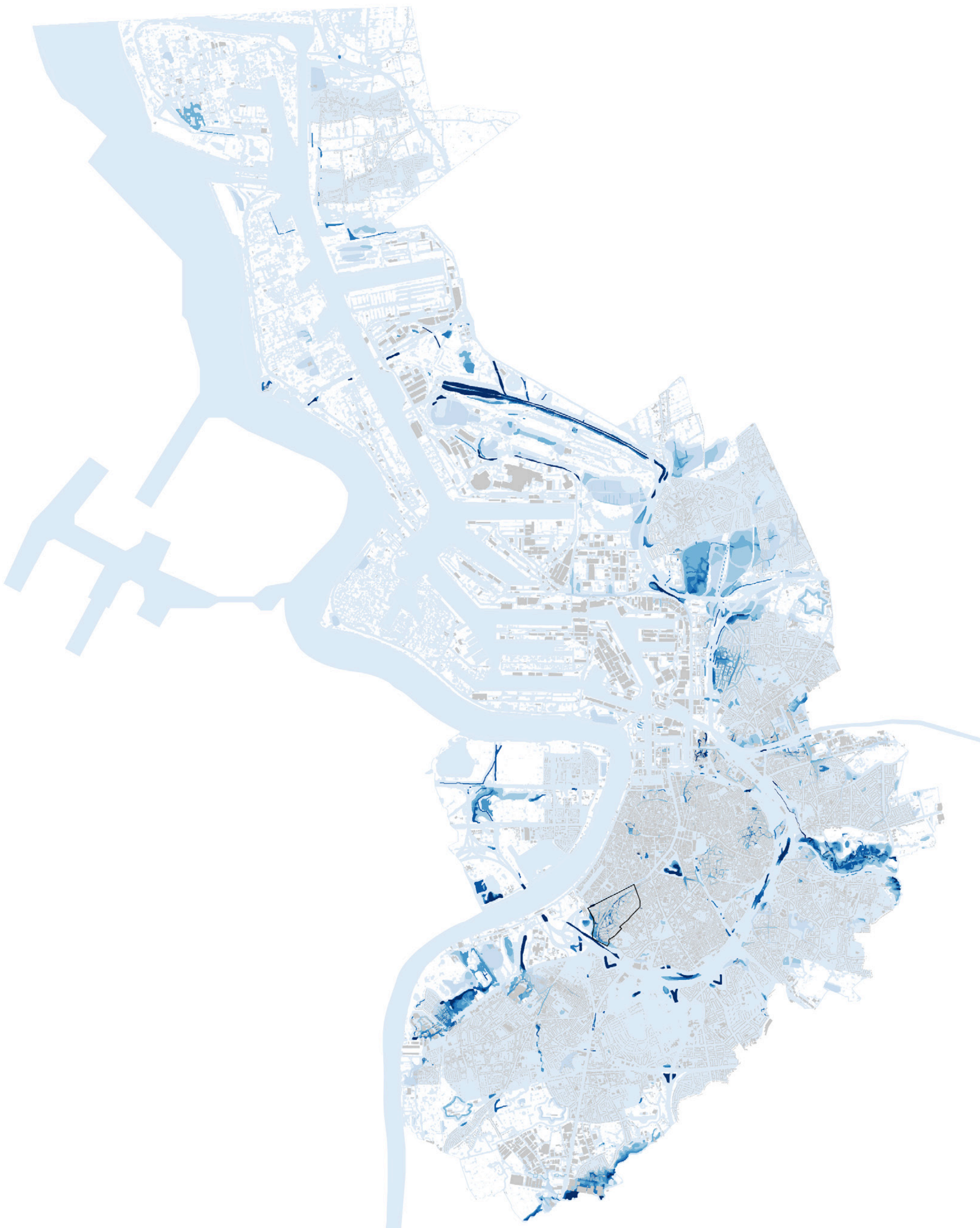


Fig. 3.4. Water depth during a 1000-year flood in high impact 2100 scenario (Sophie Leemans, 2019)

Mapping Brederode

Brederode is with its 0,72 km^2 and 11.722 inhabitants a relatively densely populated neighbourhood in the city of Antwerp (City of Antwerp, 2019). Because of the high proportion of inhabitants of West Asian descent, the neighbourhood has the common nickname "Little Istanbul". Brederode has little open public space but houses many facilities like schools, care facilities, local shops and restaurants (Secchi & Vigano, 2009). Besides the **residential** character and **local centrality**, the neighbourhood has two **metropolitan** borders, as it is flanked by two urban axes: the Leien in the north and the Antwerp Ring in the west.

A combination of its location in relation to the Scheldt, a high proportion of hard surfaces, an insufficiently dimensioned sewage system and local height differences means that Brederode has little to no resilience concerning flooding (Van Havere, 2018). Both water coming from the river as water coming from the sky will threaten the neighbourhood more frequently in the future, as the risk of both phenomena will increase.

Fig. 3.5. Brederode S 1:10.000 (Sophie Leemans, 2019)

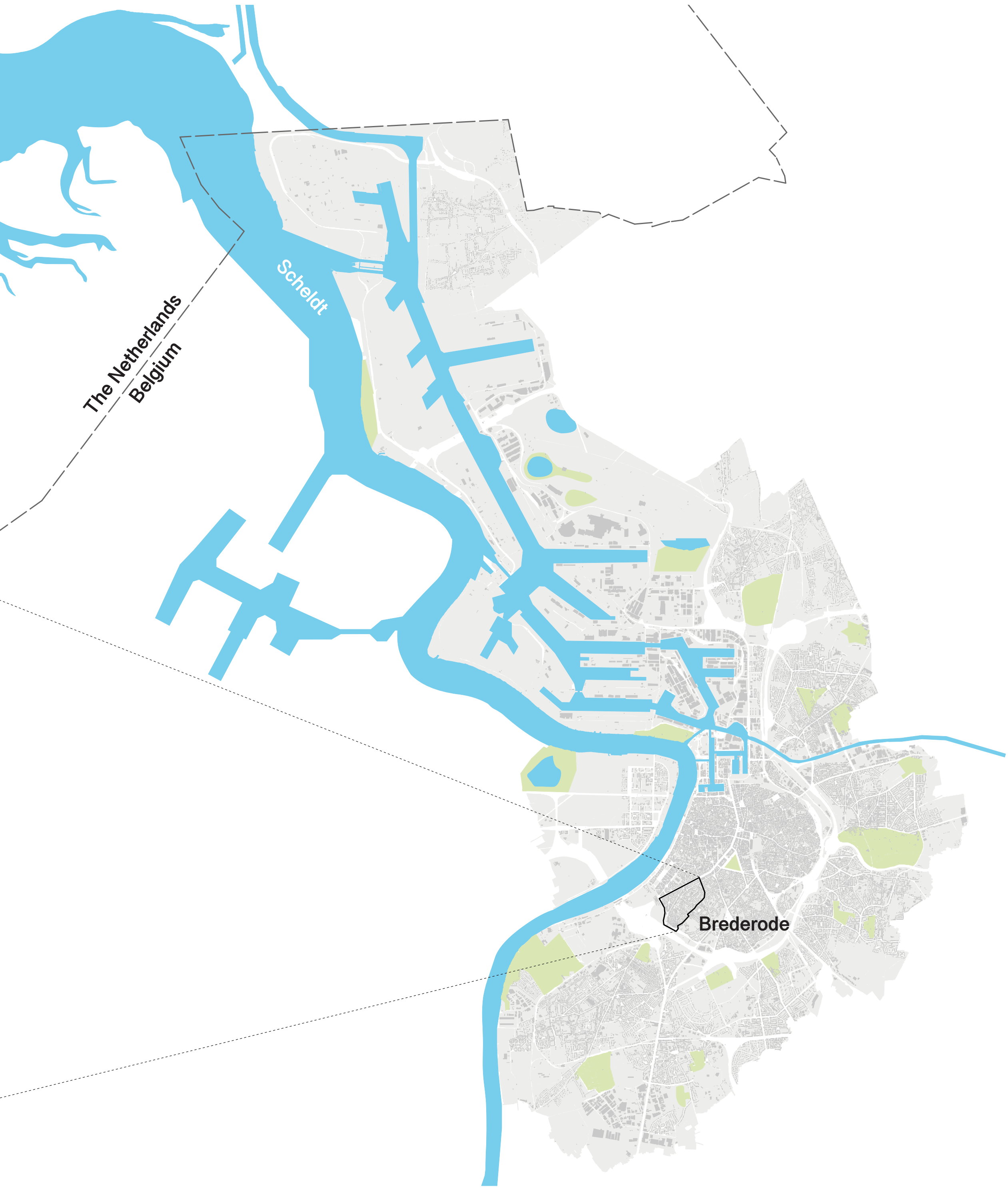
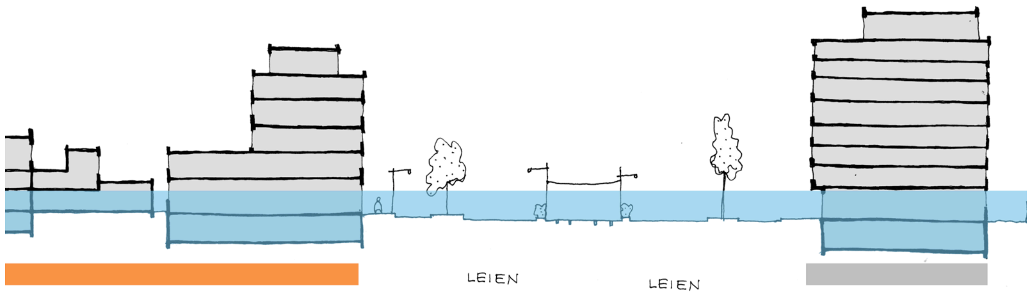


Fig. 3.6. Antwerp S 1:150.000 (Sophie Leemans, 2019)

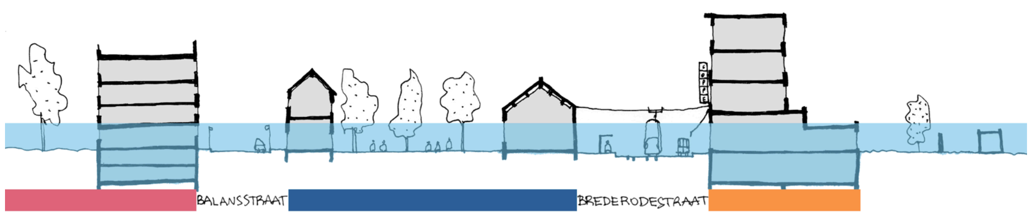

metropolitan
local centrality
Halfmaan
square
Troonplaats
Den Be

Fig. 3.7. Brederode mapping and facilities (Sophie Leemans, 2019)

metropolitan



local centrality



residential

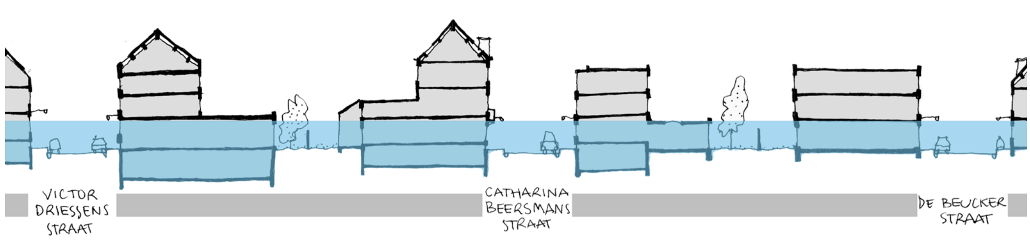


Fig. 3.8. Brederode sections S 1:1000 (Sophie Leemans, 2019)

metropolitan

local centrality

residential

Fig. 3.9. Brederode facades S 1:1000 (Sophie Leemans, 2019)

An adaptive water network: urban flooding as incentive for incremental positive change

In the context of Antwerp efforts have been made on a regional scale recovering natural flooding areas to protect urban areas from large volumes of water. However, in the city center itself the interventions are limited to renovation the Scheldt Quays: a defense wall to keep the water as far away from buildings as possible. Even though it might seem to be an effective knock-on solution to flooding, in reality it disrupts the natural flooding process. As mentioned before, this means that they increase the long-term risk of flooding. On top of that a wall doesn't include a solution for severe rainfall nor for flooding out of filled up sewerage.

In response to this problem I want to propose an integrated architectural redevelopment for high risk urban areas allowing water where it **naturally wants to flow**, temporarily store it for local use and dry periods and let the unused share infiltrate in a staggered manner. This implies a mentality shift in the way of thinking we generally have today about water and

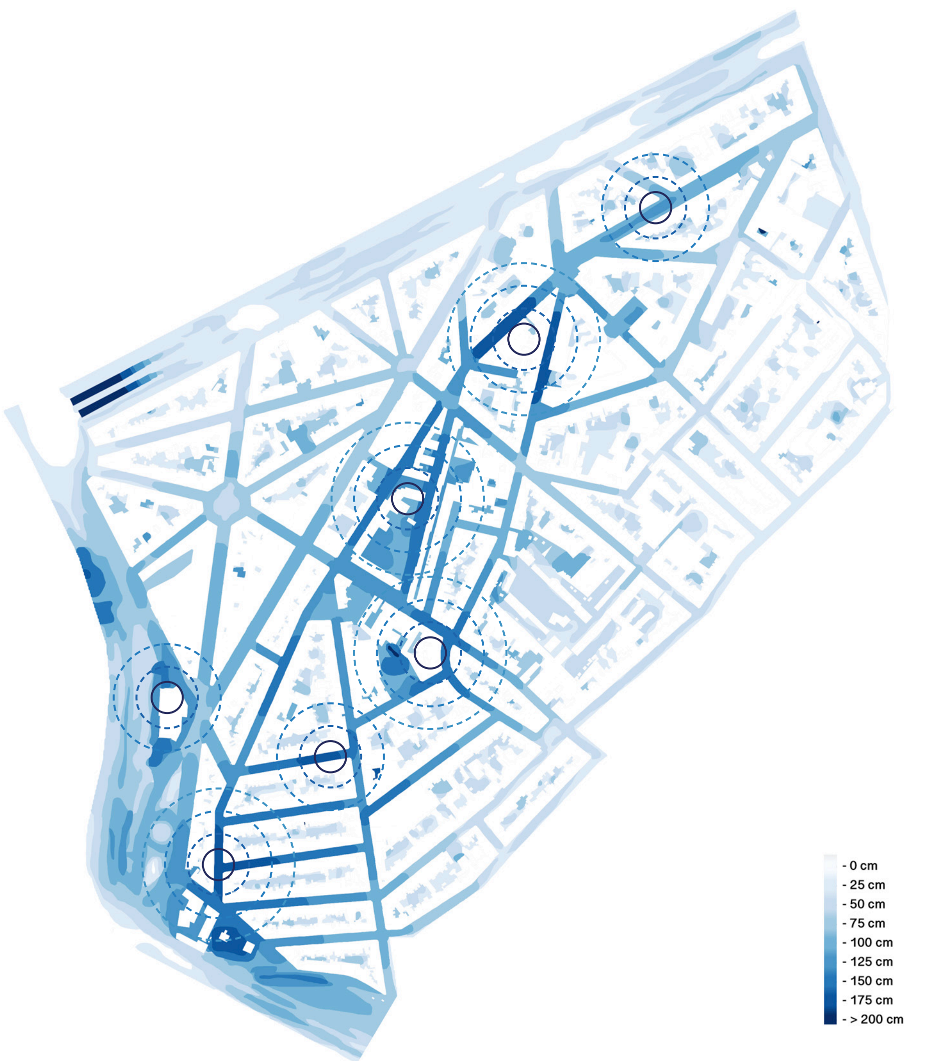


Fig. 3.10. Water depth during a 1000-year flood in high impact 2100 scenario (Sophie Leemans, 2019)

flooding. Large infrastructural interventions will still be necessary to manage the amount of water flooding from rivers, but they cannot all be based on the idea of defense in order to be resilient for a sustainable future.

Since city centers usually don't have open space leftover ready for large infrastructural interventions, this design rather proposes an additional **network of small scale interventions**. It finds its existence in the partial occupation both in space and time of niche space (basements, streets, empty lots, ...) with adaptive structures connected to each other. These interventions carry the function of links in a network to be switched on or off depending on the weather conditions.

The proposal does not (only) want to prepare the area for **emergency scenarios** with water depths of 2 meters, but above all wants to explore and highlight the **positive effects** of allowing water (again) near our habitats. By implementing these necessary infrastructural interventions, valuable new collective spaces will be generated by and for the inhabitants, improving the neighbourhood from within for a sustainable future.

Fig. 3.11. Implementation of an adaptive water network of small scale interventions in Brederode (Sophie Leemans, 2019)

At the start of the design process I formulated the following statements as important conditions or backbones for the end result. The design proposal should be understood as an approach with **broad applicability** in order to propose a new way of thinking in response to flooding. As a result it should positively **integrate every weather condition**, showcasing these through scenarios. This implies that the architectural interventions would have to be **adaptive through space and time** and depending on the weather situation be able to be **(de)activated by locals**, relieving city services from extra work during extreme weather events. Starting with the incentive of possible future emergency scenarios, the design should offer more than an area's redevelopment purely in function of that. The complementary idea is to **add valuable space** found within the existing urban fabric through double use for a positive, sustainable future.

The network of small scale interventions is based on four ways of dealing with water:

(1) The most desirable is to **infiltrate** the water as close as possible to the location where it appeared. This can be done through small, local solutions like green roofs, (semi-) permeable surfaces and green space. Besides that, I propose to use the inside space of a building block as infiltration basin.

(2) Because it is impossible to always let water infiltrate exactly where it appeared the second preferred option is to **connect** it to a location where it can. This would be done through a gutter network in the street profile with underlying pressure pipes to pump it to a pump house which occupies a building plot at the edge of an infiltration basin.

(3) Even though the pumping network should be dimensioned in a way for it to handle peaks of rainfall, there could appear a situation where it won't be sufficient or where it is just more desirable to temporarily **buffer** the water. This then happens in paved space (public or privately owned) that can function as temporary water reservoir.

(4) Depending on the possibility of placing infiltration basins and the range of the accompanying pumping network it could happen that there are locations that cannot be incorporated in the range of the pump. In that case I propose to **protect** the most vulnerable buildings by adding a structure bordering the sidewalk. This structure is conceived as a contemporary colonnade and can be charged with different types of program, depending on the function of the building behind it.

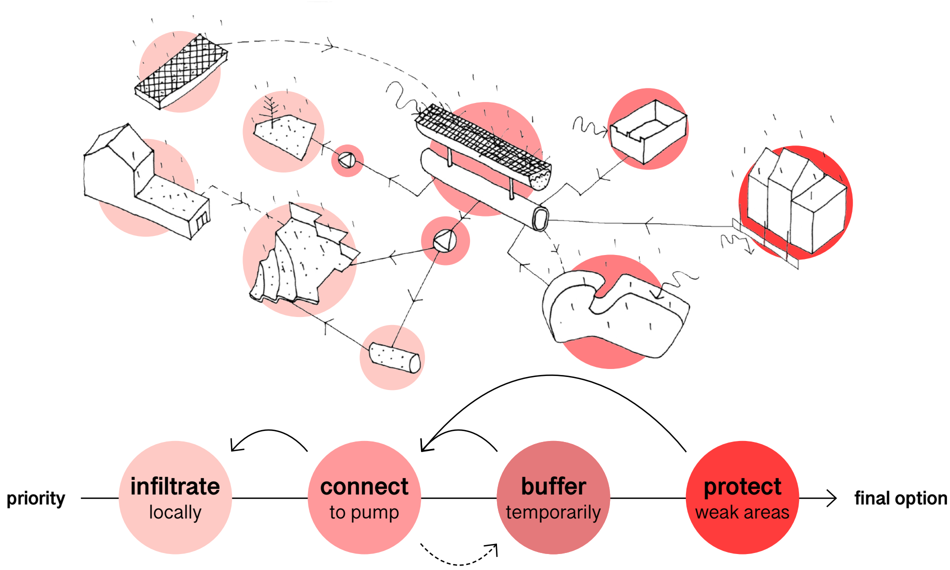


Fig. 3.12. General scheme of the proposed network (Sophie Leemans, 2019)

In the specific case of Brederode this general scheme translates to **one building block infiltration basin** situated in between the Balansstraat, the Lange Elzenstraat and the De Braekeleerstraat connected to a pumping network with a radius of 250 meters measured from the pumping house in the De Braekeleerstraat.

Besides that, I propose **three smaller networks** connected to existing green spaces (the garden of the service center Hof Ter Beke, the former Zuidervelodroom and grass field of Chiro Lore) that can infiltrate the collected water.

At last I propose single **protective facade structures** around a large part of the Leien and on the connecting corner to the Ring of Antwerp, and double ones on the axis Paleisstraat - Balansstraat and a part of the Brederodestraat. These specific locations would receive the largest volumes of water in case of severe flooding.

Since the area of intervention is very large, in what follows I will select relevant sections of each intervention to elaborate on the architectural intervention in detail.

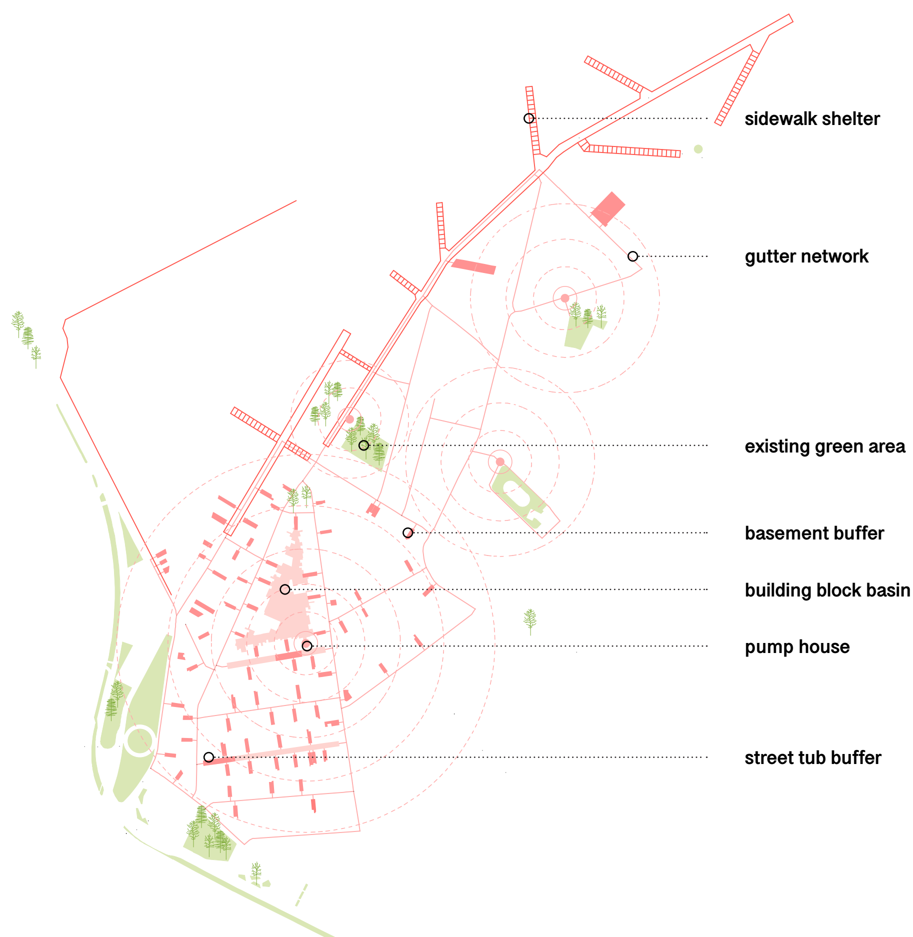


Fig. 3.13. Adaptive intervention network in Brederode (Sophie Leemans, 2019)

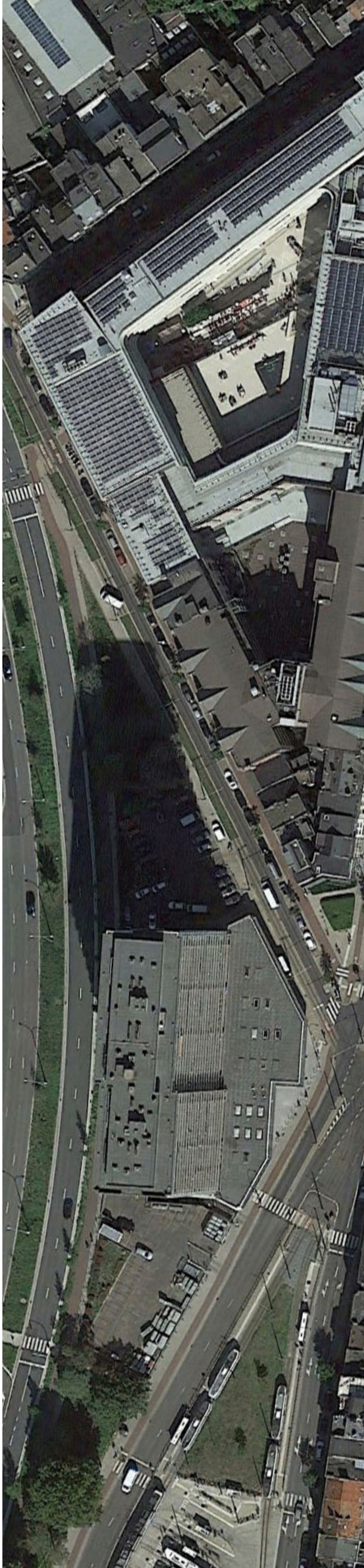


Fig. 3.14. Brederode S 1:1500 (Google Earth, 2019) ▷

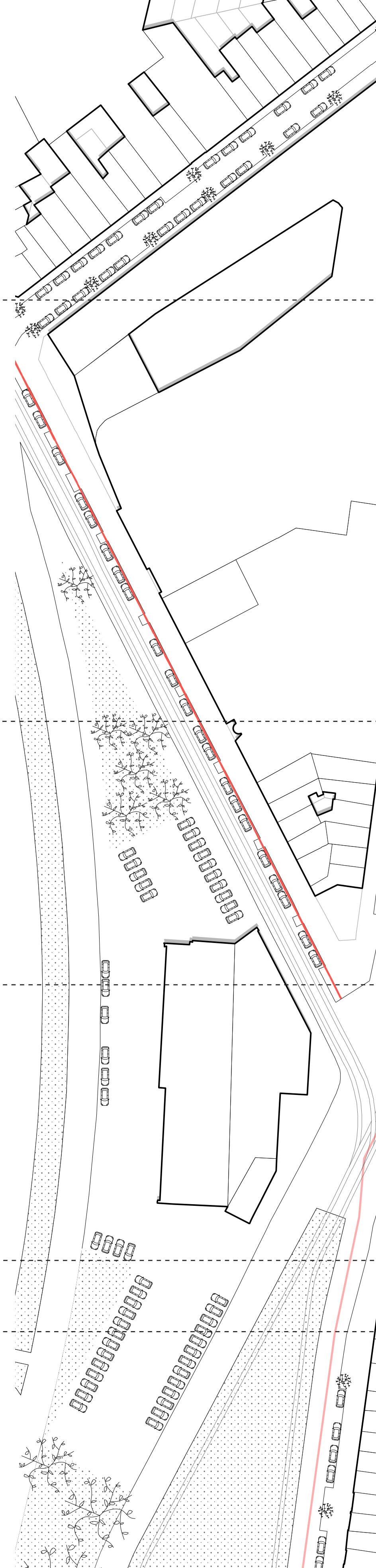


Fig. 3.15. Brederode S 1:1500 (Sophie Leemans, 2019) ▷

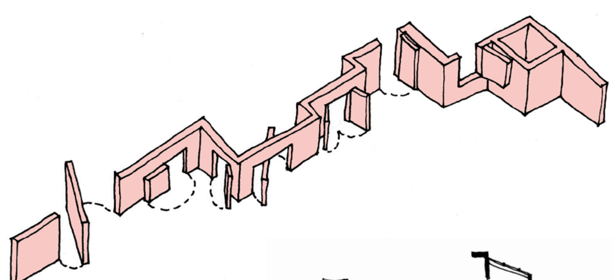
(1) Infiltrate locally

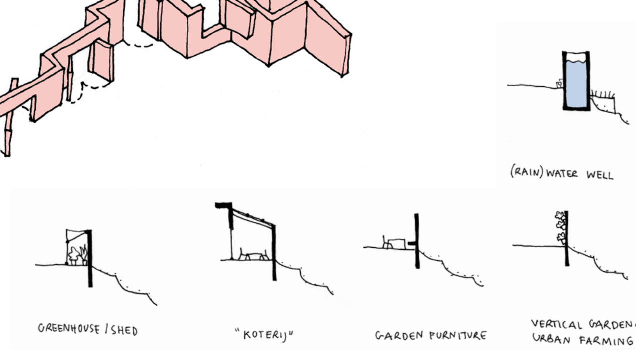
The most desired way of closing the natural water cycle is to infiltrate it as close as possible to where it appeared. In cities this is often impossible, as they are largely covered in hard surfaces (buildings, asphalt, ...) and therefore collect rainwater to transport it elsewhere through sewerage. Instead of getting rid of water as fast as possible I propose to collect it in the **inside space of a building block**.

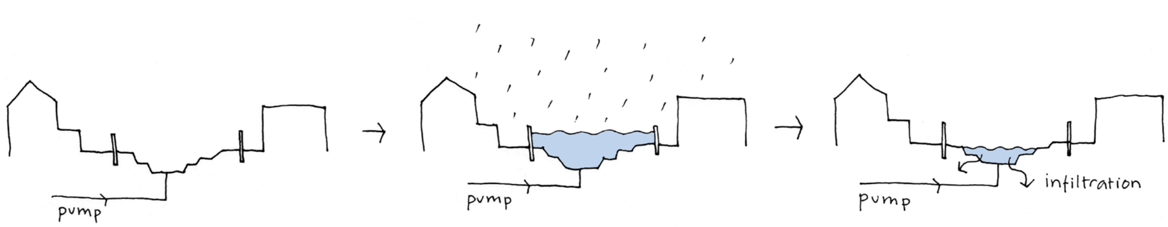
The architectural intervention consists of the placement of a 3 meters high and 2 meters deep **concrete wall** with hatches. The walled area is a 4200 m^2 **infiltration basin** that can hold large amounts of water. The surface consists of a landscape with different levels which means the deepest level will hold water almost permanently and the highest one (closest to the wall) will only flood when excessive amounts of water appear in a limited time frame (see basic calculation). The amount of accumulation of water has to do with the soils infiltration capacity and water permeability. This can be improved through an aggregate layer and piping network on top of the existing soil.

The water wall is placed in such a way that it cuts the non-built-up part of the plot in parts of 1/4 and 3/4. The idea is that the **property rights** of the owners are left untouched as the borders of the plots still exist. However if the owners choose to put up a fence at the borders in the newly designed part of their garden (3/4) it should be a water permeable structure as parts can be flooded at some point.

Conceiving the water wall as a second layer of the existing rear facade it is a basic structure and therefore carries the function of a **canvas** that can be made use of or left untouched as the owners like. Neighbours can also opt for a local wall deduplication forming a common water reservoir that can be connected to a small scale natural water cleaning system. Small cycles and buffers to hold water for a longer period of time like these are necessary as winters will become wetter and summers drier.





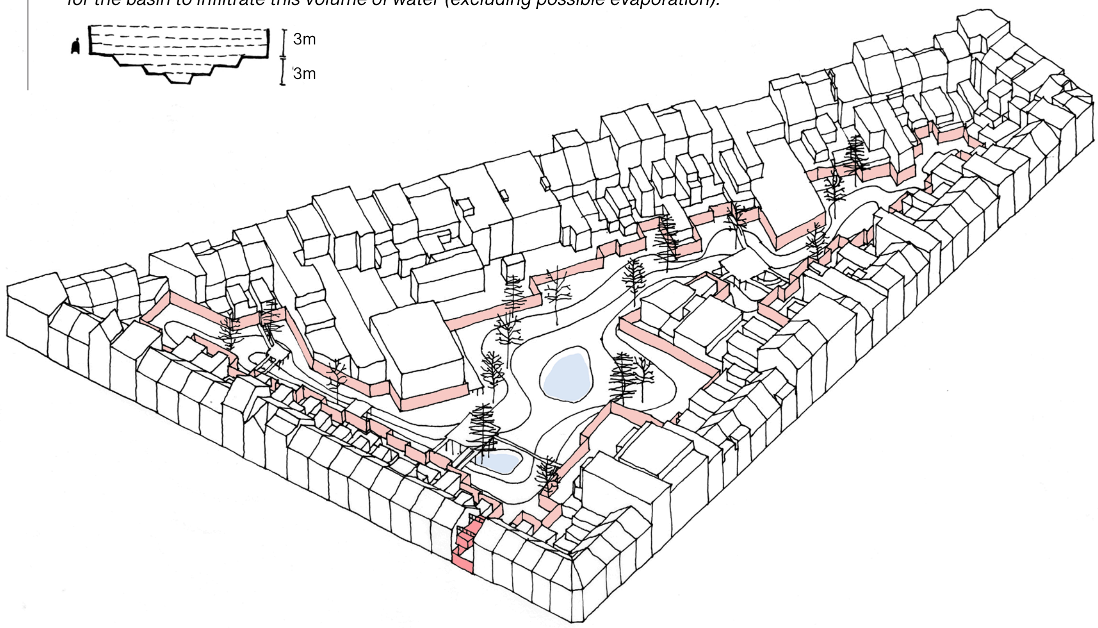


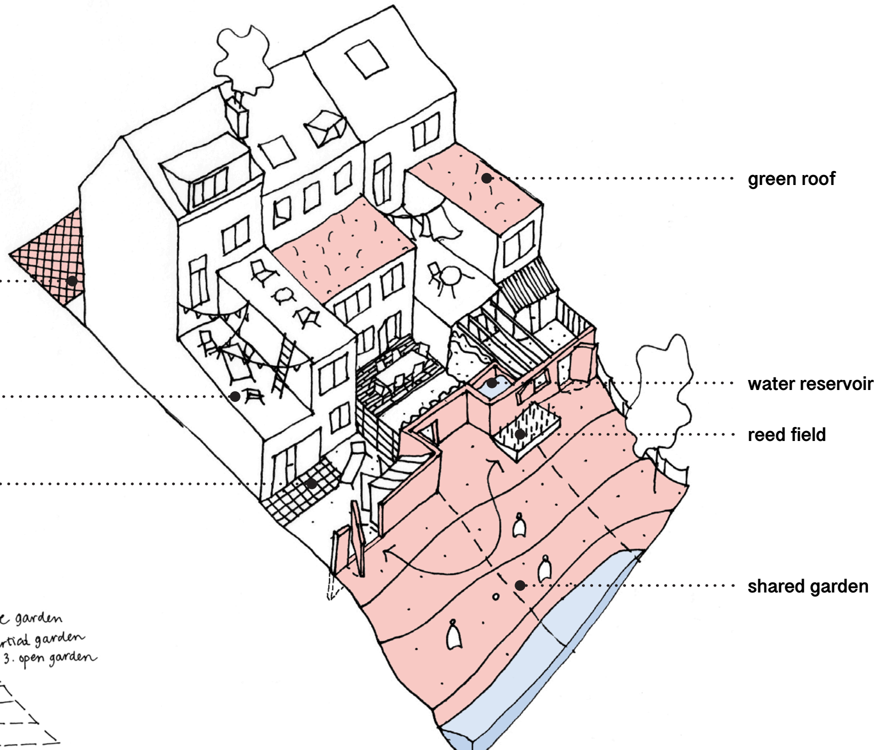
Rainfall quantity and infiltration capacity

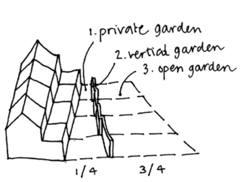
The building block basin here has a surface of 4200 m^2 with an average depth of 2 meters and height of 3 meters. That means the basin has a total volume of 21.000 m^3 = 21.000.000 liters.

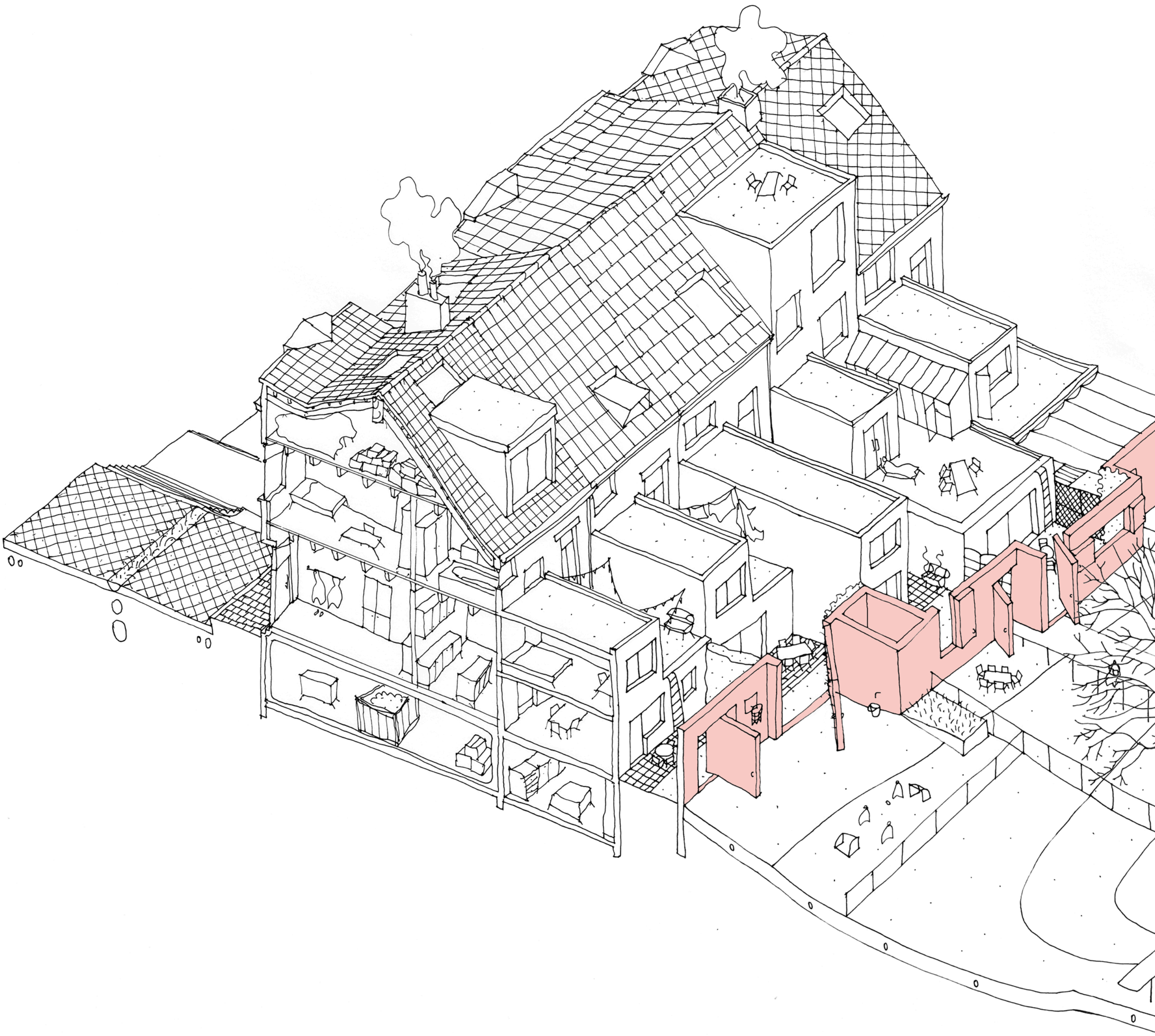
Hydrologists calculated that once in 30 years we can expect 62 mm/m^2 (= 62 l/m^2) of rainfall in one day (Deboosere, 2019). The pump house has a range radius of 250 m and thus covers a street surface of 5800 m^2. Then the infiltration basin would receive a water volume of 359.000 liters (62 l/m^2 x 5800 m^2) in one day which would mean a water level of approximately 2 meters measured from the deepest point (-3 m).

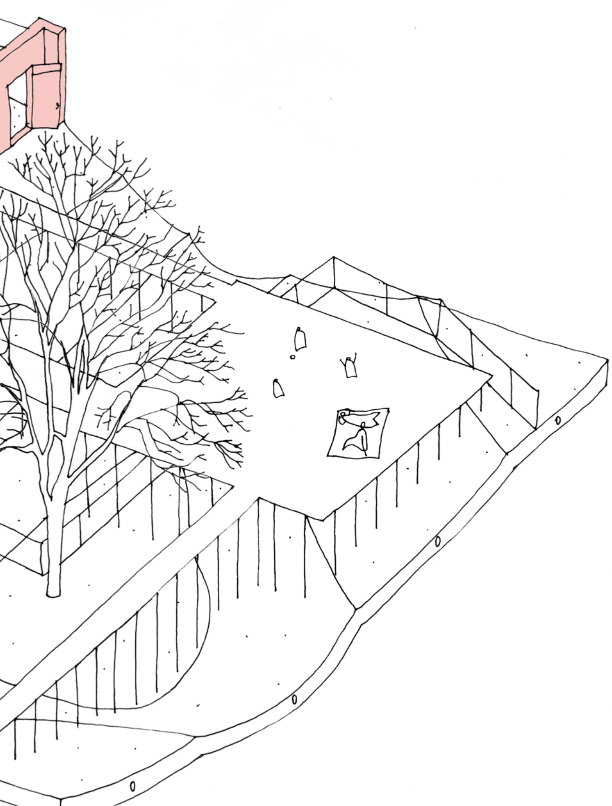
Keeping the soils water permeability in mind (0,05 m/day) it would take 40 days for the basin to infiltrate this volume of water (excluding possible evaporation).

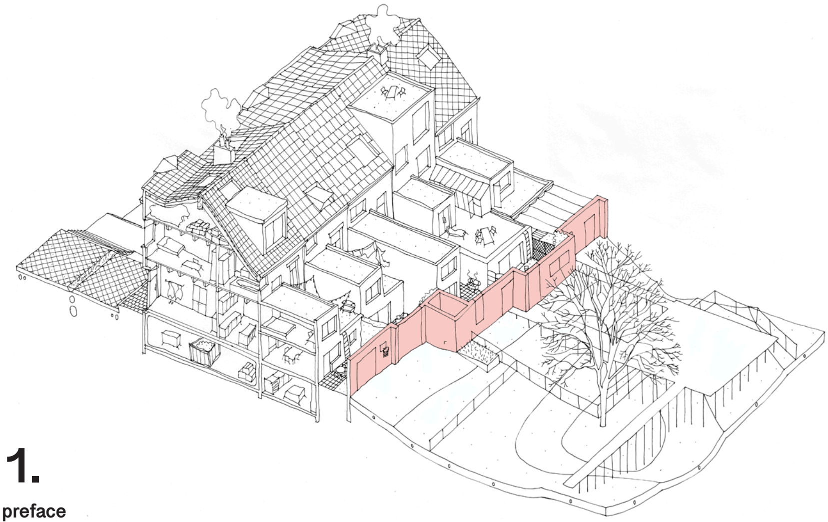












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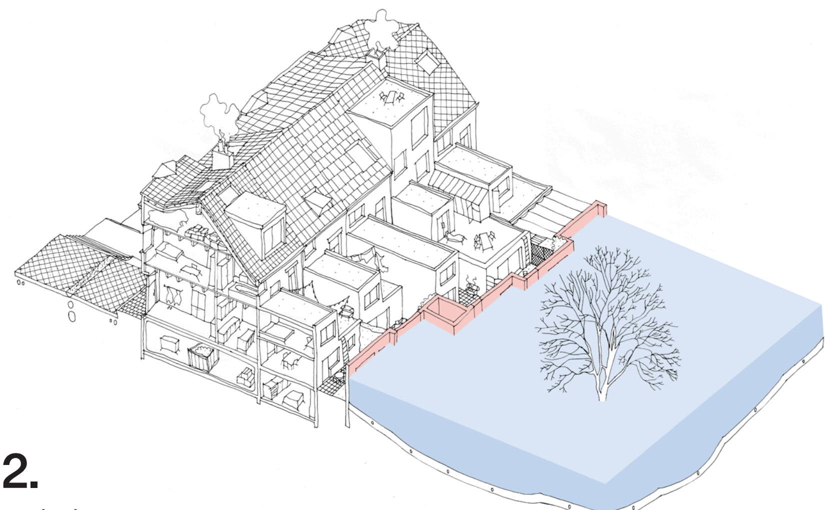

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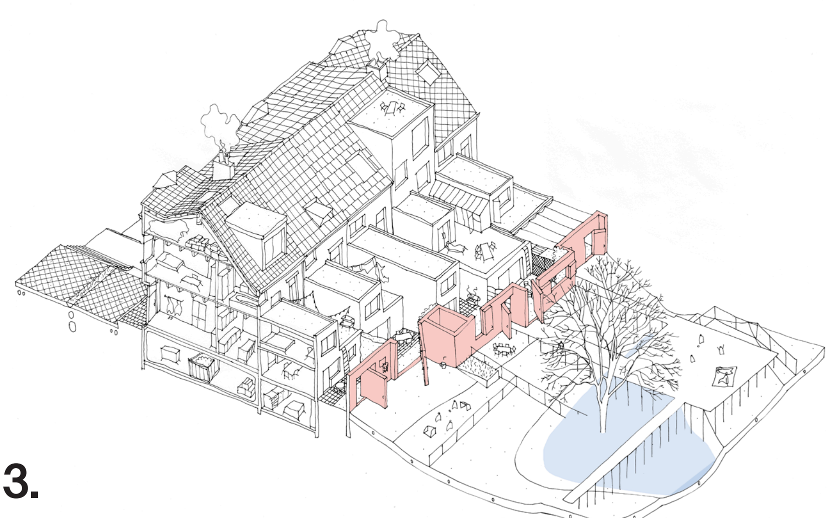

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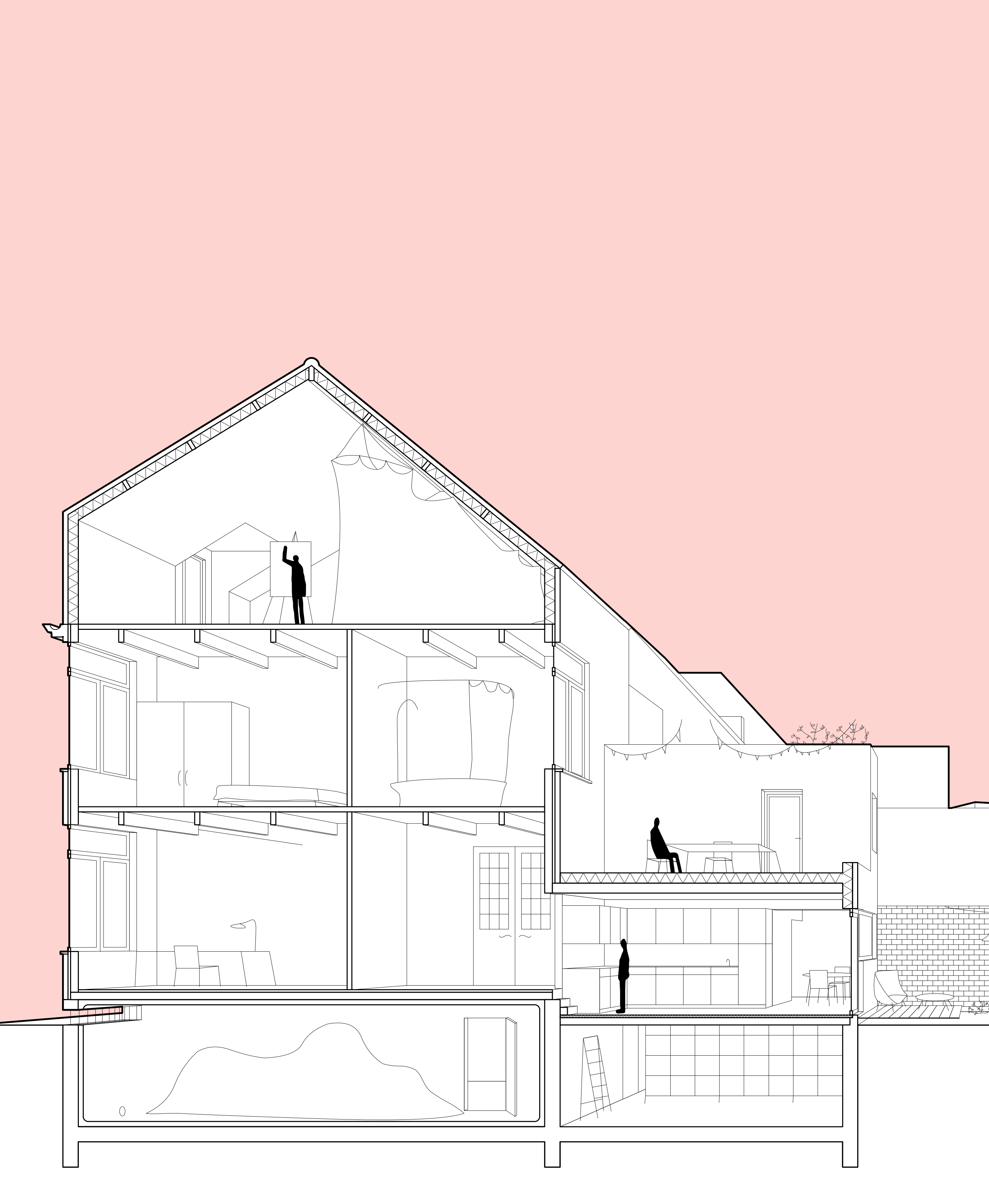


(2) Connect to pump

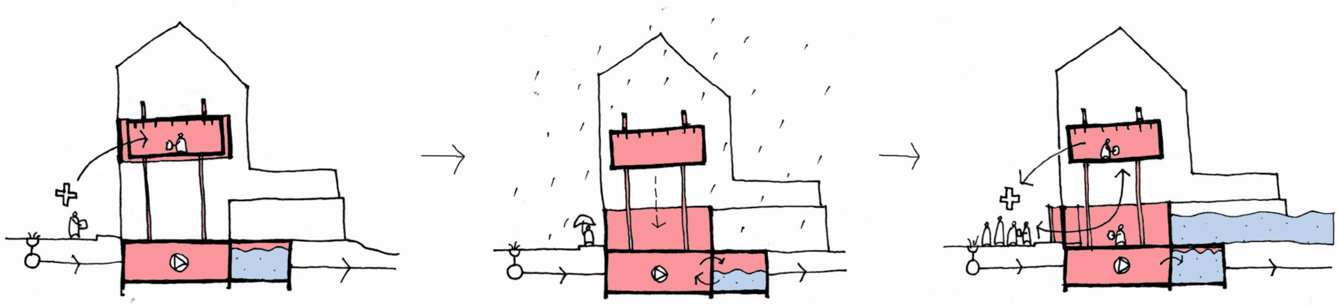
As it is impossible in cities to make sure rain infiltrates where it has fallen the second option is to connect these remote areas with a pump sytem. In this way the water can be **transported** to the closest area with infiltration possibilities. There is a need for a new network besides the existing sewerage system, since this one is already overloaded (one of the causes of urban flooding) and is mostly designed as a gravitary system, without pressure. To be able to pump water to a certain location pressure pipes are needed since these have a stronger membrane fit for pumping pressure.

The construction of a new pipeline network implies thorough road works. Since the proposed gutter network is a link in a larger system it can be **constructed in different phases** as the needed accessibility of the street and the availability of financial resources allow. Starting from the pump house the network can expand step by step, connecting the vulnerable for urban flooding areas.

The network consists of a **visible gutter** filled with plants like yellow iris, different types of reed and grasses. They ensure a primary cleaning of the collected water. At certain points, the street gutter is connected to an underlying **pressure pipeline**. This transports the water to a pump house which is located at the border of an infiltration area. In the case of a building block basin this could cover the surface of one building plot to be bought by the government or a government company (non built-up, one owned by a city development company like AG Vespa, a vacant building, a plot for sale, ...).

The design of a pump house consists of three basic elements: an **emergency unit**, a water **lock envelope** and a **pump room**. In case of a weather prediction for a severe storm (mostly this is known 72 hours before it hits) the hanging emergency unit can be loaded with medicines and other primary utilities needed after disaster events like a storm. When the water on the inside of the building block basin rises above street level a concrete envelope locks closes off the basin as extension of the water wall. The pump room is located in a basement and consists of a room with the actual pumps and a room filled with water since the pumps need a water buffer to empty before starting. The volume of water is a minimum of what the pump drains away in one minute. So for a 500 m^3/h pump this means 8,5 m^3.

The lock has multiple modes depending on the situation. When both above ground volumes are raised in the air an entrance towards the building block basin appears. However it is not the intention for non-inhabitants to make use of this space, as it is still private property. The entrance opened or closed off suiting the occasion.



Rainfall intensity and pump power

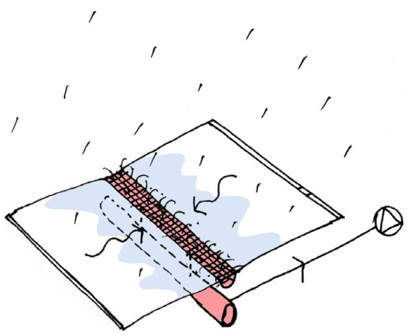
Our pumping house has a range radius of 250 meters and covers a hard street surface of 5800m² (we expect the rainfall on the building rooftops to lead to the existing sewerage).

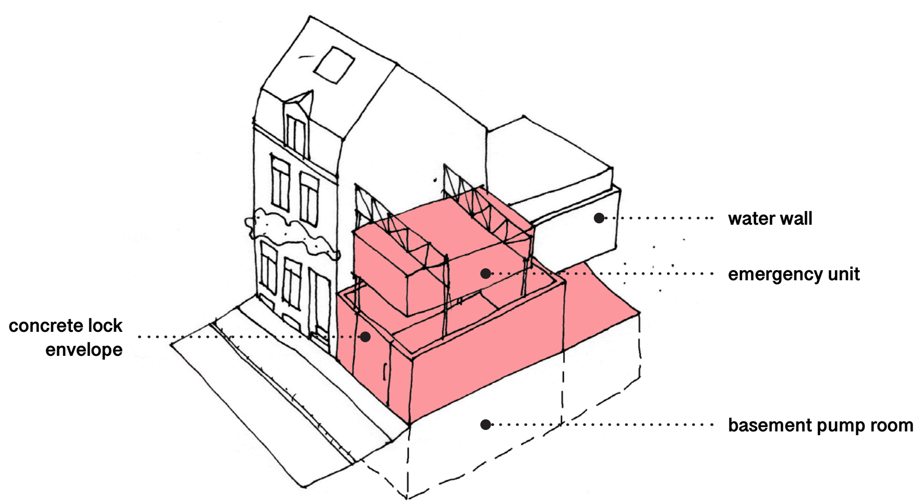
Hydrologists calculated that once in 100 years we can expect 19 mm/m² (= 19 l/m²) of rainfall in 10 minutes in Flanders (Deboosere, 2019).

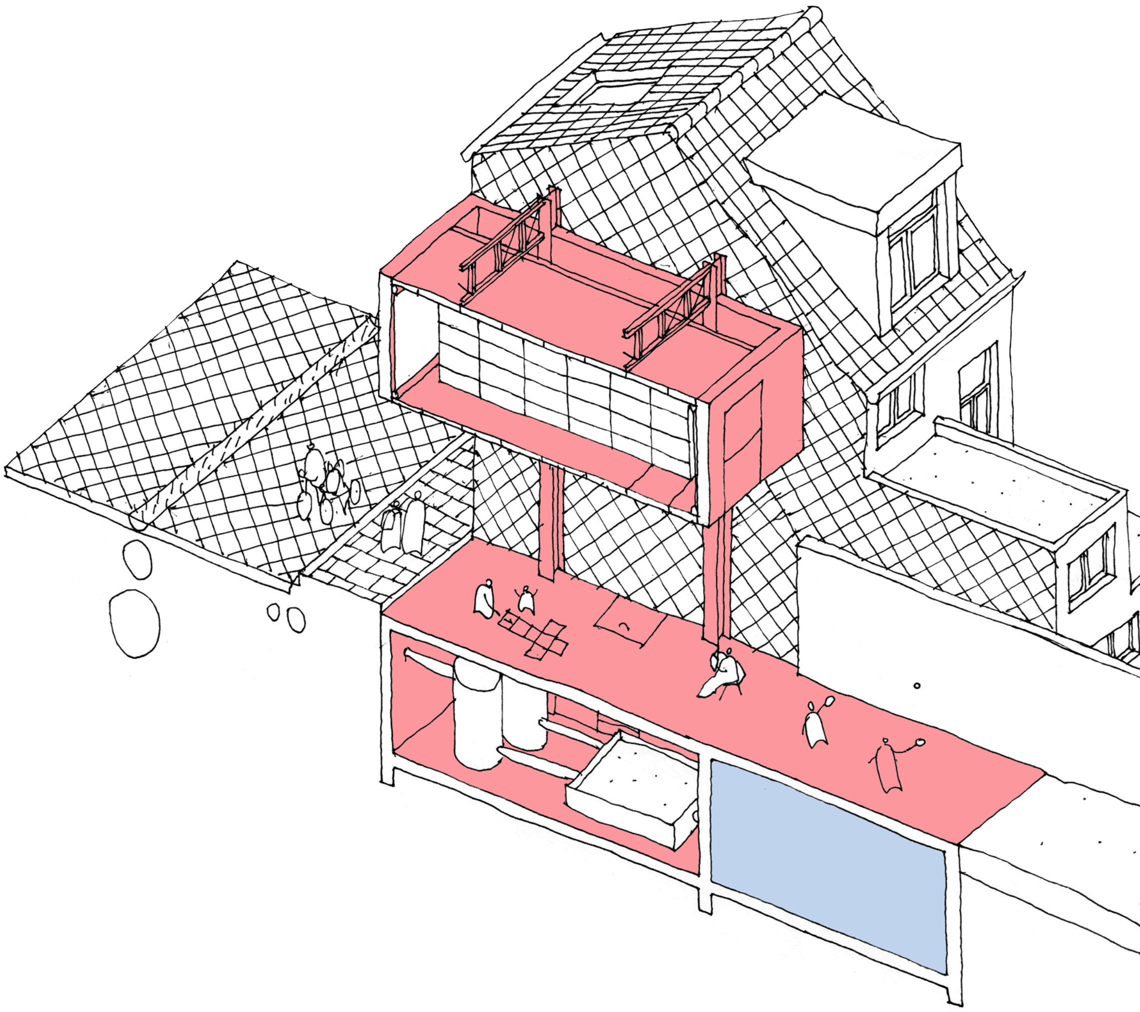
19 l/m² x 5800 m² = 110.200 l/10min = 11.020 l/min = 11 m³/min = 660 m³/h

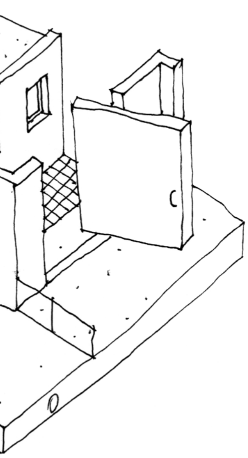
This means that to handle this once in 100 years event our pump house needs a pump power of 660 m³/h. For safety reasons it is better to make use of a combination of more than one pump.

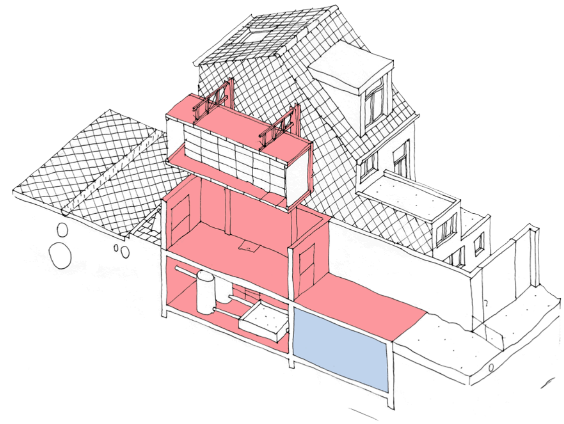
In this case that could be two DAB pumps of 500 m³/h (SMC 12/1). These are 2249 mm long with a diameter of 298 mm and a 20 cm connection. In this case the water runs through the pipe at a pace of 4,5 m/s.











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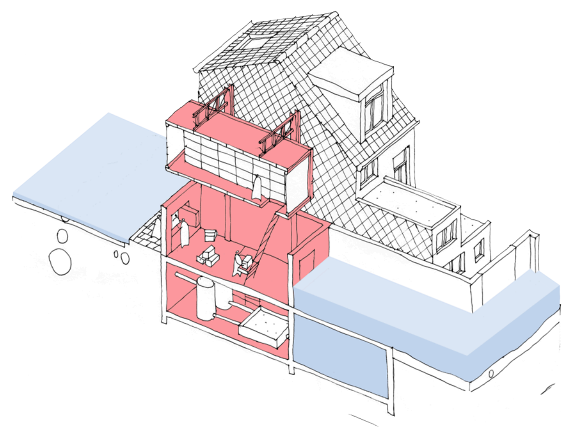

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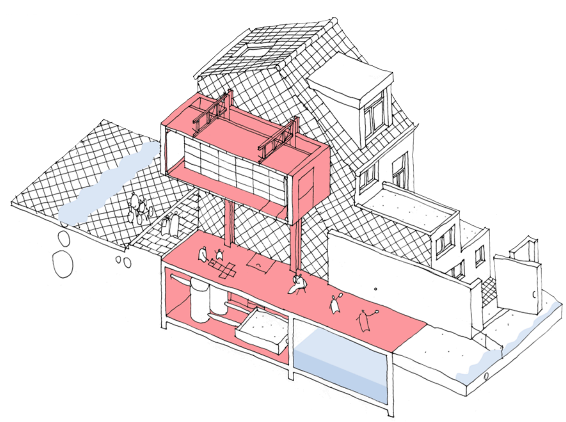

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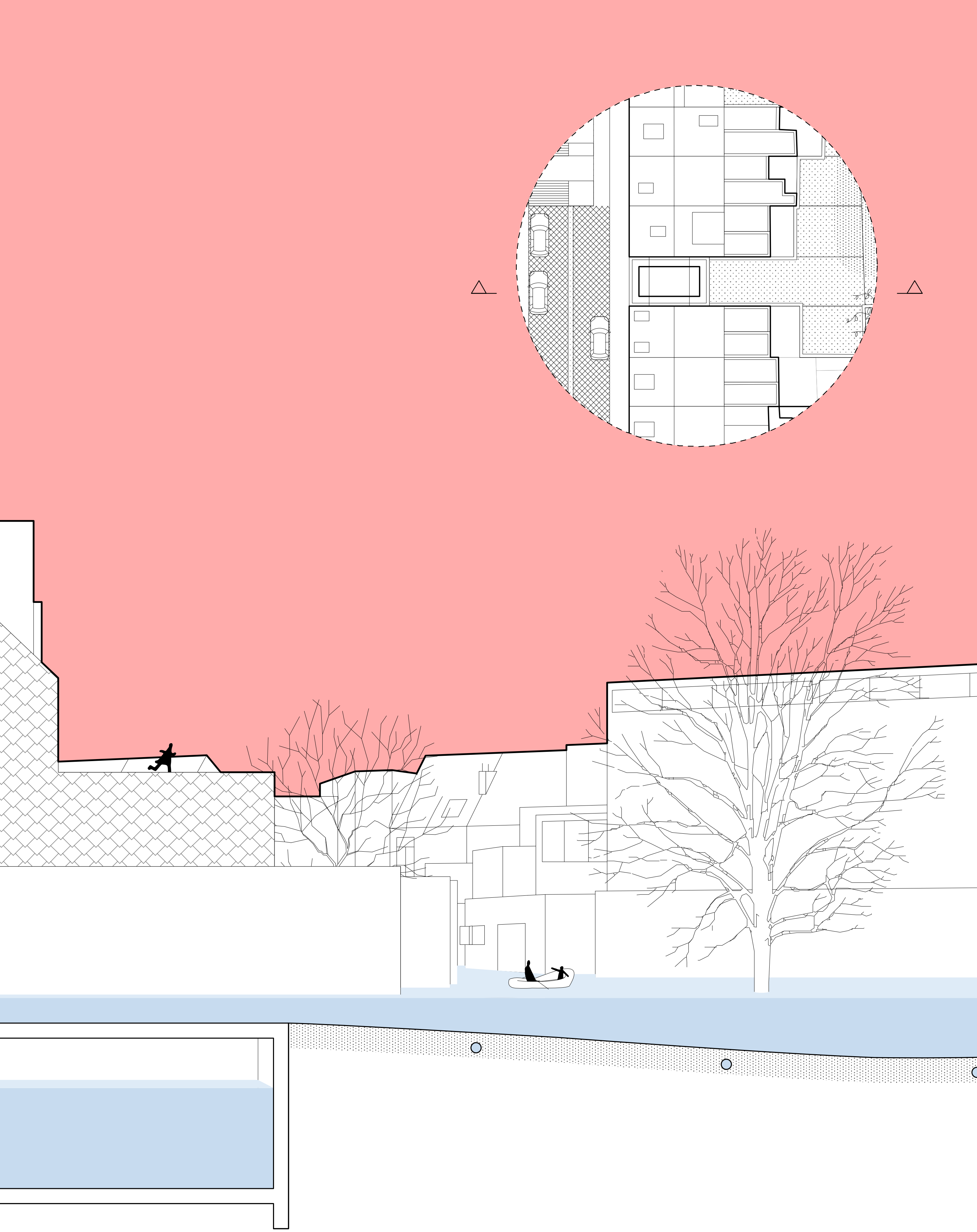


(3) Buffer temporarily

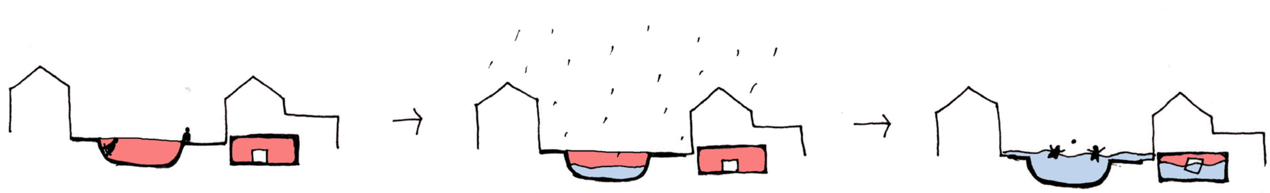
Sometimes it could be more interesting to have space available to temporarily buffer rain water. Even though the gutter and pump network is dimensioned for peak weather events, it is still possible for a situation to appear where it happens that the **pump power is not sufficient** enough to drain all the rainfall away in time. In this case easily accessible buffer zones should be ready to receive large volumes of water to prevent the surrounding vulnerable buildings from flooding.

On the other hand, while winter will become more wet (more intense and more frequent rainfall) **summers will become more dry** (heatwaves, droughts, low ground water level). In this case it is clearly more desirable to buffer rain water over a longer period of time instead of draining it all away as fast as possible. A possibility could be, besides the collection of street rain water, to also connect **downsprouts** of surrounding buildings to a buffer zone. In this way it won't be drained through the sewage system straight away, but is it temporarily retained for grey water use (washing cars, watering plants, flushing toilets etc.) in case of a water shortage threat.

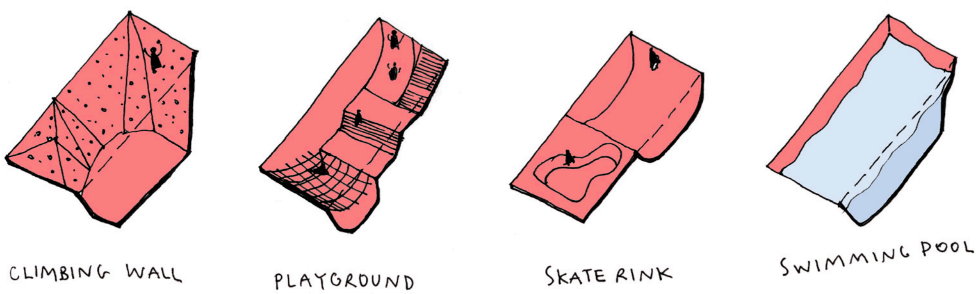
Since the water has to be retained over variable time spans (from several days and weeks to several months and seasons) it is important to design the buffer zones in a way they are considered **valuable both in wet and dry situation**. To be able to collect water in a safe and sustainable way hard surface walls like concrete are necessary. These hard surface buffer zones can be situated in public or private space, depending on the availability.

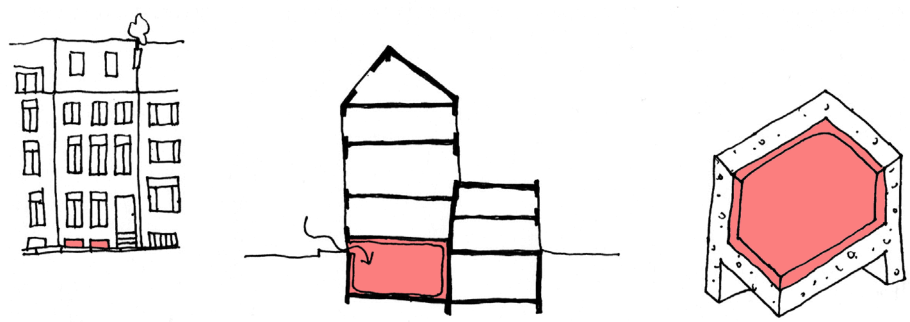
In **public space** I propose to find existing hard surface areas that can be redesigned or redeveloped over time. This can be small squares, (parts of) dead end streets, parts of non-through traffic streets, residual public space etc. By digging out the existing hard surface a new collective space for neighbours to meet appears, as the function of this space depends on the neighbourhoods needs.

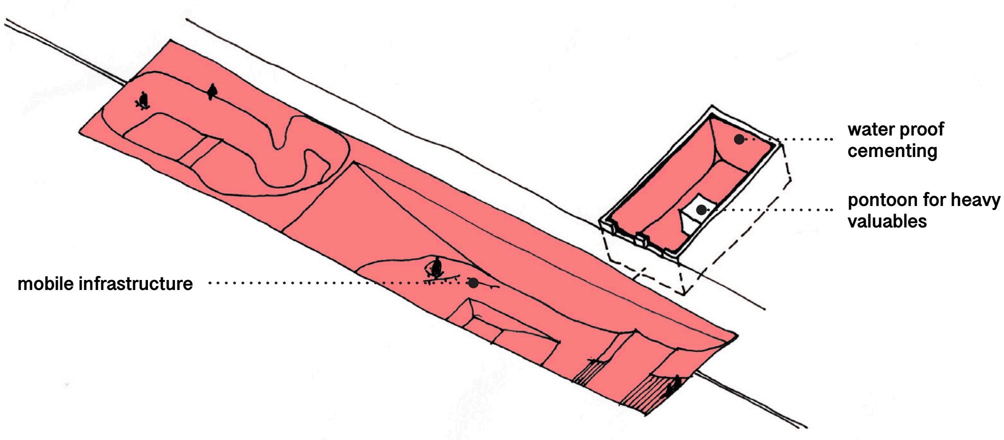
In the specific case of Brederode an option appears to find water buffer areas in **private space**: many houses in the residential part of the neighbourhood have characteristic basement windows. In case of a severe flood these indoor spaces would be the first ones to flood. By simply applying a water proof cementing layer and a connection through the wall to the pressure pipeline, a collection these basements could significantly reduce the impact of a severe storm in the neighbourhood. Assuming that this kind of extreme weather event only appears with a once in 100 years chance, we can assure that the owners won't have to move the whole content of their basement on a yearly basis.

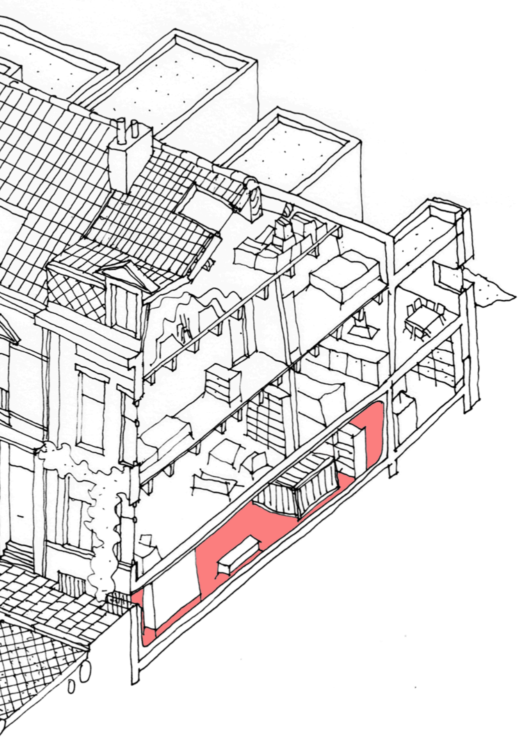


The resource of **funding** depends on the situation: when a public square needs thorough renovation within the reach of the existing pump network the government should be obliged to redevelop it in a water resilient way. Another way could be private funding: a group of neighbours decide to rebuild their dead end street to collect rain water from their roofs so they can use it for grey water purposes. In the case of the basement buffers owners get a tax allowance for making their house flood permitting.









1.

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2.

weather impact

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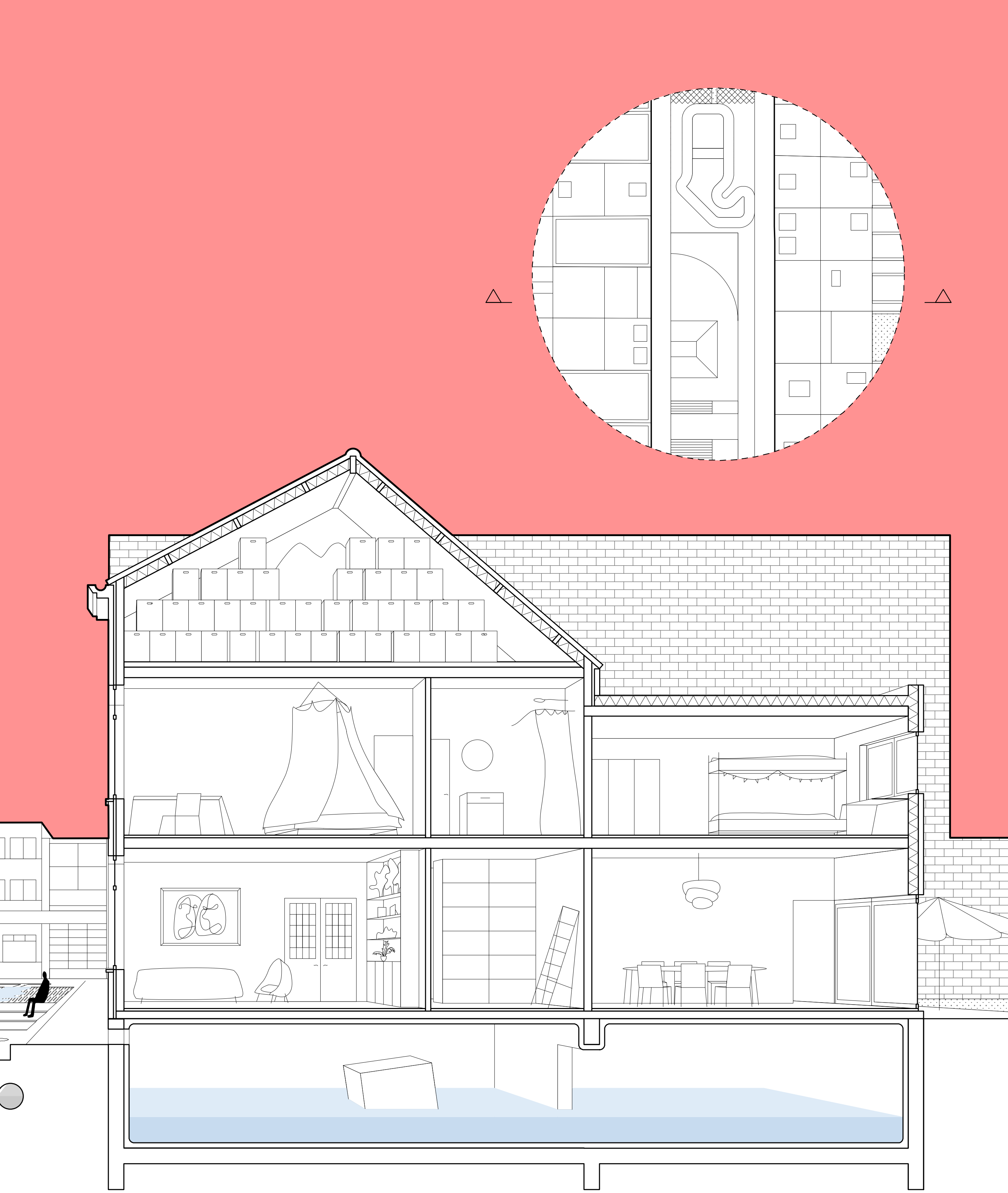
3.

resilience



(4) Protect weak areas

Depending on the possibility of placing infiltration basins and the range of the accompanying pumping network it could happen that there are locations that cannot be incorporated in the range of the pump. As the placement of a building block basin is quite a radical intervention and has specific requirements like sufficient building block space, it is not always the ideal solution. In that case I propose a final option to protect the left over weak areas.

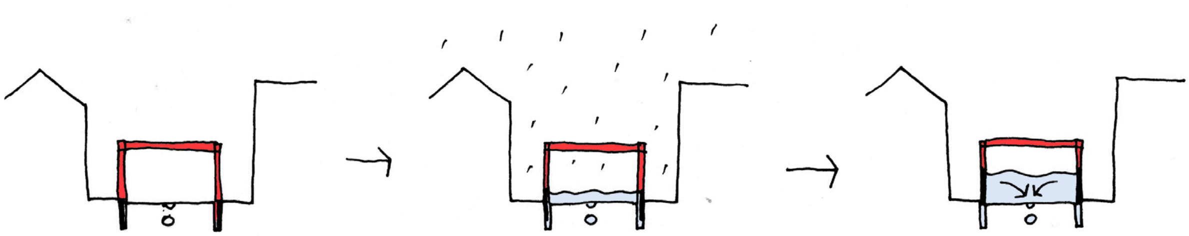
In the specific case of Brederode there is not enough existing green space to infiltrate all rain water of the flood risk zone besides the ones connected to the building block basin. Therefore I tried to design a minimal structure that adds value to the collective space instead of reducing it. The intervention can be considered as an **elementary infrastructural addition** to the street. It is a contemporary colonnade of steel HEM450 columns clamped in a trench on the axis of the current sidewalk curb.

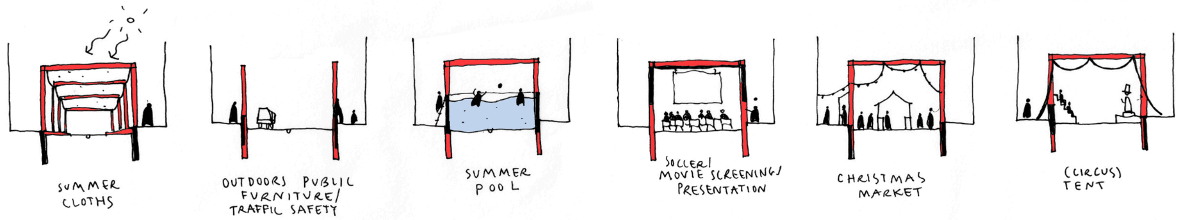
The columns each stand axis on axis 6 meters apart with hollow structured concrete slabs of 600 x 300 x 30 cm sandwiched in between. In dry situation these are invisible on the street level as they fit in the 3 meter deep trench. In case of sufficient continuous rainfall (and the existing sewerage system besides will start flooding) the small cavity in between the concrete slab and the trench is filled up with water and this subsequently pushes the hollow concrete slab upwards (**Archimedes' principle**). This means the space in between the colonnade gets filled up with water but the sidewalk and the buildings behind stay dry.

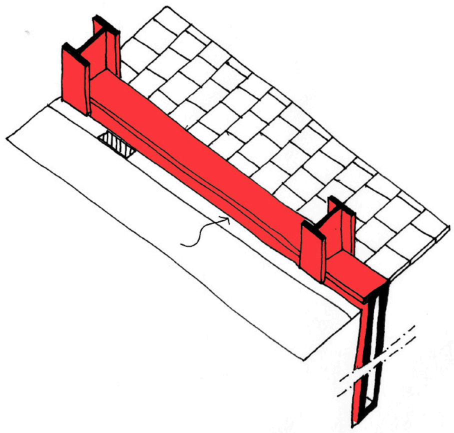
Even though it is structurally seen not necessary to connect the columns on both sides with each other, this can be done as the **connecting steel beam** can function as basic public infrastructure, to be used in different ways depending on the (weather) situation. The columns and beams are a skeleton that can be dressed and adapted depending on the events taking place underneath.

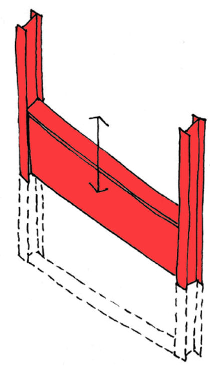
To maximize the multifunctionality and possibilities of the bare structure certain slabs can be supported by a **hydraulic pump system**. This allows the concrete slabs to move up or downwards mechanically without the presence of a volume of water. For example it might be interesting to do this for a part of a smaller street to allow the concrete slabs to become walls and be filled up with water during summer like a pool, or a temporary movie theatre or stage for a local concert or festival. Likewise in winter parts of streets can be closed for a winter market or an ice rink.

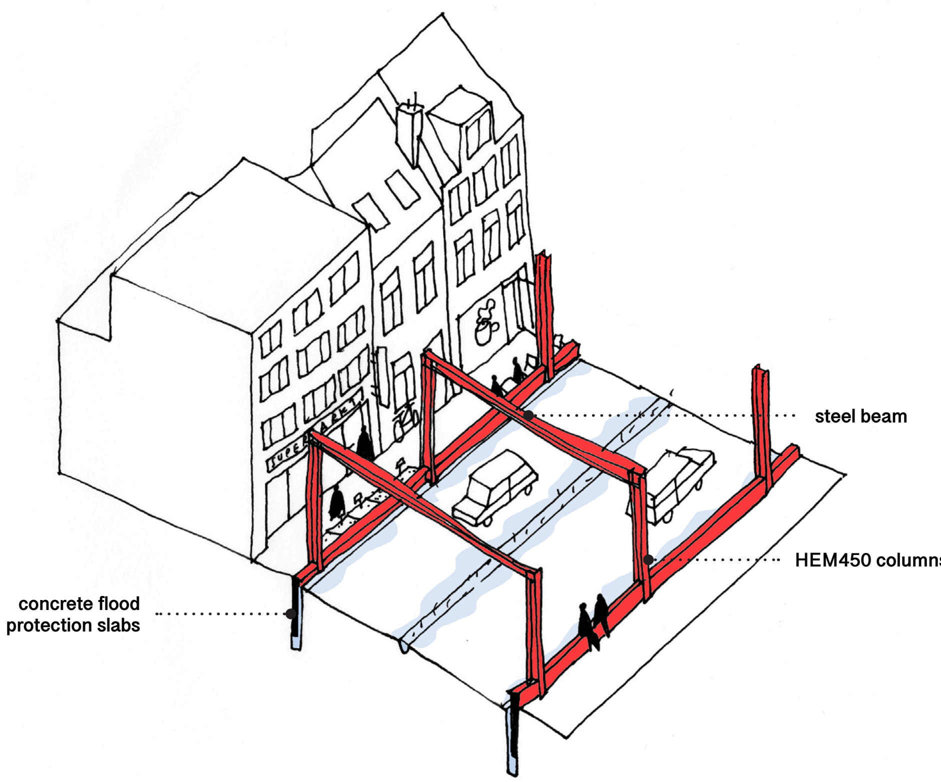
The idea is to return the streets to the neighbourhood as **valuable collective space**, as this is something Brederode lacks. The steel structure should make it easier to organise events for people to gather and meet in the streets.

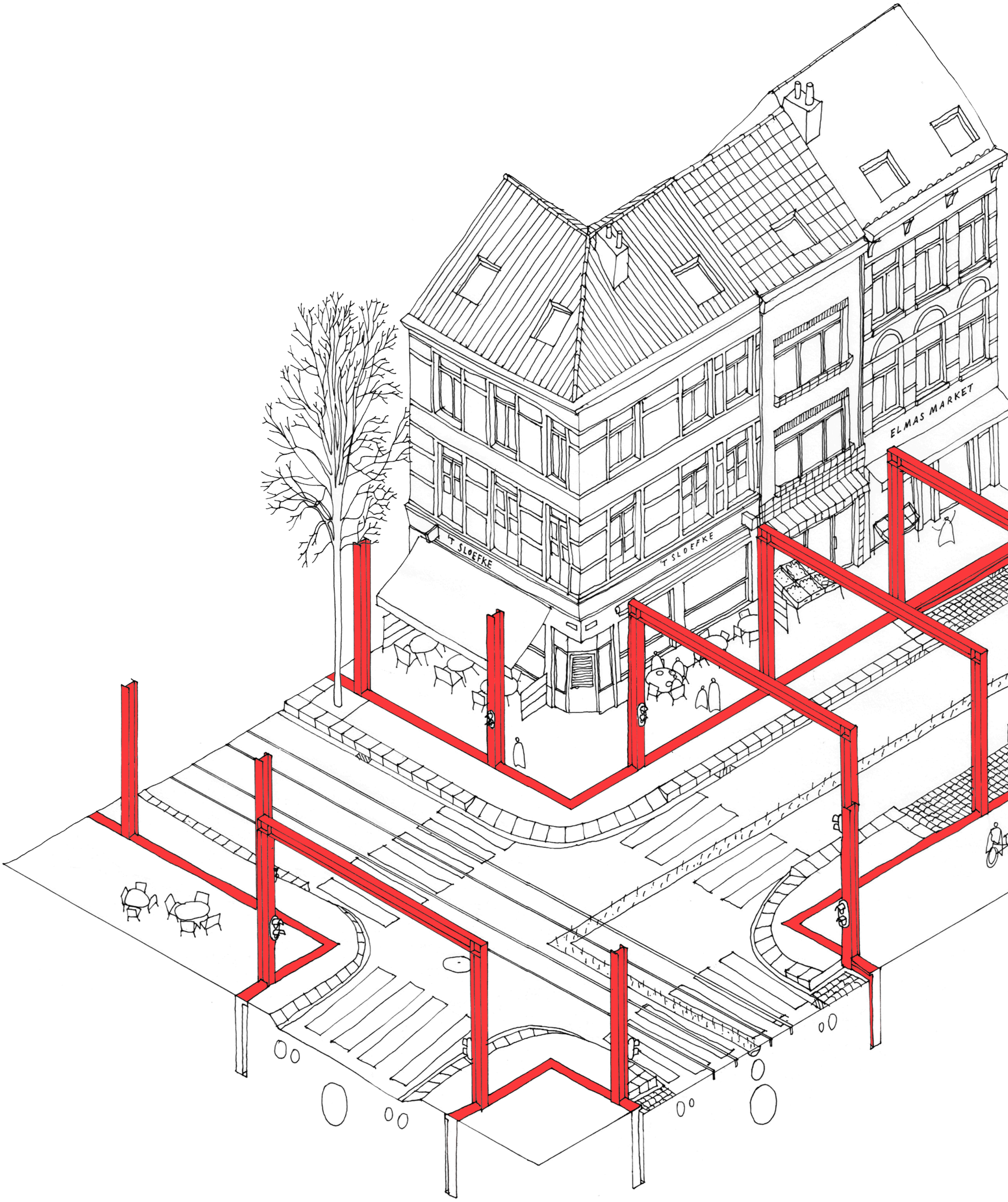



SUMMER CLOTHS
OUTDOORS PUBLIC FURNITURE/ TRAFFIC SAFETY
SUMMER POOL
SOCCER/ MOVIE SCREENING/ PRESENTATION
CHRISTMAS MARKET
(CIRCUS) TENT






steel beam
HEM450 columns
concrete flood protection slabs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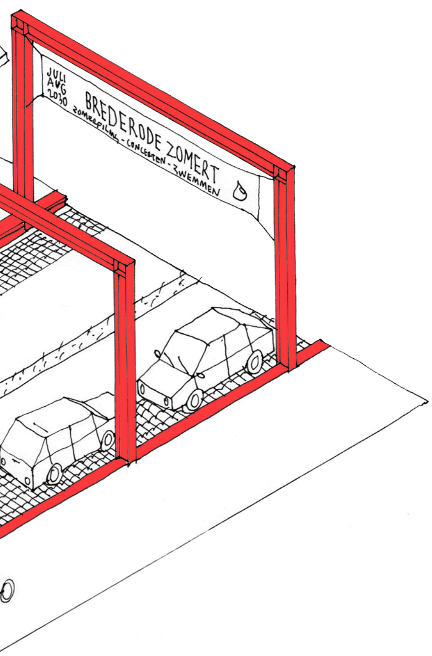
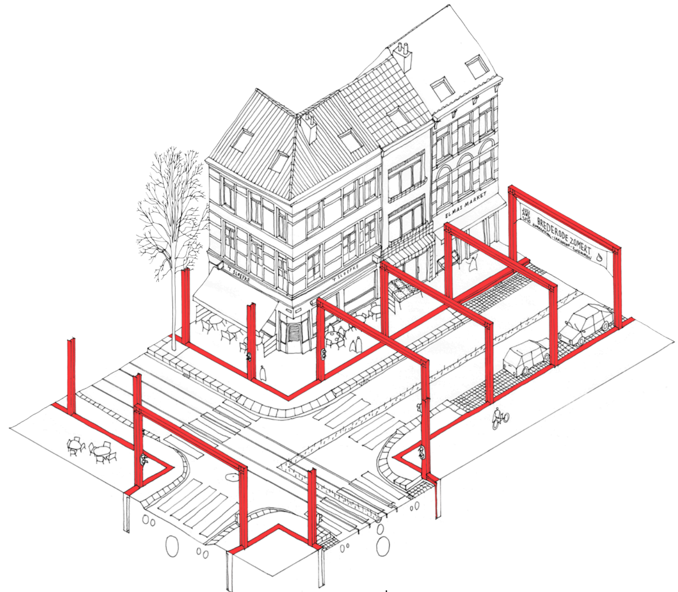
'T SLOEFKE
ELMAS MARKET





1.
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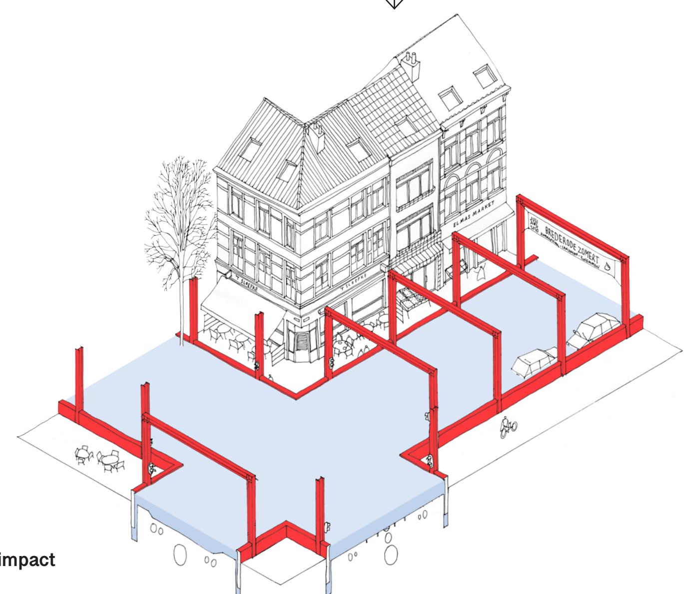

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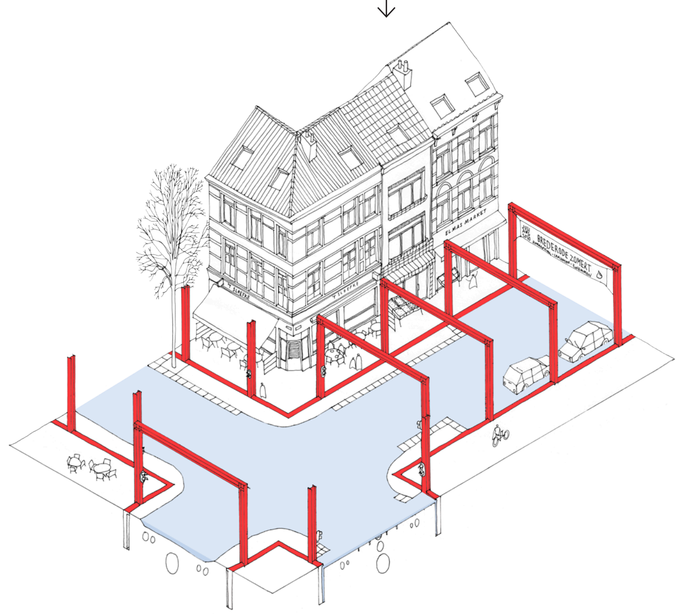
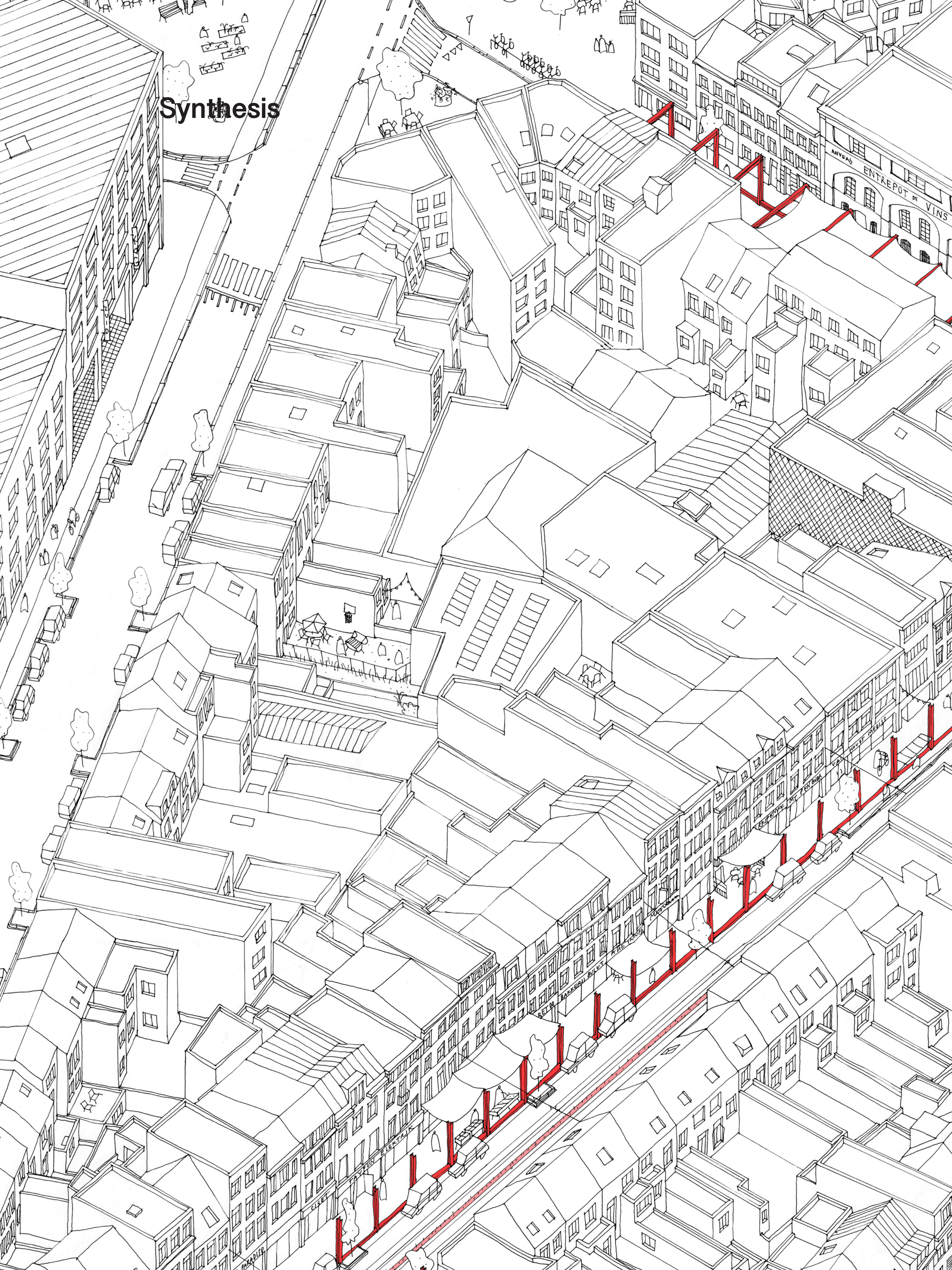


3.
resilience


'T SLOEFKE
ELMAS MARKT
21 juni - 21 augustus 2030
Brederode zomert
zomerfilms - optredens - openluchtzwemmen - rommelmarkt

Synthesis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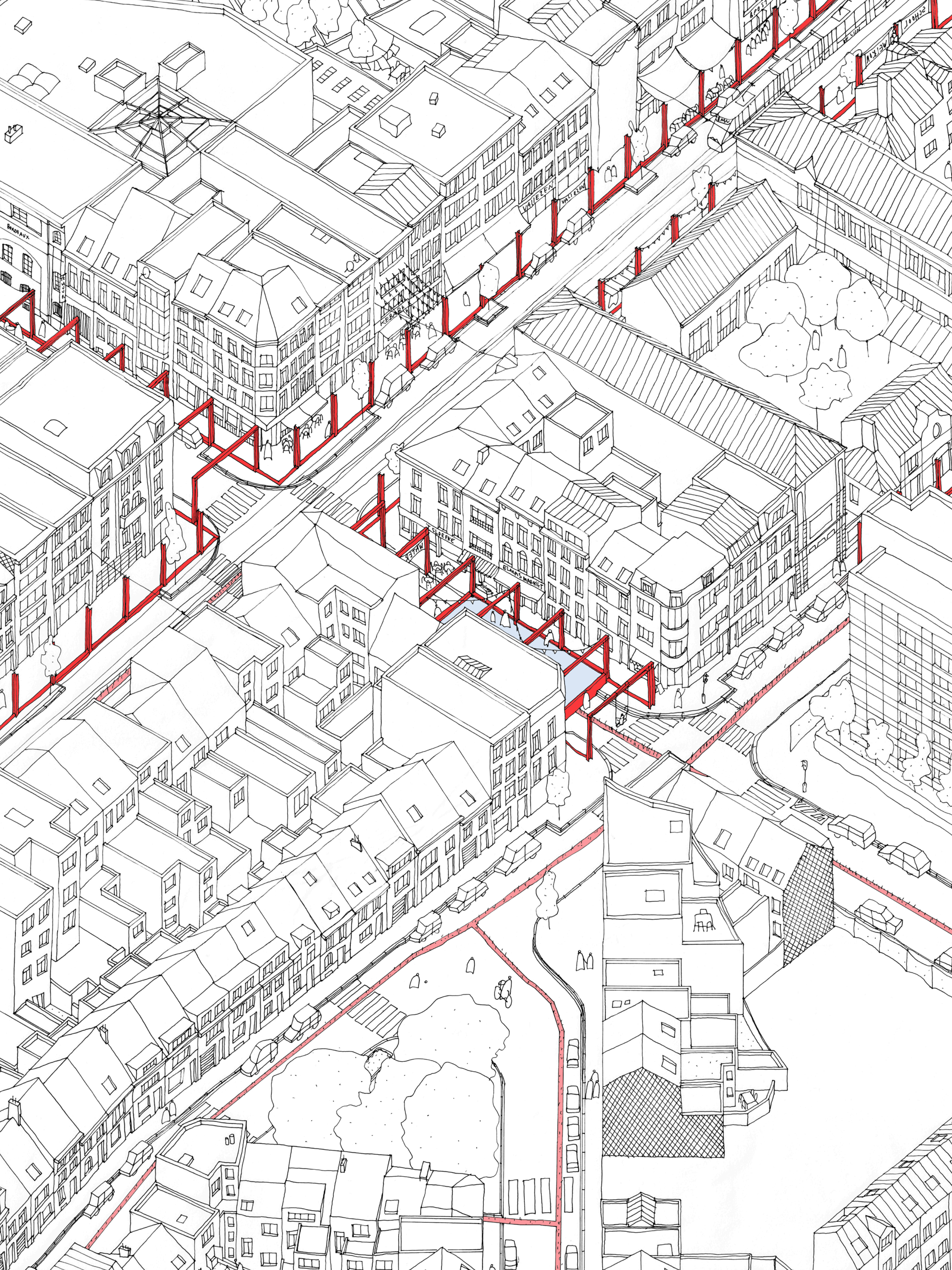
TAYFUN ELEKTRIK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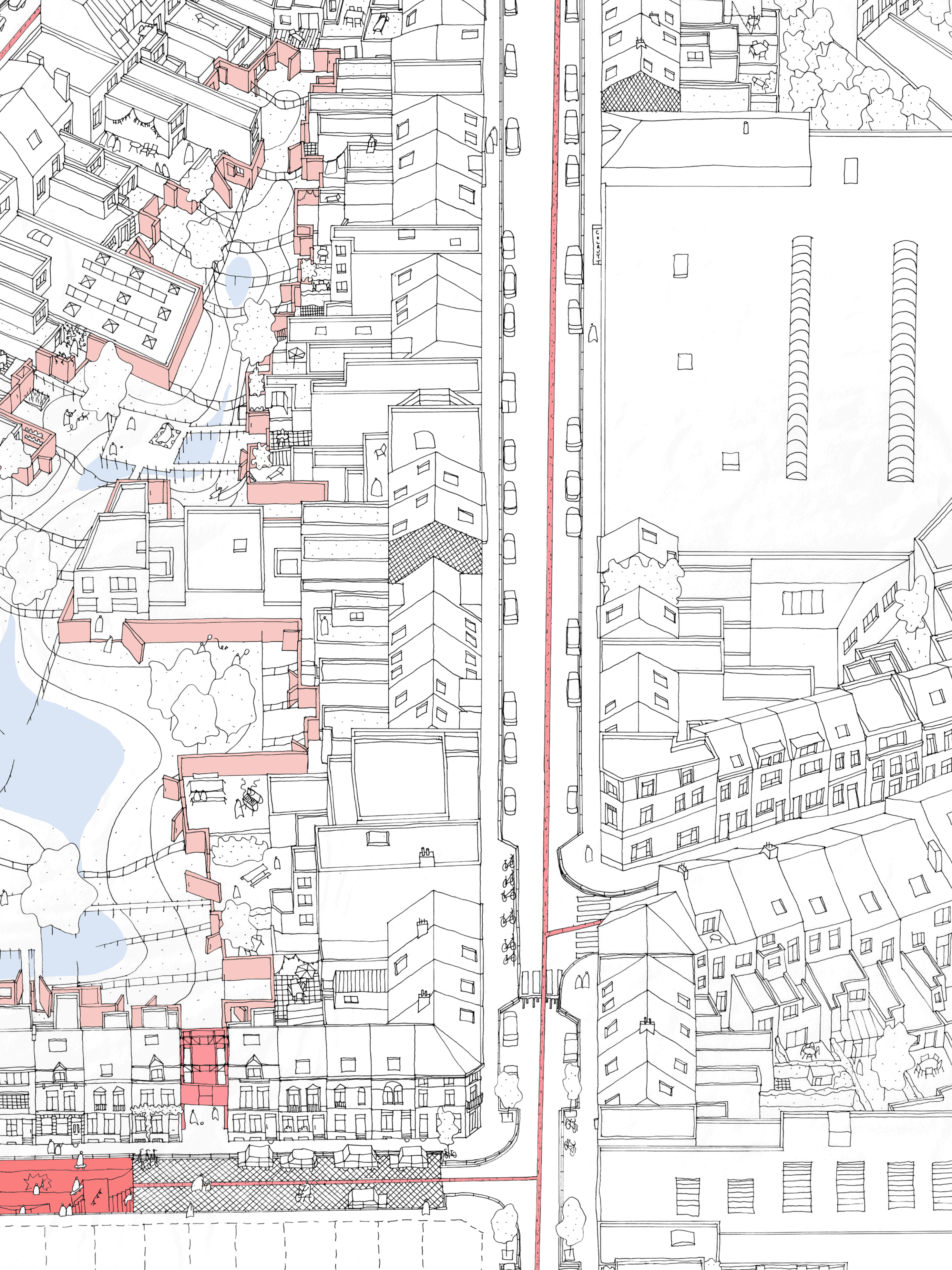
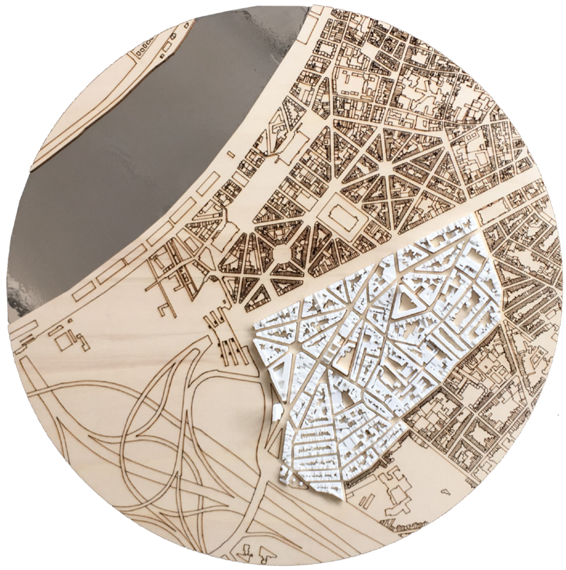
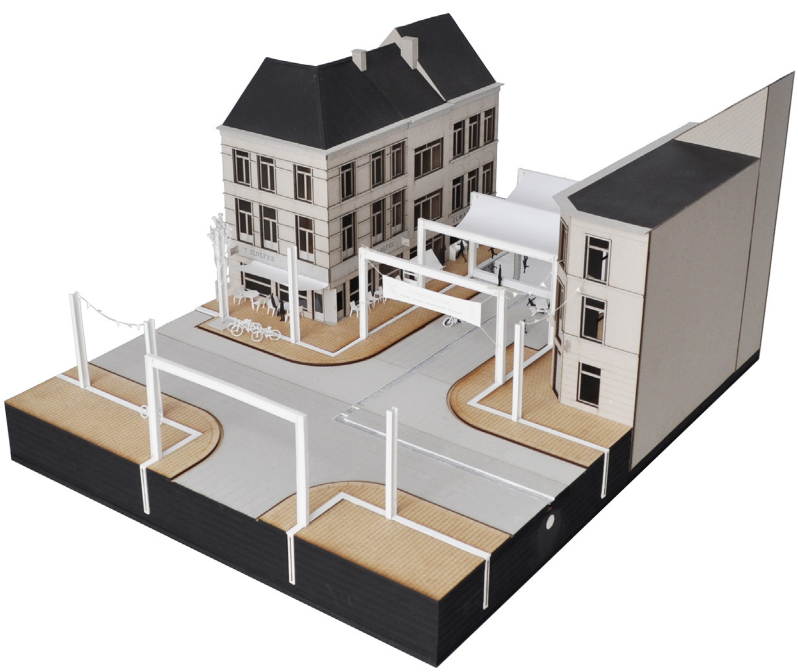
ELMAS MARKET
VALIEZEN
VALIEZEN


HAPPY BIRTHDAY

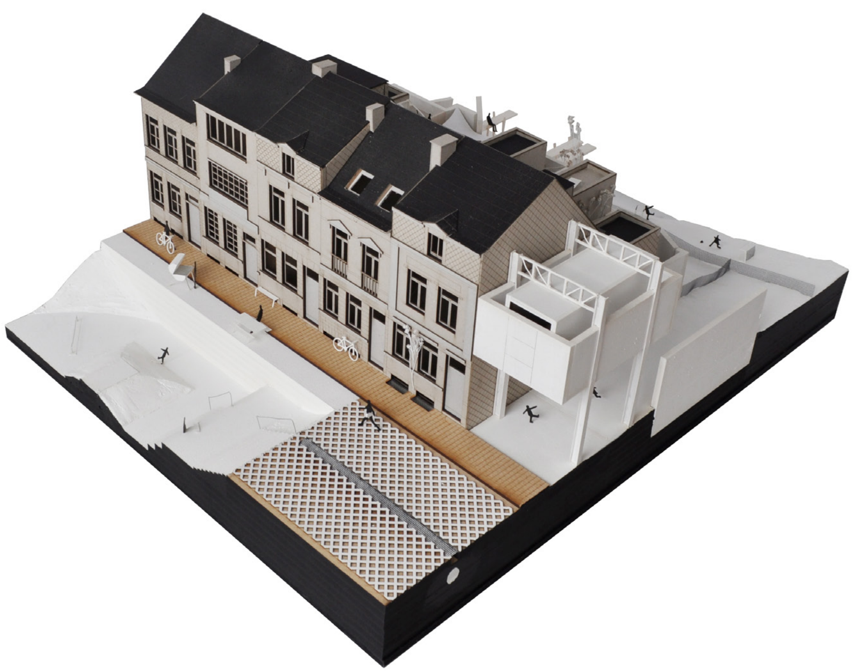
Models



Site model S 1:3500

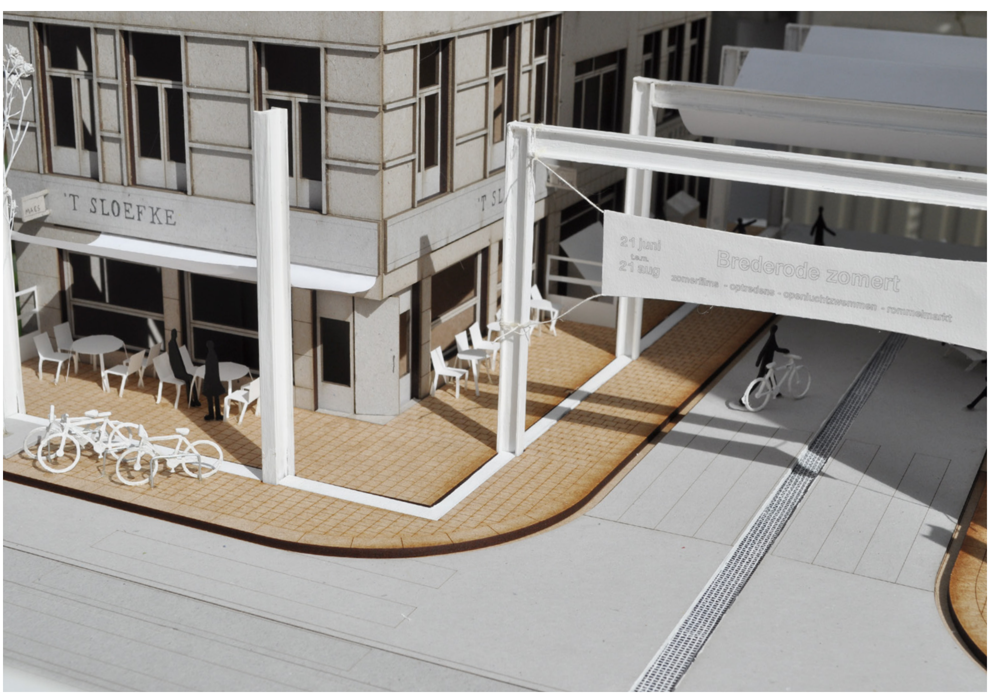


Model S 1:50



Model S 1:50


ELMAS MARKET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Brederode zomert
zomerfilms - optredens - openluchtzwemmen - rommelmarkt

Model S 1:50

Model S 1:50

Reflection

Personal findings

When I started developing the first ideas for this master dissertation, it was a sense of urgency (driven by the effects of climate change) that led me to the topic of urban flooding. In the first place I developed a mentality on how to deal with water which is different from the main discourse today. Along the way I realised solely thinking in disaster scenarios is not a socially sustainable way to redevelop a neighbourhood for the future. On the contrary, it reinforces a fear of water. That's when I started to think of urban flooding as a possible catalyst for positive incremental change.

In 2017 I wrote a paper on Sustainability and the Design Professions, where I argued for a general mentality shift as one of the keys to ecological sustainability. This means that in the case of this dissertation topic the presence of water has to become an absolute added value, now and in the future. I did not (only) focus on the passive presence of water (such as a pond), but especially on the active use: water as an active agent to help shape the daily environment and subsequently to have a community-forming effect. Historically, humans have always searched for the presence of water as a vital equal who must be able to live a life of its own an thereby structures the life of humans (as a primordial rule).

Reading newspaper articles and watching documentaries have heavily impacted my view on the topic and therefore urged me to bridge the gap between an academic design project and a daily reality. I tried to imagine architectural interventions that do not appeal to a distant future but a realistic now. This means I avoided single building plot design with an all-dissolving megastructure. Instead, I wanted to design a network of small-scale spatial interventions through using undervalued existing space (both private and public). To me this has a larger relevance because of partial development opportunities and high engagement of the inhabitants. Therefore it adds to the above mentioned mentality shift.

Further research opportunities

Throughout the course of the year I learned many things about architecture and climate change, and architecture and water in specific. However I realise the course of one academic year (of which 5 months exclusively dedicated to this dissertation) is not enough to understand the full impact of this large issue. Above that, knowledge about this topic is produced every day as we are only discovering many consequences long after the damage is done.

In the first place I developed I strategy / policy / mentality on water management in cities. I tried to translate these ideas to spatial proposals for the specific context of Brederode. This means the strategy can take on a different physical appearance in a different cultural or spatial context. Therefore this dissertation leaves opportunities to extend and expand the research.

Even though I feel like this will always be a disclosed design process I feel like I managed to provide a relevant proposal today that imagines a tomorrow based on what we inherited from yesterday.

Bibliography

Textual references

p. 10 (UN-Oceans, 2016)
UN-Oceans. (2016). *UN Atlas of Oceans.* Retrieved 2 May 2019, from www.oceansatlas.org/subtopic/en/c/114

p. 12 (Flanders Environment Agency, 2019)
Flanders Environment Agency. (2019). *Climate Portal Flanders.* Retrieved 12 March 2019, from klimaat.vmm.be/nl/web/guest/klimaatverandering-wat-is-dat
(Leemans, 2017)
Leemans, S. (2017). *Sustainable development and the design professions.* Unpublished manuscript, Chalmers University of Technology, Gothenburg.

p. 13 (Aerts et al, 2009)
Aerts, J. C. J. H., Major, D. C., Bowman, M. J., Dircke, P., Marfai, M. A., Abidin, H. Z., ... Reeder, T. (2009). *Connecting Delta Cities. Coastal Adaptation, Flood Risk Management and Adaptation to Climate Change.* Amsterdam: VU University Press.
(Strauss, Kulp & Levermann, 2016)
Strauss, B., Kulp, S., & Levermann, A. (2016). *Reply to Boyd et al.: Large long-term sea level projections do not mean giving up on coastal cities.* (Vol. 113).

p. 14 (Temmerman & Kirwan, 2015)
Temmerman, S., & Kirwan, M. (2015). *Building land with a rising sea.* Science, 349(6248), 588-589.

p. 15 (Institution of Civil Engineers [ICE], 2010)
Institution of Civil Engineers. (2010). *Facing Up to Rising Sea-Levels: Retreat? Defend? Attack?* United Kingdom: Institution of Civil Engineers.

p. 16 (Flanders Environment Agency, 2019)
Flanders Environment Agency. (2019). *Climate Portal Flanders.* Retrieved 16 March 2019, klimaat.vmm.be/nl/overstromingen

p.18 (Statistics Flanders, 2019)
Statistics Flanders . (2019). *16% van totale oppervlakte in Vlaanderen is verhard.* Retrieved 3 May 2019, from www.statistiekvlaanderen.be/verharding
(Panorama, 2013)
Panorama. (2013). *Verdronken Land: Vlaanderen onder water?* Retrieved 16 March 2019, from www.youtube.com/watch?v=ppT5R46ytrY

p. 20 (Temmerman & Kirwan, 2015)
Temmerman, S., & Kirwan, M. (2015). *Building land with a rising sea.* Science, 349(6248), 588-589.
(Van Havere, 2018)
Van Havere, C. (2018). *Impact van de klimaatverandering op stedelijke overstromingen.* Leuven: KU Leuven. Faculteit Ingenieurswetenschappen.

p. 24 (City of Antwerp, 2019)
City of Antwerp. (2019). City in numbers: database. Retrieved 3 April 2019, from stadincijfers.antwerpen.be/databank
(Secchi & Vigano, 2009)
Secchi, Bernardo, & Vigano, Paola. (2009). *Antwerp, territory of a new modernity (Explorations in/of Urbanism 2).* Amsterdam: SUN.

(Van Havere, 2018)
Van Havere, C. (2018). *Impact van de klimaatverandering op stedelijke overstromingen.* Leuven: KU Leuven. Faculteit Ingenieurswetenschappen.

p. 34 (Deboosere, 2019)
Deboosere, F. (2019). *Wat is het verschil tussen regenintensiteit en regenhoeveelheid?* Retrieved 13 May 2019, from www.frankdeboosere.be/vragen/vraag36.php

p. 38 (Deboosere, 2019)
Deboosere, F. (2019). *Wat is het verschil tussen regenintensiteit en regenhoeveelheid?* Retrieved 13 May 2019, from www.frankdeboosere.be/vragen/vraag36.php

Figure references

Cover figure. National Archive The Netherlands. (1953). *Queen Juliana visits the flooded area, ruined houses, february 1953.* The Netherlands: Photo Collection RVD / The Royal Family.

Fig. 0.1. Friedrich, C. (1823). *The Sea of Ice* (oil on canvas). Hamburg: Kunsthalle Hamburg.

Fig. 0.2. Own work.

Fig. 0.3. Friedrich, C. (1818). *Wanderer above the Sea of Fog* (oil on canvas). Hamburg: Kunsthalle Hamburg.

Fig. 0.4. Superstudio. (1972). *Rescue of the Italian historic centres, Florence.* Retrieved 12 March 2019, from www.wantedinrome.com/news/superstudio-radical-italian-architecture.html

Fig. 0.5. Laforet, V. (2005). *New Orleans and the damaged Superdome.* Retrieved 12 March 2019, from 4christe.tripod.com/Damage3

Fig. 1.1. Capra, F. (1958). *Climate Change 1958: The Bell Telephone Science Hour.* Retrieved 13 March 2019, from www.youtube.com/watch?v=m-AXBbuDxRY

Fig. 1.2. Own work.

Fig. 1.3. Own work.

Fig. 1.4. Bendiksen, J. (2011). *Home for the moment.* Retrieved 3 May 2019, from www.nationalgeographic.com/magazine/2011/05/bangladesh/#/11-displaced-family-meal.jpg

Fig. 1.5. Comite Regional de Tourisme de Normandie. (2018). *Mont-Saint-Michel.* Retrieved 13 March 2019, from www.normandie-tourisme.fr/decouvrir/les-incontournables/les-grands-incontournables/mont-saint-michel-106-1.html

Fig. 1.6. HafenCity Hamburg GmbH. (2016). *Aerial view on HafenCity Hamburg.* Retrieved 13 March 2019, from www.hafencity.com

Fig. 2.1. Beeldarchief Rijkswaterstaat. (1953). *A dike breaks in Den Bommel, South-Holland as a consequence of the storm.* Retrieved 12 March 2019, from beeldbank.rws.nl

Fig. 2.2. Vlaams-Nederlandse Scheldecommissie. (1976). *Ruisbroek.* Retrieved 12 March 2019, from www.vnsc.eu

Fig. 2.3. Panorama. (2013). *A complete neighbourhood in Overboelaere, Geraardsbergen is flooded.* Retrieved 16 March 2019, from www.youtube.com/watch?v=ppT5R46ytrY

Fig. 2.4. De Scheirder, K. (2013). *The Scheldt Quays in Antwerp flood while the defense wall behind protects the inner city.* Retrieved 16 March 2019, from www.hln.be/in-de-buurt/antwerpen/-t-stad-zet-zich-schrap-voor-stormtij~a699c41d

Fig. 2.5. Sigmaplan. (2018). *The Kruibeke polders, Flanders' the largest controlled flooding area.* Retrieved 16 March 2019, from sigmaplan.be/nl/projecten/polders-van-kruibeke

Fig. 2.6. Poelmans, L. (2010). *Modelling urban expansion and its hydrological impacts* (Doctoral dissertation). Retrieved from Lirias. (Source ID LIRIAS1738410)

Fig. 2.7. Sigma Plan. (2019). *Overview of the Sigma plan projects.* Retrieved 16 March 2019, from sigmaplan.be/en/projects/

Fig. 3.1. Flanders Environment Agency. (2019). *Climate change and flooding.* Retrieved 20 March 2019, from klimaat.vmm.be/nl/web/guest/klimaatverandering-in-detail

Fig. 3.2. Own work. Map information retrieved 20 March 2019, from publicwiki.deltares.nl/display/CAW/Waar+komt+het+water+vandaan

Fig. 3.3. Climate Central. (2019). *Surging seas. Seeing choices.* Retrieved 21 February 2019, from seeing.climatecentral.org

Fig. 3.4. Own work. Map information retrieved 16 March 2019, from klimaat.vmm.be/nl/web/guest/klimaatverandering-in-detail

Fig. 3.5. Own work. CAD base layer retrieved 20 March 2019, from www.geopunt.be

Fig. 3.6. Own work. CAD base layer retrieved 20 March 2019, from www.geopunt.be

Fig. 3.7. Own work. Map information retrieved from Secchi, Bernardo, & Vigano, Paola. (2009). *Antwerp, territory of a new modernity (Explorations in/of Urbanism 2).* Amsterdam: SUN.

Fig. 3.8. Own work.

Fig. 3.9. Own work.

Fig. 3.10. Own work. Map information retrieved 20 March 2019, from klimaat.vmm.be/nl/web/guest/klimaatverandering-in-detail

Fig. 3.11. Own work.

Fig. 3.12. Own work.

Fig. 3.13. Google Earth. Screenshot retrieved 26 May 2019, from Google Earth.

Fig. 3.14. Own work.

All images / drawings after Figure 3.14. are own work.

Back cover figure. Constantini, L. (2012). *A man and woman swim in flooded Piazza San Marco in Venice, Italy, on November 11, 2012.* Retrieved 2nd June 2019, from www.theatlantic.com/photo/2012/11/venice-under-water/100403.

Inspiration and background information

Aerts, J. (2012). *Climate adaptation and flood risk in coastal cities (Earthscan climate).* London: Earthscan.

Aerts, J. C. J. H., Major, D. C., Bowman, M. J., Dircke, P., Marfai, M. A., Abidin, H. Z., ... Reeder, T. (2009). *Connecting Delta Cities. Coastal Adaptation, Flood Risk Management and Adaptation to Climate Change.* Amsterdam: VU University Press.

Jha, Abhas K., Bloch, R., & Lamond, J. (2012). *Cities and flooding. A guide to integrated urban flood risk management for the 21st century.* Portland: The World Bank.

Boer, F., Jorritsma, J., & Van Peijpe, D. (2010). *De urbanisten en het wondere waterplein.* Rotterdam: 010.

Centre Pompidou Malaga. (2017 December 15-today). *Modern Utopias. A journey through the art of the 20th and 21st centuries.* Malaga.

Centre Pompidou Malaga. (2018 November 8-2019 February 10). *Building air. Inflatable architecture and design, 1960-1975.* Malaga.

D'Auria, V., De Meulder, B., Gosseye, J., & Shannon, K. (2008). *Water urbanisms* (UFO (Urbanism Fascicles OSA) : explorations of urbanism 1). Amsterdam: SUN.

De Meulder, B., & Shannon, K. (2013). *Water urbanisms East* (UFO : explorations of urbanism 3). Zurich: Park books.

De Morgen. (2016). *Frank Deboosere: "Een superstorm in ons land? Dat is een kwestie van tijd".* Retrieved 12 February 2019, from https://beta.demorgen.be/tech-wetenschap/frank-deboosere-een-superstorm-in-ons-land-dat-is-een-kwestie-van-tijd~bb9541a8/

Dreiseitl, H., & Grau, D. (2014). *Waterscapes innovation: Planning, building and designing with water.* Hong Kong: Design Media Publishing.

Hendricks, R. (2014). *Rebel Architects: Nigeria Working on Water.* Qatar: Al Jazeera.

Meyer, H., & Nijhuis, S. (2013). *Delta urbanism: Planning and design in urbanized deltas – comparing the Dutch delta with the Mississippi River delta.* Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 6(2), 160-191.

Moimas, V. (2018). *Building air. Inflatable architecture and design, 1960 – 1975.* Edition with exh. Malaga (Centre Pompidou) 2019.

Nillesen, Anne Loes, & Singelenberg, Jeroen. (2011). *Waterwonen in Nederland: Architectuur en stedenbouw op het water.* Rotterdam: NAi uitgevers.

Vigano, P., Fabian, L., & Secchi, B. (2016). *Water and asphalt: The project of isotropy* (UFO, Explorations of Urbanism; 5). Zurich: Park Books.

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