RELOCATING ROTTERDAM

//The task of spatial planning and urban design throughout scales in the context of extreme flood risk scenarios in the Netherlands//

Jet ten Voorde

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Final Report January 2018

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Cover image design: The island of Rotterdam (image by author)

“You never change anything by fighting the existing reality.

To change something build a new model, that makes the existing model obsolete.”

- Buckminster Fuller

Acknowledgements

You are currently reading my master thesis, the final product of my graduation year! Today I write this note of thanks as the final step of my thesis. This turbulent year has learned me a lot. Not only about the topic of this thesis, but also about myself, people I value and about placing things in perspective.

This year has taught me- more than previous years- how important it is to reflect on your work and how valuable it is to be able to discuss and get input from others. Therefore I would like to thank the people that have supported me and helped me throughout it.

Foremost I would like to thank my mentors Birgit Hausleitner and Taneha Bacchin, being my dream-team. Their limitless advice and links to references have helped me to make the vague idea into a tangible design proposal. The constructive meetings we have had and the questions they posed, got me back on track again. Moreover their enthusiasm, involvement and patience have brought me to finishing this thesis. I loved it how we could dream together about the maybe … 's of the future. I can truly say I could not have hoped for a better mentor team.

I thank my friends for their support in many different ways; inspiring talks over numerous (free) coffees, lasagnas, walks, support-selfies, complaining or brainstorm sessions, and most of all the fun we have had during the past year and before. Esther, Marit, Piet, Layla, Vincent, Twan, Johannes, Sumanth, Robin, Astrid and roomies, thanks for being in my life.

Special thanks to my family; my father Paul and mother Bernadette and my sisters Pien and Loes, for their limitless support and advice. Thanks so much for helping me and for being an inspiration, not only now but for already 25 years.

And of course thank you Nico, I am so glad we were in this together. Thank you for being you and thank you for believing in me.

Lastly, reader, I would like to thank you for taking a look in this report.

“Amsterdam, die groote stad,
Is gebouwd op palen.
Als ze nu eens ommevalt,
Wie zal dat betalen?

Amsterdam, die groote stad,
Is gebouwd op palen.
Als men de stad ommekeert,
Dan kan men erin verdwalen”

“Amsterdam, that big city
has been built on wooden posts
If she would collapse,
who would pay the costs?
Amsterdam, that big city
has been built on posts,
if we turn her upside down,
people can get lost”

A children’s song about our capital being build on pillars.

Summary

The Dutch approach of draining, dredging and reclaiming of land has shaped the Netherlands throughout history. The location of the Netherlands near the sea and in the delta of several big rivers has brought the Dutch on the one hand trade and food, knowledge and progress of economy and technology. Even today water, water management , could be seen as a national pride and something that shapes the mindset of the Dutch. On the other hand the delta position of the country has brought a long history of floods. The position towards water has changed over time from accepting the water, to fighting it. Human interventions led to a cycle of heightening dikes and pumping out the water or forcing the water into structured narrow pattern with dikes and breakwaters. It brought the country to the situation we are in today: its national center is located in an area that is highly exposed to flood risk, being located in areas that are below sea level.

As the current notion of risk used in the Netherlands has a strong focus on reducing the probability that flooding occurs, it leaves little attention for reducing exposure and vulnerability, as the other components when defining risk. Socio-economic trends show that the areas below sea level will be only more densely inhabited with people and will experience only more economic growth. **This along the predicted sea level rise and greater fluctuations in river discharge compel research on spatial planning and urban design to look far into the future, to widen their scope and to anticipate developments further ahead.**

This project aims at transition of the current way the Netherlands deal with the increasing treat of water zooming in on the situation of the city of Rotterdam and proposing to create more adaptive capacity of the spatial structure in order to deal with future uncertainties in the context of extreme climate change scenarios.
The scenario the project is dealing with, shows that 3 meter of sea level rise before the year 2100 and drastic precipitation changes could become reality. T**his thesis focuses on the possibilities of restructuring the Randstad region throughout the scales (in space and in time), including Rotterdam, assigning densification zones and areas of relocation towards reduction of flood risk exposure of the extreme flood scenario.** The project explores what it would mean for the city and the citizens of Rotterdam if all the areas below sea level get relocated to higher grounds. The transformation of infrastructures and networks is described on a spatial level at the city, neighborhood and at street- scale. Design interventions show what Rotterdam could look like in 2060 and what spatial qualities it could bring if we already start now to prepare the city for the future. This contribution of spatial planning and urban design can help filling the gap of knowledge about the spatial uncertainty climate change brings. It can also help in finding new ways of dealing with water that can prolongate the line of water expertise of the Dutch. Truly new visions on this subject can only emerge by leaving the beaten track.

Keywords: **Adaptive capacity, extreme scenario thinking, climate change, spatial transformation, densification, GeoDesign, multi-scalar approach, Rotterdam.**

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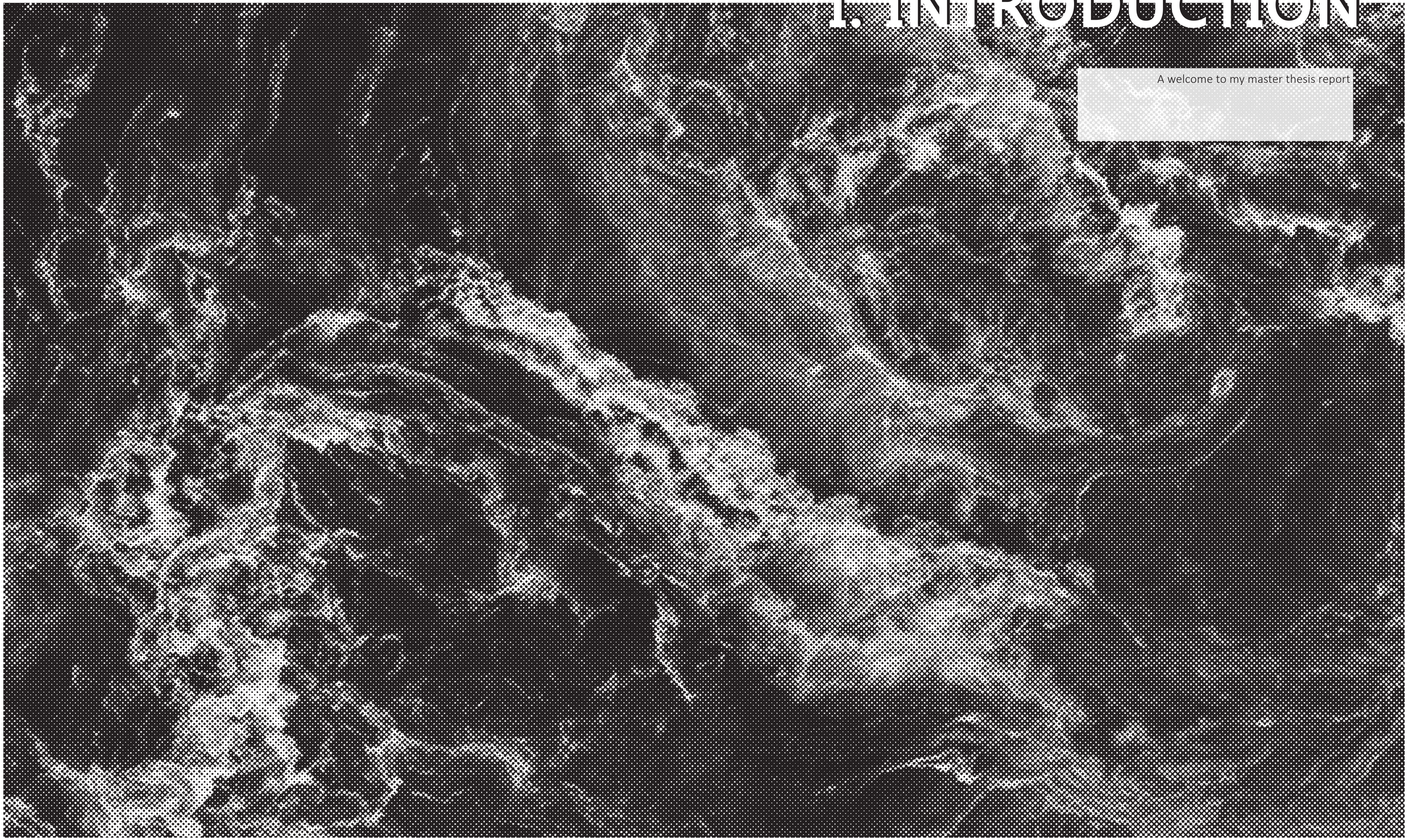
A welcome to my master thesis report



I want to start this report with a little rap,

About Rotterdam and the next step

Building with dykes will be so passe

So lets find an alternative for the Dutch dyke trace

The first step is to look for higher grounds

Plateaus, islands or just little mounds

Then make sure you are in the evacuation zone

So when a on-to-10 000 strucks, you wont be alone

The new Rotterdam may be a bit more dense

But in return great new nature in my defense

The goal is to lift up the city as a whole

So interaction and cohesion between the people

So move to the island oft Rotterdam

And be prepared for whats to come

Why did I choose this topic?

This is the final report of my master thesis. It aims to represent the findings of the past year. The project is explores ways to adapt and transform the current structure of the Randstad and questioning the current location of the center of the Netherlands.

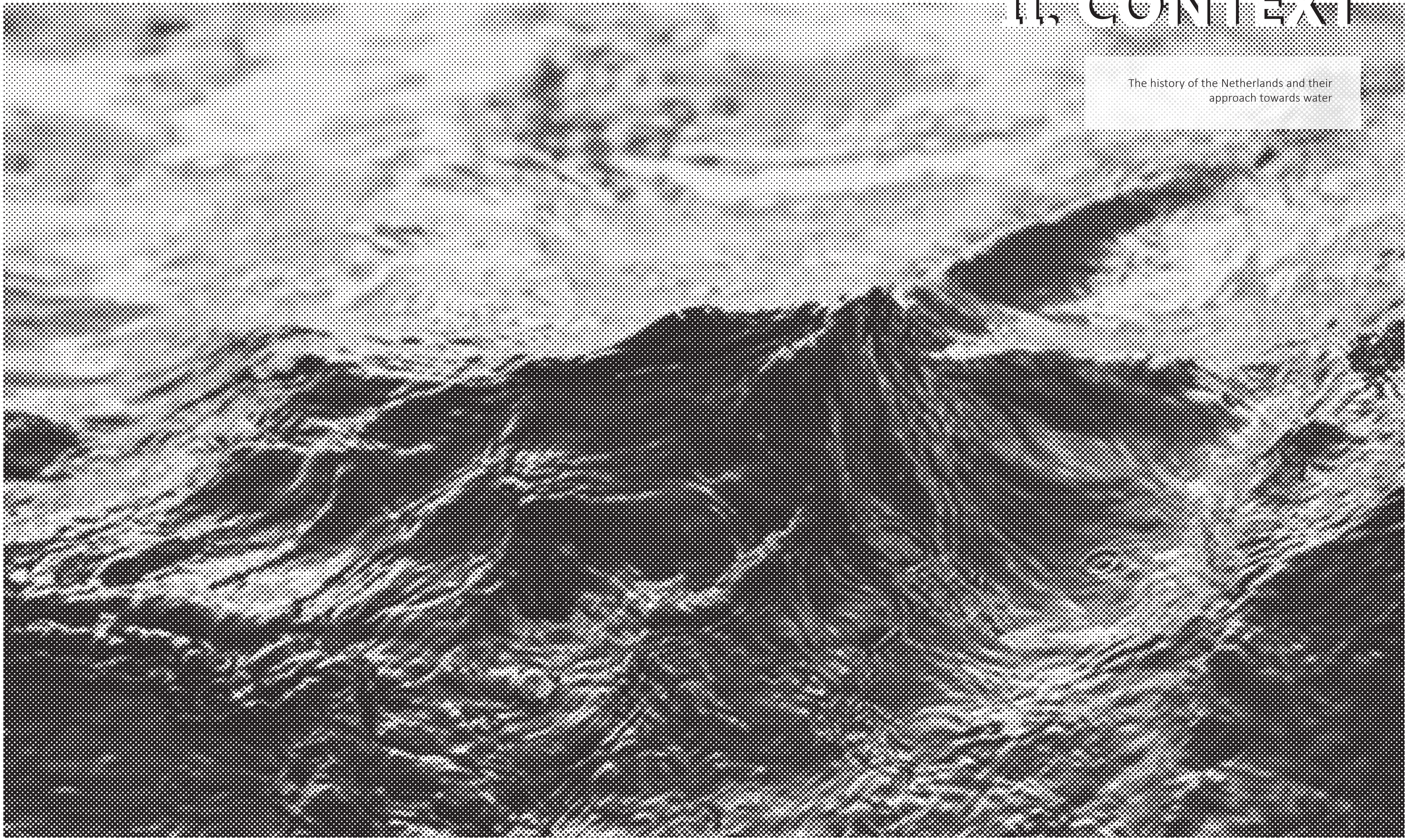
The topic of this project has been triggered since the start of my master program at the TU Delft. Learning more about the water systems that we use in order to make our country inhabitable, I also got to know some inside of how vulnerable we are; a highly-urbanized region located in a Delta. International students mentioned the awareness and fear they have living under the main sea level. Never before have I been so aware of the fact that I am living below sea level, and with me 3,9 million more people. The Dutch, as the leading country of the world in the context of water management, need to keep innovating the systems not at last to safeguard their own country from flooding.

One aspect that makes the Randstad so vulnerable being under main sea level, is the high density aspect of the area. The water issue is often approached from a full engineering perspective, where the more spatial and social factors are being underexposed. This is therefore the field from where I would like to contribute. Therefore the choice of the Urban fabric research group is logical, approaching the water problem from a different angle and look for example for adaptive capacities within the fabric of the city and system. The Delta Intervention research group as a second group helps to bridge between this urban context connection to the threat of water in the Delta zone.

Figure 1 | A view on the River IJssel close to Deventer, my hometown. The river runs along the house of my parents and gives unique and spectacular views every day. Living next to river shows the power and fluctuations the water can have. (Photo by author, made sept 2017)

II. CONTEXT

The history of the Netherlands and their approach towards water



//The relation towards water

The Randstad with its seven million inhabitants, functions as the economic and social center of the Netherlands. This western region or metropole area owes its thriving economy for the most part to the favorable location where it is positioned; in the delta of the big rivers Maas, Rijn and Schelde. However, the location in this delta is not the only determining factor in the development of the Randstad area, and the Netherlands in general. There was a lot more to it to make the low-lands inhabitable and as thriving as they are nowadays. Already in the 9th century the Dutch started to drain water of swampy areas to nearby rivers, using the tidal flow. By doing so farmers that were part of the feudal system could get a parcel of land under the condition that they were responsible for this piece of land (see Figure 2). This made the lower areas suitable for agriculture or livestock.

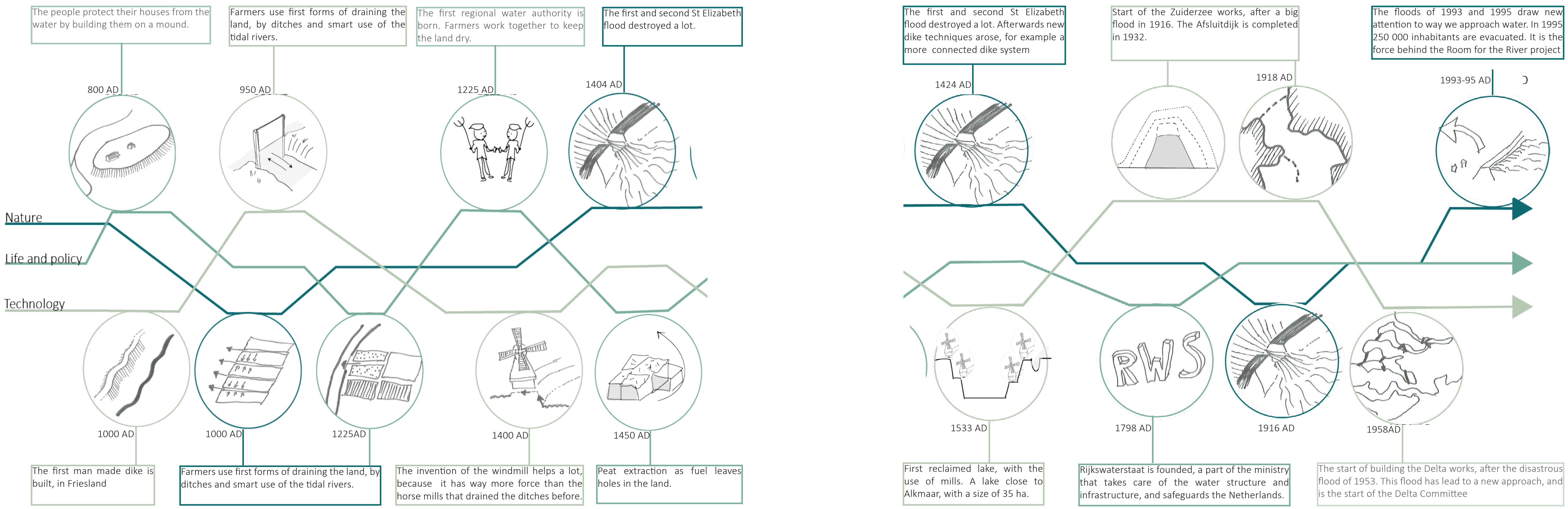
In general organization of draining and reclaiming land goes parallel with political and technical changes, as shown in the timeline below. After reorganizing to a more regional approach of draining the land in the 13th century the swampy delta region of the river Rijn and Maas became one of the first forms of civil society. The farmers started to work together, making sure their piece of land would stay dry, and the first Water boards were born.

The regional approach in land reclamation led to a shift in the direction and methods the water was drained due to trade-offs between the landlord of Holland and the landlord of Utrecht. Where in the former situation the water was drained to the more inland positioned Oude Rijn the new situation discharges the water to the water body IJ on the North side of Holland and the Nieuwe Maas on the south side of Holland. This directly resulted in a weaker position of trade for the city of Leiden, as there were now new places in the North and South more suitable for harbor function.
The new river mouths as result of the change were strategically interesting places for trade and therefore extremely suitable for new urban settlements. Especially when the peat areas of Holland were better protected by dikes at the North and the South, the dams located on this dikes were ideal spots for economic growth(Meyer, Bobbink, & Nijhuis, 2010; Meyer & Bouma, 2016). From that moment on the economical investments and the number of inhabitants have only increased. The cities grew up to the key players that they are today. This has led to the fact that the Randstad, the most urbanized area of the country, where up to 70 percent of the gross national product is produced, lies almost completely below sea level(Doorn-Hoekveld, 2014).

Managing to keep the water within the river basins and protecting the hinterland by dikes to protect the life in the settlements has not always been on the high level that is reached nowadays. Inventions and intervention related to reducing the risk of flooding are strongly related to the events of flooding, for instance the 1953 flood that served as an event to focus on the protection of the Zeeland area and resulted in the Delta works. Another example is the decision to build the 'Afsluitdijk' after the 1916 flood (Olsthoorn, van der Werff, Bouwer, & Huitema, 2008).

The timeline below shows that new technological intervention are often initiated after a disastrous event or threat (see figure 2). It can even lead to new flood management strategies. After the flood in 1953 the first Delta commission of the Netherlands set norms per dike that state to what event the dike should be able to protect the hinterland. The norm is based on the impact and consequences that a flood would have. These consequences are as well based on the number of lives as on the economic value that would be lost. The focus therefore shifts to a reduced risk approach. The current levels of protection are set that the diked areas of the Netherlands have a chance of flooding less than 1/250 per year(Pieterse et al., 2009).

Figure 2| This timeline shows technical innovations and historic events and how they influence each other. (Image by author)



Throughout time the attitude the Dutch have towards water is changed from accepting the water in the beginning (building on mounds) to defending (building dykes) and later controlling (polders) and in the final stage manipulating (making a lake from a sea) (Hooimeijer, Meyer and Nienhuis, 2005)(Figure 3). The phases are related to water changes of all water bodies (sea and river). The rise of sea level relates directly to the possibility of discharge of water from the rivers to the sea. If there is a storm surge, the threat of floods comes as well from the sea as from inlands, since the rivers cannot discharge their water to the sea.

After the (almost) floods in 1993 and 1995 and with the start of the project "Room for the river", the approach has changed to accepting the water a bit more: it needs space. The goals of the project "Room for the River" are clearly stated and are related to the amount of water the rivers need to be able to cope with and at the same time improving the spatial quality of the area (Figure 3) . The amount of water the rivers should be able to deal with in 2015 are 16 000 m^3/s for the Rijn at Lobith and 3 800 m^3/s for the Maas at Borgharen. On the longer term respectively 18 000 m^3/s and 4 600 m^3/s for the Rhine and Maas should be aimed at(Ministerie van Verkeer en Waterstaat, 2004). The flood protection and precautions that are planned need to deal with these high peaks, even though the average runoff is (only) 2 200 m^3/s in the river Rijn and 200 m^3/s in the river Maas. Due to the changing weather conditions and due to increasing speed of inland water discharge this water all comes together in the Delta and can result in high peaks. Note that already with a flow rate of 7 000 m^3/s the floodplains (uiterwaarden) are flooded (Figure 4). Interventions that have been used to do so focus mostly on temporarily water storage or taking obstacles away from the floodplain (Rijkswaterstaat, n.d.). However, besides creating room for the water, it is still being manipulated and controlled. Is this approach of dealing with the water sufficient for the future? Can the Dutch system of water management thrive even in the light of the changing context of for example climate change?

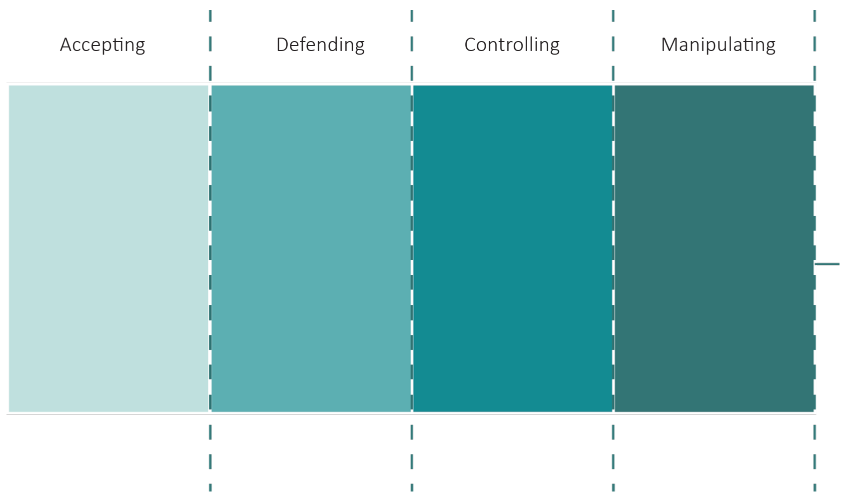


Figure 3 | The perspective the Dutch have had towards water throughout time. Currently the Netherlands are in the manipulating phase, but slowly allowing more space for the water. (Image by author)

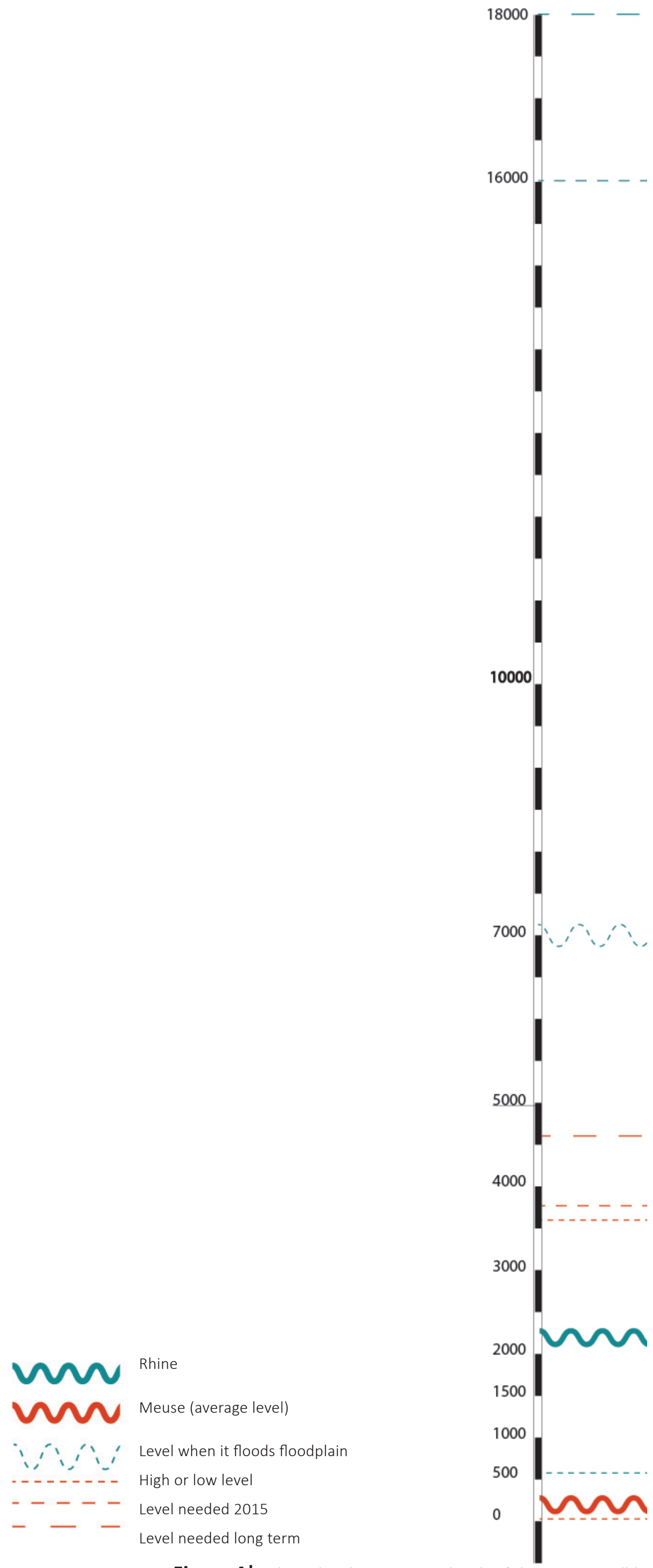
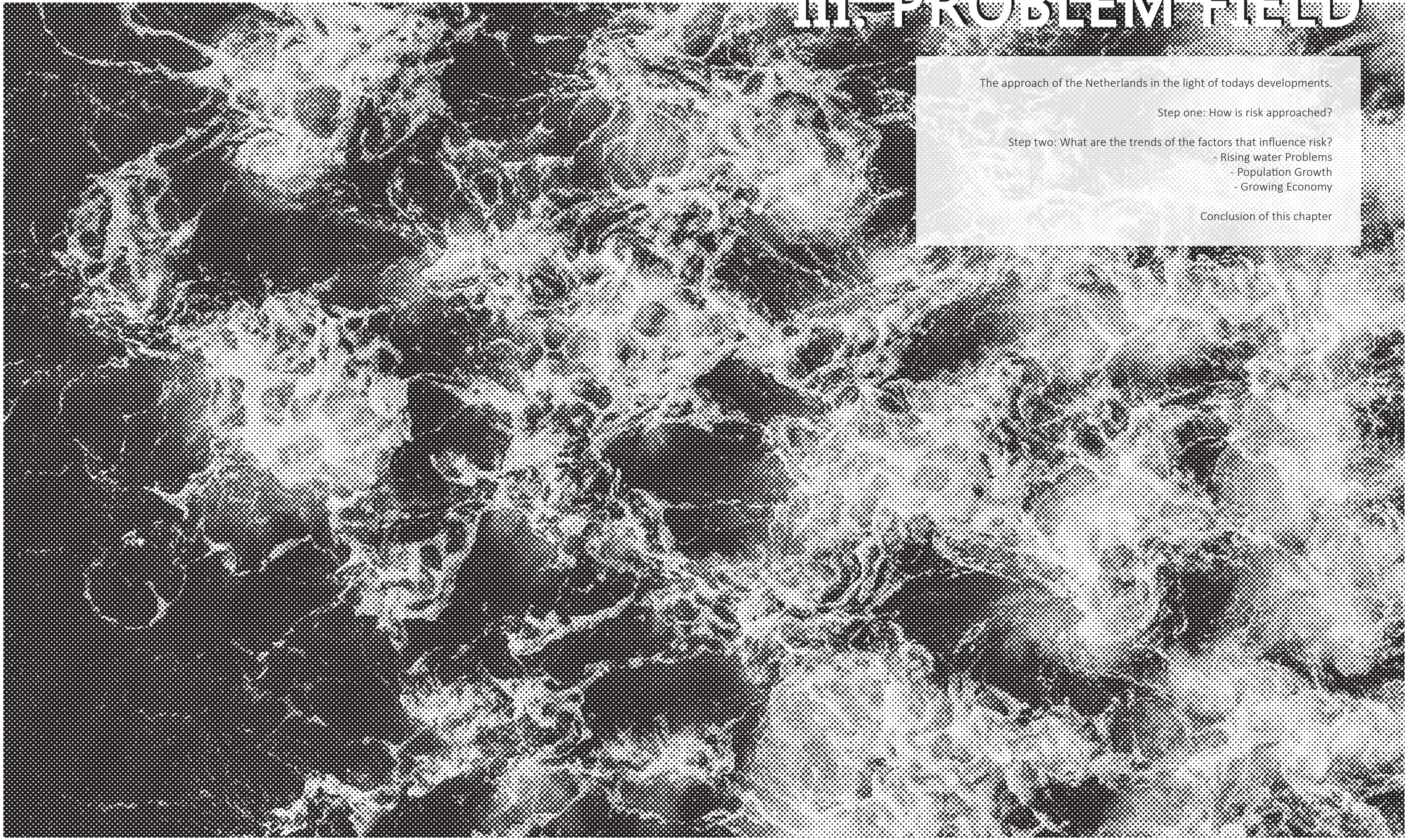


Figure 4 | This ruler shows various levels of the rivers Rijn (blue) and Maas (red). The average, peak and goal discharge in cubic meter per second is showed. For reference: an Olympic pool contains around 3750 cubic meters of water. (Image by author)

III. PROBLEM FIELD



The approach of the Netherlands in the light of todays developments.

Step one: How is risk approached?

Step two: What are the trends of the factors that influence risk?
- Rising water Problems
- Population Growth
- Growing Economy

Conclusion of this chapter

// The notion of risk

In this chapter the notion of risk and the trends describe the problem fields that will lead to the problem statement. After the disastrous flood in 1953 that took the lives of more than 1800 people and destroyed an enormous area in the south of the Netherlands, a new flood management approach started: The first Delta commission was born. In their report the Delta commission introduced the concept of flood risk management, where the optimum of safety of an area is based on the probability and the consequences of a disaster(Deltacommissie, 2008). Floodsite (2009) stated that flood risk management "pertains to dealing with flood risks based on the notion that these risks cannot be reduced to zero other than at the expense of other societal goals"(FLOODsite, 2009). The overall objective of flood risk management could therefore be "reducing flood risks to a societally acceptable level, against societally acceptable costs", as Asselman et al state in their report(Asselman et al., 2012).

The notion of risk is generally explained in one of the following ways(Figure 5):
1. A multiplication of the probability and the consequences of a certain flood.
2. A geographical overlay of hazard and vulnerability

Depending on the field in which the risk factor needs to be defined, the calculation of probability and consequences is based on different aspects. In case of a flood disaster in the Netherlands the emphasis is put mostly on loss of life and economic losses. However, Asselman et al describe that psychological impact or damage of cultural heritage could also be added to risk consequences, as well as the more intangibles aspects of social equity and ecological integrity.

After 1953 the safety norms are determined based upon the formula of probability times consequences. These safety norms prescribe per flood defense system up to what extent it should be persistent. As an example, a dike that has a 1 to 2000-year norm has to be persistent to resist the highest combination of water levels and wave height that have a chance of existence every once in 2000 years(Most, Slootjes, Schafoort, & (STOWA), 2014). This level of protection is ensured per dike section, and per aspect of a complete section. **However, in an audit that was carried out in 2006, to check upon the current norms set per dike and achieved per dike, there is a big discrepancy, as the Delta committee mentions in their report of 2008** (Figure 6) .

> "The latest audit (1 January 2006), however, revealed that 24% of our flood defenses did not meet these current (outdated) standards, while nothing could be said about a further 32% (see Figure 8). This report also revealed that 22% of the civil engineering works did not meet these standards whereas 49% of these works could not be assessed. Moreover, one should realize that for the present and the future, large investments in housing, industrial estates, and infrastructure are planned in the low-lying areas of the country. In the short term we thus face many challenges to exploit the opportunities." (Deltacommissie, 2008, p.23)

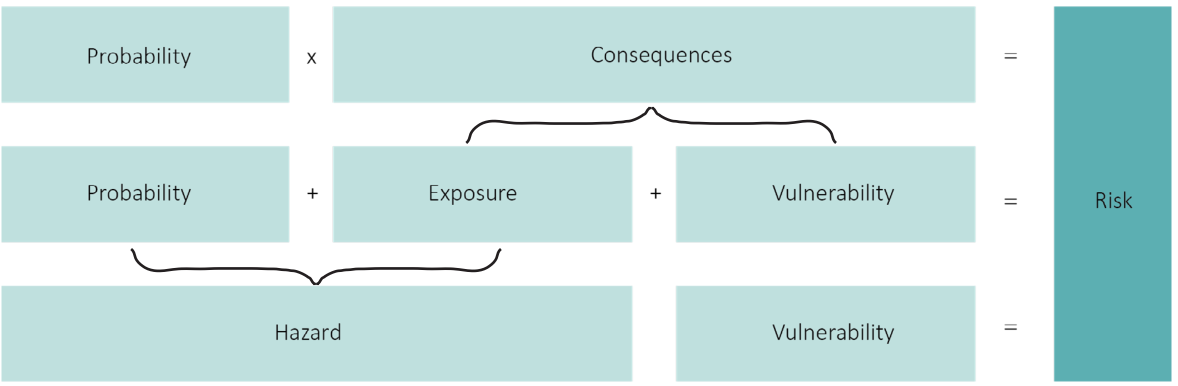


Figure 5| The three ways to conceptualize flood risk: (1) probability times consequences and (2) geographical overlap of hazard and vulnerability. In the middle the three components that define these (3). (image by author after Van der Pas et al., 2012, cited in Asselman et al., 2012)

Results second safety assessment
Primary flood defenses, 1 January 2006

Figure 6| The current situation of the dikes, and whether they meet the norms or not. A rather large number is not meeting the criteria. (Source: Rijkswaterstaat: department of hydrology)

Therefore the way that these norms work slightly has changed in the past decade. Instead of the probability of exceeding the norm, where the flood defense is not adequate to a specific event, the focus shifts towards the probability of flooding, being the chance that the pressure on the flood defense is higher than the strength of the flood defense. In contrast to the first approach the section of a flood defense system is approached as a whole. This means that the chance of flooding is an overall number set for the complete section(Min. Van Infrastructuur en Milieu, 2014; Most et al., 2014).

Defining a norm based on risks consequences leads to a problem in the way that the water is managed. First the flood defense gets improved to protect the value that is posed at risk within this certain area. Then with increasing the safety of this zone, developers will be stimulated to establish more value in this area. If the risk formula is applied again on the same area, the socio-economic consequences have grown what results that the norm has to be adjusted(Pieterse et al., 2009). This shows the unilateral approach that the risk management in the Netherlands currently has. It currently focuses mostly on decreasing the probability of flooding and almost ignores the other key aspect of reducing risk: reducing the consequences of flooding. (Figure 5)

The way the Netherlands approaches risk differs from the approach in other countries. It also differs from approaches described in literature, where vulnerability is one of the key components when defining risk ((Figure 5). Besides the fact that the way the Dutch flood management system approaches risk is disputable (see paragraph adaptivity theoretical framework), the current system is subjected to a downwards spiral. This can be explained by an example: A certain dyke-ring is protected with a dyke with a norm, which meets the criteria to make an area safe. In consequence, people feel safe, move there and start investing. This increases the consequence a flood could have. So the norm is not sufficient. The dikes become higher and stronger, but this raises the risk because of the consequences (Figure 7). As explained in the above the water management in the Netherlands is not only addressing the prevention of a flood. There is a system of three layers of safety, that follows the steps prevention, spatial planning and disaster relief. The focus of the Netherlands is on the first step-the prevention (Pieterse et al., 2009).
The impact of the consequences and the probability on the complete notion of risk are changing over time and space, as a result of natural and socio-economic trends, that will be explored in the next paragraph. It is important to take notion already in an early stage of this report that the threat of flooding can be caused by other events than sea level rise. Besides the probability that a natural event results in failure of a defense system, there are other externalities that can cause a problems, such as terrorism or loss of electricity.

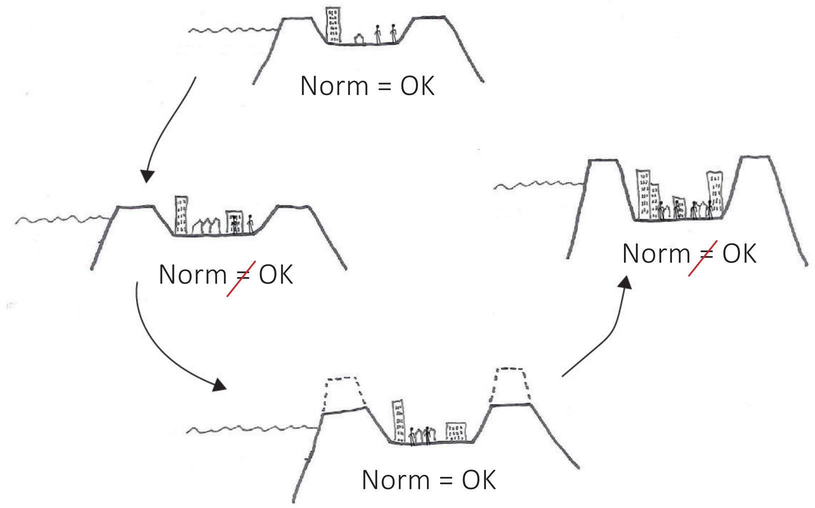


Figure 7| This shows the unilateral approach the Netherlands currently has. There is a norm, to make an area safe. Then people move there and start investing. This increases the consequence a flood could have. So the norm is not sufficient. The dikes become higher and stronger, but the risk goes up because of the increasing consequences. (Image by author)

// Trends

As the notion of risk in the Netherlands is approached as the multiplication of probability and consequences, natural and socio-economic trends have an influence on the change of these aspects over time. **Worldwide an overall trend can be seen in the natural catastrophes, as they have increased over the last decades** (Figure 8). Kates describes how figures of the Swiss Reinsurance Company show two trends that are interrelated: the number of natural catastrophes at one side and increasing population and Gross World Product at the other hand (Kates, 2012). As the Swiss Reinsurance company defines natural disasters as “either economic losses and/or casualties”, it is logical how a growth in population and Gross World Product influence the amount of disasters, since it is more likely that a hazard has disastrous effects (Visser, Bouwman, Petersen, & Ligtvoet, 2012, pp. 50–53).(Figure 8)

To be more specific about the Dutch context the following trends that influence the risk of flooding will be discussed below, explaining these trends:

- Rising water problems
- Growing economy
- Growing population

Rising water problems
The most urging problems that can result in catastrophes in the Netherlands have to do with water. Four categories will be explained to get some insight on the latest levels and predictions.

- Sea level rise
- More and more heavy precipitation
- Increasing River water discharge
- Maintaining the quality of water

Sea level rise
The most evident trend that has been a rather big contribution to the risk factor of Randstad area of the Netherlands is the sea level rise and its impact on coastal zones. As it is common knowledge climate change has speeded up the global warming and has influenced acceleration of the sea level rise in the past decades. (See Figure 9). Even though different figures on this subject are based on different scenarios, they all have in common that sea level rise is inevitable. This affects countries around the world and especially delta regions will suffer from coastal high water (Kates, 2012). This is clearly stated when the height map of the Netherlands and the sea level rise trend are looked at, as shown in Figure 12 and Figure 9.

The sea level rise is predicted as an increase from the current water level, most often as an absolute value which is comparing the current water level to the level of the future. The relative sea level rise also takes ground subsidence into account. On average of the past millennium, the surface level of the diked areas in the Netherlands has been decreasing 0-4 mm per year (Ministerie van Verkeer en Waterstaat, 2011). Currently the subsidence is going much faster subsiding with tremendous speed up to 25 mm/year (Erkens, Van Der Meulen, & Middelkoop, 2016). Deltares even prospects that the ground level in certain areas in the west of the Netherlands will decrease with the same amount as the sea level will rise as a result of ground subsidence(Deltares, 2008). **The speculations on how much the level of the sea will increase differ, latest update is a rise up to 3 meter in 2100, made by KNMI in April of 2017 (KNMI, 2017).**

Years	1970	1980	1990	2000	2010
Natural Catastrophes	100	134	359	406	521
Population	100	121	143	162	186
Gross World Product	100	155	237	339	449

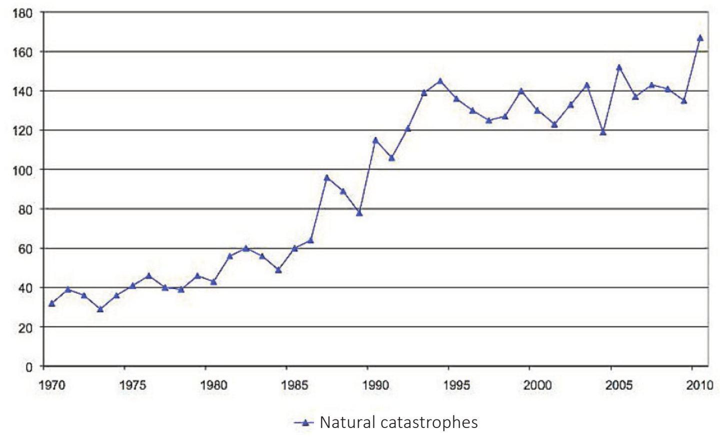


Figure 8| Natural Catastrophes, World population, Gross World Product, 1970-2010, 1970 =100. The effect of an event is higher due to increasing population and GWP. (Information Catasrophes:by Swiss Reinsurance(2011),Population and Gross World Product Del.org(1998) and update to 2010.)

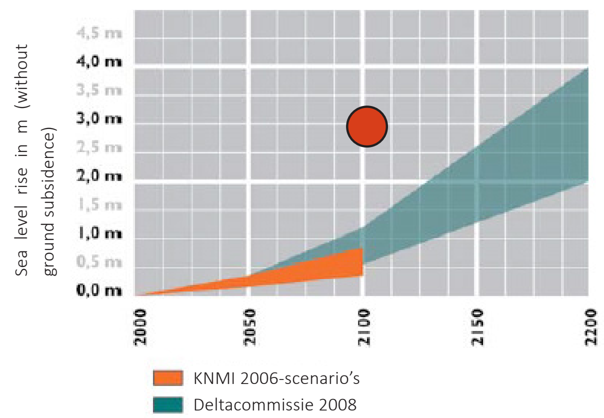


Figure 9| Sea level rise scenarios. The sea level increase off the Dutch coast expected for the future. The ground level subsidence is not taken into account. The scenarios do differ, but looking further than 2100 shows that the sea level rise is only increasing more. (Source: Deltacommissie,2008). The latest update of the KNMI in April 2017 explains an increase of the prediction to a 3-meter rise of sea level.

Precipitation
The rising temperature on earth has an impact on the weather trends as well. Deltares explains that global warming will lead to more extreme weather conditions worldwide. In the Netherlands there will be more precipitation during winter, and less during the summer and the events in summer and winter will be more intense, affecting the inland water flows (Deltares, 2008; Ministerie van Verkeer en Waterstaat, 2011).(Figure 10)

High river discharge
The effect global warming has on precipitation rates shows directly in the water discharge of the big rivers in the Netherlands and the surrounding countries: low river levels in summer and high river levels in winter, with the extra note that extreme peaks will occur more often (Deltacommissie, 2008). These extreme peaks are an accumulation of the precipitation peaks in the complete Rijn and Maas water shed. (Figure 11)

Water quality
The ground subsidence in combination with the sea level rise cause an increase of seepage. This seepage water is partly saline and needs to be flushed away with fresh water. Salination is disastrous for agriculture and horticulture and for natural ecology in general. The shortage of fresh water supply in summer contributes in a negative way to these activities too. Besides these effects, the higher temperatures put the quality of open water in danger(Deltacommissie, 2008).
Two other trends that have to do with risk: the growth of economy and population.

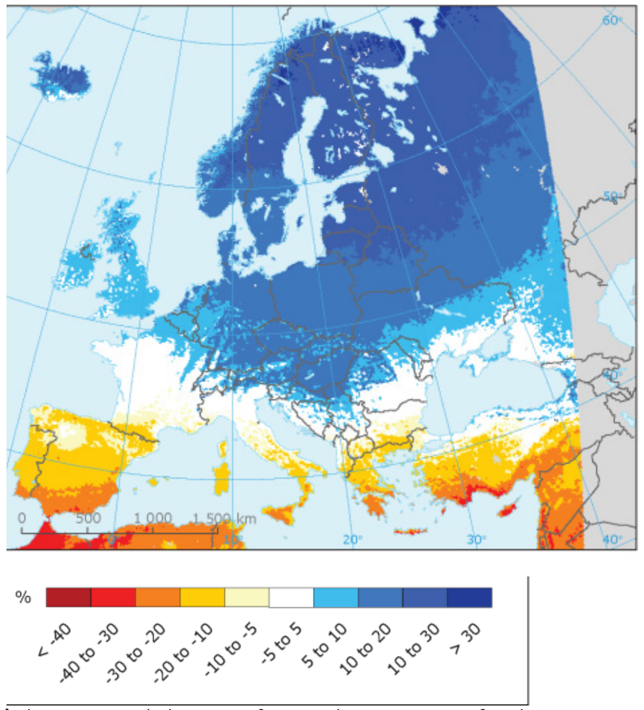


Figure 10| The projected changes of annual precipitation for the year 2100. In relation with the catchment area of the Dutch Rivers Rhine, Meuse and Scheldt be a higher discharge in the rivers. (Source: European Environment Agency)

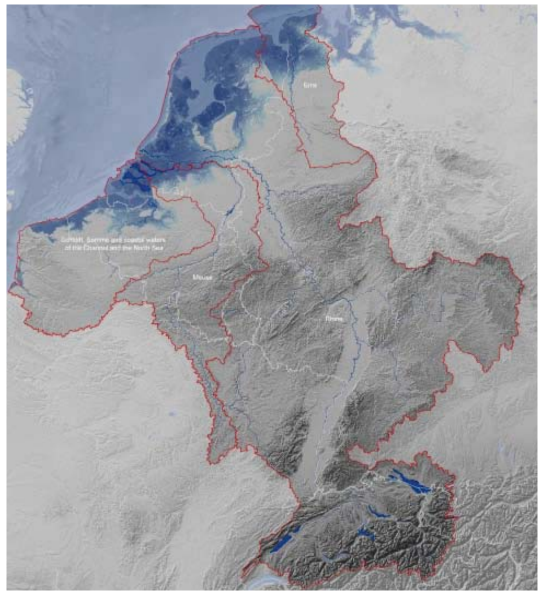


Figure 11| The catchments of the river Rijn, Maas and Schelde and in the top of the river Ems. The water discharged is collected in a large area. Map by M. T. Pouderoijen, Delft University of Technology.

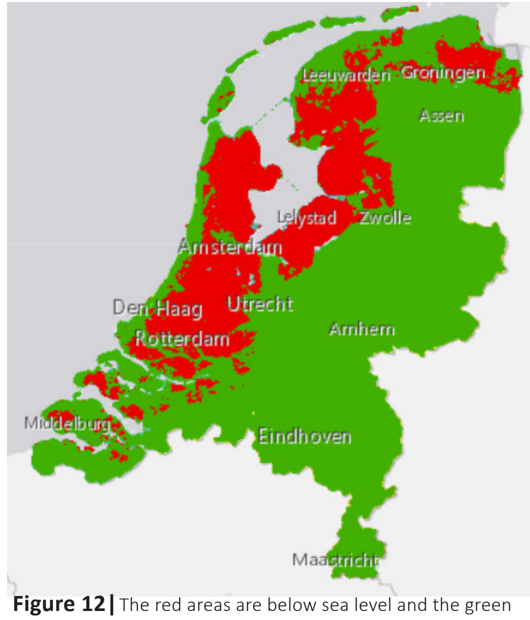


Figure 12| The red areas are below sea level and the green areas not. Due to ground subsidence and the sea level rise, the red will expand. (source: krnwtr.nl)

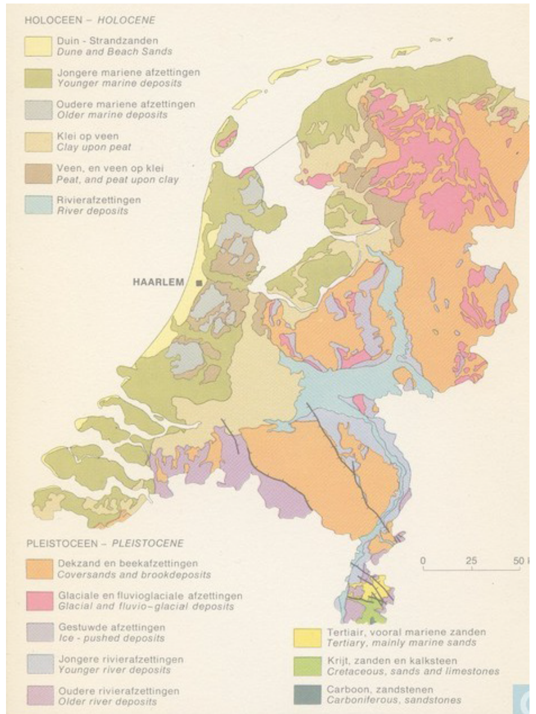


Figure 13| The geological map of the Netherlands provides information about for example the permeability of the subsoil layers. It also shows that the Randstad is for a large part built upon peat, that is known for subsiding, This can result in even lower ground levels in the future. (Source: catawiki.nl)

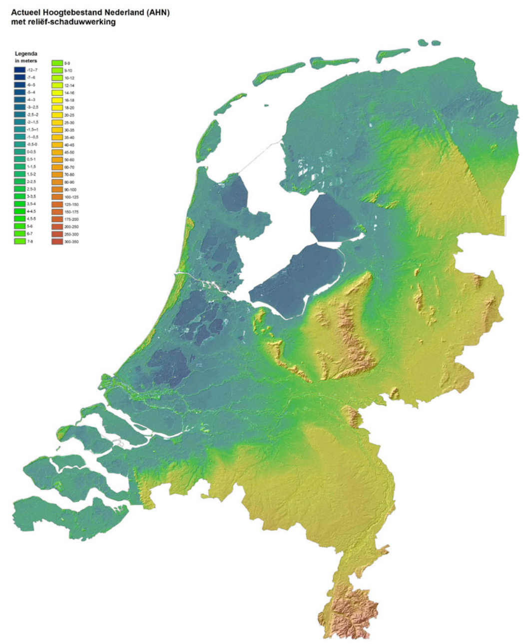


Figure 14| The height map shows the lower areas in the West part of the country. Being below sea level is not so special in the Netherlands, since 26% lies below sea level. This depth increases the risk, since the probability of flooding is higher. (Source AHN)

Growing economy trend

The urbanization of the diked areas has increased six-fold during the 20th century, which results in an exponential growth of potential flood damage. The speculations for the Randstad region are that it will absorb more than half of the economic growth of the Netherlands (Deltacommissie, 2008). De Moel et al. state that the potential economic flood damage will continue growing ten-fold this century (de Moel, Aerts, & Koomen, 2011)(see Figure 17 and Figure 20). This is clearly visible in the norms that the dykes need to meet, which are the highest in the Randstad dyke ring 14 (Figure 15).

Population growth

The population growth effects the risk of flooding as well, as there are more lives put in danger. Figures of the Central bureau of statistics show that at least up till 2025 the population of the Netherlands will increase (Figure 16 and Figure 18). Especially the municipalities in the west, the ones that are situated below sea level, show growth in population. For the period 2010-2025 an increase of around 700 thousand inhabitants is expected in the Randstad area, and around 400 thousand household, mostly by birth and immigration (CBS, 2017). The economic strength of the Randstad area attracts inhabitants of the east, north and south to the more vulnerable west (van Eijsbergen, Poot and van de Geer, 2007). The growth of population does not necessarily result in more deaths or injuries when a flood occurs, as evacuation strategies can mitigate the effect. However, an event would affect more people and their lives.
In the next page different maps show information about the Netherlands, concerning the trend that have been discussed.

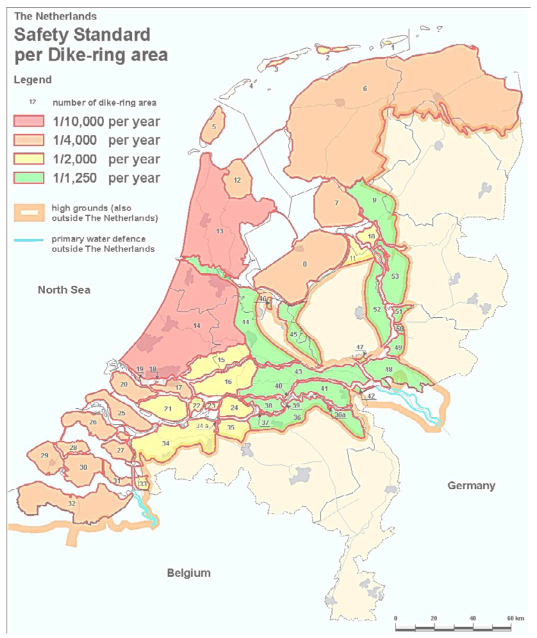


Figure 15| This map shows the dyke ring system in the Netherlands. Per dyke ring the value of the economy and the amount of people is determined, based on this the level of protection is set. The Randstad is mainly covered by Dyke ring 14, that has a protection level that needs to be able to resist a combination of the highest water level and wave height that can appear in 10 000 year. However, the probability can never be brought back to zero. (Source: hydraring.files.wordpress.com)

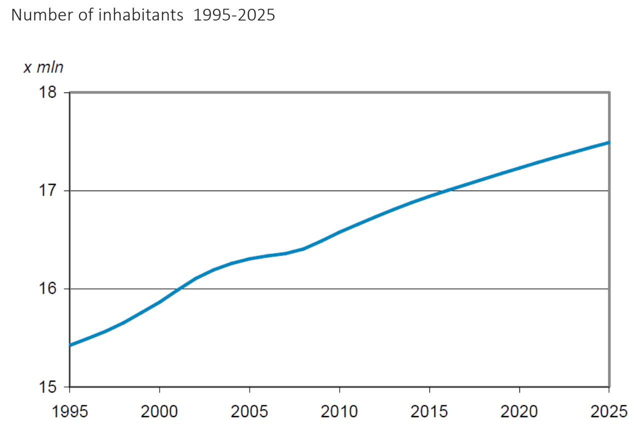


Figure 16| The trend of population growth. Predictions till 2025. The Randstad area becomes even more vulnerable because there is a lot of resettlement from people that move from the east and south Netherlands towards the Randstad. (Source: CBS, bevolkingsprognose 2010-2060)

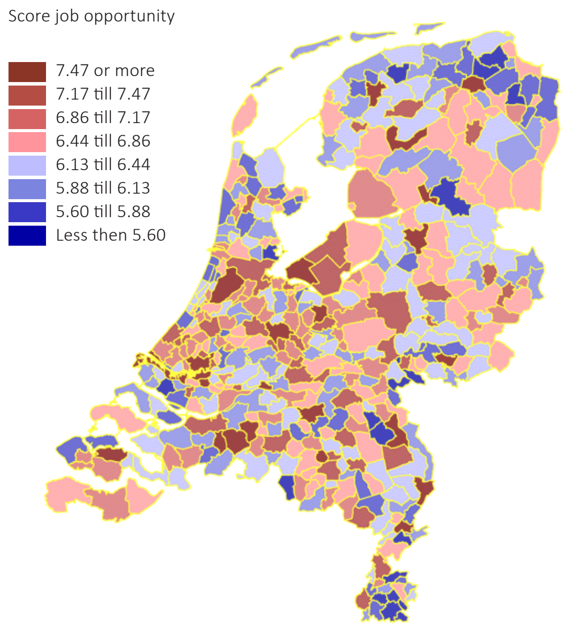


Figure 17| This map shows the economic value in job opportunity. The Randstad has high marks and therefore hosts a lot of jobs, leading to economic importance. The mark of the region is based on job availability, the amount of starters and the completion of new office space. A remark has to be made that this is the situation before the economic crisis. (source: Elsevier 2004)

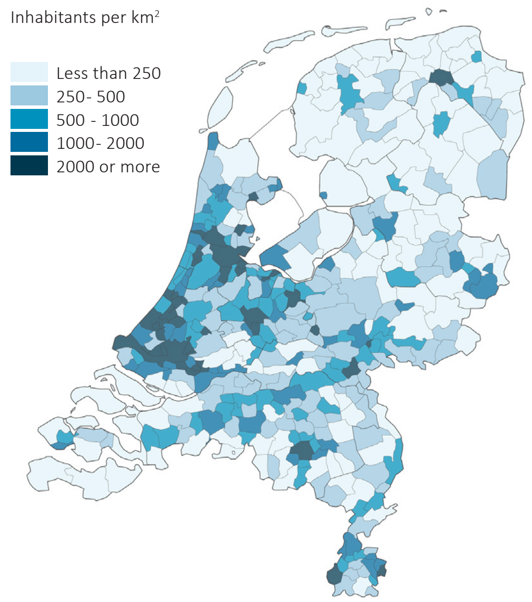


Figure 18| The density is a good estimate of the consequences of a disaster. How many people are put at risk? The Randstad area is highly populated, so it has a higher risk level.(Source CBS) At this moment almost 4 million people live below sea level. If the level rises with 1 meter, this increases to almost 7 million people. (Source http://www.citg.tudelft.nl)

Figure 19| A photo of one of the breaches of the flood in 1953 in Zeeland. You can see the speed that the water has when flowing to the hinterland, leaving a path of destruction. (Source: Rijkswaterstaat)

What do these trends mean for the future?

The climate change, economic growth and the population growth compel the government to look critically at the flood risk management approach the Netherlands currently has (van Eijsbergen et al., 2007). The past decades there has been a shift in the water management approach; moving from fighting against water to working with nature to give space to the water. However there have not been elaborated strategies about adjusting the way risk is approached. The current spatial planning and water management strategies are being measured by the engineered approach of flood risk with two defining factors, probability and consequences. Vulnerability and adaptive capacity are left out as components of the risk equation. Time is a very important factor in this problem, as the system needs to be able to adapt to changes that happen over time.

The advanced technology that is used in the defense system of the Netherlands does not leave much room to focus on other aspects that could reduce the risk. Moreover these technologies do not urge the urban development to look for suitable land but made it possible to urbanize areas that are geographically not the most suitable for this land-use. In other words, the geographical layer is less influential than the topographical layer in determining where to develop urban areas.

Besides this, the current approach of flood management has a relatively short-term planning. The scenarios within this short-term planning result in a lack of attention for the long-term visions. The government is more likely to invest in less abstract ideas, resulting in a 20 years perspective, than in a long-term vision.

IV. PROBLEM STATEMENT

This chapter links the trends of water problems, population growth and economic growth to the current approach the Dutch have towards the water.

The aim of thesis focuses on the possibilities of restructuring the Randstad region throughout the scales (in space and time), assigning densification zones and areas of relocation towards reduction of flood risk exposure under climate extremes.

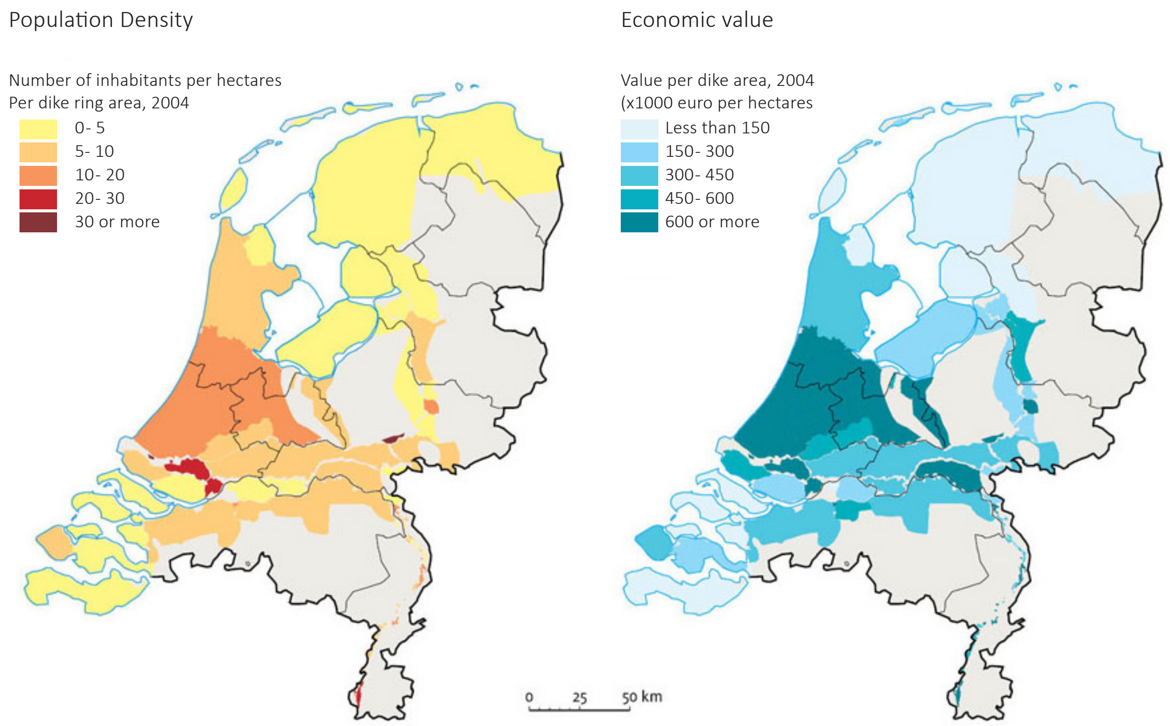


Figure 20| The density of inhabitants per hectare and the economic value per dike ring in euro per hectare. It shows how vulnerable Dike ring 14 (the darkest one) is, in terms of consequences and shows the importance that a new approach to risk should be used. (Source: Planbureau voor de Leefomgeving, Noordhoff Uitgevers.)

//Problem Statement

The Randstad is the social and economical center of the Netherlands, where more than seven million people live and where up to seventy percent of the gross national product is produced. Compared to other Delta countries the location of this socio-economic center below sea level is remarkable. The Dutch approach of drain, dredge and reclaim that has shaped the Netherlands throughout history, is mainly focused on fighting water. This human intervention led to a cycle of heightening dikes and pumping out the water and brought the country to the situation where we are in today. Its national center is located in an area that is highly exposed to flood risk being located in areas that are below sea level. Within the municipality of Rotterdam these depths reach up to 6.67 meter below NAP. As the current notion of risk used in the Netherlands has a strong focus on reducing the probability of flood occurrence, it leaves little attention for reducing exposure and vulnerability, being the other components when defining risk. Socio-economic trends show that the area below sea level will only be more and more inhabited with people and economic growth. This along the predicted sea level rise, greater fluctuations in river discharge and the inclining surface compel research on spatial planning and urban design to look far into the future, to widen their scope and to anticipate developments further ahead. As the need for a more drastic large scale approach is increasing, research is required to explore what this means for lower scales as well. The city of Rotterdam can be an example area since it has a high variety of heights. This leads to the main research question of this thesis:

How can the spatial structure of Rotterdam be transformed in order to prepare for extreme flood scenarios?

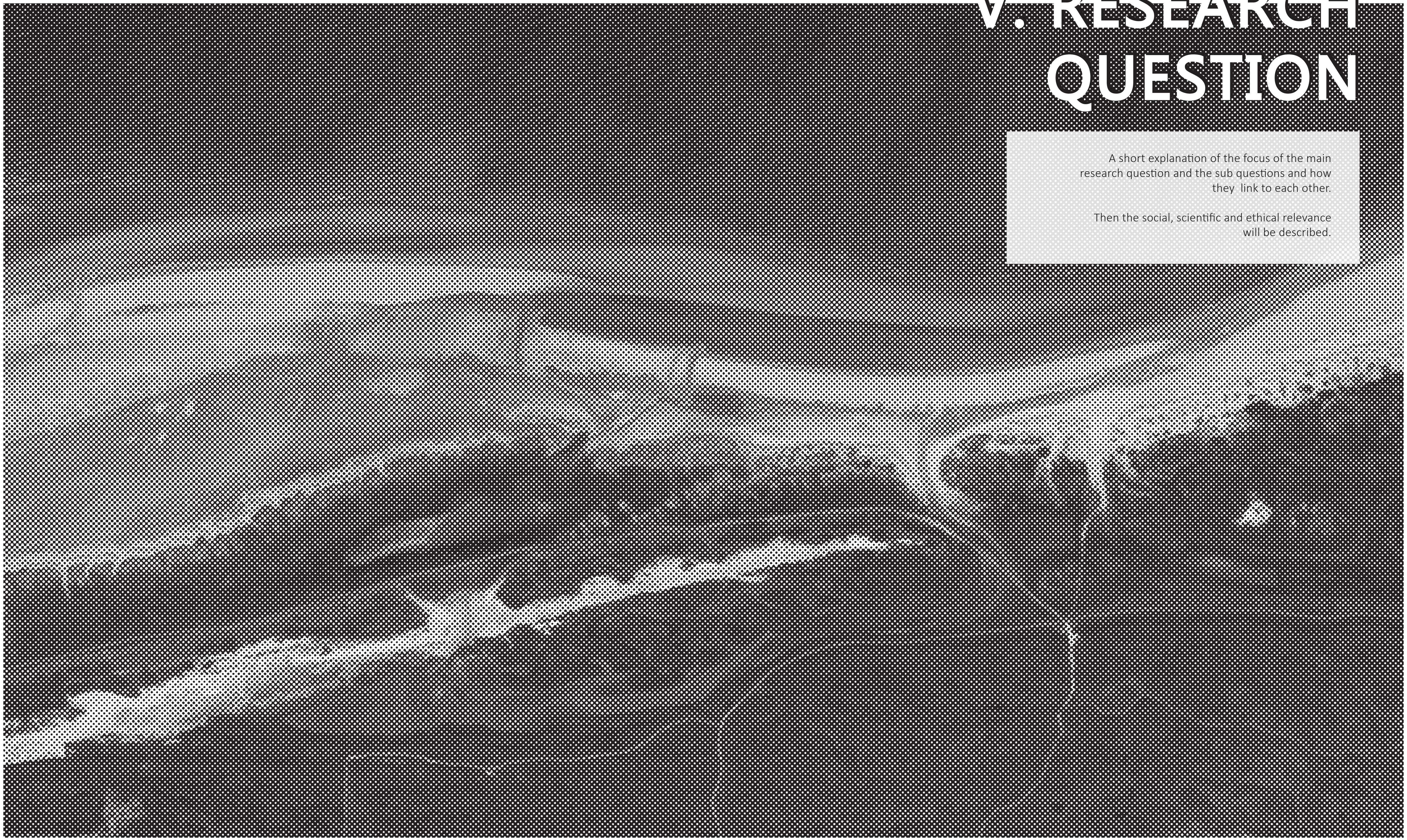
The aim and focus

The project aims at transformation of the current way the Netherlands deal with the increasing threat of water, proposing to create more adaptive capacity of the spatial structure in order to deal with future uncertainties in the context of extreme climate change scenarios. A reduction of the vulnerability of the highly-urbanized delta region Randstad results in an overall decrease of risk. This is where the field of spatial planning and urban design could contribute largely. **This thesis focuses on the possibilities of restructuring the Randstad region throughout the scales (in space and time), assigning densification zones and areas of relocation towards reduction of flood risk exposure under climate extremes.** The Randstad region is chosen as it is the economic and social center of the Netherlands and therefore very vulnerable in terms of flood risk. Rotterdam as a city will be used to translate the new approach to spatial interventions. The interventions on city, neighborhood and street scale show what a new approach will mean for the inhabitants of the city, since a broad support is needed for extreme changes. Truly new visions on this subject can only emerge by leaving the beaten track.

V. RESEARCH QUESTION

A short explanation of the focus of the main research question and the sub questions and how they link to each other.

Then the social, scientific and ethical relevance will be described.



// Research questions

The main research question stays rather broad, but the sub-questions focus on more specific parts in order to get more information as input for the design phase, and then for answering the main question. The temporal frame that is used in this thesis has mostly to do with uncertainty, and therefore lies in the far future (2060). As the aim is to transform the way that the Netherlands deal with the threat with water, using spatial planning and design interventions, the following sub questions have been set. The sub questions can be divided in two groups, the one concerning what is currently there (with the focus on flood risk) and the other what could be there (with the focus on activating potential) (Figure 21). In these questions the fields *reducing flood risk* and the *spatial structure* can be clearly seen. For finding an approach that is not only focusing on preventing a flood, but looking at the spatial planning and evacuation as well, the natural suitability for settlement could be explored. This would result in areas that are less suitable (need to be relocated) and areas that are more suitable (could be densified). How, when and where this process of densification can take place needs to be translated into a design. The project is therefore dealing with several scales: the national scale (the approach), The Randstad scale (zooming in for suitability) and the city, neighborhood and street scale (for translating the findings to the spatial interventions).

1. What are the uncertainties in the Netherlands (national scale), Randstad (region scale) and Rotterdam (city scale)?

As the socio-economic system has numerous trends and developments going on it is important to explore possible scenarios and set the most extreme one as the future. When this scenario is set, backtracking can help defining what steps have to be taken in order to transform the system towards this uncertainty.

2. What measures diminish the risk of flooding?

As the risk formula shows three components that define the total amount of risk, it is important in what ways the contribution of these can be controlled in a way that the risk of flooding reduces.

3a. What people and features are exposed to floods?

When a flood would occur, how many people and what features are at risk? It is important to investigate the amount of people, economies and other social or economic features that are present in an area that has risk of flooding.

3b. What areas have potential for densification and how should they be densified?

As one of the solutions is to make the areas that are not suitable for inhabitation available for other land use. Areas that are more suitable for land use can be inhabited by people that used to live in less suitable areas.

4. How can we deal with uncertainty?

As the far future is very uncertain, the need to find ways to adapt the structures in such a way that they can be positive for several futures.

5. What spatial measures can be taken in order to increase the adaptive capacity?

In order to increase the adaptive capacity an exploration of other projects is helpful to list optional interventions.

6. How can the finding of theory spatially be applied in the Dutch socio-economic system?

Synthesis of all findings, in a design proposal.

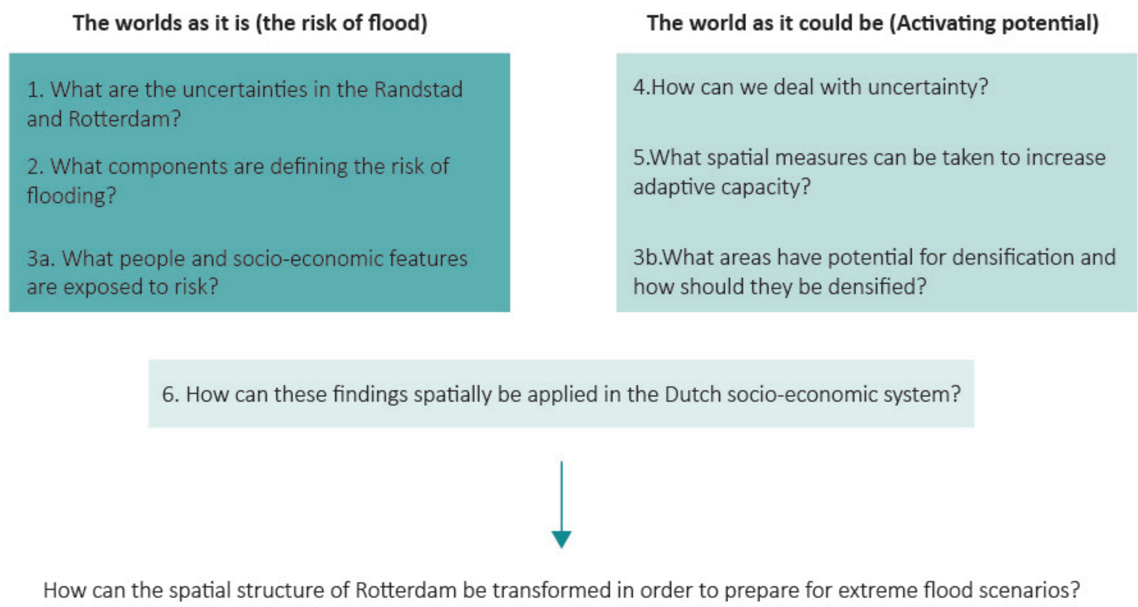


Figure 21 | A schematic overview of the research questions and sub questions. They are divided in *what there is now?* And *what could be there?* (Image by author)

//Societal and Ethical Relevance

Before the research is further described the societal, scientific and ethical relevance of it is described. As the probability or exposure of a flood can never completely be brought back to zero it is valid to consider a scenario of transforming the economic and societal center of the Netherlands. Since reducing the probability of a flood is currently resulting in a lack of reducing the exposure and the vulnerability of a system, the system is awaiting a collapse. Spatial planning an urban design can contribute in the safety of the society.

The pressing incentive is the trend of changing climate (changing precipitation and sea level rise) that varies between a low and high rise estimation. In global scale the estimation of the precise rise is not clearly stated, but the options vary from sea level rise to extreme sea level rise. With the current attention that is globally shown, the topic of climate change and the drastic results this can have are of high relevance.

The inhabitants of the Netherlands have the feeling that they are ‘safe’ and that the government/Rijkswaterstaat protects them. Politicians often deal with topics that they can use to show in their next campaign. The longer term plans that are discussed often show a short-term threat. For how long will the government be able to say that they can protect the country from flooding?

The ethical dimension of this thesis has two main sides; on the one hand our right to well-being and safety and on the other hand the responsibility as human beings towards our ecosystem. Both are rather obvious an ethical question as the decisions made around this topic concern a lot of people and a large ecosystem.

As a spatial planner and urban designer, I feel the urge to address the vulnerability of the society in the current system. Not only do we put the lives of almost 1,5 million people in danger, but also, we have pushed the ecosystem into the structure that we needed to create this unsustainable solution. The Dutch have blocked natural processes of sedimentation and the river flows and find themselves in the downside of this.

How we came in this situation is clear, but continuing within this system of manipulation of the water (and placing lives and ecology in stake) while knowing current information and models is another step. The problem that is stated in this thesis is already pressing, but with the trends of climate change and urbanization is it rising every day.

Figure 22| There is information and awareness that the sea level will rise, but the spatial consequences not so much in the picture. The magazine Sir Egmund poses the question what would happen if the sea level rise will be extreme. This is closely related to the question of this report. (Source: (Sir edmund, 13 January 2018), p.33-35)

//Scientific Relevance

The Dutch are leaders in the water management world, guiding other Delta areas to new flood protection systems. The Dutch apply their knowledge gained since the beginning of the country to protect other regions in the world in similar conditions regarding water challenges. Applying techniques like dikes and dams in other deltas brings these into a vulnerable condition as well. A new approach that really stops fighting the water, can be a next step in the Dutch approach. Space for the river is a first step acknowledging the space water needs in order to keep the country safe. The Dutch delta is a very extreme situation where the most vulnerable area is also seen as the heart of the nation. By exploring the options of resettling urban areas to create space for the water, the Randstad project could be a next step in the Dutch approach.

As green-blue networks have become a crucial component in the organization of metropolitan growth, this large-scale project can show how resettlement and green blue structures can be combined. The systematic approach of assigning certain clusters to densification and others to relocation can contribute to the theory of increasing the adaptive capacity of a large-scale system, taking deep uncertainty due to the time span into account. The translation of this strategy into spatial interventions can help visualizing how the Netherlands could look like.

In research about this topic, the spatial side of planning with uncertainty or scenario planning is often missing. The models stick to graphs and words but lack the spatial component of uncertainty. It is important to explore what impact an extreme scenario has on the spatial infrastructures as well as on urban life.

There is a lot of research about how to deal with (deep) uncertainties. Scenario and probability models show what the possible future could bring us. These models can show the range, probability or options of possible future events. There has been done a lot of research on the role of adaptive capacity in dealing with this uncertainty. However, the spatial aspect of this research is often not highlighted.

Therefore the project defines design principles from literature and then translates them to a spatial design. When the principles are made spatial it often shows the need of more research of, for example other fields. The different features and predictions and models come together in the spatial implementation of this uncertainty.

The spatial planning project does not match with the time frame of political plans. A project can easily span over 20 years (where the political cycle only has 4 years). This could also mean that there is changing political and thus changing financial support within the process of a project. For scenario thinking this loop is even longer. The scenarios can go into the far future. Since there are a lot of time frames to think in, it is logical for politics to look within a scope of preferably 4-10 years up to maximum 20 years, since that is more clear and certain. However by doing this, the changes that are made stay within the same system, within the same paradigm.

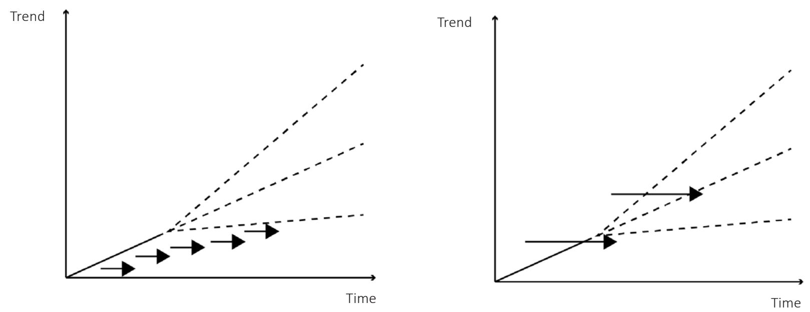


Figure 23| Scenario and trends are used to deal with an uncertainty. The government focuses mostly on short term plans and investments. In this way the focus shifts often automatically to the least extreme scenario, and it stimulates incremental transformations, step by step. What if the government can invest in a strong base, that aims towards a more extreme scenario? (Image by author)

VI. METHODOLOGY

An explanation of the methods used to get answers to all the sub questions. The theory of GeoDesign is explained as method and is also used to order of the report.

// GeoDesign

To answer the main research questions several methods will be used. The aim of the methodology chapter is to explain the structured process that will be used to answer the research (sub) question. The techniques of getting knowledge vary per sub question as some are more scientifically based in opposite to the design based questions. The framework that will be used to structure the process towards the design is GeoDesign. This method of Steinitz integrates context analysis, design and evaluation phases into a set advanced design solutions (Lee, Dias and Scholten, 2014). Steinitz has built up a method to overlay geographical information by using GIS technology (Figure 25). Steinitz assumes that all type of data is in some way spatial, and that spatial data can be somehow georeferenced. By using these layers suitability maps can be formed using information from multiple fields, and moreover the design can be made in geographical context. In this method the design can be tested for several scenarios. Overlapping thematic layers and analyzing them to asses the best or the worst locations for a certain use has been done before, by Ian McHarg (McHarg, 1969). He did not use the term GeoDesign, but his way of thinking formed the outline of the GIS-approach of today. Defining the suitability for a certain use has been one of the key methods used in my project.

The framework of Steinitz also splits the steps from a current situation to a new situation in 'The world what it is' and 'The world as it could be', similarly as the division of research sub questions (Figure 21).

The world as it is (could be seen as an assessment phase):
- Data inventory : How can the geography of the area be described?
- Process models: How does the Risk Management system currently work?
- Capability/sustainable models: Is the current system working well?

The world as it could be (could be seen as the intervention phase)
- Design and sketch: What alternatives of the structure are there?
- Evaluation and analysis: What are the consequences of this change?
- Decisions: How should the spatial structure be changed?

Throughout the project the scale will change to move from the large scale of the water management scale of the Netherlands towards a low scale design proposal in Rotterdam, up to street level. This means that the steps made in the structure of GeoDesign can be repeated on several scales. The first steps of exploration of how the water systems work are already introduced at the first part of the report and even led to the problem statement stating that this current system is not working well if we take the trends into account. On this larger and more generic scale the more literature based questions will be answered. To be more specific, the next steps will zoom in to the Randstad region and will cover the area that is under guidance of the water boards of Delfland, Schieland en Krimpenerwaard, De Stichtse Rijnlanden, Hollandse Delta, Amstelen Gooi en Vecht and Rijnland. Using GeoDesign clusters will be made that have to be relocated, and others that can be densified. How this densification will take place in space will be shown on city, neighborhood and street scale.

Within this area the sub-questions will be answered that have to do with data analysis: what is currently present in the areas exposed to large amount of risk? Where would it be more suitable for people to live? The data will be used to check if an area is, to a certain extend, (un)suitable for living and on the other hand (un)suitable for densification. Based on this check, clusters can be made with the suitability information of both living and densification. The next step will be on the city scale, starting again to see how the system currently works within the city.

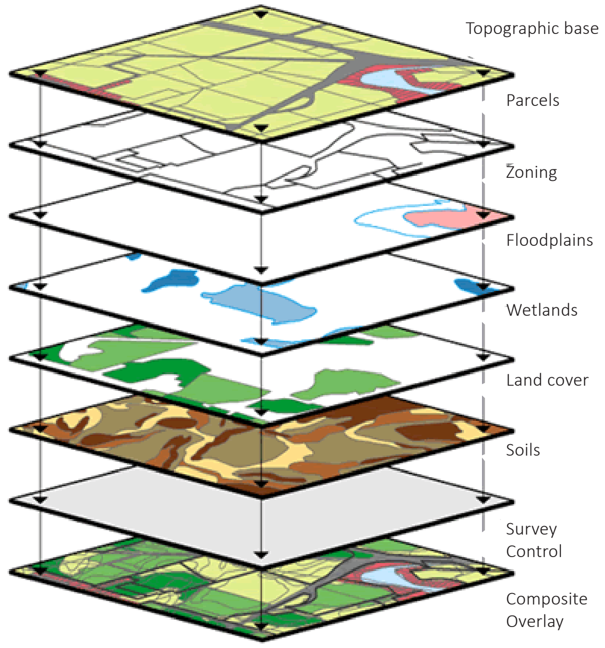


Figure 25| Maps that contain information from several fields can be combined to define areas that are suitable or not suitable for a certain intervention or a certain use. This can be visualized by overlaying these maps and if maps have more importance a certain value can be given to each of them. (Source: Longley et al., 2010)

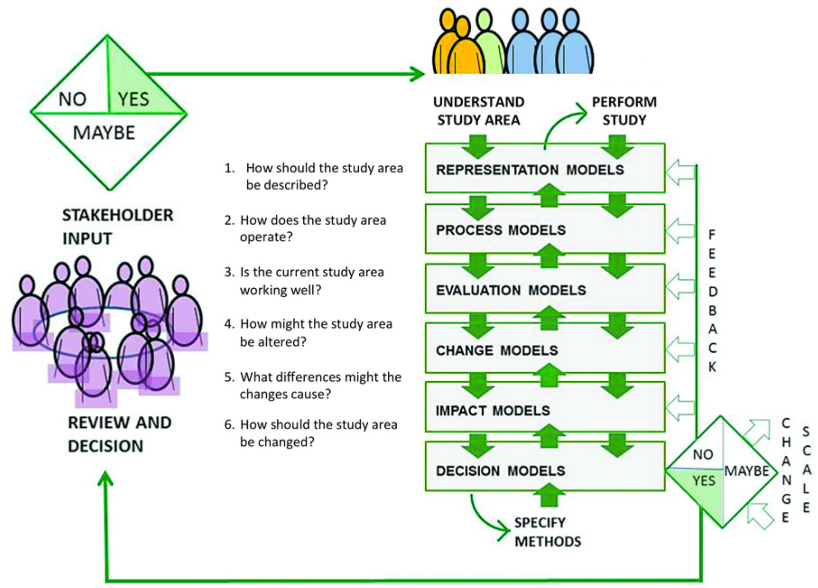


Figure 24| The six questions that need to be asked, following Steinitz' GeoDesign method. (Source: Steinitz, 2012)

//Method per sub question

In Figure 26 an overview of the three pillars analysis, theory and reference projects are shown. They will each result in design principals that will be used in the designing phase. Stating that the approach towards water should change as a result of the question what areas would be suitable for settlement (regions scale) and what areas should be relocated. How to densify the suitable areas spatially and what this means for the inhabitants needs to be explored on the city, neighborhood and street scales. This will be explained in more detail in chapter 9. The three pillars in figure 26 shape the outline of the following chapters.

First the theoretical framework will discuss:

1) How can adaptation reduce risk?
2) When did the city of Rotterdam start to expand in naturally seen unsuitable areas?
3) How can we use the notion of density for defining where we can relocate people?
4) What is the influence of the mental and social aspect of the city on this process?
5) How can these findings be projected using scenarios?

Then the **second** pillar is the GeoDesign assessment, where current models are analyzed to see if they are usable in the future. The findings of the assessment on the higher scales lead to new questions for the lower scales. The extensive analysis maps can be found in the analysis booklet, that tackles the assessment questions per scale. The most important findings and conclusions are summed up in this booklet in chapter 9 and more detailed in the appendix assessment booklet.

The **third** pillar explains extra design principles that are derived from analyzing reference projects. The outcome of these chapter will be the starting point for the design phase. The analysis and design on the separate scales influence each other.

How this method will result in an answer to the main question is explained below, where the six sub questions can be divided in three groups depending on in what way the core of the answer can be provided: by literature(1+2+4+5), by data and analysis(3a+3b) and by design(6).

1. What are the uncertainties in the Randstad?

As the project aims on deep uncertainty, a common way to deal with this is using scenarios. To make the scenario, assumptions are made based on trends or previous experiences. As the Netherlands have several experts concerning the trends that have to do with water, the flood defense systems are prepared to a certain extend of change in the future. By reading and exploring literature, the global and national trends will be put into a scenario. When this scenario is set, the requirements of the spatial structure can be determined.

2. What measures diminish the risk of flooding?

Another sub question that should be answered by exploring literature is about measures that reduce risk of flooding. First more general ways of adaptation will be explained. Also the approach towards the notion of risk will be highlighted. In literature several ways of defining risk are described, the approach of the Netherlands will be zoomed in at. Then measurements that are currently used in the Netherlands will be grouped into these ways, resulting in possible improvement per field.

3.a What features are exposed to floods?

Applying spatial analysis and modeling, the entire Randstad region is analyzed based on a set substratum conditions, such as height or type of soil, and urban densification resulting in areas that are highly exposed and areas that are more suitable for further development. The suitability method of Ian McHarg and GeoDesign of Steinitz combine different layers containing information geographically. The layers can express whether that certain feature is suitable or not for a certain type of use or development.

3.b What areas have potential for densification?

Current critical infrastructure and functions play a major role in the possibility of densification. Since the suitability for functions based on the substratum is determined in question 3a, the features exposed to extreme risk need to be relocated. The design principles are influenced by geospatial knowledge, and therefore Geo and Design come together: GeoDesign. This method of Steinitz integrates context analysis, design and evaluation phases into a set advanced design solutions(Lee, Dias and Scholten, 2014).

4. How can spatial planning help in dealing with uncertainty?

As the far future is very uncertain, there is a need to find ways to adapt the structures in such a way that they can be positive for several futures. A theoretical framework is used to explain the notion of adaptive capacity and its contribution to dealing with uncertainty. How should a structure adapt to what could be there?

5. What spatial measures can be taken in order to increase the adaptive capacity?

In order to increase the adaptive capacity, an exploration of other projects is helpful to list optional interventions. On a specific location the temporal layer becomes also important. By using the scenario of question 1, requirements for the new structure can be defined to what extent the system should remain adaptive.

6. How can these finding spatially be applied in the Dutch socio-economic system?

The city of Rotterdam is chosen as an example site to translate the findings of theory and reference projects into spatial transformation. Therefore on the city, neighborhood and street scale spatial analysis and design iterations will bring the theoretical principles to a spatial intervention.

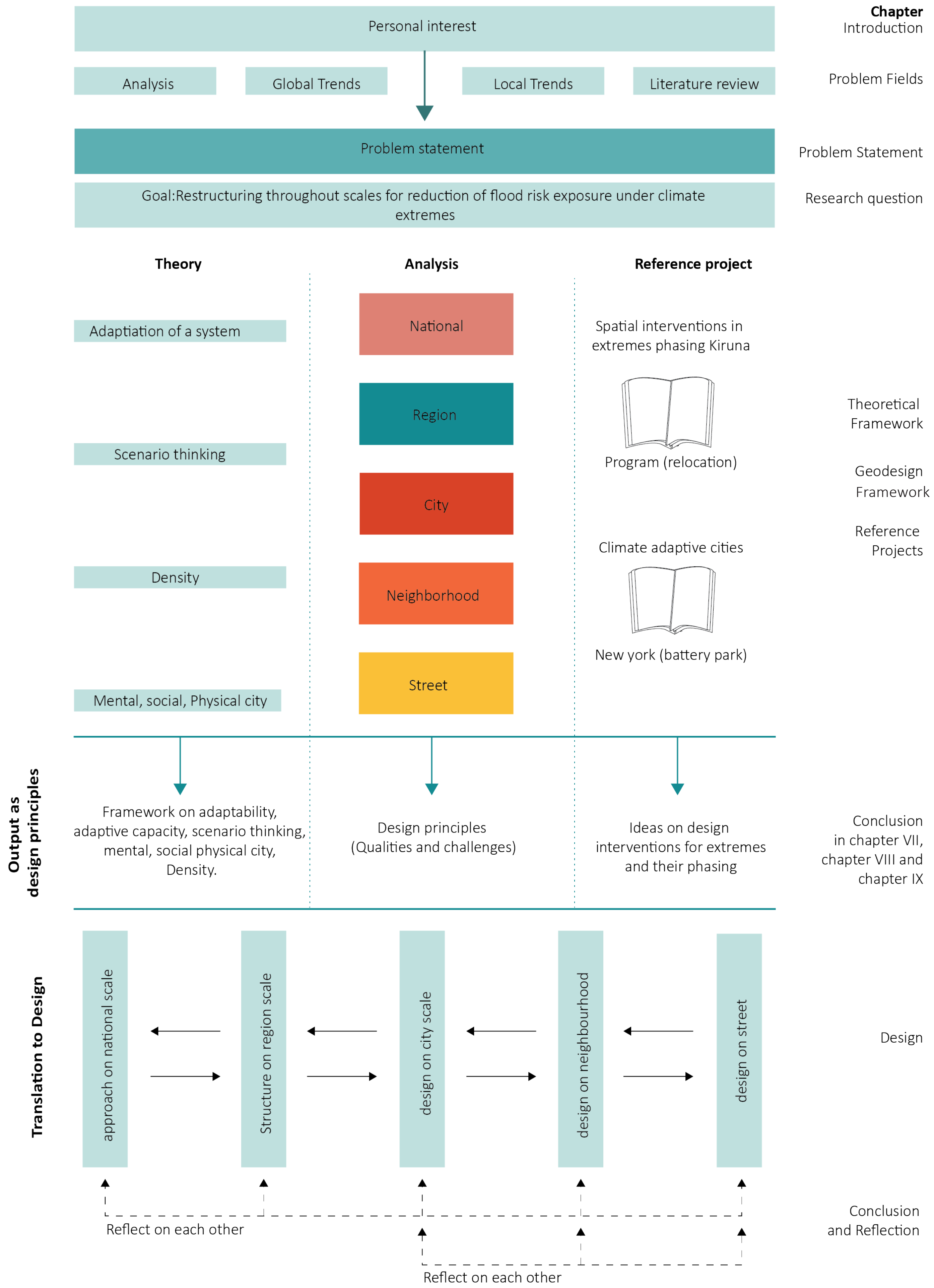
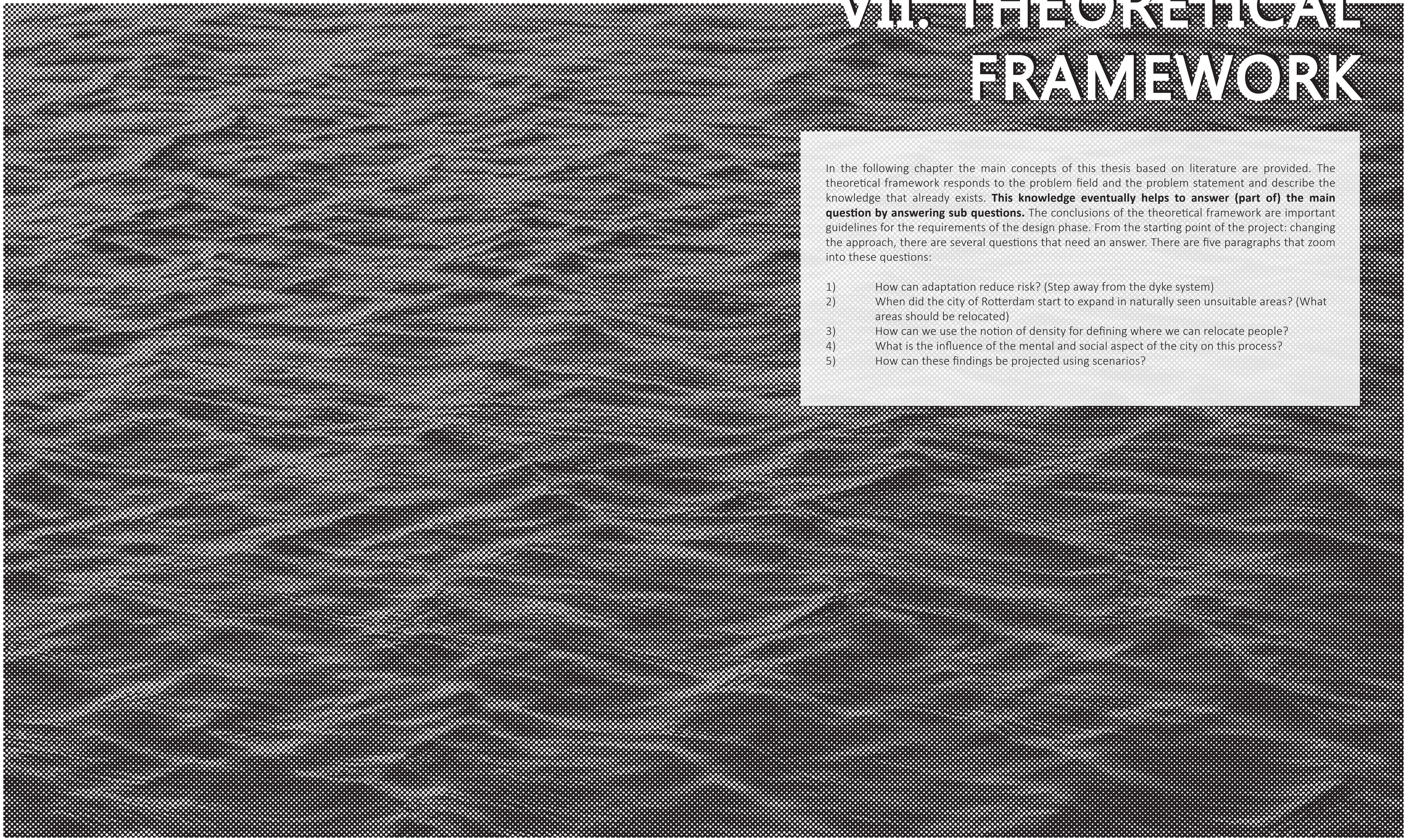


Figure 26 | A schematic overview of the project and its methods, and how the findings come together in design principles that are the starting point of the design. (Image by author)

VII. THEORETICAL FRAMEWORK



In the following chapter the main concepts of this thesis based on literature are provided. The theoretical framework responds to the problem field and the problem statement and describe the knowledge that already exists. **This knowledge eventually helps to answer (part of) the main question by answering sub questions.** The conclusions of the theoretical framework are important guidelines for the requirements of the design phase. From the starting point of the project: changing the approach, there are several questions that need an answer. There are five paragraphs that zoom into these questions:

1) How can adaptation reduce risk? (Step away from the dyke system)
2) When did the city of Rotterdam start to expand in naturally seen unsuitable areas? (What areas should be relocated)
3) How can we use the notion of density for defining where we can relocate people?
4) What is the influence of the mental and social aspect of the city on this process?
5) How can these findings be projected using scenarios?

7|1 How can adaptation reduce Risk

The origin of the term adaptation can be traced back to the natural sciences, in particular evolutionary biology (Smit and Wandel, 2006). In the terms of a socio-economic system such as communities or cities the term adaptation is used to describe adjustments in response to certain stimuli, for example climate change (Smith et al., 2000). As described in the problem statement there has been a worldwide growth of population and economic wealth. Those two aspects are defined as consequences in the definition of risk, in which risk is described as the product of these consequences and the probability of a hazard (Jonkman, van Gelder and Vrijling, 2003; Kates, 2012) (Figure 29). The *consequences* along with the increase of extreme weather events result in an increasing number of catastrophes worldwide (Kates, 2012). Our systems are so severely exposed to risk that it compels us to improve the ability to cope with such risks. Jeager(2010) even named this as the key challenge for human kind today (Jaeger, 2010).

The notion of risk

The ability of coping with risk can, for one, be enlarged by dealing with the negative effects of the different components that define the amount of risk a community is exposed to. The notion of flood risk as a mathematical function of the probability and consequences of an event is favored by engineers, as the probability can be reduced by strengthening the flood defense (Naulin, Kortenhaus and Oumeraci, 2011; Asselman et al., 2012). From a more social perspective flood risk is often explained as a geographic overlay of (flood) hazard and vulnerability of the society (Asselman et al., 2012)(Figure 27). Planners prefer this approach as they tend to take the hazard as a given feature and they see planning as a way to adapt to this given feature. *Vulnerability* can be defined differently depending on the field it is used in. In the respect to climate change the Intergovernmental Panel on Climate Change defined vulnerability in their Fourth Assessment Report as a "function of exposure, sensitivity, and adaptive capacity"(Field et al., 2012). So reducing the risk would either reduce the probability, limit the exposure or reduce vulnerability or a preferred combination of these.

The flood management and risk reduction touches upon various fields, from governmental issues and behaviorism to territorial planning. This chapter will focus on the risk of flooding and specifically on the role urban design and spatial planning have in reducing it. The Netherlands will be used to provide clear examples of the topic. The main goal of this chapter is to add the reduction of exposure and vulnerability to floods to the Dutch design agenda of urban design and spatial planning. A sub goal is to define design principles that enlarge the adaptive capacity of the spatial aspects in the Netherlands regarding floods. In order to do this, general theory principles of adaptation and adaptive capacity will be discussed first. The components used to calculate risk (probability, exposure and vulnerability) will be guiding the second part of the paper, where these components get more concrete in the context of the Dutch delta system. This will guide the answer to the question: How can spatial planning and urban design contribute in reducing flood risk?

Adaptation to reduce risk

As described in the introduction the notion of risk in general is described in two ways: the multiplication of probability and consequences or as the geographical overlay of hazard and vulnerability (Asselman et al., 2012). In the first notion the vulnerability and the exposure are merged to *consequences,* whereas in the second notion the component exposure is part of hazard, influencing the vulnerable areas. To bridge the two definitions we need to explicitly distinguish exposure as one of the components defining risk, resulting in probability, exposure and vulnerability as the components in the risk formula ([van der Pas, 2012],cited in Asselman et al., 2012). Reducing risk could thus be achieved by (1) reducing the probability (e.g. improve protection like dikes, barriers, pumps), (2) limiting the exposure (e.g. create multiple lines of defense) and (3) reducing the vulnerability (e.g. building elsewhere (spatial planning) or preferably a combination of those (Bacchin, 2017). All these changes could be seen as "processes or actions in a system (household, community, group, region, country) in order to better cope with, manage or adjust to some changing conditions, stress, hazard or opportunity, stated by Smit and Wandel as the definition of adaptation (Smit and Wandel, 2006). Adaptations can vary in scale (local, community, system), time (reactive, concurrent, anticipatory) and system (autonomous, planned)(Smit and Wandel, 2006). Therefore adaptations are a promising way to adopt a new view on reducing risk of flooding in the Netherlands.

Within the field of spatial planning a division of three sets of adaptation has been made; **adaptation as resilience, adaptation as transition and adaptation by transformation** (Folke et al., 2010; Pelling, 2010). Prior to this trichotomy, the distinction was based on types of resilience, as shown in Figure 28. Resilience has several definitions as it is used throughout various fields and scales. In this thesis the definition of resilience in a system is used, adding *the ability to adapt and transform to face slow environmental changes* to the more engineered definition "*being able to bounce back after disturbance*"(Holling , 1973), which alone does not cover the systemic scale(Carpenter et al., 2001; Pickett et al., 2014).

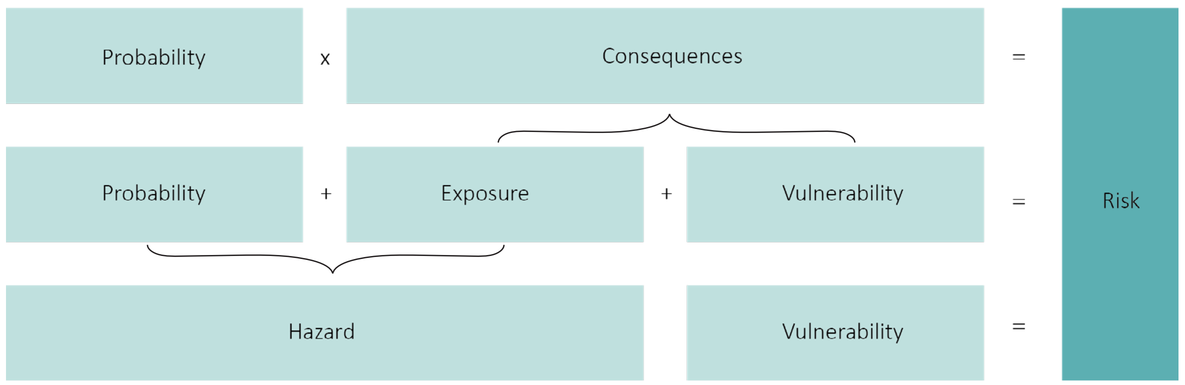


Figure 27| The two ways to conceptulize flood risk: (1) probability times consequences and (2) geographical overlap of hazard and vulnerability. In the middle the three components that define these. (Image by author after Van der Pas et al., 2012, cited in Asselman et al., 2012)

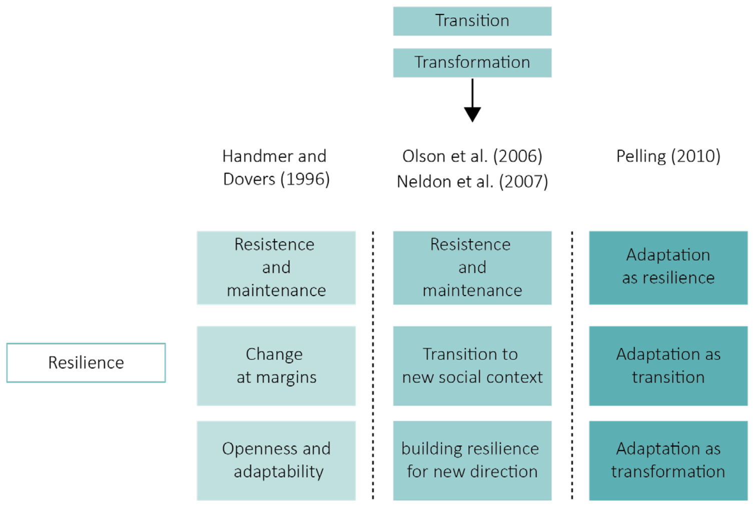


Figure 28| The term resilience and its definition changing in time. There is a shift visible that allows more transformation to a new system. (Image by author)

Resilience, transition, transformation
To reach the definition adaptation has today within the field of spatial planning, Pelling shows the origin of it in literature. As Figure 28 shows, the first trichotomy of resilience is made in 1996 by Handmer and Dover; resilience as (1) resistance and maintenance; (2) change the margins; and (3) openness and adaptability, where the second class is considered to be the most common response to environmental threat([Handmer & Dovers, 1996] cited by Pelling, 2010). In this class there is an acknowledgment of the risk the system is exposed to, but only limited changes are made within the restrictions of the system, often focused on the stability of the near future and less on the well-being of future generations (Pelling, 2010). Olsson and Nelson distinguish transition and transformation in separate classes, already creating more room for moving towards a new direction(Olsson et al., 2006; Nelson, Adger and Brown, 2007). As transition and transformation have a strong connection to the nature of adaption, a different set is established by Pelling, dividing adaption on the system scale as: adaptation as resilience, adaptation as transition and adaptation as transformation (Folke et al., 2010; Pelling, 2010; van Veelen, 2016).

Pelling (2010) explains that adaptation as resilience aims to improve the performance of a system, without actually changing the guidelines or routines. As shown in Figure 31 the steps are often incremental and therefore building upon decisions and adaptations in previous stages. Adaptation as resilience supports the continuation of (parts of) the system and stimulates changes that enable this system. Actions that protect priority functions of the current systems and that create the possibility to bounce back to this system characterize this class as well (Pelling, 2010). An example of the dyke system can make this more clear. Adaptation of the system as resilience would mean making the dykes higher so that more water in the future can be discharged. When the adaptation is transitional, the actions aim to improve the current system and to optimize it, but these changes are still based on the rules and techniques of the current system. It would mean finding alternative ways of dykes, such as the Room for the River, where large ponds are created by rebuilding the dyke further away from the river, or making a creek. The last class aims to adapt in a way that develops a radically different policy, a rigorous change of the ongoing processes and approaches of the system(van Veelen, 2016), or a change of the initial conditions (IPCC et al., 2012). This would mean that using dykes for protecting the lower grounds is not longer an option.

Adaptive capacity
A successful system must adjust to a changing template based on the internal and external drivers of the system structure (Pickett et al., 2014). Adaptation could be seen as the manifestation of adaptive capacity, and therefore the last is an import element to clarify. To explain adaptive capacity the adaptive cycle of Holling and Gunderson (Figure 30) will be used, distinguishing four phases in the dynamics of a socio-economic system: first the r- phase of exploitation, then the K-phase of conservation, followed by the Ω-phase of release and finally the α-phase of reorganization and placing them on the axes of potential and connectedness. These are in a conceptual way the phases that a socio-economic system goes through, where the end of the K-phase is the point where the importance of adaptive capacity comes in.

The adaptive cycle developed by Holling (2001) shows four distinct phases that a socio-economic system is following. The first stage (r) of exploitation, then conservation(K) where the system is stabilizing and waiting for a collapse in the release phase (Ω), followed by reorganization (α). The side path after the reorganization phase shows the option of a transformation towards a new system. (Image by author after (Gunderson and Holling, 2002)).
As the system becomes more connected, the ability to deal with disturbances could decrease. This shows in the K-phase; the system is after a period of development and stabilization waiting for an accident to happen, as Holling states (Holling, 1973). The stage from the r phase to the K phase (foreloop) is often described as the slower phase of growth and stabilization and the Ω-phase to the α-phase (backloop) is said to be the rapid phase of reorganization leading to renewal (Gunderson and Holling, 2002). The system becomes less resilient as it moves towards K due to a higher connectedness based on the previous state of conditions. The adaptive capacity comes in as the capacities a certain system must adapt to conditions at a certain point in time. If the system is too connected, without enough space for adaptation, it would more likely to fall deeper in the release state (shift from K to Ω-phase) and also that there are less opportunities and more constrains during the period of reorganization(Resilience Alliance, no date). If there is more adaptive capacity, a system can respond to the changing conditions on any facet of an ecological or complex urban system, it can anticipate and transform its structure, functioning or organization to better survive these changing circumstances(Saldana-Zorrilla, 2007).

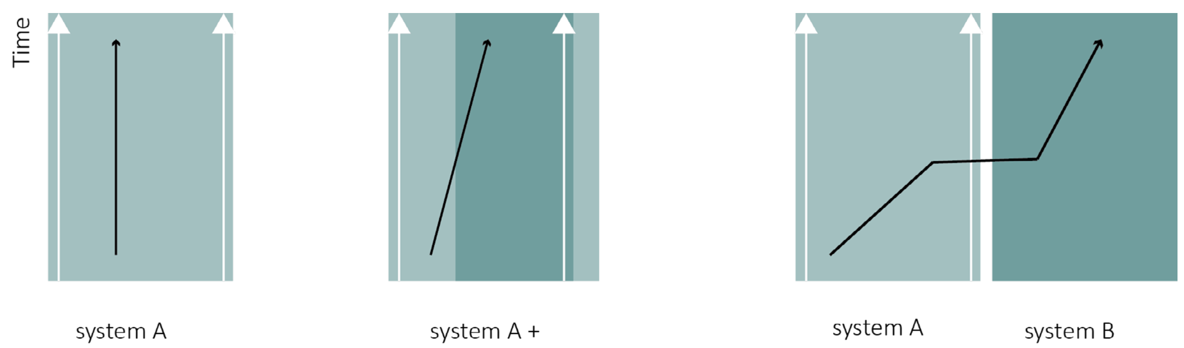


Figure 29| The Three ways of adaptation following Pelling(2010). On the left adaptation as resilience (incremental changes within the same regime), in the middle adaptation as transition (changes that try to optimize the system, but the main structure of the system remains), and on the right adaptation as transformation (moving towards a new structure and regime changing the main structure and regime of the old system). (Image by author)

The notion of risk in the Netherlands
Now the definitions of adaptation, adaptive capacity and risk are established, those can be projected on the urban context, taking the highly-urbanized delta system of the Netherlands as an example by defining interventions that have been already applied and what effect they have had. Adaptation responds to changing conditions, as previously described. In terms of complex urban systems, the changing conditions could take place on several facets, like social, migratory, economic, climatic and environmental conditions (Pickett et al., 2014). Examples of trends in the Netherlands that result in changing conditions as a result of climate change are rising sea levels, increased and more intense precipitation and higher river discharge(IPCC et al., 2012). These conditions increase the risk of flooding. Especially since large parts of the Netherlands are suffering from ground subsidence as well. The areas that are exposed to flood risk at most are the low-land parts in the west of the country and the flood prone areas of the large rivers. In total 55% of the country is protected by flood defense (Asselman et al., 2012). Besides the environmental trends, socio-economic changes play a role in defining risk. In the Netherlands these trends show increasing figures in economic and social value for the Randstad region, that lies for a large amount below main sea level (van Eijsbergen, Poot and van de Geer, 2007; Doorn-Hoekveld, 2014)(van Eijsbergen, Poot and van de Geer, 2007).

Probability
The Dutch notion of risk is the one favored by engineers and focuses on the reduction of the probability and not so much on the consequences (number 1 in figure 27) (Asselman et al., 2012). As the notion of risk could be divided into probability, exposure and vulnerability, it is important that the risk management focuses on all three manners, for the system to maintain. Relating to the three manners to reduce risk, storm surge barriers and dykes focus in the Netherlands on reducing the probability of a flood (figure 27). Every defense system has to meet a level of safety based on the consequence it would have if a certain defense system would fail; a dike with a 1 to 2000-year norm, has to be persistent to resist the highest combination of water levels and wave height that have a chance of existence every once in 2000 years(Most et al., 2014). Some interventions that significantly reduced the flood probability are the Maaslandbarrier (large scale), a dyke (medium scale) or a pump (low scale) (see Figure 32). Kennis voor Klimaat lists six criteria well implemented water defenses should be rated upon: (a)The technical design; (b)The manageability of the defense; (c)the option to expand; (d)the pressure on space; (e) the embeddedness in surrounding; and (f) extra functions(De urbanisten et al., 2010). Especially criteria (c), (d),(e) and (f) deal with spatial quality. A challenge besides the substratum conditions in protection improvement in the Netherlands is the intensive use of space, especially in urban areas. Therefore ways of multi-functional use of flood defenses are being explored, such as a multilevel quay where the least vulnerable functions such as traffic are positioned close to the water, whereas housing takes place on the higher and safer level(Hooimeijer, Meyer and Nienhuis, 2005). A downside of multi-functional robust defenses is the increase of cost compared to traditional dikes. Asselman et al. soften this statement by adding that long-term robustness needs less maintenance which is beneficial on the long term(Asselman et al., 2012). The examples show that the Netherlands focus a lot on reducing probabilities, but that there is an insufficient connection to reducing exposure and vulnerability with these interventions.

Exposure
The exposure in terms of floods has to do with how fast, how far and how deep the flood will advance (Asselman et al., 2012), and therefore exposure is mainly important after a first defense mechanism fails. Multiple defense lines or compartmentalization are measurements aiming

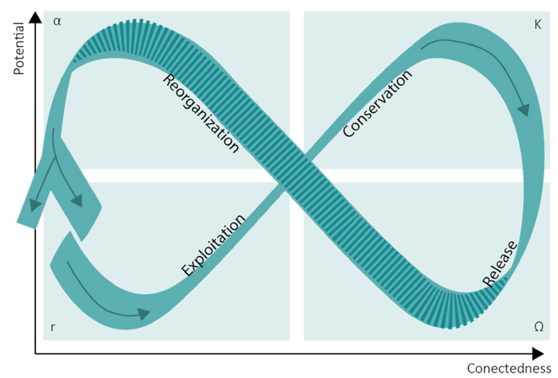


Figure 30| The adaptive cycle developed by Holling (2001) shows four distinct phases that a socio-economic system is following. The first stage (r) of exploitation, then conservation(K) where the system is stabilizing and waiting for a collapse in the release phase (Ω), followed by reorganization (α). The side path after the reorganization phase shows the option of a transformation towards a new system. (Image by author after (Gunderson and Holling, 2002)).

on reducing the exposure to a flood if it would occur (Figure 32). As compartmentalization means splitting up into smaller portions, Klijn et al. state that the main goal is to diminish the surface of the area that could flood after failure of one defense mechanism (Klijn, Asselman and Van Der Most, 2010). A downside is that the water will be spread less resulting in a higher depth. The Netherlands is split up into 53 dike rings ranging from less than $1km^2$ surface to $4900\ km^2$ .Sub compartments are implementable depending on the current shape of the dyke ring, the orientation of the hazard source and the physiographic characteristics that are already there (for example infrastructure lines). A large benefit of extra embankments as sub dykes is the reduced exposure to people present in the area, as there are more safe heavens in terms of evacuation. A last principle of exposure is the characteristics of the risk. As the Netherlands is placed in between the rivers on the one side and the sea on the other, it is necessary to consider the general aspects diverse types of flood will bring, such as duration of the flood, river floods last in general longer (up to several weeks), and sea surges drop back often after two days.

Vulnerability

The last factor after probability and exposure, that defines risk is the vulnerability of a system. Decreasing the vulnerability of a socio-economic system is, in contrast to the more engineered factor of reducing the probability of a flood, the preeminent factor involving spatial planning (Asselman et al., 2012). In spite of the guiding principle water has in spatial planning nowadays , the attention to the spatial planning and urban design influence on vulnerability of the socio-economic system is close to zero in the Netherlands, due to the high levels achieved on the protection level (van der Brugge, Rotmans and Loorbach, 2005; Asselman et al., 2012). However, via zoning plans, made for new developments, municipalities could demand to make flood proof measurements or even forbid development at some areas. An example of reducing the risk via spatial planning is the project Room for the River, a program aimed on giving the water more room to manage higher water levels. At Nijmegen, a city located along the river Waal, the dike is replaced 300 meters inwards, that opened up space for a bypass. Fifty households had to be relocated, as the new zone can flood. Besides improving the protection and reducing the vulnerability the project also brings attention to water to the people living in the city.

The connection of adaptive capacity to measurements that decrease the risk of flooding is the uncertainty of the extent of adaptations that will be used. The socio-economic trends are extrapolated and therefore get more uncertain towards future. The determinants that define exposure and vulnerability are often similar to the determinants influencing or constraining the adaptive capacity (Smit and Wandel, 2006). For example the determinant land-use: If the use of the land is very fixed, such as large infrastructure or urban developments, the adaptive capacity decreases, as it is not easy to change the land-use over time. The determinants of exposure, sensitivity and adaptive capacity are dynamic, vary over time, vary by type and are place and system specific (Smit and Wandel, 2006). An important conclusion is that interventions made on one scale can influence the adaptive capacity on other scales in positive or negative way. Besides this, interventions that reduce for example probability can influence the adaptive capacity of other components (Figure 31).

Conclusion

The main goal of this chapter was adding the reduction of exposure and vulnerability to floods to the Dutch design agenda of urban design and spatial planning. Therefore the notion of risk is being parsed into the components probability, exposure and vulnerability. For each of these components interventions can reduce the negative impacts they have on the calculation of risk.

As a socio-economic system is exposed to threats that change over time, it is important that the interventions do not reduce or do enlarge the adaptive capacity of the system. In this way it is less likely that the system will collapse completely when a change or threat such as flood happens and it is easier to reorganize. Specifically in the Netherlands the approach in reducing risk is focused on reducing the probability of a flood. A lot of improvement can be done in reducing the exposure and vulnerability and thus the risk. **Spatial planning and urban design interventions such as flood-proofing, zoning or building elsewhere could be guiding design principles that will give the highly-urbanized delta of the Netherlands more capacity to adapt. These are important findings for the sequel of this project.**

Size of intervention	Reduces probability of a flood	Reduces the exposure after failure of defense	Reduces vulnerability of the socio economic system
Small scale	A Pump of a polder	Redundancy	Flood-proffing buildings (elevating, floating)
Middle scale	A dyke o a dyke ring	(sub)compartmentation	Securing sources of contamination (oil tanks)
Large scale	Maaslandbarrier (multiple dyke rings)	Multiple lines of defense (sea wall, dyke, higher track)	Relocat socio-economic important aspects or invest elsewhere

Figure 32 | Interventions at different scales and targeted at different components to reduce risk(image by author)

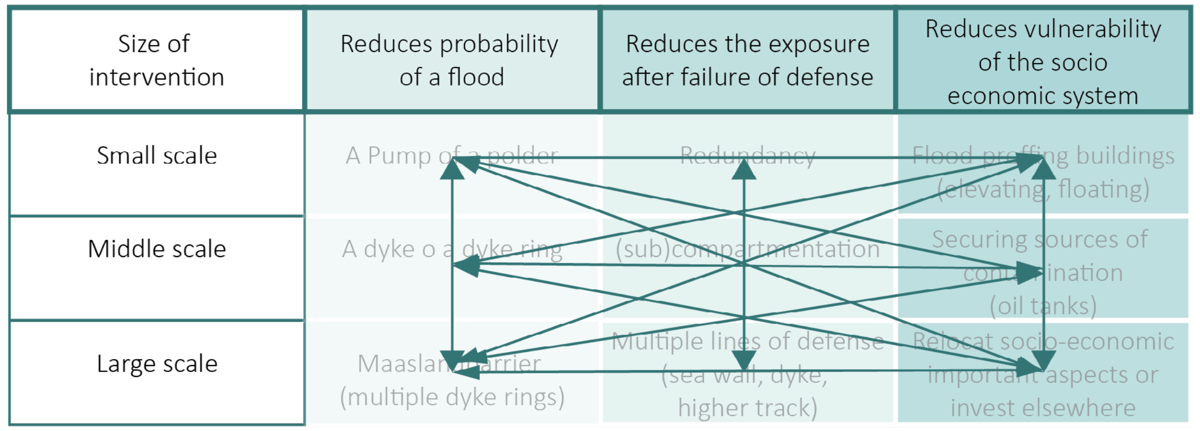


Figure 31 | Interventions at different scales and targeted at different components to reduce risk influence each other.

7|2 When did Rotterdam expend in areas that are not suitable for settlement?

The current developments and knowledge gathered in previous sections about the effects of climate change on the level of the sea made me aware of the Netherlands's vulnerable position. The fact that the Nether-lands, or low-lands, are partially below sea level has had an enormous influence on the way the Dutch have built up their country (Hooimeijer, Meyer, & Nienhuis, 2005). The continuous fight against the water from the sea and the water from the rivers can not only be found in the innovative ways of water protection but penetrates even in the way the governmental structure has been shaped. Knowledge of how to deal with water, increased and made it possible for the Dutch to inhabit parts of the land that could be the bottom of the sea. Historic maps show that the old settlements were mainly located at the higher grounds, whereas the lower parts were used for agriculture. Maps of cities of today indicate that the low parts around cities that used to be floodable are now used for suburbanization, resulting in an interesting shift between the edge of city and (water)ecology. Exploring the course and changes of this edge over time will be the main goal of this chapter. What elements define the borders and boundaries between city and surroundings? How did these edges change over time? Is this shift still sustainable in the future? The edge of the city of Rotterdam will be explained using the concepts of two researchers: Wenche Dramstad and Ian McHargs.

Ambiguous edges

The place where one environment differs significantly from the environment next to it is described as an edge, following Dramstad, Olson and Forman (Dramstad, Olson and Forman, 1996). This is the ecological approach of a boundary. A administrative or human boundary is an artificial division between two areas. The first type is often complex, curved and soft, where the administrative edge is often straight, drawn and hard. If the two boundaries do not overlap, a buffer zone between the human habitat and natural habitat is created. Looking at the edge between the urban environment and the natural environment shows a change over time. Figure 33 visualizes that the city centers tend to be located on the higher grounds, whereas the suburbs have been developed in the lower areas. By expanding the human development into the natural environment, the natural edge has been pushed aside. Are these new urban settlements or expansions sited at suitable areas? And what happens with the tasks and functions that this land used to fulfill?

Suitability

Before this essay continues in exploring these questions for the city of Rotterdam, the suitability theory will be elaborated on. Suitability is one of the many key words of Ian McHargs' Design with Nature. It emphasizes Design *with* nature to show the strong cohesion that Design and Nature should have according to McHarg (McHarg, 1969). **This theory shows that the potentials and the restrictions nature provides should be taken into account when designing.** McHarg provides an example case of deciding where to place the course of a highway. In the process of assessing all the factors and fields involved, eventually there will be an outcome of one or several best options depending on what weighs most in the consideration. In case of a highway crossing a city center, the costs of the project increase as a result of demolishing social structures or the loss of social values as a result of the construction of the highway (Figure 34). McHarg mentions that not only social processes can be expressed in values and costs, but physical and biological processes as well. Therefore a balance needs to be found in the values and costs that a certain project would bring, but taking the three fields (social, physical, biological) all into account. This could mean that a highway crosses an area of nature, but tries to diminish demolishing crucial areas for the ecology present or irreversible losses and even using the scenic values that the nature could add here. So for a certain function a suitability map could be built up, to test for several layers whether an area is suitable for this function or not. When the suitability of several layers are combined or put on top of each other, the outcome will give several options of where the more suitable areas of different layers overlap. Depending on what is more important a selection of the options can be made to decide where the intervention has to be located.

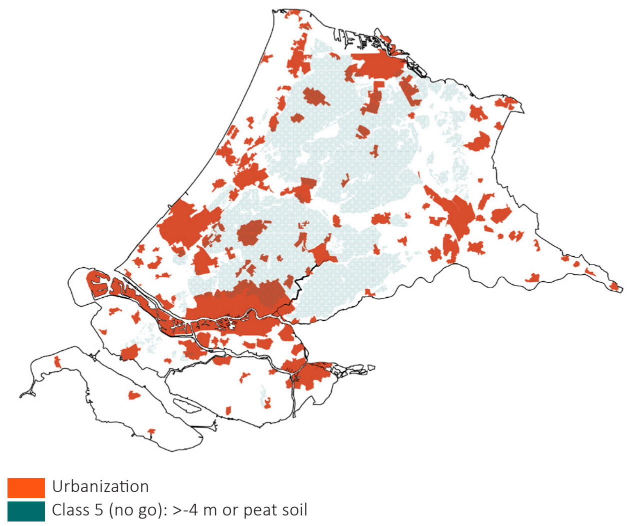


Figure 33| This map shows the area that is below-4 meters NAP, or has a peat soil. The red are cities in the Randstad. The older city centers are not located in the green part, but the suburbs are. (Image by author)

The context

To be able to define what is happening at the borders of the city of Rotterdam, where city meets ecology, the elements that shape the edges have to be defined. Using maps and analysis these edges will be determined throughout the history of Rotterdam, starting in 1270 when the site of Rotterdam was determined as the place where the River Rotte was dammed.

The area in the south of Holland was inhabited a long time before the first settlement of this city started. There were already some settlements on the higher ground such as dunes or on higher river banks. In order to make the land useful for small scale agriculture the habitants used the tidal flow of the water to make the grounds dryer. Ditches were dug and small baffles prevented the water for getting in and allowed the water to get out when the low tide arrived (Meyer & Bouma, 2016). From the 11th century on, the Dutch started to drain the soils on a larger scale resulting in the inclination of the already low land (Meyer, Bobbink, & Nijhuis, 2010). They had to come up with a system that was able to prevent the inclined grounds from flooding: the dyke. In the middle of the 13th century the river Rotte is dammed in order to regulate the water level at the other side of the dyke. A small settlement located on this dam and on the river side of the Rotte is the start of the city of Rotterdam. One note is the important change in the water system that made the river Rotte interesting to settle: before the year 1200 the drainage of the peat area had been mainly done using ditches that led the water towards the Oude Rijn as a tidal river(Meyer & Bouma, 2016). However, the coastal situation of the old Rhine that used to be beneficial for trade and therefore for cities, had changed. Sludge in the old Rhine decreased the function of drainage of the peat hinterland (Meyer & Nijhuis, 2014). To be able to continue the draining from the peat the water system changed completely, using the IJ on the north and the new Meuse on the south to fulfill the task of tidal drainage. To organize this, the earl of Holland and the bishop of Utrecht had to work together. On this large scale they rearranged, connected and adjusted the course of peat rivers and weteringen-small canals that collect water of the ditches and leads it to the surrounding river. The peat rivers that were oriented in north-south direction like Amstel, Gouwe, Rotte and the Schie became the main drainage rivers and therefore interesting spots for settlement, especially after the hinterland was protected with dykes, and the rivers where dammed to keep the drainage process going (resulting later in Amsterdam, Gouda(m), Rotterdam and Schiedam)(Meyer et al., 2010).

In landscape architecture the first step for preparing natural land into agricultural land by an intervention is described as the shift from natural landscape to cultural landscape. Inge Bobbink explains that there are several layers in a system that influence each other (Bobbink,

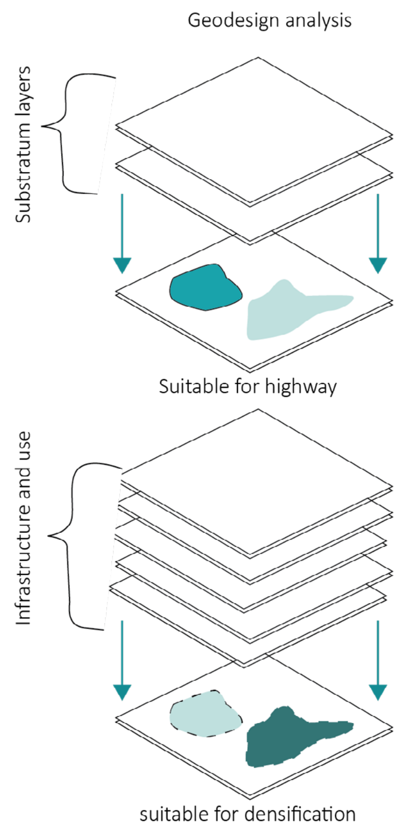


Figure 34| Different aspects can be constructed, checking the suitability for each aspect. If the maps are overlaid, a general suitability map appears, showing what area could be most suitable or the least suitable for a certain use. (Image by author)

2009). As the scheme shows, we start off with the natural layer, shaped by geomorphology, water, soil type etcetera. As soon as man use interventions in order to use the land, cultural elements are added. In the case of the surroundings of Rotterdam cultural elements can be ditches or dykes. The next layer is the urban layer, again influenced by the layer beneath it (Figure 36). So the urban layer develops itself on favorable positions close to rivers, but high enough to stay dry (Figure 35). The image shows the streets for example that emphasize the course of the river, and the location of Rotterdam is defined at the spot where two rivers meet (and one is dammed).

The edge

From a historical perspective it is interesting to discover what elements define or have defined the edges of the city and how they relate to the role ecology plays around cities. By exploring the events in history that made the city expand, it is more important to find what geographical features have defined the location of the edges than the reason why the expansion took place. In the next pages the changing edge of the city and its defining features are described. (Drawings based on https://www.rotterdaminkaart.nl/)

The series of maps of the city of Rotterdam and its expansion provide information about the changing relation between the city and her surrounding, and to a certain point provide information about what features define city expansions and their edges. They show that the starting point of the settlement is defined by geomorphological features as rivers and higher banks. The city walls are strategically placed next to the surrounding rivers, appealing for trade and easier to protect the city for invaders. The settlement started to grow when the dyke was built more regionally, the dykes built for smaller polders are often used as roads, since they are elevated. The landscape start to be more cultivated and the peat is used as fuel. The surrounding area of Rotterdam is full of polders with ditches and small peat lakes. When the city started to expand in 1825 the main incentive is to claim more space close to the river to develop the harbor. **The developed techniques by that time are more advanced, and natural features start to play a less important role in where urbanization is located.** These techniques also made it possible to inhabit even the lowest lying areas that used to be full of water.

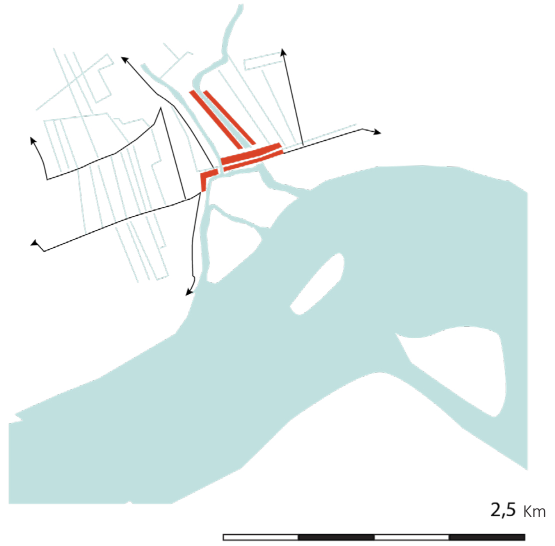
Relating back to the theory of Dramstad, Olson and Forman about edges, the majority of the edges in the historic maps are based on height difference or water-land transitions. Later on urban features such as highways, train tracks or harbor grounds become the edge of the city. The construction of dykes made the edge of water and land change drastically from border to boundary. The relationship between the city and the water has changed as well. In the first settlements the houses were only build on higher grounds. The intervention of the dykes allowed the city to expand, by now using the grounds that used to be flooded.

Tilman (1997) states: "Having outgrown their natural jackets, cities now contain within their borders various relationships between urbanism and landscape" (Tilman, 1997).

This statement shows exactly what the maps of the growth from 1940 to now show: **areas that used to be peat lands, ended up in being lakes, then got transformed to building plots for urbanization.** The landscape and the city are intertwining and the intrinsic suitability of the natural layers stopped being the determining factor of where expansion and developments should take place. The structure where the urban landscape follows the cultivated landscape has altered. Developments in the urban layer influence now also what has to change in the natural or cultural layer.

Conclusion

By not only analyzing the historic maps but also observing at the features that defined the edge of the city we see a change over time. Relating these findings to the theory of Dramstad, Olson and Forman it can be conclude that the edge between city and surrounding has changed in two ways: Firstly the edge has become more explicit. The determining features that shape the edge are more often lines like roads or train rails, where before height or natural elements shaped the edge. Secondly the edge now includes part of the surroundings in the urban structure. The urban settlement has spread into nature. This exchange of natural land, such as the peat lakes, that became urbanized in the 20th century, can be questioned according the theory of Ian McHarg. Where the edge of the city in former times restricted the built area to spots that were naturally on more suitable lands for this function, the changing course of the edge allowed the city to expand on grounds that were not suitable for building upon before. **Urbanization has used space that naturally was used for water storage.** The two functions interfere and overlap and both require more space. This area of conflicting land use can result in problems of flooding, that only get more severe taking the changing weather conditions into account. Therefore this paragraph ends with the statement that **for the future a new balance needs to be found between the city and its surroundings, taking the natural suitability of a place into account.**



First Settlement
River
Direction of expansion

Figure 35| The first settlement of Rotterdam, located on the Dam of the Rotte. (Image by author)

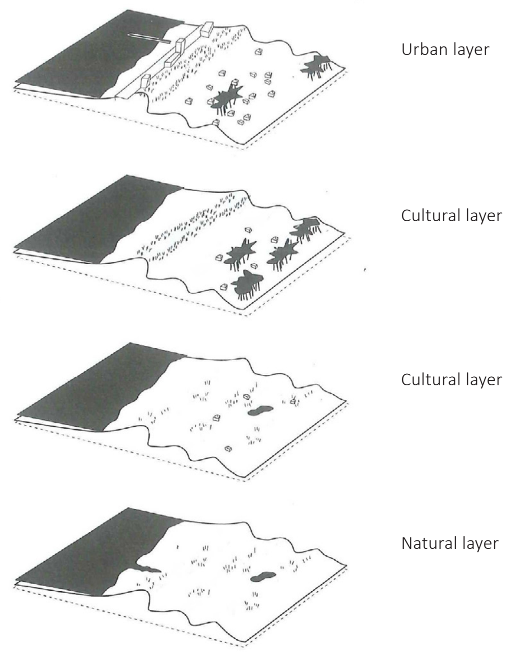


Figure 36| Layer structure of landscape: the natural layer, the cultural layer and the urban layer. (Source: Inge Bobbink, 2009)

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// The expansion of the city over time

1340

After the construction of dykes, the peat rivers needed to be dammed to be able to close the dam when there was high tide and open it when it was low. The dyke did not continue at the arms that reach form the dam to the new Meuse. They flooded often as a result that the position is in the concave side of the meander. In 1360 the dam in the Rotte became important as a point of trade. The river became also a connection from the Meuse to the lands inside of the dykes 'Holland' area. The city had walls with three access gateways, Delfste Poort, Goudse Poort and Schiedamse Poort.

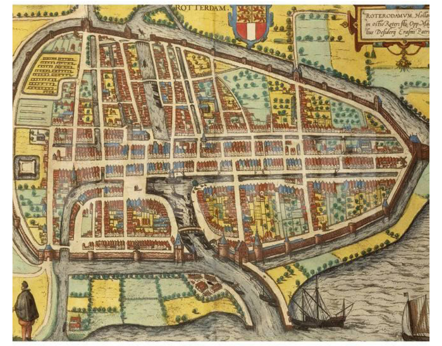
1. The Dam of the Rotte, placed on the crossing of the river Rotte and the dyke of the New Meuse
2. The higher grounds of the river bank of the Rotte


Source: Stadsarchief Rotterdam

1570

The importance of Rotterdam for Holland became grew because the Netherlands needed a harbor. The city started to grow and one of the floodplains that was a mash, was transformed to waterstad. This part of the city had large contrasts with the older city part behind the dyke: waterstad was less dense, had more panoramic views and had a more regulated clean water system. Later this became the city center.

1. City wall This wall was placed on the inside of the waterways.
2. The left waterway was men-made to connect to Delft and other cities in the hinterland.
3. Also an expansion on one of the floodplains was developed. The edges of this area where defined by the natural shaped floodplain, and drained with ditches. The sand bars defined where the building plots came. Since the area was outside the dyke, the streets where made 2,5 m above sea level to limit the floods up to once every two years.


Source: Stadsarchief Rotterdam

1690

The harbor expanded and due to the attractive environment, the waterstad part was besides port houses and trade houses also used as a residential area. There was still not a dyke, so the residents had to live with regularly inundation.

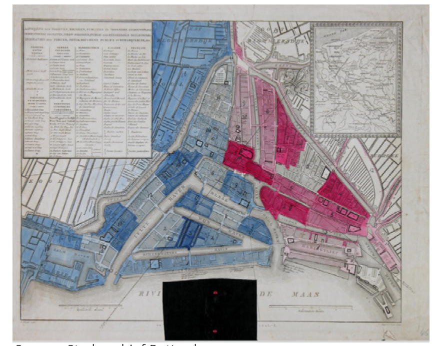
1. The shape of the expansion was pragmatic: Sand bars were build area and mashes where transformed into canals.
2. At the east side a new dyke forms the edge of the extra harbor space.


Source: Stadsarchief Rotterdam, drawing J. Blaeu

1850

At the end of the 17th century the amount of inhabitants of the 140 hectares of Rotterdam was around 50.000, resulting in a overpopulated city. Only at 1825 the first buildings were built outside the city walls, of rich people that could afford to build an extra house. The peat surroundings are excavated to provide fuel for the growing city.

The edge of the city remains the same. Only it is a bit less abrupt, since some houses start to spread around the polders. A large difference we see in the landscape, in the north close to Kralingen there are peat lakes as a result of excavation.


Source: Stadsarchief Rotterdam

1890

An enormous increase in inhabitants leads to an enormous expansion. Decreased numbers of infant mortality and immigration of people that will work in the harbor contribute to this. The market grows again and the construction of The Nieuwe Waterweg (1866-1872) have led to a boost for the port. The harbor expands to the other side of the river. The city expands outside the walls Cool, Nieuwe Westen and Oude Westen. Besides building new neighbourhoods the expansion included annexations. Small settlements like Delfshaven, a small harbor workers and fishermen village, were added to the city of Rotterdam. Respectively Delfshaven (1886), Kralingen, Charlois, Overschie, IJsselmonde (1895) result in an growth of almost 50.000 inhabitants.

1. The edge of the new shape of the city is partially defined by previous settlements like Delfshaven or Kralingen that started to grow in old estates or at the riverside of the Schie.
2. At the North side of the city a train track can be seen as the edge from city to surrounding.
3. The peat lakes are turned into agricultural lands with the help of pumps. The land is reclaimed again to use.

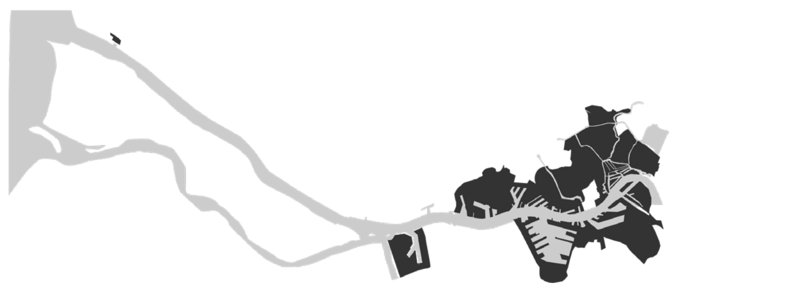

Source: Stadsarchief Rotterdam

1945

In 1904 the annexation of Hillegersberg (3.957 inhabitants)
In 1914 the annexation of 's-Gravenzande/ Naaldwijk (currently Hoek van Holland) (3.149 inhabitants) It used to be governed by the Hague. The settlement started after the Nieuwe Waterweg was dug and this was the edge of Holland(municipality Hoek van Holland, n.d.).
In 1934 the annexation of Pernis. Hoogvliet, Poortugaal and Rhoon (7175 inhabitants). These annexations together with natural growth and immigration resulted in an amount of 620000 inhabitants.

1. Hilligersberg: edge is the peat lakes on the North side.
2. 'S-Gravezande has two edges of sea and the Nieuwe waterweg. And at the north to the tramline towards the Hague.
3. Pernis is an old farmers village and positioned on a former foreland. The edges are defined by the dyke and older roads.
4. Also Hoogvliet and Portugaal and Rhoon lay low and do not show clear reason for edges on all the sides. Portugaal has one edge of a former dyke. The annexation was the start of development of harbors in that area.
5. Another edge within the city shows the land of Hoboken. This land was owned by a family and was only since 1924 owned by the municipality.


Source: Stadsarchief Rotterdam



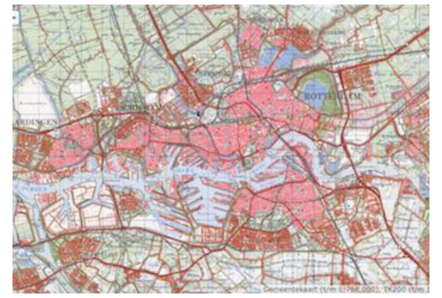
1970

In 1941 the annexation of Hillegersberg, IJsselmonde, Kethel and Spaland, Overschie, Schiebroek (57.344 inwoners)

Schiebroek used to be a small village organized next to a road. This was built on peat grounds, therefore it was changed to a polder system. It is an area with average of 5m below NAP.

Besides the annexations the enormous expansion of the harbor mark the developments in this time slot.

1. IJsselmonde has on the west side the train track and is edged on the east side with the A15 highway.
2. Kethel and Spaland are developed in between the A20 and the A4
3. Overschie is a small settlement next to the schie, at the place where later on the schie got connected to Rotterdam and the Meuse. In the North it was on the edge with peat rivers. Later on these were reclaimed.
4. Schiebroek is a small settlement on low grounds, in a polder system and is still surrounded by dykes as edges.
5. The harbor areas are outside the dykes, leveled up and have the characterizing scalloped outline. To enlarge the area land has been reclaimed at the west side.


Source: Stadsarchief Rotterdam

2008

The area within the administrative borders of Rotterdam start to be more and more urbanized. At the north east where in 1850 the landscape was marked by peat lakes new developments for housing pop up. The inclination continues and the northern neighborhoods are sinking. The edges become more forced in a way that there are better techniques to drain the polders

1. Roads are heightened every now and then so they shape often the edge in the sinking land.
2. Artificial edge of reclaimed land for harbor in the east.


Source: Stadsarchief Rotterdam

7|3 How can density be used for relocation

Changing the approach towards water by eliminating dykes mean that a lot of land will become uninhabitable. The lower areas need to be relocated to grounds that are naturally suitable for settlement. However the urban fabric itself needs to be suitable for densification as well. **Therefore a density analysis will show more insight in the types of building blocks and public space in Rotterdam.**

Density is a term used often in urbanism, starting already in 1909 when Unwin stated that a maximum amount of houses per acre could have an influence on the quality of an area (Pont & Haupt, 2010). Density is used to express the relationship between a certain amount of entities in a certain area. For a long time it has been used as a normative tool to set minimum or maximum densities for a certain place. Nowadays there is less connotation of good or bad density, but there is a large difference in the way cities of different densities perform, depending on what feature is looked at. However, density can be described in a descriptive way as well.

Therefore it is important to distinguish that there are several concepts of density, each providing a different set of information. Not alone between fields density is used in different ways (residents per unit or amounts of jobs per person), but even within the field of urbanism and planning density can result in different types of information. The same amount of dwellings per hectare could be find in a completely different urban fabric (Figure 37).

Notwithstanding the ambiguity of a density value the need for describing an urban block and its performance led to continuation of using this concept. Berhauser Pont and Haupt state that density contains valuable information about a building block and can be explained in a less abstract way. Therefore a multi variable density concept is introduced by Bergauser and Pont consisting of intensity (Floor Space Index), compactness (Ground Space Index) that together can provide more relevant information about a urban block or city (Figure 38, Figure 39). Especially since the character of density is rather concrete it can help in expressing values that are less tangible, such as livability and connect them to these concrete values of an area.

The combination of the values that FSI and GSI show us not only the amount of space that is used for dwelling, but can also give information about for example the amount of public space that can be used for green blue and grey infrastructure. In the scope of this project density is important to express the changes that can be made to the current urban fabric. If the scenarios of the future will be the most extreme ones, it could mean that the inhabitants of unsuitable areas in the Netherlands need to be relocated elsewhere. Could such relocation and therefore densification take place in the existing urban fabric?

Calculating the FSI and GSI values of the urban fabric of Rotterdam can help us later on in the project to assign what types of densification could fit where.

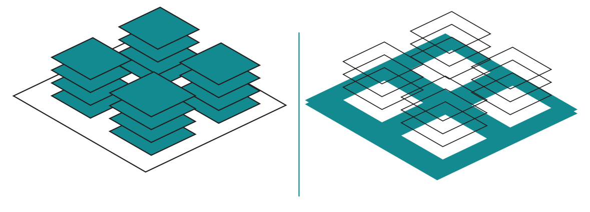


Figure 38| Floor Space Index (FSI) is derived by dividing the total amount of floor area to the complete area (Source: (Pont&Haupt, 2010))

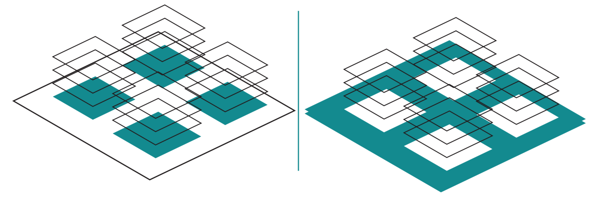


Figure 39| Ground space index (GSI is derived by dividing the footprint to the complete area. (Source: (Pont&Haupt, 2010))

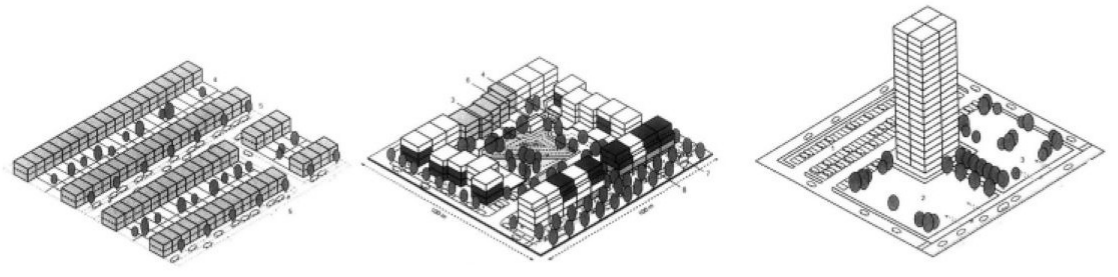


Figure 37| Three areas with 75 dwellings in one hectare (source Hernandez Per &Mozas, 2004)

FSI map Rotterdam

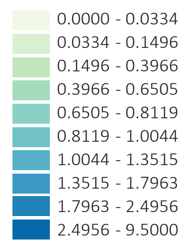


Figure 40| The city of Rotterdam and its FSI values show a wide variety throughout the city. Off course the harbor area has low values. The density values give information about the areas where densification (in more floor space) could be an option. (Image by author)

GSI map Rotterdam

0.000 - 0.013
0.013 - 0.055
0.055 - 0.115
0.115 - 0.192
0.192 - 0.239
0.239 - 0.278
0.278 - 0.322
0.322 - 0.373
0.373 - 0.435
0.435 - 0.529
0.529 -1.000

Figure 41 | The city of Rotterdam and its GSI values show a wide variety throughout the city. Off course the harbor area has low values. The density values give information about the areas where densification (in more ground space) could be an option, or where there is a lot of ground space available for example water or green. (Image by author)

The current density in the municipality of Rotterdam has a broad range, especially since the harbor areas are rather large without many buildings. Figure 40 shows the FSI value per block in Rotterdam and Figure 41 the GSI value per block in Rotterdam. The outlines of these blocks are a combination of the street network, the neighborhood border and the waterscape (Figure 42). The combination of the GSI and FSI can provide information about the type of densification that can take place in a certain neighborhood (Figure 43).

For the project it means that densification could take place in areas with a low FSI. Areas with a low GSI could accommodate water storage.

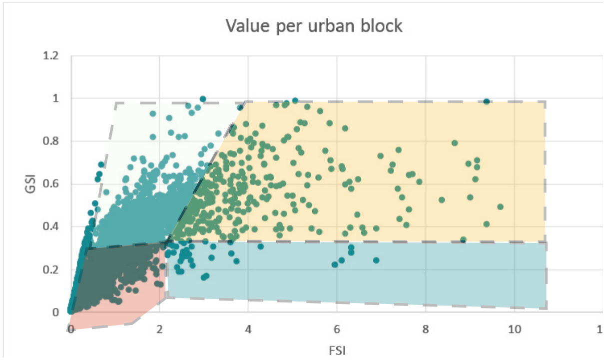


Figure 43 | The values of all the neighborhood plotted show the amount of combinations. Design interventions can be connected to this clusters. (Image by author)

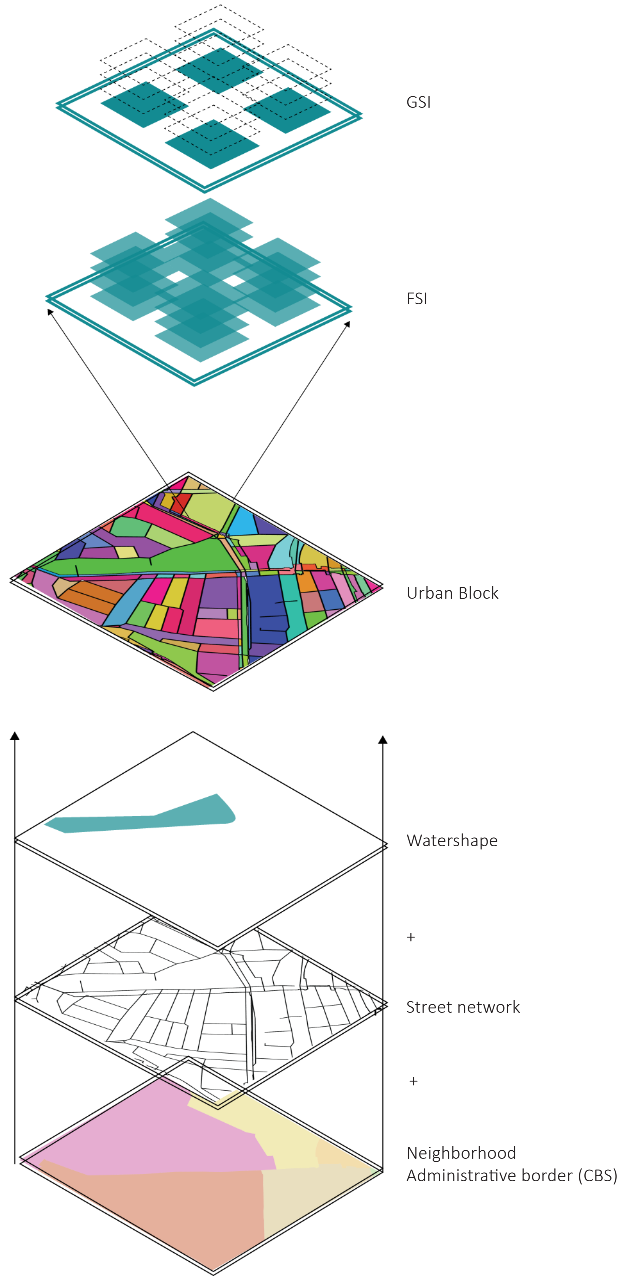


Figure 42 | How to get the density values of the urban block? The urban block is defined by the road structure, large water bodies and the administrative neighborhood borders. Together they shape the urban block. (Image by author)

7|4 What is the influence of the mental and social city on the physical city?

For changing a physical aspect of the city, the social and the mental city need to be understood. Not only for analyzing them, but also **for using the knowledge for creating an intervention that the people will use.** The narrative of a place is therefore necessary to take into account. The city and its people influence each other. The identity of a city shapes the mindset of its citizens and the other way around. Think about it, the creativity that for example Berlin hosts attracts new artist and therefore it stays buzzing in creativity. As Jan Gehl has been quoted very often "First we shape the cities -then they shape us " (Gehl, 2010)

Human interaction plays a key role in life. Looking back to the ancient times of for example the Greek, the main square (Agora) was the most important place in the city. This was the place where people would meet each other, where discussions took place and where the citizens could vote. Nowadays cities are used in a different way, especially because our day takes place in multiple places that are not so related to each other. We work in one place, but sleep in another and we go for a walk in again another place. This could lead to losing the feeling of community, interaction and sense of place (Verwilt, 2016).

This feeling of community can be stimulated by creating or discovering a narrative of the place. The French philosopher Foucault says that there are always unmappable elements such as landscapes, buildings squares and places that are part of our dream world instead of the 'real' world as described by Miskowiec (Miskowiec, 1984). If these dreams are about a society, it often is a perfected form and therefore an unreal place or utopia. These utopias could be tried to reflect and project on real life and would then become places with the character or simulation of one aspect of the utopian dream. Foucault names these 'heterotopia' emphasizing the contrast of the non-placeness of an utopian situation and the placeness of heterotopian. An example is the burning man festival in America, which is a temporary utopian dream where society shares their valuables. The idea of creating a temporary community is the starting point of this festival. The shared narrative and mindset of the people that go to this festivals shows the cohesion that a community can bring (Verwilt, 2016). This could be important especially when a project is rather extreme. The need to get the citizens aboard is high. In the hypothesis of replacing the neighborhoods to higher grounds it is important to find the characteristics of each neighborhood and find a way to create this feeling again, taking the new improvements into account.

Therefore in the project the city will be viewed upon from three perspectives: The physical, the social and the mental (Verwilt, 2016)(Figure 45).

The physical city is about what is physically there, like critical infrastructure, water storage systems, infiltration beds, functions and buildings. It is the cities structure that can support the social and mental city. Its structure, open and closeness and connectivity are the basis of a good social and mental city.

The social city is about the people in the city. Who is living where, is the city diverse? Do the people feel safe? Do people meet? The prerequisites of these social interactions are based in the physical layer.

The mental city is about the narrative. How does the city or neighborhood feel? What is the mindset of the people in a certain area? Is there a feeling of community? Are there activities in the urban space where people can participate? Does the urban environment stimulate movement and meeting? Again the prerequisites are formed in the physical layer.

All the three perspectives need to be analyzed before new interventions are made. Preferably an interventions links to improvement on more than 1 aspect. An example is a defense wall that functions as elevated pedestrian path. **In this way the spatial qualities are within the interventions that are necessary for protection reasons and the city gets improved on both physical as social way.** For the project this means that the design interventions need to contribute to at least two of the aspects. The lower the scale of intervention, the more important the mental and social component become (Figure44).

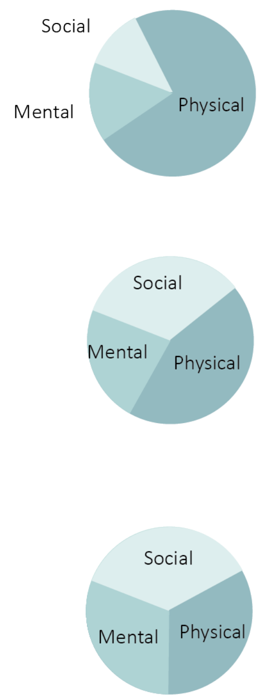


Figure 44| Depending on the scale of intervention there is a balance between the three components. The lower the scale of intervention, the more the social and mental part play a role. (Image by author).

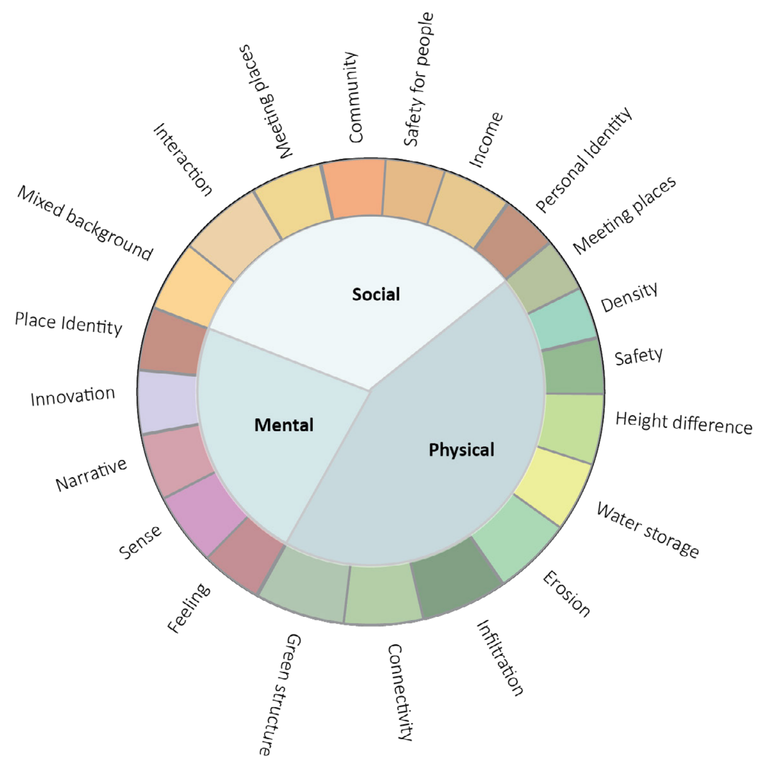


Figure 45| The three cities (physical, social and mental) play a role in analyzing and defining a city. The physical component has the most important role, especially on the larger scales. However, the other two are important for making a design that has spatial qualities as well for the people as for the water management principles. (Image by author)

7|5 How scenarios can help to project in the far future

Scenarios are described as possible future outcomes (G. Peterson, G. Cumming, 2003). They describe a possible future and therefore do not show what will happen but what could happen. With possible paths a scenario can explore possible paths of uncertain aspects of a topic. This can help decision makers in viewing several uncertainties simultaneously before making a choice (Lee, 2016). There are several levels of uncertainty with corresponding ways of dealing with this uncertainty. The lowest level would be a clear enough future. The second level would mean an that alternate futures are there, but they all have some sort of probability that they will become reality. The third level means a multiplicity of plausible futures. There are no probabilities and the interventions that have to be made need to correspond with all the optional scenarios. The fourth level deals with deep uncertainty, where the future has multiple insecurities leading to optional futures in every direction (Figure 48) . This project deals mostly with uncertainty on the third level, since there are scenarios for the sea level rise and precipitation figures. Especially with the amount of data that is accessible nowadays scenarios can be more accurate and contain information from various fields. However, the future also deals with population growth, changing political environments and the power of private organizations.

Steinitz, the author of GeoDesign, shows in his book the importance of the use geographical information in the planning process (Steinitz, 2012). He has built up a method that uses geographical information in combination with scenario based design. By questioning the current functioning of an area, it provides optional directions of how this area could be in the future (see Figure 47).

By gathering data of a certain system or area and analyzing it, some potentials or weaknesses will be found. These can be used or improved in a design. These three steps (data, analysis, design) form the basis of GeoDesign. This design needs to be reflected again on what this design would change for the future. New improvement could be found and adapted. When the context changes again, alternations can be made and a new scenario is produced. Time is an very important factor in scenario thinking. Uncertainties differ enormously in range when the time slot changes. For example the weather can be forecasted for tomorrow in a more accurate and precise way then the weather of next month. The scenario will become more detailed the more the 'now' approaches the future (Figure 47).
Scenario thinking can help to develop new knowledge that can solve problems in the future (Sarpong & Maclean, 2011). The scenario for climate change shows for example that there could be longer periods of drought and more heavy rain events. Then the design and policy set can be developed that can perform better with these events.

In the Netherlands, the KNMI has made four scenarios of climate change. These are based on the world wide temperature rise and on the other hand on changing air flows. The change in temperature will vary from intermediate to warm, the airflow will vary between low and high value. This results in scenario A) Intermediate temperature rise and low influence of change in air flows, B) Intermediate temperature rise and high influence of change in air flows, C) Warm and low change in airflows and D) Warm and high change in airflows(Figure 46 and Appendix 1).

From these scenarios some clear design task arise, such as reducing the Urban Heat Island effect, improving the water defense systems, improving infiltration, slowing down the rainwater runoff. In the scope of this thesis scenario thinking is actually the basic principle. This shows in the main question: How can the spatial structure of Rotterdam be transformed in order to prepare for extreme sea-level rise. **The question is based on the possible future where we have to deal with extreme sea level rise and changes in precipitation.**

The scenarios show a range of variability in the future. It could be helpful to look at the more shallow uncertainties to see what the scenarios have in common. If a tipping point has been reached, it could mean some of the scenarios are not longer relevant and the focus needs to be shifted towards others.

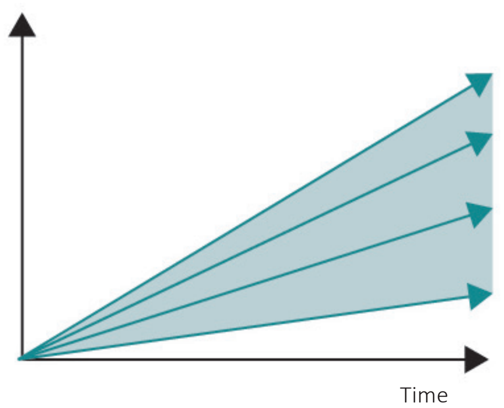


Figure 47| The scenario range is larger when the time span gets longer. The shape of the uncertainty is important as other data can influence the range. (Image by author)

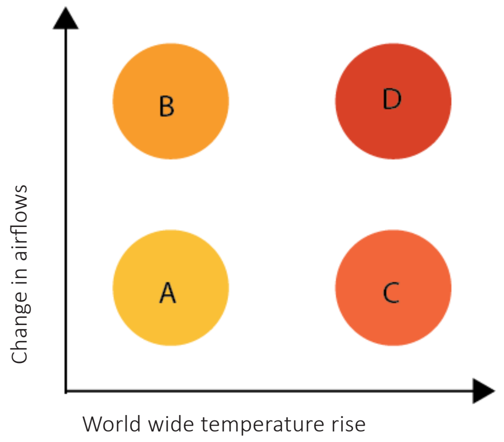


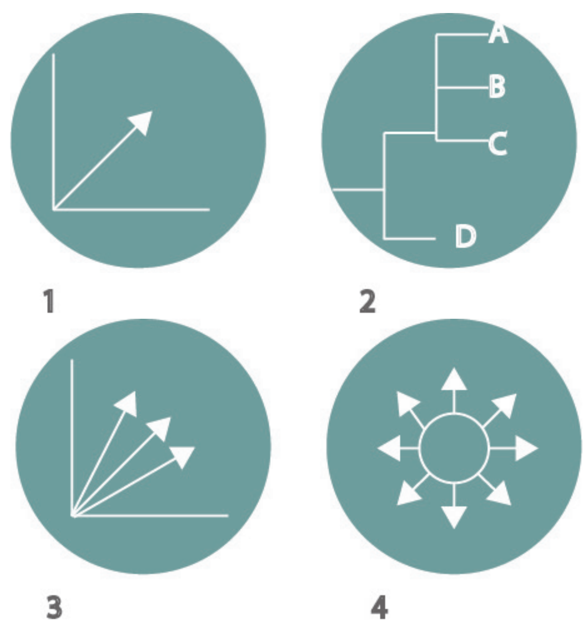
Figure 46| The four scenarios of KNMI for the Netherlands: scenario A) Intermediate temperature rise and low influence of change in air flows, B) Intermediate temperature rise and high influence of change in air flows, C) Warm and low change in airflows and D) Warm and high change in airflows. (Image by author, based on (KNMI,2014)

The downside of making incremental changes within the water system, is that they can result in a safety paradox, where the system at some point will not be prepared for the most extreme scenario. An example is the incremental change of making a dyke higher. This intervention will result in a more expensive transformation if in the future this dyke needs to be pushed back. However if the interventions remain space for deflecting to more extreme scenarios the adaptive capacity can be enlarged (Figure 49).

For this project the starting point is already more extreme, to see what kind of spatial impact this could have and what kind of interventions are needed. Since it is not the question if the Sea level is going to rise, but rather when it is going to rise, the phasing of the project is key.

Conclusion
Since this event is placed in the future (2060) a lot of context can change. Therefore it is important to track the tools used in this design process. The trends of the problem field show part of the scenario we are dealing with. For this project the following figures are the scenario that is used:

- Population growth (for Rotterdam up to 650 000 inhabitants in 2050 (CBS, 2013).
- Economic growth
- Rising water problems:
-Sea level rise (up to 3 meters)
- More and more heavy precipitation
- Period of drought



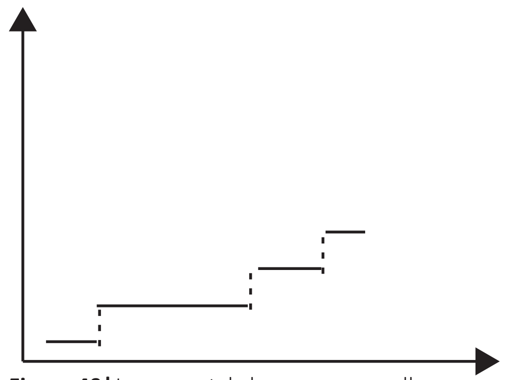
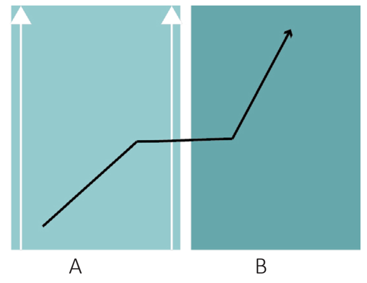


Figure 49| Incremental changes are small adjustments made towards an end result. They can be changes that are common steps in al scenarios. (Image by author)

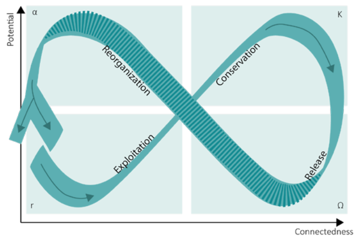
Figure 48| Four levels of uncertainty. The lowest level would be a clear enough future. The second level would mean an that alternate futures are there, but they all have some sort of probability that they will become reality. The third level means a multiplicity of plausible futures. There are no probabilities and the interventions that have to be made need to correspond with all the optional scenarios. The fourth level deals with deep uncertainty, where the future has multiple insecurities leading to optional futures in every direction. Scenario thinking is placed in the third level. It does not have probabilities. (Image by author, based on (Courtney, 2008))

7|6 Conclusion of theoretical framework

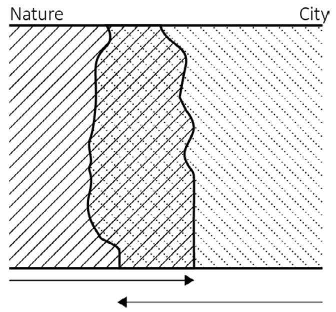
The main conclusion of the aspect from theory and what the findings mean for this project are shortly listed below.



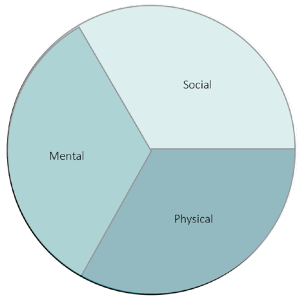
Transform current approach
The current approach towards water is not sustainable for the future, taking the trends into account.



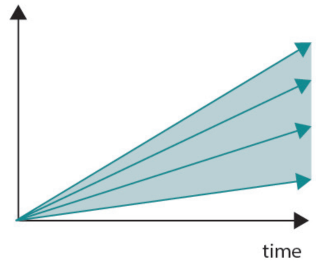
Enlarge adaptive capacity
The new system should be able to adapt when future changes occur.



Relocate the lower grounds and densify the higher ones
The natural suitability should play a role in defining where to settle. The edge between city and surrounding becomes defined by height and soil type.



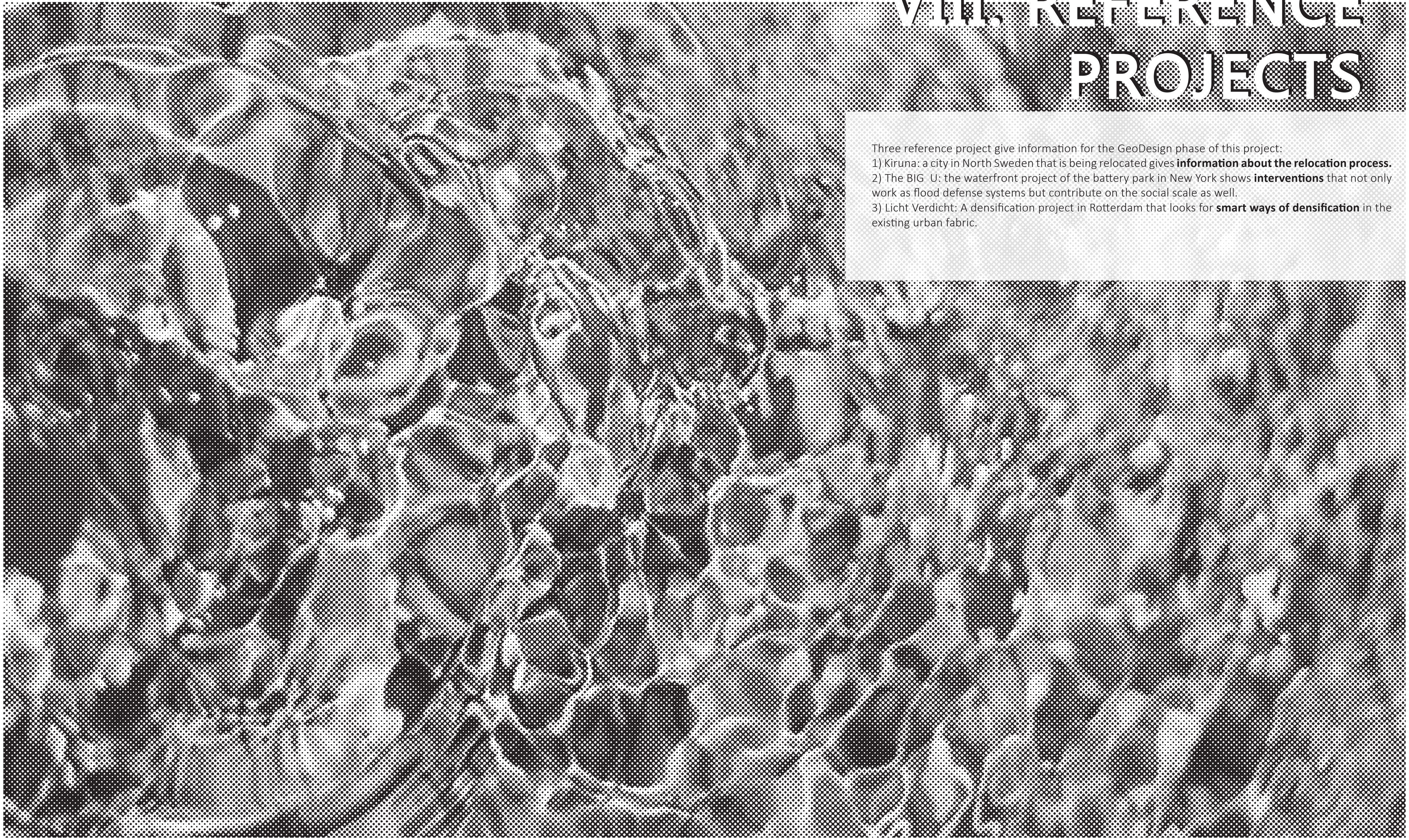
Design for physical, social and mental city
Design interventions should contribute to at least two components.



Use the extreme Scenario
To see what impact climate change could have, spatially seen. Show that the design is not 'set' but can change and adapt over time.

VIII. REFERENCE PROJECTS

Three reference project give information for the GeoDesign phase of this project:
1) Kiruna: a city in North Sweden that is being relocated gives **information about the relocation process.**
2) The BIG U: the waterfront project of the battery park in New York shows **interventions** that not only work as flood defense systems but contribute on the social scale as well.
3) Licht Verdicht: A densification project in Rotterdam that looks for **smart ways of densification** in the existing urban fabric.



8|1 Kiruna- the process of relocation

The city of Kiruna is located in the most Northern part of Sweden, above the polar circle. The city was founded in 1900 by the state owned mining company LKAB, to provide a basis for the people working in the iron ore mine. The company expanded the mine every year since the ore is located deeper in the ground. The next phase of this expansion brings part of the city in danger as it is positioned on top of the planned expansion. Therefore the city of Kiruna decided together with the mining company to literally move the city 2 kilometers to the east**. As this is very recent example of relocating a town, the project can give more information about the way the phasing works.** The winning design has been made by White Arkitekten in collaboration with Ghilardi + Hellsten Arkitekter, Spacescape AB and Vectura Consulting AB and proposes a phased transition of the city and its citizens to the east. The biggest challenge they define besides the physical transformation is to move the social aspect and the identity. To translate this identity and the values the citizens give to certain places an anthropologist makes a more tangible input for designers of the interviews they have had (Figure 51).

A lot of synergy is proposed within the transformation to create a more sustainable, more attractive, more mixed and less dependent city. Besides this the goal is to create a city capable of changing, by keeping planned space for further development of changes**. In the phasing of the project there is adaptive capacity to cope for political, environmental and spatial changes.**

The project starts by creating the new city center at the outskirts of the current. This center has to compete with the old or current city center. It is important that the two centers do not necessarily compete, but rather complement each other in the first phase. Therefore Ghilardi explains that temporary functions and events are necessary. In this way the functions can be slowly implemented in the new center without having a long period of decay in the old area. The paradox of moving the city is that is has to do with crating a lively are at the one side of an axis, whereas at the other side a slow decay is taking place (Figure 50).

2014-2020:The first phase of the project is building the new city center, including a city hall and some functions like shops and a swimming pool.

2020-2033 : Then some building blocks with a higher density are built to host the people that have to be relocated the first.

2020-2033: Increase amount of meeting places in order to create a lively and mixed public space .

2033: Then the old city center becomes less important as more of the functions move towards the new center. This creates an expansion of the new center towards the old center, it starts to connect the two centers, but finally decays the location of the old center completely since it is on the remove zone.

Input for Relocating Rotterdam:
A good note is that in all the stages the intervention keep space for future changes. Especially for keeping space for new infrastructure and room for more eastwards expansions there is space left. Some people give critique on the fact that the city only moves 2 kilometers away, but the planners mention that in this way the old city identity can be maintained and continue with the activities that make the city worth existing. For Rotterdam this could have an effect on the harbor.

Figure 50| The stages of moving the city show that there will be two city centers at some point. These should not compete with each other, therefore temporary functions can help to make both centers lively. In the final phase all functions of the old center are replaced either by the new center or by function along the new main road. (Image by author)

Figure 51| The view on Kiruna in 2100 when the city relocation has been completed. The schemes show how the new center will gain in the amount of functions over time. It guides to a new direction of the main axis. Changing the centralities is an important point in the relocation of Rotterdam. (Source: white Arkitekten)

8|2 The BIG U- the resilient waterfront

The BIG- team is led by Bjarke Ingels Group and includes a lot of other companies that deal with fields as landscape architecture, water management, urbanism and ecology. This team has together developed a plan for the New York waterfront (or the BIG 'U") that brings the concept of social infrastructure and hedonistic sustainability together. By connecting public infrastructure with social programs, the team tries to create new forms of urban life in the city.

The incentive of this project was hurricane Sandy, that destroyed a large part of the urban area of Manhattan. The storm destroyed much of the infrastructure, stopped the economic heart of the Financial District for over a week and trapped people in their apartments. The project aims to not only focus on improving the infrastructure in traditional meaning of the word, but think of it as social infrastructure. The large-scale protective infrastructure should therefore be combined with a commitment to meaningful community engagement (Figure52).

The team has three main connection goals:
-Resiliency infrastructure + People
-Resiliency infrastructure + Program
-Resiliency structure + Community

This result in a multi disciplinary approach that aims to improve several aspects within one project.

" The artful combination of a classical engineered infrastructural element with desirable social functions of each community can produce an almost unnoticeable protection."(BIG team, 2014)

In other words, if the interventions that can reach the water management protection goals can be combined with public or social functions, they improve the public space in stead of dividing or degrading it.

In order to come up with a contextually appropriate intervention BIG team defines a vision per area. In this way the local conditions can be taken into account to create from a set of interventions a tailor made design.

The team has constructed some design principles or ideas for the area in order to discuss them with the public. Some examples are shown on the right page (Figure 53). **These 'general' interventions toolkit can be transformed to fit in the structure of the specific area. These interventions can also be used in the Relocate the Randstad project. They need to contribute in their own way to the social and mental qualities and issues.**

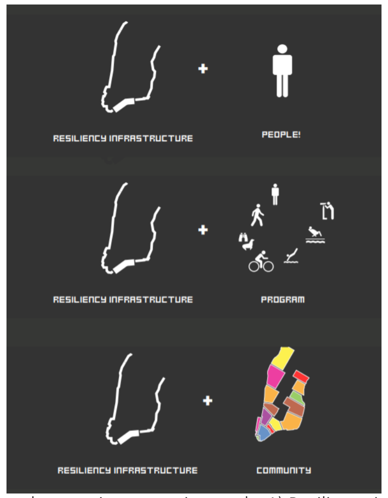
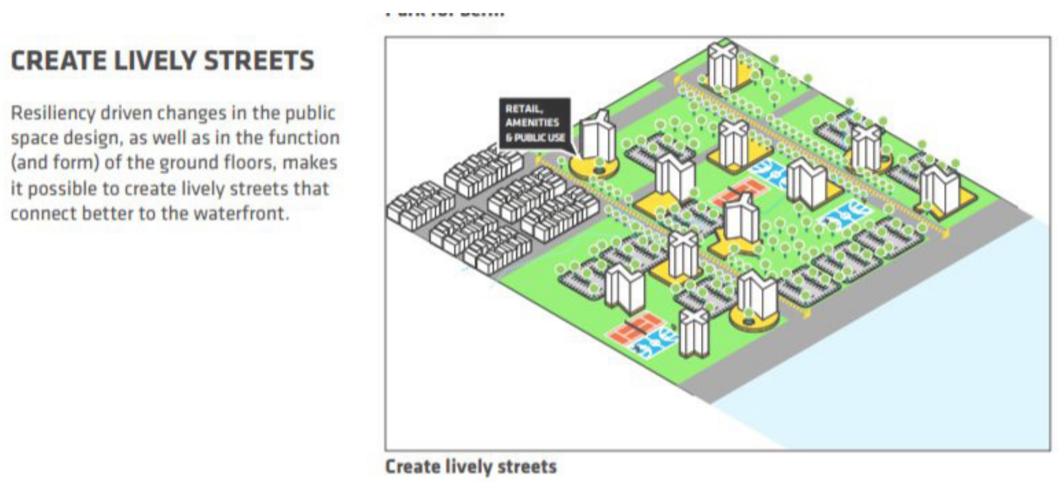


Figure 52| The team has three main connection goals: 1) Resiliency infrastructure +people; 2) Resiliency infrastructure + program and 3) Resiliency infrastructure + community. This approach is beneficial because it boosts the social and physical components of the city within one project or intervention. (Source:(BIG team, n.d.)p.3)



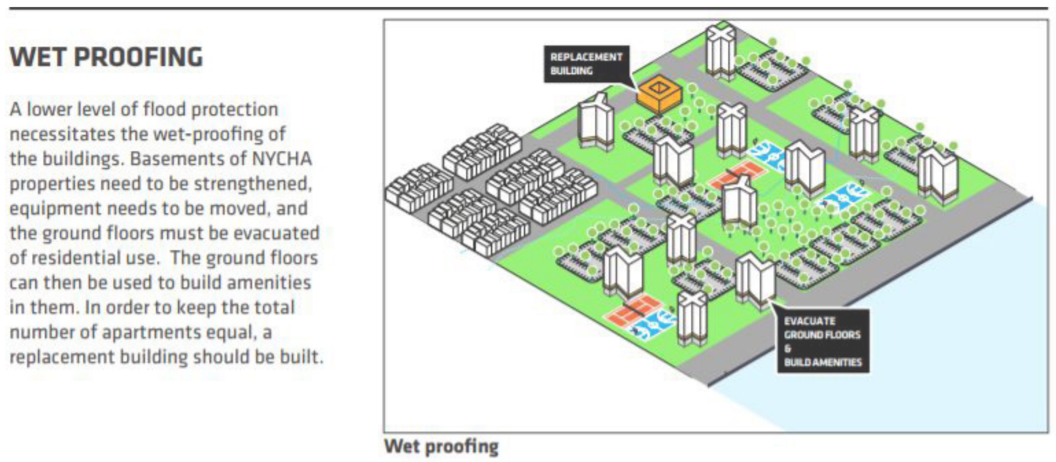


Figure 53| Three interventions show the connectedness of intervention for flood protection on the one hand and social stability on the other. The synergy is beneficial on financial grounds, on social support and on awareness. (Source:(BIG team, n.d.)p.189-193)

8|3 Slightly densified- densification options

Densification of existing urban fabric is currently a relevant topic since a lot of cities all over the world want to increase the amount of floor space in the center. The high value of floor space make it profitable for developers to top up existing buildings in order to create more floor space with using less ground space.

In 2016 the BNA (Royal Institute of Dutch Architect) started a design research Licht verdicht-Slightly densified – that explores ways of **densification in an existing urban context**. The city of Rotterdam has been chosen for this experiment. Seven teams have designed a proposal to densify on top of existing buildings. The large quest for densification that is needed for the Relocate Rotterdam project can relate with the outcomes of the research of the BNA. **The proposals show that there can be added not only floor space, but also quality of life.** The construction of the existing building is often not completely used. In other cases extra constructional elements are added to carry the new load. Figure 55 shows the smart use of the existing construction and the new elements that need to be added to carry the load of the new building block. The design (a collaboration of KCAPIMd, Fakton Development an Wijnand Galema) uses the roofs as a extension of the public space. In a way it is possible to escape from the city streets and go to the roofs to relax. Figure 54shows another result of the research, a collaboration of NOAH, HOSPER, Zonneveld ingenieurs and Studio Drift, where the densification results in a vertical city. A multifunctional building block provides a diverse view: offices with gardens, living and culture. These project show large scale densification and add often more that double of the floor space compared to the existing building. **The projects can visualize how a densification could work and helps this project in providing examples.**

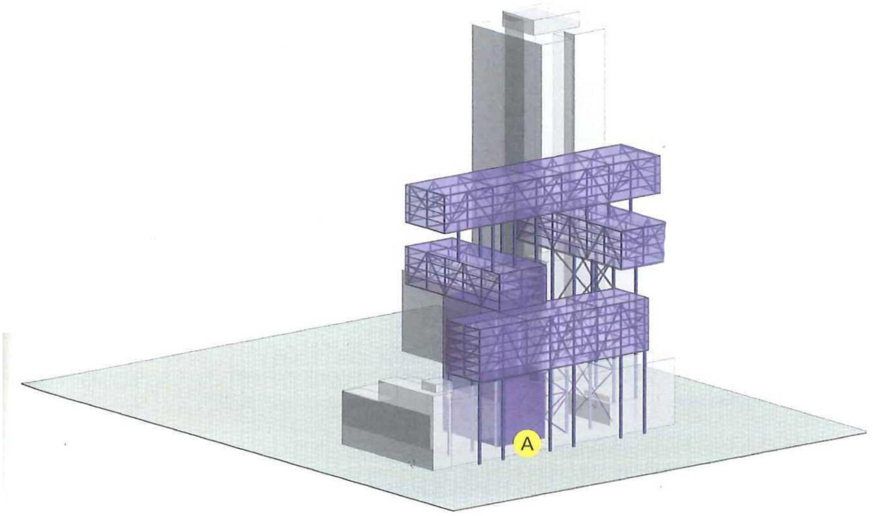


Figure 54| A schematic overview shows how large blocks can be added to the Kruisplein (Weenapoint). This example adds no extra load to the construction of the existing building. Its new structure allows the blocks to 'fly'. (source: (Sanson & Schoorl, 2017), p. 93)

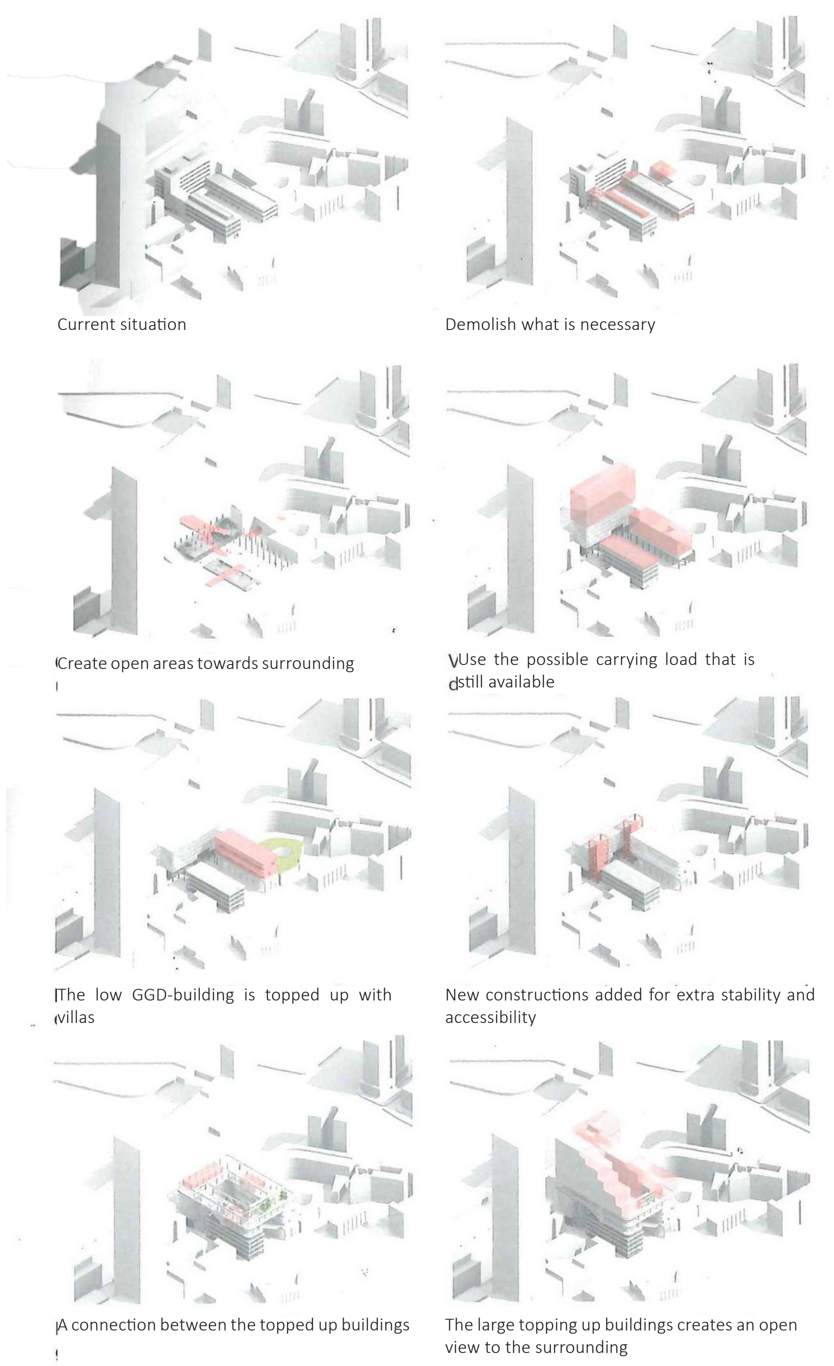


Figure 55| Step by step these images show what is added to the current situation. Extra load is added to the existing construction, but new elements are added as well. Besides extra floor space this design gives more public space on several levels. (Source: (Sanson & Schoorl, 2017), p. 93)

IX. GEODESIGN FRAMEWORK

This chapter uses the theory of GeoDesign to define:

What is already there?
The main findings of the assessment phase are listed in this chapter (complete assessment in analysis booklet), forming the input for a possible design outcome.

What could be there?
Translate the qualities and the necessary changes of the current built environment into a spatial design output.

Since adaptivity is one of the design principles, the phasing and flexibility of the design is important. Therefore the impact over time will be visible in the design as well.

This chapter is organized to look in each paragraph at these aspects per scale;
1| Explanation of GeoDesign Framework
2| Defining the scales
3| (Inter)National scale
4| Regional scale
5| City scale
6| Neighborhood scale
7| Street scale

The City, neighborhood an street scale will contribute to the 'What could be there" in design.

1| Explanation GeoDesign Framework

The first part of the GeoDesign questions focus on what is there now (Figure van methodology). This could be seen as the assessment of the place. By gathering data from several fields, looking at how the data is combined in geospatial terms and taking the trends into account, the current approach can be critically be assessed. This results in the one hand in qualities of the place or of the approach that could be used for the future. On the other hand it brings features or processes to the surface that could be changed or improved.

The outcome of the assessment per scale of intervention could be seen as design principles that either show what qualities should be kept or what elements should be changed. Together with the principles that are already stated in the theoretical framework the iterative design process could start as described in the methodology. The main points of the assessment are written down per scale in this report. The extensive assessment can be read in the extra analysis document.

The second part of the GeoDesign questions focuses on what could be there. The focus of this lays on the design iteration and the evaluation of how this design reflects back to the principles made.

The paragraphs of this chapter correspond to the five scales. Per scale the assessment and the design phase are showed. **The assessment and design phase of the separate scales influence the other scales as well.** Interventions on lower scales can contribute to design principles set on the higher scale assessment. And the assessment on lower scales can be directed by question that came up at design of the higher scales.

The first two scales (national and regional) focus mostly on the assessment and less on the design. They explain why a change in approach towards water is needed and what areas should be relocated and what areas should be densified. **The city, neighborhood and street scale have a focus on design** to show what this relocation and densification would mean for the urban structure (see figure 56).

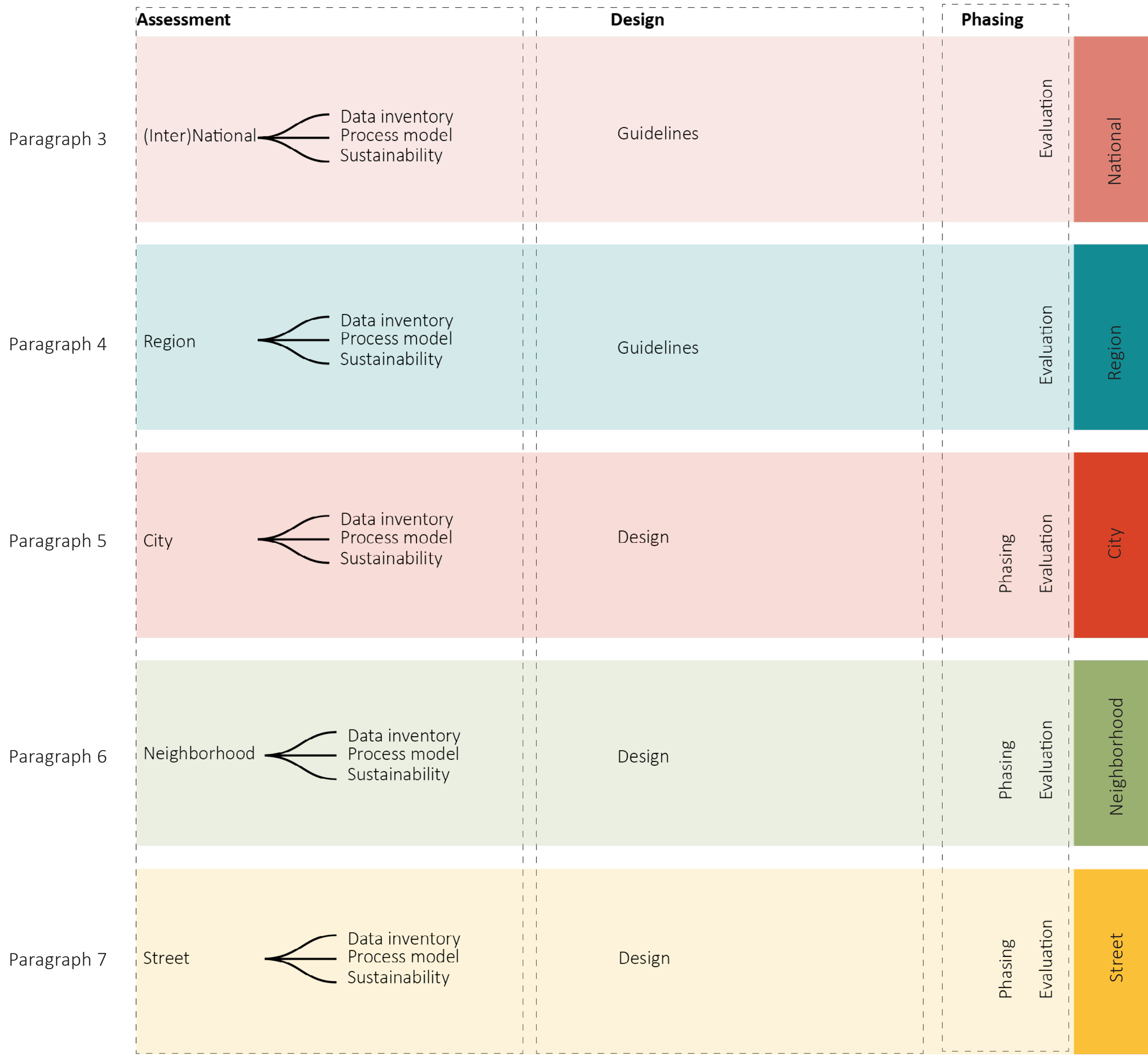


Figure 56| The scheme of the steps made (assessment, design, phasing) per scale ((inter)national, regional, city, neighborhood, street). The scales correspond to the paragraph numbers. It is important that the output of the first two scales are guidelines that shape the direction of the lower scales design interventions. (Image by author).

2| What are the scales?

The process of analysis and steps towards a design will be structured using the framework of GeoDesign, of Carl Steinitz (Steinitz, 2012). In this way each step can be made more explicit and clear. As has been described already in the problem analysis, the water system of the Netherlands works throughout several scales. The interdependence of these layers on each other is high, since all the systems are connected. To find out the impact of design principles for the large scale, the smaller scale has to be analyzed as well (and the other way around). Five scales will be analyzed, respectively the System scale, the region scale, the city scale and the neighborhood scale and the street scale (Figure 57).

(Inter)national scale -Netherlands and Rhine basin
To understand the water system of the Netherlands the relation between the rivers and the sea is important. The analysis will focus on the river Meuse and Rhine, their tributaries and their course towards the sea. The water system covers up the complete catchment of the rivers and therefore exceeds country borders. Where do people live? What is the current approach? Part of the analysis has been already discussed in the problem field chapter. This scale looks also to management and policies of water and spatial planning. These are defined on the higher levels of the government.

The Region Scale -Randstad
Zooming in to the Randstad scale, makes it possible to explore the most valuable area of the Netherlands. Since the Water boards are together with the municipality responsible for the water task, a region is marked that takes several administrative borders into account. The selection of the area is based on the administrative boundary of the water boards. The water boards have a history that go way back and are still responsible for the management of water on the regional scale (water quality, water defense) and a close connection to the municipalities about spatial planning (Assessment booklet, Figure 11)). Since the project aims on changing the structure of the Randstad to reduce risk, this regulatory boundary is a logical option. **It is important to keep in mind that activities and networks exceed borders.** However, for the sake of clarity these borders are used to define where to zoom in. The water boards that are together covering the dyke ring 14, containing most economic and social value, are Delfland, Schieland en Krimpenerwaard, De Stichtse Rijnlanden, Hollandse Delta, Amstelen Gooi en Vecht and Rijnland (See Assessment booklet Figure 12).

City Scale - Rotterdam
The translation from the larger scale to the small scale requires a reduction in size of the site. The suitability maps specify the suitability values for each neighborhood in the Randstad region. However a city works as a cluster of neighborhoods. The networks and infrastructure are larger than the neighborhood scale. Therefore analysis on the city scale is important: What are the clusters, how does the city work in terms of critical infrastructure? Rotterdam is chosen as a city of further exploration. The Randstad analysis shows that Rotterdam contains of neighborhoods that vary from suitability level 1 to 5 within the borders of one municipality. Also the suitability for densification vary. **Moreover the height level of some neighborhoods in Rotterdam are one of the lowest in the country.** The analysis for this scale are described in a way that they could also be done for other cities.

Neighborhood scale - Katendrecht
The outline of changes can be designed on a larger city scale, but the analysis stays rather rough. To take the livability and human factor in the analysis as well, there will be zoomed in on one neighborhood (Katendrecht) that can be an example for this scale. Katendrecht is used since it is a harbor area that is already transformed to an urban area, so it can show densification and transformation as one of the first areas.

Street Scale
Within the neighborhood the design on the street level funds the intervention to reach its goal on the higher scales.

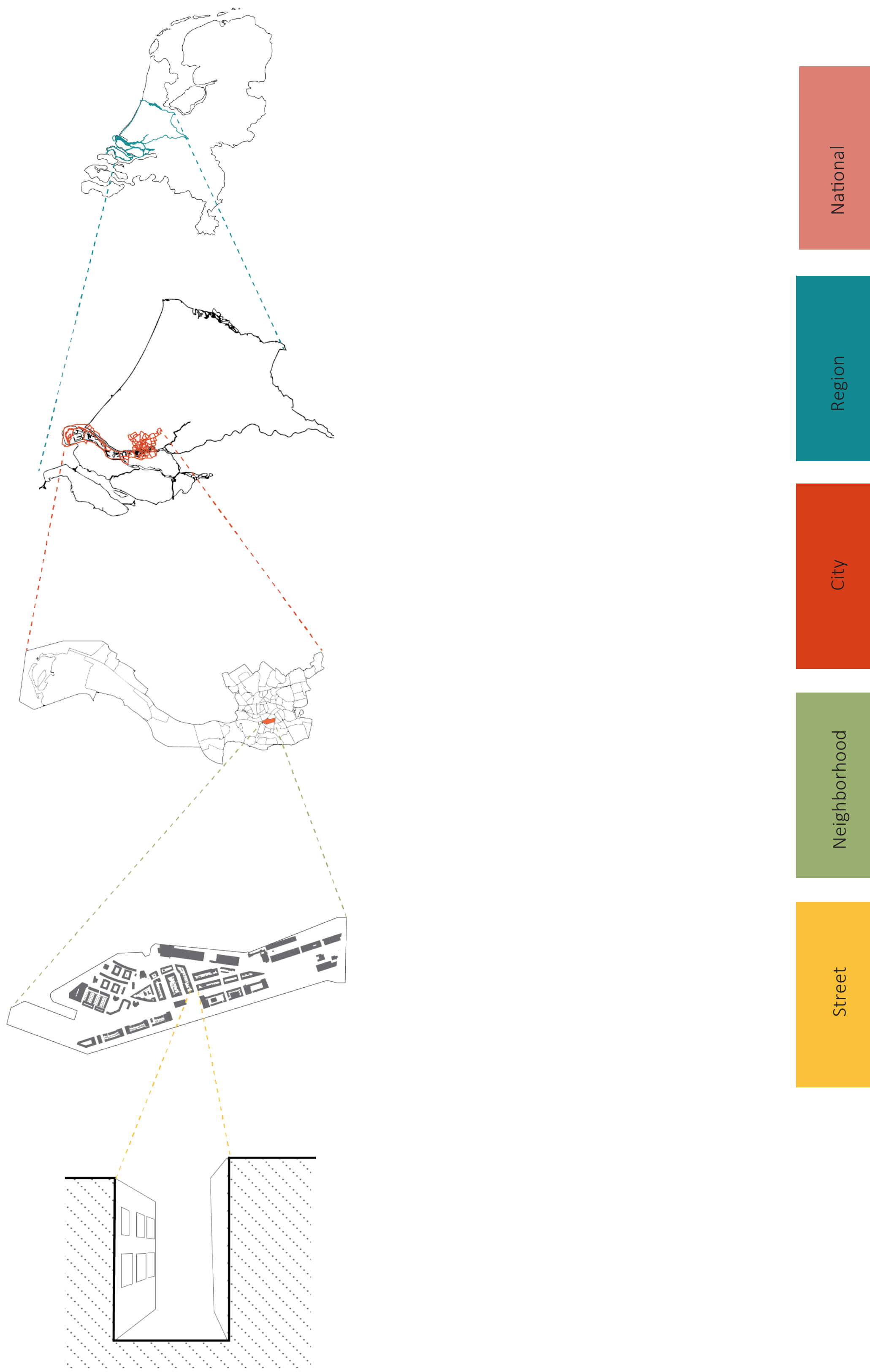


Figure 57| The chosen scales ((International), regional, city, neighborhood and street) and their borders. It is important to keep in mind that the activities, networks and ecologies do not stop at the borders. However, for this project the borders are used to specify on what area the focus lays, since not all data can be taken into account. (Image by author)

3|The (inter)national scale

The problem field and theoretical framework emphasize that the current approach leads to a negative spiral. The system scale shows the unilateral approach that the current risk management in the Netherlands has. On paper there is a multi-layered safety approach that focuses on **defense, spatial planning and evacuation** (Figure 58). However, in practice this trichotomy is not yet visible and interventions focus essentially almost on the defense part (appendix 2).

Besides that the assessment shows that there are factors that either increase the water problem (climate change (increased river discharge, extreme precipitation, drought and sea level rise), ground subsidence, the reference level of NAP) or increase the uncertainty of future models (the difference in gravity on the geode, external and internal migration towards the Randstad). The current approach for example has blocked out the natural system of erosion and sedimentation in order to protect the land. The pumping and peat extrusion result in extra land subsidence.

The innovative line the Dutch have had in history regarding water could continue with exploring a new approach.

How long do we continue heightening up the dykes? **The important role the Randstad plays for the society combined with the rising water threat results in the urge to find a new system that approaches risk differently but enhances the qualities the delta has.** This is therefore the main guideline that the assessment on this scale brings. Abstaining from using dykes raises the question **what the higher grounds are that do not flood when there are no dykes.**

Figure 58| Scheme of the Multi layered safety approach in the Netherlands. The first layer is focused on prevention or dyke improvement. The second layer focuses on spatial planning and the contribution it could have in terms of risk. The third layer is about evacuation: if the first layer and the second layer do not prevent an area from flooding, it is best t have clear evacuation and safe spots. (Source: Beleidsnota Waterveiligheid 2009-2015)

Figure 59| The Randstad as cluster of four cities, positioned in the Delta of the Netherlands. (Image by author, data from SRTM)

// Design properties- national scale
The national scale shows the unilateral approach that the current risk management in the Netherlands has. The country has blocked out the natural system of erosion and sedimentation in order to protect the land. The pumping and peat extrusion result in extra land subsidence. How long do we continue heighten up the dykes? The important role the Randstad plays for the society combined with the rising water threat results in the urge to find a new system that approaches risk differently but enhances the qualities the delta has.

// Qualities//

//Enhancing Multi-level safety approach//
Emphasizing e on spatial planning and evacuation level as well.

//Keep being innovative in water engineering//
Find ways to deal with the water problems of the future

//Using the water we have in the delta//
Make use of the leisure qualities and transport options of water.

// Changes//

//Making use of the sediment of the river//
The dykes prevented for heighten up the hinterland, so subsidence and tectonic plate changes could not be corrected. The low lands are fed with sediment now.

//Prepared for the consequences of climate change//
Increased river discharge
Extreme precipitation
Drought
Sea level rise

//Investing in the higher grounds //
Accepting that parts of the Netherlands are below sea level led to discovering other centralities in the country.

// The question for the next scale- regional
If heightening up dykes is no longer the approach, the low located areas need to be defined. What areas are not suitable for settlement because of their natural condition? And how many people live in these areas? If the naturally seen unsuitable areas need to be relocated, the next question is to where? In other words, what areas are suitable for densification? These questions are explored on one step lower than the national scale: the regional scale.

4| The regional scale

On one scale smaller, the regional scale explores what abandoning the dyke system would mean for the economic and social center of the Netherlands. Within the Randstad two suitability maps are constructed to find out:

1) What areas are naturally seen suitable for urban settlement?(Figure 60 top)

2) What areas are suitable for densification? (Figure 60, bottom)

Both maps are constructed following the GeoDesign method of overlaying geographic information to define whether an area is suitable for a certain type of use or not. The layers contain different types of information that define partially the suitability. For the first map – suitability for settlement – only two substratum layers are used; the **height map** and the **soil type map**. Height plays logically seen an important role in defining what areas are not suitable for living without dykes, since the lower the area, the less suitable. The soil type map explains mostly that peat areas are less suitable since the result in ground subsidence and are therefore making the ground lower.

The second suitability map is based on **the presence of critical infrastructure** such as hospitals, road network, electricity and gas stations. Figure 61 displays how the GeoDesign method is used to spatially overlay different types of information. The complete constructions of these maps and their value in defining the suitability is explained in the extra analysis booklet.

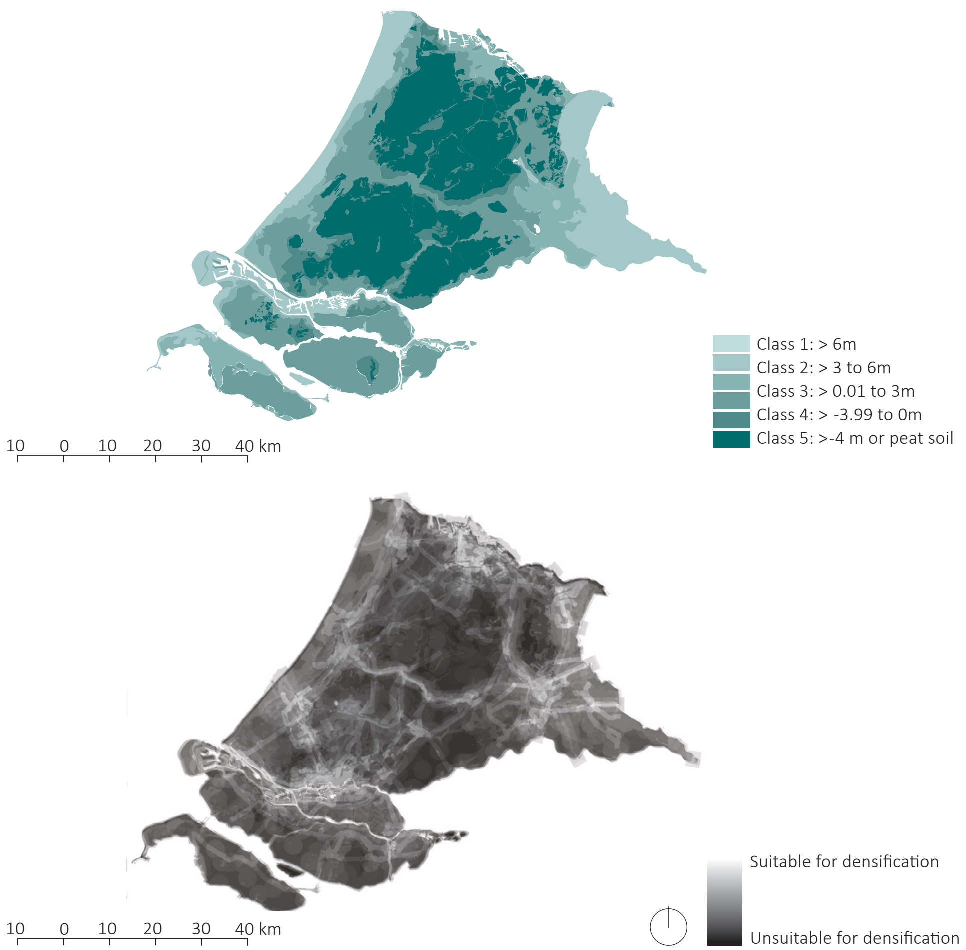


Figure 60| The two suitability maps. Above the suitability for settlement based on substratum layers soil type and height. Below the suitability for densification based on the presence of critical infrastructure such as hospitals, roads and electricity network. (Images by author)

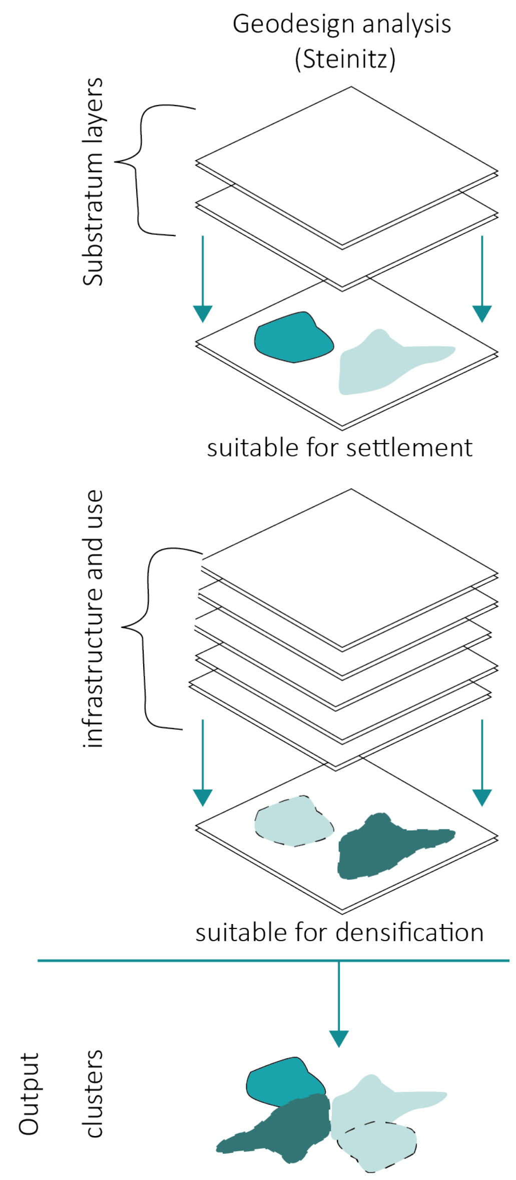


Figure 61| The Layers in overlay will together deliver suitability maps. There are two suitability maps constructed, one that shows the suitability for urban settlement and the other shows suitability for densification. (Image by author)

Suitability for urban settlement and the city

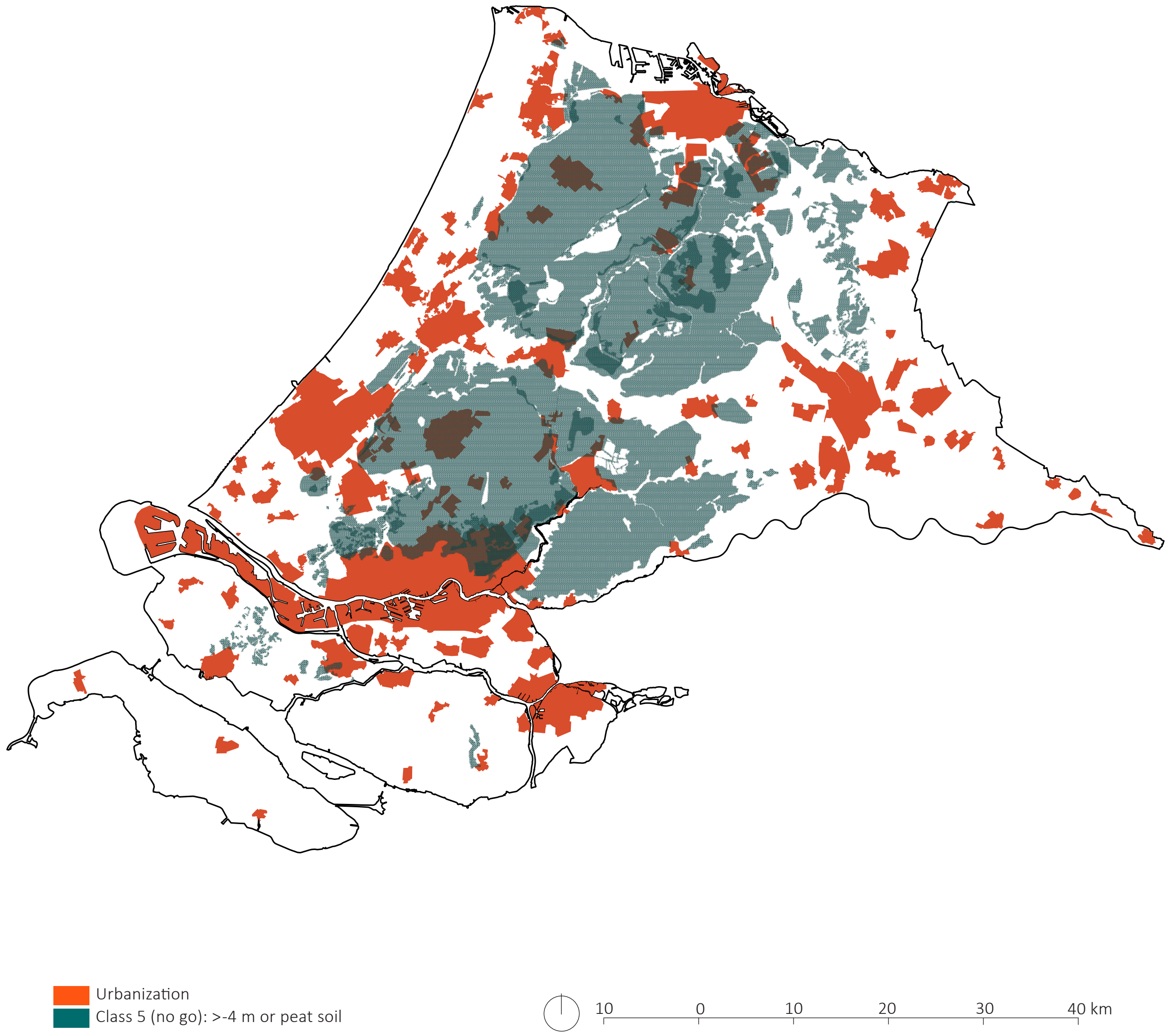


Figure 62 | To create the map that shows the suitability for urban settlement, the substratum layers 'height' and 'soil type' are combined as explained in the legend of the previous pages. The green area in the map shows the no-go area, a combination of the two least suitable areas in terms of height or soil type. This means the area is either below-4 NAP or its soil consist of peat. If this map is combined with the city shapes it is interesting to see that most of the city centers are outside the no-go area. The expansions and suburbs only grew there after the Dutch were able to control and manipulate the water. The suitability and the no go areas are now determined, but what does this mean? What are the patterns? How many people are actually exposed to extreme risk? How many houses are there in the area's? (Image by author)

Suitability for densification and the city

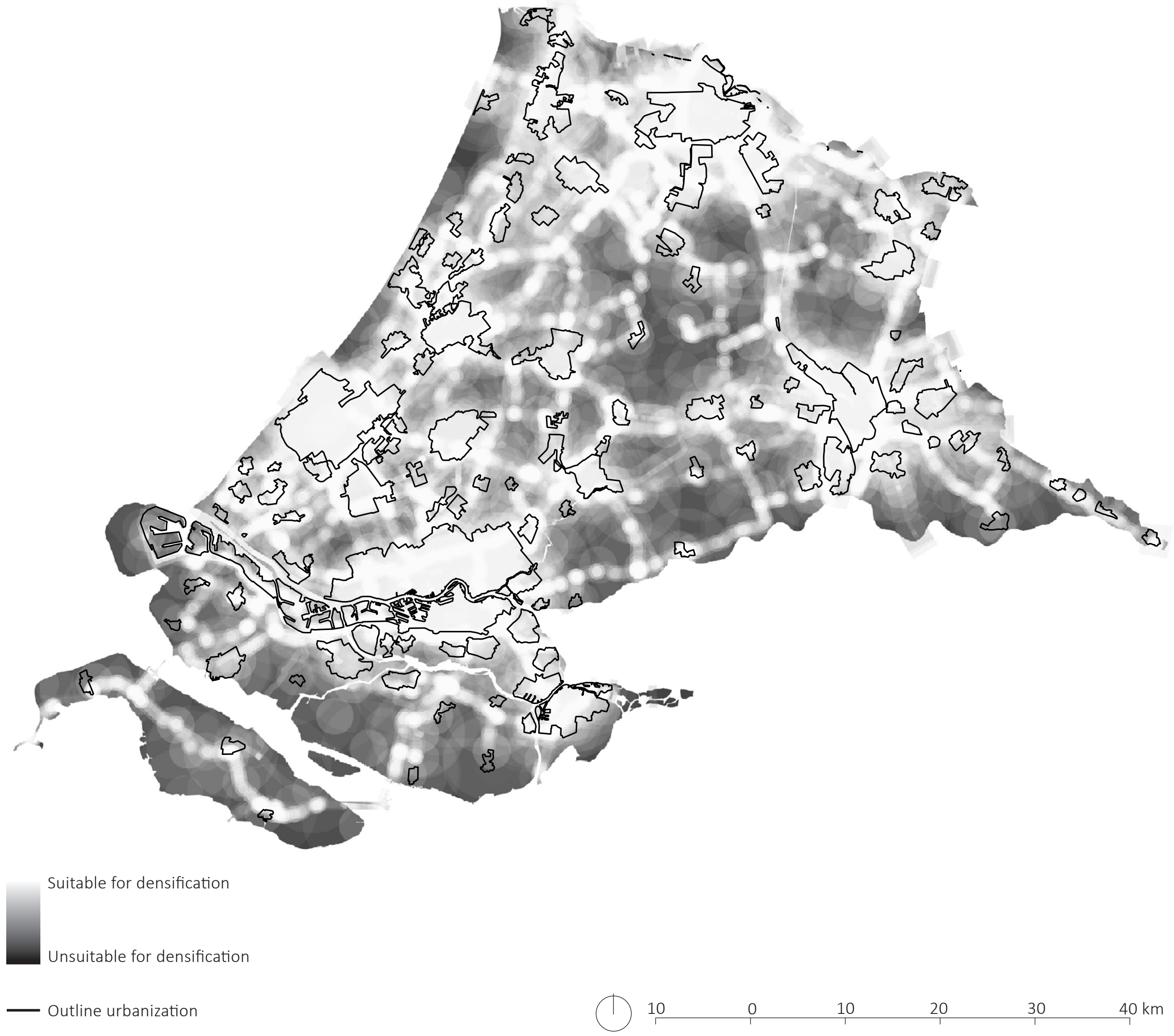


Figure 63 | To create the map that shows suitability for densification the layers of critical infrastructure, energy infrastructure and transport are taken into account. The image shows the outlines of cities in combination to the suitability to densify. A logical conclusion is that the city areas are all very suitable for densification, since the city has already a lot of critical infrastructure available for its own inhabitants. A black spot (unsuitable) is visible south east of Amsterdam. This could be explained by the fact that there is a lot of agriculture and lakes, so less facilities. The land is also very wet as is visible by all lakes and ditches. What happens if the two suitability maps get combined? (Image by author)

What are the clusters of suitability?

The number of exposed citizens in the no go area is around 1,18 million people. The total amount of citizens that live below sea level in the chosen region is around 1,45 million people (the CBS numbers are used for this calculation, see analysis booklet).

The combination of the two suitability maps show the mismatch areas in terms of land use and the suitability for that land use (Figure 66). The substratum layers height and soil type are a datum difficult to change, especially on a larger scale. The main layers that defined the suitability for densification are also hard to change, though easier than the substratum ones. New networks can be built in areas that would be suitable for settlements.

If the approach of risk on the system scale focuses not anymore on reducing the probability but brings the planning and evacuation layers into the scope, it changes a lot on how the system and region work. In this way the multilayer approach will focus on all three layers. As the analysis shows 1.4 million people are living at a place that is only protected for flooding by the first layer. According to the planning layer, these areas would not have been marked suitable for urban settlement on the first place. Figure 64 shows that the mismatch areas only increase when the sea level would rise. This results in a system where people can no longer live below sea level (especially with the changing conditions). The action linked to this is to relocate the people that currently live in the 'low' cluster. Based on the suitability maps, clusters are made to show what actions are needed (Figure 64 and Figure 65).

More concrete this means that:

Cluster high risk/low suitability has to be relocated. This cluster does not have a lot of infrastructure now, so therefore not a lot of inhabitants, probably mainly agricultural or industrial areas.

Cluster high risk/high suitability has to be relocated. This cluster contains a lot of inhabitants and building. This will make it more difficult and most of all more important to relocate.

Cluster low risk/high suitability has to be densified. This a very suitable cluster since it is on high grounds and has a lot of critical infrastructure. The infrastructure has to be adapted to be able to host more people, but it does not have to be built from scratch.

Cluster low risk/low suitability has to be transformed before it can be densified. Critical infrastructure is needed before residential functions can be added.

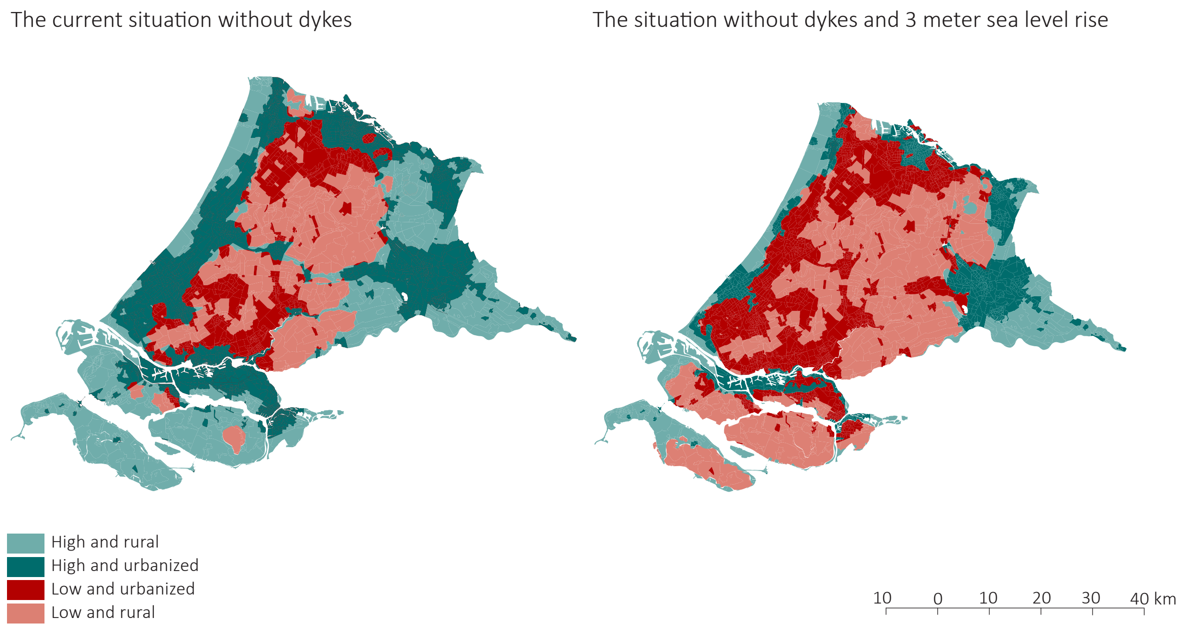


Figure 64| The map of the Randstad region shows the combination of low and high land and urbanized and rural areas. The low areas on the left map are the ones that are currently below sea level (Class 4 and 5 in the analysis booklet). On the right map the area that is up to 3 meter above sea level is marks as 'low', following the scenario of 3 meter sea level rise in the theoretical framework. (Image by author).

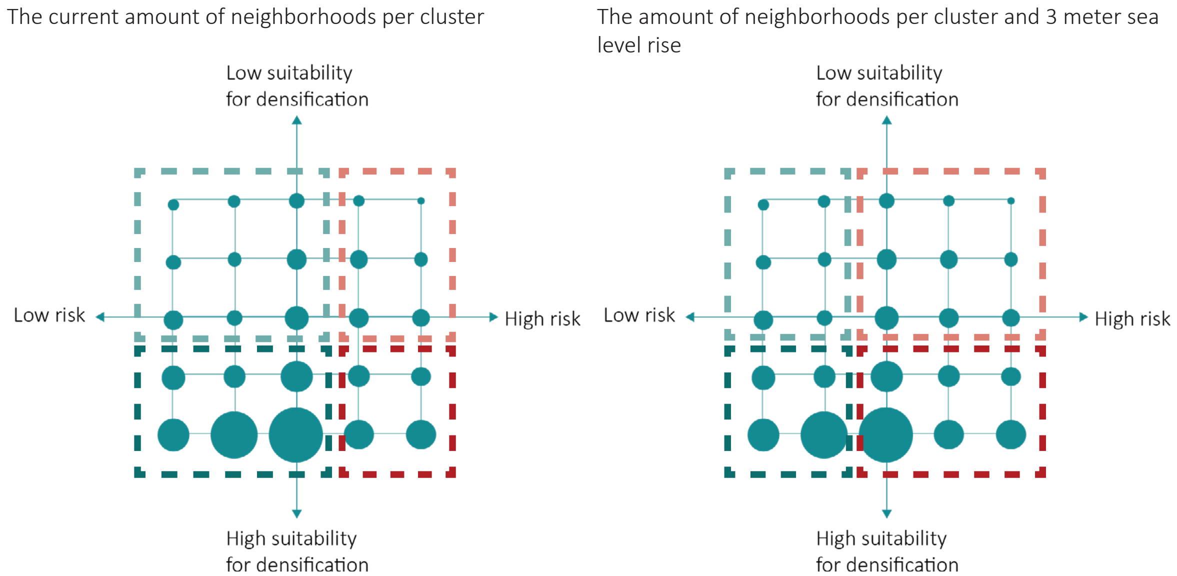


Figure 65| The size of the dots represent the amount of neighbourhoods that is placed in this class. The left image shows the current situation, where the areas below sea level are marked to have a 'high risk'. On the right this cluster includes all the areas with a height value between 0-3 m as well (related to the sea level rise of the scenario described in theoretical framework). (image by author)

The guidelines of the regional scale

These groups all have different potentials and threats if the trends and the scenario of the future are taken into account (Figure 67). **Group one has potential for future development**, since the substratum layers can facilitate urban development. Group two seems to be the most threatful for it has two negative factors in terms of suitability. However, this group is logically seen less vulnerable then group four, since the low suitability for densification can be explained as a low urban function at the moment. In other words, the amount of people living in the group two area is significantly smaller than the amount of people living in group four areas. **Group two needs evacuation on the small scale** and could function as room for the water. Developing a more elaborate evacuation system is one of the key tasks for the neighborhoods in group four.

For **group three both layers are positive, therefore densification is the main task** for these neighborhoods. The clustering of neighborhoods has been made on a large scale. Per area a more specific analysis is needed to be able to find more specific design goals. The GeoDesign steps of 'the world as it is' are resulting in the option of changing the layers that people have added to the natural landscape in order to benefit most of the intrinsic values of the area and minimize the socio-economic cost.

The neighborhoods that have a large difference in suitability in the two maps are have a mismatch, considering the hypothesis of flooding the lower areas and densification of the higher areas. Either the area should not be urbanized or the area could be densified more.

From the theoretical framework the importance of adaptive capacity became clear. To enlarge this is thus one of the design principles. Despite the fact that height class 3 lies currently above sea level (0-3m) it cannot be used as a densification area. This would diminish the effect of the new approach since it should be able to cope with future changes. If the current scenarios vary already up to a sea level rise of 3 meters, there would be no capacity to adapt towards the future (Figure 64).

The two maps on the left page show what neighborhoods could be clustered as 'suitable for densification' now, but would not last if the sea would rise (0-3 meters). The figures below show how this uncertainty takes away a lot of neighborhoods from being suitable for densification, and puts them in the position that they should be relocated. These areas do not have to be relocated immediately, but this will be discussed at the phasing.

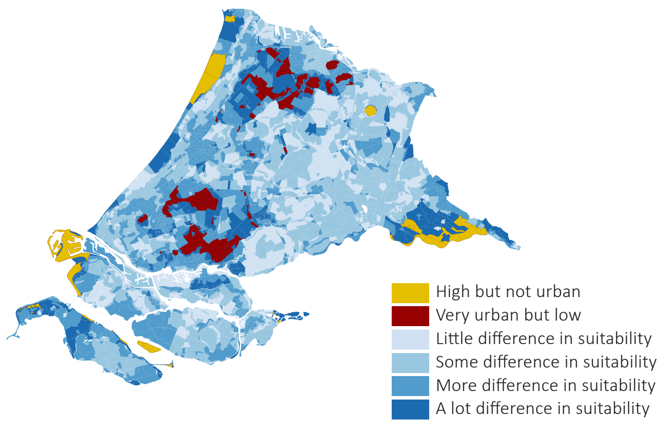


Figure 66| This maps shows the neighborhoods with the largest differences between the two types of suitability. In yellow the high areas that have no urban function and in red the low areas that are highly urban. These are the two most interesting groups since the mismatch is the biggest. (Image by author)

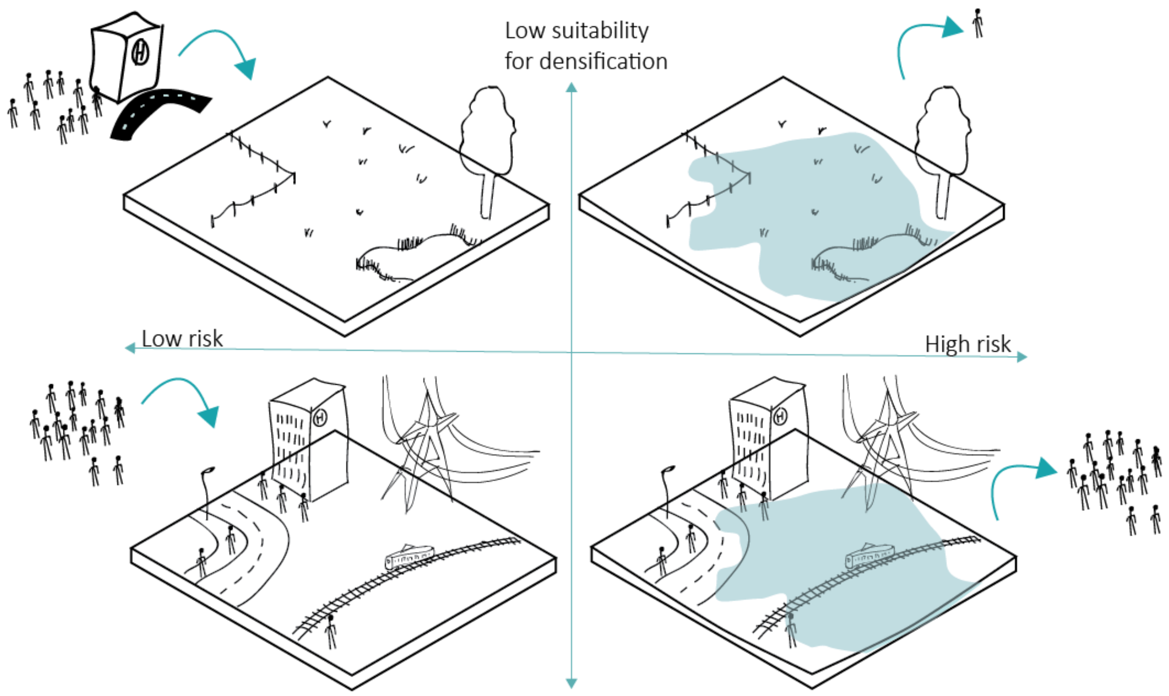


Figure 67| The spatial impact of each cluster. The clusters on the left have potential for densification, where the clusters in the right need relocation of functions. The most ideal relocation area is left-down, since the infrastructure for settlement is yet present. (Image by author)

Figure 68| A visualization of The Randstad area that shows the amount of land that currently would flood if there was no dyke system. It shows how much land is below sea level, and therefore naturally unsuitable for settlement. (Image by author)

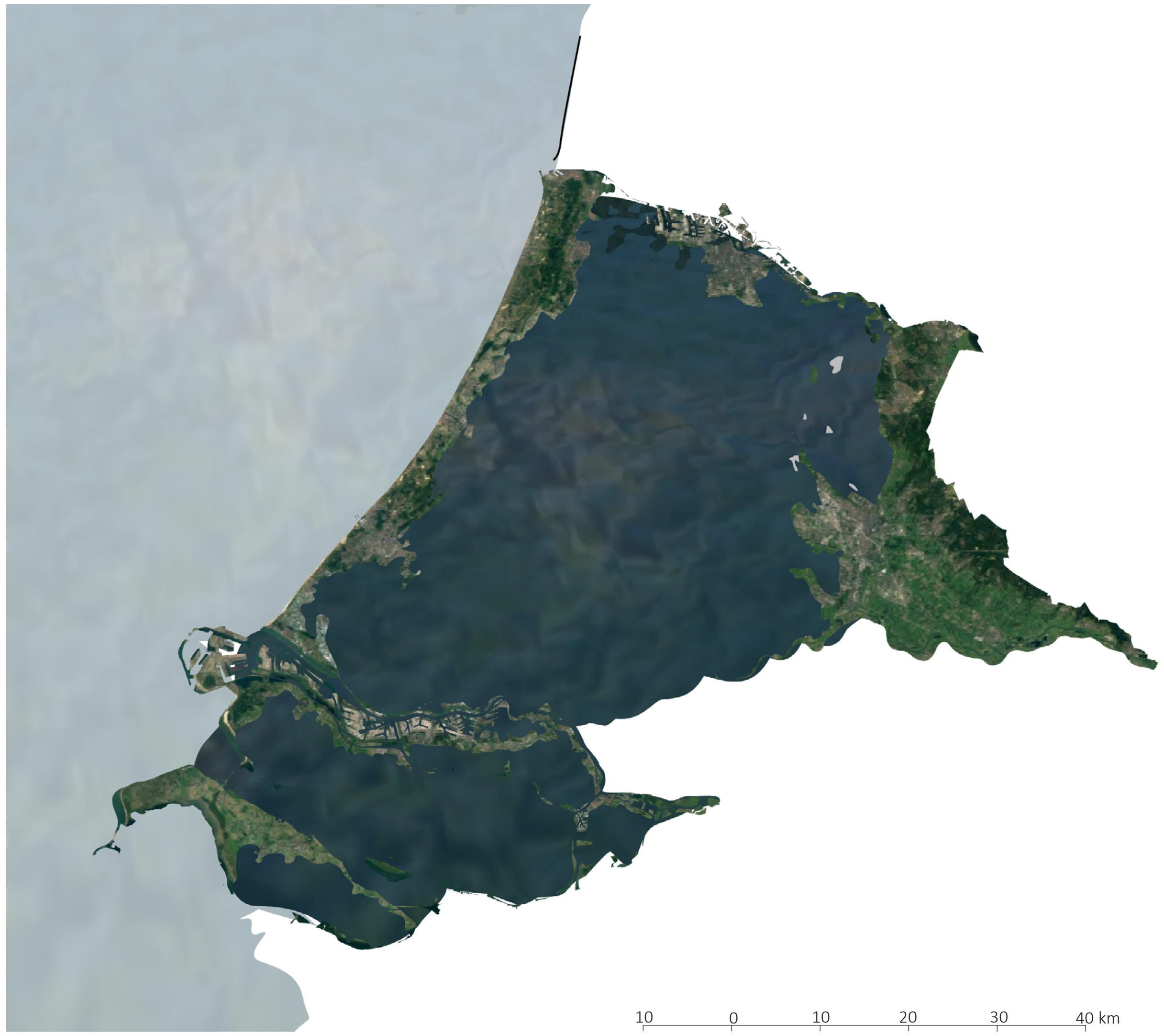


Figure 69| A visualization of The Randstad area that shows the amount of land that would flood if there was no dyke system and the sea level would rise 3 meters. In combination with the map on the left it shows the increase of landloss as a result of sea level rise. (Image by author)

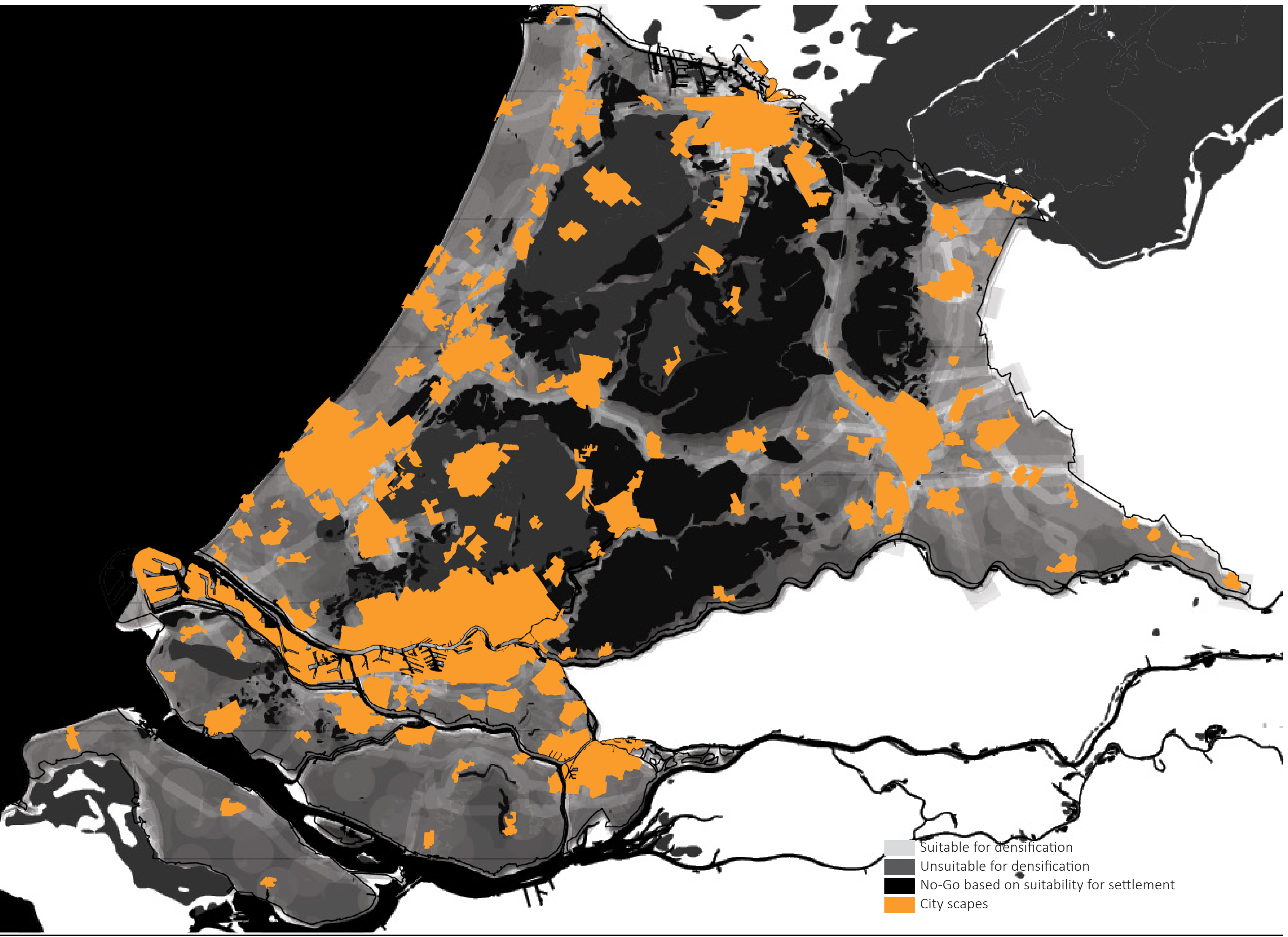


Figure 70| The suitability maps show the unsuitable areas of the Randstad, and highlight the suitable areas. Design objectives are derived from the suitability maps and shape the outline of zooming in to the lower scale.

// Design properties- Region scale
The region scale takes a closer look to what elements are actually placed where. The Randstad region is vulnerable as dyke ring, but what does this dyke actually protect? What areas should be relocated in a new system and where can they be relocated the best? The overview shows that around 1 million households are built and around 1,4 million people live in an unsuitable location in terms of risk. At the other hand there are locations where potential could be activated: higher grounds that have no urban function yet.

// Qualities//

//Cluster of cities //
Benefit of the cluster, but do not be dependent on the cluster. (This is the change).

//Critical infrastructure//
Use the critical infrastructure that is already there.

// Changes//

//Cluster of cities//
Be less dependent on cluster. In case of extreme flood the cities need to function as well.

//Relocate unsuitable areas//
Define settlements based on the substratum layers.

//Densify suitable areas//
Define settlements based on the suitability for densification.

//Relocate economy in unsuitable areas//
Invest in industry at the higher grounds

// The question for the next scale- the city scale
If certain areas need to be relocated, and others densified, what does that mean for the people? What would it mean for the urban fabric and the infrastructures? In the next scale the translation of the guidelines and design principles are translated to a spatial design for the city of Rotterdam. From this scale on the social and mental component of the city start to play a larger role.

5 | The city scale

As paragraph 1 of this chapter describes is the city scale the first scale that translates the design principles and guidelines into spatial design. Therefore in the next three paragraphs **the guidelines from the higher scales** and **the design principles from the lower scales** need to be taken into account as well as the **guidelines from the theoretical framework.**

In the assessment and design the adaptive capacity will therefore be explicitly visible and explained. The lower the scale, the more important the social and mental component will be visible as well.

The city scale will show the case of Rotterdam. First of all since Rotterdam has one of the lowest inhabited polders within the municipality borders. Besides that **Rotterdam has a high variety on both suitability maps: A height range from class 1 to class 5 and a suitability range from 1 to 5 as well (see figure 71,72,73).**

Rotterdam is a true harbor city. The success of the city as industrial city grew and the city outgrew its city walls in the nineteenth century. People started to live in lower areas. The harbor expanded more to the West. The Nieuwe Waterweg made it possible that larger ships could enter the harbor as well and the capacity of the harbor only got larger. The city harbors got transformed to neighborhoods. The harbor structure is still recognizable by the waterfront, but also by the infrastructure that shows slowly bending roads build upon the former train rails.

The assessment of Rotterdam and the design interventions that follow from the regional question have to focus on how the structure of the city needs to be changed if only the higher grounds can be used. This will be done using the following seven themes:

- 5.1 **Usable land:** what land is usable for settlement and densification in Rotterdam?
- 5.2 **Road structure**
- 5.3 **Green blue infrastructure**
- 5.4 **Evacuation network**
- 5.5 **Densities**
- 5.6 **Centralities**
- 5.7 **Living environment**s
- 5.8 **the layers together**

All the design principles per theme are showed on the next pages, explaining how they contribute to an approach with adaptive capacity. After the themes have been explain separately , they will be showed combined.

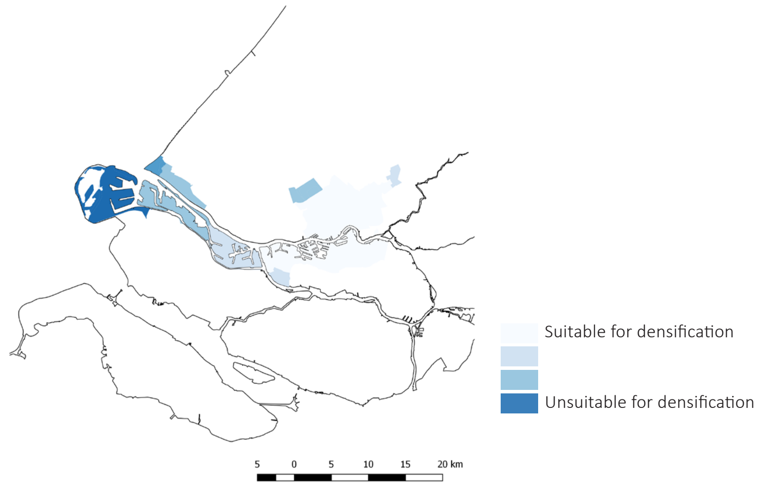


Figure 71 | The suitability in Rotterdam municipality based on the suitability for densification. The (white) center shows that there are sufficient functions available so that densification would be possible. The newest land reclamation (Tweede Maasvlakte) has currently not the right properties for residential densification, which is logical since it is reclaimed to be a port.

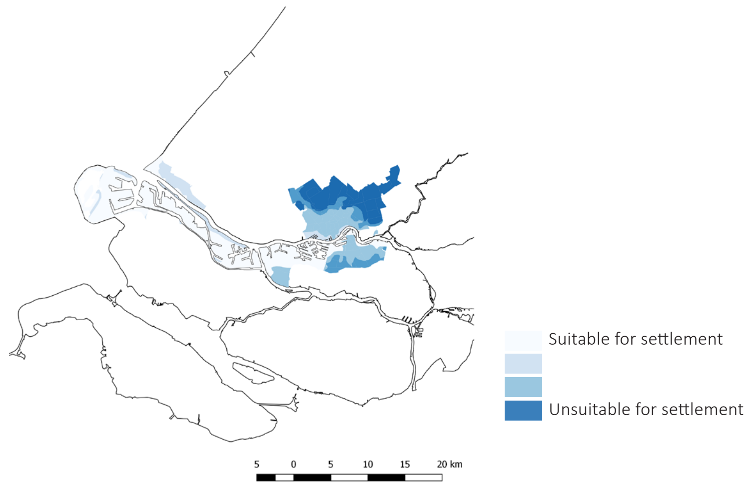


Figure 72 | The suitability in Rotterdam municipality based on the suitability for urban settlement. The suburbs is clearly placed in the lower areas (even in the former peat lakes). The outer dyke area (harbor) has a surface of around 4 meters above sea level. This is logically since the land is not protected by dykes and has to be accessible for boats.

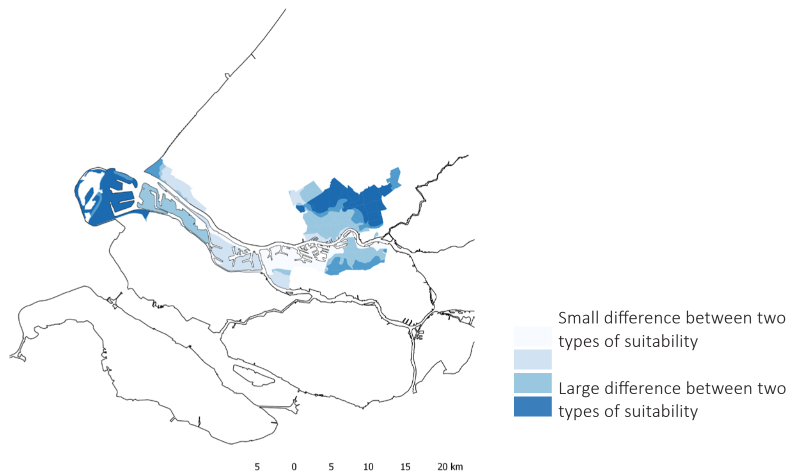


Figure 73 | This map shows the combination of Figure 76 and Figure 77. It shows that Rotterdam has a wide variety of suitability of both maps, what makes it an interesting city to use for a spatial translation. (Images by author)

5|1 Usable land

The most defined theme is the usable land. **What land can be used for the city if the approach changes and dykes are no longer the standard?**

The first harbors of Rotterdam where build upon natural higher sand grounds that where shaped by the river New Meuse. When the harbor expanded the techniques where more elaborated and artificially new islands where made using the silt and sand combination that was dredged from the river. Since the harbors needed to be accessible from the sea, they are in an area without dykes. Therefore the height map of the surface level shows a high harbor ‘island’ in the middle of the low lands (Figure 75). However, this area is marked as ‘exposed to floods’ since it lays outside the dyke. On the border of the harbor ground and the hinterland a dyke is constructed. **The Dutch system is in this case exceptional, since the urban activity takes mainly place on the lower lands behind the dyke as shown in figure 74.** These height differences are visible in the urban structure, if however you pay attention to it (figure 75). For example the dyke where de Kunsthal building is built against. Or the slope when you try to cycle over the Erasmus bridge that starts already before you reach the water. Or the parallel road when you walk on the Mathernessedijk that lies some meters lower.

In the suitability for settlement map it is clearly visible that the rivers lay higher then the surroundings. This is due to the sandy and clay soil that the river bed brings as sediment. The ground under the river is not subsiding as the peat soil of the surrounding. This makes it possible to heighten up the grounds and make sure that they not incline under the weight of the artificial land.

Besides the higher harbor land there are more higher lines visible in the height map of Figure 75. A simplified version of this map is shown in figure 76, where the high grounds are hatched and the higher lines are shown. These lines often are dykes, roads, train rails or a combination of these.

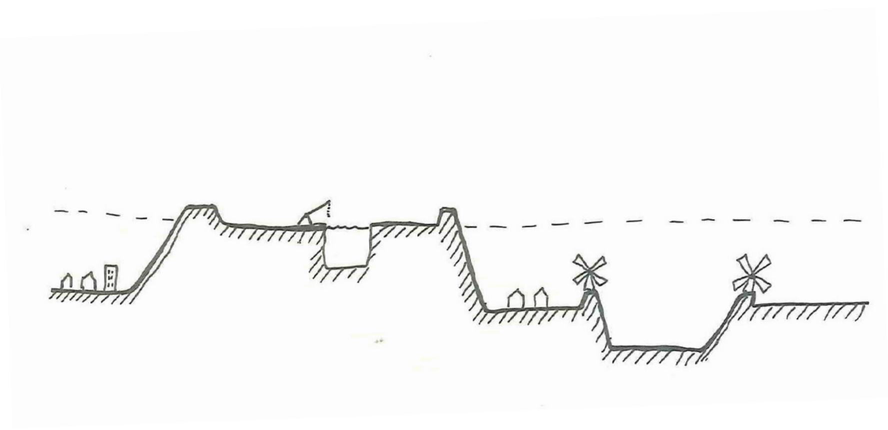


Figure 74| This schematic section shows the higher harbor grounds. Between the harbor and the hinterland there is a dyke. Urban development takes place in the lower area behind the dyke. (Image by author)

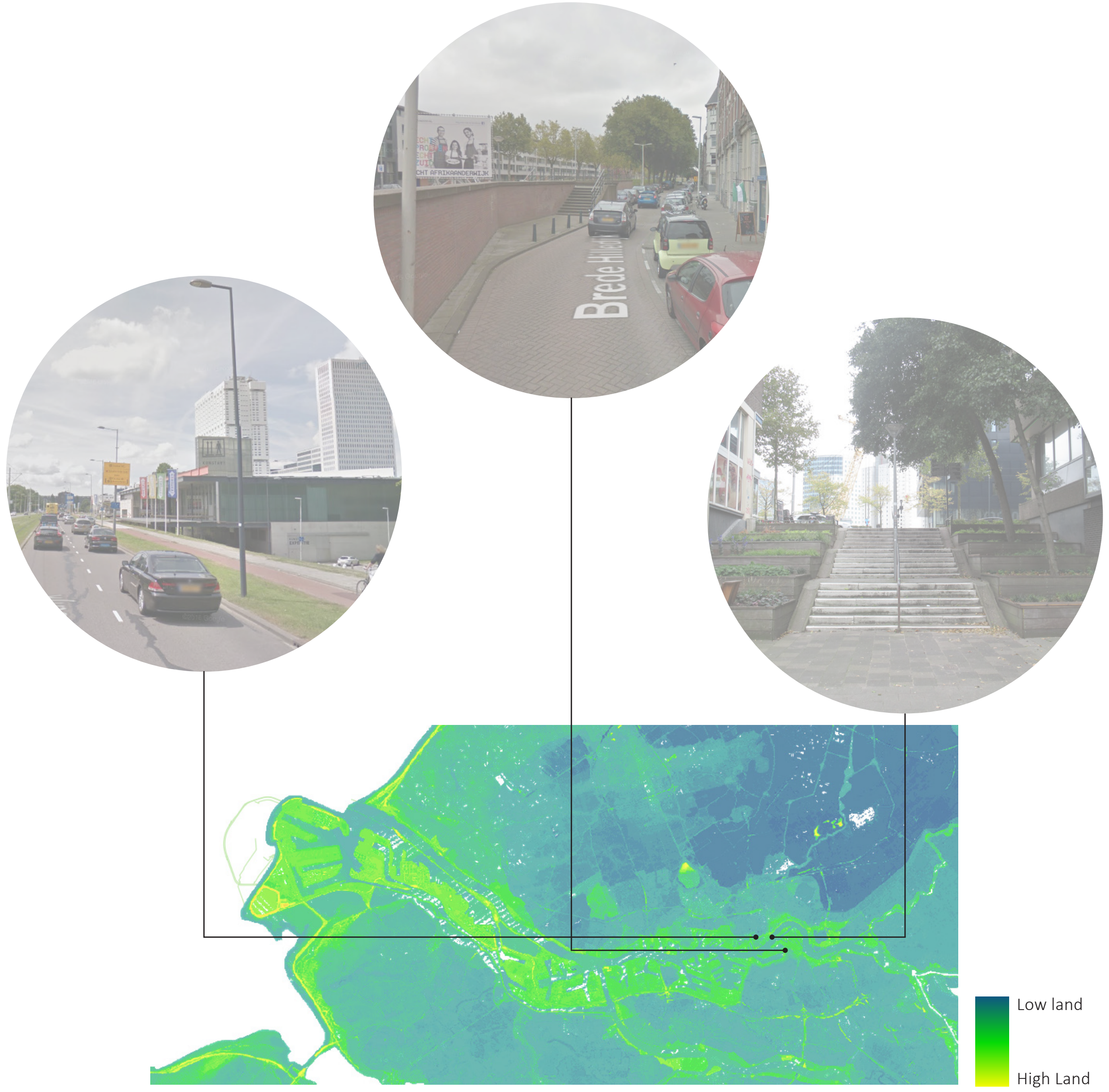


Figure 75| The height map of surface level of Rotterdam shows that the harbor is a high island in midst of low lands. This is due to the fact that the harbor needs to be accessible by the boats from the sea and needs to be above sea level (4-5 m) (image from ahn.nl)

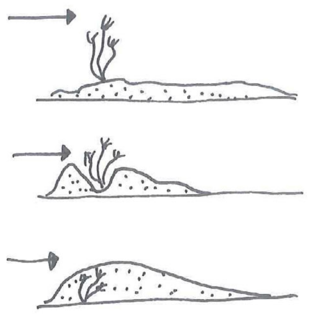
Figure 76| The high land as an island surrounded by lower grounds. The red line represents the dyketrace. It shows the flipped condition of the Netherlands where land below sea level is used for urbanization. (Image by author, based on the above height map).

City

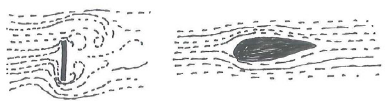
How to keep the high land? Now the new border of urban land is defined, it needs to be kept safe in future weather conditions. Figure 77shows the basic principle of **erosion** and **sediment placement.** The tapered edges will erode and this sand or clay will be deposited at placed where the current is less slow or disrupted. The wind has an influence on higher grounds as well.

The sediment that is deposited in the delta in the lowest phase is mostly clay and fine sand. The harbor is dredged to maintain the depth needed for the ships to enter. Only in the harbor area of Rotterdam more than 14.5 million cubic meters of sand and silt is dredged annually (N.V. Havenbedrijf Rotterdam, n.d.). The main responsible actors for this are Rijkswaterstaat (dredging of the Nieuwe Waterweg) and the Port of Rotterdam for the harbor.

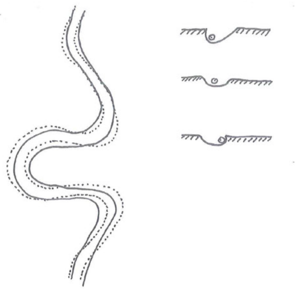
The higher grounds are now divided in the North and south bank of the river. This makes the waterfront along open water longer. The waterfront is subject to erosion from the river. The river (as a potential cause of flooding) splits the city in two. (See figure 79).**To protect the high ground it could help to reduce the flow of the river Nieuwe Maas, so less erosion can take place. The 'island' could be better protected when the flow is rearranged and when sediment banks are used to arrange sediment supplement flows from the west and east.**



Wind erosion



Water erosion



Water erosion

Figure 77| Principle drawings of wind erosion (top), Waterflow erosion (middle) and river course erosion (bottom). (image by author)

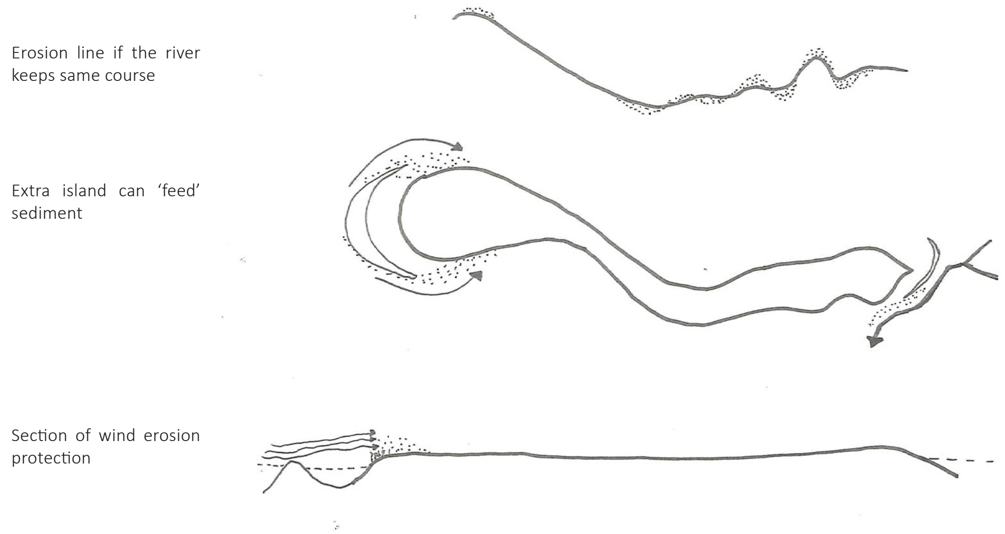


Figure 79| The current river flow splits the city in two and causes extra erosion on the river banks. (Image by author)

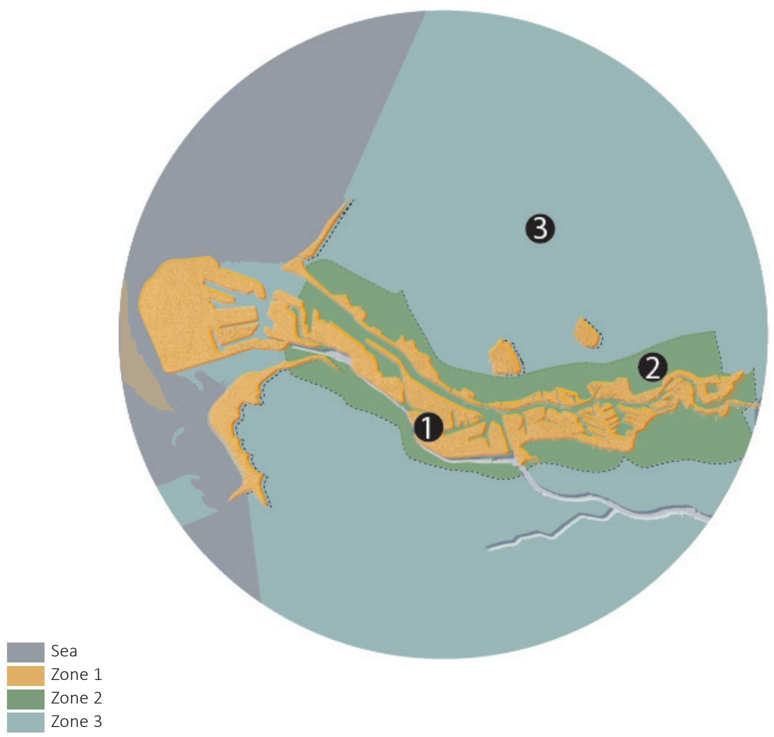


Figure 78| The three zones of Rotterdam. The higher (1) is used for residential functions and it accommodates all the essential elements to make the city function. (Image by author)

What would it mean for the river structure as the discharge of the water of the Nieuwe Maas is shifted to another outlet? (Figure 80). The assessment shows the current discharge ratio of the river Nieuwe Waterweg (Extension of Nieuwe Maas) and the Haringvlietsesluis in the south. As explained before the Netherlands lay in the delta of the Maas, Scheldt and Rhine. Within the Delta these rivers split and merge, and each tributary has a distinct name. Figure 81 shows a schematic overview of these rivers and tributaries that are connected somehow with the water that flows through the Nieuwe Maas.

The Lek, Waal and Maas discharge their water in the Nieuwe Maas and the Haringsevliet with the ratio Lek:Waal:Maas 1:4:1 and Nieuwe Waterweg:Haringsevliet 3,5 : 1,5. Shifting the discharge to the Haringsevliet would mean a complete discharge via the Haringsevliet 0:6 as figure 80 explains.

The options to rearrange the river structure needs an explanation of the levels of water that is used in the Netherlands. The lower level of the Randstad are polders. These are drained to a collecting water body that has a higher level (Boezem). These Boezems are then again pumped to a higher level of the river. The rivers need to keep a certain slope to be able to discharge the water to the sea. (See figure82) **This system of pumping results in the fact that the rivers are higher than the surrounding, and they lay as higher veins in the landscape**. Rearranging the course will mean that it is easy to make the river flow a different path. However, since this path crosses the dyke that keeps the river now in place, the lower land will fill up with water. The benefit is that the old river structure delineate until where the water flows.

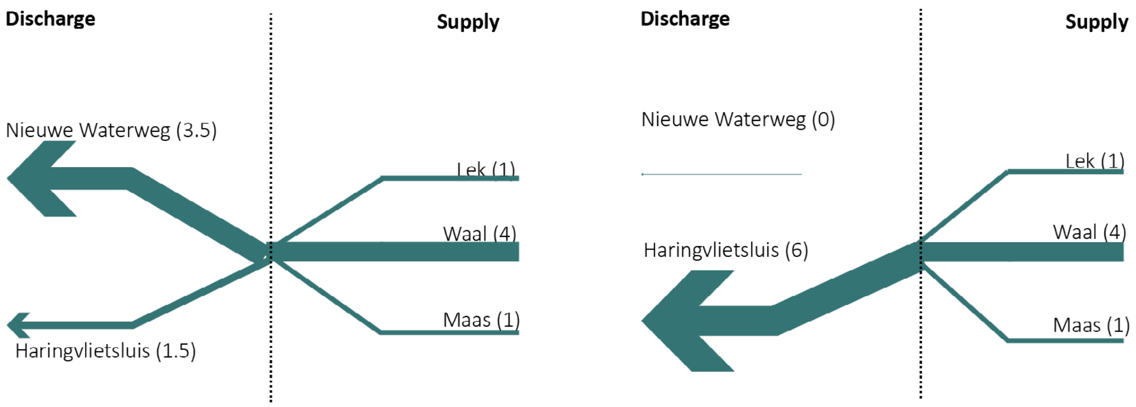


Figure 80| Schematic overview of the discharge proportion of the water in the Nieuwe Waterweg, Haringsevliet and the Lek, Waal and Maas. On the left side the current situation. On the right the proposed change. (Image by author, inspired by (Meyer et al., 2016), p. 53))

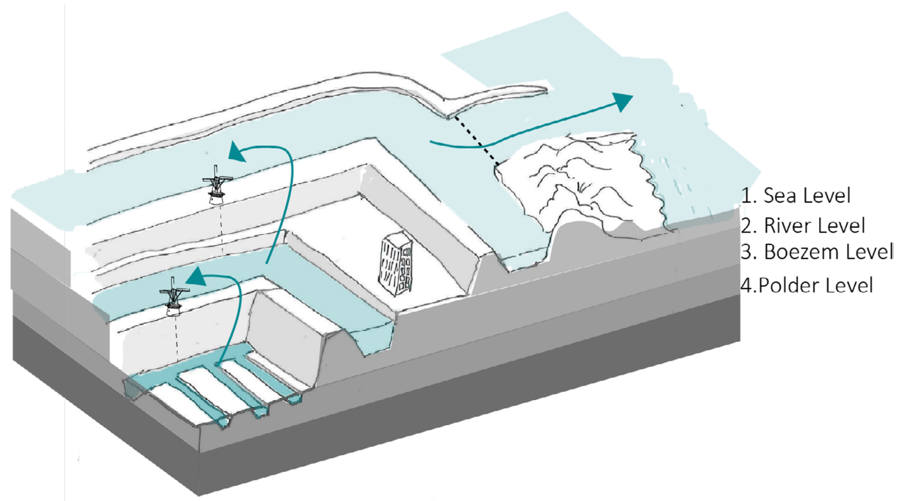


Figure 82| A schematic overview of height layers of the water discharge system: Water from the polders (level 4) gets pumped to the Boezem (3). This is pumped to the river (2) that discharges to the sea (1). The river is therefore higher than the surroundings. If a river dyke breaks, the water will flow in the lower area. (Image by author)

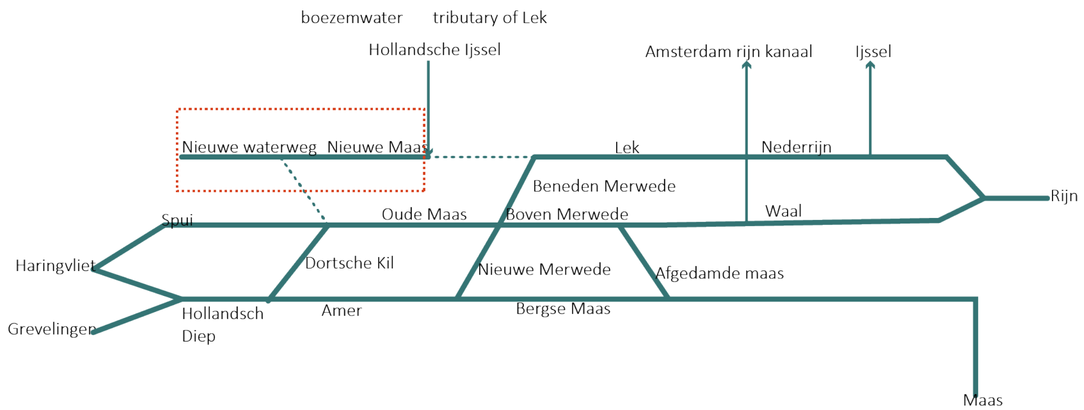


Figure 81| This scheme shows a simplified version of the rivers and their tributaries and connections. Only the rivers that influence the flow of the Nieuwe Waterweg and Haringsevliet are shown. The dashed line shows the current situation. Without this line it shows the proposed situation where the discharge is completely via Haringvlietsesluis. (Image by author)

Figure83shows a way how the discharge of the water can be rearranged in such a way that the Nieuwe Waterweg will not flow any longer through the city. For this map the height map is decisive. The height lines of some infrastructure elements shape a patch of land that is surrounded by higher grounds (figure 76). **This area can therefore easily be used as a planned overflow system**. The image below shows a distinction in 3 zones:

- **Zone 1** is the high area and is suitable for densification. The erratic shape of the grounds is defined by harbor grounds. In the future this area can be shaped more smooth to prevent erosion and enlarge zone 1. **This is the area where urban development and residential activity has to be. It also accommodates all the essential elements to make the city function.** This area is the only one with natural height.

- **Zone 2** is a low area, but is delineated by higher lines of infrastructure. **This area is not safe for residential function, but can be used for temporary use or leisure.** Since the water will flow here once in a while, it could stimulate the natural sedimentation process.

- **Zone 3** is the lowest area and is connected to the river as result of the rearrangement. This is a place that will be more permanently filled with water. **It could be used for leisure.**

Thus by creating layers with restrictive land-use the value of lives or development that could be lost in a flood can be minimized. This is an important step in moving to a new approach. Investing in grounds that are above sea level makes it more prepared for future changes. **These new borders are naturally set and therefore not so flexible.** However, using sedimentation principles the shape could be adapted or expanded.

Figure 83| The process of rearranging the river to the south. The higher infrastructure lines prevent the water from flowing into zone 2. It could be that zone to is used to overflow. (Image by author)

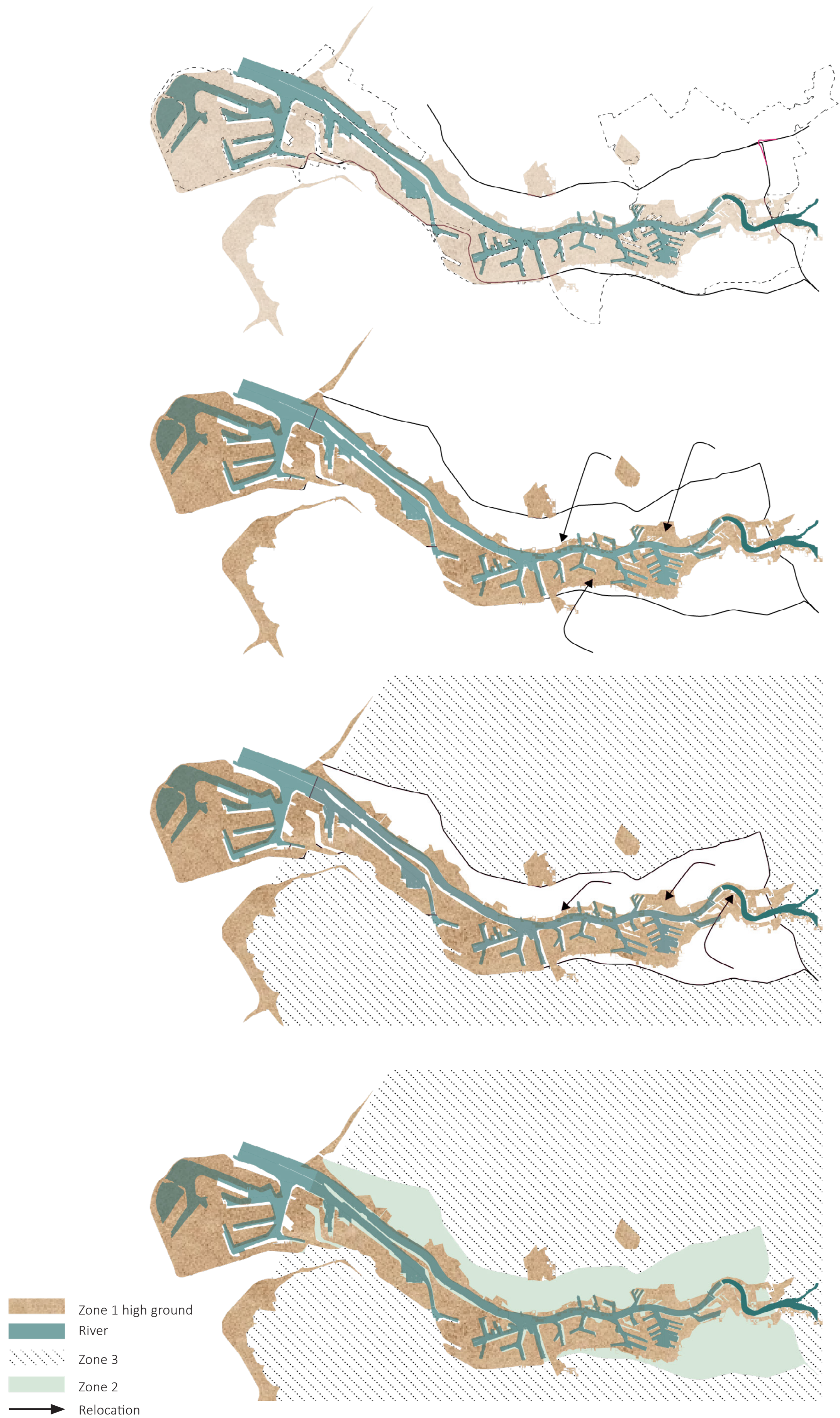


Figure 84| The changing borders of the city of Rotterdam. First based on the administrative border, moving to a height based border. This results in three zones. (Image by author)

5|2 The grey network

Now the usable land is defined, it is important to look at the impact of this for other layers. The critical infrastructure and the green/blue and grey infrastructure play a large role on where the new densities will be. On the other hand the current use and buildings influence these infrastructures. Either way every proposed intervention needs to connect and respond on what is already there. As explained before the process is not linear. This can lead to design decisions in one theme (grey infrastructure) that is adapted to another (housing).

The analysis of the road network as it is now (as shown in the analysis booklet and in figure 85), clearly shows where the network is the most dense. The road analysis showed the following aspects, interesting for the design:

- The darker the road, the more roads can be reached within 1000 meter. This shows a central point
- The highway roads are not highlighted in this map, since they do not connect to a lot of side roads. The do not shape a ring .
- There are not so many North south connections (since bridges have to be very high because of ships).
- There is a very structured grid road network in the harbor, and a train track network as well.
- The south bank has a more dense road network than the north bank.

Now the usable land has been defined it is important that the road structure corresponds to the zone 1 area. Within this area the development of a ring road could contribute to the accessibility of the entire area. Creating more north south connections is another factor that contributes to this. Since the city of Rotterdam is mostly used for industry on the west side and for urbanity on the east side, it is logical that the road network will expand starting east (see Figure 86). The road structure basically is already there over the entire island, except the north-south connections. However, by marking specific ones as main roads and others as sub-roads the accessibility can be improved. **For future changes or events it is important that the road system shows redundancy and that connectivity stays even if some roads are no longer accessible due to the event. The high suspension road and highline could for example keep connectedness in times of a severe flood.(See neighborhood scale)**

Figure 85| The centralities of the network based on the amount of streets within reach. (Image by author, using PST tool)

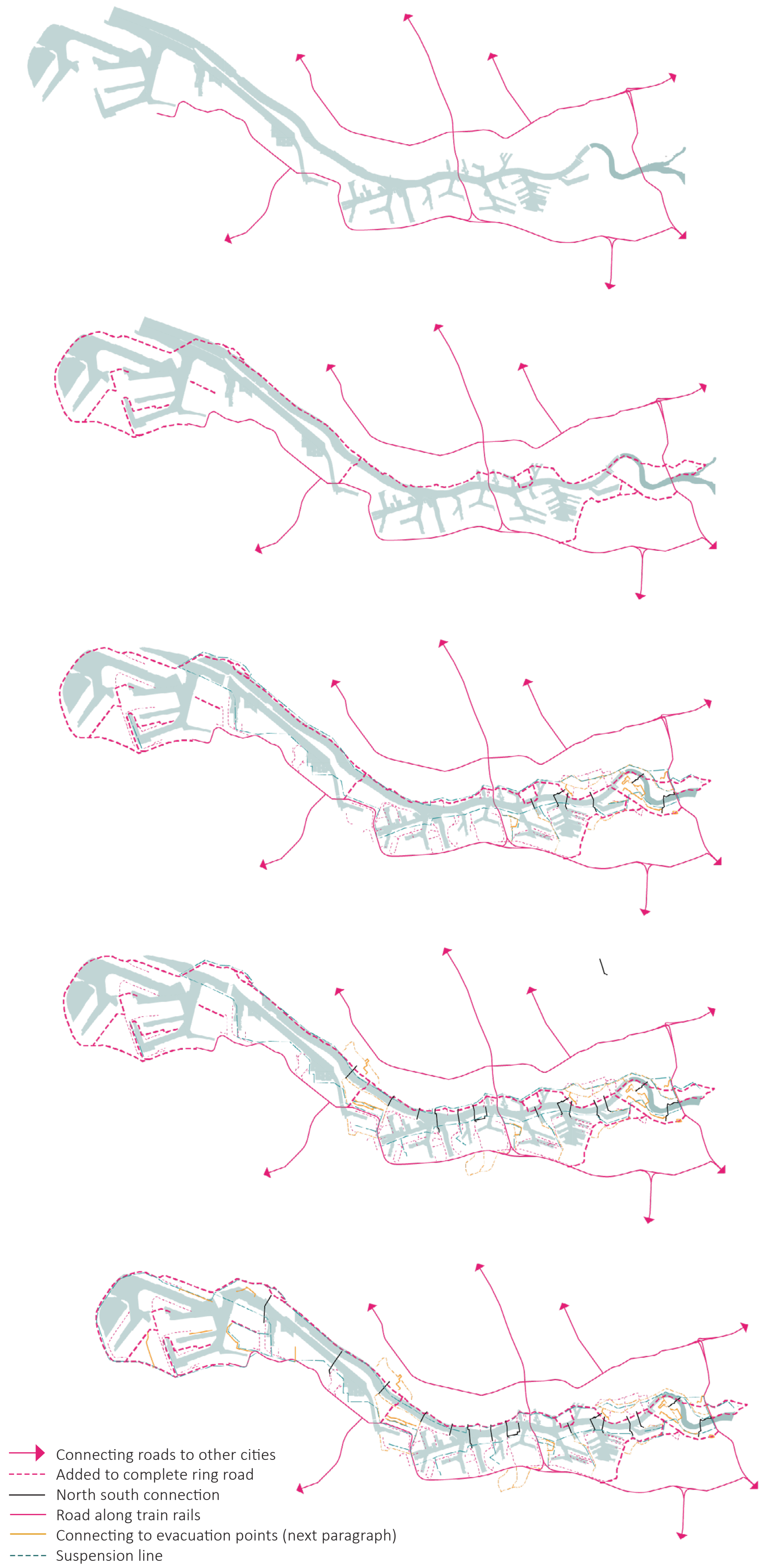


Figure 86| The stages of the road network. First the current network (1), connecting this to a ring and start north south connections(2), Start evacuation network from the east towards the west (3) Develop more bridges and expand the road network to the west (4) resulting in an optional road structure that also connects the most west parts to the evacuation system, depending on the other developments (5). (image by author).

5|3 Green and blue infrastructure

The analysis shows large green patches. They can be better connected via corridors or green lines. This would stimulate the biodiversity within the green area. **The green connection can be achieved by using the grey infrastructure, since streets can function as green corridors**. This can be combined with design principles on lower scales.

Goals for the blue infrastructure are to be able to respond better on the changes of the future. Water can help cooling down when for the higher temperatures. Open water can help store the extreme precipitation, to be able to use it again in dryer times. By delinking the Nieuwe Waterweg an enormous reservoir is created within the island of higher grounds. This reservoir can store rainwater that has been collected in the neighborhoods. Besides this it can function as a sweet water reservoir in dry times. The water can have a bigger role in transport as well. Since the main traffic on the Nieuwe Waterweg is currently shipping ships the connections via or above the water do not take place so much. The bridges have to be very high, since large ships have to pass. Unlinking the river can mean that the water can be used for leisure or public transport more easy.

If the urban fabric or the third and second height zone are relocated, the green and blue fingers will spread to the outsides. **Especially zone three can be used for bringing back the natural processes of deposition of sediment.** The citizens can use the third zone for leisure or floating farming. The second zone can be used for temporary activities. Especially when the scenario changes, it can be adapted to the possibilities. This zone could be used for agriculture or allotment gardens, that will flood intermittently depending on the future.

In terms of adaptivity the green blue infrastructure is extremely important since the possible threats have to do with water. By improving the ability of the network to drain water if needed or storing it for dryer periods the impact of weather peaks can be made smaller. It is important to realize that the green blue works as a network and therefore needs to be local but connected.

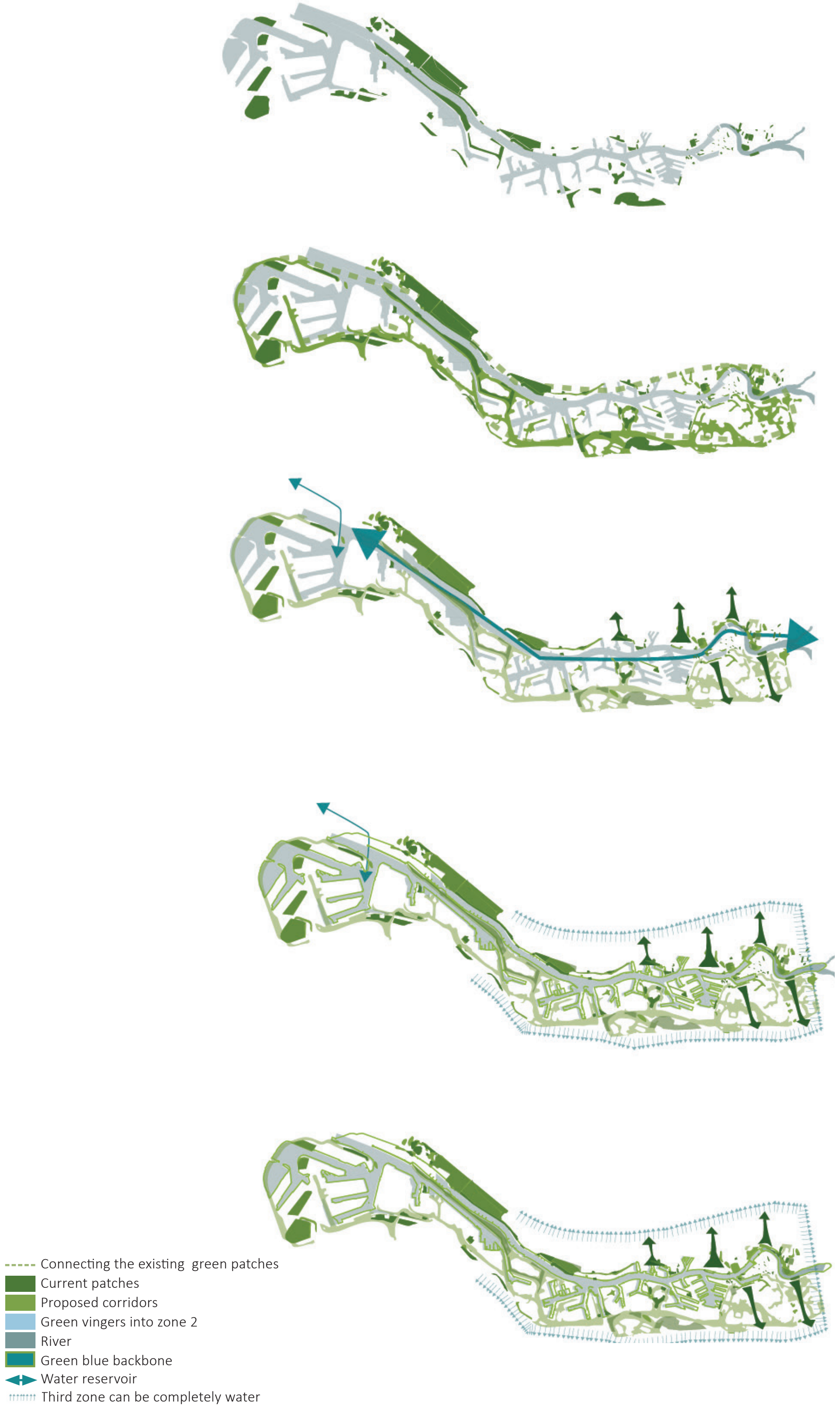


Figure 87| The stages of the green and blue. Goal is to connect them to increase bio diversity. It is important to make a local but connected system, so low scale interventions can contribute to the large scale goal. The water backbone can be used to buffer or to store water for dryer periods. (Image by author)

5|4 Evacuation network

Even though zone 1 lies 4 to 5 meters above sea level, the area could flood in case of an extreme storm surge or extreme rainfall. **As evacuation is also one of the three layers of safety, there should be evacuation points that are connected to an evacuation network.** Therefore this layer has a close link to the road network and the critical infrastructure. The analysis (see analysis booklet) showed the critical infrastructure and the important buildings (such as hospitals or public buildings). Based on the function of the building a maximum distance to an evacuation point has been set .The network of evacuation buildings and their connection to the main road is based on the reach per evacuation point. There is a group that needs evacuation within the building itself, since the people inside are difficult to bring in motion:

- Hospital
- Homestay
- Elderly houses

Then there are buildings that need to have an evacuation point within 1000m since they have a high occupation:

- Schools
- Public facility (swimming pool, museum)

Based on the circles on each building and their reach, evacuation points are defined. The residential areas need to be connected to the evacuation system as well. By covering this area with the 500 m diameter circles the evacuation point network can be added in a way that each circle contains at least one point. The road network is again developed based on the evacuation points.

The evacuation network has multiple functions, since the evacuation points in a normal can be used for other functions (such as health centers), and the higher roads that connect the centers can be used in a normal situation as well. T**he centers are ought to have food, drinking water and blankets to function as shelter during a storm. Afterwards the people can go back home using the highline, suspension line or boats** (as described in the road network, and more detailed on lower scale). This line is accessible on several points, even when a flood occurs.

The evacuation system makes it possible for the city to adapt temporary to a system where the ground floor is not accessible. The critical infrastructure needs to be working even in the case of a flood. By restricting residential functions to the higher floors the lives of people should be able to continue.

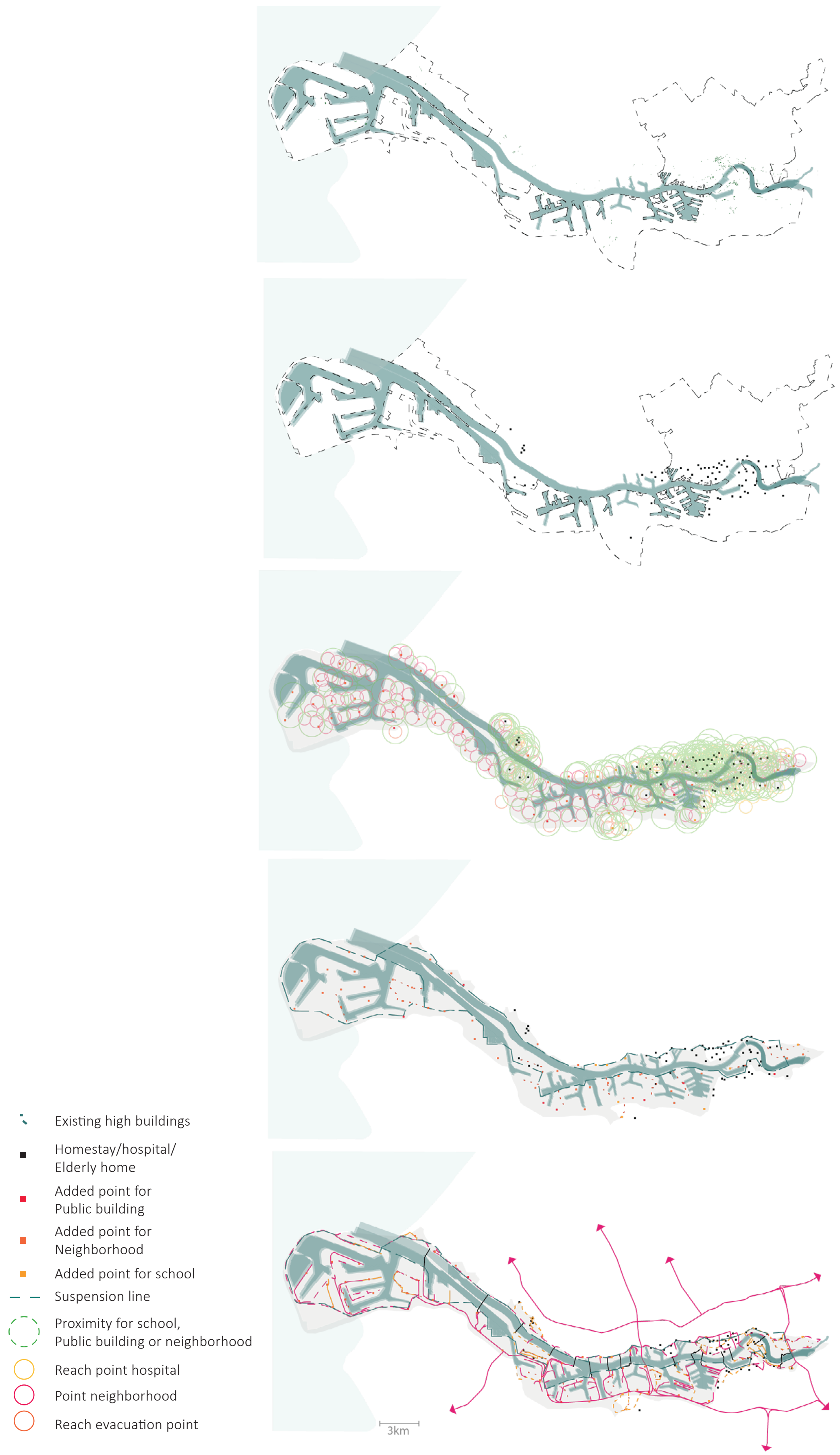


Figure 88| First the current high buildings need to prepare as evacuation point: water, food and blankets. Then facilities like hospital, homestays and elderly houses need to become evacuation point, since the inhabitants are less mobile. Then evacuation points need to be constructed to make sure all long stay buildings can reach an evacuation point within 1000m. The evacuation system needs to be connected to the highline/suspension line.

5|5 Densities

The usable land has been defined, as well as the green, blue and grey structures. The areas that are now 'left over' can be used for urban development. To define the building blocks, the urban development area has been split by the road structure that is currently there. These block do not mean that every block has to be filled with residential use. It is important to take the uncertainty of the future into account. The present cannot tell what functions or densities we need in the future. T**he plan first has to be able to relocate the people that have to be relocated from zone 3 and 2 to zone 1.**

If part of the city needs to be relocated to the higher grounds the higher areas will get a higher density. As the theoretical framework- paragraph densities- explains, **the density FSI and GSI can provide information about where densification can take place and in what way.**

This page shows three different neighborhoods of Rotterdam, that have a distinct GSI and FSI value. As exploration to see how many people could live in the higher land 3 neighborhoods are duplicated over the whole area. Zevenkamp, Oude westen and Stadsdriehoek perform very different on the density scale. What would happen if we densify the whole high area with the same FSI and GSI value as oude westen? **How many people could the higher grounds host?**

Figure 91 shows that the density of Stadsdriehoek and Oude Westen could meet the amount of inhabitants that the trend of population growth shows: 650 000 inhabitants.
For densification in areas with a low FSI value, the existing buildings could be topped up with a light frame to create more floor space per m2. For areas with a low GSI there could be more buildings added in the urban block, since there will be more unbuilt square meters in this area. For areas with a low GSI and a low FSI new buildings with more floors could be added (Figure 90).

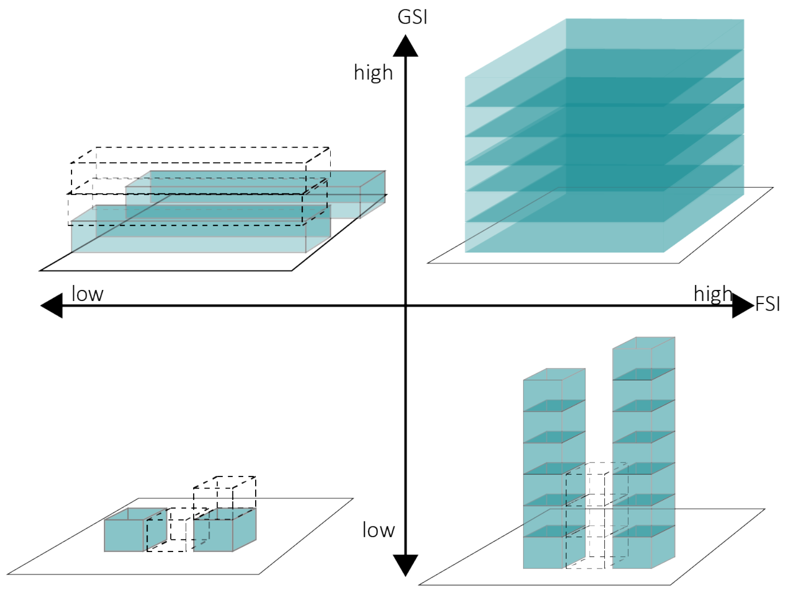


Figure 90| The combination of FSI and GSI and the possible additions. Low GSI means that new buildings could be added (or space for water storage), low FSI could mean that new floors can be added. A combination is also possible. Increasing the density has also its influence on liveliness of an area and the option to share goods. (Image by author)

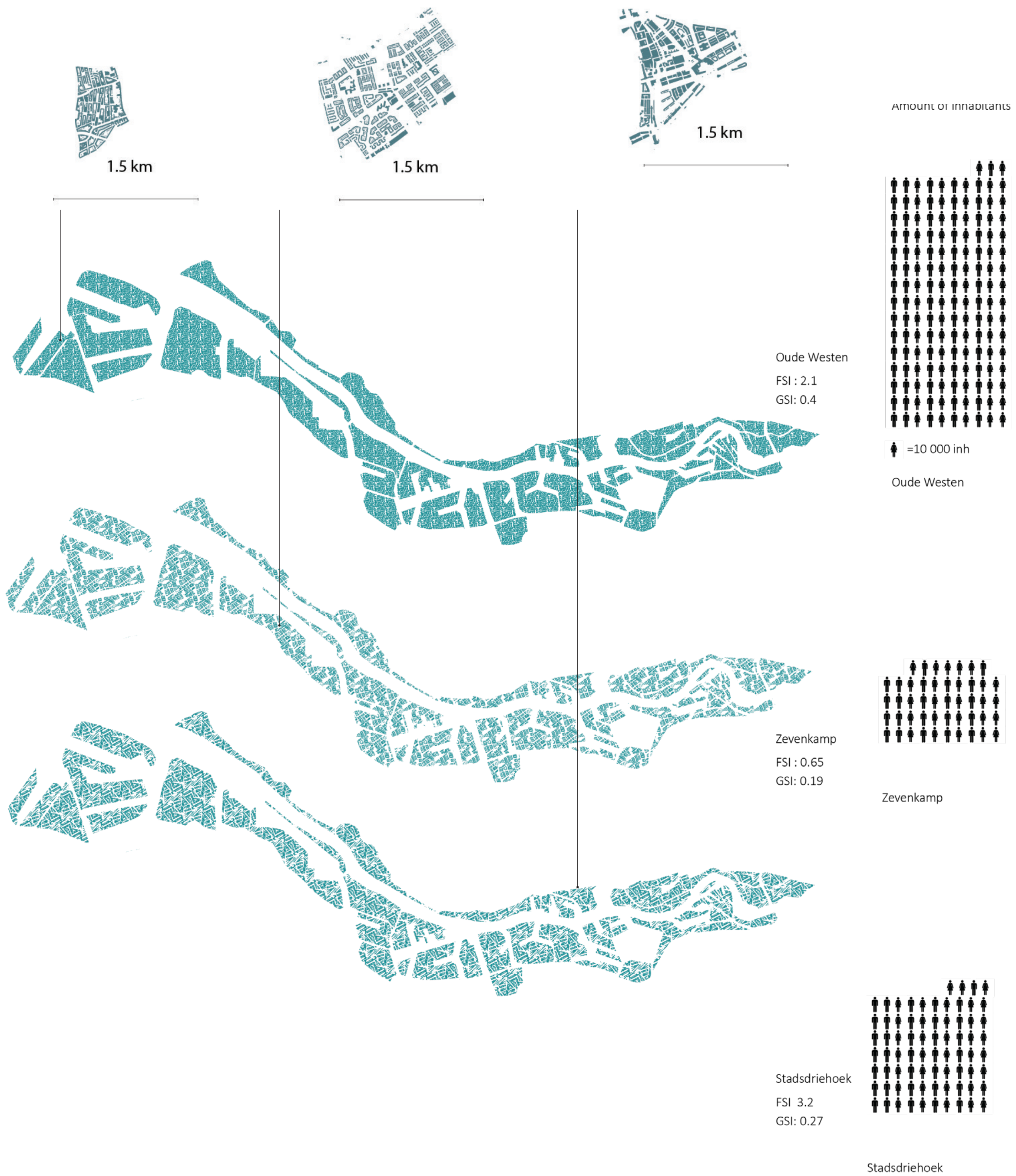


Figure 91| Three schematic ways of densification of the areas that could be usable for dwelling. It is just to show the influence of different densities and it can explore how many inhabited can be accommodated on the higher ground (minus the space used for road network, green an blue infrastructure). The predicted amount of inhabitants in 2050 for Rotterdam would be 650 000, an amount covered by the Oude westen and Stadsdriehoek option. (Image by author)

The distinction in density is correlated to the city environment. Often there is a high density in the city center and a lower density in the suburbs. This is not only about the density of dwellings per square meter but also about the amenities per area. One of the objectives was to create a more mixed environment. To create more liveliness and create the possibility of a sharing society, there will be a more spread set of amenities in the city. Especially since the ground floor cannot be used for any residential functions, this opens up the possibility to accommodate office, garage or retail functions.

The densification process starts in the areas that already have critical infrastructure, the east side. There are already harbor (higher) areas that have been transformed to urbanized areas (see theoretical framework paragraph 2 - suitability). The harbor activity is moving in west direction, since the large boats still need to be able to access (figure 92). The east harbors could first transform and densify. There are still a lot of oil harbors too, that could start the transformation after the depletion of oil. The movement of the harbor is partially currently visible (for the east harbors). However, the west part of the harbor is not yet planning to move. This is a large assumption. However, the tweede Maasvlakte could be accessible via the other side as well.

The densities could vary per neighborhood, as a result of getting a variation of living environment. The amount of square meter per inhabitant could change over time, resulting in different densities per timeframe as well. It is important that within the built environment plots are left empty to be able to construct new buildings or amenities later on. Moreover it is important to continue building with flat roofs to be able to add functions on the roof as well.

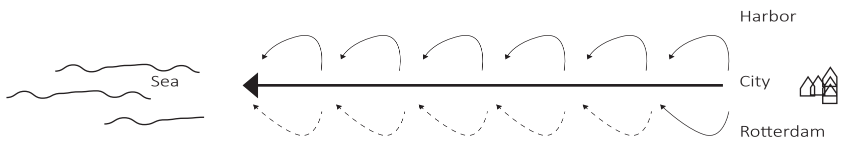


Figure 92| The harbor activity has been moving towards the west for a while already, leading even to the expansion of Maasvlakte. The more eastern harbors are already city harbors, where residential function is added next to some old industry activities.

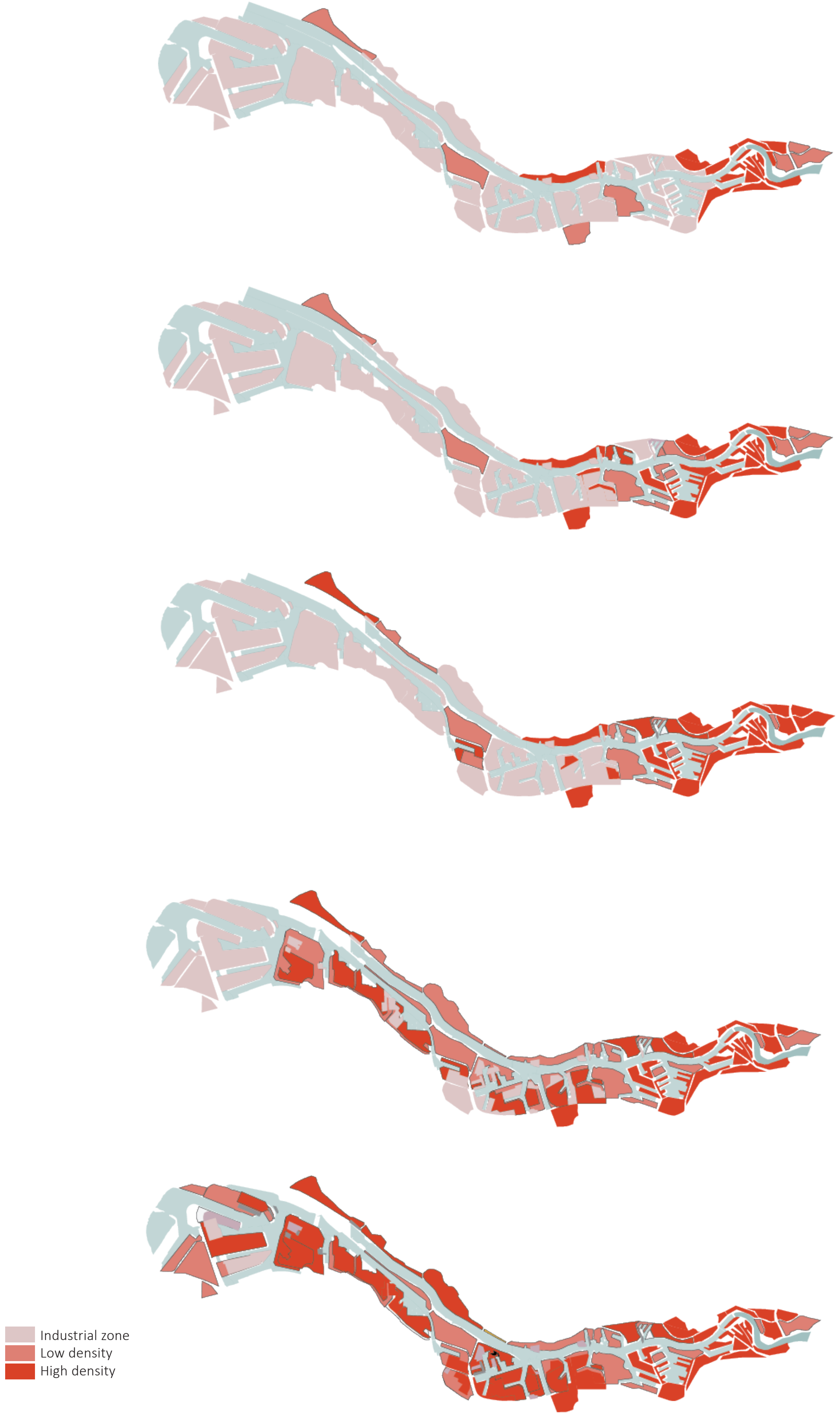


Figure 93| The densification process starts in the east part. It is important to develop a variety of densification areas to create a mixed city. This corresponds to the paragraph 5|7 about living environments. The densification process has a lot of adaptivity options, since it is a filling in process. (Image by author)

City

5|6 Centralities

When relocating and densifying a city the centralities play a key role. The people need to be relocated in a place where new centers start. As the reference project of Kiruna shows, **creating new centralities will degrade the old ones.** The key is to add centralities step by step. Since the shape of the island is rather long it seems logical to create a decentral network. There are currently some urbanized spots along the island. Rozenburg, Hoek van Holland and Pernis have a rural character, with low FSI values. The West part of the island has already a more city environment. **The relocation will logically expand from the already existing centers to the outskirts.**

Since the ground floor cannot be used for residential functions it can be used for either offices, shops or other functions. This can help to create a more lively city that has several centralities (one of the design principles form the analysis booklet). The urban life can play on a more local scale, if the citizens want to. This is important since the shape of the city is rather long. The road network and the transport aspect of the river makes sure that all centralities are accessible from other centralities. If the urban life can play on the lower scale it could contribute to the community feeling.

Where the centralities will exactly develop is not clear and depends on the development of other functions or the density of the residential function in an area. There are some areas that are already centralities, so logically seen the centralities will expand from these areas. **The centralities have to grow, but can be stimulated by developing more functions in a smaller area.**

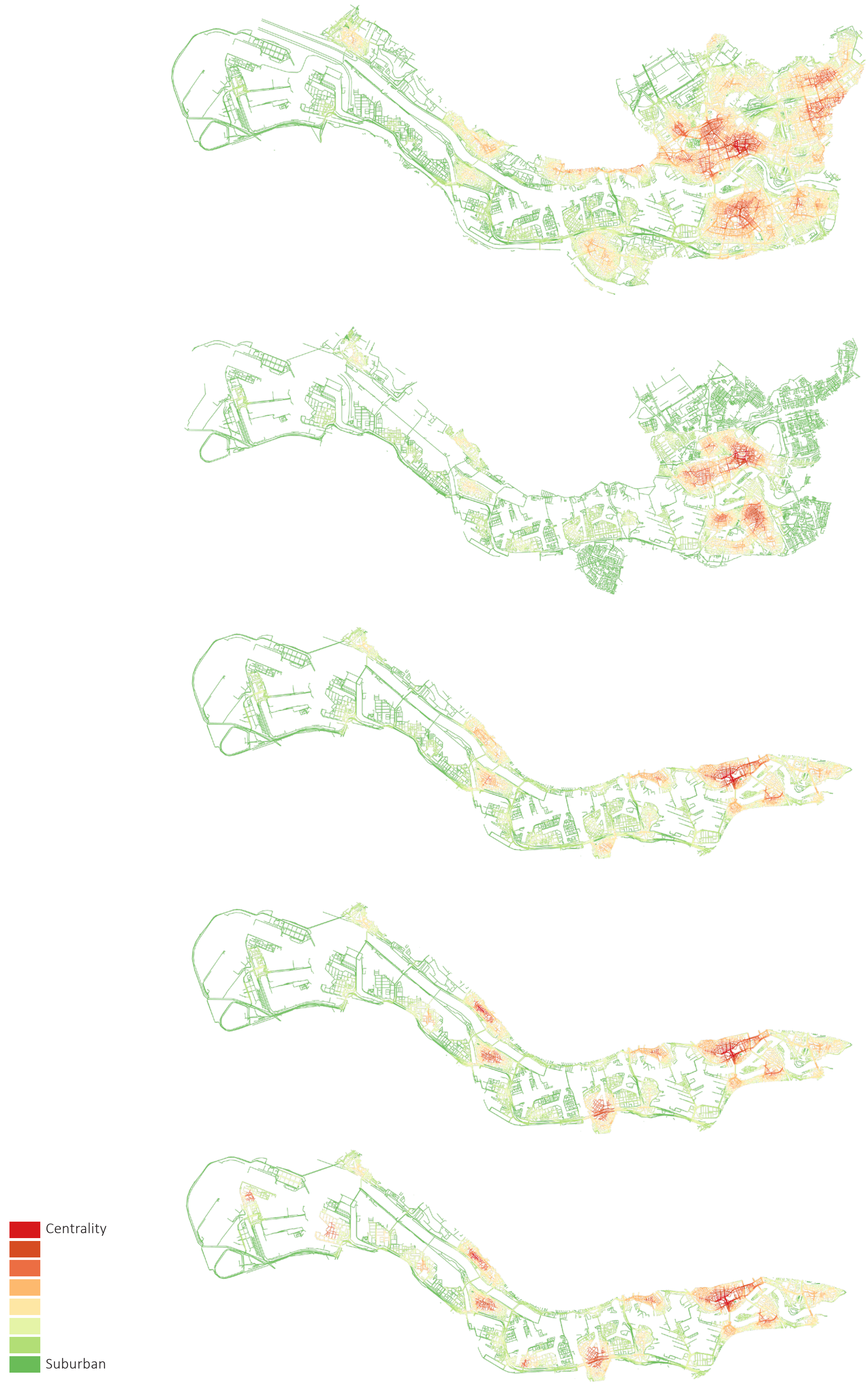


Figure 94| The centralities of the current situation show the city center and some sub centers (like Pernis). By densification it is possible to create a multi centrality system. Especially since the ground floor can be used for functions, it is easier to stimulate centers where they are preferred, depending on the developments in the future.

5|7 The living environments

Within the city there is a diversity of milieus. The dense city center where a lot activity is going on in contrast to the quiet outskirts of the city. **The aim is to densify, but that does no mean the city will be transformed to a monotone environment of dense fabric.**

Especially since it is important that the citizens are willing to relocate. The variety in the size of the roads, the distance of the blocks and the size of the blocks contribute to this environment. For this map there is a rough division in high urbanized (like the oude Westen), suburbanized (Zevenkamp) and Creative urbanized (a combination between industry and residential use). Moreover the map shows the availability of the areas to become densified.

The harbor is now filled with industrial activity. However, the harbors close to the city center become more empty. The transshipment harbors are placed more to the west since the ships have grown bigger and cannot enter the harbor so far anymore. In the middle chemical plants and oil harbors set the tone. Oil is a depleting fuel, resulting in a stage where these harbors can become urbanized as well.

The actual development of environments is hard to determine. However, it is possible to stimulate diversity within each area. This is an important factor for the lower scales. The environments can of course also change over time and therefore need to be adaptable. It **is important to offer a mixed housing type and keep the options for more densification etcetera open**, for example by building only with flat roofs.

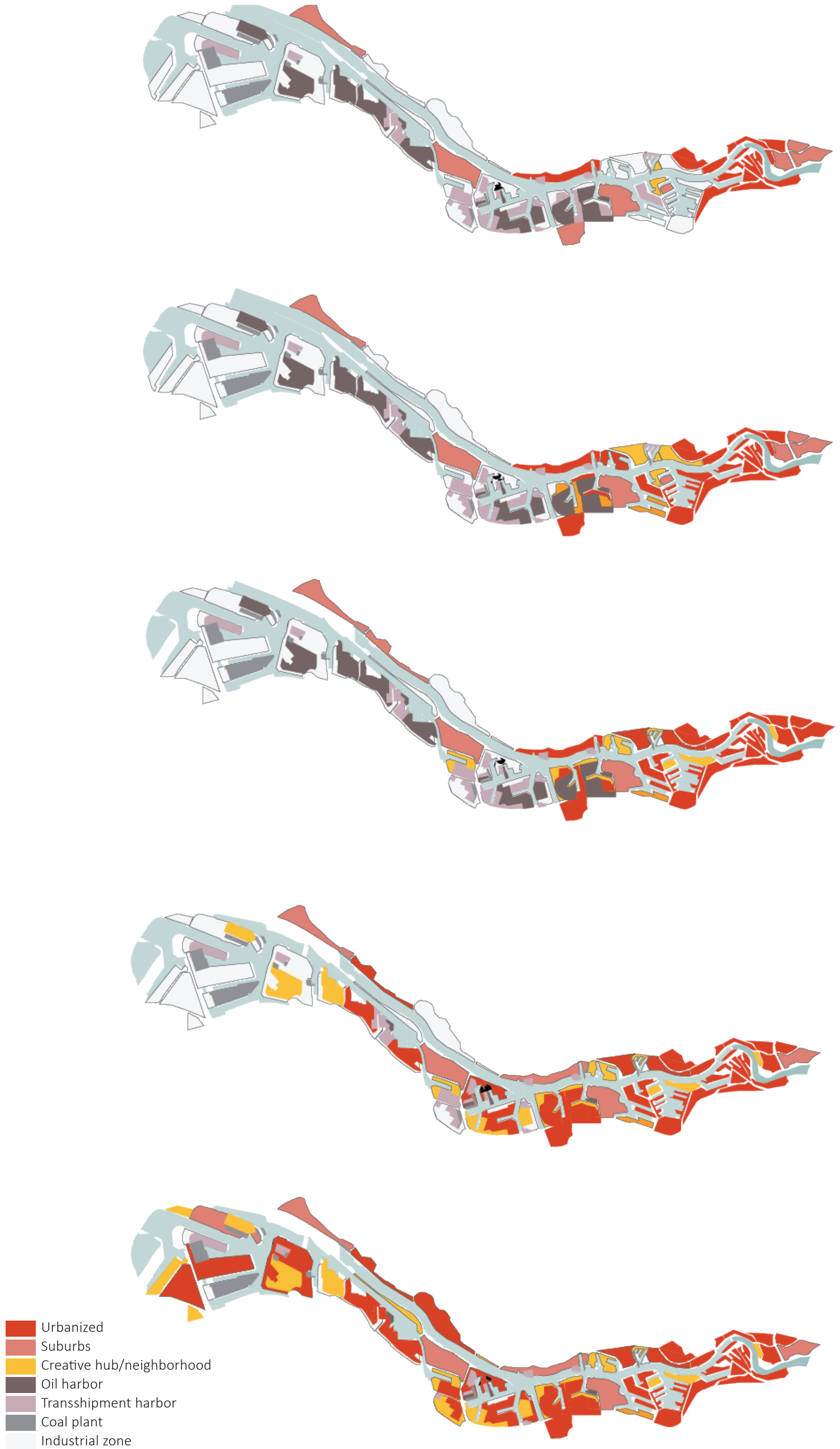


Figure 95| The areas that are currently urbanized stay urbanized. The harbor areas can slowly be transformed to urban areas. It is of course depending on the developments around the harbor, is it going to expand, is oil depleting? (Image by author)

5|8 The layers together

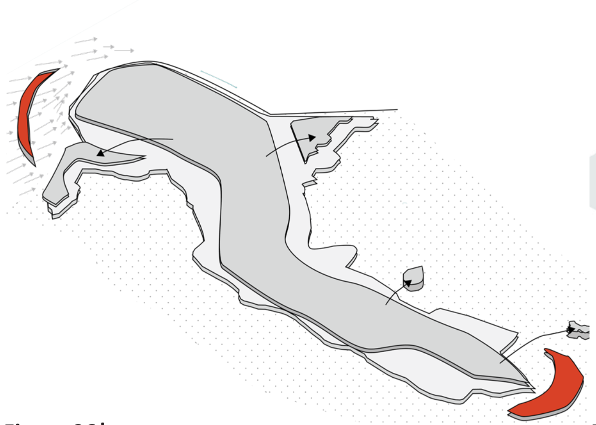


Figure 96| Usable land
What land has to be relocated to where? What grounds are usable for development? All essential element of the city should be within zone 1. The second zone can be used for temporary use, and if needed as a flood plain. Zone 3 is completely under water. Sediment islands can help shaping the higher ground and protecting it for erosion.

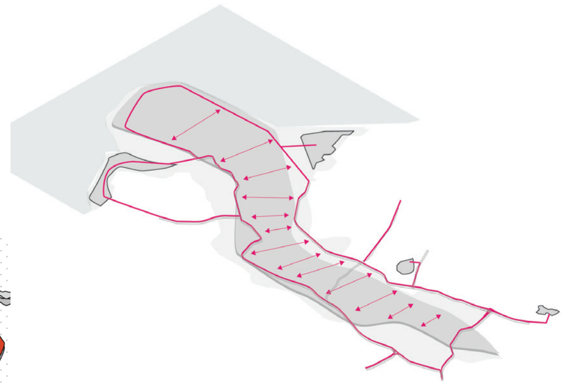


Figure 97| The road network
The road network is mostly based on roads that already exist. Parts of the ring road and north-south connections are added to stimulate the accessibility of the longer stretched 'island'. The evacuation road connects all the evacuation centers.

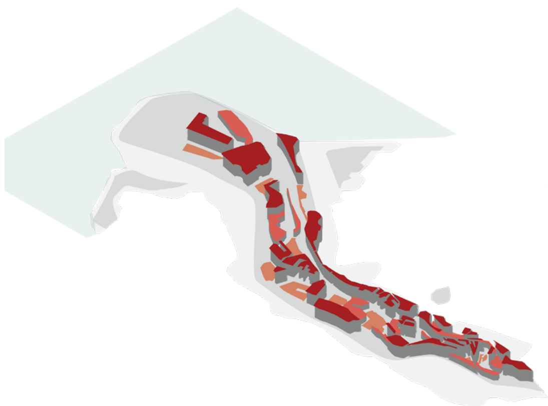


Figure 98| Densities
A distinction in densification, depending on the wishes of the people but also on the trends. Does the city have to accommodate more people, then more dense areas should be developed.

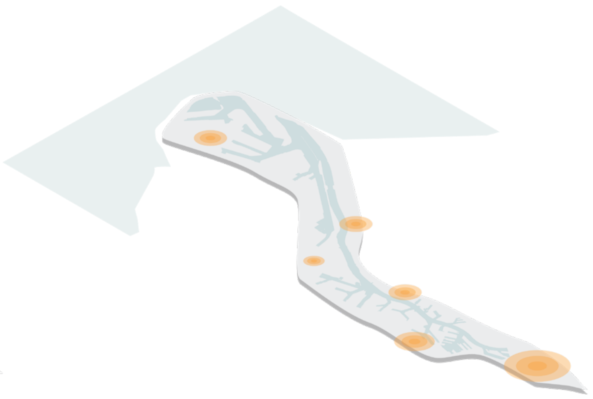


Figure 99| Centralities
The wish to create a mixed and lively city can be stimulated by creating a strong community. Therefore it is important to make several centralities that are well connected. Within this centralities the sharing community can be stimulated (see analysis booklet).

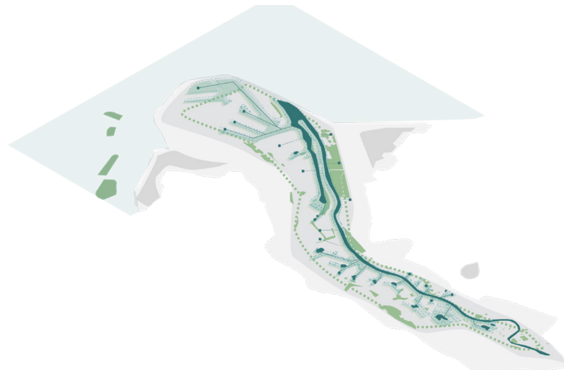


Figure 100| The Green Blue network
The Green blue network needs to be able to respond on climate changes (slow changes) and weather changes that follow from climate change (events). A connected network can help distributing the water and collecting it. A connected green structure can benefit biodiversity and contributes to a the livability as well.

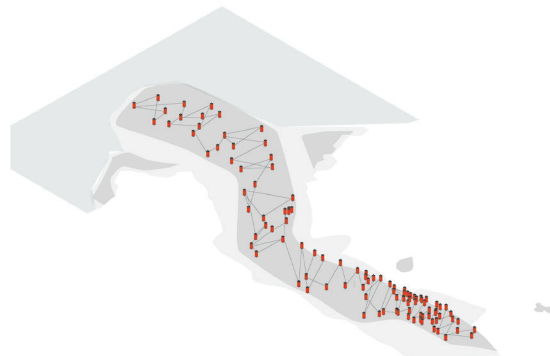


Figure 101| The evacuation network
Besides the zone restriction of residential function only above sea level, there need to be made more interventions to be able to keep the system going in case of a severe flood. Therefore evacuation centers are there for shelter and need to be connected with a higher road system.

Figure 102| Living environments
A mixed and lively city needs a variety of environments. The current use of the area could define the atmosphere of the transformation. Also the current harbor activity can be partially transformed to housing, and partially to new kinds of industry.

Even though the layers have been discussed separately they influence each other a lot. By combining the main goals of the layers the interventions can be easier realized.

- The zone 2 borders aligns with the road system that connects to other cities. The zone 2 is blocked as a dyke, but since there is no permanent settlement behind it, it can be used as organized water inlet if needed.
- The rearrangement of the river limits the amount of large boats that have to pass the city. The large boats will be (from the second phase) limited to the very west. This means that the east part can have lower bridges that make accessibility better.
- It also results in the option to using the water as a pond and reservoir of sweet water. The water can get more functions (leisure and transport) resulting in a closer relation between citizen and water.
- The zone two and three area can be used for a green and blue nature area, for leisure and maybe floating farming or temporary allotment garden options. The city becomes more dense, but nature is always around the corner.
- Creating a dense city boosts the possibility of a sharing economy and a lively public area.
- The moving harbor activity from east to west corresponds with the centrality system, that expands in the same direction.
- The shape of the harbors make it more easy to localize the green and blue infrastructure, as they are shaped as fingers in the fabric.
- The industrial layer of the harbor is already structured in a road system that could function as a grid in an urban environment.

It is important that the interventions get more detailed in space in the next scale to enlarge the synergy and also connect more on the social component.

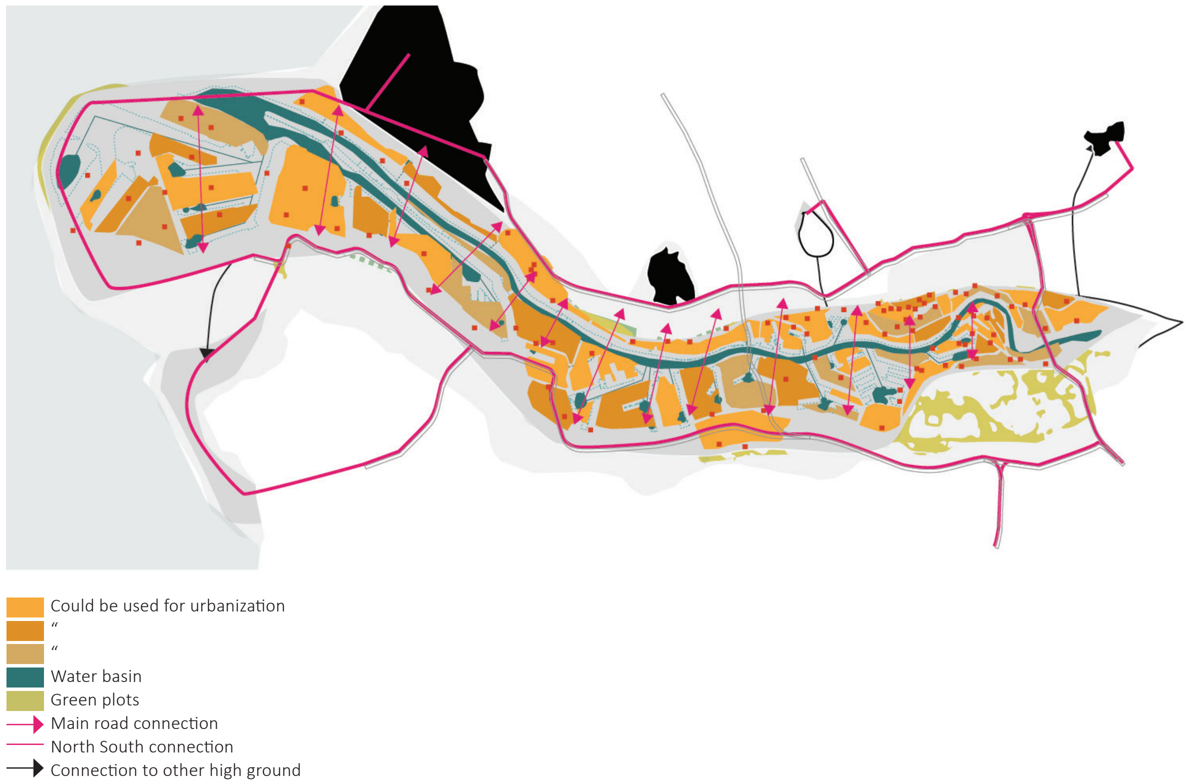
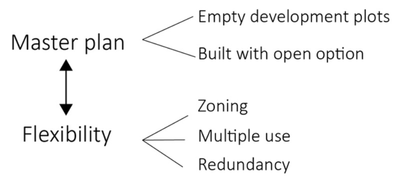


Figure 103| A combined map of the design principles on the city scale. As the design framework showed, the principles have to be achieved within one major restriction: the limit of suitable land. The extreme scenario limits the amount of available space to the higher grounds.

The layers describe a transformation from the situation now to a future situation, but the future will not look like the last steps of the ranges. The adaptivity chapter describes that a system needs to be able to cope with changing conditions. The infrastructures need to be able to cope with the range of futures that scenario thinking brings us. But it also needs to be able to adapt again, since the scenarios can change as well.

It seems that Flexibility and 'masterplan' are two opposites in designing on the city scale (see Figure below). The masterplan defines yet what should be built where. The flexible plan leaves detail up to later phase and is more a guidance plan. **These changes are related to time, but more related to developments in other layers.** If for example the necessity for housing in this area rises, the road system needs to adapt faster to get to the new developed areas.



The layers that have been discussed in 5|3 to 5|7 vary in their contribution to adaptivity and also in their flexibility. The usable land layer for example, has a clear border that will not change a lot during the project. The only changes are expansions based on new sedimentation, but these are rather small. The density layer on the other hand is very dependent on the population and migration trends (Figure 104). The road layer is using most of the roads that are already there. It depends on how quick the developments in the harbor go how quickly new bridges need to be built. It also depends if the suspension line is built in stages, or starts to connect the complete circle all in one. The green blue system need to be able to adapt smaller and even seasonal changes. Centralities are related to the speed of development and can also decay if other centralities become more central.

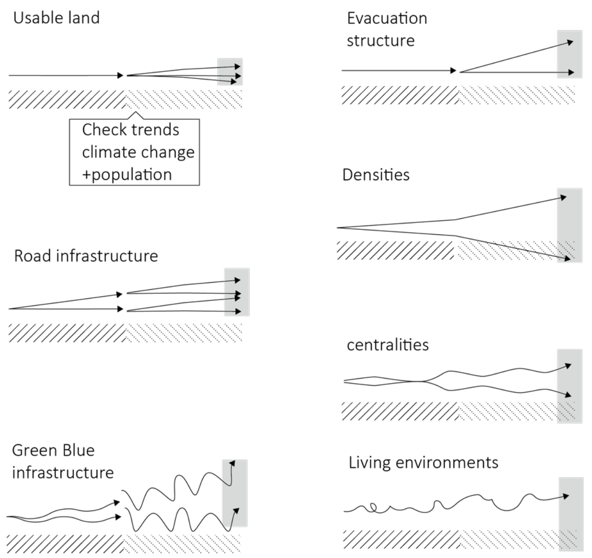


Figure 104| The ways of adaptivity in the layers. Some are more rigid (usable land) and have not so much flexibility, where others are more described as guidelines that have to be filled in at the time of development. (Image by author)

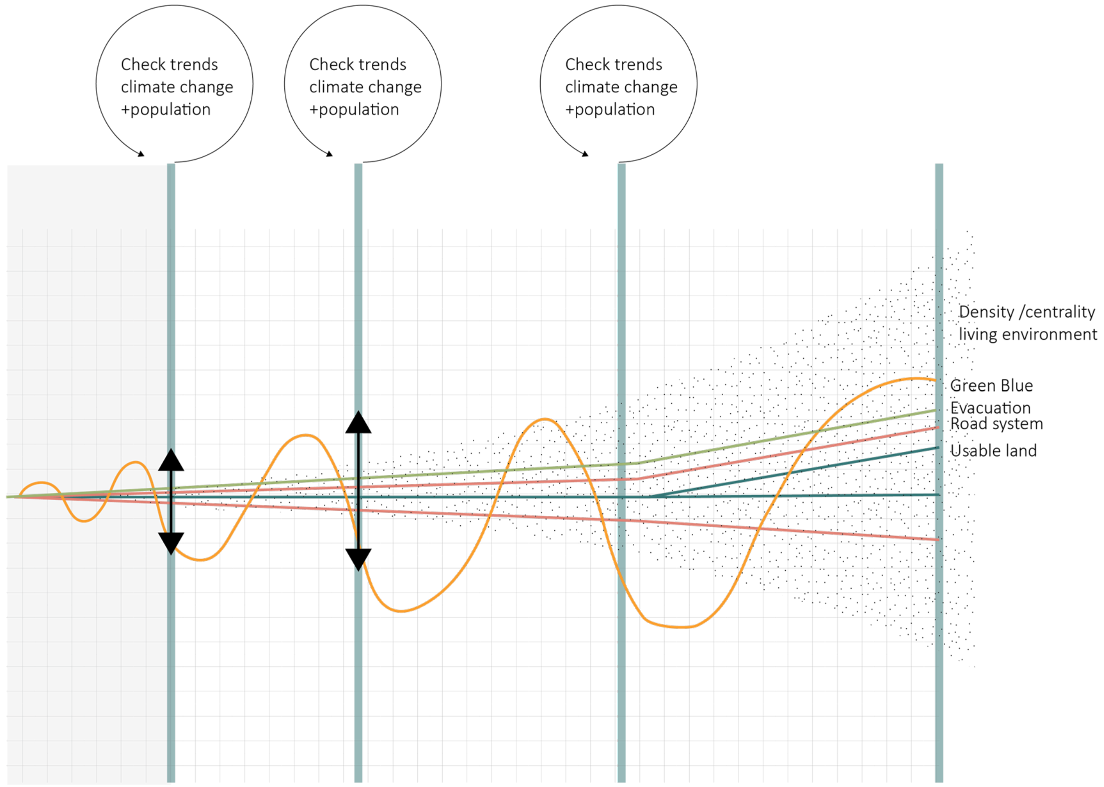


Figure 105| Some layers are more defined than others. All the layers need to contribute in a way to flexibility or adaptive capacity. The design does not have to think 200 years ahead, but it should be possible to adapt the system without rebuilding it all. (Image by author)

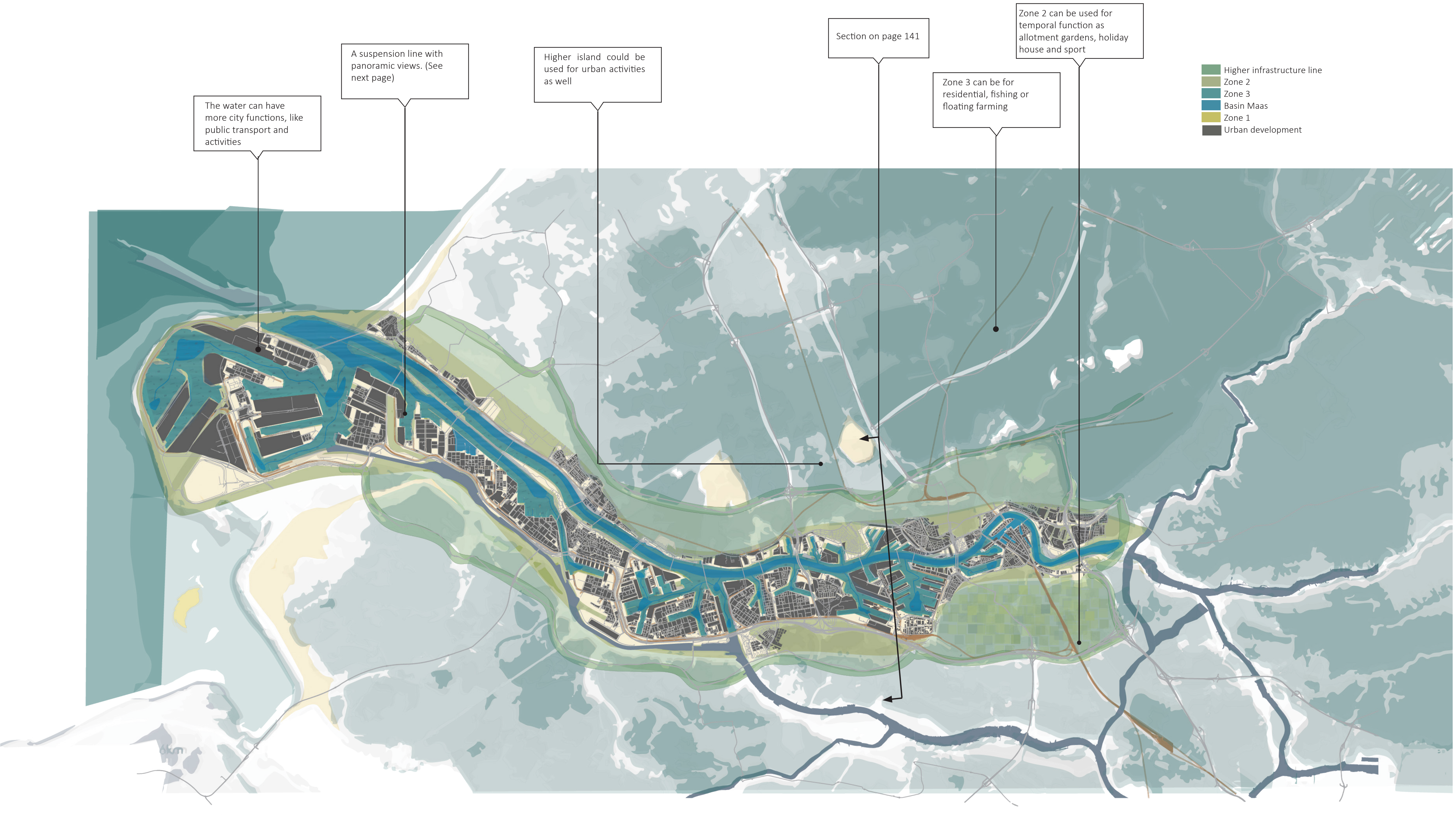


Figure 106| This city scale map shows how all the previously discussed layers come together. It is clearly visible that there are three zones, and only zone 1 is used for urbanization. The patches of dark grey show where urban development could take place. (Image by author)

Figure 107| A suspension line can have multiple functions, shelter when it rains, and a higher walking or biking line on top of it. It is cheaper than a tube and it can function if there is a major flood. This is an example of the suspension line in wuppertal (source: LLdesignroom, https://lldesignroom.wordpress.com/page/2/)

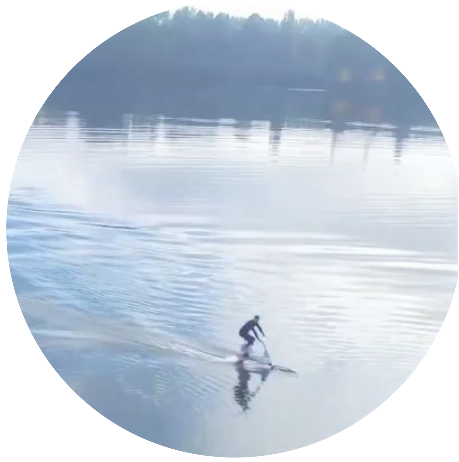


Figure 108| Transport over water in forms of boats, floating walking paths or water bikes, as shown in this example could increase when the water is no longer a transport water way. The river in the current situation splits the city into two parts, but could be a connected by adding functions and bringing the citizens in contact with the water. (Source: manta5, https://manta5.com/)

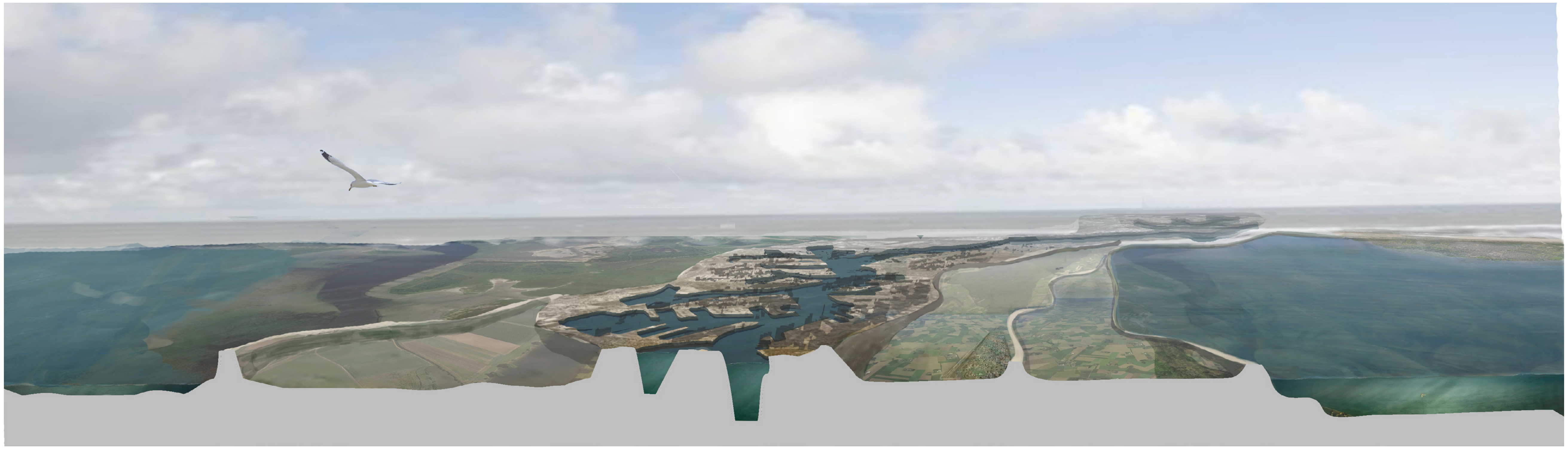
Figure 109| Adding leisure or cultural functions to the water, permanent of temporary could increase the water life. There are a lot of harbor areas, that could be used for floating pavilions such as this one in Zürich, that hosts activities and can function as a movie theatre. During summer it is a swimming attraction and bar as well. (Source: studio Tom Emerson)

Figure 110| The second zone can be used for temporary use, such as allotment gardens, or summer housing. This area could be used to produce food on a small scale. (Source: https://www.allotment-garden.org/)

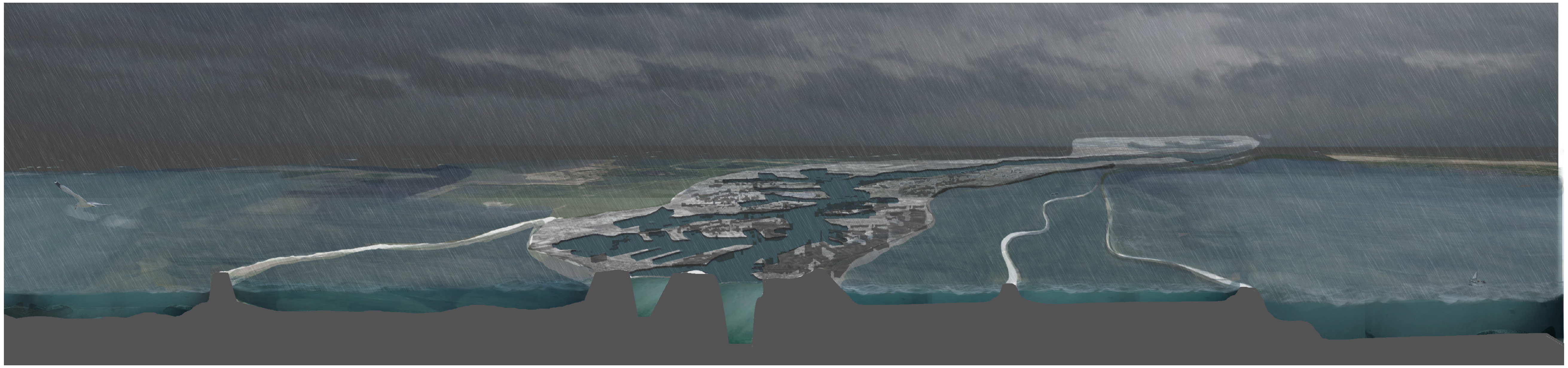
Figure 111| Floating farms could be used in all the three zones. This example is designed for Rotterdam by Beladon and hosts cows. Floating farming could also be done on sat water and for example harvest seaweed. (Source: Beladon)

Figure 112| Floating art of Cristo, to create a walking connection to higher (is)lands. This could be also other type of roads. (Source : Wolfgang Volz, Artwork: Christo)

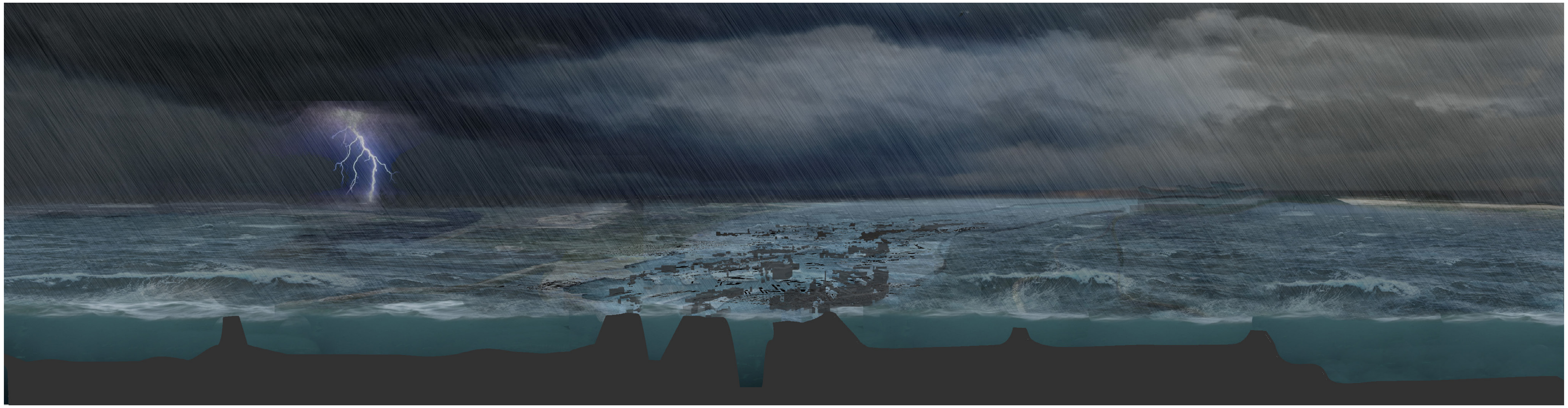
Standard water level



High water level



Extreme High water level



City

Figure 113| The three zones and based on the available land the networks. The image shows the temporary use of zone 2, the natural use of zone 3 and the urban use of zone 1. (Image by author)

// Design properties- City Scale

The question for this scale was to explore what a change in approach means for the city structure. This scale was the first spatial translation of the previous chapters. It shows the connectedness between networks and how they overlap. The city scale also takes the current situation into account, what kind of city is Rotterdam? How many people live where? Although the physical component of the city still plays the largest role, the mental and social component begin to influence design decisions as well.

// Qualities//

//High grounds//
Use the high grounds for future development

//Water backbone//
Use the water backbone as buffer or as retention basin

//Use the existing road network/
The city has an organized road network, even in the harbor there is a clear structure.

//Existing green patches/
There are already large patches of green. They can create a connected network using streets as new connection lines.

//Industrial atmosphere//
The former harbor areas give an industrial atmosphere

//Industrial buildings//
The large industrial buildings and machines of harbors can be used for new industries (3Dprinting lab)

//Bicycle transport//
The municipality wants to be the bicycle city of 2018

// Changes//

//Open up the built up surface/
To improve infiltration of rainwater

//Water backbone/
Give the river more functions to make it a connecting factor instead of a gap.

//Evacuation system/
Focus also on the third layer of safety approach. Create a clear evacuation system.

// Generate green energy /
For energy supply for the city.

//More mixed neighborhoods/
Embrace diversity by creating mixed housing

//Shared economy/
In the light of sustainability space and goods could be shared

//Community/
Every neighborhood should have a community place or center

//Space for recreation within 500 m/
Every citizen should have space for leisure within 500m

//Awareness/
The built environment can contribute in raising awareness for the climate change.

//Interaction between citizen/
The interaction between citizens should be stimulated

City

Neighborhood

// The question for the next scale- the neighborhood scale

Adapting the urban structure (from densities to transport) has a large impact on the daily life of the citizens. In order to make the people support the plan, it is crucial to show the spatial quality of the proposal. This scale will again be more influenced by the social component. For this project one neighborhood is chosen, to show what it could mean for the citizen if only the higher grounds can contain the essential aspects of a city. Some principles that follow from the assessment of the city scale need to be shown spatially; every neighborhood should have an evacuation center and road, a community center and empty plots to reserve space for future developments. Moreover the densification process needs to be explained on this scale.

6| The neighborhood scale

This is the introduction to the smaller scale, where design plays a large role in describing what it would mean for the citizens to change the structure of the city. **To be able to develop the city as a whole in a different way, the design needs to be made more tangible.** To see what the impacts are of the current infrastructure in terms of dimensions and to see how much space is now used for what, the project zooms in to the neighborhood scale, in particular Katendrecht. Rotterdam has a lot of different typologies in neighborhoods. In this paragraph **it is therefore shown how a neighborhood could look like, but it is important to notice that every intervention need to be looked upon more closely in its own context.** Katendrecht would thus be an example for other neighborhoods, especially in the way of analyzing it. However, the Design interventions are linked to the local context of this neighborhood. They can function as an example for more neighborhoods. This scale will reflect directly back on the use of space and the impact on the life of the citizens. To be able to start the design phase the analysis of these areas focuses mostly on the current lay out of the urban structure and the way it is used by the people living there. As the other scales the qualities and changes will be discussed to prepare the design properties.

The main reason why the neighborhood of Katendrecht is selected as being an example is the fact that it is an old harbor transformed to an residence area. There is still some industry left. **The example of Katendrecht can show how densification in a existing city structure can take place**. It would also be one of the starting points of the densification that could expand to the neighborhoods of Heijplaat and Waalhaven. It is important that the findings on the city scale can be further explored on the neighborhood scale.

Katendrecht has a rich history as a small part of land that was dyked in the 14th century and under government of a landlord. More recent (1895) Katendrecht has been Annexed together with Charlois to the municipality of Rotterdam. Katendrecht has a variety of atmospheres going from dense in the east (1) to park neighborhood (3) in the west. Since Katendrecht is surrounded by water there are also waterfront housing. The water that surrounds Katendrecht gives the opportunity to have great views from the Katendrecht waterfront to the opposite sides of the water.

Besides the connection to the water and the long waterfront, the previous harbor life can be recognized in more features. The roads bend slowly as they were former rail tracks and there are still some industry buildings left (phoenix hallen).

Figure 114| This image is made between (1920 and 1930) and shows the industrial Katendrecht. In the middle the housing blocks are already there. The docks are functioning. (Source: Stadsarchief. Rotterdam.nl)

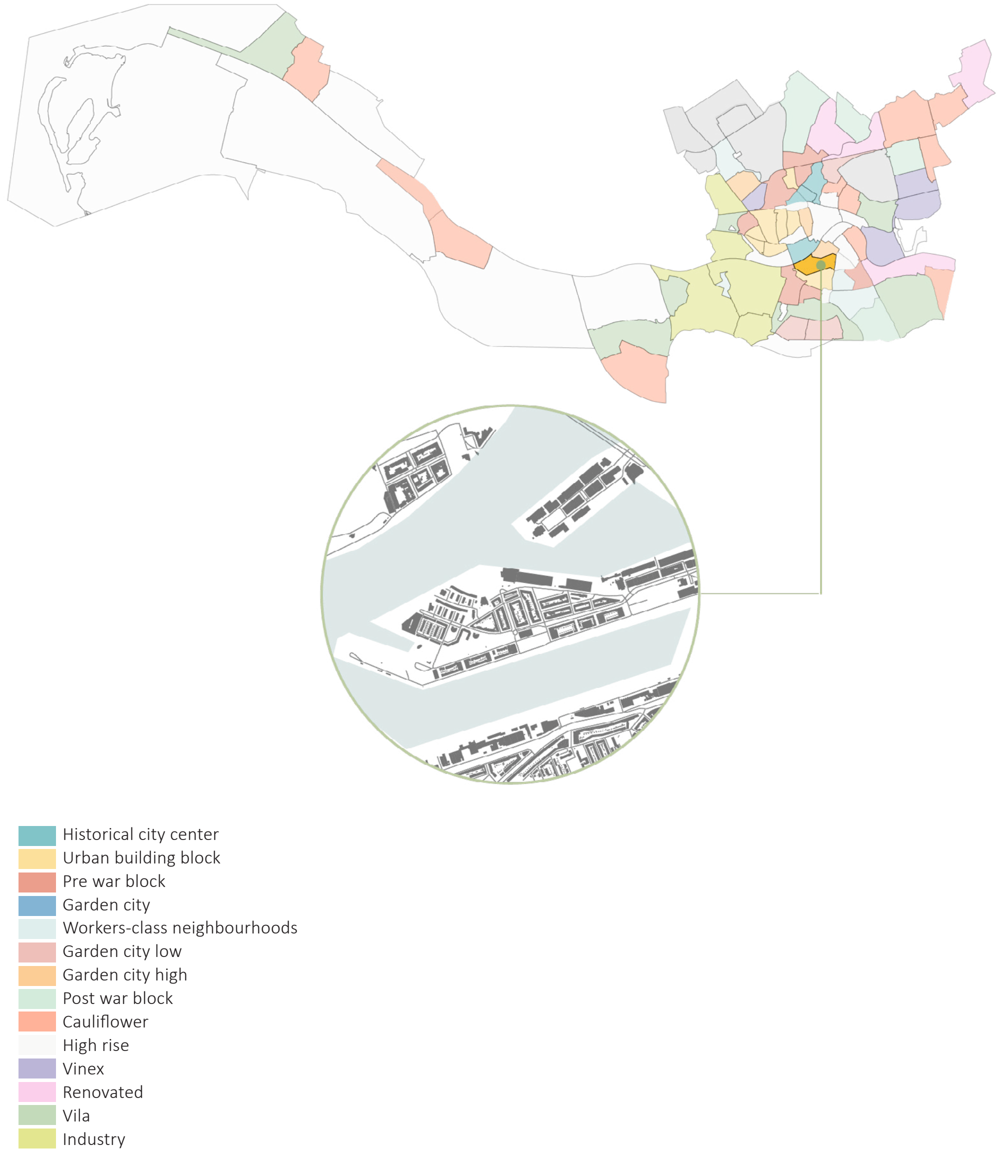


Figure 115| The diversity of types of neighborhoods in Rotterdam could be clustered in this way. Katendrecht could function as an example for other neighborhoods. However, every area has its own context that needs to be taken into account in the assessment and design phase. (Image by author based on Wijkprofiel.Rotterdam.nl)

Function

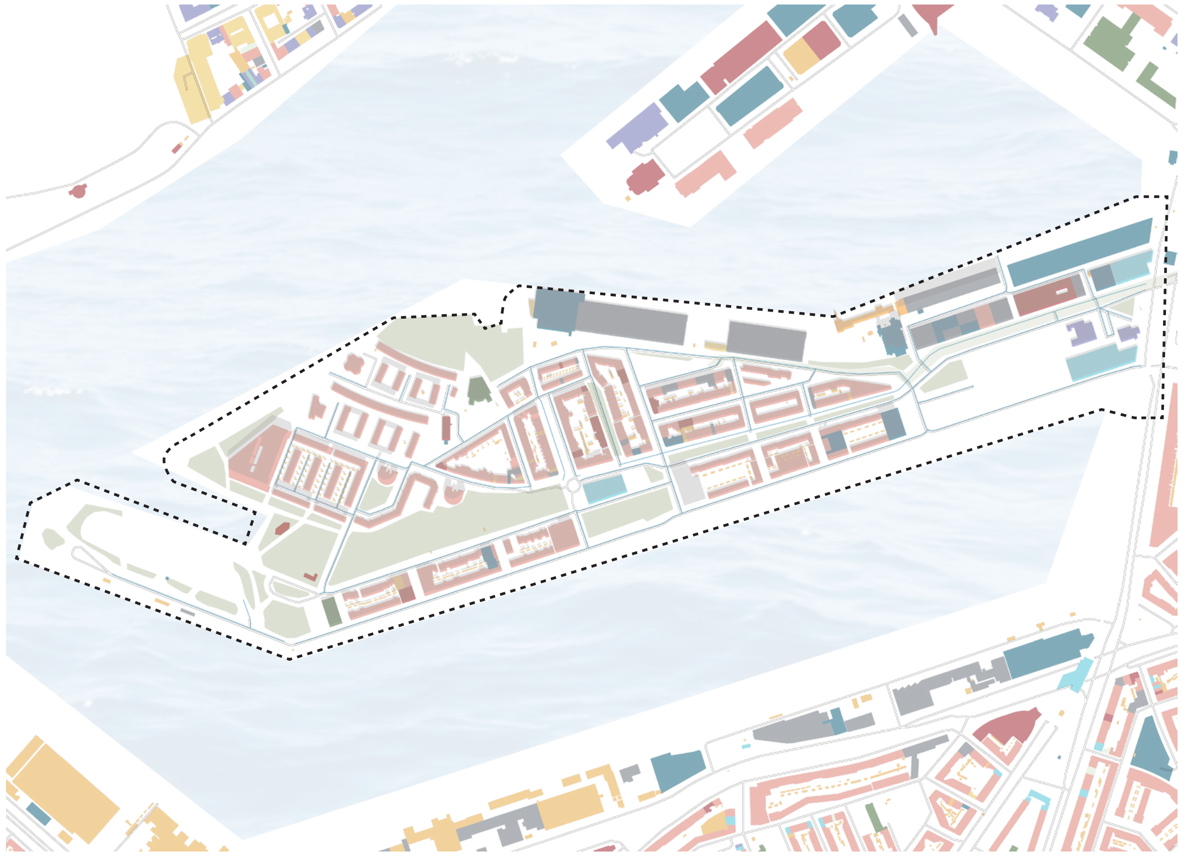


Figure 116| The functions and use of the buildings in Katendrecht. This image provides a bit more background information about Katendrecht, it shows the green park area and also the more dense center. For a more elaborate analysis and more maps, see the analysis booklet. (Image by author)

FSI- values per block

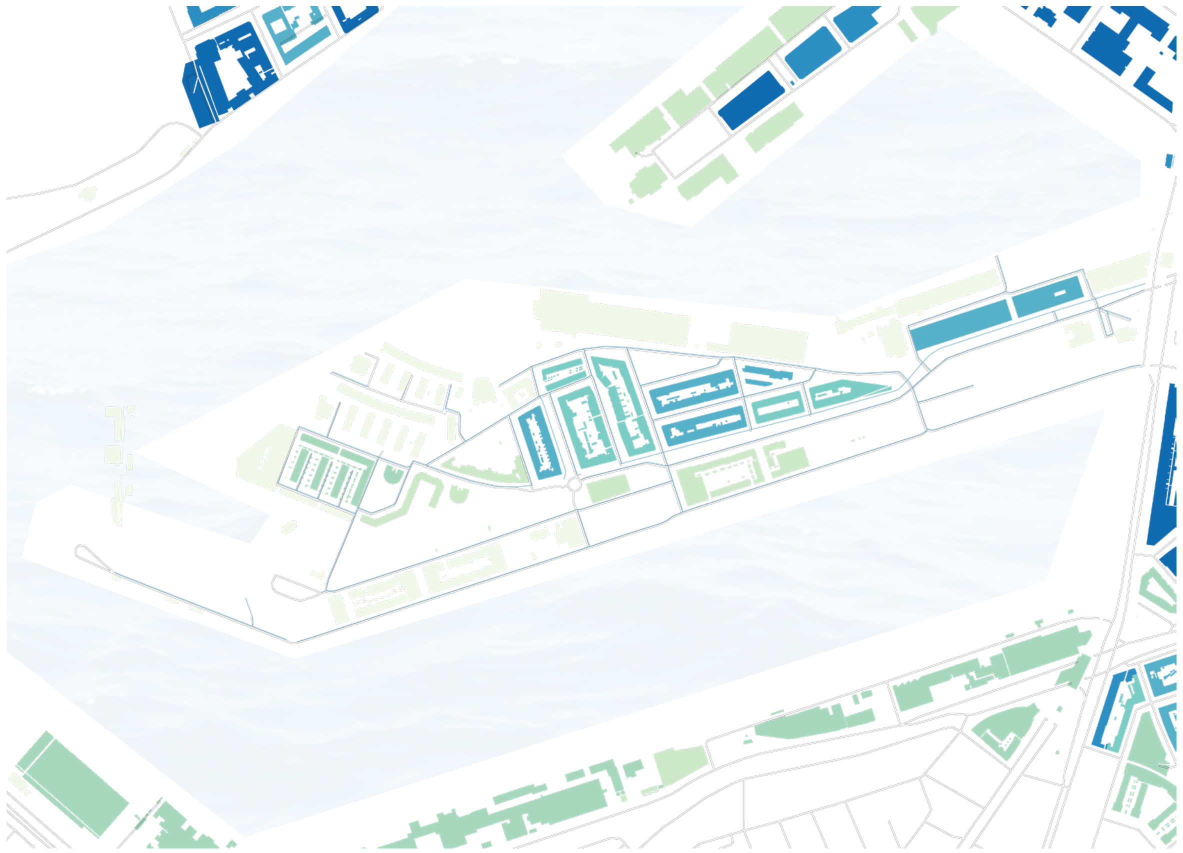


Figure 117| This map shows the FSI values of the Katendrecht area. This is important information for where densification with extra floors is possible. This will be explained on the next page. (Image by author)

From the design principles in the analysis booklet, there are four goals from the previous scale that need to be explained specifically. Every neighborhood should **densify**; have an **evacuation network** (building and road); a **community center** and **empty plots for future development** (Figure 119). The crucial activities of the city need to take place on higher floors, since floods can be higher. Besides this the overall goal is to emphasize and improve the spatial qualities of the area (more detailed in analysis booklet), and translate the design principles of higher scales into the lower scale (Figure 118). It is important to find overlap in these principles:

- Use the long harbor waterfront as a quality
- Highlight special view points on the rest of the city
- Increase the mix of housing
- Create a local green blue infrastructure
- Stimulate interaction between citizens
- Stimulate sharing economy

The neighborhood scale paragraph will first focus on ways of densification (6|1), then on the evacuation network (6|2) and then on the wet-proofing of the ground floor (6|3). These findings will be combined in maps and shape he question for the street scale (6|4).

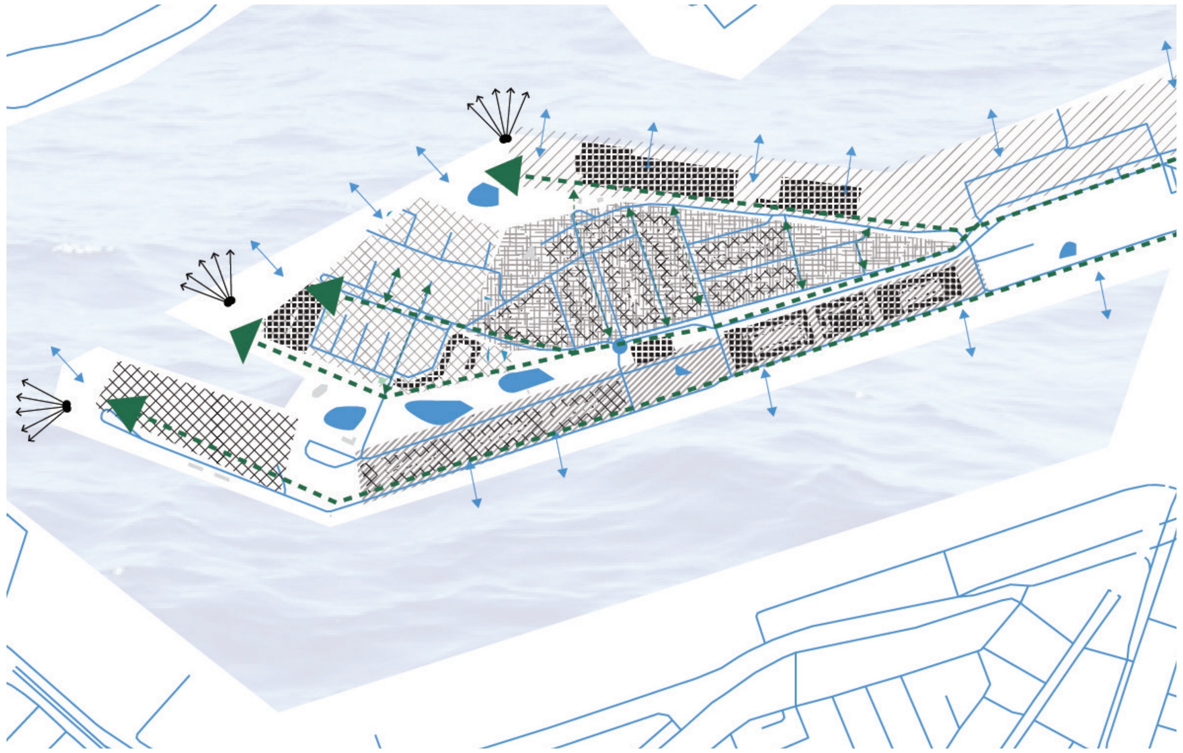


Figure 118| This drawing shows roughly on what connections or points an improvement could be made or an emphasize could be made. Use the green corridor, emphasize the waterfront and viewpoints, create more diversity etc. (Image by author)

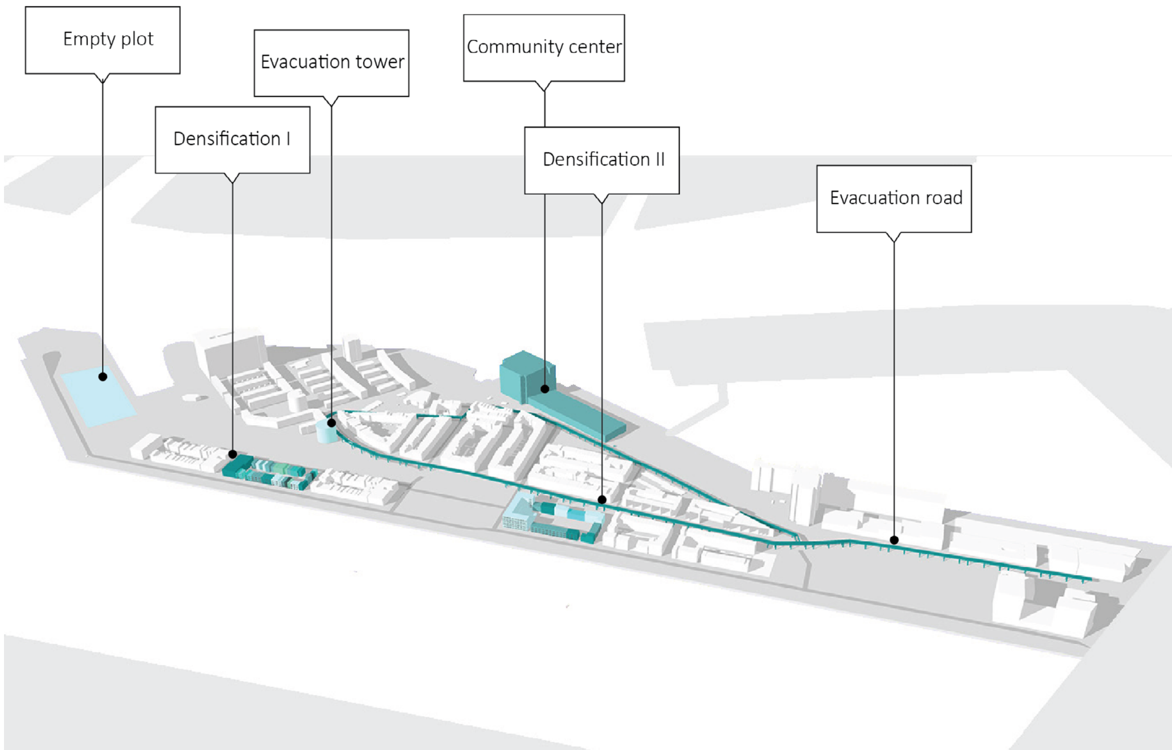


Figure 119| The focus area within the neighborhood will explain how densification, evacuation and the community center work. These themes would be important for every neighborhood to develop interventions on since they contribute to goals on the higher scales or are part of networks of the higher scales. (Image by author)

6|1 Ways of densification

The driver for densification has become clear in the project so far; we have less land to accommodate the people and the city. **On the city scale the FSI and GSI figures show where new building blocks could be constructed or where new stories could be added (**in theory) (see chapter IX, city scale, paragraph 5). This could be seen as direct densification. There are interventions that contribute in indirect way to densification as well. This paragraph describes them all:

- **Densification of people (direct)**
- **Densification of functions (indirect)**
- **Densification of goods (indirect)**

T**he indirect densification combines or shares other elements of life in the city in order to use less space.** This is based on the concept of densification of functions and use. When a space is used more intense during the day by several types of use that have distinct time slots the use is densified. The space that becomes vacant in return can be used for residential function. This can also be for use within building blocks, such as shared living rooms, laundry rooms and kitchens in order to accommodate more households per building.

The direct densification can be achieved in several ways as shown in Figure 120. Constructing a new building on a currently empty plot is a quite straight forward option (1). Topping up existing buildings can increase the FSI. Depending on the state of the existing building, floors can be added on the current construction (2). In the center area of Katendrecht however, the buildings are rather old. A solution could be to make an exterior construction that carries the extra floors (3). This could also be done as a construction that spans over several houses (4).

On the right page clusters of building years are shown. (Figure 124, 121,123 and 122)

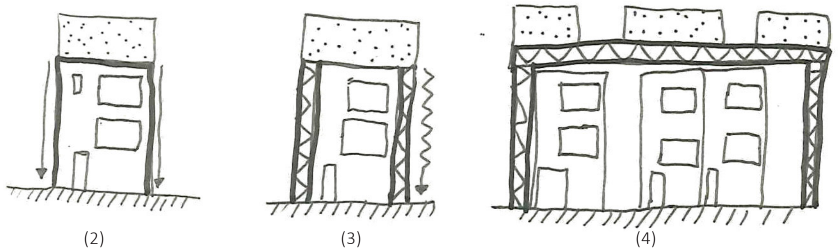
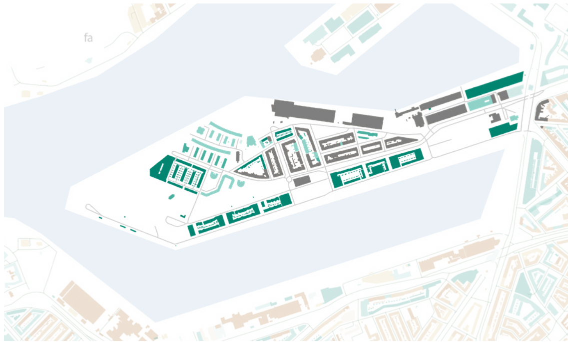
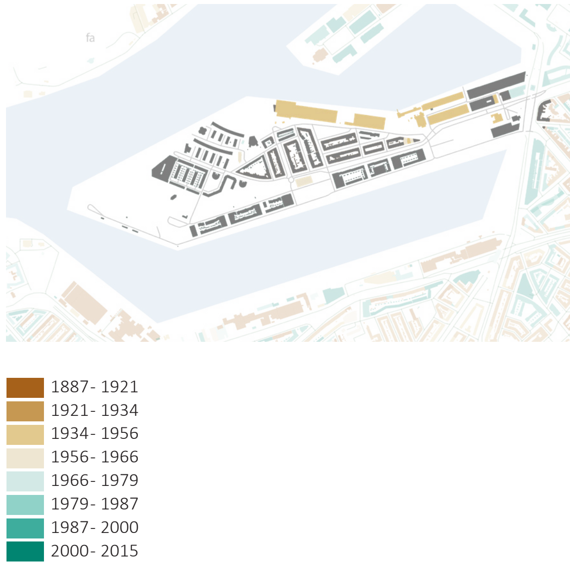


Figure 120| A schematic drawing of the options of direct densification. It depends on the strength of the construction of the current building. For example docking buildings are often heavy constructed, so new structures can built on top of them without adding external construction.





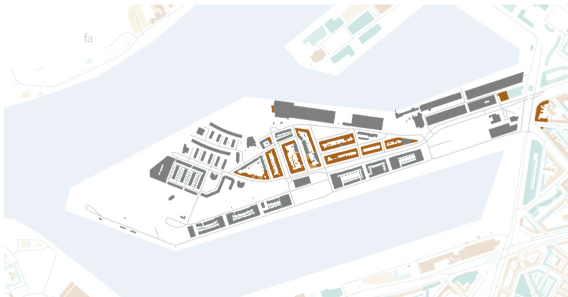


Figure 124| These maps show the clusters of building age, to see what kind of topping up could work on the construction (in general). Above the new built buildings, below the older ones. (Image by author)

Figure 121| Mei architecten in designed an apartment building on top of the Phoenix food hall: the robust construction of the shed can carry extra load. (Source: Mei architecten)

Figure 123| Plegt-Vos made a construction over another dwelling building, without adding carry load to the old structure. The area can be densified in this way. (Source: Plegt-Vos BV)

Figure 122| Unilever Main office, design by JHK Architecten in collaboration with West 8, adds a building with external construction that goes over other buildings. (Source Image: Jan van Helleman)

Besides direct densification, the urban fabric can get densified in indirect ways as well. **If other functions can take place in a smarter way so they need less space, the residual space can be used for residential function.** An example could be a school, that is only used for educational functions between 9-16 h. After that it could be used for cultural classes, and in the evening even as a cinema. In this way the building is used more hours per day (see Figure125). If the activities take place during the complete day, this is beneficial for the liveliness of the street, especially if the functions are located on the ground floor. There are many possible combinations of buildings and functions, for example restaurants in the catering areas of offices, shops and bars that share squares or public parks and sport facilities. Figure 129 shows in more detail what functions could share spaces, based on the time slot that they are used during the day. To explore the time slots per function the diagrams on the left show when 4 types of functions are used during the day. To explore the time slots per function the diagrams on the left show when 4 types of functions are used during the day. One circle represents 24 hours.
For Katendrecht this results in shared use of a building, that will be shown in the map in figure 126.

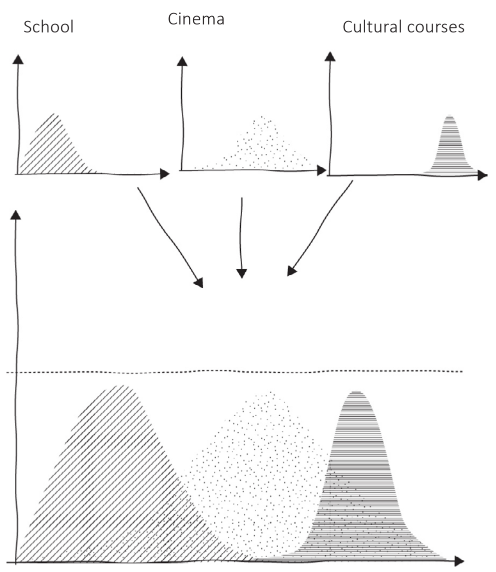


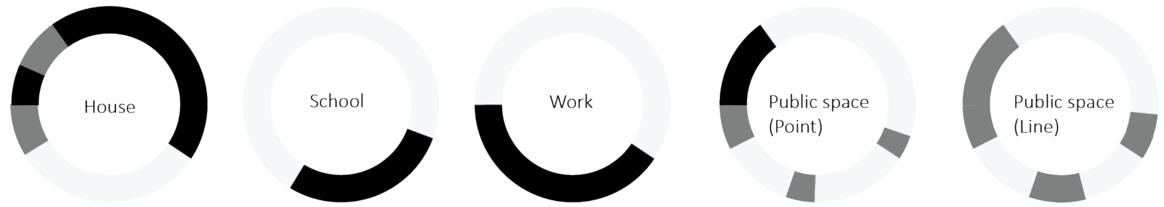
Figure 125| Sharing a building over time for several functions can help in the densification process and contribute on the social level to liveliness. This example shows a school building that is used for cultural classes in the afternoon. In the evening the beamer rooms can be used as a cinema. (Image by author)

Figure 126| The maps of Katendrecht show what buildings and what public space could be used for the similar functions sporting, eating and meeting. In this way overlap can be found, to combine functions, in relation with Figure 115. (Image by author)

The densification of use does not necessarily have to be in public space. It could also mean sharing functions within a residential building. The system of shared kitchens and shared laundry rooms and shared living rooms can result in higher amount of residents per building. It can also stimulate sharing other goods (such as tools) and activate the interaction between people. The sharing community is therefore valuable for the physical component of the city, but also for the social and mental component. This sharing society could be seen as densification of goods. By sharing for example the kitchen with other residents, improves the interaction an could also stimulate the cohesion. For sharing goods with the whole neighborhoods (such as tools, ladders or electric bikes) the community center could be a place where the people go. **Sharing goods as cars or washing machines leads to less consumption per inhabitant.** A collective parking lot per neighborhood can also help for the street scale to stop parked cars in the street and activate a pleasant street environment. Reference projects show how spaces in a residential building can be shared (Figure 127), or can be combined with other functions (Figure 128).
In combination with adding floors, it could mean that a shared facility as a shared living room is added to the block so that currents and future inhabitants benefit from the added function.

Figure 127| Sonnweldviertel from Kada connects the semi public facilities like shared kitchen and laundry room with yellow hallways. With sharing these facilities the apartments can be smaller and therefore the building can accommodate more people. (Source: Kada)

Figure 128| This bar in Gent shows a combined function of cafe and laundry service, since you have to wait for your laundry anyways. The wasserettebar combines two functions in an interesting way. (source:Dezeen, image by: Pinkeye)



Garden	Play ground		Park	Walking path
			Swimming pool	
	Sport field		Sport field	Park
			Shops	
	Cafeteria	Cafeteria	Restaurant	
			Square	Square
			Theatre	
		Rooms with beamer	Cinema	Open cinema
	Classrooms	Large meeting room	Community place	Street
	Drawing/music room		cultural centre	
	Gym		Sport centre	
Parking		Large parking lot	Parking	

Figure 129| The circles show the activity plots of the home, work, school and the public space. In this way overlap can be found for possible densification in use. (Image by author)

6|2 Evacuation Network

From the evacuation network on the city scale there needs to be an evacuation road and center in every neighborhood. This is necessary in case of a severe flood, to protect the citizens of this area. There are several types of evacuation buildings, some are located within hospitals and others are positioned in the center of a neighborhood. When a extreme flood is there, that also floods the street level up to the first floor, the evacuation road needs to be still accessible and leads towards the evacuation center. **The center has to have supplies like blankets, and is meant for temporary shelter, for people that where not able to reach there home in time.** Therefore the facade should contain a flashlight system so it can warn and guide people (Figure 130).

The construction of an elevated road structure can be combined with the public transport that goes through the entire city, the suspension line. This will be explained in the Street scale. The higher function brings possibilities for this central street, as a kind of promenade trough the neighborhood. The underneath space could be used for activities or shelter from rain or sun.

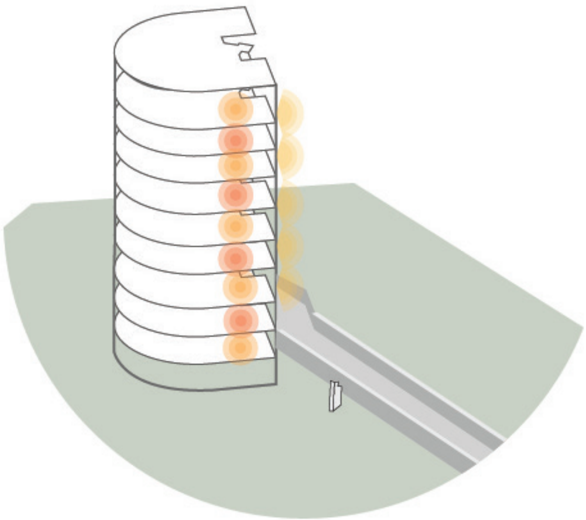


Figure 130| An evacuation building needs to constructed or entitled in every neighborhood. It needs to connect to the evacuation road and has to have lights to make it visible in case needed. (Image by author)

Figure 131| The evacuation network needs to be easily accessible from all the neighborhood and has to have a central position. This figure shows how every street connects to the higher line. There are several staircases that make the high line accessible. Also there are emergency ladders to climb on other sports.

6|3 Wet-proofing

As the evacuation paragraph described, the city should still be able to function, even in case of a severe flood. **One restriction that followed from the assessment of the city scale in combination with the goal to enlarge the adaptive capacity is that the crucial elements of the city need to be above the first floor.** This wet-proofing of the city can be done in various ways. First of all the residential restriction to not use the ground floor for dwelling. Within a building block there can also be done other types of flood proofing:

- The shape of the block can create a dry courtyard.
- The open parts of the block could be closed with stairs and a higher inner courtyard.
- The entrances can be made higher,
- The facade can be made without windows (or pressure proof glass).
- There could be additive protection sheets that can be placed in case of a flood.

The streets can be made more wet proofed as well:

- Heighten up parts of the center can shape a higher block
- Using steps and slopes can guide higher paths
- Using additive protection at the beginning and end of the street
- Making a platform as connection line
- Slope the streets so the water gets discharged to lower surface water areas.
- Create a subsurface net that keeps the street and its attributes at place.

Doing so can protect the houses and streets for an extreme flood, but can also prevent the complete neighborhood to flood if the level is just 50 cm for example.

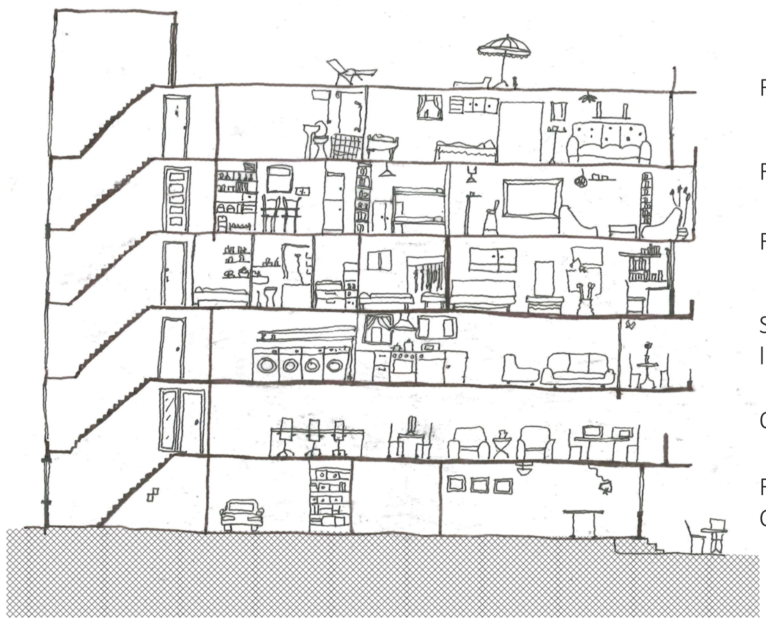
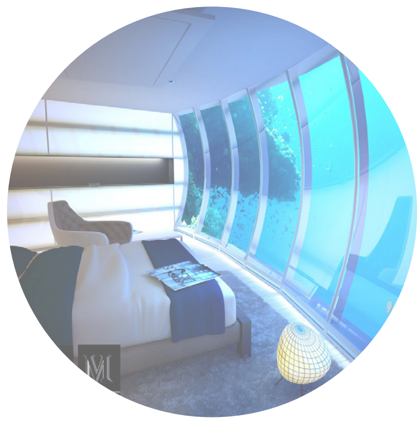


Figure 132| Zoning within the building can restrict people sleeping at the ground floor. If a flood would occur unexpected the people living there are still safe. Moreover this allows a facade that is adapted to the wet-proofing options.

Block with water on the outside

Entrance is high

Option to place bulkhead



Use waterproof facade

Figure 133| Four references show ways to make the area wet proof. Top image is the Bodium castle (source: timeout.com) and shows how the water can be blocked outside by the building block to create a dry courtyard. High entrance of a house in Amsterdam (source: google streetview) and bulhead in Deventer (source: google streetview) and below a view of a room with underwaterproof glass (source:Deep Ocean Technology)

6|4The layers together

The layers of the city scale relate to the layers in the neighborhood. The translation to the small scale is schematically shown in Figure 134. I**t is clearly visible that the social layer becomes to be more important and also more dependent from the people that live there**. The neighborhood has to function as well during a flood, which reflects on the social spaces. If the public space is completely flooded, the community centers, shared kitchens, rooftops and higher road become more important and become social places themselves. The activity moves from the public space to the collaborate space as the ground floor is not accessible. The citizens can use the high line, suspension line and boats to get to other parts of the city, but for social activities they can stay in their own area. The first scheme shows the grey (road), green and blue infrastructure and how they respond on block level to the scenarios of climate change. **The lower scale green and blue network should be able to deal with the changes and to provide for example cooling, in times of a heat wave.**

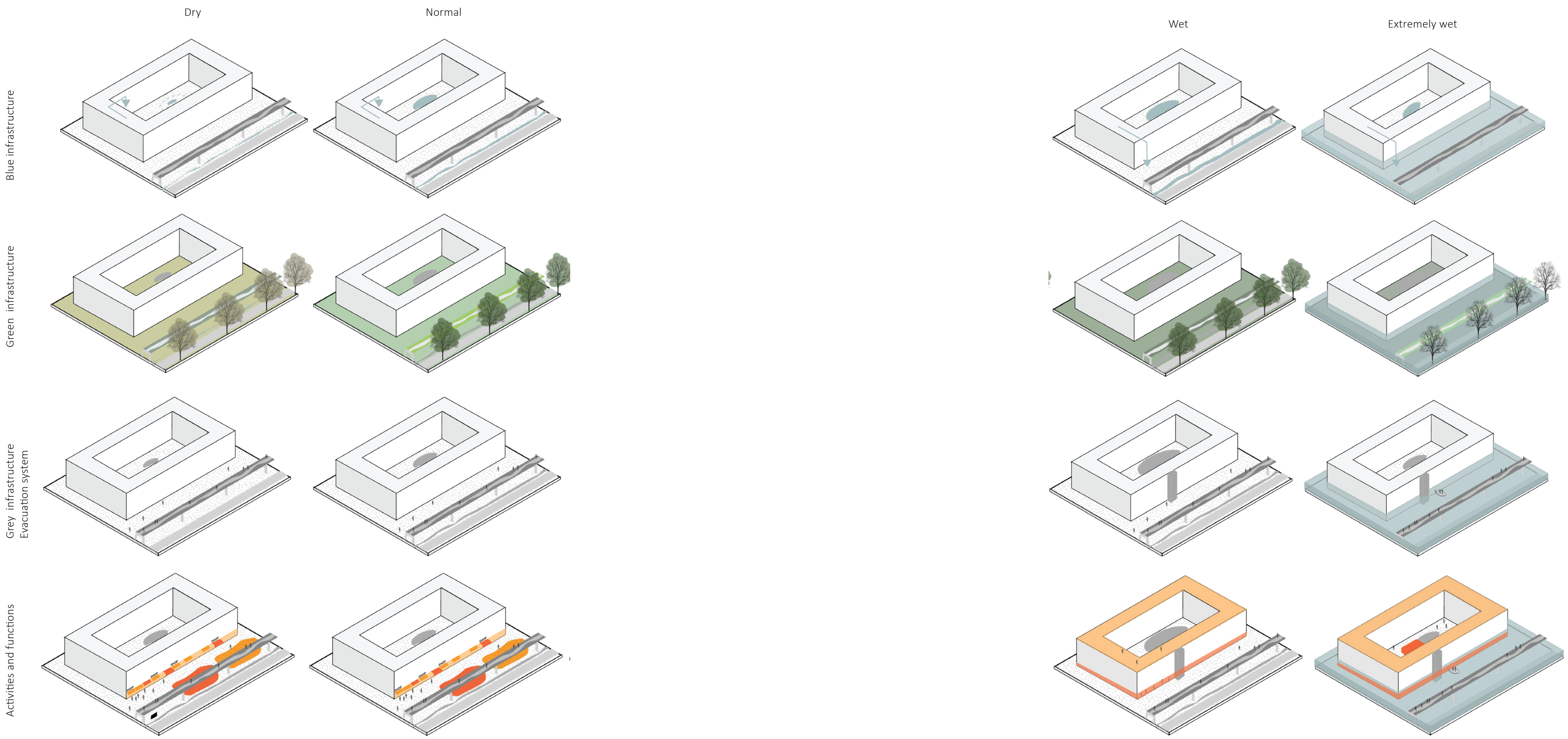


Figure 134| This grid view shows the adaptation of the green, the blue, the road and evacuation and the activities layer in four climate scenarios. Especially the relation between the activities and the usable land for this is interesting. When a flood occurs, the activities densify even more and can only take place within or on top of building blocks. (Image by author)

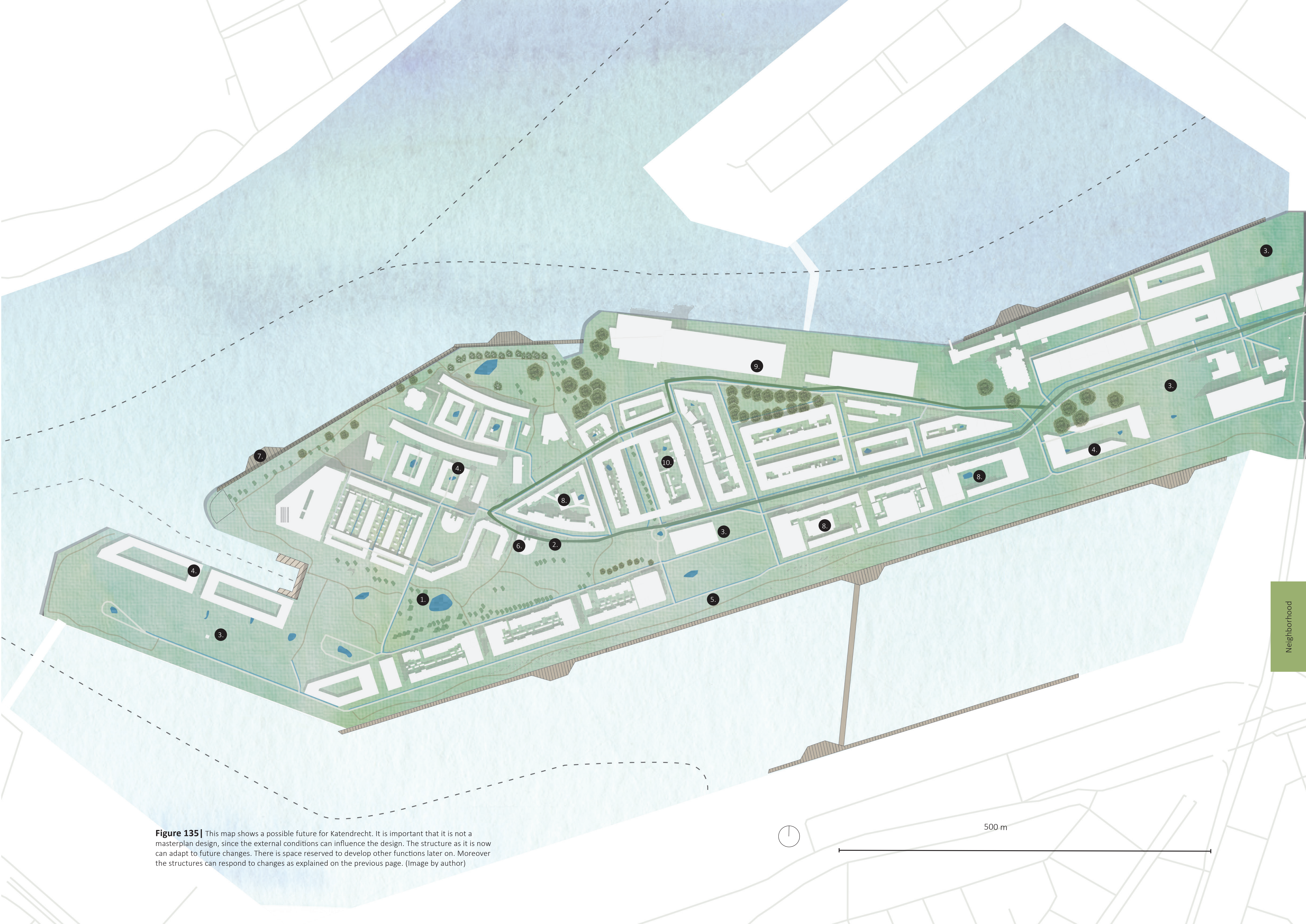
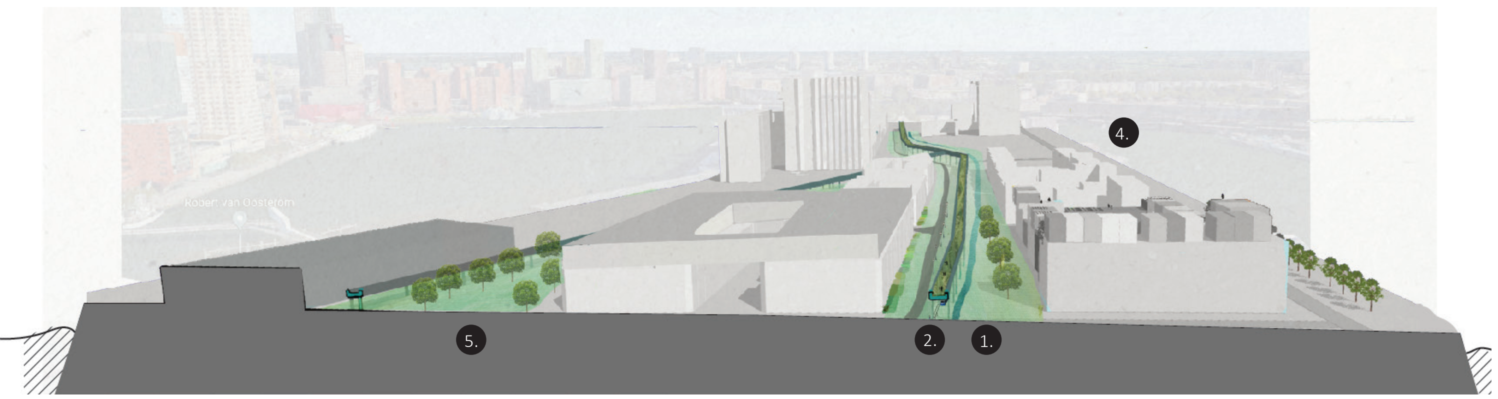


Figure 135| This map shows a possible future for Katendrecht. It is important that it is not a masterplan design, since the external conditions can influence the design. The structure as it is now can adapt to future changes. There is space reserved to develop other functions later on. Moreover the structures can respond to changes as explained on the previous page. (Image by author)



1. Local water ponds for cooling or as storage of water in wet times.
2. The evacuation road and partially the suspension rail (public transport)
3. Space reserved for future development or adding of function
4. Newly added building for densification of the GSI
5. More green pavement (see street chapter)
6. The evacuation building, central, and connected to the evacuation road
7. A floating path along the river that opens the water up for activities
8. Added buildings for shared kitchen and laundry
9. The community building where sharing goods is made available and stimulated
10. Water ponds inside the block can help for droughts.

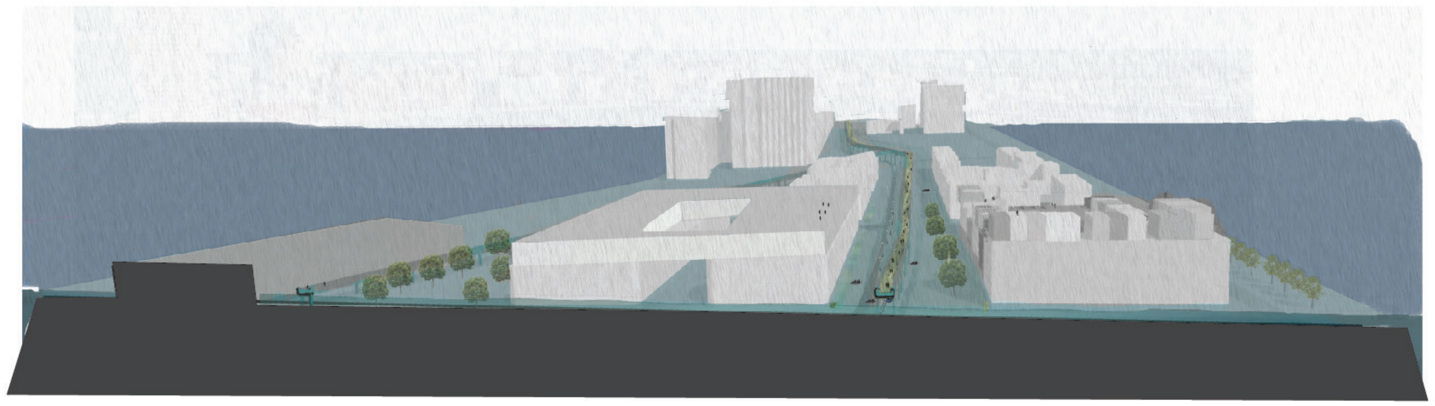


Figure 136| Two sections of the same neighborhood show how it functions in time of a flood and in 'normal' state. (Image by author)

Figure 137| A schematic view of the densification of a family house block. For diversity purposes this block can be topped up with a row of apartments. The access can be made with external staircases. It important that the roofs stay flat, to open up the possibility for functions as greenery, roof farming or sporting. (Image by author)

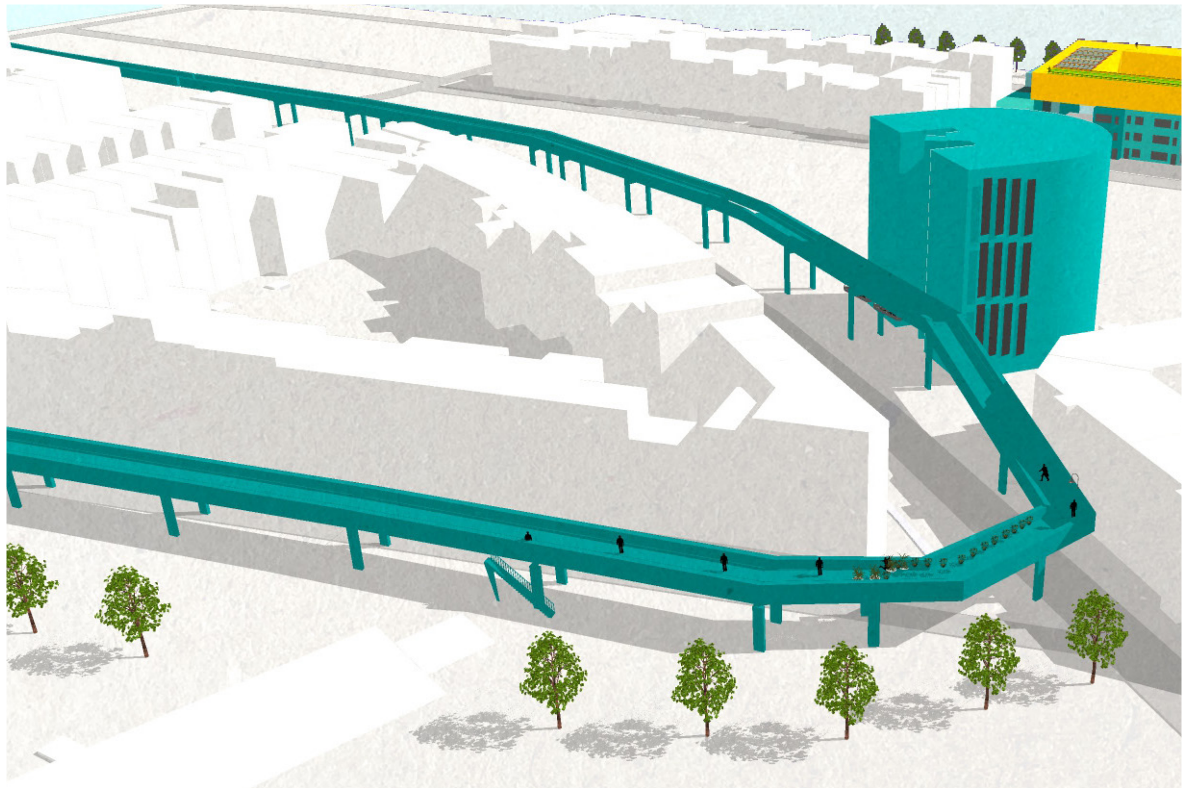


Figure 138| This schematic view shows the evacuation building that is also the station of the suspension train. This central place in the neighborhood is easily accessible in case of a flood. (Image bu author)

Figure 138| An impression of the Deliplein in Katendrecht during a flood. It shows that the water becomes a way of transport (Image by author)

Figure 139| Impression of a view in Katendrecht on the city. There is a closer connection between the people and the water. At the other side the suspension train network is visible. (Image by author)

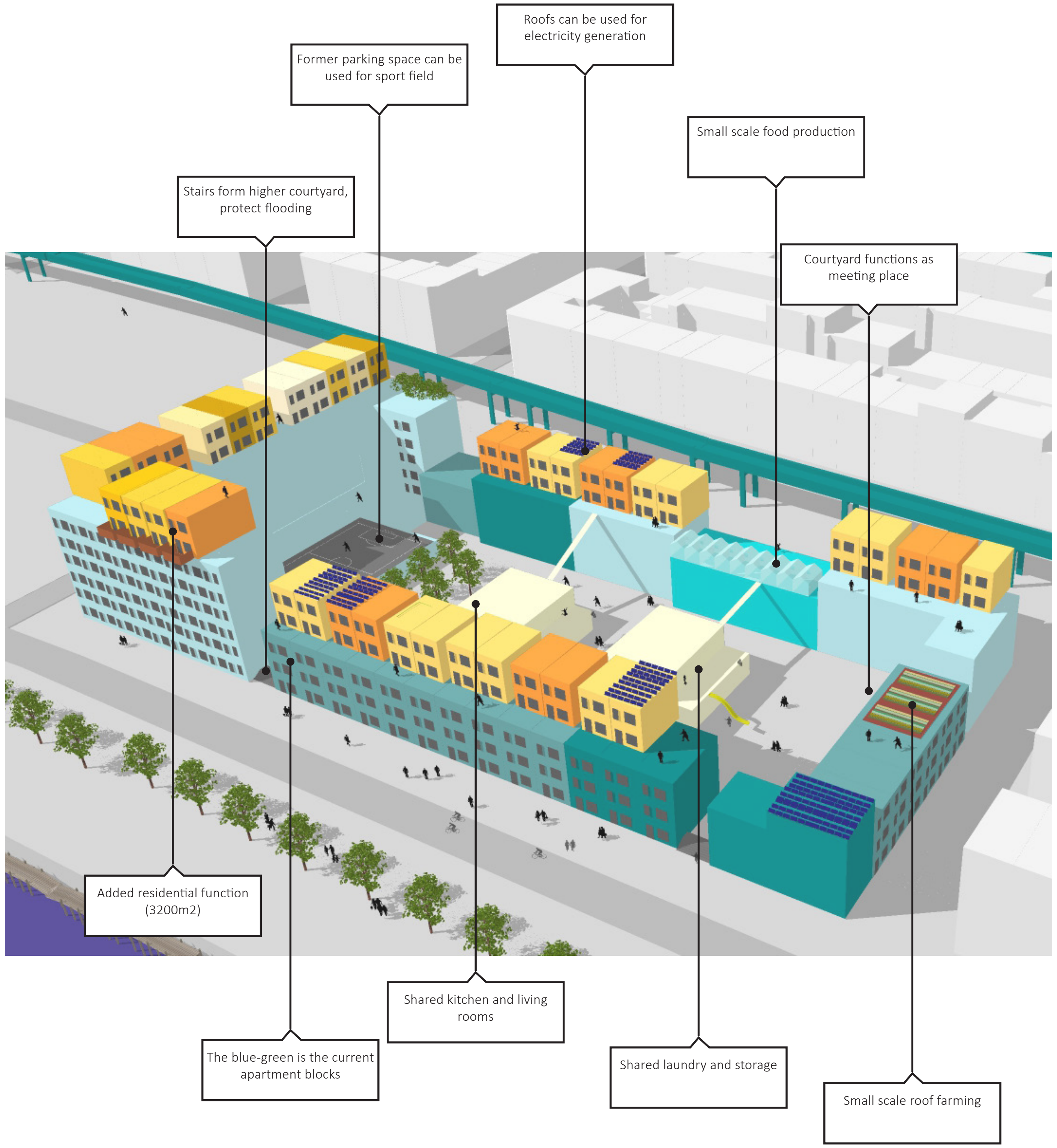


Figure 140| Impression of an apartment block that is transformed to accommodate more people. It shows what elements of the design principles are in here. (Image by author)

// Design properties- Neighborhood
The question for this scale was to explore and visualize what it means for the citizens to densify the network as a result of only using the higher land. The social life gets densified as well, which has its positive feedback on the interaction of citizens. By densification the residential blocks can get more mixed if the type of housing is mixed and varies in apartments and family blocks. By stimulating the sharing of spaces and tools this interaction is increased even more. The neighborhoods needs to have a local green blue network, that is implemented along all the streets. The new basis is green, grey infrastructure is only there where needed.

// Qualities//

//The green street//
There is a green connection trough Katendrecht that leads to the parks in the west. This green corridor connects several green patches.

//The industrial background//
The roads on former tram lines and the industrial buildings in the North hint to the former harbor function. This could be emphasized more.

//A long waterfront//
The views you can get in Katendrecht are beautiful. The waterfront is very long.

// Changes//

//Diversity in urban blocks//
The densification has to respond to the different types of urban block, also the FSI and GSI values.

//Green Streets//
The green street could expand and made more use of by adding functions besides it. Also the blue infrastructure could connect with it.

//Creating a blue infrastructure//
Katendrecht is surrounded with Water, but there where no ponds or ditches inside the neighborhood.

//Use the waterfront//
There could be made better use of the visual quality of the waterfront. Also it could be used to connect people to the water or create awareness of the changes in the water level.

//Sharing in the mindset//
To aim at a more sustainable city network, the urban fabric can contribute to stimulating sharing within the community. By opening shared shop where people can share goods as hammers, or having a carpool parking lot.

//Densification in use//
There are several buildings ore spaces that are used for the similar use. By combining for example a school building for education, cultural lessons and a cinema in different time slots, the space is used more optimal.

// The question for the next scale- the Street scale
The lowest scale this project is dealing with has to show how small interventions lead together to a change of network. Also it should show how intermingled the physical, social and mental scale are on this scale. So on this low and most precise scale, how does it all come together?

7 | The Street Scale

The street level connects the principles of higher scales to the most tangible, citizen scale of the project. This scale brings the road network, the green and blue infrastructure, the evacuation system and the densification approach to the lowest level. It also gives new information about the way that the citizens can be stimulated to interact. So in the subparagraphs the following aspects will be shown, collecting it all in a visual support:

- 7 | 1 **the grey, green, blue network**
- 7 | 2 **the evacuation network**
- 7 | 3 **the social street**
- 7 | 4 **wet-proofing**
- 7 | 5 **the layers together**

The street scale mainly deals with the street section, and therefore takes the first floor of the building into account. It also looks at the subsurface area. Figure 141 shows the current street section of two streets. One is a peculiar street in the green zone. It is not a representative street for other streets in Katendrecht. However it is the location of the evacuation road and therefore an important street to show. Figure 141 also shows a more common road in this neighborhood.

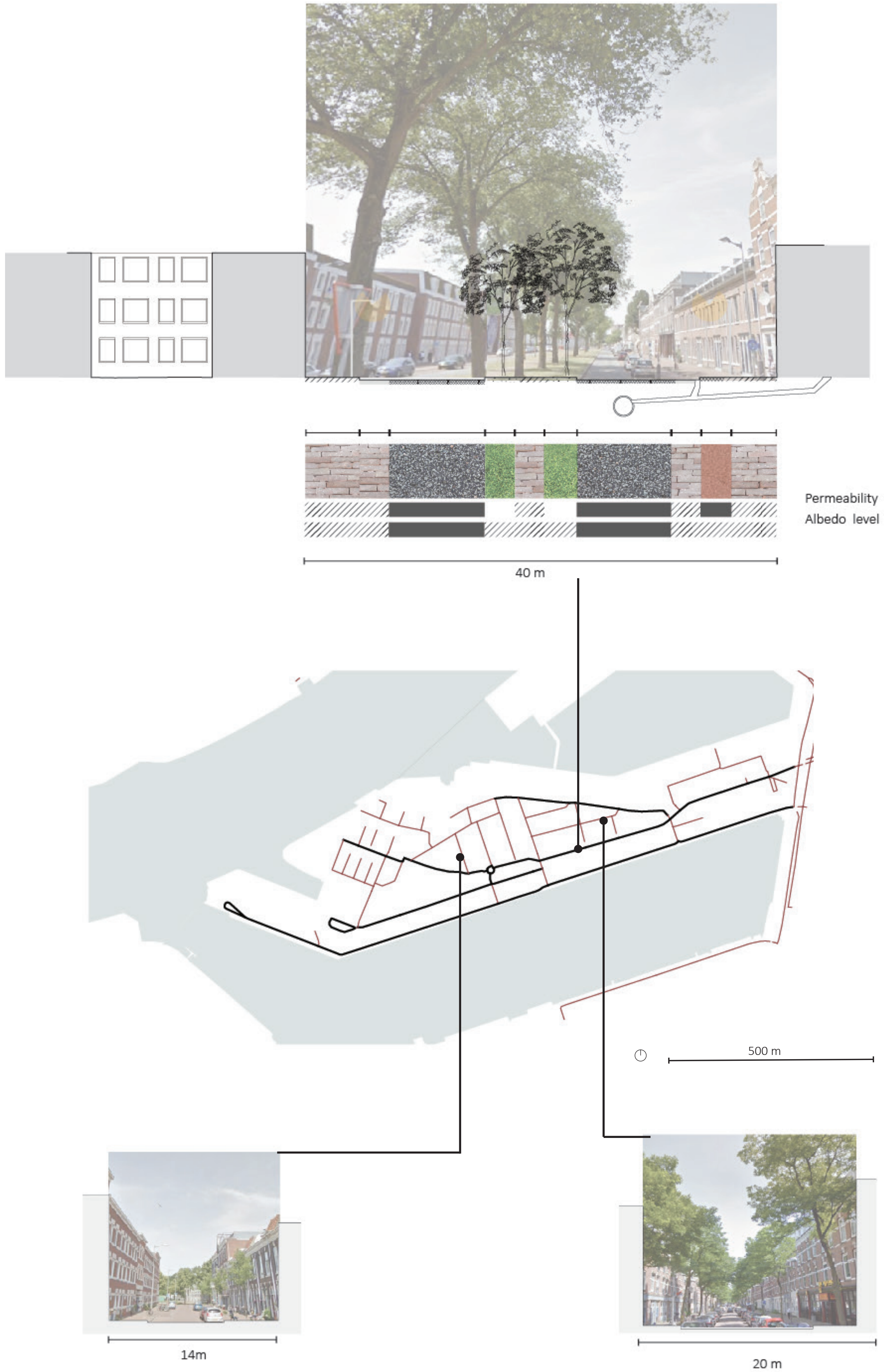


Figure 141 | The two main types of roads and their sections. The brick roads often reach from one facade to the other and limit the possibilities for infiltration. (Image by author with snapshots from google streetview)

7|1 The green, blue and grey infrastructure

Roughly there are two types of pavement in the streets of Katendrecht: asphalt and red bricks (see analysis booklet and Figure 141). The asphalt roads are placed in east west direction and function also as main access roads. The perpendicular and smaller roads are paved with bricks. There are almost no unpaved areas in the street section of most streets. Only the 'brede hillerdijk' has a green island in the middle of the lanes.

The brick roads have a small height difference to lead the water to the street, where the manholes are positioned. The asphalt roads have two levels: the water from the pedestrian lane flows to the cycle lane where it is collected in the gutter and manhole. There is a second manhole on the car lane. Even though the gaps between the brick allow the water partly to infiltrate, a large part will end up in de sewer system and result in extra pressure. **The improved green blue infrastructure uses the street section to already respond to the weather conditions on the lowest scales.** Green areas improve the infiltration (Figure 142) and local ponds or ditches can temporary store the water and slow down the runoff. Green and blue can also cool down the streets in days of droughts. Therefore a ditch is added along all streets, that can drain the water to local ponds or towards the main water backbone, the former Maas. The complete paved surface of the area with now an then a patch of green is transformed to a green surface with paved areas where necessary (Figure 143).

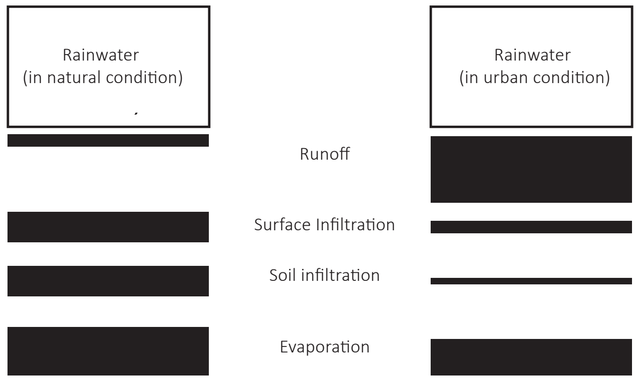


Figure 142| This image shows the amount of the rainwater that either runs off, infiltrates in the surface, infiltrates in surface and deeper soils or evaporates in two situations: the urban condition and the natural condition. The high amount of runoff is a result of the large amount of paved surface in cities. The use of permeable pavement contributes to infiltration and reduces the rely on the sewer system. (Image by author, based on U.S EPA, 2003)

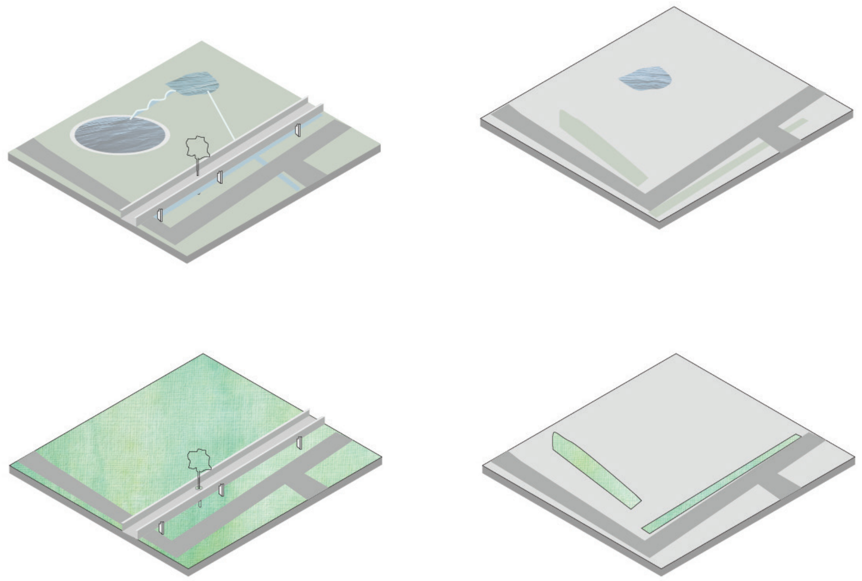


Figure 143| The complete paved surface of the area with now an then a patch of green is transformed to a green surface with paved areas where necessary. (Image by author)

7|2 Evacuation network

The evacuation road is one of the central roads of Katendrecht and therefore accessible in case of a flood. A part of the higher road is used for public transport as well. Figure 145 explains the multifunctionality of the higher road. **The added function creates a route that is covered and offers space for small pop-up shops or sporting areas.** The road is accessible via stairs, and there are emergency stairs. In the suspension line stations there are elevators. The staircases have Evac-chairs in case of an emergency. The elevated road has handles to connect boats to, in case of a flood the people can still use the higher network and can use boats to get to their houses.

Highline in New York

Coulee Verte in Paris

Figure 144| Two references show elevated paths in the city; the highline in New York and the coulee verte in Paris. These parks can be used by pedestrians and cyclist. (Source: Mathieu Anfonso (above) and Source: Alamy (below)).

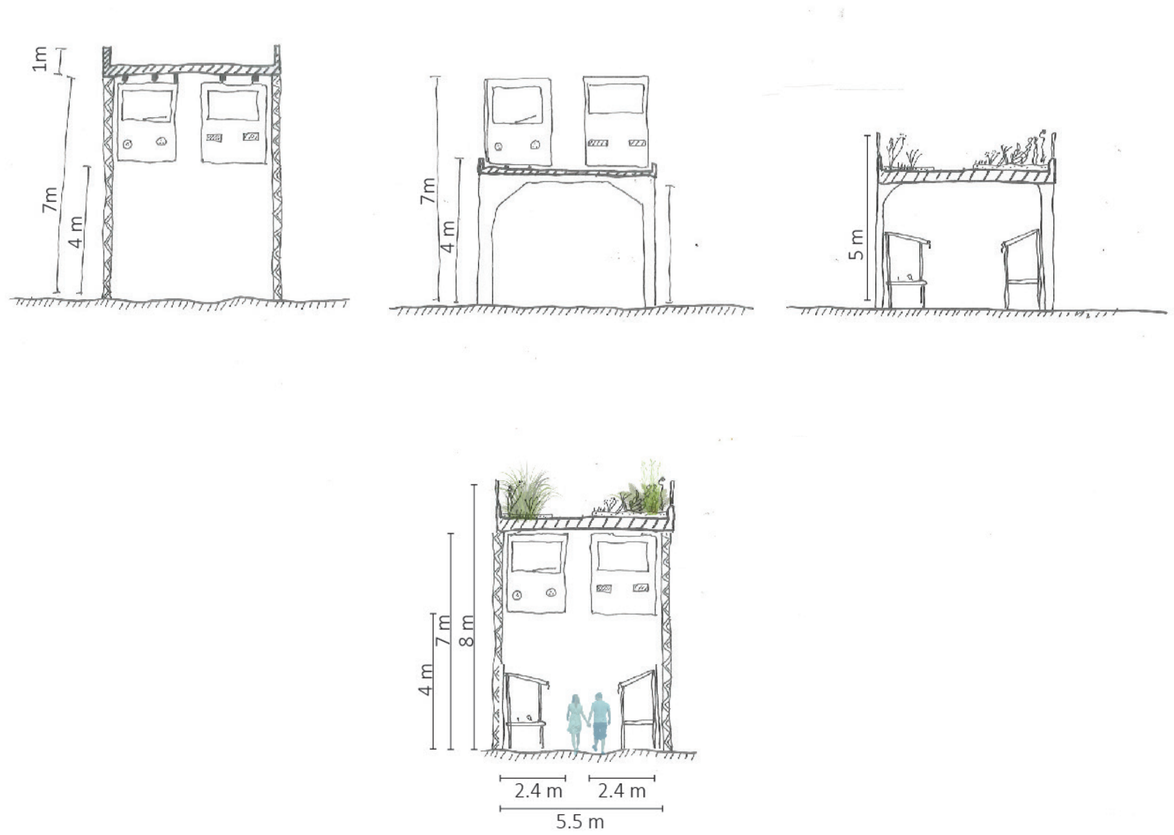


Figure 145| The evacuation road has to be higher than the first floor, so it can still function if a large flood occurs. As explained in the neighborhood scale there will be a suspension rail that connects all the neighborhoods. The multifunctionality of the structure that needs to be built for this is shown in the scheme. On top of the structure a walking and cycling path is made. Underneath there is space for social functions. (Image by author)

7|3 The social street

The street level can stimulate interaction between the citizens, which is extremely important in the densification process. In order to make people willing to share goods and spaces it is important that they already form a connection. The current street section can be improved regarding this aspect since there is little urban furniture available that invites people to come together. The green blue infrastructure changes on the street level have changes the section by taking green surface as the norm and only add pavement where needed. Limiting the amount of pavement, together with the system of shared cars, opens up the space of parked cars. This immediately makes more space for a personal touch in the street. **If every house gets a small patch for personalization it will decrease the harsh border between public and private and it stimulates the feeling of responsibility for the street (Figure 146).** The ground floor cannot be used for residential use, but can be used for public functions or storage. The densification of functions can contribute in a lively street where there are often more people, resulting in a feeling of safety.

The street scale specifically offers space for participation events and activities initiated by the citizens. Sport tools in parks or barbecue places could be developed, depending on the wishes of the people in the area. The free ground floor and the space that is not any longer used for parked cars, since there is a shared car system, can be used by the citizens. Every street is still accessible for cars, only the parking takes no longer place in the street.

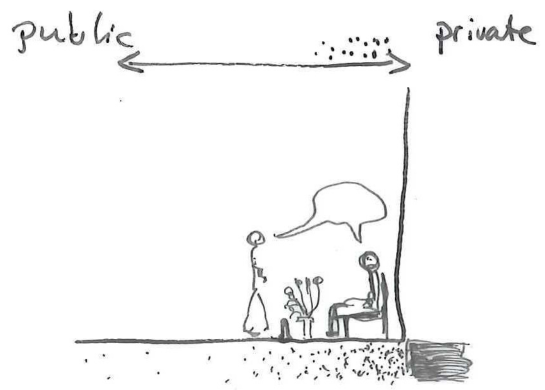


Figure 146| Zoning within the building can restrict people sleeping at the ground floor. If a flood would occur unexpected the people living there are still safe. Moreover this allows a facade that is adapted to the wet-proofing options. (Image by author)

Street

7|4 Wet-proofing

The neighborhood scale showed how to use stairs to protect a building block courtyard from immediate flooding. The same could be done for streets. Especially in the center of Katendrecht the streets would stay dry, using small interventions (Figure 147 and Figure 148). The wet-proofing sub paragraph of the neighborhood scale show that height differences and also partition tools can prevent the area from immediate flooding. Moreover high entrances and steps can help. If the water is high enough the street can be used for personal boats to reach other destinations. When the flood is going down, it is important that the water drains towards the ponds and ditches. In the subsurface nets can be implemented to keep the soil on its place and reduce erosion.

Elevated square in Delft

Steps to make elevation in Venice

Figure 147| Reference of the beestenmarkt in Delft show an elevated square, which makes the square accessible when a small flood occurs (source: Groen blauwe netwerken) and steps in Venice that make a difference in elevation (source CSI multimedia).

Figure 148| This map shows the streets that could be made higher by adding steps. Since a lot of the older building blocks are closed the intervention takes place on the street and makes a higher and therefore dryer island. (Image by author)

7|5 The layers together

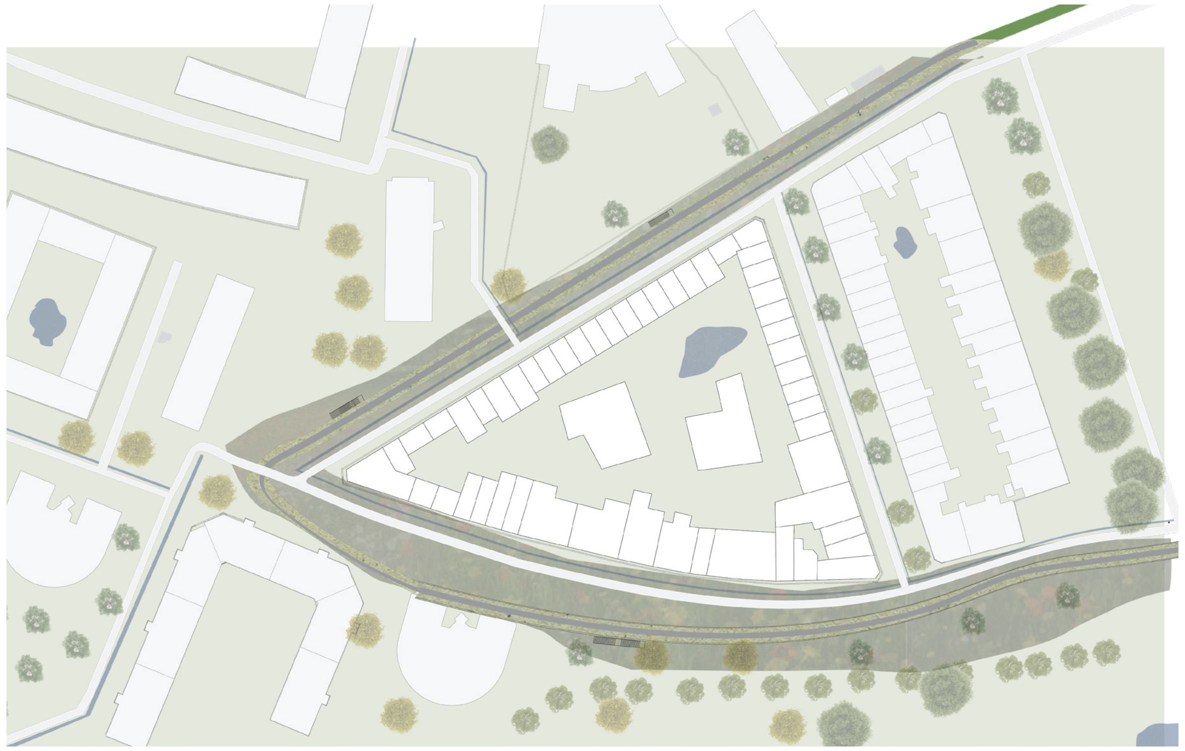


Figure 149| The streets will be small lines surrounded by green areas. Along every street there is a small ditch. (Image by author)

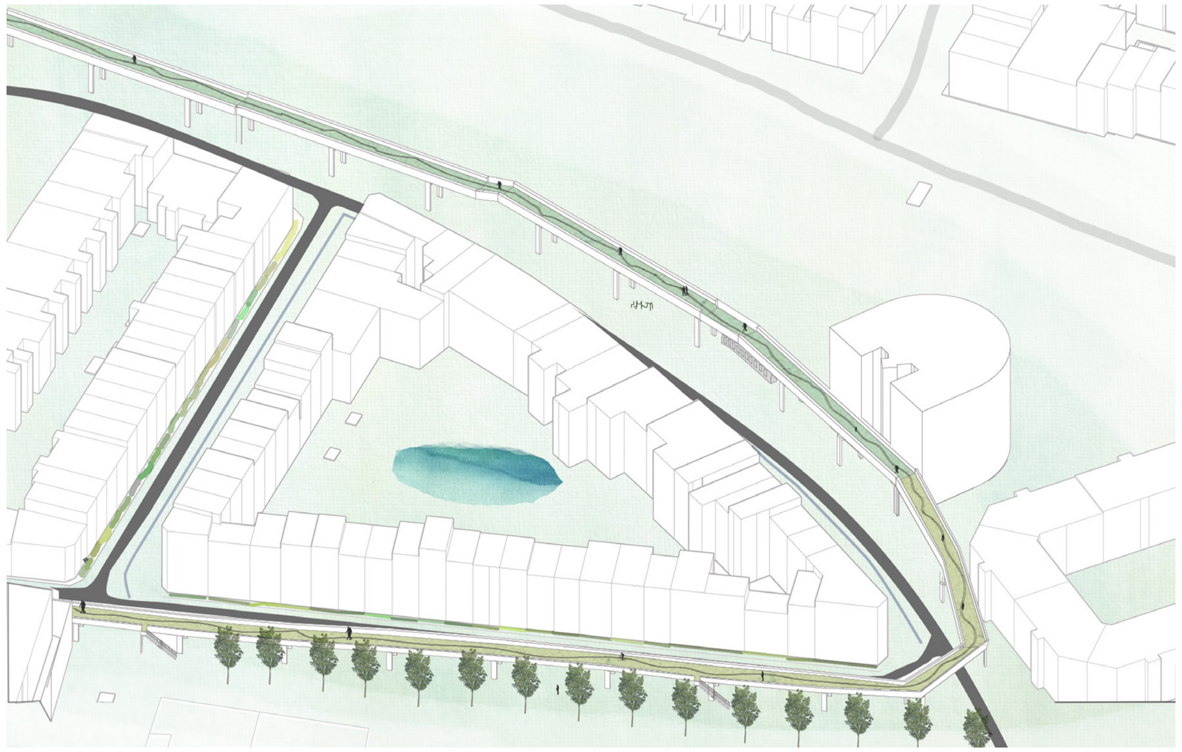


Figure 150| A 3D shows how the evacuation road is an elevated element. The streets will be small lines surrounded by green areas. Along every street there is a small ditch. (Image by author)

Figure 151| This section of the street shows the qualities it can bring to add more green and blue. The elevated road offers a highline. Underneath there can be functions as sports, markets or just a dry place to walk. There are privatized pavements to reduce the edge between private and public. (Image by author)

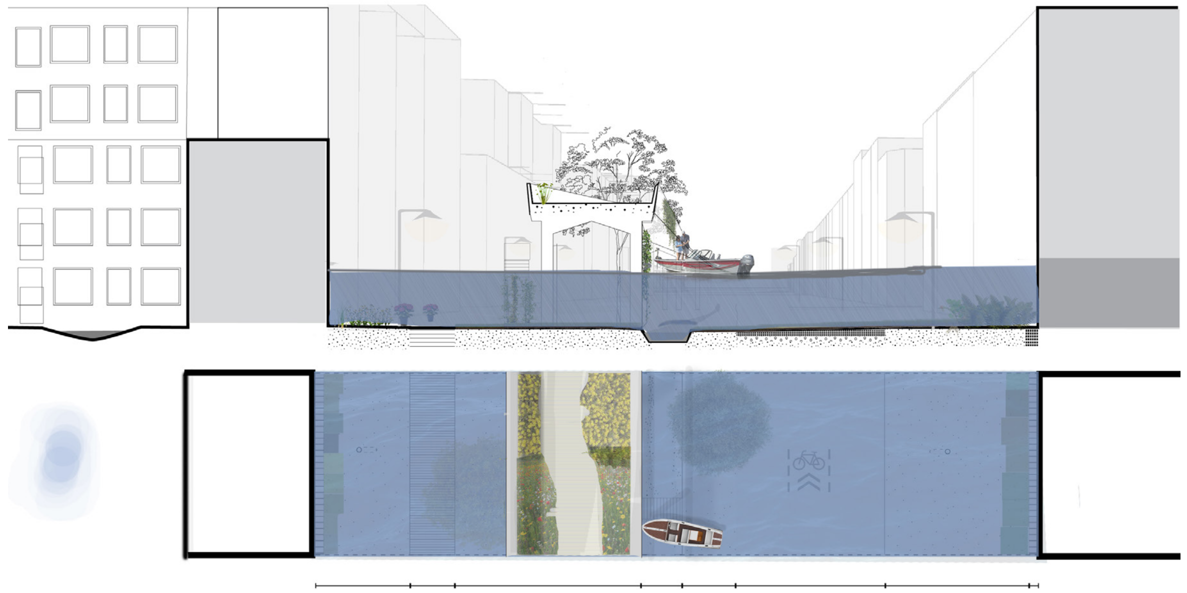


Figure 152| This section of the street shows the qualities it can bring to add more green and blue. The elevated road offers a highline accessible if there is a flood. It can connect to other neighborhoods (image by author).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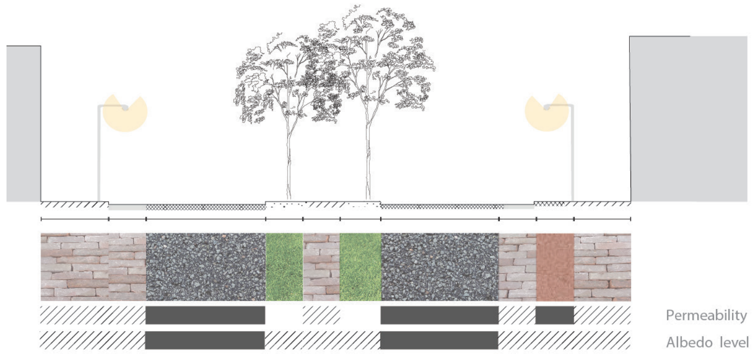
GARAGE
KATENDRECHT



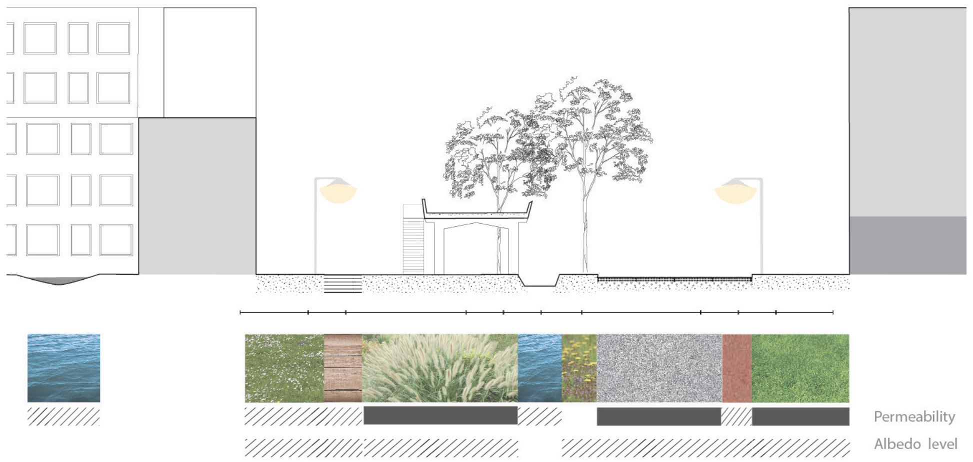


Figure 153| Conclusive map of the adaptation of the street section shows the qualities it can bring to the street. Changes of an approach need to be achieved on the street level as well (image by author).

// Design properties- Street scale
The street level brings all the networks together in the smallest detail. Not only get the Grey, Blue and Green infrastructure connected with each other, they also get connected to the social component of the city. The change of a system needs also bottom up action. This can be stimulated on the street scale.

// Qualities//

//Space for personalized pavement//
Some streets have marked a small piece of the road available for residents to personalize. This is now implemented in more streets.

//Higher entrances//
Some houses have the entrance on a different level than the street. This can be beneficial when a small flood occurs.

// Changes//

//Improve infiltration/
The street offers a more connected line of infiltration, to release pressure on the sewer.

//Green in the street /
Green in the street has cooling down capacity, water storage and makes it a more pleasant area.

//Street lights//
They are improved to shine more smart and improve safety feeling (only to the ground, different time slots)

//Meeting places//
The street offers a space that is a bit more private than public, and generates areas where people can meet or talk.

//Less parking spots//
Decreased amount of parking space (also stimulates shared car use).

//Less paved area//
The streets where paved from door to door, this is improved.

GeoDesign Conclusion

The iterative process between analysis and design and between the different scales have resulted in a proposal that works on multiple scales for changing the approach. Three aspects that have been discussed in the theoretical framework will be reflected on the GeoDesign framework now:

Adaptive capacity
Changing the approach on the national scale itself contributes to the adaptive capacity of the nation as a whole, since the dependence on one system -the dyke system- is reduced. The new approach focuses on all the elements that define risk (probability, exposure and vulnerability). Moreover the proposal suggest an more decentralized functioning of the city. This means that in times of a flood the centralities can function on itself, but the benefits of a large cluster can still be used in a 'normal situation. The interdependency between cities or areas within the city is decreased and this can help protecting against a complete collapse. On the lower scales the spatial uncertainty is reserved to keep plots open for future development. Moreover the green, blue and grey network work throughout the scales and can therefore deal with externalities locally.

The suitability
The suitability plays a key role in the design. The design principles are realized within the boundaries that have been defined by natural suitability. This could strengthen the grounds again with new sediment supply.

Physical, social and mental component
The role that information plays in the designing process changes through the scales. Data driven maps define the outline on the larger scales. The information is derived from platforms that gather their information from models etcetera. The lower scales are dominated by the 'feeling' information that is assembled. The scales also refer to the important actors; large scale addresses instances of the top-down approach, whereas the lower scales ask for a bottom up support. There are scale-specific layers and layers that work over several scales. The green, blue, grey, evacuation network works throughout all scales. The centralities and densities layer are essential for the lower scales. The design shows what impact it has on the citizen when the approach towards water management is changed in order to increase the adaptive capacity.

X. CONCLUSION

This chapter concludes the findings of the report and therefore gives an answer on the sub questions an de main question : "How can the spatial structure of Rotterdam be transformed in order to prepare for extreme flood scenarios?"

Conclusion

The combination of population growth and rising water trends as currently seen in the Netherlands, compel for a different approach of dealing with water. The approach as it is today focuses on reducing the probability of a flood. However, this is not sustainable considering the future effects of climate change. Throughout history, a shift can be observed from accepting the water to defending, controlling and manipulating it. **Hence, it is time to take a step back and reposition the society towards nature and take natural suitability for settlement into account.** Rejecting the dyke system asks for development on higher grounds. Defining suitability of the substratum layers can emphasize the intrinsic possibilities of the geographical context. **This suitability rearranges the edge between city and surrounding. In other words, it brings the edge back to a more natural balance between city and ecology.**

The starting point of this research is an extreme scenarios in which the water figures change drastically . The suitability maps show that a large amount of neighborhoods need to be relocated resulting in densification in the naturally suitable neighborhoods (based on substratum layers). The city network and infrastructure need to adapt to a way where only the higher grounds are used for essential elements of the city. For the city of Rotterdam the defining networks (the grey, blue and green infrastructure) shape the areas that can be used for densification. The transformation as proposed in this thesis, is not designed as a masterplan since it is subjected to future changes and it needs to be able to adapt.

The answer on the main question of this project, *"How can the spatial structure of Rotterdam be transformed in order to prepare for extreme flood scenarios?"* Is given in a framework that takes the design principles of several components into account. The principles from the theoretical framework provide the focus on transformation thinking and enlarging adaptive capacity. First, the higher grounds (taking an increasing sea level into account) should be defined. Then the structure layers of the city need to be adjusted to the new border between city and surrounding. These layers ideally have an overlap. The translation to a lower scale needs to focus more on the social component of the city to create synergy between interventions and to enlarge the support of citizens. The interventions of the low scale should align with the goals on the national or city scale and vice versa. The principles that follow from the assessment could vary when it is done on a different location. However, the frameworks including the steps that have been made to come to a proposition, show how a structure could be transformed and could become useful for other locations. It is important that the layers that are essential for defining suitability for settlement can vary per location, however it is necessary to look into the infrastructure layers as well as the urban fabric to be able to transform the city to an approach where less land is available.

The projects starts in explaining why the current approach should change and then opts a way to do it. To be able to close the loop of stating the system should change, the step of intervention still needs to be made. The loop is the following (Figure 154).

1)changing the system (no dykes)
2) relocate low grounds,
3) densify high grounds
4) translation to what it means to the citizen and city spatially
5) the last step is to check if the proposed transformation could help diminish the flood risk.

As the design shows, the approach has been changed by focusing on all three factors that define risk. It also increases the adaptive capacity in order to be able to change for change of conditions. The design shows thus that the overall risk is reduced. Before implementation there needs to be conducted more research. The scale of the projects compels for research at least in the fields of governance, water management and anthropology.

Sub-questions:

1. What are the uncertainties in the Randstad and Rotterdam?
This research deals with uncertainty in water figures and the uncertain amount of inhabitants. The uncertainty asks for an iterating process that takes adaptive capacity of the system into account. Trends in population growth and climate change have to be considered in their full range. Design interventions need the ability to adapt to this range of possible futures. Therefore, this study looks at the socio-economic trends , showing a growing number of inhabitants and economic activity in 2060. The projections of the KNMI 2017 report show that a 3-meter sea level rise is possible . in combination with a growth of population. The system should be able to adapt to this future.

2. What measures diminish the risk of flooding?
The risk formula shows three components that define the total amount of risk; probability, exposure and vulnerability. It is important to consider in what ways the contribution of these components that can be controlled in such manner that the risk of flooding reduces. Currently, defense mechanisms are mainly used. However, making the system redundant and taking the evacuation layer and the spatial planning layer into account are necessary to diminish the risk as well.

3a. What people and what features are exposed to floods?
The amount of people that are present in an area that has risk of flooding has been estimated on 1.5 million people and 700.000 households. This means that these people have to be relocated elsewhere and that the densification processes have to accommodate this amount of people.

3b. What areas have potential for densification and how should they be densified?
One of the solutions is to make the areas that are not suitable for inhabitation available for other land use. Areas that are more suitable for land use can be inhabited by people that used to live in less suitable areas. Based on the critical infrastructure, the analysis on region scale show what neighborhoods are suitable for settlement and suitable for densification. The design phase on the city scale shows where the residential zones should be. The harbor area lies outside the dykes and therefore is higher (4-5 meters above NAP). For Rotterdam this would be a suitable area to densify the people and functions that had to be relocated from the lower areas. The ground floor cannot be used for residential use, but can be used for storage, shops and public functions. The densification process influences the centralities and the type of density per area.

4. How can we deal with uncertainty?
As the future is very uncertain , the need to find ways to adapt the structures in such a way that they can be positive for several futures. Adaptive capacity is a way to do this. To reduce the change on collapse of the system there should be enough flexibility (in space and dependence) of the system to cope with changes in the future. For planning it is important to build redundancy and reserve space for future changes. Another way is to think in scenarios. In this way we protect the system to develop in the paradigm it is in. Knowing the range of possible futures stimulates to keep options open to go towards possible futures. (See chapter theoretical framework scenario thinking).

5. What spatial measures can be taken in order to increase the adaptive capacity?
Interventions that reduce probability, exposure and the vulnerability of a flood can be made on the large and the small scale.. On city scale, the grey, green, blue, density, centrality and land-use layers deal in a different way with adaptivity. However, they all take future changes into account. The densification layer is less specific designed as it is dependent on the input and respondence of the citizens. The usable land layer is the most clear defined layer as it shows where the new settlements will be, based on hard substratum data.

6. How can the finding of theory spatially be applied in the Dutch socio-economic system?
The synthesis of the findings shows the design throughout the scales of space and time. The physical component of the city is important in all scales. However, the lower the scale, the more important the social component becomes for an intervention. Especially since the project needs a wide support it is important that interventions have a social or mental component besides the physical component. In general the higher scales show measurements that have a top down character and that are based on the geological suitability that data shows, where the lower scales depend on the bottom up 'feeling' information of the citizens that will have to support the project.

These six questions shape the answer on the main research question. It is important to note that this project is just one way of transforming the spatial structure. Decisions and hierarchy of several layers are explained in the analysis and design chapter. **Thus this shows it is one of the possible outcomes of changing the system. The research shows the importance and the possibility to change the approach for water that is maintained at present in the Netherlands.** It shows the design objectives and the way these work through the scales. It does not show the final outcome of how I think that the Randstad will look like in 2060, since these system should be adaptable for changes that I cannot have insight in today. However it shows the importance of considering the deep uncertainties that long-term thinking brings along.

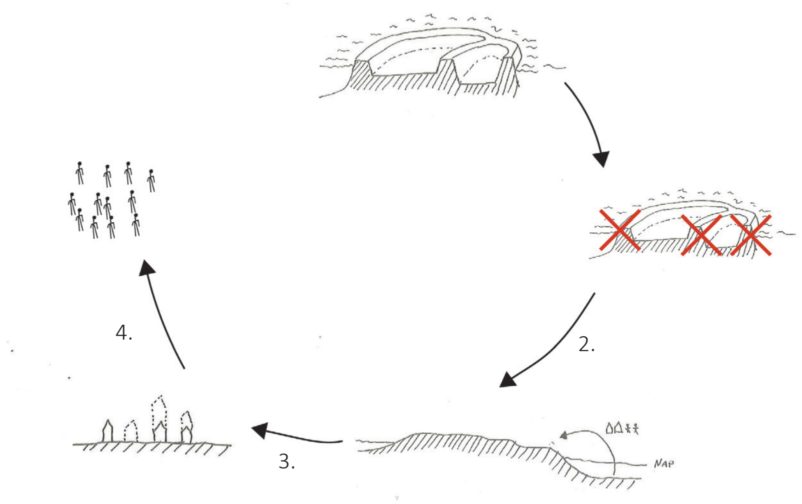
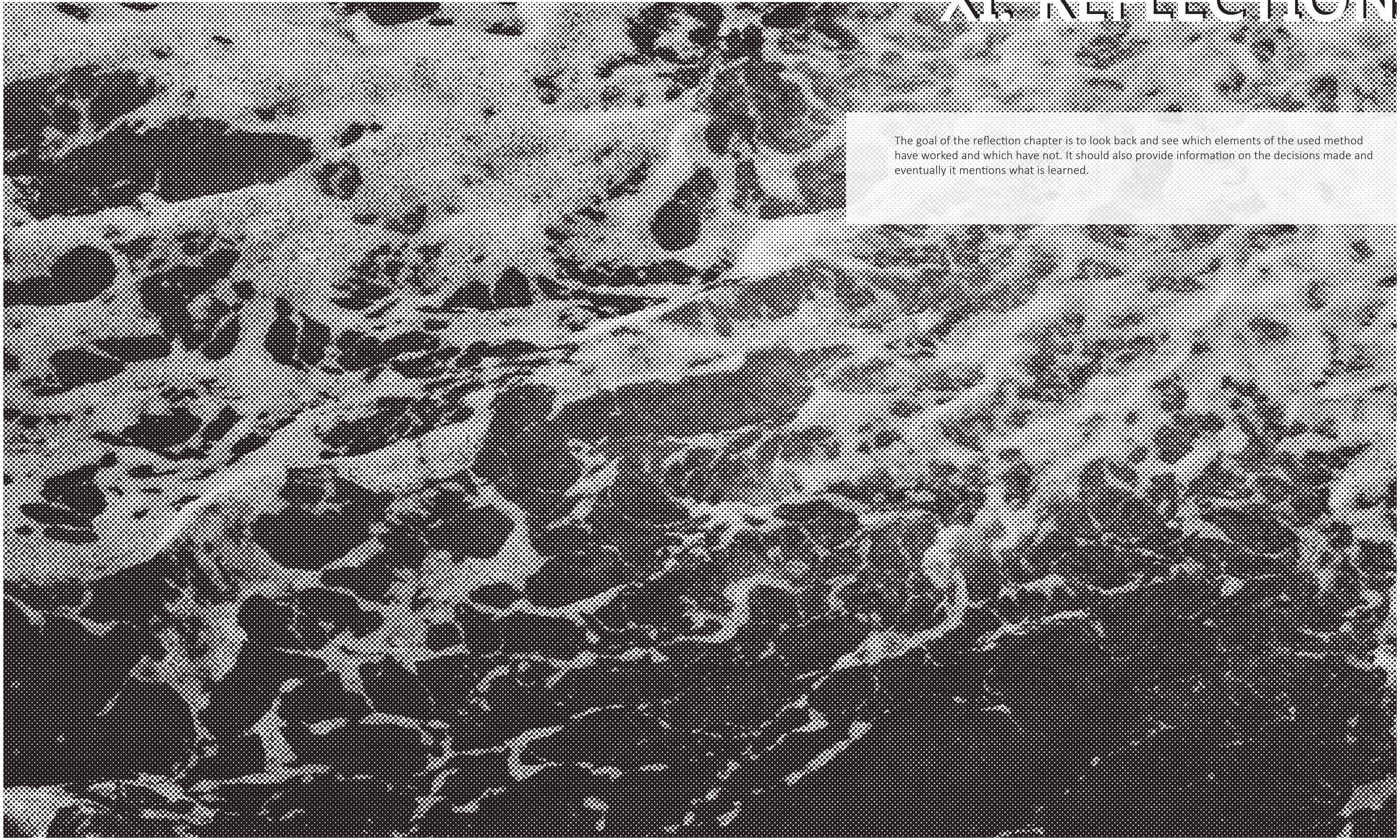


Figure 154| The trends compel for a new approach (1). To increase adaptive capacity of the overall system the dyke system should be transformed (2) which results in densification on the naturally suitable lands. Relocation and densification need to take place. The impact on the citizens is shown (4). (image by author)

XI. REFLECTION



The goal of the reflection chapter is to look back and see which elements of the used method have worked and which have not. It should also provide information on the decisions made and eventually it mentions what is learned.

Reflection

The starting point of this master thesis was an extreme scenario and the primary question what this extremity would mean for the spatial structure. In small steps the project moves from more fundamental questions (about criticizing the current approach) to a spatial design on city level and neighborhood and finally on design on street scale.

This approach clearly has it limits, since it translates a hypothesis of an extreme scenario to a proposition. A scenario is not without reason one among others. It is very unlikely that this extreme scenario will become reality. By choosing the extreme, the conversation is opened up about the approach towards water management the Netherlands currently have. I emphasize that the proposal will not become like this in reality since the future will change the context we are dealing with. Nevertheless this research and design proposal are valuable as it makes the models that we have shaped about the future more spatial.

The method of GeoDesign has been very useful for assigning suitable relocation areas. The method makes it possible to combine different types of information and link them geospatially. For the higher levels (national/regional/city) this works well, since the data based layers are most important. For the lower scales the social value and atmosphere play a larger role. These type of information is more difficult to assign values to, since they are more subjective. The iterative process where the design gets influenced by other scales combines the top-down approach of the GeoDesign with the bottom-up lower scale information. We could say that the data approach has its limit, for grasping also the human perspective. This needs to be explored using design.

The outcome of the research shows an extreme proposal that deals with an extreme scenario. The adaptivity and uncertainty that come along makes the proposal a strategy rather than a blueprint. Some steps have to made now. Others steps could change over time. We should stop investing in lower grounds, since they will sooner or later flood. The phasing of the project starts therefore with the current situation that makes it already good to relocate the zone 3 area.

There are more fields that need to contribute to conduct knowledge about disciplines that I have no knowledge of. To change the approach as a whole, information is needed from policy makers, hydraulic engineers, social sciences and developers. I tried to use my profession as an urban designer to give an answer on the task we have ahead of us, using my expertise of making figures spatial. Now the discussion could start involving decision makers and experts to start the change of the current system as soon as possible.

Uncertainty

The uncertainty that comes with designing plan for the far future has limits as well as opportunities. The project can make assumptions as long as these are explained. . In scenario thinking these uncertainties are plotted in a graph that sets a certain change on the y-axis and time on the x-axis. In this case the ascending line shows us that sea level rise will happen, but the question is when. For the nearby future the range of sea level rise covers a rather small amount of centimeters, but for the future it shows a large variability. However if we update the range to the current situation this will result that the change for the nearby future always seems to be in a manageable range. Scenarios often describe a lot of trends of different features (for example population growth, sea level rise, precipitation changes). However the combination of these different options are mostly described in words or graphs. The KNMI for example, has four scenarios in order to combine two different features (change in airflows and change in temperature rise). Another graph shows the estimated population growth. In the future these scenarios will not occur separate. They will have an enormous impact on each other, especially in terms of space. For example sea level rise will make less land(especially in delta areas) inhabitable. Another trend shows that more people will start to live in cities and over two-third of the large cities are positioned in Deltas. In graphs and words the spatial factor that these features need are not taken into account, let alone the uncertainty of the available space in the future.

The phasing of the project shows that it is already necessary to relocate the zone 3 area in the current context. Design decisions can be made in a way that the approach can be adapted to the extreme situation without blocking the other extreme. The method of defining what areas are suitable for settlement show for example that currently there is urbanization on unsuitable grounds. If the scenario would change over time, the suitability maps would change as well. Therefore a buffer is built in and the 0-3 meters above NAP cannot be used for densification as well.

My project tries to tackle this spatial aspect by translating the extreme scenario to a spatial design. The boundaries and ranges of the uncertainties of the features are still an estimation. Maybe the future will show that this scenario is not extreme at all. Maybe the "high" scenario will be the lower one in 30 years. Or maybe the future will show that the climate will not change at all as we predicted and a whole new set of variables will come in. Or the lower estimation will become reality.
This project is therefore a statement project, that shows the drastic changes we should start to make already now to be able to deal with the future changes. Even though it is based on an enormous amount of assumptions it is an example of how the adaptive capacity of the Netherlands should change, since the current system will not be able to deal with the extreme scenario.
In the light of this extreme scenario the project could have taken more extreme prerequisites. The 300 year + prognoses show that sea level could rise many meters more. Why would we then invest in a project that is still only 5 meters above sea level? The decision to relocate Rotterdam within the administrative borders of Rotterdam has to do with the public support such a large project should get. There is a reason why the citizens live in Rotterdam. The delta position has also brought trade and harbor life.

The activity of the harbor is an assumption made and is not discussed enough in the project. The rearrangement of the river system has a large impact on all harbor activities. The harbor is the reason of existence of the city of Rotterdam. If the harbor has to make place for urbanization, maybe the city itself does not need to be on this specific location anymore. However, the project does not express specifically what happens to the harbor. Since the development of densification starts at the east side of the city, it will take time before urbanization of the Maasvlakte would be necessary. Closing of the Maas could also work whilst keeping the harbor activity (Figure 155).

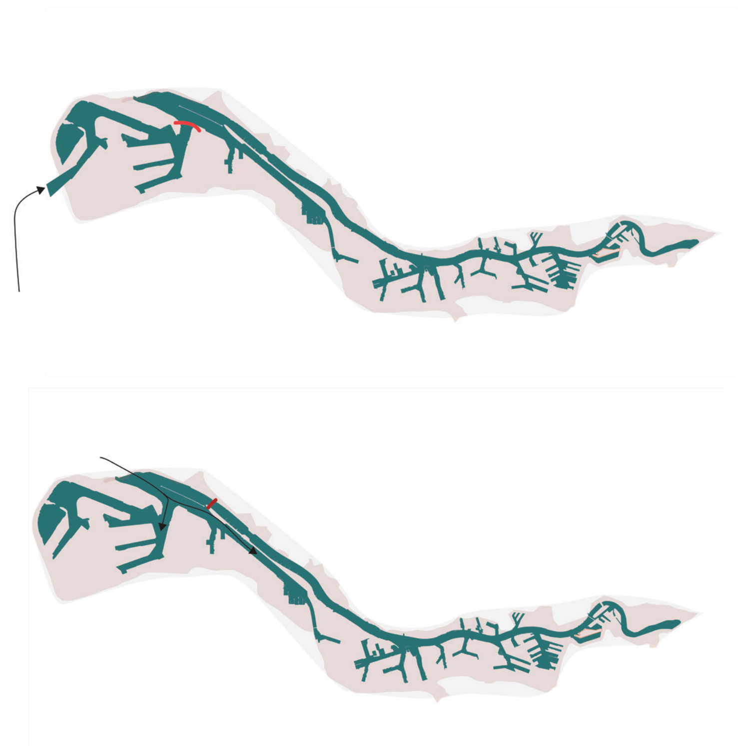


Figure 155| Options to keep the harbor partially open within the same proposal. There should be more research about the future of the harbor to define the amount of space needed. Or maybe the harbor can experiment with a new way of floating expansion, move more westward. (Image by author)

Transferability
One of the reasons that the project location is in the Netherlands is that the Dutch are a leading example in the water management throughout the entire world. Wherever a project is about hydrology and water safety the Dutch are involved. The system we have in the Netherlands is built upon a long history of working with water, shifting from accepting to defending to controlling to manipulating the water.

This last step evolved especially after the big flood of 1953 in the south. However, the approach the Dutch have can be improved as well. Just because the Netherlands is a leading country in terms of water management does not mean their approach is up to date. Slowly we can see that the water is more accepted again (for example in the room for the river) but this change is going very slow. Therefore the Dutch should keep looking for the possible changes of the future and not put their nation at the risk of the current system. The new approach would then be a next step in their water management knowledge that they can exploit to the rest of the world.

The way that this project has looked at suitability in layers has been used before (Ian McHarg method). The combination of linking clusters as a conclusion of these suitability overlay can be applied on other locations as well. It is important to define what layers are critical for the specific task that is there. The height and soil layer are defining the suitability for the Netherlands very well, since they have the most impact on the risk here. On other locations it could mean that other layers define the clusters. One other remark are the borders that are used. The systems of the region do not stop outside the administrative water board line. The fact that decisions are made within these borders does not mean that those decisions do not influence the area outside of the border. This is an important note for the system scale. The effects of the region scale have to be projected to the system scale. If the approach of the project is transferred to another region, it should also reflect on the higher and lower scales.

To practice
The connection of the project with the practical world is mainly to use it as a statement. Long-term project thinking is essential when talking about uncertainties. It takes a lot of time to change and transform a system. The scenario thinking makes it possible to look further then the set boundaries that the governmental structure sets. The government can change its course every 4 years (as result of the democratic system). This can be problematic for projects with a larger time scale. Politicians have to answer their voters where the money goes and why they invest in what. Inherent to this it seems less logical to invest in a very long term project since the politician will not get any benefit from this when the next elections will take place. The case of Room for the river in the Netherlands has been developed under the delta program and has therefore its own board and also a financial system that was no longer part of the national government after the decision was made to invest in this program. In this way the fluctuations of politics and where each cabinet spends its money on did not influence the project anymore.

To be able to explain relocating the Randstad financially, the project needs to show the benefits and qualities the new project can provide. Even though the project works throughout scales, a lot more designing needs to be done to show the final island of Rotterdam and the relocated Randstad as a whole. The design of the Region and the city scale are not yet developed spatially. The design starts at the city scale and shows Rotterdam as an example project for the Randstad scale. To be able to see what the effect would be on the entire system more research and design need to be done. The project shows also only two example neighborhoods and how they respond to the city networks. To be able to match the to-be-relocated neighborhoods, a larger variety of interventions need to be tested spatially. Moreover in this phase the visual and graphics of the design are still in process. They are extremely important for the goal of the project (making a statement of change).

The relationship between the theme of the graduation lab and the subject/case study chosen by the student within this framework
The statement project shows a new urban block or a new city system that deals with flood in a different way than the conventional dyke approach. To be able to step back from the water defense approach the spatial conditions of a city have to be reviewed. At first the project mostly focuses on the water management of the Netherlands and how the spatial design and planning field is underrepresented in decreasing risk. The theoretical framework of city and surrounding shows that the trend of having to deal with more water (climate change) and hosting more people (population growth and migration to economic center) meet in the city. The research group of the urban fabric looks at both tangible and intangible aspects of the urban environment. How can the current fabric be changed in order to deal with the changes of the future? As has been shown in the design framework the design principles (mental, social and physical) shape the outline of the design, considering the physical changes as a result of climate change, and limiting the available space because of extreme sea level rise, resulting in the necessity to change the current fabric. The new roads and blocks have to be able to deal with more common changes like heavy precipitation but also have to function in the more extreme events (when the first floor of buildings and streets are flooded). Despite the changes needed for physical conditions the identity of the city and the neighborhood need to stay as well.
Besides that the project has a lot to do with densities. By clustering areas into groups of GSI and FSI values the urban blocks can be adapted in a way that they can host more people.
It would have been interesting to see how the areas that need to be relocated would adapt. What happens with the urban fabric when it is built for more intense use, but slowly the citizens leave and the structure is in decay? Can we stop investing in the current system that lies below sea level? How long can it still function? This part has not been elaborated on in my project, but would need further research. There are reference projects (like Kiruna) that show it on a different scale, but for the scale of Rotterdam more research needs to be done.

The relationship between research and design
There is a lot of research about how to deal with (deep) uncertainties . Scenario and probability models show what the possible future could bring us. These models can show the range, probability or options of possible future events. There has been done a lot of research as well on the role of adaptive capacity in dealing with this uncertainty. However, the spatial aspect of this research is often not highlighted. Therefore the project defines design principles from literature and then translates them to a spatial design. When the principles are made spatial it often shows the need of more research of, for example other fields. The different features and predictions and models come together in the spatial implementation of this uncertainty.

The relationship between the methodical line of approach of the graduation lab and the method chosen by the student in this framework
One of the methods that the research group of Urban fabric use is scenario thinking. Desirable futures can be explored using scenarios. These findings can be translated to designs that support adaptive and prospective environments. The project deals with an extreme scenario to see how the structure of the city needs to change to be able to deal with this scenario. It is important that other fields that have not been the main goal of this thesis play a role in the design phase as well. A sharing city, urban heat island effect, sustainable infrastructure, inequality are other themes that have influenced the design.

The relationship between the project and the wider social context
As has been described before, the trends being part of the flood risk tend to increase. As the probability or exposure of a flood can never be brought back completely back to zero it is valid to consider a scenario of transforming the economic and societal center of the Netherlands. Since reducing the probability of a flood is currently resulting in a lack of reducing the exposure and the vulnerability of a system, the system is awaiting a collapse. Spatial planning an urban design can contribute in the safety of the society (Figure 156). The pressing incentive is the trend of sea level rise, that varies between a low and high rise estimation. In global scale the estimation of the precise rise is not clearly stated, but the options vary from sea level rise to extreme sea level rise. With the current attention that is globally shown, the topic of climate change and the drastic results this can have are of high relevance. The project needs broad support in order for it to make a change in the current system. Therefore the qualities of the new approach should be highlighted. One of these qualities is showing the costs in perspective. At first sight this project seems unrealistic and beyond the possibilities of the nations to realize. However, if we look at the sum of the costs that are currently made for water defense and dyke maintenance (these are yearly costs), it could be made visible that the costs of this project are not that high in perspective of the long term investment. Moreover the transformation in this case is not only focused on water defense, but enriches the city life as a whole. By tackling a lot of problems and challenges in an integrated project, the costs that would go to for example creating social cohesion, road maintenance, decreasing Urban Heat Island effect and making the city center more lively, can be added to this yearly costs. As the project aims on transforming the current urban fabric and also densify the amount of people per square kilometer it is necessary to take social inequality into account. One of the goals of the municipality is to create a more mixed city. By densification in the current fabric, mixing can be stimulated.

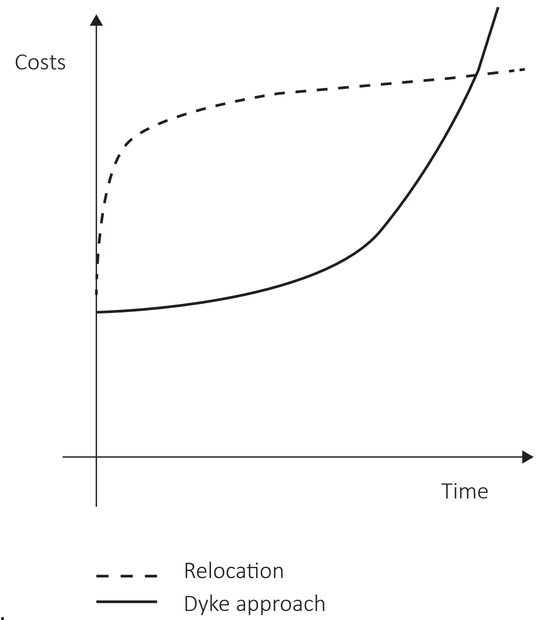


Figure 156| The costs of this project seem extreme. In respect to the long-term the costs are not so extreme. The maintenance of the current approach will only coast more, as a result of climate change and a growing population. There is a point where the two would cross. There needs to be conducted more research about the financial part of the project to estimate this more clear. (Image by author)

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XIII. APPENDICES

1| List of Figures

2| climate scenarios KNMI

Temerature Rise Warm winter Hot summer	Temerature Rise varies per scenario. In the far away time slot the changes become larger	B D A C
More precipitation, more extreme events higher intensity	Dryer Summers in B and D	B D A C
Sea level rise Sea level rise speed increases	Sea level rise related to worldwide temperature rise.	A D
changes in wind are relatively small	Wind had natural varia-tion	B D A C

3| Interview

Interview Lilianne van Sprundel – liaison staff Delta commissioner
This interview is held in order to find some background information about the way the delta commissioner forms their plans. It is therefore a non-structured interview. The text below gives a short wrap-up of the conversation I have had with Lilianne van Sprundel. It highlights the more important information that can be used for the graduation project.
The Delta program could actually be divided into 3 sub categories:

- Deltaplan Water safety
- Deltaplan Sweet Water
- Deltaplan spatial adaptation

The last Deltaplan is new in the series of Deltaplans and completes the triptych of the Dutch Delta program and is focused on the spatial part of the influence on the future water task. Related to this we have the multi-layer approach of safety: Prevention, spatial planning and evacuation. In practice it seems quite difficult to use all the layers. Often prevention is still seen as the key tool to make the Netherlands more safe. They have tried to make the Island of Dordrecht explore if spatial planning could take place in order to keep the island and the town from flooding. Dordrecht was one of the first cities that really tried to find a spatial planning solution, but in the end the choice was made to higher up the dykes again. Often the costs are the reason to stick to heightening up the dykes.
The past year the scenarios about the sea level and the weather have changed because of an acceleration of sea level rise and therefore the Delta Program may change the more extreme scenario . If the most extreme scenario would become reality, the current systems in the Netherlands may not be sufficient, so speeding up or changing the interventions could be necessary. Even if we would continue in making the dykes higher, it would not be enough to prevent the water from coming in.
The evacuation layer was also a bit underexposed the past years. To highlight the importance of emergency preparation new projects have started. In September 2017 the Stress test took place, where several municipalities tested what would happen if the water gets behind the dykes. Moreover the safety regions (another administrative division) need to make a calamities plan to show what they do to prepare their citizens to a possible disaster. The Delta Program stimulate municipalities, provinces and water boards to look at the spatial planning to see if they can take measures to reduce the risks of flooding.