Towards Living with Water

In search of new perspectives towards living with the increasing risk of flooding in the densifying outer dike area of the urban center of Rotterdam

Master thesis

J.E.H. Grevink | Architectural Engineering | 2020-2021

Under supervision of: | Delft University of Technology
Dr. F. L. Hooimeijer | Faculty of Architecture and the Built Environment

Preface

This research introduces the main topic for my graduation project and is also the result of my persnal curiosity towards 'living with water'. The main topic and associated problem statement has primarily come from my personal curiosity towards 'living with the increasing risk of flooding', in the context of the Dutch housing shortage on which the Architectural Engineering graduation studio is focusing.

To me personally, the presence of natural water has always had the ability to instantly make me feel at home anywhere around the world. The calmth of the sea regularly enables me to sort out my thoughts and think more clearly during chaotic periods. Even more, it enables me to experience the raw power of nature, the thrill while surfing along with dramatic waves but also the sometimes overwhelming panic after a small mistake.

Therefore, the unprecedented phenomenon of accelerating sea level rise and increasing risk of flooding from rivers in The Netherlands poses an interesting challenge. Especially during the next few decades when the housing shortage will lead to a vast amount of residences to be developed in the midst of a flood hazard. Being a young architect, I see it as an opportunity to combine my passion for architecture with a deeper understanding of the growing threat rising water poses to the built environment. My aim is not necessarily to solve the complex issue on my own, but rather to investigate into, and add to, the growing amount of possible architectural solutions generating resilience, which, in turn, could be implemented or used as food for thought in the near future. Also I see it as an opportunity to explore the possible qualities living with natural water could bring to everyday life, with in mind the devastating power it can bring as well.

On the one hand this personal interest provides me with a lot of curiosity towards the subject, which helps me to dive deeper into the research topic. On the other hand it also provides me with a lot of subjective assumptions and un-argued ideas solely based on my personal experience. As Andrej Radman stated in one of his lectures: *"it can be essential to rid oneself of oneself in order to be able to observe a topic in a scientific manner."* (Radman et al., 2020). Throughout my research and design process I therefore constantly try to be aware of this, sometimes unconscious, behaviour and try to train myself to think outside of my personal experience, ultimately leading up to a project based on facts, theories and experiments rather than personal interpretations.

To keep me on the right track during my research Dr. Fransje Hooimeijer guided me in conducting my research. Therefore I would like to thank Fransje for her genuine interest in my take on this research topic and enabling me not to get lost in the vast amount of resources which can be found today. She has helped me, and encouraged me, to get a better understanding of how to unravel a complex issue into more clear and manageable parts.

As this research forms the foundation of my graduation project at the TU Delft faculty, Architecture track, it will result in a site specific design proposal. The final project will largely be based on the findings of this research. While this research mainly focuses on the larger-scale phenomenon of rising water, the design project will elaborate on more detailed practical solutions. Leading up to, during and also after the period of interrelated research and design I am more than open to any kind of (critical) feedback, ideas or brainstorming sessions regarding this topic.

J.E.H. Grevink

June, 2020

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Abstract

As a result of global warming sea levels have recently started to rise and pose threatening scenarios to increasingly densifying urban areas worldwide. As the low-lying Netherlands will be one of the first to witness the consequenses of rising sea levels and increasing river water discharge, alternatives for its built environment will have to be explored in order to be able to adapt in time. As the Netherlands has been successfully holding off the water for decades, the country is globally seen as a pioneer in water management solutions. Therefore the Dutch are in the position to lead by example. However, the phenomenon of rapidly accellerating sea level rise is something Dutch water management has never dealt with before. Uncertainty and rapidly changing predictions make it difficult to decide on drastic and costly measures in time. In order to facilitate a transition from the established defensive landscape towards living with water instead, a new flood resilient building type can facilitate in adapting to near future predictions, while also raising awareness for the urgency of rising water levels and contributing to the current housing shortage. In order to achieve this it is necessary to step away from the defensive landscape and outdated water management strategies. This research will elaborate on predictions regarding sea level rise and changing weather conditions in the densifying outer dike area of the urban center of Rotterdam. Contemporary approaches towards building dikes, the importance of engaging private parties in generating flood resilient solutions and the possibility to utilize water and flood defence barriers as a flexible building ground in densifying urban areas will be discussed. Ultimately leading to a novel mixed-use housing typology with the overarching goal to reduce the flood risk in densifying outer dike areas and contribute to a changing mindset towards living with the increasing risk of flooding.

Introduction

Climate change is a subject which often remains abstract. An Earth with an average temperature of 4 degrees higher in 2100, is this bad? A sea level rise of 3 metres higher, is this much? Put more clearly: The survival of The Netherlands is at stake and new forecasts do not make it any better. For a long period of time a sea level rise of 85cm by 2100 was predicted. However, predictions do get higher and higher. Ten years ago the KNMI calculated in decimetres, now it already is about metres (Bregman, 2020).

Maarten Kleinhans, professor of physical geography at Utrecht University, states: *"You sometimes hear the argument that climate change is "uncertain", but that does not apply: the sea level is rising, the question is just how fast."* (Kleinhans, 2018). According to Kleinhans there is a realistic chance near future generations will have to say goodbye to cities like Rotterdam, Amsterdam, The Hague, Delft, Leiden and Haarlem. Centuries of heritage, culture and history will literally be washed away. As soon as The Netherlands is flooded, the infrastructure and economy will succumb and people will have to move to the eastern parts of the country or rebuild their lives abroad (Kleinhans, 2018).

Urgency of extreme sea level rise

In a worst case scenario, when the world doesn't lower the emission of greenhouse gases fast enough, we can end up with a sea level rise of almost 3m in 2100. Another century later it could be 5 to 8 metres (Haasnoot, 2018). *"Scientists have been telling for years that this is coming, and the world still does not want to listen decently."* (Kleinhans, 2018).

To paint a picture that appeals more to the imagination, Kim Cohen, geographer at Utrecht University, sketched a map of The Netherlands in 2300, after the costly fight against the water is lost (fig. 1.1) (Cohen, 2019). Where controlling climate change is depending on global policies, the adaptation to any unfortunate outcome is in our own hands.

Global causes

Melting land ice results in higher sea levels, and in addition, warmer water also expands. Furthermore, the low-lying Netherlands is extra sensitive to the melting of the Antarctic. The gravity of the kilometres thick ice sheet attracts gigantic amounts of water. This attractive force is so big the water is standing at an angle against the ice, as an enormous mountain of water. When the icecap melts, the attractive force diminishes, the water at the Antarctic drops and as a result the sea at the north side of the world rises (Shepherd, 2018). Right next to The Netherlands.

Dealing with uncertainty

Especially regarding predictions on sea level rise, the uncertainties in scientific models are big. But the risks, in particular for the low-lying Netherlands, are big as well. Research on the ice caps showed ice at the Antarctic is melting much faster than expected. In the past decade even three times as fast as before (Shepherd, 2018). Scientists of today are mostly concerned about the tipping points. These tipping points occur when the glaciers at the Antarctic are so unstable there is no way back. It is not known exactly where these points lie, but they could be reached within the next twenty years (Verheggen, 2013).

Uncertainty about the speed of the process makes it difficult for policy makers and stakeholders to respond adequately and initiate long term projects facilitating adaptation. This makes it hard to adapt to the new circumstances in time since plans take time to be developed before they can finally be realized (Schuttenhelm, 2019b). However, one thing is certain, a choice has to be made.

1.1 Map of The Netherlands in the year 2300 in an extreme scenario, Kim Cohen (Cohen, 2019)

Project definition

Problem statement

As a result of global sea level rise worldwide articles are beginning to state: *"The Dutch Have Solutions to Rising Seas. The World Is Watching."* (Kimmelman, 2017). It seems it is assumed that Dutch water management interventions such as the Delta Works, constructed as a response to the 1953 flood disaster, are a means to avert the consequences of extreme sea level rise on the long-term. However these infrastructure projects are not designed to withstand the effects of the currently predicted increasing sea water levels and more frequently occurring extreme weather conditions (Bregman, 2020). Nevertheless, it seems self-evident to many Dutch people that the government will take responsibility for acting on time.

When the predicted acceleration in sea level rise appears to be true, the current flood defense strategy is not prepared for a shift towards the required change (Bloemen et al. 2017). This is because the required shift is limitied by current standards of society that are against certain changes. As a result, there will be an increase in both transfer costs and strategy-dependency that makes it more difficult to do the required shift. (van der Meulen, 2018). To make sure preparedness, rather than a disaster, leads development, various outcomes of increasing sea level rise and the required adjustments therefore needs to be researched and made visible for the people.

Backing up the need for a different approach is professor Kleinhans' theory stating the risk of flooding comes from lasting changes in climate, sea levels and river discharge, instead of accidental extreme weather events. Whereas occasional extreme weather events have resulted in situations of temporary 'shock', lasting climate change will result in long term 'stress' which requires a different approach. Saline water will seep underneath the costly dikes and will cause problems regarding drinking water, agriculture and nature (Kleinhans, 2018). According to Henk Ovink, Special Envoy for International Water Affairs, the biggest worldwide challenge lies in the field of availability of water, purifying water and other new applications to counteract the consequences Kleinhans describes (Ovink, 2020).

On the other hand, flood risk is also affected by the degree of vulnerability of the built environment and its inhabitants. The amount of possible victims and damage to the built environment in the event of a possible flood is of great importance in decision-making (Pieterse et al. 2009). In this way the flood risk of an already flood prone area will raise as a result of densification. Due to the national housing shortage the aim is to build 58.900 houses in the inner-city area of Rotterdam before 2030, primarily intended for starters and middle income groups (Groenemeijer et al., 2020). For various areas this results in a higher flood risk due to both the changing climate as well as densification, as this leads to an increase in vulnerability (fig. 2.1, 2.2).

Ahmed Aboutaleb, Dutch politician of the Labour Party and Mayor of Rotterdam, said of the city: *"Rotterdam lies in the most vulnerable part of the Netherlands, both economically and geographically. If the water comes in, from the rivers or the sea, we can evacuate maybe 15 out of 100 people. We have no choice. We must learn to live with water."* (Kimmelman, 2017). Although dikes protect the low-lying parts of the city, also in the densifying outer dike area sensitive areas can be identified (Gemeente Rotterdam, 2014).

Seen the reduction of greenhouse gas emissions and limiting global warming is not entirely in the hands of The Netherlands alone, there has to be a plan takes into account the possibility the country will not survive. Therefore, experts warn that alternative opportunities must be explored in time (Schuttenhelm, 2019a). Especially while the rest of the world does use the Dutch approach as an example, we shouldn't sit back and solely rely on the defensive landscape that has been designed based on assumptions made in the past. Instead, we should search for new perspectives on how to live with the increasing risk of flooding, act in time, and lead by example.

Research questions

A timely response will be crucial to adapt to a rapidly rising sea level and the increasingly often flooding of rivers, that flow through the economic centers of the Netherlands, in time. To assure a national catastrophe won't be needed to provoke action to be taken, the research poses the following question:

How can a new building typology, generate resilience to flooding in the densifying urban environment of the outer dike area of Rotterdam, aid in the Dutch housing shortage and represent the urgency of timely adjustment to extreme sea level rise?

In order to answer this question a collection of consecutive sub-questions is lined up:

1. What are the predictions for sea level rise and changing weather conditions in The Netherlands?

2. In what ways can the built environment of the outer dike area of the center of Rotterdam be made resilient towards the predicted consequenses of extreme sea level rise and changing weather conditions in the near future?

3. What requirements will the design have to meet to initiate the next step towards living with water and make its program profitable for its surroundings at the densifying urban outer dike area of Rotterdam?

4. What design principles can be used for the design to help meet the established requirements?

5. How can an architectural intervention portray the challenges of extreme sea level rise on the long term, while the phenomenon involves a great deal of future uncertainty and rapid change in predictions?

Hypothesis/objective

The starting point for this research is based on the assumption that a new building typology can contribute to reducing the housing shortage while generating resilience instead of vulnerability to flooding. The overarching goal is to reduce the flood risk in densifying outer dike areas and contribute to a changing mindset towards living with the increasing risk of flooding. In the context of the current defensive mentality, communicating through architecture a new perception, which embraces and benefits from the qualities natural water can bring to the built environment, will ultimately aid transition through increasing awareness.

The typology will be designed as a diagram flexible to be reinterpreted and deployed in various similar physical contexts dealing with similar conditions. It will be designed to be part of a bigger network of spatial interventions and function along with other existing water management solutions. The diagrammatic design will manifest itself in the form of a detailed design for one of these locations. For the purpose of this detailed design the research will focus on experimenting with design principles rendering visible and utilizing natural water to enhance spatial qualities benefitting everyday life. The final design will be presented as an imaginative case-study and can be seen as an experimental form of research.

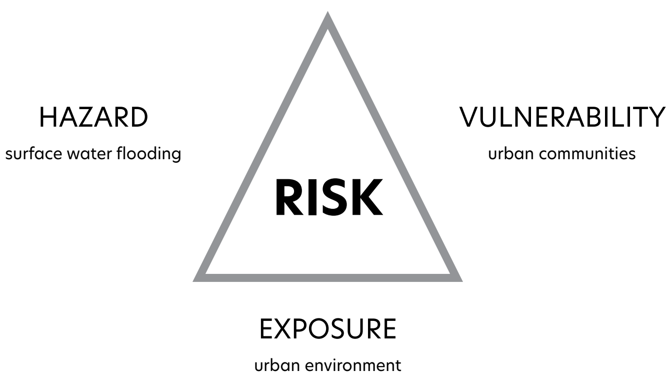
Positioning

On the one hand this research focuses on the study about the practice of living with the temporality of flooding (fig. 2.1, 2.2) and the spatial qualities natural water can bring. The research therefore zooms in on the current Dutch defensive landscape, recent predictions and transition strategies in order to determine how a more integrative and resilient alternative can be initiated. For this it is essential to investigate into how to deal with uncertain predictions related to long-term planning practices.

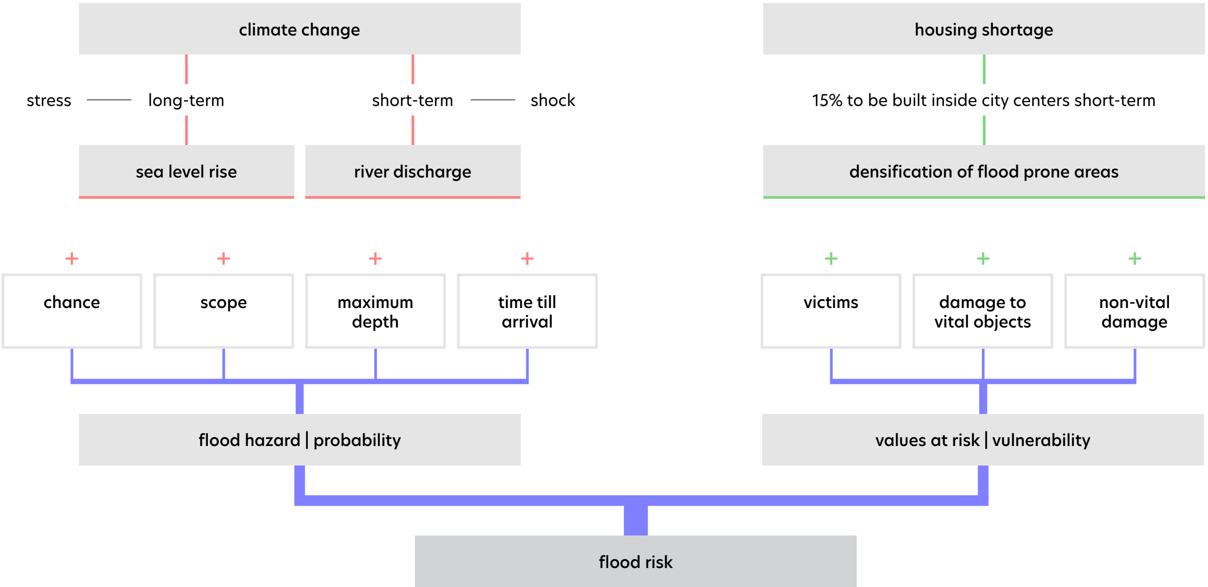
On the other hand it takes into account the aim for intensified use of space in urban areas, the efficiently combining of functions and decentralization as prescribed in 'Vijfde Nota ruimtelijke ordening' (Bruinsma et al., 2018). As a result, the market driven, neoliberal building policies which partly caused the Dutch housing shortage and excluded different classes and population groups from inner-city areas. Increasingly often the functional and societal needs seem secondary to the economic importance which poses a difficult context for architectural innovation (Hulsman, 2021).

Since roughly 90% of the world's bigget cities are located at or near a waterfront, also outside The Netherlands it is relevant to rethink the way we utilize the open space water brings to densifying city centers. As floating urban components are less permanent and can add a variety of functions to the current mostly static grid of cities, using water as a building ground, the current space is relieved and allows for a new density (Olthuis, 2014).

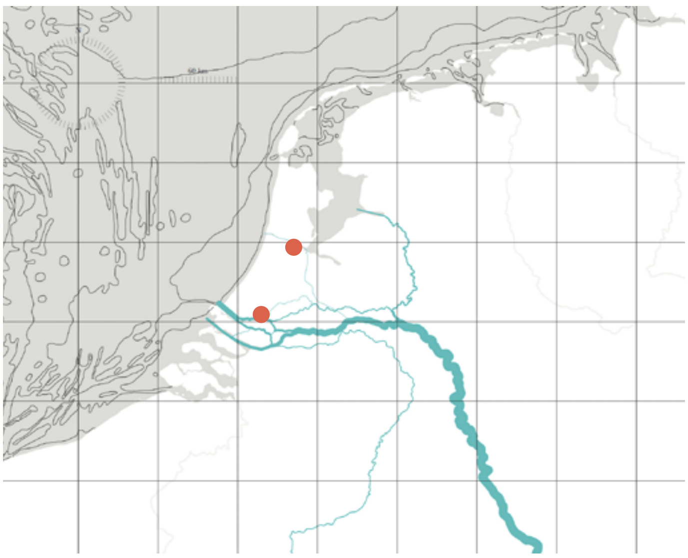
As the diagrammatic design will need to be tested on various sites in order to be deployable inside a bigger network of water management solutions, the in the short-term to be redeveloped inner-city ports of Rotterdam and Amsterdam will be taken as test sites. Whereas Amsterdam has to cope with a bigger need for housing, Rotterdam experiences more urgent water management issues due to its position along the river Nieuwe Maas (fig. 2.3, 2.4).

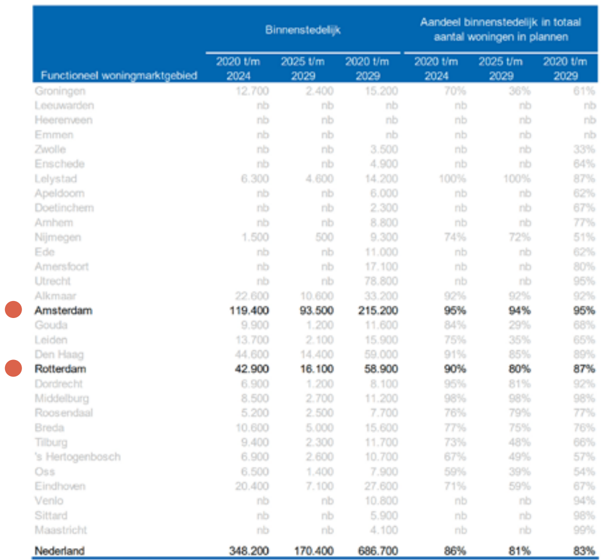


2.1 Flood risk triangle, adapted from (Kaźmierczak et al., 2011)



2.2 Dependencies influencing flood risk, own illustration based on (Pieterse et al., 2009)





Functioneel woningmarktgebied	Binnenstedelijk 2020 t/m 2024	Binnenstedelijk 2025 t/m 2029	Binnenstedelijk 2020 t/m 2029	Aandeel binnenstedelijk in totaal aantal woningen in plannen 2020 t/m 2024	Aandeel binnenstedelijk in totaal aantal woningen in plannen 2025 t/m 2029	Aandeel binnenstedelijk in totaal aantal woningen in plannen 2020 t/m 2029
Groningen	12.700	2.400	15.200	70%	36%	61%
Leeuwarden	nb	nb	nb	nb	nb	nb
Heerenveen	nb	nb	nb	nb	nb	nb
Emmen	nb	nb	nb	nb	nb	nb
Zwolle	nb	nb	3.500	nb	nb	33%
Enschede	nb	nb	4.900	nb	nb	64%
Lelystad	6.300	4.600	14.200	100%	100%	87%
Apeldoorn	nb	nb	6.000	nb	nb	62%
Doetinchem	nb	nb	2.300	nb	nb	67%
Arnhem	nb	nb	8.800	nb	nb	77%
Nijmegen	1.500	500	9.300	74%	72%	51%
Ede	nb	nb	11.000	nb	nb	62%
Amersfoort	nb	nb	17.100	nb	nb	80%
Utrecht	nb	nb	78.800	nb	nb	95%
Alkmaar	22.600	10.600	33.200	92%	92%	92%
Amsterdam	**119.400**	**93.500**	**215.200**	**95%**	**94%**	**95%**
Gouda	9.900	1.200	11.600	84%	29%	68%
Leiden	13.700	2.100	15.900	75%	35%	65%
Den Haag	44.600	14.400	59.000	91%	85%	89%
Rotterdam	**42.900**	**16.100**	**58.900**	**90%**	**80%**	**87%**
Dordrecht	6.900	1.200	8.100	95%	81%	92%
Middelburg	8.500	2.700	11.200	98%	98%	98%
Roosendaal	5.200	2.500	7.700	76%	79%	77%
Breda	10.600	5.000	15.600	77%	75%	76%
Tilburg	9.400	2.300	11.700	73%	48%	66%
's Hertogenbosch	6.900	2.600	10.700	67%	49%	57%
Oss	6.500	1.400	7.900	59%	39%	54%
Eindhoven	20.400	7.100	27.600	71%	59%	67%
Venlo	nb	nb	10.800	nb	nb	94%
Sittard	nb	nb	5.900	nb	nb	98%
Maastricht	nb	nb	4.100	nb	nb	99%
Nederland	**348.200**	**170.400**	**686.700**	**86%**	**81%**	**83%**

2.3 Distribution of river water discharge in The Netherlands, edited from (van der Meulen, 2018)

2.4 Amount and share of inner-city plans by functional housing market area, from 2020 till 2029, edited from (Groenemeijer et al., 2020)

Predicted challenges towards 2100

Some of the current measuements against flooding are raising of the dikes and allowing rivers to overflow up to a certain extent. The question arises, is this enough? And for how long will it suffice before we need more measurements? The rise of sea levels is not a recent development, but it is increasingly rising faster then anticipated. So its clear what to prepare for, the main question is: What are the predictions for sea level rise and changing weather conditions in The Netherlands? This chapter will give an overview of the most recent scientific predictions that are being made on sea level rise and changing weather conditions, taking the urban center of Rotterdam as an example.

Predictions for sea level rise

In a study that measured precisely the sea levels on a global scale from 1993 to 2006, a rise of around 3 millimeter has been measured on a yearly basis (fig. 3.1). This yearly average was higher than the average of the 20th century. This trend in increasing rise of sea levels can be seen since the 18th century (Church, 2014).

When making the assumption that the procceses that are responsible for melting the ice caps, like greenhouse gas emmisions keep accelatering the melting proces, the result could be up to a near 3 meter rise in sea level by 2100. (Schuttenhelm, 2019a).

A decade ago scientist agreed upon a maximum of one meter increase in sea level by 2100. By now this estimate has been tripled. Eventhough this is a wors-case scenario that is not the most likely to occur, the effects are major. In a research from Marjolijn Haasnoot, senior researcher on climate and water at the Deltares knowledge institute, it is stated that the effects of one meter increase already is difficult to cope with. The existing flood resistance plan had been designed based on the before mentioned increase of one meter in sea level rise. Haasnoot also states that there could be a point of no return somewhere between one and two meters. Having reached that point, major transformative interventions will be necessary, for which various alternatives need to be developed (Schuttenhelm, 2019a).

Michael Oppenheimer, Professor of Geosciences and International Affairs at the Princeton Environmental Institute, states that currently there is no plausible scenario that will halt sea level rise within the 21st century. *"We've got to deal with this anyway, the only aspect we will be able to have influence on is the speed at which it happens."* (Voosen, 2019).

The current state of policies of countries allow them to continue the consumption of fossil fuels and can result in a global sea level rise of up to 1.1 meters. However, if the countries heaviliy cut back in their greenhouse gas emissions, the rise can be reduced to somewhere in between 0.29 and 0.59 metres by 2100 (Voosen, 2019).

Not to mention, it will not stop after 2100. The effects of sea level rise are on a global scale, creating new surfaces that will show a lasting effect for the upcoming millenia. It has been established that it will be difficult to preserve the ice caps in Greenland and West Antarctica, and the same counts for the mountain glaciers. If you add the expansion of warming ocean water to that, it has been estatimated that a minimum rise in sea level of 10 metres will occur. Even if we do everything we can to achieve the goals of the Paris climate agreement to stay below an increase of 2 °C globally or even below 1.5 °C (Schuttenhelm, 2018a).

Predictions for weather conditions

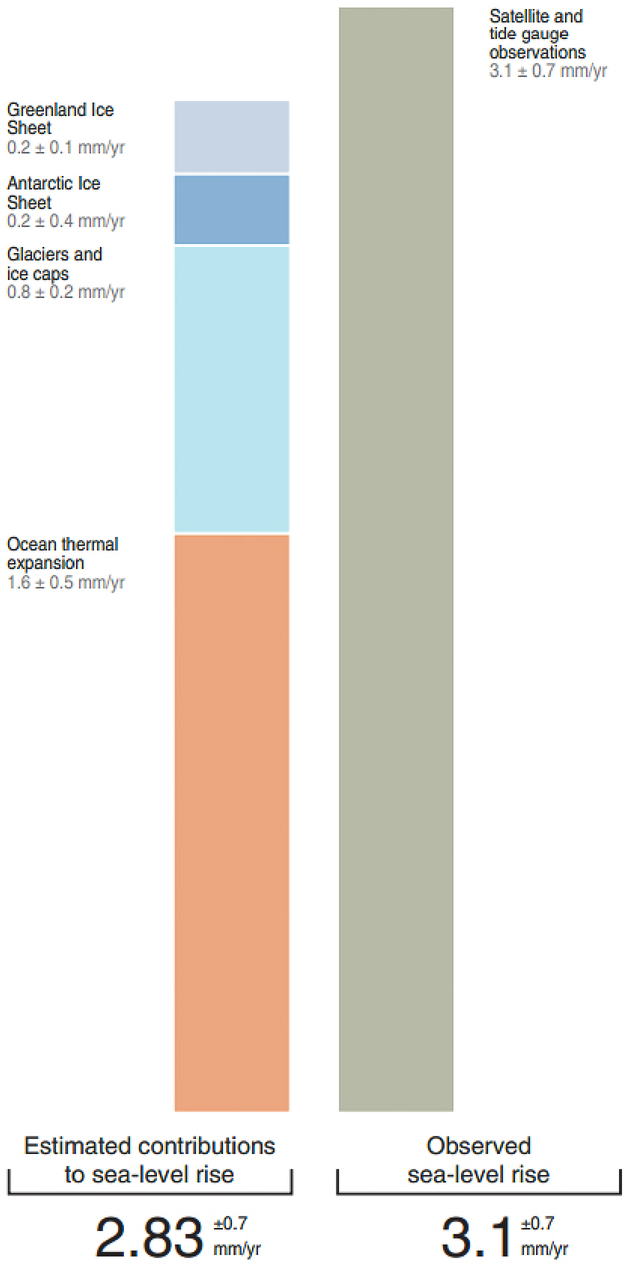
Next to the threat of rising sea levels also more extreme weather conditions are an incidental effect of climate change. More frequent heavy rainfall, storm surges and rising temperatures resulting in long periods of draught will also have a significant impact on the urban environment (fig. 3.2). If we dont take action, the frequency of catastrophic storm surges will increase significantly in the next 30 years, Oppenheimer says. *"What was a 100-year event is a yearly event by 2050"* (Voosen, 2019). For Rotterdam, next to sea level rise it also involves effects such as Rainfall and drought (fig. 3.3, 3.5) which affect river flow, groundwater levels and land subsidience.

All of these effects are related and reinforce eachother. However, each of them need a different kind of approach and the necessary measures can either reinforce or hinder eachother.

Consequenses

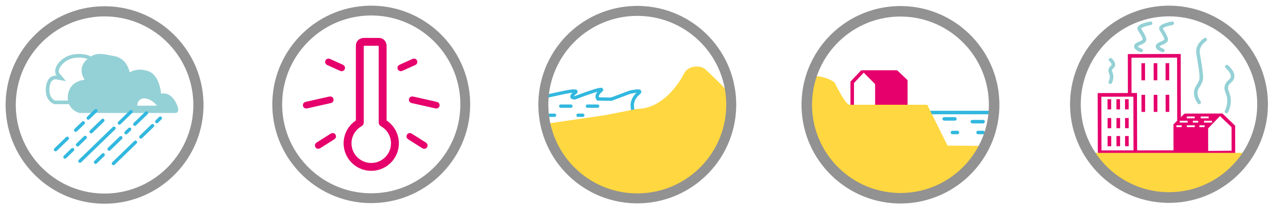
For the outer dike area of the urban center of Rotterdam (fig. 3.4), where more than 65.000 people are living and also the biggest port of Europe is located, various additional consequenses of sea level rise and changing weather conditions are occurring. One of the consequences of the rising sea level is an increase of salinity in the water at collection points for fresh water and groundwater. The rising sea levels potentially causes a higher level of pressure resulting in seepage with negative consequences for the quality of the water and the need for extra discharge capacity. For the city of Rotterdam, in times of prolongued dry and warm periods, the demands for energy will increase to provide cooling, together with the demand for freshwater to retain the proper surface and groundwater levels. The periods' higer temperature can result in a decrease of water quality and stimulatie the growth of harmful organisms such as blue-green algae. As a result, the city has a lower liveability rate which can be seen in figure 3.3 and 3.5. (Gemeente Rotterdam, 2020).

Furthermore, the water level of the rivers have to be reduced. In order to achieve that, it is neccessary to create more flexibility for the capacity of the rivers at 39 locations in the Netherlands. One way to do so is by, relocating dikes further inland, constructing high-water channels and lowering the floodplains in some locations (fig. 4.4, 4.5). Some of these locations will be flooded during high water level periods, allowing the river more room. This results in an easing of the pressure on the dikes and other water systems (Rijkswaterstaat, 2019). In this way the distribution of river water discharge of the main rivers (fig. 2.3) running through The Netherlands can be regulated. However, the densifying urban outer dike area of Rotterdam doesn't provide sufficient space for these kind of solutions.

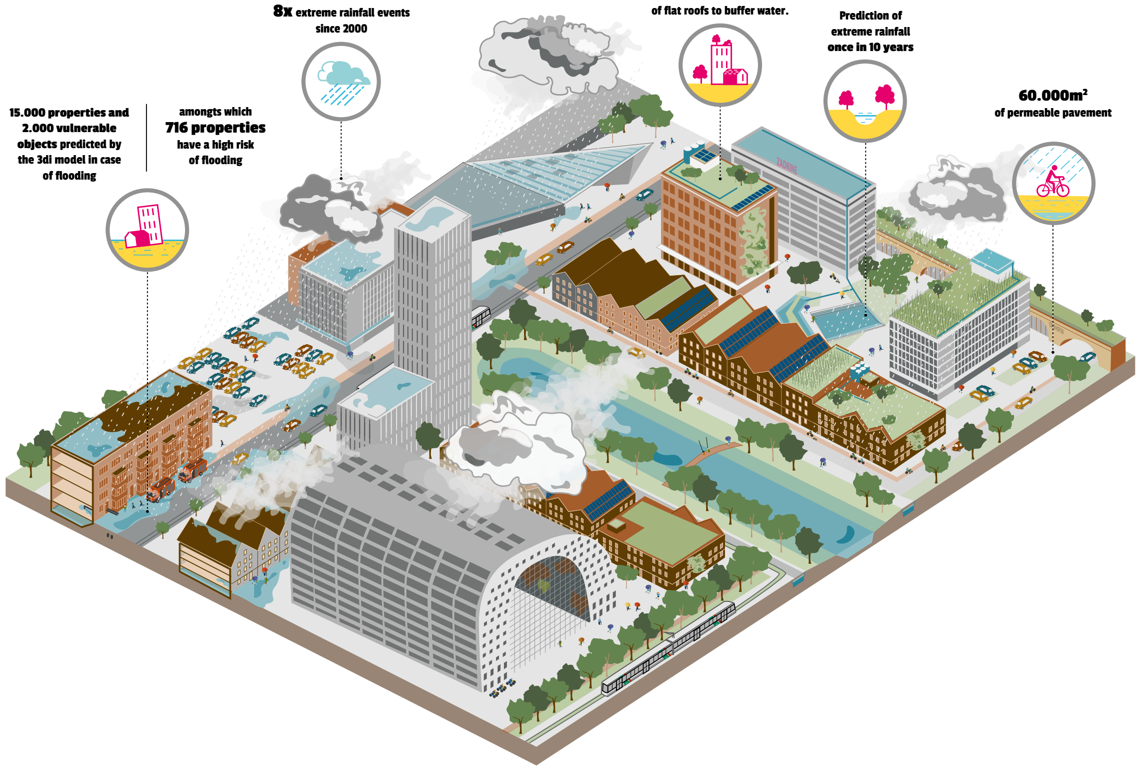


3.1 Estimated contributions to sea-level rise from 1993 to 2003 (Church, 2014)

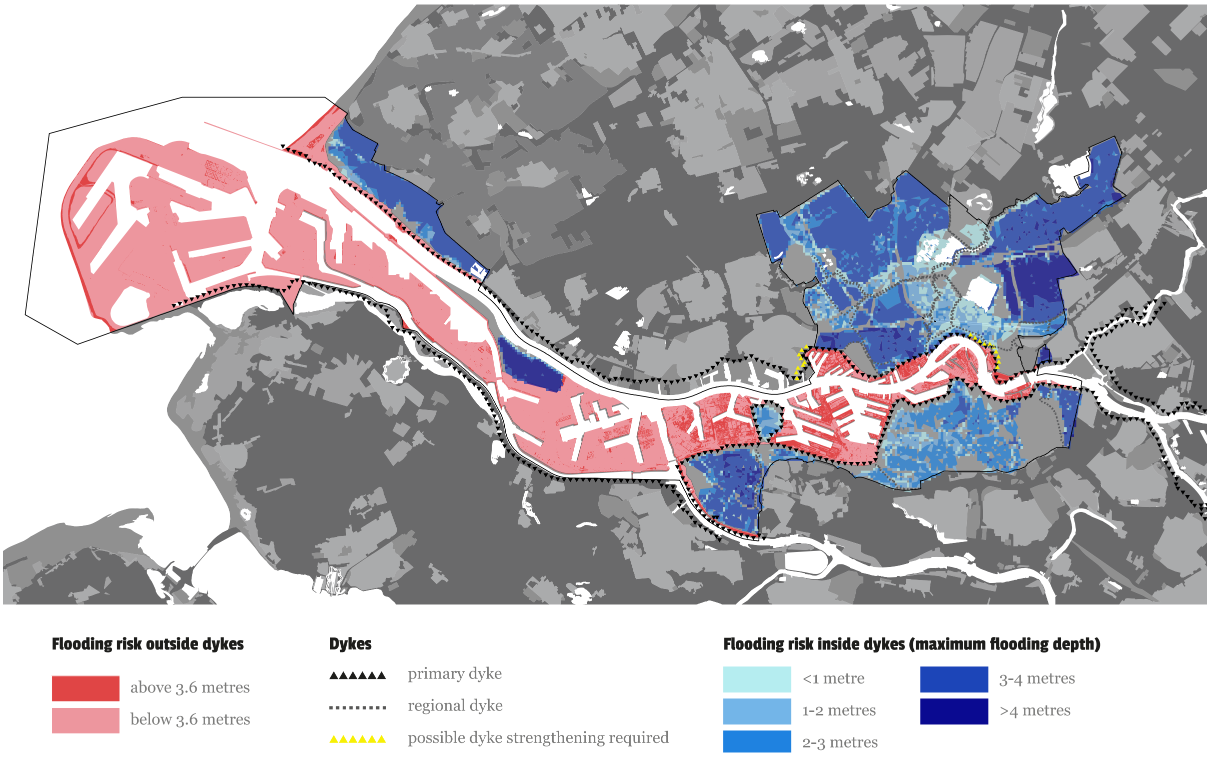
Rainfall	Heat	Sea level rise	River discharge	Drought

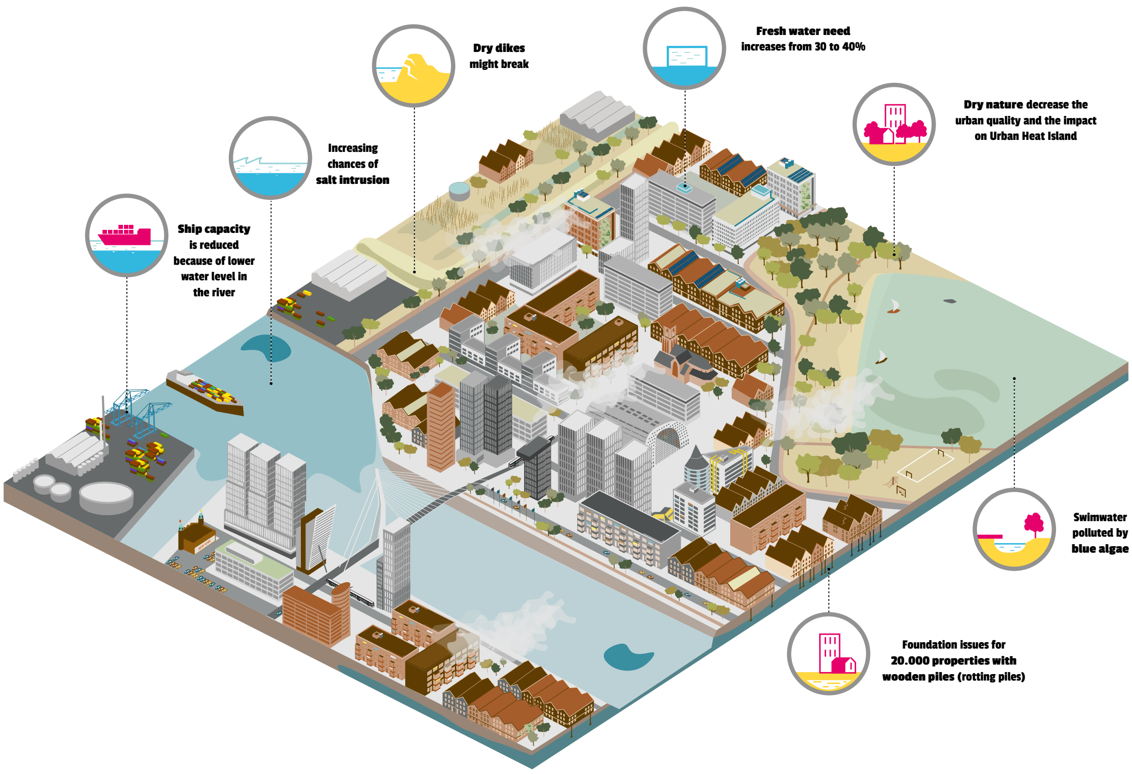


Rainfall	Heat	Sea level rise	River discharge	Drought
rainfall increase 925mm	maximum daytime temperature rises from 36°C to 39°C	sea level rise of 40cm by 2050 and 100cm by 2100	river flow increases in winter	from 7 nights of >20°C to around 3 weeks by 2050
wetter winters and more extreme rainfall volumes	from 20 to 35 sum-mery days by 2050	this causes high water levels to rise in Rotterdam	lower river water levels in summer	>30°C from 1 day now to 5-12 days by 2050
maximum daily rain-fall rises to 94mm by 2050	average temperature rises from 22.1°C now to 23.5°C by 2050			rainfall shortage increases from the current 230mm to approx. 288mm by
number of days when rainfall >50mm increases	from 48 to 20 days of frost by 2050			



3.2 Predictions for changing weather conditions in the center of Rotterdam (Gemeente Rotterdam, 2020)
3.3 Challenges in preparation to heavy rainfall in the center of Rotterdam (Gemeente Rotterdam, 2020)





3.4 Flood risk in the inner and outer dike area in Rotterdam (Gemeente Rotterdam, 2020)
3.5 Challenges in preparation to drought in the center of Rotterdam (Gemeente Rotterdam, 2020)

A contemporary approach towards building dikes

The Dutch history is rich of stories about flooding and technical solutions to effectively control the water. One example is the draining of low-lying wetlands to cultivate agriculture or to create new residential areas. These plots are then protected by dikes. However, the lowering of groundwater is not free of risk as it causes subsidence. Also, the dikes prevent the natural influx of sludge that would help to prevent the subsidence (Kleinhans, 2018). The most prominent example of floods in Dutch history is the North Sea flood of 1953 (fig 4.1).

Today, the entire urban area of the Randstad is one huge polder, home to approximately 10 million people and is the beating economic heart of the Netherlands. In many parts of the world, in total around half a billion people are living in similar conditions, like flood-sensitive river deltas. In those locations, the threat does not only come from accidental extreme weather events, but also from multiple lasting changes in climate and the rise of sea levels. When sea level rises substantially, saline water will creep underneath the raised dikes resulting in problems for the drinking water supply, agriculture and nature. Building larger dikes is costly and still fails to stop the leakage below them (Kleinhans, 2018).

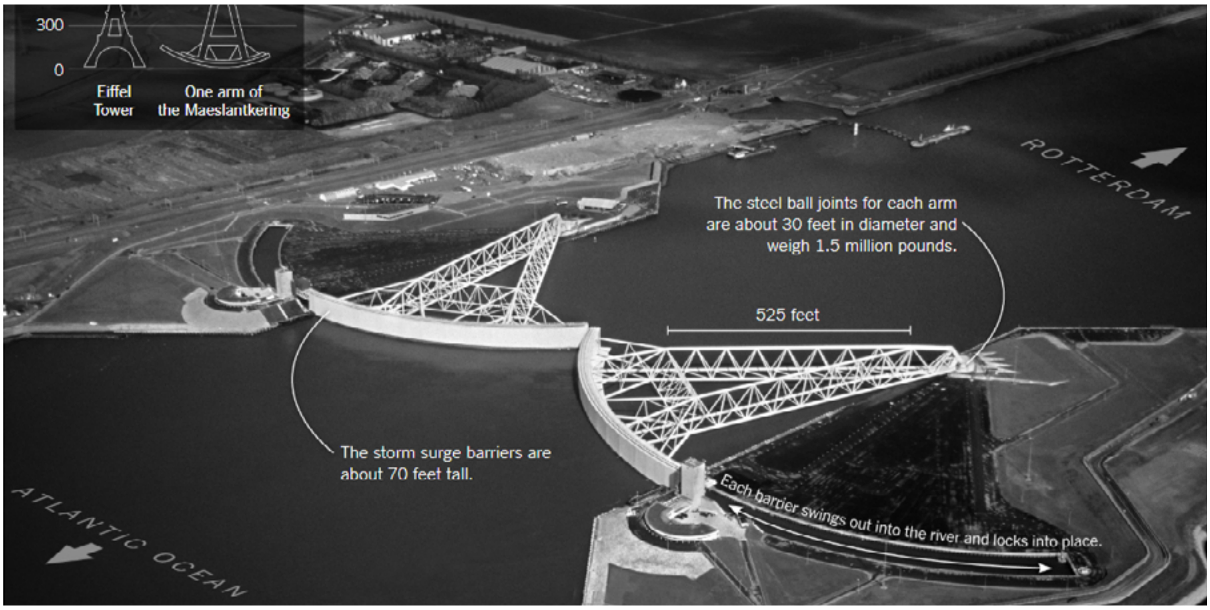
Dikes and sluices are often thought of in protection against water but these won't be able to save the world by itself. According to Henk Ovink, Special Envoy for International Water Affairs at the Kingdom of the Netherlands, the biggest worldwide challenge lies in the field of the availability of water, purifying water and new applications. Think of extracting energy out of waste water (Ovink, 2020).

Multifunctional alternatives

Bringing together different expertise and ‘building with the help of nature’ would make much more sense than endlessly fighting the water. A result of this approach is the Zandmotor. By heigtening a part of the beach with a large amount of sand at once, repeated disturbance of the fragile seabed is prevented. Through natural erosion nature spreads out the sand along the coastline itself (TU Delta, 2014).

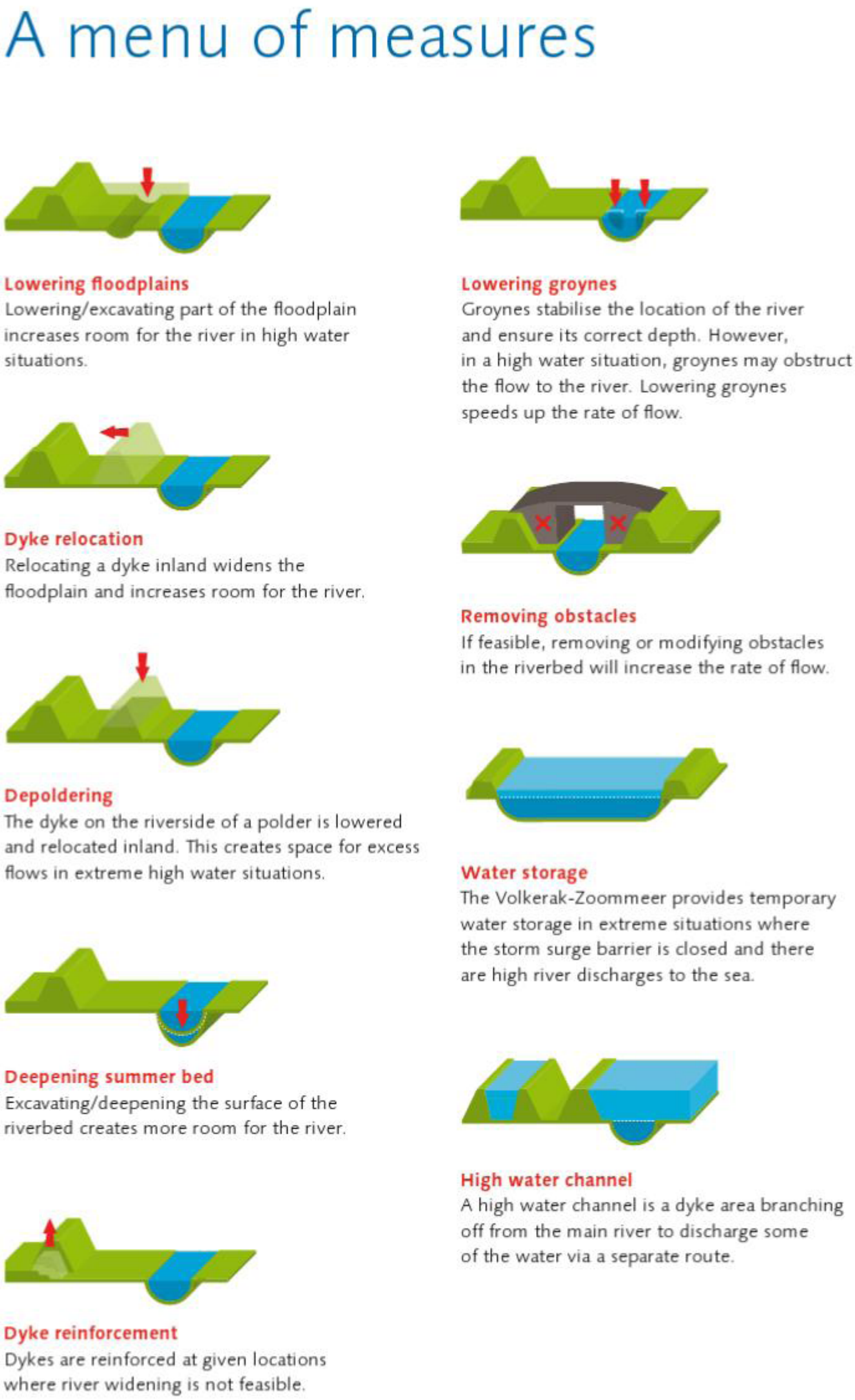
Once the world’s busiest port in the world, Rotterdam’s port still functions as the biggest port in Europe. Every year it operates tens of thousands of ships from around the world, supplying many countries with almost every type of goods. To Rotterdam, with more than 600.000 inhabitants, the port still forms the basis of the city's industry. According to port officials, the port is good for around 90.000 jobs, and there are many more workers whose businesses depend on the port. Therefore it is very important to protecting the port (Kimmelman, 2017). The functioning of the port and the prevention of the flooding of the city is currently dependent on the Maeslantkering (fig. 4.2).

Beyond the Maeslantkering, in the center of Rotterdam, there are plenty fortifications, both on a bigger and smaller scale. An example is the 'Dakpark' (fig. 4.3), giving the dike more functions then just to protect from flooding. It doubles as a much needed shopping center for the neighbourhood, and also has a public park on the roof. Currently. the shops face towards the waterfront and help with the upkeep of the park financially. According to one of the developers, Mr. Dassen: *“We became invested in getting more people involved in all kinds of civic issues. Water inevitably becomes an integral part of this process. We believe you get the smartest solutions when communities are engaged and help make the links between water and neighborhood development.” (Kimmelman, 2017)*.



4.1 A storm surge in 1953, killing more than 1,800 Dutch people, Co Zeylemaker (ANP Archief, 2008)
4.2 Maeslantkering, Frans Lemmens (Kimmelman, 2017)
4.3 Dakpark Rotterdam, Buro Sant en Co (Sant en Co, 2013)

4.4 Room for the river measurements throughout the Netherlands (Rijkswaterstaat, 2020)



4.5 Room for the river measurements throughout the Netherlands (Rijkswaterstaat, 2020)

Perspective

In order to understand how a transition from the current defensive landscape towards new resilient flood risk management strategies can be facilitated, the work "New Netherlands" (van der Meulen, 2018) can be used as a starting point. Van der Meulen, researcher at Urbanism TU Delft, concludes that a shift away from the current flood defenses and flood risk management is required in order for transitional approaches to be implemented. The difficulty with these transitional approaches lies in the possibility that the context will change over time.

Managing this transition therefore constantly requires influence and adjustments in governance systems and societal patterns (Rijke et al., 2012). Crucial in this transition is to emphasize on prioritizing development resulting in preparedness above responding to floods after the event (Rotmans et al., 2001). Transition management has a need for the development of a long-term perspective that takes the desired societal changes into account, to guide accelerated social innovation in the short-term, ultimately leading to changes in the societal structures which initially shaped the problem (Loorbach, 2010).

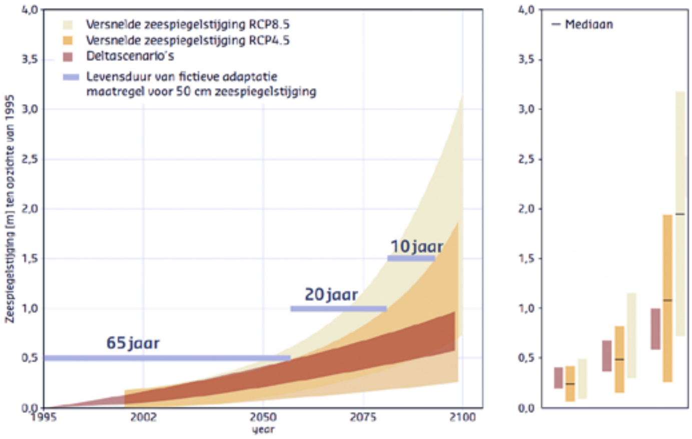
As the right approach has to be based on predictions, a well-considered response is crucial in order to avoid having to regret costly interventions in the Dutch landscape at a later stage (Haasnoot, 2018). This causes a dilemma between the need to act in time, and the need to 'wait' for reliable long-term predictions to base the proper approach on. An intervention to withstand 0.5 m sea level rise in 1995 was still sufficient to be able to last approx. 65 years. In 2060 the functional lifespan of this intervention has already decreased to 20 years (fig. 4.6). This means adaptation with relatively small steps is becoming increasingly difficult. Static interventions will be effective for shorter periods, which leaves little time for planning and implementation. An option would therefore be to take several larger and flexible measures instead (Haasnoot, 2018).

Stated by Dutch landscape architect Rob Roggema, the best approach would be to *"navigate"* the problem (Roggema, 2012, p. 39, 40). According to Roggema spatial planning mostly focuses on relatively short-term plans in a context of predicted long-term changes (fig. 4.7). In the design process of a spatial plan, the quantitative demands determine the spatial layout and once the individual parts are embedded in the plan the future is fixed which causes problems on the long-term (Roggema, 2012). Therefore, best approach would be to determine the best possible direction towards a far-future solution, while on the go constantly adjusting the route. Therefore in order to be able to "navigate", a long-term solution must have flexibility as one of its core features.

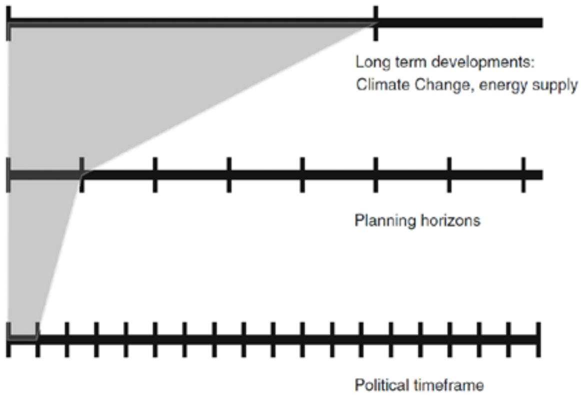
Change in perception

As the recent "Room for the River" project shows a shift towards deliberately 'letting flood', a more adaptive landscape is already being introduced (Rijkswaterstaat 2019). Facilitating further transition is not expected to have one fixed solution. Such a transition of an established system addresses countless interrelated problems and is expected to be only possible when initiated gradually and considered as an evolving process (van der Meulen, 2018).

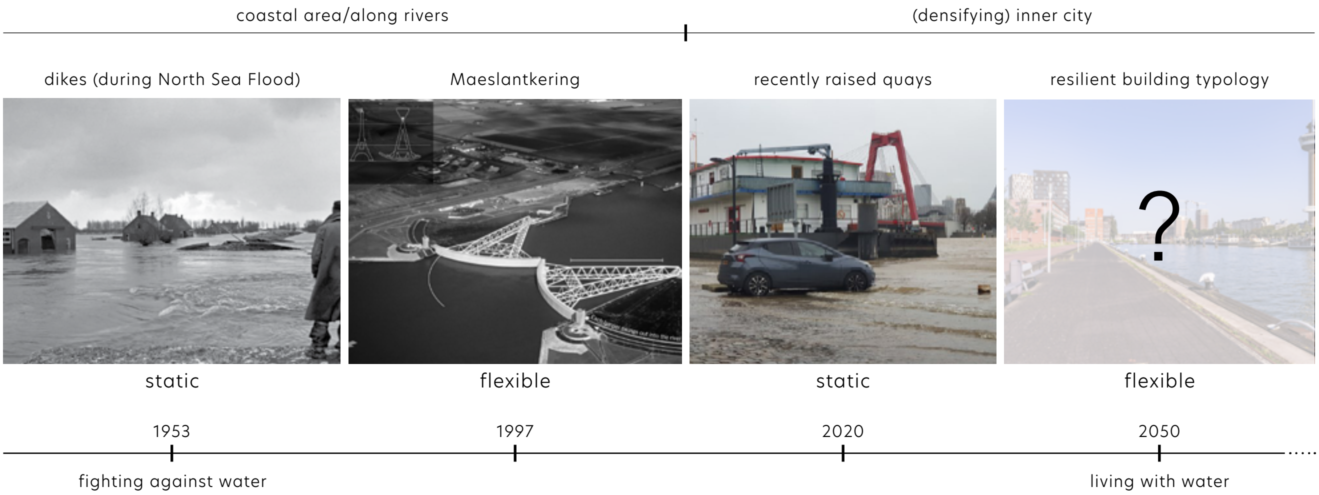
In order to navigate this process the theory that design has the strength to facilitate one's imaginations and to initiate a collective behavioral change is essential (Brugmans, 2018). It is important that the current generation demands change and becomes mobilized. This can be done with the visualization of futures. (Alkemade et al., 2018). By showing a future with a convincing narrative, that informs and unites people to make complex decisions. That will result in action and opposing the resistance giving standard, architectural design has the ability to address the new complexity of a future with an increasing risk of flooding (Ovink et al., 2018). Now is the time to utilize the power and strength that design can bring in terms of communicating new perceptions (van der Meulen, 2018).



4.6 Reduction of the functional lifespan of adaptation measures to 0.5 m sea level rise (Haasnoot, 2018)



4.7 Connection between long-term and short-term (Roggema, 2012)



4.8 Mentality towards flood barriers after the Dutch flood disaster in 1953, own illustration based on respectively (ANP Archief, 2008), (Kimmelman, 2017), (Port of Rotterdam, 2020), own photograph Parkhaven Rotterdam, 2020

Generating resilience in response to prediction

A large amount of the Dutch population is currently living and working in the Randstad. One characteristic of the Randstand is that it is the lowest-lying region in the country with the weakest soil. The central government, provincial and local authorities and regional water boards have recently come to an agreement to increase the amount of green zones in cities and to have a bigger water storage. Unfortunately, eventhough these measures are reducing effects of climate change such as urban heat island effect and pluvial flooding, they do not address the inevitable flooding due to a rise in sea level. (Ovink, 2020).

With the predictions currently made in mind, in what ways can the built environment of the outer dike area of the center of Rotterdam be made resilient towards the possible consequences of extreme sea level rise in the near future?

Broad involvement

As could be seen in the example of 'het Dakpark', the involvement of users and business comunity in necessary to achieve a lasting effect and to make them more engaged in climate policies. Especially in Rotterdam, where the cities property is 60% privately owned (fig. 5.1), involvement of private owners is of great importance. Not to mention activities where where the link between public and private activities is explored together and awarded with added value (fig. 5.2) (Gemeente Rotterdam, 2020).

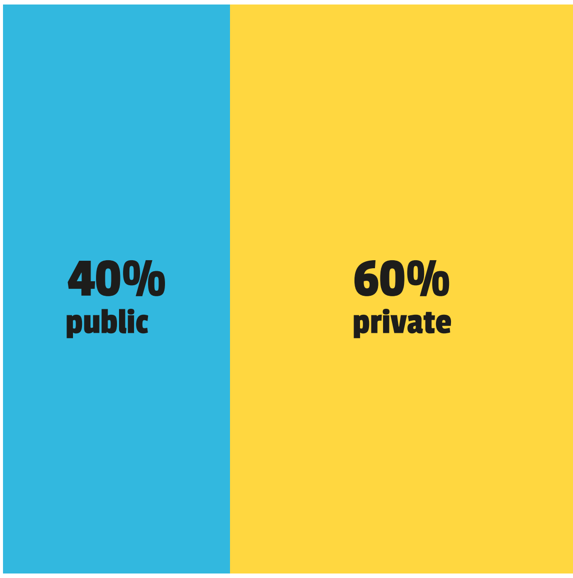
There might also be an awareness issue on the risks of not taking enough action. In the Netherlands, generally, the population has faith in that the government will provide protection against the rising water. But the population might lack awareness on topics such as what location might entail more risk to flooding as it affects their possibility to insurance. In many urban outer dike areas, for instance in Rotterdam, the responsibility in case of a flood lies with the individual residents (Kleinhans, 2018). Therefore it is in the private parties best interest to participate in flood resilience developments (fig. 5.2). On the other hand, more clarity about flood risk could lead to loss of value in certain flood-sensitive areas and will not seem inviting towards long term investments.

Resilient solutions

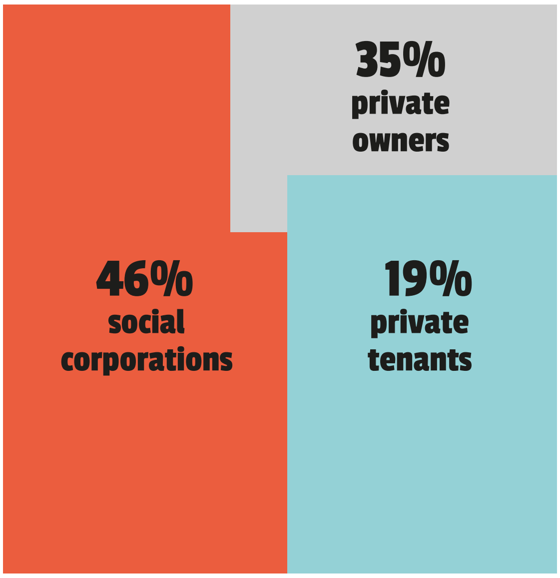
The Delta Commissioner recently stated that it is not too late to introduce major shifts in the areas of housing, agriculture, fresh-water supply and spatial planning. The goal to reduce greenhouse gas emissions gives room for innovation. This can make sure that the Netherlands will remain an attractive country to invest in the future. However, to be able to achieve this, a vision for the Netherlands of the near future is lacking (Kleinhans, 2018).

Cities, often situated on the coast or next to a river, are having to cope with pollution, subsidience, floods and densely populated areas. By tackling all those problems all in one, such a city can be accelerated. To be able to achieve this, which also is what makes it complex, there has to be worked towards transitional change (Ovink, 2020). According to Ovink: *"Money shouldn't go to stupid projects any longer. I can build a road from A to B with a short financial return, but that it makes biodiversity vulnerable, displaces people and does not contribute to climate resilience is not in it. There are 3,700 dams on the drawing board that will be built if nothing happens. All with a negative impact on climate, people and biodiversity."* (Ovink, 2020).

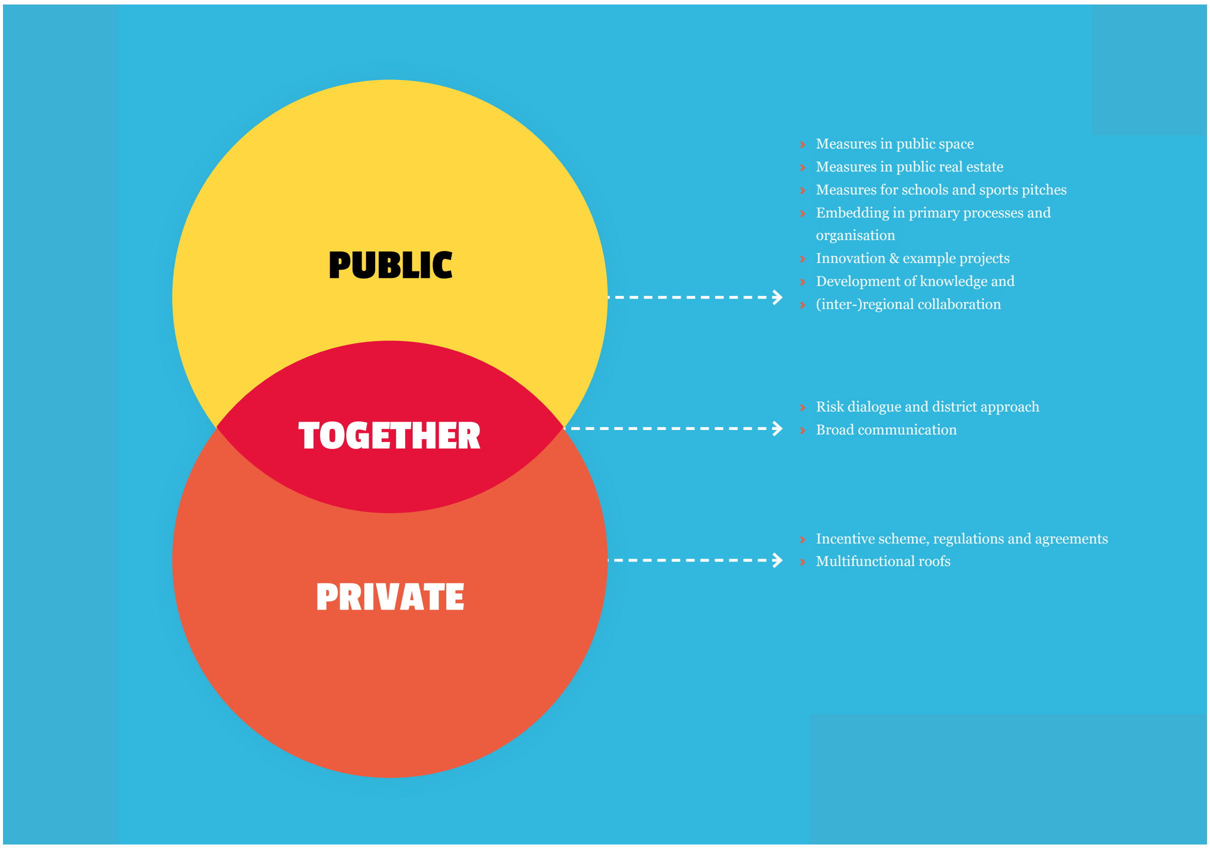
In order to realise resilient solutions in time, broad involvement and close collaboration between public and private parties needs to be established. In addition a clear innovative vision towards (flood) resilient solutions should ensure all various expertises and stakeholders work towards a common goal.



Ownership in Rotterdam



Home ownership in Rotterdam



5.1 Proportion of public and private ownership in Rotterdam (Gemeente Rotterdam, 2020)
5.2 Approach of public and private measures in Rotterdam (Gemeente Rotterdam, 2020)

Towards living with water

The architectural design project will portray the use of natural water in a way that it will encourage its inhabitants and visitors to let water, in all its different forms and circumstances, enhance their experience and quality of life. Which ultimately aids in the transition towards wider involvement and a more durable approach towards urban water management interventions. How can an housing project encourage inhabitants and foreign visitors to take action to invest in a flood resilient built environment in The Netherlands?

Water as a flexible building ground

As the phenomenon of rising water levels involves a great deal of future uncertainty and rapid change in predictions, architects should consider urban components that are dynamic instead of static. Floating urban components are less permanent and can add a variety of functions other than housing to the current static grid of cities. By using the space that is now existing urban water as a building space allows for a new density, providing opportunities for cities around the world to respond flexibly to climate change and urbanization (Olthuis, 2014).

The prognoses is that by 2050 approximately 70% of the world's population will live in urban locations. Considering the the fact that around 90% of the world's largest cities are situated on the waterfront, we have reached a point in time where we are forced to rethink the way we live with water in the built environment (Olthuis, 2014). Given the unpredictability of future developments and unanticipated needs we should come up with flexible strategies to be able to take into account the only constant, which is change.

To make it feasible to utilize water more frequently as a flexible building ground in densifying urban areas new regulations and policies will need to be developed. In order to encourage private parties to invest in ways to live with water a certain amount of regulation is needed, not only to control the outcome, but also to provide confidence.

Dutch Housing Shortage

The city of Rotterdam (currently 620.000 inhabitants) will grow towards 700.000 inhabitants by 2037. The rising housing prices make the city financially less accessible for starters and elderly. Also, people appear to value houses which are flexible in its use on the long term. There should be sufficient possibilities to combine a house into a living and work environment, especially after the transition towards working from home as a result of the corona crisis. Due to the growing amount of grants for sustainable housing and growing accessibility of for instance solar panels the popularity of sustainable living is increasing rapidly (fig. 6.1) (IN10, 2017).

To provide sufficient housing Rotterdam strives to provide 56.000 houses at inner city locations by 2030. This will lead to an expansion of the urban center towards the former harbor areas with an attractive living/work climate close to the current city center. The former ports, which provide a promising site to develop popular residential neighborhoods, will be at the core of a modern inner city along the river (König, 2020).

Already there are plans to invest 233 million euros in 7 urban projects to provide a pleasant living environment within the next 10 years. These projects mainly consist of an increase of green areas, recreation and less car traffic. At the Rijnhaven a housing project of 8.500 houses is planned, the Maashaven will be partly reclaimed into land and turned into a public park and along the Nieuwe Maas, next to the new Feyenoord stadium, a new tidal park will be implemented (König, 2020). As a result of this planned densification along the Nieuwe Maas in the outer dike area of Rotterdam, also the risk of flooding will rise substantially as far more people will be affected in case of flooding.

De percentages tellen op tot meer dan 100%, omdat Rotterdammers meerdere antwoorden konden geven (60,5% heeft duurzaam gebouwde woningen gekozen, maar ook een aantal andere antwoorden)

'WONINGEN BEREIKBAAR VOOR MENSEN MET EEN KLEINE BEURS'
IS HET MEEST GENOEMD IN ZUID (52,4%)
EN HET MINST IN CENTRUM (38,5%)

'DUURZAAM GEBOUWDE WONINGEN'
IS HET MEEST GENOEMD IN WEST (67,2%)
EN HET MINST IN ZUID (57,3%)

'FLEXIBELE WONINGEN DIE JE BETER KUNT AANPASSEN'
IS HET MEEST GENOEMD IN CENTRUM (60%)
EN HET MINST IN WEST (50%)

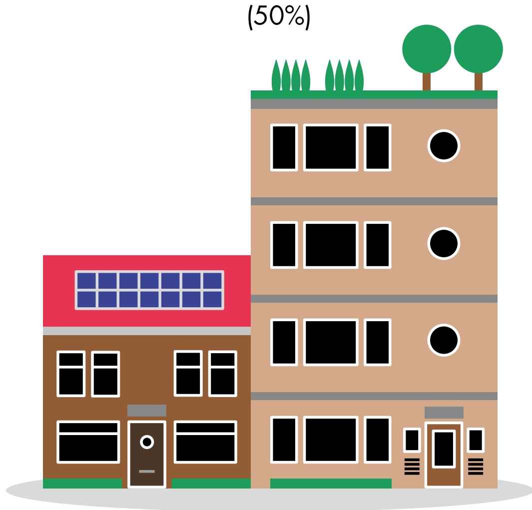
ROTTERDAM NU.

TOP 3 WONINGTYPES IN ROTTERDAM

26,2% Eengezinswoning
23,9% Portiekwoning zonder lift
23,7% Portiek/galerijwoning met lift

Meest voorkomend zijn één-persoonshuishoudens met
46,1% (BRON: BUURTMONITOR 2017 OBI)

13% van de 65+ inwoners is (zeer) ernstig eenzaam
(BRON GEZONDHEIDSMONITOR)



6.1 Response of Rotterdammers to the question: "what kind of houses should we build right now to prepare us for the future?" (IN10, 2017)

Flood resilient building types

As in the near future a vast amount of housing projects will be built in an increasingly flood prone area, what flood resilient building types could be implemented to reduce the impact of a potential flood?

Sacrificial ground floor (fig. 6.2)

Suitable for: new/existing buildings
In areas which are likely to flood, shifting residential functions to the first floor, and utilizing the ground floor for functions such as parking or storage in times of no flooding, greatly reduces the risk of flooding (Pelsmakers, 2014) Providing people with the possibility to live on the ground floor until the flood risk gets too high is also a possibility. However, unforeseen combinations of heavy rainfall, high tides and storm surges can pose threatening scenarios on the short term.

This building type is difficult to implement in dense urban areas where the plint is often intensively used for public functions such as shops, restaurants and other semi-public functions.

Wet and dry proofed buildings (fig. 6.2)

Suitable for: new/existing buildings
In areas which may potentially flood, to ensure minimal damage occurs to properties in case of flooding buildings can be wet-proofed. This can be done by using water-resistant materials as concrete or tiles and building more robust walls and fixtures. Also electrical controls and appliances should be placed higher. Besides new structures, also existing structures can be wet-proofed. This one-time investment will result in minimal damage in case of a flood.

A slightly more thorough procedure would be to dry-proof new and existing buildings. In this way, in case of a flood, the water will be kept outside and does not cause any damage to the interior. However, this procedure is more costly and needs fully water resistant materials and details te be implemented (Pelsmakers, 2014).

Building on stilts (fig. 6.2)

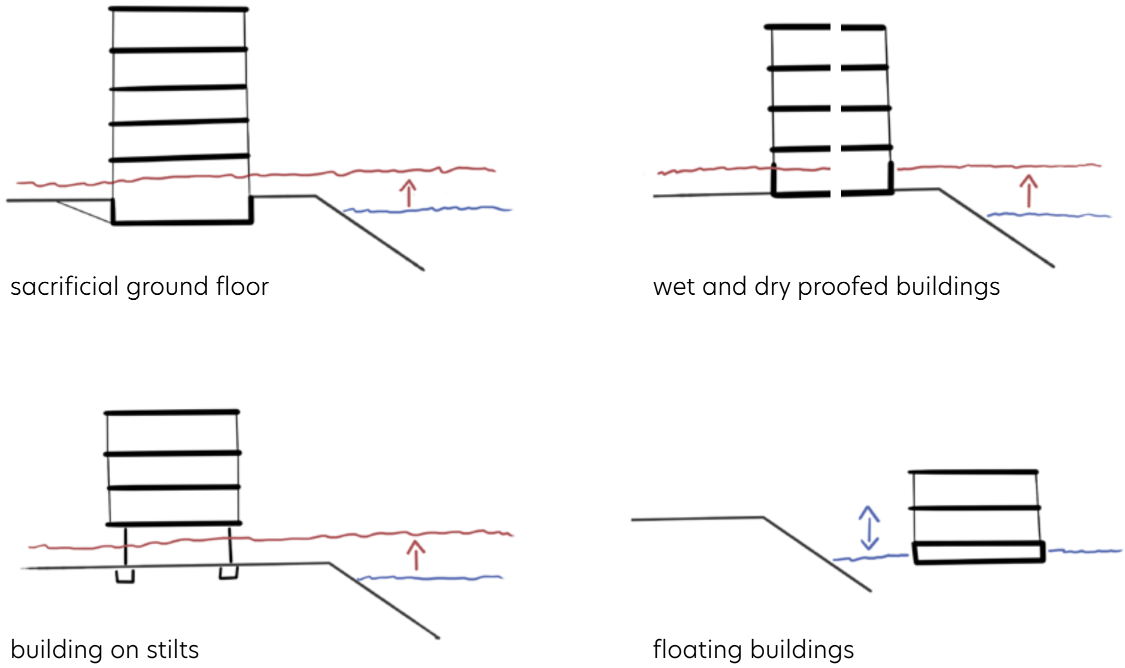
Suitable for: new buildings
In areas with a great possibility of flooding it is suitable to build on stilts. To ensure safety of the construction, additional protection of the stilts is needed against breakwater and potential debris.

The area underneath the building is difficult to use as a public park won't be able to grow underneath the structure. Also a lack of surveillance and ownership will cause security issues in a dense urban environment (Pelsmakers, 2014). To be able to bridge the gap between the city its infrastructure and the first floor, ramps, lifts and walkways will be needed to be implemented into the already fixed and dense urban environment.

Floating buildings (fig. 6.2)

Suitable for: new buildings
As floating buildings are build directly onto water they will be resilient to any amount of water level rise as they will simply rise along with it. Also the need to reclaim land before a new structure can be built is not necessary. Essential pipework can be made waterproof and flexible to allow for the vertical movement of the building (Pelsmakers, 2014).

Floating buildings are mostly limited to two storeys in height, which does not allow optimal use of the available space in a densifying urban center. However floating structures can be resilient towards flooding, they still remain dependent on its connection to the vulnerable urban infrastructure around it.



6.2 Flood resilient building types, own illustration

Functional integration

As the described flood resilient building types are difficult te be implemented into a densifying urban center the need for flood defence barriers seems almost unavoidable. While striving towards living with water, how can we integrate flood resilient building types into flood defence barriers in order to optimally use the scarce space in densifying city centers?

In dense urban areas where space can be scarce concepts of multifunctional land-use can enable space to be used more intensively. The multifunctional use of space can be achieved by integrating multiple functions in one building or construction. The degree of spatial integration can be distinguished in four spatial dimensions of multifunctionality. With the four dimensions it is possible to evaluate to which degree space and function integrate (fig. 6.3) (Veelen, 2015).

<u>Shared use</u>

Without the need for any adjustments to the basic structure, it is possible to use a flood barrier for functions such as recreation, infrastructure or argricultural purposes.

<u>Spatial optimisation</u>

In order to make space for other buildings, which are not part of the flood defence, the shape of the flood barrier can be adapted. The spatially most compact shape is reached when a vertical retaining wall is applied, replacing a slope, leaving space for housing or other urban functions.

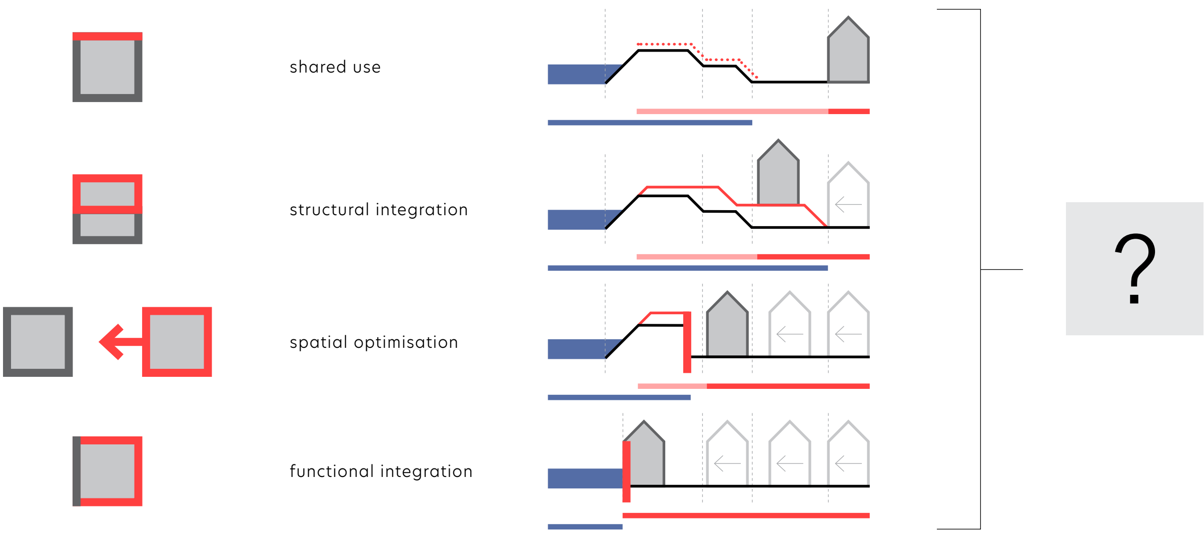
<u>Structural integration</u>

When a dike is over-dimensioned and doesn't need all its capacity to function as a flood barrier, a structure can be built on, in or under the flood barrier without having to function as a barrier itself.

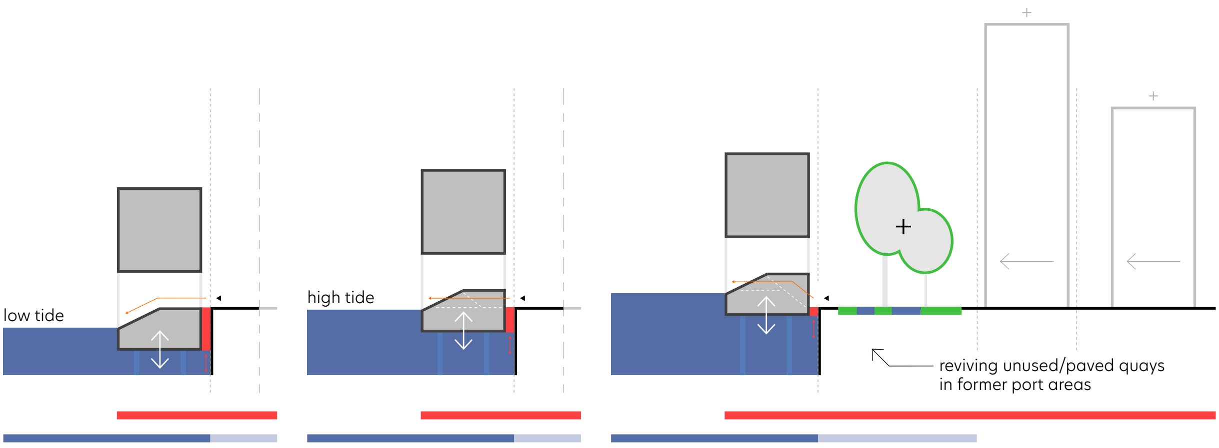
<u>Functional integration</u>

When a structure with a function of its own also functions as a flood barrier then the biggest amount of space can be gained. However this concept is technically feasible, precedents are hard to find and the design asks for well considered decisions regarding safety measures (Veelen, 2015).

In striving towards efficient use of space in densifying urban waterfront areas, various, already implemented, integration concepts (Veelen, 2015) combined together could form a new type of building typology (fig. 3.1). Combining the principles of shared use, structural, spatial and functional integration could pose an innovative next step towards living with water in densifying urban areas (fig. 3.2). The sub questions in order to come up with workable design principles: How would a typology like this work both socially and technically? In what ways could this typology be beneficial to the densifying flood prone area behind it? What other qualities will it be able to give back to the city? How would it be implemented into the already saturated urbanizing context? What will the mandatory requirements be for the individual parts of this building typology in order to make it feasible and flexible long-term?



6.3 Degrees of spatial integration, own illustration based on (Veelen, 2015)



6.4 Example of a schematic proposal for a hydraulic building typology along currently vacant quays combining shared use, structural, spatial and functional integration, own illustration

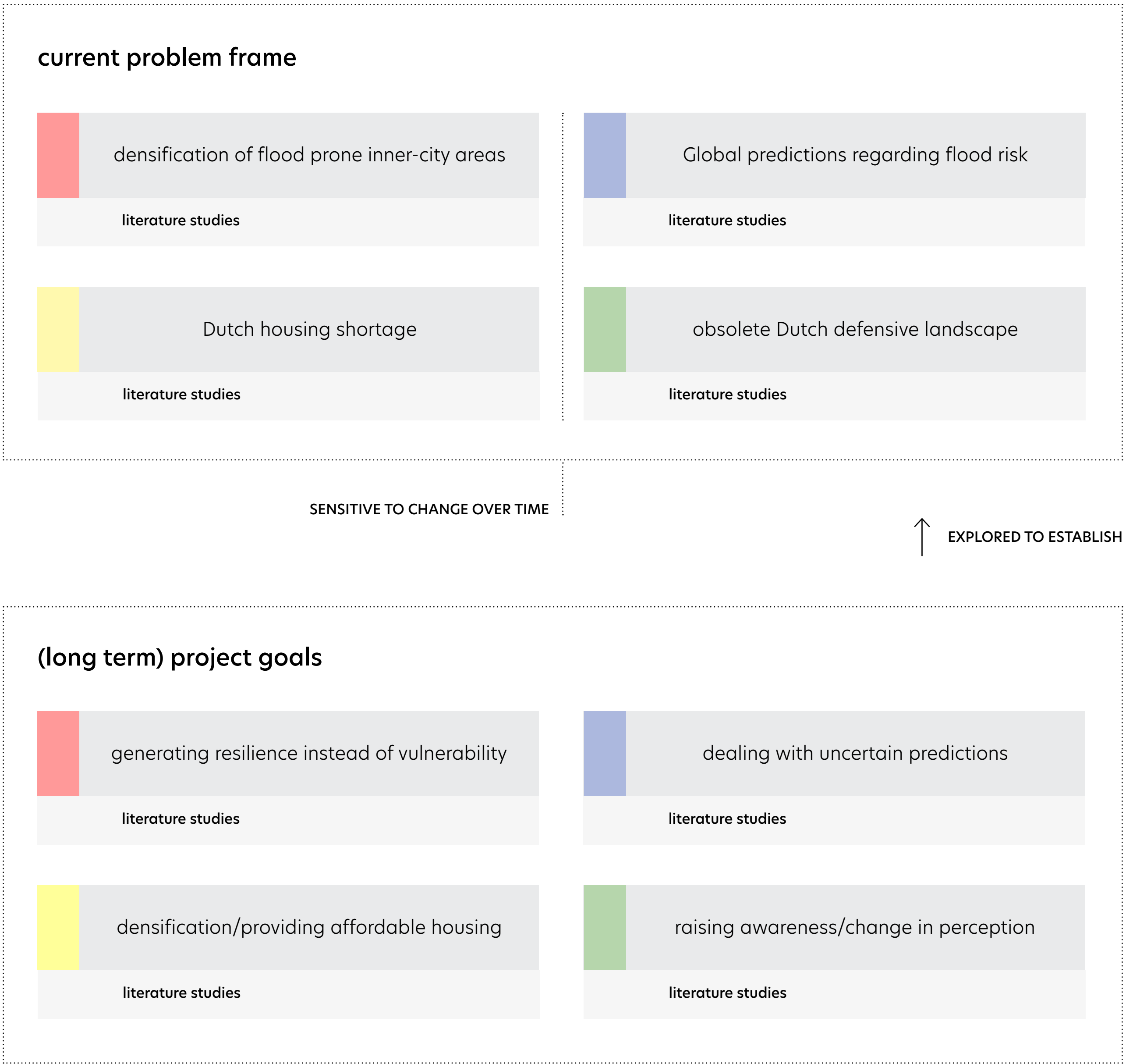
Project site

However dikes protect the low-lying parts of the city, sensitive areas can be identified in the urbanized outer dike area. Due to the low flow speeds, damage to the homes is often limited to the interiors on the ground floors. Still, chances are that such floods will occur in the near future will happen more often (Gemeente Rotterdam, 2014).

In order to generate flood resilience in the outer dike area the housing project will focus on densifying (former) ports which are currently being developed into dense residential areas (fig. 6.5) As the new building typology, of housing integrated with a multifunctional flood barrier, will make use of the currently mostly empty quays the project will be situated along these quays inside the outer dike area of Rotterdam (fig. 6.5). In order to give insight into how this new typology can be implemented in various densifying neighborhoods, each with their own characteristics, functions and needs, the masterplan of the project will focus on sketching an appropriate program for all 3 sites. From this large scale a single floating unit will be worked out in further detail. Most attention will go towards the detailed design as it will show how the project works socially as well as technically. Whereas the large scale masterplan will give a suggestion of how the detailed design could be implemented, extended and how it provides flood resilience on a bigger scale.

6.5 Outer dike area Rotterdam, The Netherlands, own edit from (Google Earth, 2021), height measurement (AHN, 2020)

Project goals



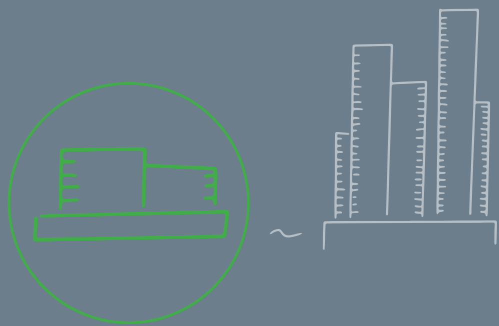
7.1 Overview of current problem frame and corresponding long term project goals, own illustration

Overview of concept design principles

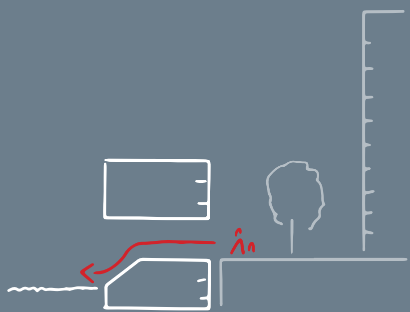
Urban Environment

Possibility of 'land reclamation' in densifying urban centers for flexible purposes

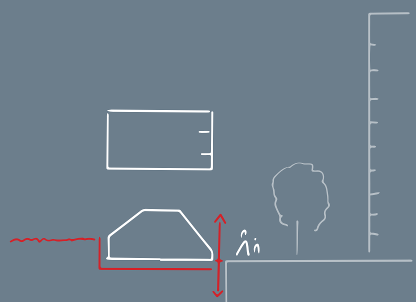
Self-sufficient amphibious structures in order to avoid complex connections with infrastructure on the mainland



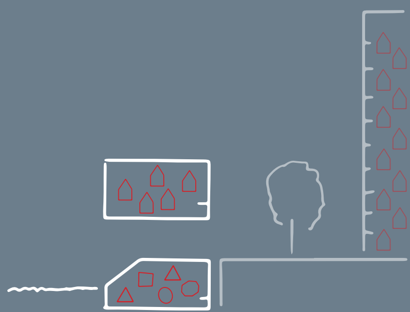
Amphibious structures that make the border between urban center and natural water accessible to the public ...



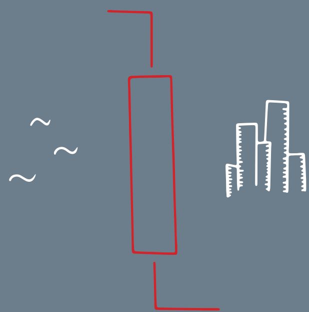
which in times of flooding of the river will also function as a flood barrier in order to protect the existing city center



Housing a residential and mixed use programm dependent on the needs and plans for the adjacent city center



Functioning as a link in a larger network of flood barriers and water management solutions along the river



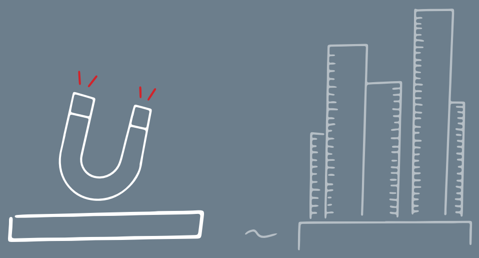
Outcome

An accessible waterfront which diversifies the existing area and allows for a flexible programm in the future

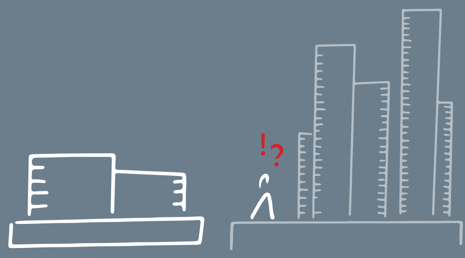
Structural and functional integration of the project in order to ensure both spatial optimisation and flood resilience

Symbolic

Housing public functions to continuously attract new visitors and add to the exististing programm

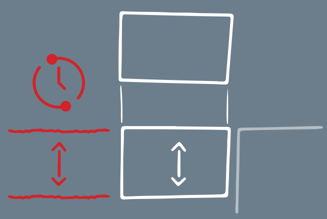


Tidal changes and high water levels having a direct effect on the program and accessibility, in turn raising awareness

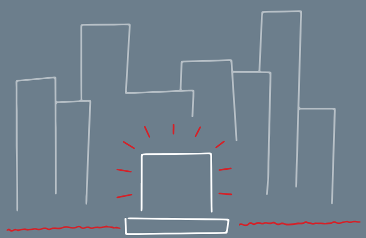


Providing a wide variety of year round activities for households and public audience to experience the benefits of living with water

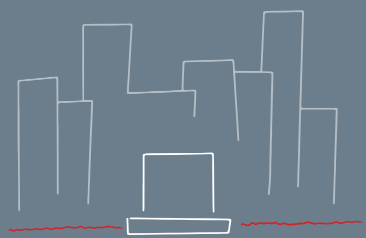
Apart from flooding, daily tides (approx. 2 cycles a day) provide continuous change in height during day and night



Natural water body provides impassable open space without the need for physical obstacles which obstruct the view towards the project



Ensuring lasting open space with minimal maintenance required around the project



Outcome

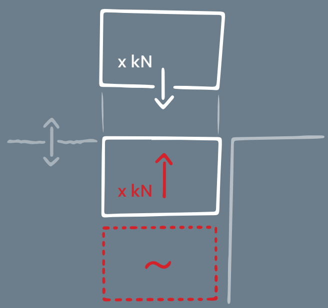
A new building typology which provides the opportunity for various households to live with water and remains seen by new visitors from outside

'Selling' the benefits of living with water to a wider public in order to raise awareness towards the rising flood risk

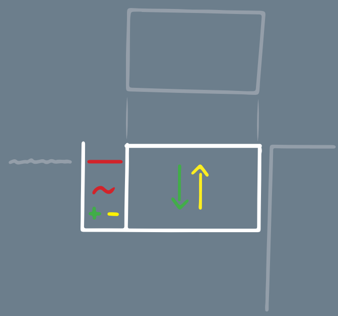
(instead of a cry for help)

Technical

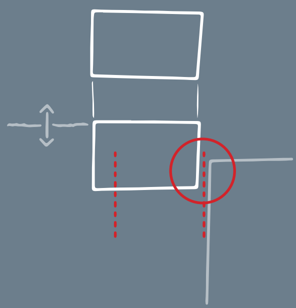
Water delivering the lifting force needed for the amphibious structure to rise into it's position as a flood barrier



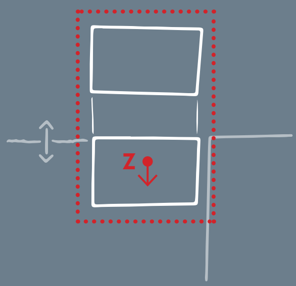
Water buffer to control floating height, provide stability and assure flexibility for future (weight) changes



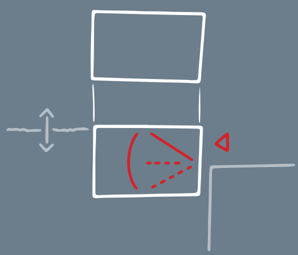
Steel anchor poles guiding the structure up and down while the gap between structure and quay is sealed



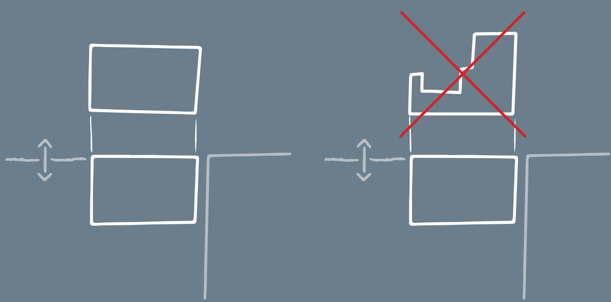
Focus on lowering the center of gravity to increase stability and therefore provide the possibility to build higher



Flexible stairs, ramps and plateau lifts moving along with the continuously changing height allowing continuous accessibility



Even weight distribution throughout the structure to provide balance and eliminate the need for compensation



Outcome

A mechanism, powered by water, allowing people to live in direct contact with the waterside while automatically able to transform into a flood barrier

Outcome

Providing density, structural flexibility and the capacity to anticipate to uncertain predictions regarding sea level rise on the long term

Sequel

In order to gain a deeper understanding and establish the right relationships between the illustrated findings and design principles, this chapter will look into which existing architectural research methods can be applied and combined in order to develop a site specific design proposal which contributes to achieving the long term goals.

Time-based approaches

Instead of what we need right now, the question should be about what is needed in the far-future (Hein et al., 2020b). While keeping in mind the transition requirements and a clear overview of recent scientific predictions, how can a flexible far-future solution be determined towards which can be navigated? To set the route for future developments, various time-based approaches can be applied. The interrelated use of forecasting, backtracking and backcasting (fig. 9.1) enables to find the best solutions from history, the present and the desirable future (van den Dobbelsteen et al., 2006).

Material study

The sustainable way of building involves the limited use of concrete which in The Netherlands is gradually more frequently being replaced by timber construction (Hulsman, 2021). In the case of the proposed hydraulic building typology this material preference gets an extra dimension as the weight of the construction will largely determine the volume. The starting point that comes with this distinction will be to use concrete if there is no other option, and to use wood where it is possible. To determine exactly where this distinction will be made material studies have to be carried out regarding buoyancy, weight, manufacturing and water resistance.

Regarding the construction the project will also utilize the 'open building' principles (fig. 9.2) examined within the Architectural Engineering graduation studio in order for the project to assure flexibility and durability.

Analysis of reference projects

In order to distill from relevant architectural reference projects (p. 41, fig. 10.1) usable design principles in a responsible way the following questions posed by professor Carola Hein should be kept in mind: How can we use interpretations of the past to propose certain design decisions which will shape the future built environment? How to avoid findings to be based solely on personal interpretation? (Hein, 2020a). Therefore in this analysis what will be important is to explore the thoughts behind the projects, to try and understand which reasons led to its creation. In this way not the form or function will be analyzed, but the resulting capabilities, that can be redeveloped and used again (Radman et al., 2020).

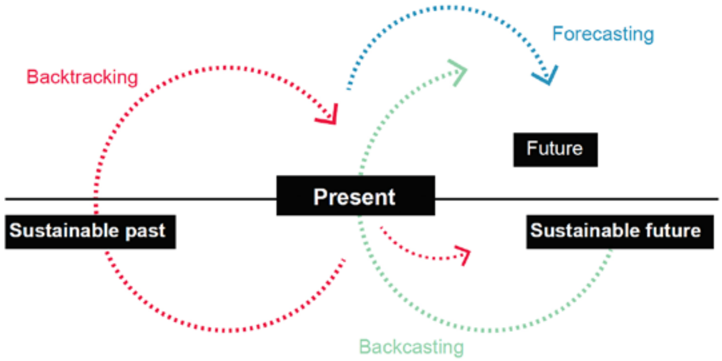
Research by design

As all architecture can be seen as a form of inquiry, which takes on different manifestations in different moments in time and space, during the process there is no clear distinction between the research and design part (Mejia et al., 2020). In order to produce new knowledge through the act of designing a back and forward process between the interconnected research and design is needed. In this way design principles resulting from research can be experimented with and tested in a site specific context. In turn, unforeseen obstacles emerging from the design process can be investigated further (Vos et al., 2013).

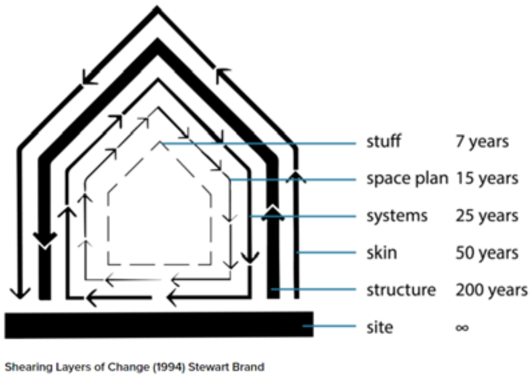
Posed by professor of design studies Nigel Cross the process consists of three, often unconsciously, interrelated aspects (fig. 9.3) that build on relevant first design principles as design guides in engineering (Cross, 2006). As the described problem goals are complex with no fixed solution criteria, the design process has to be transformed into a process of continuous feedback. The process needs to become reflective for it to be constantly adjusted and directed to build towards the desired future (Roggema, 2016).

As briefly explained by Roggema (Roggema, 2012, p. 84), the 3 methods can be described as:

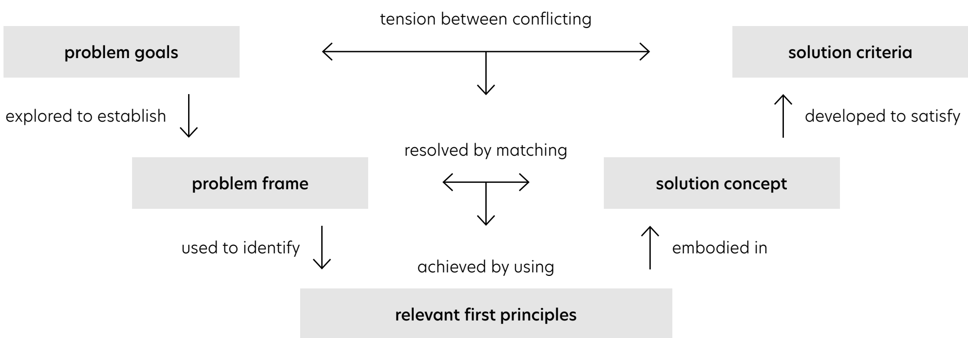
- Forecasting: *"Predicting the future starting from present".*
- Backcasting: *"To define the desired future, and derive from that the steps to be taken to realise that future".*
- Backtracking: *"Going back in history to find a sustainable equilibrium, which functions as an inspiration for defining a desired future system and derive from that the steps to realize it".*



9.1 raphic explanation of the forecasting, backcasting and backtracking methods, illustration by F. Lafleur edited from (van den Dobbelsteen et al., 2006), (Hooimeijer, 2016), explanation cited from (Roggema, 2012, p. 84)



9.2 Shearing layers of change (Brand, 1994)



9.3 Diagrammatic model of creative strategy, own illustration edited from (Cross, 2006)

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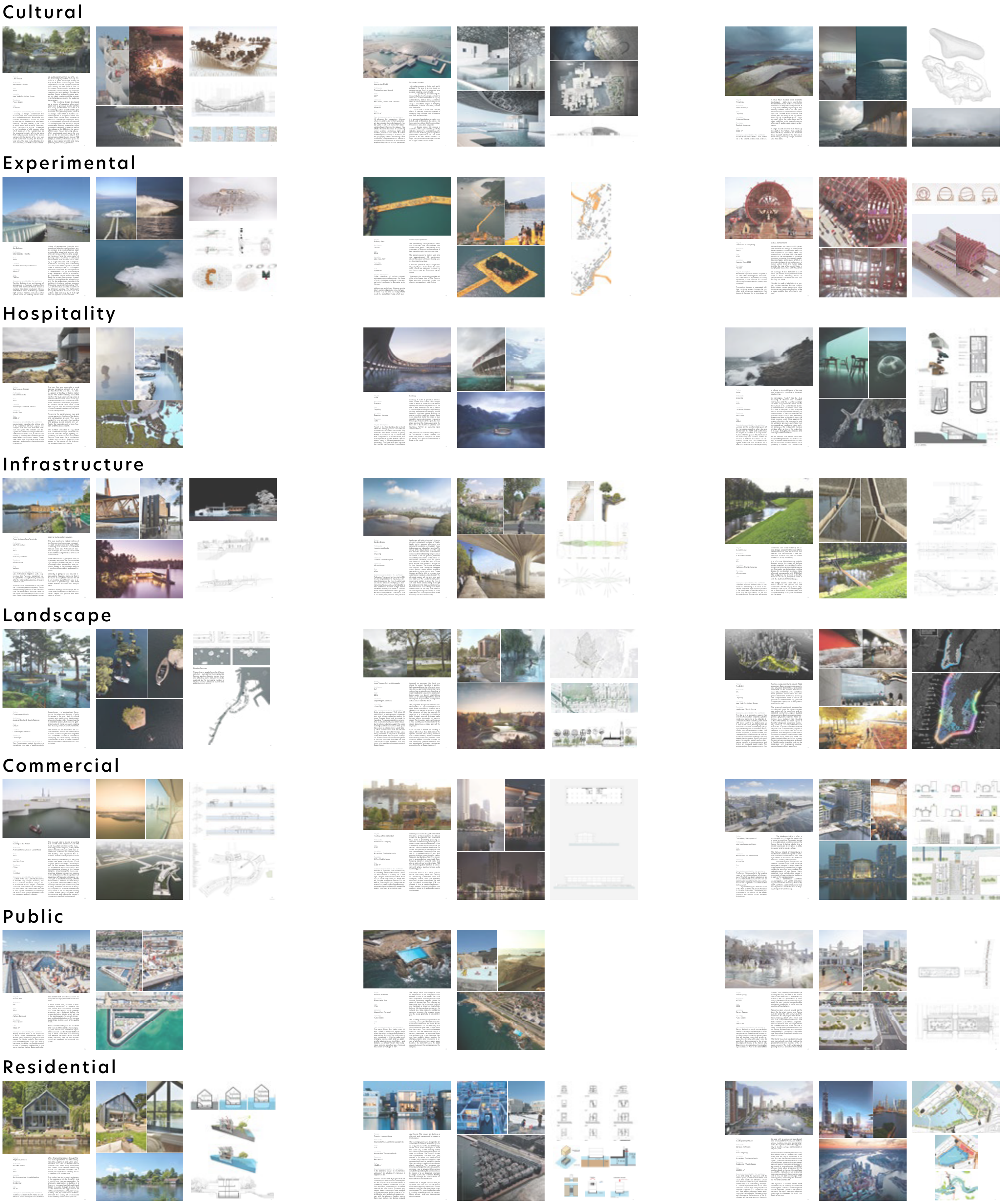

10.1 Curated collection of 24 contemporary (mostly) built architecture projects, on various scales and typologies, with a strong emphasis on enhancing life through the use of natural water features, own edit (Sources: p. 18)

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