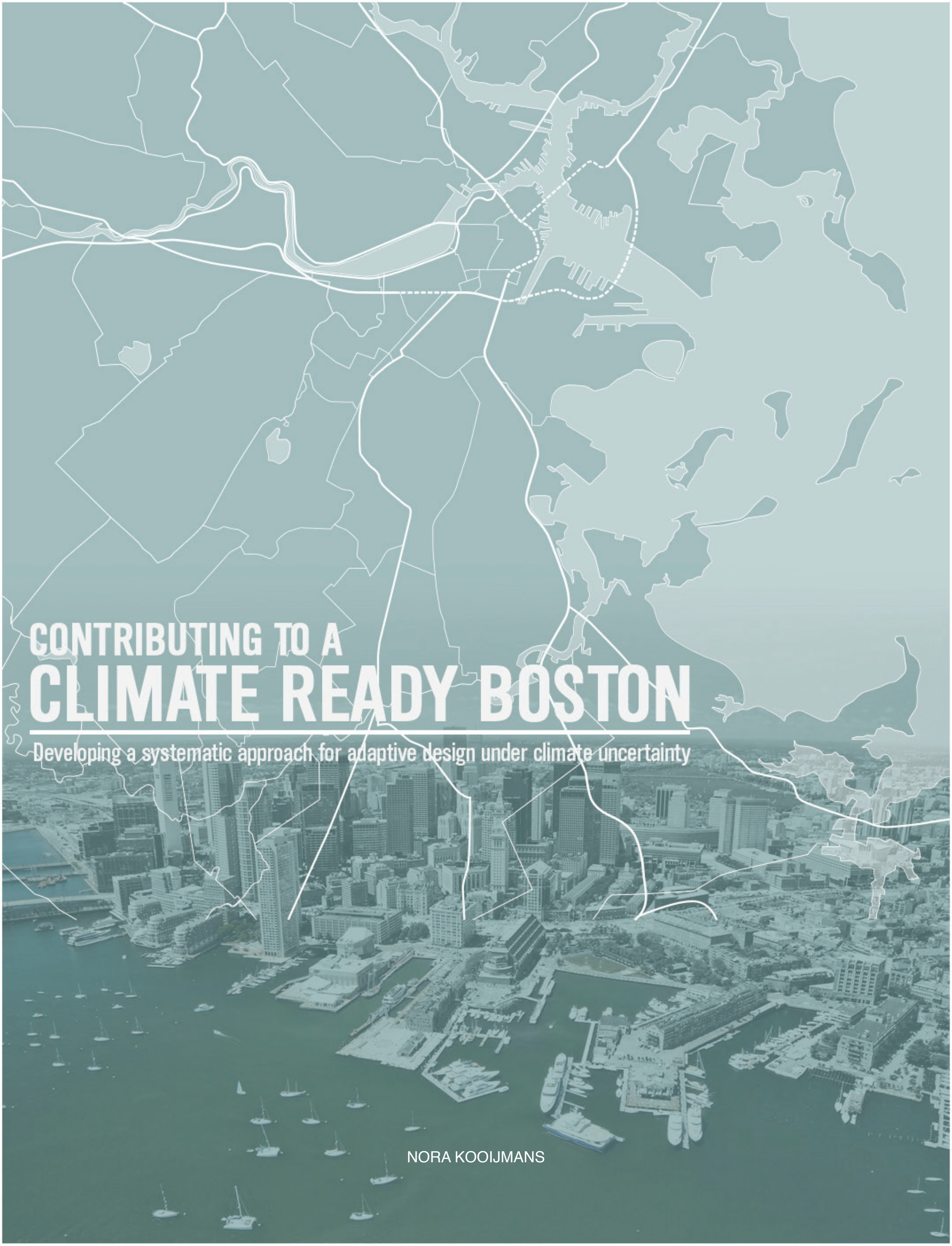

CONTRIBUTING TO A
CLIMATE READY BOSTON

Developing a systematic approach for adaptive design under climate uncertainty

NORA KOOIJMANS

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CLIMATE READY BOSTON

Developing a systematic approach for adaptive design under climate uncertainty

A thesis submitted in partial fulfillment
of the requirements for the degree of

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Developing a systematic approach for adaptive design under climate uncertainty

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ABSTRACT

Sea level rise is a new threat facing the coastal city of Boston (USA). Uncertainty around how much sea levels will rise, the effects on storm intensity and frequency, and what impacts these changes will have, make spatial adaptation in coastal cities a challenge that requires new practical and adaptive approaches. However, in landscape architecture, these approaches are currently lacking. This master thesis focuses on contributing to flood risk reduction in Boston by developing such an approach that helps create landscape architectural designs that account for significant uncertainties. The approach functions as a guide in the design process that can help landscape architects shift away from the ambition to achieve static, predefined outcomes and move towards creating adaptive designs. It was partly developed through review of existing planning approaches and draws upon the Pathways Mapping Tool that is turned into an iterative design tool that allows the designer to keep a broad view of all the possible adaptation options and it stimulates designers to look far into the future and think about long-term adaptation options. The design for Boston is used as a case study to test the approach. The case study resulted in an adaptive design for Boston that creates on-going development and improvement of the chosen area, providing it the ability to be responsive to its dynamic environment and adaptable to maintain its functionality. This way, the design accounts for uncertainty and validates the developed approach. The results indicate that the approach could be worthy of replication or broader dissemination, helping the wider global community of coastal cities in trying to address the challenge of adapting to an uncertain future climate.

Terms

Flood risk reduction, climate uncertainty, adaptive approaches, Climate Ready Boston, landscape architectural design

PREFACE

This thesis report is part of the MSc program Landscape Architecture at Wageningen University. During my master studies I became increasingly interested in climate change adaptation and I therefore strived to gain more expertise on the topics of climate, sustainability and climate responsive design. This thesis is a product of this attempt.

For my thesis I chose to focus on design for flood risk reduction in coastal areas, which led me to the research of the Climate Ready Boston initiative, which Wageningen University is a part of. For my research I was able to go to Boston and meet with professor Paul Kirshen from UMass Boston, who is one of the researchers for the Climate Ready Boston report on the city's vulnerability to climate change. My visit to Boston and the experiences and conversations there, made me realize even more that the city is in serious need of solutions, which increased my ambition to find these solutions and think of innovative ways to help the city to adapt to sea level rise and coastal hazards, and to create a spatial design that will make the area more resilient to flooding.

Although hazardous, coastal and climate processes are fascinating. Through this thesis I gained personal interest in the uncertainties that are inherent to these complex processes and the way people attempt to deal with them. Research into uncertainty created the awareness that these uncertainties are everywhere, which creates the need to understand and deal with them. The biggest lesson I learned is that uncertainty can not be taken as an excuse for inaction. Many examples, such as my own research, have demonstrated that, to quote Wang & de Neufville (2014): eventhough the future is unknown, the unknown is not unmanageable.

I would like to thank the people that helped me during my thesis:
First of all, I would like to thank my supervisor Prof. Dr. Adri van den Brink from Wageningen University for his time, wisdom and support. A special thanks goes out to Paul Kirshen from UMass Boston for welcoming me, for sharing his knowledge and guidance in (and outside of) Boston and for or offering me a warm environment full of inspiring people and events. I can't thank you enough.

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1 INTRODUCTION

(Hofmeester, n.d.)

1.1 COASTAL CITIES AT RISK

Figure 1.1
Worldmap with indications of coastal cities with more than one million inhabitants (Electrek, 2015)

With growing global concerns for sustainability and safety because of water-related problems such as coastal flooding, the performance of the landscape surrounding us is becoming a subject of major interest. It is no longer expected that the landscape is infallible and well-performing coastal protection systems are no longer taken for granted. It is becoming evident that we have designed our cities to be very vulnerable to flooding. Take for example Dutch cities like Amsterdam and Rotterdam that are situated below sea level. These cities face many flood risks that can cause damage and safety problems, since floods can take lives, destroy human properties, harm economies, harm the environment and make fertile land unusable. To prevent this, the Dutch have always been forced to take action and find the best ways to protect themselves. Of course, this is the reason why water management became a Dutch expertise and why the Dutch are still gaining more expertise everyday.

This water threat, however, isn't uniquely or primarily Dutch; besides Dutch cities such as Amsterdam and Rotterdam, water has also started posing a threat for Venice, London, Jakarta, Bangkok, Dhaka, Mumbai and many other world cities. It is believed that this threat will increase, because global climate change could lead to even more frequent and intense flooding in coastal areas (Hirabayashi et al., 2013). In the future, more high population-density coastal areas (see Figure 1.1) will need the knowledge, skill and expertise to be able to adapt to increased flooding because of climate change and population growth.

In this thesis, I focus on one of these coastal cities in danger: the city of Boston, United States. Citizens and the City Government of Boston are increasingly aware of their vulnerabilities. The intensity of the problem of urban flooding in Boston became clear in 2012 when Hurricane Sandy caused major damage to New York, New Jersey, Haiti, Jamaica, Cuba, Canada, Dominican Republic and the Bahamas. Boston was only hit by the tail-end of this superstorm plus the storm struck when the tide was low, and therefore it is said the city escaped from deep floods of several feet in low-lying areas of the city (Douglas et al., 2013).

In reaction to this wake-up call, an organization called Greenovate Boston published a report called Climate Ready Boston (Spector and Bamberger, 2013). This report presents the key findings of the Climate Preparedness Task Force, as directed by the then-Mayor Menino (February 5, 2013). The report draws attention to the effects of climate change and has highlighted the city's vulnerability to storm surge, intensified/increased rainfall and extreme heat. Besides this, the Bostonians were also alarmed by a report from 2013, entitled Future Flood Losses in Major Coastal Cities. The report, commissioned by the World

Bank, ranked Boston the eighth highest metropolitan area worldwide in expected annual economic losses ($237 million) due to coastal flooding (Hallegatte et al., 2013). These reports are proof of the fact that Boston is in serious need of solutions that help prepare it for the future.

To find solutions and to exchange knowledge, the City of Boston and the Netherlands agreed to work together more closely on sustainable urban development and water management. The project Climate Ready Boston is part of this collaboration. Climate Ready Boston is an initiative to develop resilient strategies, which will prepare the city of Boston for climate change. This master thesis is written to contribute to finding these strategies by taking the city of Boston as case study for my research. The general focus of my thesis is to find spatial solutions for flood risk reduction in coastal cities.

1.2 CASE SELECTION: WHY BOSTON?

There are several reasons why Boston (Figure 1.2) is an appropriate case study for doing research on the topic of design for flood risk reduction.

Boston as a prototype
As described by Swaffield in Van den Brink et al. (2017), case studies are often used in landscape architectural research, since they are very useful for the investigation of complex phenomena such as designed landscapes. I selected the case of Boston as a 'paradigmatic case'. Flyvbjerg (2006) explains that paradigmatic cases have prototypical or metaphorical value.

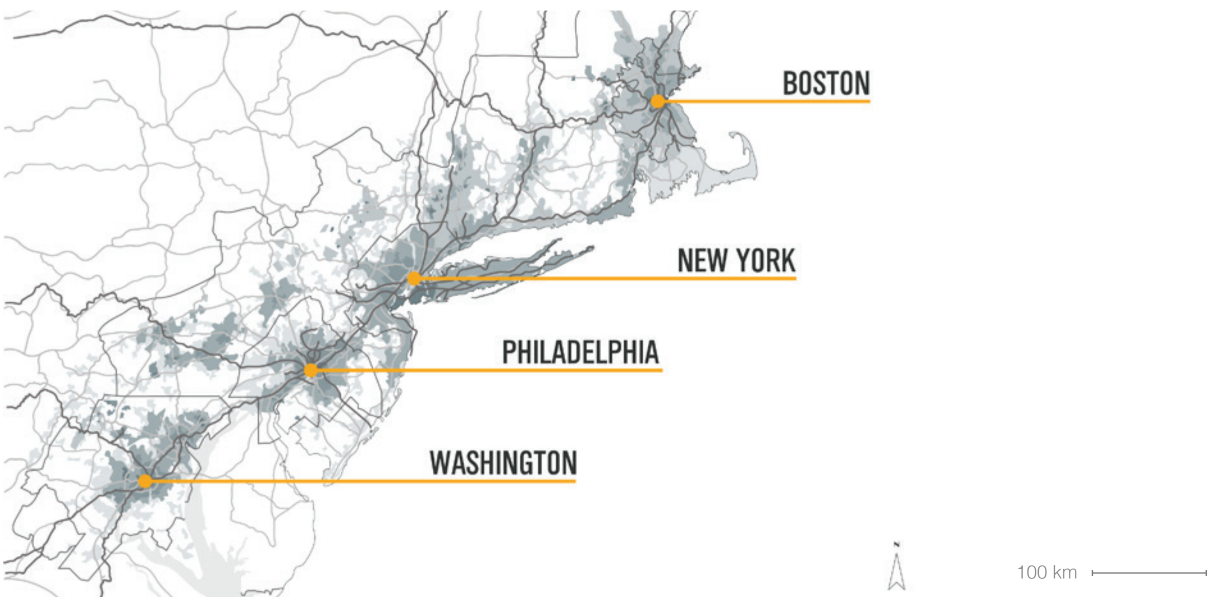


Figure 1.2
Boston as part of the agglomeration Washington, Philadelphia, New York City and Boston, USA

The case of Boston is a good prototype of a densely urbanized coastal city that has a high vulnerability and exposure to flood risk. In the future this exposure and vulnerability will increase, because the hazard increases and because these cities are under pressure to expand. Due to pressure of population growth and rising property prices, developers are densifiying urban areas along the coastline and building on lands previously left unoccupied because of their low-lying locations. New design for the future of the city is always bound by these past and current choices on configuration of the densely built city, which sometimes makes it difficult to adapt to future climate change. This expansion and densification represents a situation that has general relevance for many coastal cities. By selecting this prototypical case, the conclusions of the research may also be relevant for the design of other flood risk reduction plans in other densely built coastal cities.

A proactive city, open for change

Even though the city has only begun to study how to prepare for the rising tides in the past two decades, Boston can be called a U.S. leader in climate action. Since 2000, when the then-mayor Menino publicly and officially acknowledged human induced climate change and pledged to setting clean energy goals, the city has taken many initiatives to mitigate and reduce its greenhouse gases (GHG) and made a commitment of attempting to be emission free by 2050. The city has also put quite a lot funding in climate research, the development of adaptation strategies and it has set up a few smaller-scale pilot projects within the city that help improve flood resilience on these locations and simultaneously serve as case studies (P. Kirshen, personal communication, October 26, 2017).

The problem however is that although Boston is ahead of the curve in terms of studying the problem and creating policy, as it hosts many universities that employ some of the leading experts on sea-level rise and storms, no substantial actions have been taken. Similar to the world scale, this could be caused by a lack of tools to take action. Another problem is that the city is mostly left to its own resources. Even though the city gets support and directives from the state level, the state doesn't have a lot of budget to spend on climate action to financially support its cities and counties (P. Kirshen, personal communication, October 26, 2017). Boston also cannot rely on (financial) support from the federal government, since current president Donald Trump, has stopped all federal climate programs and policies. Most of the climate action funding therefore comes from the city level and for example grants from foundations. Due to federal inaction, the responsibility is pushed to the local level and the city of Boston is forced to come up with its own solutions (P. Kirshen, personal communication, October 26, 2017). But since the city is well aware of the risks it is facing, Boston continues to move forward, regardless of what is going on at the national level. These are reasons why Boston would benefit from new solutions that will help them prepare for the future.

1.3 RESEARCH INTRODUCTION

1.3.1 PROBLEM STATEMENT

The problem with preparing Boston for current and future flood risk (and climate change in general) is that climate change comes with a high degree of uncertainty. This uncertainty is caused by the complexity of climate change processes, which make the future climate hard to predict. Due to uncertainty, design for flood risk reduction in flood-prone landscapes is becoming a challenge for landscape architects, because they no longer know what should be accounted for in their designs in terms of the future climate. In the worst case uncertainty can even cause inaction. Researchers observe that there are no substantial rates of implementation of adaptation measures compared to the substantial efforts and investments in adaptation science (Wise et al, 2014). This means that there is a gap between adaptation science and adaptation implementation. This is obviously an alarming observation in a world where the risks of climate change are increasing. While there might be multiple explanations for this observation, I argue that progress in the development of informed adaptation responses to climate change is likely partially hampered because designers are ill-equipped to create designs that account for climate uncertainty. In other words, there is an underdevelopment or lack of appropriate approaches for design under climate uncertainty.

Traditionally, designers often develop static plans using a single, 'most likely' future (Haasnoot et al., 2013). However, the complex nature of climate change processes limits the ability of researchers to explain and predict these processes (Moroni, 2015). Even though current climate models can help predict likely futures and it can be expected that scientists will improve in climate modeling in the future, climate models have divergent outcomes, meaning they never result in a single, most likely future. A design or plan that is based on a single future scenario is therefore likely to fail or fall short. Therefore designers should not only focus on climate models, but also on developing more innovative approaches for design under climate uncertainty, in order to improve spatial development and adjust current practices to better adapt to climate change and its uncertainties.

I argue that without the appropriate approaches in a design context, it will become difficult or impossible to adequately prepare for flooding in the future. Hence, the development of new design approaches for design under climate uncertainty that allow for more adaptive designs is becoming a relevant topic.

1.3.2 PURPOSE STATEMENT

The lack of appropriate approaches for design under uncertainty can be seen as a knowledge gap among landscape architects. Closing this knowledge gap by developing new approaches would contribute to landscape architectural research on flood risk reduction and provides insights that can be used in practice and it could simultaneously serve as a tool to fulfill my design purpose.

Design purpose
The purpose of this thesis is to create a spatial design that serves as a proposal for future developments of the landscape in Boston. The design should contribute to flood risk reduction and develop the city's ability to adapt to coastal flooding caused by climate change. I want to contribute to the welfare of the city, not only by preventing potential damages and helping the city to cope with the uncertain consequences of climate change, but also by taking advantage of opportunities that are presented through new development in the area. This could lead to collateral benefits for different communities in Boston.

Design assignment
My design assignment is to create an adaptive design for long-term flood protection for one of Boston's flood-prone areas that need to be spatially adapted in order to protect it from flooding. The design should deal with uncertainty on future flood scenarios, allowing the city to adapt to (unforeseen) changing circumstances over time.

Research purpose
In order to create such a design, I first need to investigate how uncertainty can be accounted for in the landscape architectural design of densely built coastal cities. This research can be used to develop an approach that assists with design under climate uncertainty. A well-structured, systematic approach for design under uncertainty in coastal cities would be a useful tool in landscape architecture because it will allow designers guidance in their complex challenges and it might create more efficiency in the design process, because designers won't constantly have to reinvent the wheel. By proposing such a systematic approach and investigating it further by testing it on a case study in Boston, I can create an informed design.

Ultimately, I aim to contribute to helping the wider global community of coastal cities in trying to address the challenge of adapting to an uncertain future climate, which will hopefully lead to more climate adaptation action.

1.3.3 DESIGN ASSIGNMENT AND RESEARCH QUESTIONS

To meet the purposes of this thesis, I have formulated the following questions. The first question is the main question that overarches the entire research. Since this is a design thesis, the main question is design oriented and incorporates the design assignment:

What landscape architectural design can be created, by means of an adaptive, systematic approach for spatial adaptation that will contribute to flood risk reduction in Boston?

Because I want to create the design with the help of the mentioned approach, I first need to investigate the adaptive systematic approach for design under uncertainty as a design tool. Therefore, my main research question is:

What is an adaptive, systematic approach for landscape architectural design under uncertainty?

In order to investigate and develop such an approach, I first need to research and elaborate on a few aspects separately. Therefore I have also stated a few sub questions. The first sub question helps me explain the concept of adaptiveness, by explaining how it is defined in the literature and how it is applied in landscape practice. By having a clear idea of what adaptiveness is (and could be), I can start answering the next sub question that focuses on comparing different approaches in the literature that are deemed adaptive, in order to find useful components to a new approach. When a sequence of useful components is created, I can answer what an adaptive systematic approach for design under uncertainty is. Before I can test this approach to the case study on Boston, I will first need to acquire site-specific data and insights on the vulnerability of the urban landscape of Boston. The sub research questions are:

What is adaptiveness and how is this concept operationalized in landscape architectural practice regarding flood risk reduction?

What are the components of an adaptive systematic approach for landscape architectural design under uncertainty?

What are the specifics of the Bostonian urban landscape in relation to its vulnerability to flood risk?

Once these questions are answered, I can apply the developed approach to the case study in order to create a design that will contribute to flood risk reduction in Boston. By doing this I provide an answer to the main research question. An overview of the questions is provided in Figure 1.3.

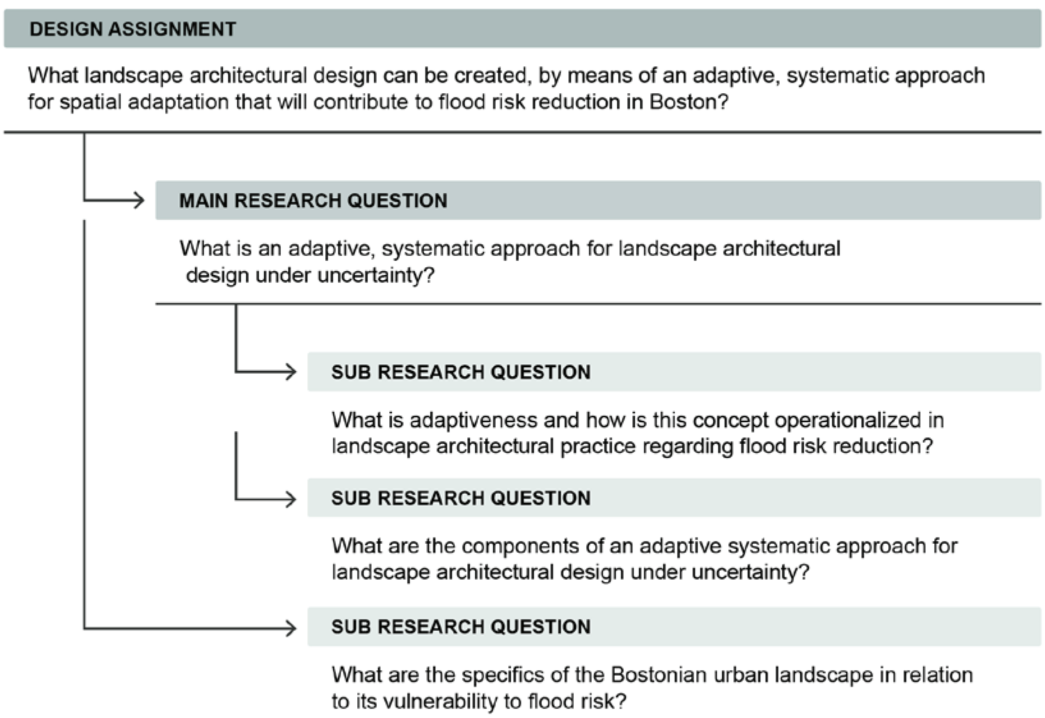


Figure 1.3
An overview of the research questions

1.4 THESIS OUTLINE

Now that the problem, purposes and questions that underlie my research and design on the topic of design for flood risk reduction are described, it is important to understand a few key concepts and theories, and the perspective from which this thesis is written. Chapter 2 therefore provides an explanation of flooding and flood risk, an introduction to complexity theory on cities, the concept of uncertainty and what this means in the context of landscape architectural design and research. This part is focused on explaining why new approaches in landscape architecture are needed. Next, I explain the methods that are used to determine what data to collect, and why and how the data are collected in order to answer my main research questions.

After explaining why new approaches are needed and what is needed to develop a new systematic approach for adaptive design under climate uncertainty, Chapter 3 provides the description of the developed approach for spatial adaptation in coastal cities that can serve as a tool to assist landscape architectural design under uncertainty. The approach is based on the concept of adaptiveness, which is first explained in this chapter. This is followed by an exploration of how adaptiveness is used in practice, and the conclusions of a review of adaptive approaches in the literature. Finally, the stepwise approach, called a ‘framework for flood adaptation under uncertainty’ is presented.

Chapter 4 presents the first part of the case study, where the first three steps of the approach are tested on the city of Boston. This part focuses on closing knowledge gaps by identifying current and future climate change vulnerabilities and understanding the landscape characteristics and opportunities of a specific place.

This is then followed by the second part of the case study, which is presented in Chapter 5. This part has a more solution-oriented focus and consists of the five steps of the developed approach that finally lead to a spatial design that contributes to the improvement of the resilience regarding coastal flooding in the city of Boston. The design that I created for this case study, represents the long-term vision, consisting of a sequence of short-term actions and long-term options for the future. I finish this chapter with an elaborate explanation and visualization of the outcomes of the case study.

In Chapter 6, I give an answer to the research questions and I explain the essential parts of my design. I discuss the main contributions of my thesis and the methods for the development and the application of the developed stepwise approach (the case study). I finish the chapter with a reflection and some recommendations together with possible topics for future research.

2 CONCEPTS & METHODS

In this chapter I first describe a few essential concepts. These concepts form a conceptual framework for adaptation under uncertainty in the context of climate change. The conceptual framework explains why it is necessary to develop new systematic approaches for adaptive design under climate uncertainty and it serves as a scientific basis for my thesis, which I will continue to build on during the subsequent chapters. The concepts are followed by the explanation of the research methods that were used to answer the stated research questions. This method-section explains what is needed to develop a new systematic approach for adaptive design under climate uncertainty and what is needed to create a design with this developed approach.

(Lischetzki, n.d.)

2.1 FLOOD RISK REDUCTION

Because the purpose of this thesis is to create a design for flood risk reduction in Boston, I first researched the concepts of floods and flood risk.

A definition of flood is when water overflows or inundates land that is normally dry. Flooding is caused by extreme water levels as a result of (1) storm events, (2) extreme precipitation and/or (3) high river discharge (Kron, 2005). In an urban setting, flooding in combination with underperformance of flood defense measures, underperformance (or overwhelming) of the urban drainage system, and impermeable or saturated surfaces, can cause problems.

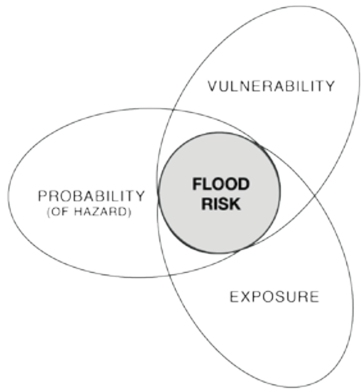


Figure 2.1
Overview of the theory on flood risk
(derived from: IPCC, 2012)

The city of Boston is prone to two types of floods: coastal and pluvial floods. Coastal floods in Boston are caused by high tides and storm surges that cause high water levels in the ocean. We speak of storm surge when a large-scale increase of water takes place, when storm winds blow water from the ocean towards the land. Storm surge can be seen as extra sea level rise on top of the baseline sea level. Storm surge-driven floods are a huge threat to coastal communities such as Boston, especially when a peak storm surge coincides with a high tide.

Pluvial floods are caused by precipitation. When large amounts of rainwater fall in land and cannot be stored or drained, it can lead to flash flooding. For Boston, the factor of greatest concern is the probability of occurrence of a combination of these two types of flood (BRAG, 2016).

2.1.1 FLOOD RISK

In literature about flooding, many terms are being used, such as flood adaptation, flood preparedness, flood proofing, increasing flood resilience, but they all mean: reducing flood risk. Flood risk can be defined as the combination of three components: the probability of hazard (the frequency and intensity of physical flood events), exposure (the population and assets located in flood-prone areas) and vulnerability (the susceptibility of the exposed elements to the hazard) (Muis et al., 2015; IPCC, 2012). This is conceptualized in Figure 2.1.

In general, flood risk reduction aims to prevent both direct and indirect damages and losses from floods. The direct damages are loss of life and the destruction of physical and human capital (e.g. buildings, cars, infrastructure) and the indirect damages and losses are, for example, production losses due to interruption of economic processes in and outside the affected area (Koks et al., 2015). To reduce flood risk, either the probability of hazard, the exposure to flooding and/or the vulnerability to flooding need to be reduced. In the following sections I explore different factors that can influence these components of flood risk.

2.1.2 REDUCING THE PROBABILITY OF HAZARD

The probability of natural flood hazard is influenced by (anthropogenic) climate change, because climate change can have an effect on sea level rise and increased precipitation patterns. As the average global temperature rises, IPCC (2013) models projected that global sea levels are likely to rise between 0.26 m and 0.98 m by 2100 (relative to 1986–2005). However, more recent research (e.g. DeConto and Pollard, 2016) indicates that sea levels could rise nearly twice as much as previously predicted by the IPCC. Sea level rise (SLR) is caused by two known processes: (1) general increase of the amount of water in the ocean and (2) the expansion of the volume of the water in the ocean (BRAG, 2016). The latter cause is called thermal expansion of the ocean, which is a process that occurs when water heats up. The other cause, the increase in amount of water, occurs when land ice (from glaciers and ice sheets) melts and runs off into to Earth's oceans (Pfeffer, 2011). Rising sea levels will increase tidal range, wave energy, and tidal inundation, which will result in increased erosion of shorelines (including existing or planned coastal engineering works) (BRAG, 2016) and increased height of storm surges and therefore increase coastal flooding frequencies (Tebaldi et al., 2012). Furthermore, climate change will also increase the average precipitation. Increased temperatures contribute to a more active water cycle. This means faster and greater evaporation and precipitation. In other words, a larger proportion of rain will fall in a shorter amount of time (Graham et al., 2010).

It is obvious that these changes in climate increase the likelihood of flood-related problems in urban areas. And therefore the flood risk to populations and economies of these areas also increases. Güneralp et al. (2015) mention that by 2030, 40% (195,000 km2) of the global urban land is projected to be located in high-frequency flood zones. That is a 10% increase in land compared to the year 2000.

The only way human induced climate change and these hazards that are projected for the future can be reduced, is indirectly through reducing emissions of greenhouse gases (IPCC, 2013). The process of reducing emissions of greenhouse gases is called mitigation. Emissions can be reduced by reducing the use of fossil fuels, which can be done by reducing total energy use and increasing renewable energy sources.

2.1.3 REDUCING VULNERABILITY AND EXPOSURE

Vulnerability and exposure to floods are largely influenced by the spatial configuration of a city. By deciding to build in flood-prone areas, the exposure of the city is immediately increased. This indicates that it matters a lot where building development takes place.

Besides the location, it also matters what is being developed in the city and how it is developed, because that influences the vulnerability of the city. Therefore the location of assets is important, as well as the way the assets are built. In the case of an already developed area, the way to reduce vulnerability and exposure is through adaptation of the built environment.

In the context of climate change, it is important to already start adapting to future scenarios beforehand, in order to prevent negative impacts of climate change in the future. Therefore the kind of adaption referred to in this thesis is called anticipatory adaptation, which is also referred to as proactive adaptation. Adaptation to climate change is defined as *"adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"* (IPCC, 2007).

Spatial adaptation will lower a city's vulnerability and exposure, which will therefore reduce flood risk. By adding this direct effect and the indirect effect of mitigation regarding flood risk to the concept of flood risk, the conceptualization derived from IPCC is further expanded, as is shown in Figure 2.2. The dashed arrow in the top of the figure shows that flood events also have an impact on spatial adaptation, when action is taken after the threat of a big flood event. As can be seen, a circular process is created through the dashed arrow on the bottom of Figure 2.2. It shows that human action and spatial adaptation and the amount of green house gasses that are produced with that, also have an influence on anthropogenic climate change. In other words, the dashed arrows in the figure now show that climate change and spatial adaptation are regarded as processes that can potentiate each other.

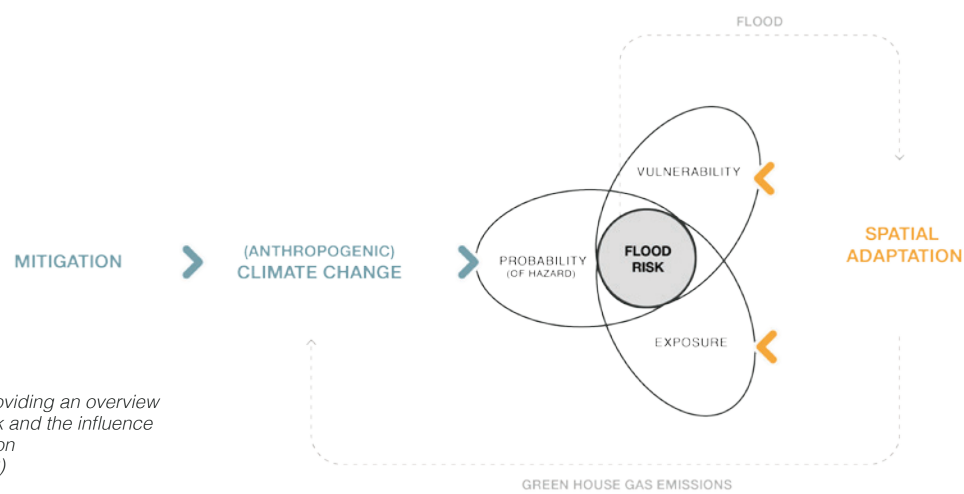


Figure 2.2
The conceptualization, providing an overview of the concept of flood risk and the influence of mitigation and adaptation (derived from: IPCC, 2012)

The conceptualization explains theory on the factors that influence flood risk. It can be concluded that, in order to reduce flood risk in cities such as Boston, the best opportunity is to reduce the exposure and the vulnerability, as these are the two factors which humans, to a certain extent, have more direct influence on (through adaptation). In contrary to the probability of hazard, which can only be influenced indirectly through mitigation efforts. Furthermore, the conceptualization helps to identify important research variables (vulnerability, exposure and adaptation), and it clarifies relationships among the variables, but it is also a very simplified picture of a reality that is much more complex. Looking at the conceptual image from a designer's perspective raises a lot of questions, such as: *What spatial adaptation measures will reduce vulnerability and exposure? How can a city be adapted to unknown future risks?*

These questions show the need for a good understanding of cities and their complexity. The following sections introduce the concepts of complexity and uncertainty that are used as a basis for this thesis.

2.2 COMPLEXITY

Designing for flood risk reduction in a city such as Boston entails dealing with complexity and uncertainty. With this section I explain the importance of making sense of the city through a complexity lens to understand the challenge that is presented to planners and landscape architects.

2.2.1 THE COMPLEXITY OF CITIES

Complexity theory is a young science that covers a wide range of natural, social and economic phenomena. From a complexity perspective in science, phenomena are considered to develop non-linearly, meaning that changes can occur unexpectedly and can have a disproportionate effect over time and space (Rauws, 2015). These phenomena are also present in the landscape, as there are many dynamic circumstances and factors that have an influence on landscape.
In the literature, cities are viewed as part of multi-layered landscapes in which various sub and supra-systems coevolve in response to changes (Liljenström and Svedin, 2005). This kind of complexity that cities posses, are similar to that of ecosystems (Portugali et al., 2012). Therefore in this thesis, I want to emphasize that cities should be seen as complex (eco)systems. Rauws en de Roo (2016, p.2) describe cities as *"open systems, which evolve through a changeable and interrelated mix of processes"*. Rauws (2015) mentions that these processes of change often evolve non-linearly, which can lead to unforeseen effects and events, because in non-linear processes of change, the cause-effect relations can be disproportional. This means that a small change within a city can have a big effect. For example, triggers such as shifts in policy and citizens' initiatives in a city can happen on a small scale, but have impact on a global level, maybe causing rising sea-levels and economic crises (Rauws & De Roo, 2016). Moroni (2015) mentions the importance of this understanding, and concludes:

"Taking the marked complexity of the city seriously would entail profound revision of not only the way in which we interpret it but also of how we intervene in its regulation".

In other words, Moroni argues that the way we see the city changes the way we treat it. In this thesis I would argue that it would not only change how we intervene in its regulation but also the way in which we design it. The next sections explain the traditional approach to design of the city and introduce the reason why a complexity perspective demands a change in the way we approach design.

2.2.2 LANDSCAPE ARCHITECTURE IN COMPLEX SYSTEMS

Landscape architects are responsible for the task of designing within complex systems. Climate change is an example of a large process that designers and planners have to deal with and incorporate into their plans. Since the landscape is very sensitive to climate change, it is a process that is predicted to have huge negative effects. This means that there is a lot at stake for densely populated cities, and therefore a huge task is presented for engineers, designers, planners and decision makers to come up with solutions for adaptation. Climate change itself is already a complex phenomenon, but trying to identify the most promising set of adaptation strategies is additionally complex. Especially because landscape architecture comes with long-term commitments; once the design is realized, the new configuration of the landscape will most likely be there for many years. This means that cities have to live with the consequences of the choices made in the design process for decades. For this reason, it is useful to be able to forecast climate change on the long-term.

The traditional way

To create designs based on forecasts, landscape architects often combine known climate conditions with well-formulated objectives, statistical analyses and algorithmic calculations (Hallegatte, 2009). Designers and planners are traditionally used to using a single 'most likely' future to develop (more or less) static, 'optimal' plans (Haasnoot et al., 2013). In other words, the design is created to suit the most probable forecasted scenario.

In this traditional way, design presupposes the ability of a designer to control all parts of the design (Portugali et al., 2012). Commissioners often expect landscape architects to be able to respond to both foreseen and unforeseen planning and design issues by embracing and stimulating the effects that are deemed positive and mitigating those effects that are perceived as negative (Rauws, 2015). According to Portugali et al. (2012) there are three main expectations. Firstly, it is expected that landscape architects are able to understand and know the city (the system) as a whole. Secondly, designers are expected to know what the effects of their designed interventions will be, and thirdly, they are expected to draw conclusions on what the optimal future state of the system would be.

However, in complex systems and because of complex processes behind climate change, these things designers are expected to know, become uncertain. Substantial uncertainty caused by complexity of climate change therefore causes these current 'predict-then-adapt' (Gersonius et al., 2013) approaches to become more difficult to apply.

2.3 UNCERTAINTY

Rapid climate change makes it harder to rely on statistics (e.g. average annual temperature and precipitation), because researchers can no longer rely on the averages from the past couple of years to predict the future conditions. That is why they have now shifted towards climate models instead of statistics in order to gather data and predictions for the future (Hallegatte, 2009). But, as Hallegatte (2009, p.241) mentions, uncertainty is a problem that makes it *"impossible to provide the equivalent of historical climate data for future climates"*, since uncertainty makes it hard to apply probabilities, and therefore researchers cannot use probabilities in models that forecast a likely future. Designers can use climate model outputs as input for their design, but the problem is that the output is never completely reliable, because uncertainty causes us to make estimates of data and the complex system, which might be different from reality. This is shown in Figure 2.3.

These estimates also cause climate forecast models

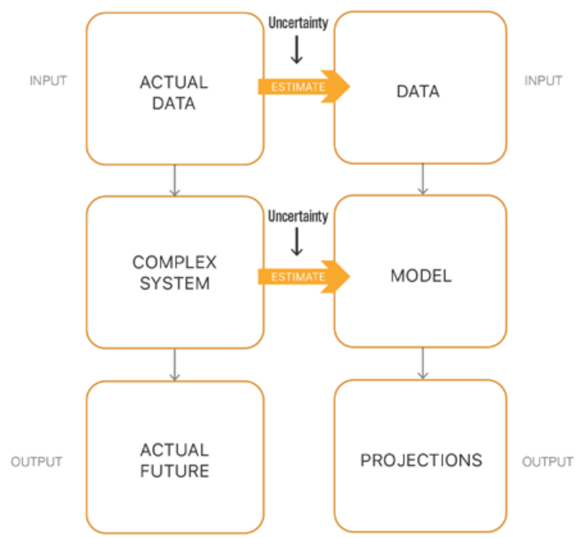


Figure 2.3
Image showing that uncertainty causes researchers to make estimates of data and the complex system to use as input for models. These estimates are used to create projections of the future situation

to have wide projection ranges. Depending on the variables included in the model and the data that are used as input, different climate models on the same topic can have very divergent outputs (Hallegatte, 2009). This is because the farther into the future, the more vulnerable the models become to uncertainty. This means that models cannot predict the future with a high level of accuracy and as a result, designers hardly gain any insight into the potential impact of climate change on a specific location, which complicates decision-making in the design process. A conceptual representation of uncertainty is made visible in Figure 2.4, which shows that predictions become less accurate the farther they reach forward in time.

2.3.1 CAUSES FOR CLIMATE UNCERTAINTY

Researchers are often able to explain principles but unable to predict in detail what will happen. An example Moroni (2015, p 251-252) gives for this is the Darwinian theory of evolution by natural selection.

"This theory is of great value for explaining how species evolution works, but it cannot be used to predict the specific direction and outcomes of this kind of evolution.(...) In other words, we are able to anticipate events as to their typical features, but we cannot fill in the innumerable, specific details beforehand."

The same counts for climate change; it is certain that climate change is happening and driven by human factors (IPCC, 2014), but its complex nature makes it hard to predict specific details such as what the impacts will be and when and where they might happen. Interdependencies of future climate policies, greenhouse gas emissions, complex climate and socioeconomic feedback loops, and unknown tipping points and our inability to predict them, make it even more complicated to project future outcomes (Tye and Altamirano, 2017).

Moroni (2015) explains that uncertainty is not caused by a lack of knowledge or information, but rather by the inherent features of our mind and the world. In other words by Portugali et al. (2012, p.213), complex systems are unpredictable, *"not because of lack of data, but because of their very nature"*. Landscape architects therefore have to accept that there is always a gap between the desired, the intended and the actual results of their design, and this gap cannot be removed by improved knowledge or information.

Besides that, human capabilities in dealing with complex issues are also imperfect. Interpretation of models is a process that involves decisions and values and is therefore subjective instead of a mechanical process (Preiser, 2016). This means that there is a normative dimension to the use of models, which also hampers accurate prediction for the future.

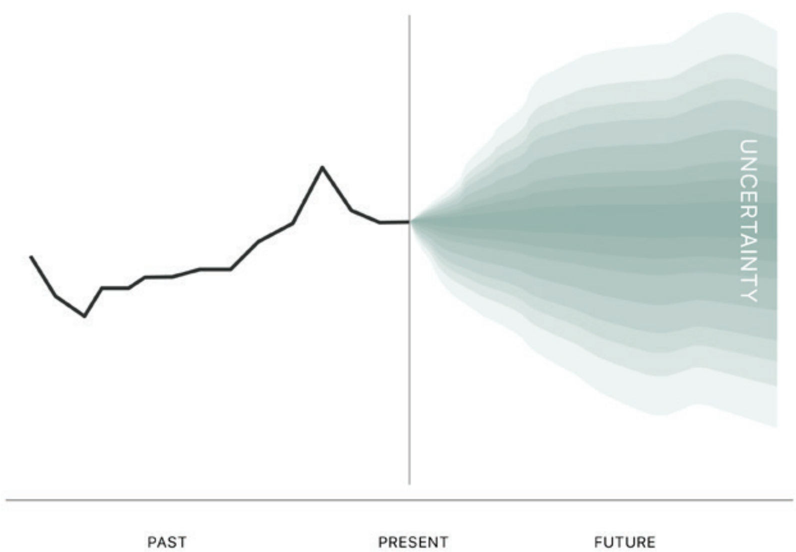


Figure 2.4
Representation of uncertainty: the further into the future, the wider the projected ranges (based on: River Plate Projects, 2016)

2.3.2 DESIGN PARALYSIS?

The many limitations and uncertainties inherent in climate predictions challenge the ability of designers to design appropriately for the future, as it makes designers ill-equipped to incorporate climate information into their design.

Within the field of landscape architecture, situations of uncertainty create contradiction, because on the one hand there is the will to create a predetermined future configuration that is calculated, tested and gives certainty, but on the other hand there is the acknowledgement that complex systems *"do not allow precise prediction of specific events or outcomes of interventions"* (Innes and Booher, 2010, p.31).

In the context of climate change, this contradiction also depicts the threat that comes with creating a static design that is completely based on predictions made by models. If a design is realized based on the output of a climate model and this output turns out be incorrect, there is big chance that the altered landscape will 'mismatch' the situation in reality, which can cause big problems in the future, because the landscape will have to be re-altered or in the worst case: a lock-in situation will occur. Landscape architects should therefore not seek to achieve a final ideal state. From a complexity perspective on cities, creating a static urban design is even paradoxical (Ahern, 2011). How can such a design be sustainable in a dynamic context where unpredictability and changing processes are always present?

2.3.3 THE NEED TO DEAL WITH UNCERTAINTY

At this point, it may seem as if I am dismissing the importance of modeling of complex systems or that I am arguing against landscape architects relying on (climate) models. This, however, is not the case. What I want to argue is that even though these models are useful for reduction of uncertainty, they can never completely take away all uncertainties.

To deal with climate change uncertainty, designers have to understand that there are two kinds of uncertainty and that both have to be taken into account in the design process. They are called epistemic uncertainty and ontic uncertainty (Walker et al., 2003).

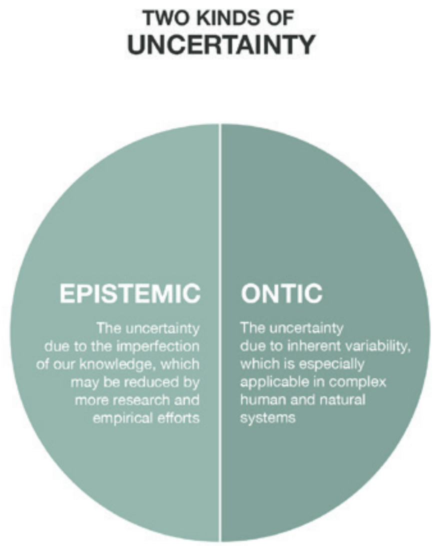


Figure 2.5
Two kinds of uncertainty
(based on information by: Walker et al., 2003)

Two kinds of uncertainty
Epistemic uncertainty is defined as uncertainty arising from a lack of accurate models, ignorance, biases and measurement errors (Tye and Altamirano, 2017). Uncertainty of this kind can be seen as knowledge gaps that can be closed by doing more research and studies. This is the kind of uncertainty where models actually are of importance. Scientists are for example still uncertain on the effect of a given quantity of greenhouse gases (GHG) on the global mean temperature (Hallegatte et al., 2012).

Ontic uncertainty, in contrast to epistemic uncertainty, is not caused by a lack of research. It is described as a kind of uncertainty inherent to complex systems and their characteristics (Tye and Altamirano, 2017). This uncertainty can be defined as knowledge gaps that will always remain. An example of ontic uncertainty reading climate is the uncertainty on future emissions of greenhouse gases. Levels of GHG emissions depend on demographic evolutions, socio-economic evolutions, available technologies, policies, and values and preferences (Hallegatte et al., 2012) and those are variables we currently can't foresee.

The different kinds of uncertainty are shown in Figure 2.5. Assessing the nature of uncertainty (epistemic or ontic) could help designers understand how certain uncertainties can be addressed (Walker et al., 2003). Epistemic uncertainty can be reduced by doing additional research, calculations and creating accurate models to improve the quality of the output, but in the case of ontic uncertainty, research like this likely would not yield an improvement in the quality of the output (Walker et al., 2003). What is important to understand is that ontic uncertainty, even though it can't be reduced by additional research, shouldn't be ignored in design, planning and decision-making processes. Both of these uncertainties have to be addressed in order to reduce vulnerability and exposure to flood risk.

Because of their clear differences, each of these uncertainties have to be approached differently when landscape architects are assigned to create a plan or design for adaptation. The combination of the two can lead to the integration of climate modeling (reducing epistemic uncertainty) and decision analysis (dealing with ontic uncertainty). The approach I develop in this thesis aims to address both kinds of uncertainty by reaching this integration.

2.3.4 THE NEED TO EMBRACE COMPLEXITY

Complexity and uncertainty within complex systems are often seen as a problem. Rauws (2015) explains that when the uncertainties that come with complex systems are only seen as problems, risks or predictions of failure, stakeholders can become paralyzed and no longer be willing to take action or make investments. This could be prevented by regarding uncertainties as a challenge and acknowledging that there are also benefits to complexity. An example of a benefit of complexity is mentioned by Rauws & De Roo (2016, p.1053), who explain that *"within complexity science, the mutability of systems is not problematized, as something to be reduced or avoided. In contrast, it is this very same mutability which provides systems with the capacity to 'survive' and adapt to volatile contexts"*. Secondly, complexity provides room for what Portugali et al. (2012) define as synergy. Synergy refers to the possibility that different phenomena and processes combined in a larger system have the potential to become a whole that is greater than the sum of the parts. Interactions and/or combinations of these different phenomena and processes within the complex system create 'added value'. This is beneficial for designers, because it automatically adds a certain extra quality to the system. A quality that can not be created in a less complex system.

In this sense, landscape architects, spatial planners, urban designers and decision makers could benefit from a complexity science perspective on cities. Seeing the city as a mutable, adapting system would encourage to plan and design in a way that generates and/or maintains urban complexity. They should embrace uncertainty and find ways to take it actively into account as a core component of urban development, instead of spending a large amount of time trying to reduce uncertainty, and deciding to wait until the uncertainties have been resolved.

2.3.5 THE NEED FOR NEW APPROACHES

As a conclusion to the previous sections, I argue that because of complexity, uncertainty and unpredictability, anticipatory adaptation of the (urban) landscape requires a new response in landscape architecture practice. This conclusion is visualized in Figure 2.6. Designers need new design approaches that allow for the lack of knowledge about future climate change. Landscape architects need to shift away from predict-then-adapt approaches and top-down, 'optimal' designs and shift towards designs that have the capacity to respond to unprecedented and unexpected future circumstances in order to maintain its functionality. This means designers should no longer focus on 'optimality' as a main goal for design. Instead, the main goal should be 'adaptiveness'.

This paradigm has already triggered a response within the planning realm; planners have started to search for planning approaches that could make cities more able to deal with uncertainties of climate change. Their ideas clearly move away from the ambition to achieve predefined outcomes and move towards creating strategies and approaches that accept ontic uncertainty and which support the ability to change plans based on new experience and insights. The same response is needed within the field of landscape architecture. Designers could benefit from adaptive approaches that can be used to structure the design process in order to deal with uncertainty.

Figure 2.6
The conceptual framework: a representation of how complexity and uncertainty form a design challenge that require an adaptive response.

Currently, there is not an agreed approach for the design of an adaptive plan under uncertainty. Developing an adaptive approach for dealing with the effects of climate change and its intrinsic uncertainties could be beneficial for landscape architecture, which is what I attempt through my research. This research will then be used test the developed approach in order to create a landscape architectural design for Boston. The next section explains which methods are used for the research.

2.4 METHODS

To investigate how I can contribute to flood risk reduction in Boston, by means of an adaptive systematic approach for landscape architectural design, I first need to answer the research question:

What is an adaptive, systematic approach for landscape architectural design under uncertainty?

To answer this question and to subsequently use and test the approach to create a design, this research is conducted according to three general methods.

The three methods that I use have been described by Deming & Swaffield (2011), Lenzholzer et al. (2013) and Van den Brink et al. (2017). The first method that describes my research is **'research on design' (ROD)**. This method is used for studies about the products of design (Lenzholzer et al. in Van den Brink et al., 2017). In this case, ROD is used to do a reference study on landscape architectural projects to find out how adaptiveness is operationalized in landscape architectural practice. The second method is called **'research for design' (RFD)**. This method is used for all types of research that support the design process and the coming into being of the design product (Lenzholzer et al. in Van den Brink et al., 2017). In this thesis, RFD consists of a desk study on existing approaches in the literature and a field study in Boston, where I obtained data that was needed for the design phase. The third method I use is **'research through designing'** (RTD). This research method is used for all research and studies that actively employ designing as a research method (Lenzholzer et al. in Van den Brink et al., 2017). RTD is used for a case study to create a landscape architectural design for flood-prone areas in Boston and to investigate the newly developed (design) approach in a real world context. It allows me to translate research into practice, to add an in-depth understanding to an emerging body of theory on adaptation under uncertainty and it enables me to draw conclusions on the application of the developed approach. The three different methods and their applications are visualized in Figure 2.7.

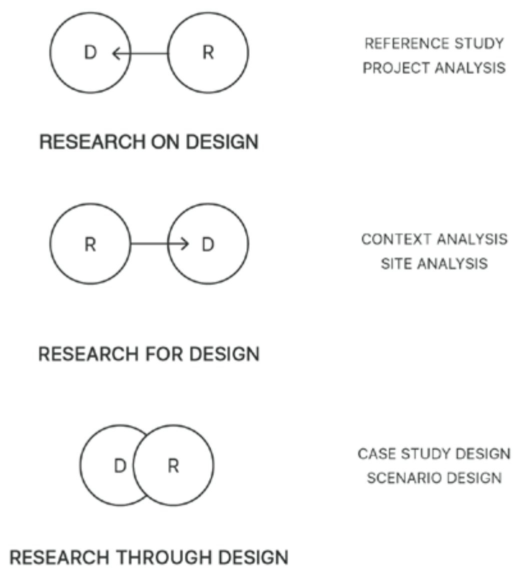


Figure 2.7
The different research methods that were used for this thesis.

2.4.1 DEVELOPING AN APPROACH TO CREATE A DESIGN

Because this is a design thesis, the most important method of my research is the research through designing method, where I test an approach in order to create a design for the case study in Boston. However in order to use this method, I first need to develop a research-based design approach, as these are currently non-existent. Therefore the design of the study starts with the research that will help me develop the approach that I can use in the research through designing phase. To develop this approach, I use a research on design method and a research for design method.

Research on design

I use an ROD method to answer the first sub research question: what is adaptiveness and how is it operationalized in landscape architectural practice? The ROD method in this case is a reference study on landscape architectural projects. A 'reference project' as understood within thesis, is an example which provides a particular instance of implementation of flood adaptation measure(s). I analyze these flood adaptation implementation projects, through a review of projects and literature on these projects. The projects were selected from a research by Silva and Costa (2018), who did a study on existing examples of public spaces with flood adaptation purposes. Through researching these reference projects, I could distinguish different underlying strategies that are used in landscape architectural practice. These underlying adaptive design strategies can be used for the design process.

Research for design

This RFD method is used to answer the question: What are the components of an adaptive systematic approach for landscape architectural design under uncertainty? For this part of my research, I conduct a literature review of literature on five prevalent approaches for adaptation under uncertainty in planning and decision-making, which helps me get in-depth knowledge on the components that are used in the approaches.

This knowledge can aid the structuring of the design process, as the outcomes of this part of the RFD-phase help me make choices for the development of the (design) approach for landscape architecture of flood risk reduction.

2.4.2 CREATING THE DESIGN (CASE STUDY)

Two methods are used in order to apply the approach in a case study and create a design. The most important method of this phase is research through designing. However research through designing can't be done without doing research for design, which is therefore done prior to the RTD.

Research for design

The RFD method is used to answer the question: What are the specifics of the Bostonian urban landscape in relation to its vulnerability to flood risk? Collecting and analyzing data to answer this research question is the initial step of the case study method. This RFD-method consists a landscape analysis in Boston, incorporating a variety of research methods such as site visits, site analysis, historical analysis, and conversations with developers, researchers, public officials, users and non-users to systematically acquire site-specific data (Francis, 2001).

The site-specific data on, for example, hydrology, climatology and geology were collected through researcher-completed observation of the chosen sites and researcher-completed study of local databases (containing existing, secondary data, collected by someone other than the researcher). The data were processed, managed, organized and represented by using research tools such as mapping and GIS to analyze and visualize spatial information. This was done to gain knowledge on spatial problems, constraints and opportunities for adaptation. This knowledge can be translated into meaningful design guidelines that can be used for the design of Boston's flood prone areas. Design guidelines are based on design principles.

Design principles are defined as "*sets of generally applicable laws, guidelines, human biases, and design considerations, all of which reflect the accumulated knowledge and experience of practitioners and researchers. They serve as a starting point for the creation of new designs to solve problems*" (IDF, 2018). Design principles serve as a starting point to help designers find ways to solve problems by enhancing usability, influencing perception, increasing appeal and making design decisions during projects. Design guidelines provide practical information on how to implement such a design principle, which can be seen as the philosophy or aim of design.

For validation of the researcher-completed studies, I have spoken with experts, such as developers, researchers, public officials, users and non-users of the area on for example hydrology, climatology, geology, landscape and/or environmental psychology to gather more (in-depth) information about problems and opportunities in vulnerable areas of Boston and to confirm my personal findings. The conversations were held in March and April 2017 and the selection of people was done through snowball method and random selection at a community meeting. I first contacted Paul Kirshen, a professor at UMass Boston who is involved with the Climate Ready Boston project and specialized in Water Resources Engineering and Management, Climate Change Vulnerability Assessment and Climate Change Adaptation Planning. He then put me in contact with experts with a lot of knowledge on the site that was chosen for design, could give valuable perspectives on my research findings; Phillip Giffee (Affordable Housing & Local response to climate change), Robbin Peach (Program Manager of Resiliency at Massachusetts Port Authority), Gretchen Schneider Rabinkin (Architect, background in improving Boston-area neighborhoods), Kannan Thiru (resident & environmental consultant for engaging residents in flood control measures) and Manlio Mendez (Resident & Community Organizer). Conversations on the results of my landscape analysis and my design proposals with these experts and conversations with residents on their preferences were used throughout my thesis.

By using different methods I researched if different methods would lead to the same results, better known as triangulation. By using these techniques for landscape analysis, I was able to contextualize problems in Boston and it helped me understand the interaction between landscape, climate change, human development and flood risk (described in this chapter) with regard to the specific case of Boston.

Research through designing

The third method I use is research through designing, which means that I actively employed the act of designing as a research method (Lenzholzer et al., 2013). The design question to be answered in this phase is: What landscape architectural design can be created, by means of an adaptive, systematic approach for spatial adaptation that will contribute to flood risk reduction in Boston?

The goal of this phase is to create a spatial design and to test and demonstrate the applicability of the developed design approach with the case study: the design for flood risk reduction in the city of Boston. *"A case study is a well-documented and systematic examination of the process, decision- making and outcomes of a project that is undertaken for the purpose of informing future practice, policy, theory and/or education."* (Francis, 2001, p.16)

The site-specific knowledge obtained in the preceding RFD-phase, combined with the newly developed approach, are translated and used as a basis for the design I create for Boston. The translation of knowledge on the Bostonian landscape (e.g. hydrology, climatology, landscape ecology or environmental psychology) and the newly developed approach, into a new spatial concept for the area, happens through sketching and design.

An RTD process is not linear but iterative. It consists of four different steps: designing, assessing, refining and testing. These steps can be repeated multiple times, until a satisfying result is reached (Cortesão 2017). The iterative process is shown in Figure 2.8.

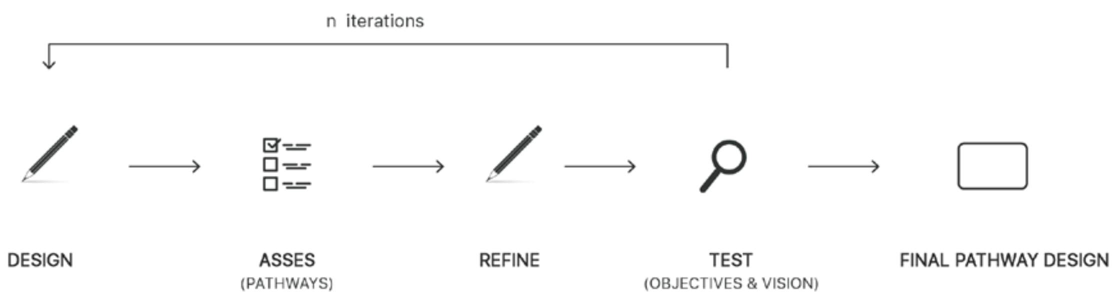


Figure 2.8
The research through designing method that was used in this thesis. (based on: Cortesao, 2017)

The goal of this case-based design is both to reach a design for Boston and to conduct in-depth analysis of the developed approach; the case study forms an example of how to use the approach in practice and helps to assess if the approach is worthy of replication or broader dissemination.

Figure 2.9 shows the methodological framework that is used for this thesis. It shows that the approach for landscape architectural design under uncertainty is based on: (1) research on the concept of adaptiveness and adaptive design strategies (2) components of prevalent planning approaches that help account for uncertainty in the decision making process, (3) inclusion of local context, through field work, landscape analysis and incorporating local objectives.

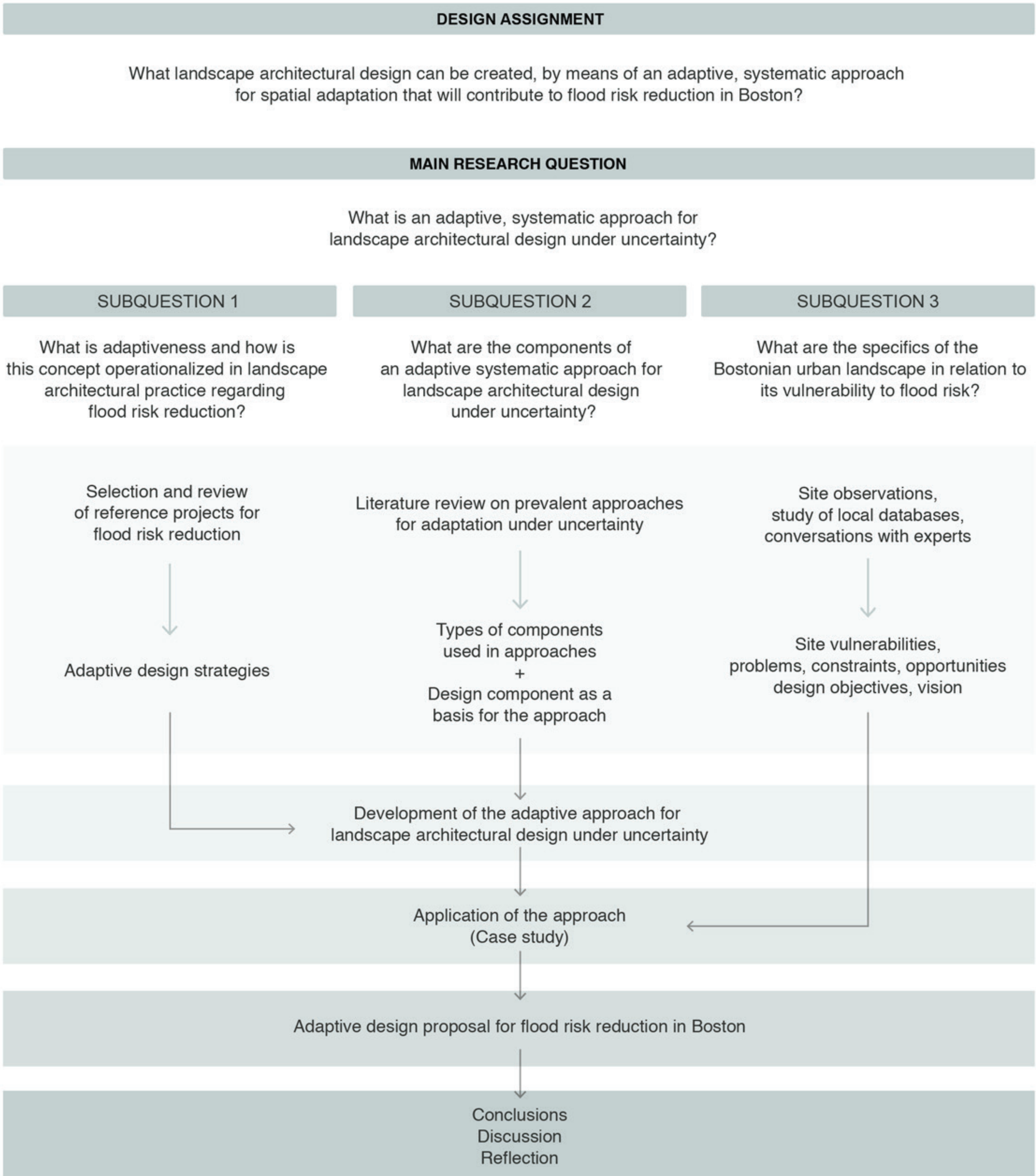


Figure 2.9
The methodological framework

3 AN ADAPTIVE APPROACH

To recapitulate, I have outlined the major threat of flood risk faced by coastal cities worldwide and the complex concepts that landscape architects need to take into account in the process of adapting coastal cities to the future climate to reduce food risk.

The previous chapters help to understand why landscape architects need new systematic approaches for adaptive design under climate uncertainty and what research is needed to develop these approaches. In this chapter the approach is developed. The question to be answered first is: *What is an adaptive, systematic approach for landscape architectural design under uncertainty?* Approaches can be described as combined sets of tools in a coherent framework (Zandvoort, 2017), but what is then an adaptive approach? To answer this, I first explain the term adaptiveness and what it implies. Subsequently, I present the outcomes of the literature review on reference projects in landscape architectural practice and the literature review on prevalent developed approaches for adaptation under uncertainty in planning and decision making literature. These reviews led to the development of the approach, of which a description is provided in the final part of this chapter.

(Image by author)

3.1 ADAPTIVENESS

According to Zandvoort (2017), who conducted research on the discourse about adaptiveness through a literature review on scholarly contributions to the conceptualization of adaptiveness, the terms adaptive and adaptiveness are used in many different ways within the literature. His research concludes that it is important to look at 'what adapts to what', when speaking of adaptiveness. In this thesis, I focus on adapting the spatial configuration of a city to climate change and the uncertainties that accompany it. Zandvoort (2017, p.70) categorizes this version of adaptiveness as 'adaptive planning'. In adaptive planning, adaptiveness is defined as *"being able to handle irreducible (ontic) uncertainty about future change"*. However, Zandvoort (2017) mentions that the literature is unclear about what this means for applying adaptiveness in practice.

To find out how adaptiveness can be operationalized by landscape architects, I have researched the landscape architectural design practice for flood risk reduction by conducting reference studies on landscape architectural projects. I used a research by Silva and Costa (2018), who did a study on existing examples of public spaces with flood adaptation purposes to identify and characterize specific public space potentialities for the application of flood adaptation measures. They have selected the cases based on comprehensive case studies highlighted in research projects, bibliographical reviews, interviews with specialists, networking or in site visits.

Adaptiveness in spatial design practice

By reviewing different international spatial adaptation projects and comparing them, I looked for the different ideas and principles that were used, which lead to an understanding that there are different underlying strategies for design in order to achieve adaptive designs. A strategy consists of *"goals, related measures and one or more development trajectories"* (van Rhee, 2012, p.18). By focusing on these strategies behind the implementation instead of the implementations themselves, I could extract information of general relevance regarding the application of adaptiveness in practice.

By investigating which strategies regarding flood risk reduction are used in landscape architecture practice, I could conclude that there are three important strategies that can be distinguished in spatial design practice that seem to acknowledge and account for climate uncertainty. Because of this ability to account for irreducible climate uncertainty, these three strategies can be called adaptive strategies.

Multifunctional design strategy (MDS) (Figure 3.1)

This strategy focuses on larger scale interventions that have multiple functions and additional benefits. Because of its multifunctionality, these strategies deliver benefits even if the future turns out different than expected and therefore they ensure that investments are not made in vain. This is similar to what researchers (e.g. Hallegatte et al., 2012) call no-regret strategies. Regret can be described as *"the difference between the performance of some strategy in a particular future and the performance of the best strategy in that future."* (Ray & Brown, 2015, p.80). The objective is to make a design perform well in any future by fulfilling multiple societal demands.

Examples from practice that fit within this strategy are the Benthemplein (Rotterdam, The Netherlands) and the Dakpark. (Rotterdam, The Netherlands). The Bethemplein is the world's first so called water square. A water square is a combination of water storage and a public square. As the designers describe: *"it makes money invested in water storage facilities visible and enjoyable"* (De Urbanisten, 2013). In dry-state, the square is used as recreational space, but when needed, it can also serve as a water basin. The Dakpark is another multifunctional project located in the Netherlands. In this example, flood protection is combined with the development of offices, shops, schools and a public park (Van Iersel, 2011).

Flexible design strategy (FDS) (Figure 3.2)

This strategy can help designers to find ways to adapt spatial configurations in a later phase, if the future turns out to be different than expected. In this context, flexibility is defined as 'keeping options open' and can be seen as a desirable feature that avoids maladaptation throughout a measure's lifetime (Gersonius et al., 2013). Maladaptation is defined as an adaptation that does not succeed in reducing vulnerability but increases it instead (McCarthy et al., 2001). The strategy favors climate adaptation measures that are reversible, removable, adjustable and/or upgradable if future climate change makes them insufficient. Flexibility should therefore be built-in in the structure.

An example of a strategy that incorporates the possibility of upgrade is the inclusion of extra strength in the base of a sea wall. The extra strength would cost a little more, but it would enable the option to extend the height of the sea wall in the future, if necessary. This way, options are kept open for the future while more expensive and more irreversible decisions (such as building a very high sea wall) are delayed until more information, on which to base those decisions, becomes available (Ray & Brown, 2015). With the built-in-possibility of a future upgrade, large potential regrets associated with either overinvestment or underinvestment in climate adaptation measures can be avoided (Ray & Brown, 2015).

Examples from practice that fit within this strategy are the Ruimte voor de rivier project (The Netherlands) and the Hefschuif (Kampen, The Netherlands). The Ruimte voor de rivier project (translated as: Room for the river) is an example of a project that acknowledges the need for learning and flexibility to deal with an uncertain future (Zevenbergen et al., 2015). By means of river widening, preference was given to a more green adaptation measures instead of hard, technical measures (such as dike reinforcement). By giving the river more space, flexibility was incorporated spatially en temporarily because it spatially offered more room for different kinds of implementations of adaptation measures and it also bought decision makers more time to make informed decisions in the future. The Hefschuif is a vertical floodwall that is anchored and stored into the ground, which can be deployed during a storm event. Because it is kept underground, the visual and physical access to the waterfront are being preserved.

Supplementary design strategy (SDS) (Figure 3.3)
This strategy supports design for short-term adaptation measures, while keeping options open on the longer term. This way flexibility is built into the decision process itself instead of in the adaptation measures. In this strategy, interventions that supplement each other are favored so that they can be added to each other over time to work together as a larger system that can keep growing along with changes in the environment. The measures are seen as pieces of a puzzle that together form a bigger whole. The objective of this strategy is to change the rhythm of interventions, in order to avoid long-term commitment and to consider future learning. This often results in sequences of multiple interventions, which creates the possibility to adapt the urban configuration more gradually instead of abruptly. The strategy enables on-going urban renewal activity.

An example of this strategy is The Dutch Delta Program, which explores different strategies to manage increasing flood risk. The Dutch Delta Program explored possible actions over a long time horizon, but only the ones that are currently needed are actually implemented, while additional measures are planned for future execution, but will only be executed if or when required.

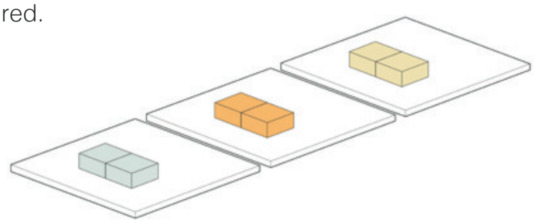


Figure 3.1
The multifunctionality strategy, showing that the shape stays the same, but multiple functions (colors) are assigned to the measure

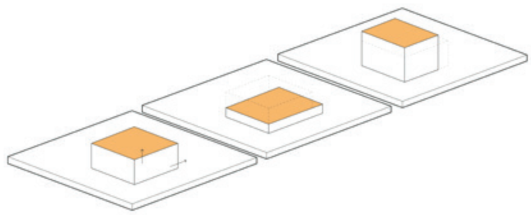


Figure 3.2
The flexibility strategy, showing the possibility to change the measure (different shapes)

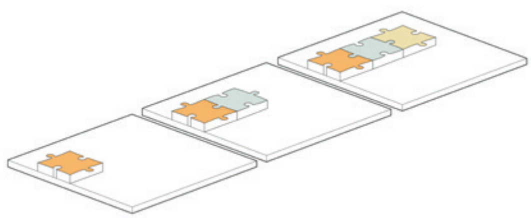


Figure 3.3
The supplementary strategy, showing measures as pieces of a puzzle that together form a working system

These strategies can be linked to three terms that are used by Smet (2017) to explain the different coping mechanisms for dealing with possible impacts of uncertainty in a plan:

- Robustness, which is achieved by a creating a robust design, that is fixed (meaning it can't be changed) and often over-dimensioned to assure at least the minimum level of service throughout its lifetime (Smet, 2017). This coping mechanism is similar to the multifunctional design strategy.

- Flexibility, which is achieved by creating a flexible design, which is proactive by choosing to include options within the initial structure. The structures themselves can be changed (Smet, 2017). This obviously fits with the flexible design strategy.

- Adaptability, which is achieved by creating a reactive adaptable design for the best-available current information, while keeping in mind that additional measures can be added to reinforce the measure. Changes can be made as needed as the future unfolds (Smet, 2017). This is also aimed for in the identified supplementary design strategy.

The three identified strategies (multifunctionality, flexibility, supplementary) are all different from each other, but what they have in common is that they are all insensitive to uncertainty about the future. The strategies can be used to apply adaptiveness in practice, since they help to create designs that focus on handling irreducible (ontic) uncertainty about future change. Choices between these strategies can be made depending on the project and its context and for example stakeholder preference. Once a preferred strategy is selected, this strategy serves as the decisive criterion for the assessment of which spatial adaptation measures should be applied. This way, the strategy can help to guide decision making in the design process.

Besides investigating how the concept of adaptiveness is operationalized in landscape architecture practice, I also investigated several approaches in the literature, that help deal with uncertainty in the decision making process, which I elaborate on in the following section.

3.2 COMPONENTS OF AN ADAPTIVE APPROACH

A systematic adaptive approach requires a combined set of tools that fit together in a framework that enables uncertainty to be accounted for in the design process. For the development of this framework, I researched several adaptive approaches in the literature. The outcomes of this investigation are described in the next sections.

3.2.1 ADAPTIVE APPROACHES IN THE LITERATURE

Through my review I learned that planning literature on approaches for decision-making under uncertainty is widespread, yet literature on landscape architectural design under uncertainty is not. The availability of a variety of (model-based) approaches for decision-making under uncertainty raised questions for me on how the various approaches are different and which ones could also be useful for the landscape architectural design process. Therefore, I did a literature review on the most prevalent approaches for adaptation under uncertainty in planning theory.

Decision-centered adaptation research

The research community has put in a lot of effort to develop various tools, strategies, approaches and methods to support and inform decision-making for anticipatory adaptation under uncertainty (Wise et al., 2014). They are created as alternatives to the current planning approaches that are unable to deal with uncertainty in general. Instead of focusing on forecasting, the research community intends to provide guides that help us make decisions within the range of possible climate scenarios. Though climate models are used in these approaches, they are not used as prediction tools as is done in predict-then-adapt decision frameworks. Instead, they are used as scenario generators, sources of insight into complex system behavior and aids to critical thinking (Weaver et al., 2013).

Prevalent themes this research domain focuses on are: uncertainty, robustness, long time horizons and climate scenarios. There is also an increasing recognition (e.g. Weaver et al., 2013) that, for these supportive approaches to work successfully, the focus shouldn't only be on improving the technical models used within it, but also on the comprehensiveness and pragmatic guidance for decision makers.

Scenario-based approaches

The use of scenarios is often the basis for most approaches to climate change risk assessment and adaptation planning (Ray & Brown, 2015). A climate scenario is defined (IPCC, 2013) as a *"plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models"*. Climate scenarios are useful for exploring impacts of possible future climates (risk assessment) and for assessment of the robustness of adaptation actions across a range of futures (adaptation planning). They are used in the absence of a clear idea of what future conditions will be. These scenarios can also be a motivation for decision-makers to better craft plans that limit the risks that cities face.

Prevalent adaptive approaches

Different comparisons of the most prevalent and most used approaches have already been done before in the literature (e.g. Hallegatte et al., 2012; Ray & Brown, 2015; Kwakkel et al., 2016). As Kwakkel et al. (2016) summarize, the acceptance of ontic uncertainty as an inevitable part of long-term decision-making has given rise to the development of new model-based tools and approaches, such as Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013), Real In Options Analysis (Wang & de Neufville, 2004; Gersonius et al., 2013) Info-Gap Decision Theory (Korteling et al., 2013; Ray & Brown, 2015), Decision Scaling (Brown, 2010; Ray & Brown, 2015), and Robust Decision-Making (Lempert & Groves, 2010). These approaches show that accurate and precise predictions are not a pre-requisite for anticipatory adaptation and they build on the idea that even if the future is unknown, the unknown is not unmanageable (Wang & de Neufville, 2014).

3.2.2 USEFUL COMPONENTS FOR LANDSCAPE ARCHITECTURE

The goal for creating the landscape architectural approach is not to reinvent the wheel, since there already are a lot of useful approaches available in the literature. Therefore I used components from existing approaches to develop an approach based on already tested approaches. However, these approaches are mainly focused on decision-making, policies and soft (non structural) strategies, which therefore makes them only partially relevant for landscape architecture. By comparing these approaches and researching the significant characteristics of their components, I investigated which type of components would be useful for the landscape architectural design process.

Although all the studied approaches generally aim at adaptiveness, they differ in their conceptualizations of uncertainty, in modeling philosophies, and in solution techniques. There are however corresponding components that can be distinguished, which can be used in an approach for landscape architectural design under uncertainty. The following section elaborates on the comparison that I did in order to find the components that are useful/favored for landscape architecture.

Components that help identify vulnerabilities

Something that most of these approaches have in common is that they take the vulnerability of the system that is assessed as a starting point. Instead of using climate change as its point of departure, these approaches focus on the existing system and its performance. These approaches don't start with the question: what is the future climate going to be like and what are its effects?, the question asked is: what climate impacts is the system vulnerable to? In different ways they all investigate what could make a plan fail. In Dynamic Adaptive Policy Pathways, for example, the question asked is: under what conditions does a plan perform unacceptably? By asking these questions, priorities within the adaptation problem are immediately identified, which is more efficient than beginning with the generation and/or interpretation of climate projections, followed by an analysis of their impacts and then prioritizing (Dessai and Van der Sluijs, 2007). These approaches therefore address vulnerability centered adaptation, which is very useful for landscape architects since their design intends to reduce the spatial vulnerabilities of an area, by focusing on adaptation of the weakest parts.

Components that help improve foresight

The adaptive approaches found in the literature are often supported by computer models. Some of them use a simulation model of the system that is analyzed, such as Info-Gap Decision Theory, to analyze the system's uncertainty and vulnerability. Simulations are also used to evaluate and run a policy against a variety of scenarios in order to obtain more detailed information about the performance of the policy, as is done in Robust Decision-Making. In Dynamic Adaptive Policy Pathways, foresight is improved by a tipping point analysis, where the moments in time in which certain actions will fail to meet performance criteria are identified.

Components that state objectives

The approaches often define the performance-related objectives. For example, in Info-Gap Decision Theory, Dynamic Adaptive Policy Pathways and in Decision Scaling, these can be called the performance criteria of the system.

Components that help explore promising options, actions and strategies

The approaches have different ways to select promising measures. The question that is answered in these components is: given that the future cannot be predicted, which actions and options are likely to perform best in the future? In Real In Options Analysis, the most 'flexible' actions are considered the most interesting strategies. In Robust Decision-Making, actions that are insensitive to the most significant uncertainties are favored, which are selected through separate evaluation by computer simulation models that perform an iterative vulnerability-and-response-option analysis (Lempert & Groves, 2010). Pathways Mapping is a tool used in In Dynamic Adaptive Policy Pathways that helps to explore different strategies. The strategies in which more irreversible decisions are delayed until more information is available, are often favored in this approach.

Components that help analyze and optimize decisions

In these approaches, decision methods are used in order to improve the effectiveness of actions and options in terms of combined objectives of adaptation and considering uncertainty. In Decision Scaling, different solutions are tested in a model to examine (for example) costs, feasibility and effectiveness to decide which solution is most promising. In Real In Options Analysis an optimization model is used to optimize strategies (Wang & de Neufville, 2004).

Missing components

All the components mentioned above can be used and incorporated in an approach for landscape architectural design under uncertainty. However, the approach should not be limited to these components, as these components only help designers to make decisions. Besides helping to make decisions, the approach should also help to create design. This means additional components are needed. First of all, an important component for a landscape architectural approach is of course the component of the design activity itself. This component should consist of drawing, mapping, creating concepts, representing, giving shape and visualizing (Lenzholzer et al. in Van den Brink et al., 2017). This design component also requires another component that the most prevalent approaches are missing: a component of inclusion of local context through fieldwork, landscape analysis and incorporating local objectives for future developments. Actions consist of mapping, analyzing and visualizing the existing situation and its issues and opportunities as part of a design process (Kempenaar et al., 2016).

A design component as a basis

I did a more in-depth investigation into the existing comparisons of the approaches (e.g. Hallegatte et al., 2012; Ray & Brown, 2015; Kwakkel et al., 2016) to find the most suitable component that could be used as a design tool in order to use it as a basis for my approach. I found that engagement with some of the tools and models used in these approaches can be complex and time-consuming, while others require les modeling-capacity. To find the most suitable component, I used a few criteria.

First of all, the component chosen as a basis for developing a landscape architectural approach under uncertainty, has to be a component that is comprehensive and relatively simple in use, due to time constraints and the (probably) limited modeling capacity of the user. Preferably, the component has to be applicable to the wide range of adaptation projects landscape architects deal with in practice. Finally, the components should also be compatible with an iterative design process, meaning adaptation measures can be modeled and/or assessed and incorporated easily and multiple times if necessary. Based on these criteria I could make a decision, which is further explained in the next section.

3.3 PATHWAYS MAPPING AS A BASIS FOR A NEW APPROACH

As a result of the comparison of adaptive approaches in the literature, I have chosen a component that helps to create an adaptive design as a basis for the proposed approach. This component is called the Pathways Mapping tool, which is used in Dynamic adaptive policy pathways (DAPP) explained by Haasnoot et al. (2013). This tool is created to offer decision support for planners during the development of an adaptive plan, but I found it has great potential to be converted into an approach that could also be useful for landscape architecture. The pathways mapping tool helps to make decisions on what measures and/or actions should be taken, in which order they should be taken and when they should be taken.

3.3.1 TIPPING POINTS

The timing of an adaptation tipping point, called the sell-by date of an action, is derived from linking the sell-by conditions with scenarios (Haasnoot et al., 2013). In other words, with the help of climate scenarios, the sell-by conditions can be translated and expressed into time. Conditions and timing of adaptation tipping points, is done by expert judgment and/or model simulations (Kwakkel et al., 2016). When (or preferably before) tipping points of an action are reached, there are a few options: (1) Reinforce, (2) Replace and (3) Switch to a new action. This tipping point approach can help determine at which point in time new actions are needed and ultimately help users anticipate and avoid undesirable lock-ins and/or path dependencies (Haasnoot et al., 2013). Once a set of promising policy actions is selected and the tipping points (or sell-by dates) of these future options are assessed an Adaptation Pathways map can be drawn.

3.3.2 SEQUENCING ACTIONS THROUGH PATHWAYS MAPPING

An Adaptation Pathways map is similar to a metro line map, with multiple lines, transfer stations and terminals. It can be created manually and the intention is to develop sequences of promising actions, called adaptation pathways. An example of a pathways map is shown in Figure 3.4. By creating this map, different pathways (or routes) can be identified and assessed. These adaptation pathways consist of arrays of relevant policy actions, of which every new policy action is activated once its predecessor fails to meet the objectives (Kwakkel et al., 2016). The designer can use the tool to make decisions on short-term actions and long-term options to maintain the flexibility to make future changes. In general, the strategy of the pathways map is to sequence adaptation strategies so that no-regrets options are taken earlier and more inflexible measures are delayed in anticipation of better information. A pathways map helps to determine which path should be followed, it explores points in time where decisions should be made and it helps determine which step(s) should be taken first.

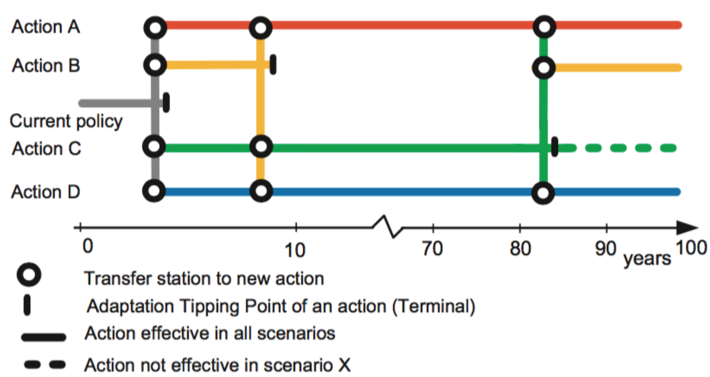


Figure 3.4
An example of an Adaptation Pathways map (Haasnoot et al., 2013, p.488).

As described by Haasnoot et al. (2013): "In the map, starting from the current situation, targets begin to be missed after four years. Following the gray lines of the current policy, one can see that there are four options. Actions A and D should be able to achieve the targets for the next 100 years in all climate scenarios. If Action B is chosen after the first four years, a tipping point is reached within about five years; a shift to one of the other three actions will then be needed to achieve the targets (follow the orange lines). If Action C is chosen after the first four years, a shift to Action A, B, or D will be needed in the case of Scenario X (follow the solid green lines)."

When creating the Pathways map, it is also important to identify triggers and signposts. These triggers and signpost are supposed to be reached before the adaptation tipping point, to take into account the lead time necessary for planning and implementing adaptation measures. This lead time of course depends on the complexity of the measure or strategy and will be specified accordingly. The moment of a trigger or signpost is visualized in the map with the vertical lines that indicate the transition to another action. They are placed before the moment the tipping point is reached. By assessing all the possible adaptation pathways from the Pathways map, the preferred pathway is selected. The preferred adaptation pathway can be used as input for a plan for action.

3.3.3 WHY PATHWAYS MAPPING?

Pathways mapping shows potential to be transformed into a tool that is useful for landscape architectural design, even though it is created as a tool for policy making. The tool has several strengths and benefits for designers and it complies with the criteria mentioned earlier, as it is comprehensive, applicable to a wide range of projects and it allows for an iterative design process.

The tool provides comprehensive and pragmatic guidance and is easy in use, as the metro map visualizations are very explanatory and relatively easy to understand and they help visualizing the different routes that are available for achieving the desired objectives. What also makes the tool easy in use is that the tool is more open ended with respect to how models can be used in it. Designers can decide themselves on how complex and computationally intensive the process will be.

Second, the tool is designed to be applicable to a wide range of adaptation projects. Multiple applications of the tool (Haasnoot et al., 2013; Kwakkel et al., 2016; Buurman and Babovic, 2016) show that it works well for policy making in smaller-scale adaptation projects and broader, large-scale adaptation plans.

Third, the tool allows reassessment by selecting short-term actions and long-term options. The outcome is a set of possible actions and it does not lead to one final solution or static outcome. The tool helps to create multiple branches of possibilities. With this feature, the tool emphasizes the need for iterative decision-management. This iterative process of assessing possible sequences of actions fits with the fact that landscape architecture itself is also an iterative process. Plans created with the tool provide the ability to adapt quickly once an action stops performing well.

An important feature of this tool is that the approach doesn't have optimality as its main goal. Rather than favoring optimal adaptation options that are irreversible and therefore can lead to maladaptation, it encourages a decision to take a more adaptive approach where decisions are made over time to continuously adapt (Jeuken and Reeder, 2011).

The next step is to explore how the tool can be integrated into a design approach that helps landscape architects produce an adaptive design.

3.3.4 PATHWAYS MAPPING FOR LANDSCAPE ARCHITECTURE

Originally, the pathways map is meant to create pathways for policy actions. However, for landscape architecture it would be useful to replace these policy actions with spatial adaptation measures. The actions used in the pathways map should be a selection of the most promising spatial measures, which can be selected according to criteria that are selected by the designer. For every project these criteria can be different, but examples can be maintenance and costs. Once the pathways map is drawn for the selected adaptation measures, a selection of preferred pathways has to be made. Depending on values and beliefs, decision makers and stakeholders can have very different preferences in pathways. Therefore, preferred adaptation pathways can be selected according to different stakeholder perspectives. However in the context of design, it could be useful to select the pathways according to different underlying design strategies. For the adaptive approach, the underlying strategies distinguished in practice: multifunctionality, flexibility and supplementary could be used.

In a design context, the created pathways map can be used as a tool for testing different designs. With the help of the constructed pathways map different designs can be created and tested according to the three different strategies. These designs give the designer feedback on the pathways map and the preferred pathways. If necessary, the pathways map and the selected pathways are altered and new or altered designs can be created. This feedback loop can be repeated multiple times, creating an iterative process, where the research informs design, and design informs the research. This way these feedback loops become part of the research through designing method. The outcome of this iterative design process is a preferred pathway that can be used to create a design.

Spatially visualizing pathways

Because the adaptation pathways are used as input for the development of a spatial design for a specific site, it would be beneficial for landscape architects to spatially visualize the entire sequence of spatial adaptation measures through time, instead of only one final end result.

The scheme in Figure 3.5 shows the idea on how an adaptation pathway can be visualized in a way that is useful for landscape architecture. The chosen pathway is spatially visualized in the center of the chart, showing the sequence of actions of the pathway for a specific site on a timeline. This way, the visualization of the design is sequenced in order to show what the landscape will look like in every phase. The various options on the top and bottom of the pathway help to keep in mind what options there are at every tipping point and see what all the options could look like spatially. It is visible that the decisions that are taken in the beginning influence the options that are available in the future. Once the designer decides to choose another option than originally planned for in the chosen pathway, the pathway visualization has to be redrawn and the landscape transformation has to be redesigned.

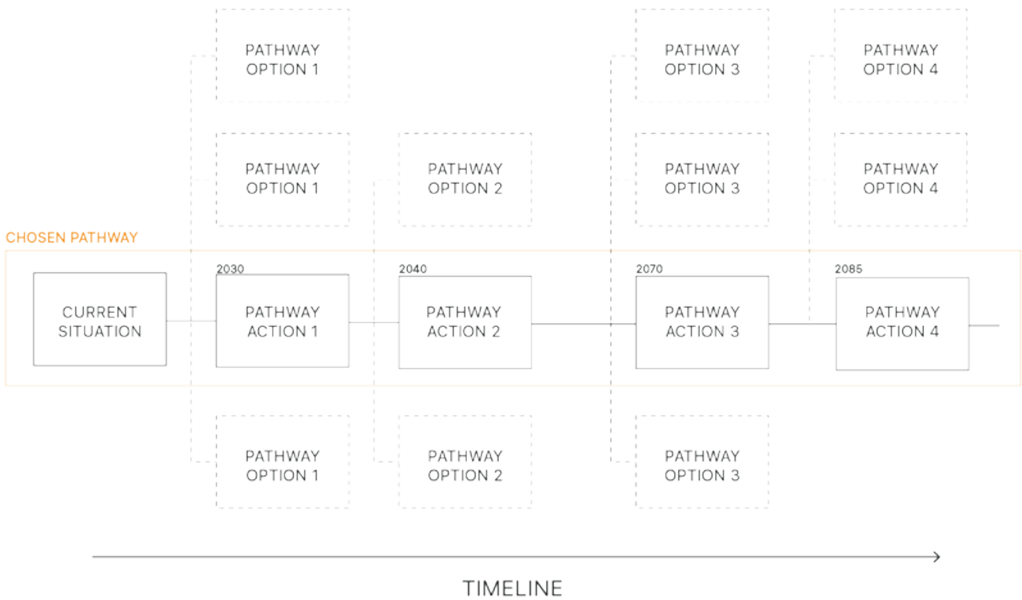


Figure 3.5
A scheme showing how a preferred pathway could be spatially visualized

3.4 LANDSCAPE ARCHITECTURAL FRAMEWORK FOR ADAPTATION UNDER UNCERTAINTY

In this section, the landscape architectural framework for adaptation under uncertainty is introduced. This framework serves as a pragmatic approach to assist landscape architects in the design process to help create adaptive solutions to long-term and uncertain circumstances. For the creation of the approach I made sure that all the identified components from the most prevalent approaches for decision-making under uncertainty were incorporated. This resulted in a stepwise approach with components that help identifying vulnerabilities, components that help improve foresight, components that help developing objectives, components that help explore options, actions and strategies, and components that help analyze and optimize decisions. Additionally, the component that helps with the design activity itself (the pathways mapping component) and a component that helps include local context, through field work, landscape analysis and incorporating local objectives were added to the framework (site analysis).

The framework consists of eight steps. This sequence of steps will result in an adaptive design, created through an iterative process of designing, assessing, refining and testing of the design and the design tools. The eight steps are divided into two phases; phase A and B, which are visualized in Figure 3.6.

Phase A is the assessment phase. This part is exploratory and consists of a divergent process, where the current and future problems and vulnerabilities are defined, the spatial situation is explored and opportunities are identified. This phase is meant to gain knowledge in order to reduce the epistemic uncertainty, for example by collecting site-specific data and data from climate models. Components used in this phase are components that identify vulnerabilities, improve foresight and analyze the landscape.

Phase B is the design phase. This part is solution-oriented and therefore the process changes into a convergent process, where options are evaluated, design choices are made and adaptation measures are designed. In phase B, steps are taken to be able to account for ontic uncertainty in the design. This is done through pathways mapping, which allows for adaptiveness in the design.

The combination of the two phases can lead to the integration of climate modeling (reducing epistemic uncertainty) and decision analysis (dealing with ontic uncertainty). The framework for adaptation is therefore capable of accounting for two kinds of uncertainty.

The steps of the framework are based on the different types of components that were found through the literature review; components that help identifying vulnerabilities, components that help developing objectives, components that help improve foresight, components that help explore options, actions and strategies, and components that help analyze and optimize decisions. The ways these components are incorporated in the approach are explained in the following sections.

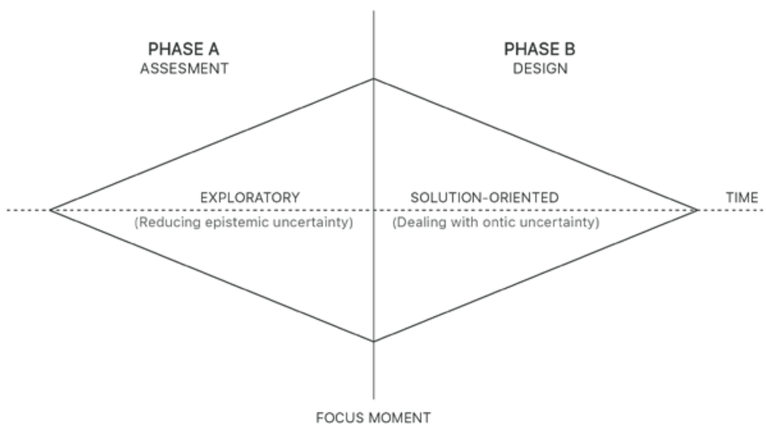


Figure 3.6
The timeline of the developed approach, divided in phase A and phase B.

3.4.1 PHASE A: ASSESMENT

Step 1 – Vulnerability assessment

The first step of the approach consists of a component that helps identifying vulnerabilities and focuses on gathering information to reduce epistemic uncertainties and takes the vulnerability of the system as a starting point. By identifying the risk in flood-prone areas, decisions for flood risk reduction can be made. To identify a system's current vulnerabilities, estimate future conditions, and to analyze system sensitivity and resilience to identify future impacts computational approaches and simulations can be used. This should be done with the best available information about future conditions.

Step 2 – Landscape analysis

When the most vulnerable areas are identified, a landscape analysis is done to further analyze problems, needs and opportunities of a specific location. This step consists of the component that helps include local context. The analysis of the landscape focuses on the context of the specific location and its physical, historical, social, economic and cultural dimensions to get a good understanding of the landscape as a complex and dynamic socio-cultural construct within its historical context. This step also helps to find site-specific design principles and design guidelines, based on spatial problems and opportunities and constraints for adaptation.

Step 3 – Objectives & Vision

This step consists of a component that helps developing objectives for the adaptive design. Establishing the development objectives and creating a vision, which the design has to contribute to. The vision and the objectives will provide a foundation for the design.

3.4.2 PHASE B: DESIGN

Step 4 – Preferred adaptation measures

In this step different types of adaptation measures that could be implemented over time in order to protect citizens, ecology, existing buildings and other properties, are identified. The step is based on the identified component that helps explore options, actions and strategies. Drawing from all the adaptation literature and practice, there is a large toolbox of adaptation measures. Therefore it is important to determine which measures are most appropriate and preferred in a specific context. To do this, all the possible measures should be evaluated according to certain criteria in order to narrow down the list of possible measures for the specific location. These criteria are project-specific and should be determined accordingly. Eventually, the chosen measures are supposed to fit within the vision and objectives for the area.

Step 5 – Evaluate

This step consists of a component that helps analyze and optimize decisions. In this step the designer uses models, the vulnerability assessment and climate scenarios, to assess the sell-by-dates of these adaptation measures. Then, the selected measures are evaluated according to criteria of the multifunctionality, flexibility and supplementary strategy to find out which measures are useful for each design strategy. This distinction between measures will be used in the next steps.

Step 6 – Map different pathways

This step consists of a design component that is used as a basis for the approach. In this step the adaptation pathways are mapped with the pathways mapping tool, suggested by Haasnoot et al. (2013). Pathways mapping helps to determine which adaptation pathway is most promising, it explores points in time where decisions should be made and it helps determine which step(s) should be taken first. The pathways can be selected according to three underlying design strategies that were distinguished in practice, which help create an adaptive design. These are the multifunctional design strategy, the flexible design strategy and the supplementary design strategy.

Step 7 – Test different pathways

This step is another part of the design component. In this step the adaptation pathways are used as a basis for design. To test the pathways, simple concept drawings can be made to explore how the pathways would turn out spatially. These first conceptual designs that come out of the selected pathways should give the designer feedback on the pathways map and the preferred pathways. If necessary, the pathways map and the selected pathways are altered and new or altered designs can be created. This feedback loop can be repeated multiple times. This iterative design process (Figure 3.7) helps to compose the map, and it helps to test different sequences and determine which of them are most feasible, attractive etc. This iterative process can make sure that the pathways map and that the resulting designs are optimized. The challenge of this step is to determine which pathway, with which underlying strategy should be pursued and why.

Step 8 – Specify an adaptive design

This step is the final part of the design component. In this step, the entire sequence of spatial adaptation measures is visualized through time. This provides details on which measures should and could be implemented, when they should be implemented, and what they would look like. Besides the visualization of the chosen adaptation pathway, the other options from the map are also visualized to help to keep in mind what options there are with every tipping point.

This final step takes the design from a high-level proposal to a detailed design; an in-depth explanation and visualization of the final, possible end result of the design proposal is created in order to provide an idea of what the far future could look like. Even though the goal of the approach is not to create a static, definitive design, the visualization is used to help imagine what the results of a chosen pathway could be.

An iterative approach

These steps are intended to contribute to an integral approach to the ongoing process of flood adaptation in urbanized areas. The outcome of this process is a pathways map and a preferred and elaborated adaptation pathway that provides details on which measures should and could be implemented, when they should be implemented, and what they would look like. What should be kept in mind is that the approach is intended to be an iterative process where continual monitoring and re-evaluation when new information is available, is necessary. Monitoring the evolution of the climate and the effects of chosen adaptation measures plays an important role, because it helps decision makers to stay on track of a preferred pathway, by evaluating if decisions can be taken according to plan, can be further postponed or should be taken earlier (Jeuken and Reeder, 2011). If staying on track becomes impossible or unwanted as new information becomes available, a switch can be made from one pathway to another. It is also possible that, despite the research on possible scenarios, changes or developments occur that were not considered, which would require reassessment of the pathways map and the design.

In the next chapters, a case study as research through designing (RTD) method is used to test the approach in practice and create a design for East Boston in order to reduce its vulnerability and exposure to flooding.

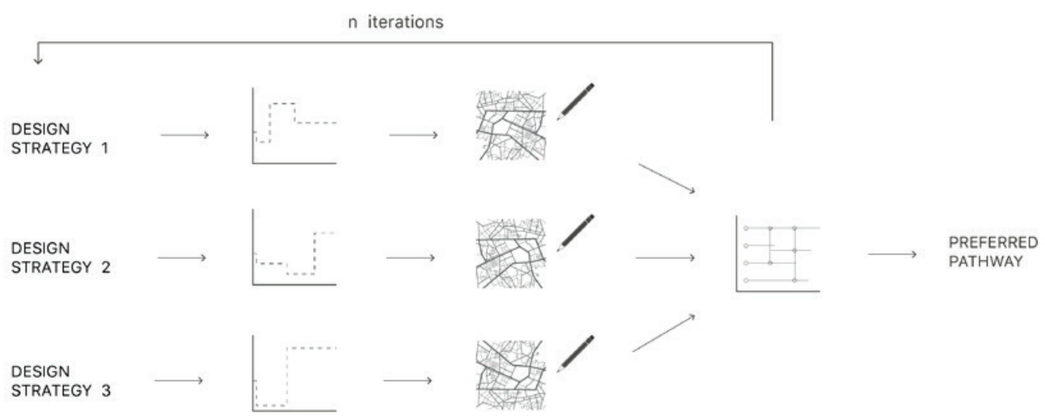


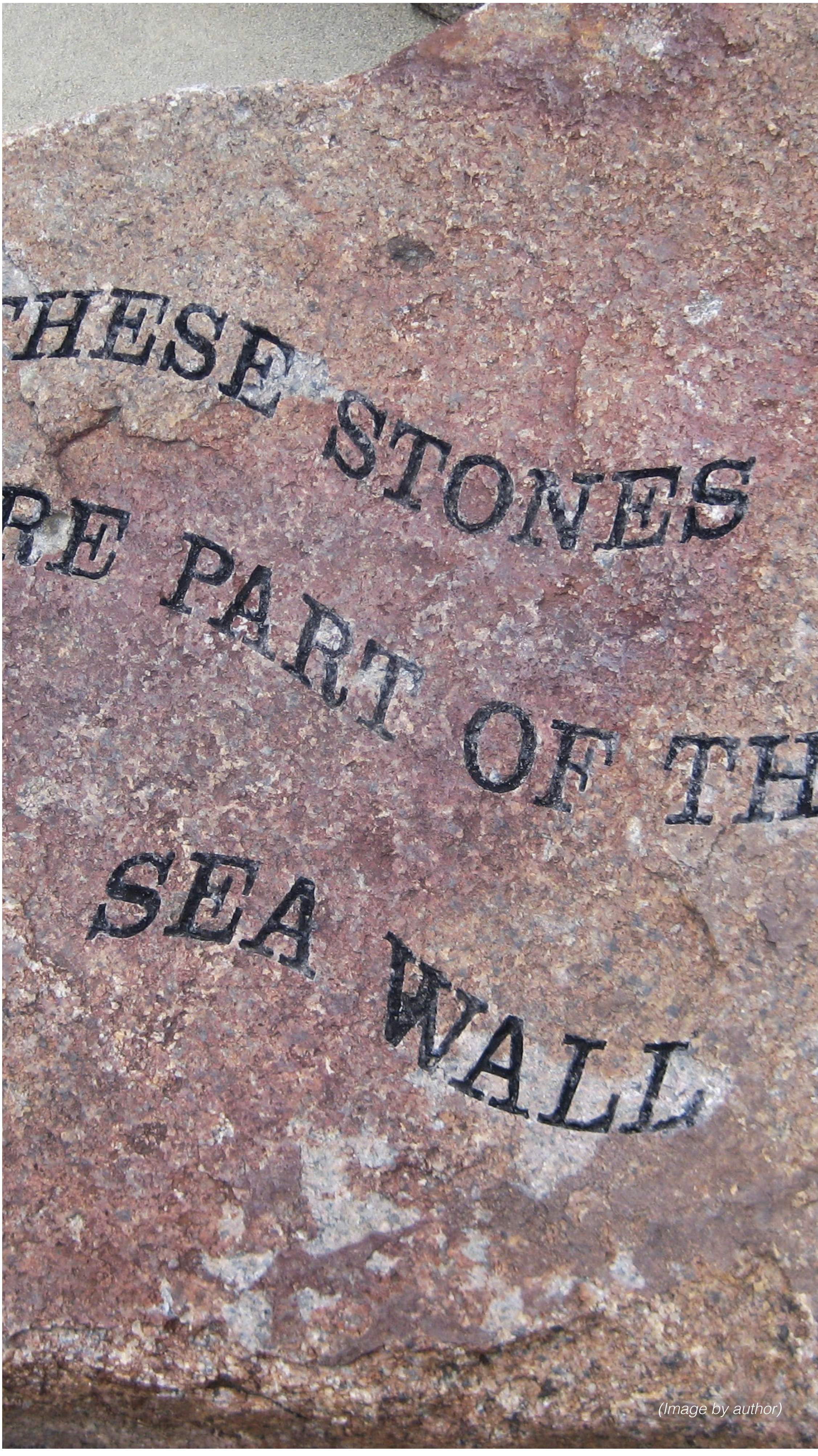
Figure 3.7
The iterative design process that helps to (1) compose the pathways map and (2) select a preferred pathway for further design

4 ASSESS-MENT

(PHASE A)

To test the new approach, consisting of a decision support framework to assist landscape architectural design under uncertainty, I apply it to a case in a real world context. The application of the approach onto the case of Boston could lead to new insights into how the flood risk of this prototypical example of a densely urbanized coastal city could be reduced. Furthermore, the case study allows me to translate research into practice, to add an in-depth understanding to an emerging body of theory on adaptation under uncertainty and I will be able to draw conclusions on the application of the developed design approach.

This chapter consists of the application of phase A of the approach, which is the assessment phase. This part, consisting of three steps, is exploratory and is meant to reduce the epistemic uncertainty.



(Image by author)

4.1 VULNERABILITY ASSESSMENT (STEP 1)

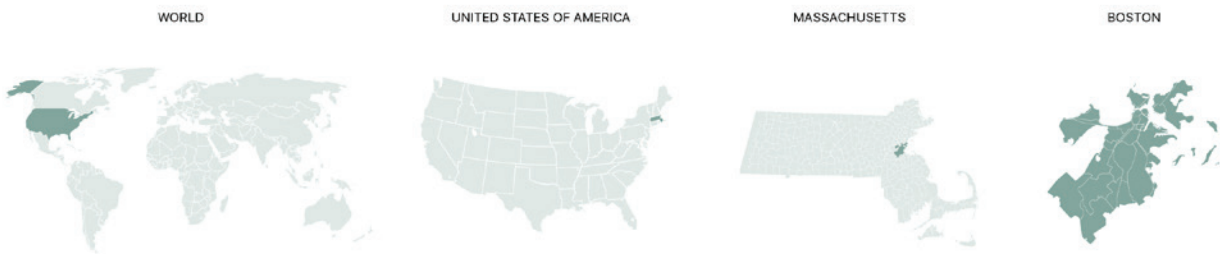


Figure 4.1
Boston within its larger context.

Boston understands that uncertainty is not an excuse for inaction. Despite uncertainty on climate scenarios, the city is proactive and assigned and co-funded a report called Climate Ready Boston, which was published in 2016 (City of Boston, 2016). The report was meant as a body of knowledge that would help to better understand Boston's vulnerabilities to climate change. It comprises modeled projections for the future of Boston to assess the impacts of climate change (sea level rise, more coastal storms, more extreme temperatures and more intense rain and snow). This extensive research on Boston's vulnerability was created through use of innovative and up-to-date techniques. For my contribution to Climate Ready Boston, I intend to use this body of knowledge and build further on it in this chapter in order to create a design for one of Boston's flood-prone areas.

The vulnerability assessment includes investigation on the probability of an event occurring, the consequences of the event, and the vulnerability of people and the natural, built, and social environments to that event. An understanding of current vulnerability and future projections and scenarios helps to obtain a better understanding of how climate change will affect the city's ability to develop them in the future. Given the perspective of my thesis, I will mainly focus on projections regarding coastal flooding for this vulnerability assessment.

4.1.1 ASSESSING CURRENT EXPOSURE

Boston is a coastal city located in the northeast of the USA (Figure 4.1). The city is bordered on the east by Boston Harbor (the confluence of three major rivers), which is connected to the Massachusetts Bay, situated in the North Atlantic Ocean. Bostonians have a love-hate relationship with their shoreline: on the one hand, the Boston Waterfront and its harbor have helped make Boston the big, thriving city it is today, but on the other hand it also presents challenges regarding safety.

Climate affected areas

The city was originally built on the Shawmut Peninsula, which was a mere 3.19 km2 in area. By reclaiming land from the sea, Boston was able to expand and eventually more than doubled in size. Nowadays, many neighborhoods in Boston are built on filled tidelands. The map of Figure 4.2 shows all the areas of land that were filled after 1630. These filled areas are very prone to flooding, because they are the lowest lying areas.

Figure 4.2
A map showing the areas in Boston that are filled (Based on: Map Works,1999).

Due to the fact that large parts of Boston are built on tidelands and because the city has approximately 95 km of coastline, this densely populated urban environment has always been susceptible to storm surge and other coastal hazards. Yet, it is important to understand that every coastal area within the city is vulnerable in its own way. Due to variation in geography and land use, some areas within the city are more vulnerable than others. In general, places in coastal cities that are the most vulnerable to flooding are urban waterfronts with piers and armoring, residential areas with and without seawalls and revetments, and undeveloped land with either rock coasts or gently sloping beachfront and low-lying coastal marshes (Kirshen et al., 2008). Examples in Boston are the industrial districts in South Boston and East Boston, Downtown with its dense commercial areas, and many residential neighborhoods along the waterfronts in Dorchester, East Boston and South Boston.

The sea level rise has already caused certain low-lying areas in Boston to flood during regularly occurring high tides, called astronomical high tides (known locally as wicked high tides). Examples are Morrissey Boulevard, which is an artery in the neighborhood of Dorchester (Figure 4.3), and Long Wharf, in Downtown Boston (Figure 4.4).

Figure 4.3 (above)
Flooding of Morrisey Blvd. caused by wicked high tide. (Anastas, 2018)

Figure 4.4 (below)
Flooding of Long Wharf caused by wicked high tide (Turner, 2017)

Sea levels

The mean sea level (MSL) in Boston is 2,66 m (see Figure 4.5). This level is measured relative to Boston's station datum, and is calculated with data from 1983 until 2001 (NOAA, 2018).

The relative sea level rise (SLR) in Boston has been occurring at an average rate of 2.81 mm (0.11 inches) per year, having caused sea level rise of almost 30 cm (almost a foot) in the past century (NOAA, 2013). This sea level rise trend is visible in Figure 4.6. The increasing trend can increase Boston's vulnerability, because every increase of sea-level rise increases the probability of flooding and can increase the extent of flooding.

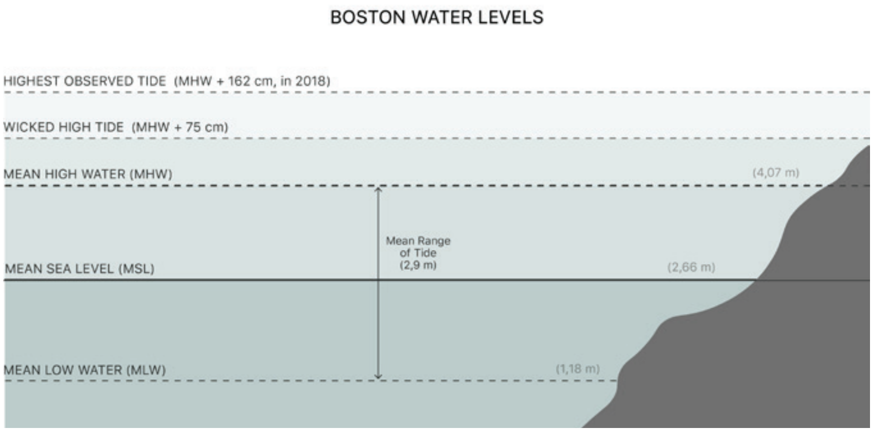


Figure 4.5
Measured sea levels in Boston, showing the relative heights and the mean tidal range (Based on: NOAA, 2003)

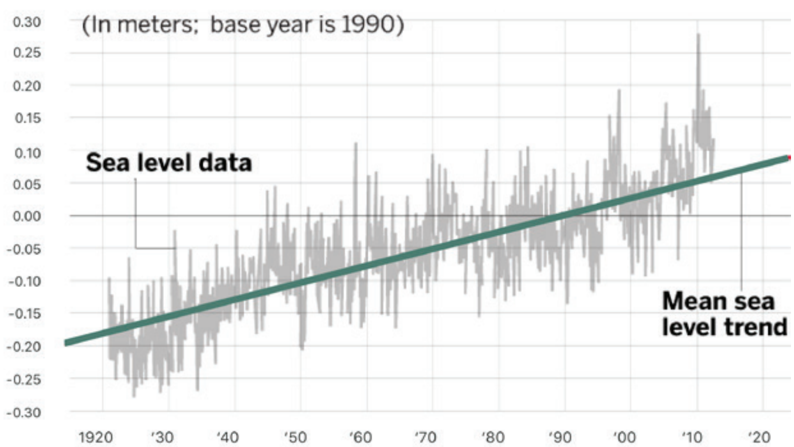


Figure 4.6
Relative sea level trend, showing the mean sea level is rising (Based on: NOAA, 2013)

Storms

In general, coastal flooding in Boston region is caused by extra-tropical storms. Extra-tropical storms have cold air at their center and are locally known as 'Nor'easters'. These storms mostly occur in between the months of September and April, and produce strong winds, heavy snow and rain. Rosenzweig et al. (2011) explain that Nor'easters are generally associated with smaller surges and weaker winds than hurricanes that strike the region, but that the effects of Nor'easters can still be big, partially because of their long duration. Long duration means that the region will have to deal with a long period of winds and high water, which means it is likely the storm will coincide with high tide(s) and cause flooding. Luckily, the city of Boston is partially protected from the damaging effects of these storms, because of some geographic characteristics of the area. The islands situated near Boston's coast (Figure 4.1) serve as an offensive line, that slows down rushing water and knocks down high waves.

Besides extra-tropical storms, tropical storms (warm air) can also cause coastal flooding in Boston, especially when they develop into hurricanes. Hurricanes can be more intense and therefore more likely to cause more intense flooding (Rosenzweig et al., 2011). However, in contrast to Nor'easters, the city of Boston is quite well protected from the full force of hurricanes because of the long arm of Cape Cod in the south (Kirshen et al., 2008). Because of this arm, hurricanes won't hit Boston with full force.

The intensity of flooding caused by storms is dependent on the tide. As Figure 4.5 shows, the tidal range (low tide to high tide) in Boston is around 2,9 m (about 10 feet). The tide height at the time the storm hits is a very important factor, because if an extreme storm (e.g. 5 foot storm surge) hits at low tide, there would probably be no flooding or just a very small amount, since the total water height would still be lower than the normal high tide. Hurricane Sandy (in 2012) is an example of a storm that hit Boston's coast at low tide. This was the reason why the storm brought little damage to Boston. However, if a 5-foot storm surge (1,52 m) would arrive at spring tide, this 5 feet of water would be added on top of the spring tide (Lynds, 2013), which would likely cause flooding to low-lying areas.

An example of a storm that hit during high tide is the 'Blizzard of '78'. Because the storm hit during one of the highest tides of the month, the sea level rose to almost 1,6 m above the mean high water level, causing flooding that resulted in major damages in Boston. This storm held the record for the highest observed tide, until this record was broken by the recent storm of January 4th, 2018. The historical coastal storms that caused the highest levels of flooding in the last century are depicted in Figure 4.7.

Because of rising sea levels and increased waterfront development in Boston, storms like the ones depicted in Figure 4.7 will cause a lot more damage today, and likely even more in the future.

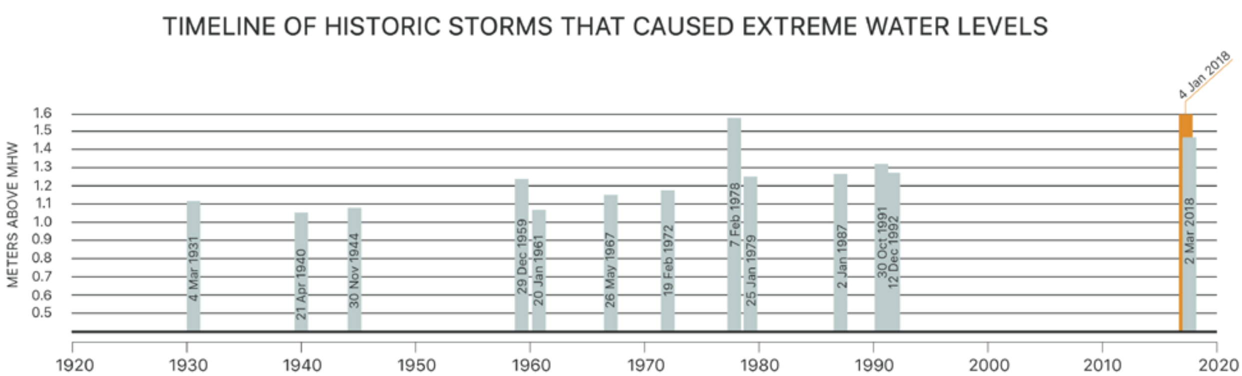


Figure 4.7
A timeline of historic storms that caused extreme water levels that exceeded the 10% annual exceedance probability levels. The record level of January '18 is visualized in orange. (Based on: NOAA, 2017)

4.1.2 UNDERSTANDING FUTURE CLIMATE CONDITIONS

Scenarios

Because the change in climate highly depends on the levels of global emissions of greenhouse gases and because we can not predict how high our level of emissions will be, climate scientists work with multiple emission scenarios to create future projections. The data that is used in the Climate Ready Boston (CRB) report is based on three scenarios from the Intergovernmental Panel on Climate Change (IPCC): Low emission, moderate emission and high emission scenarios. These climate scenarios were used in the CRB-report to estimate future probabilities of sea level rise and particular flood events. Furthermore, a physically based modeling approach for computer-based inundation mapping was used to visualize the extents of several flood events. These outcomes are used in this thesis to assess future vulnerability, which can help reduce epistemic uncertainty.

Sea level rise projections

The recent studies by the BRAG (2016) show that Boston's sea levels are likely to rise 20 cm (8 inches) by 2030, 46 cm (18 inches) by 2050, 94,5 cm (37,2 inches) by 2070 and 225,8 cm (88,8 inches) by 2100 under moderate to high emission scenarios (numbers relative to the sea level in 2000). This is visible in Figure 4.8. Because of uncertainty, these numbers should not be seen as definitive. The bars in the figure show the likely range of possible future outcomes.

Relative Sea Level rise causes increased tidal range, increased wave energy and increased elevation of coastal storm surges (Figure 4.9), which will logically increase the likeliness of flooding. Sea level rise projections associated with rapid ice melt of the Greenland and West Antarctic Ice sheets (DeConto and Pollard, 2016), will therefore likely lead to more extreme events and cause exacerbated intensity, frequency and duration of flooding and inundation. Especially in combination with storm surge.

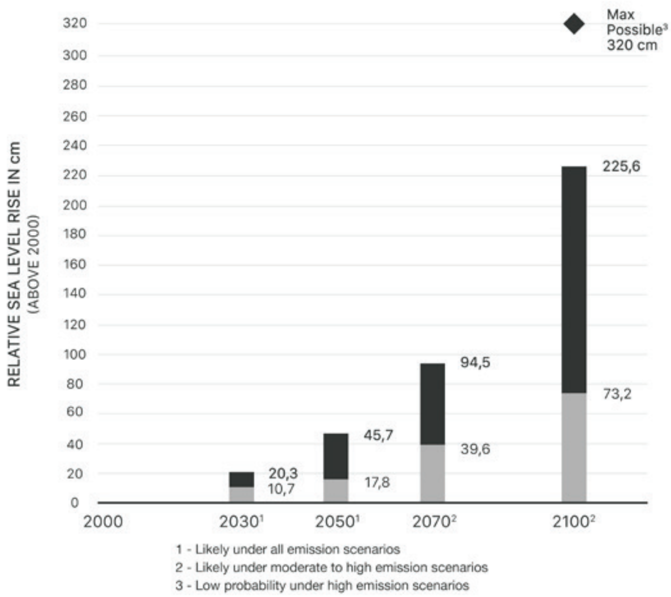


Figure 4.8
Sea level rise projections
(Based on: BRAG, 2016 & City of Boston, 2016.)

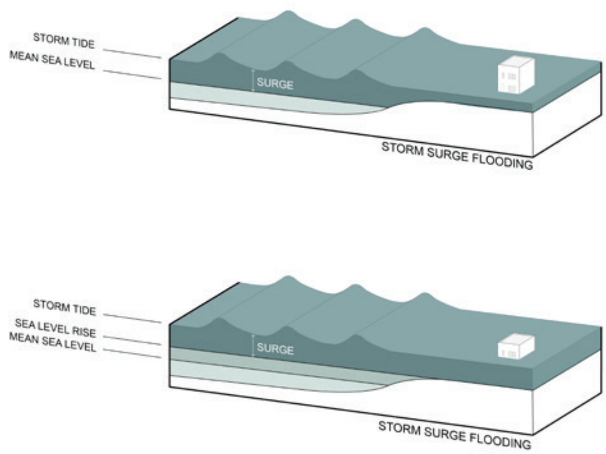


Figure 4.9
A representation of current storm surge flooding and storm surge flooding with sea level rise.

Figure 4.10
Will the past be the future?
Boston's historical coastline in 1630, similar to the coastline projected for the year 2100
(D'Ignazio & Sutton, 2016)

As is visible in Figure 4.8, researchers have projected an additional 73,2 - 225,6 cm increase by 2100 relative to the level in the year 2000 (BRAG, 2016). This could mean that in the future most of the filled tidelands in Boston will flood again, causing the land to (almost) turn back to its original outline of the 17th-century (see Figure 4.10).

Storm projections
Accelerated sea level rise in combination with storms are issues of critical concern for Boston and its surrounding region. However, no conclusions have been drawn on the future intensity, frequency and duration of the storms themselves, since there are large uncertainties about how climate change will affect future storms (City of Boston, 2016).

4.1.3 SITE SELECTION

The CRB-report has used the sea level rise scenarios and projections to characterize the risk of climate change on Boston's neighborhoods and to identify the most critical assets and vulnerable communities in Boston. The report has distinguished seven areas in Boston that are vulnerable to future climate change. These areas are: Charlestown (Charles River Dam), Charles River Neighborhoods, Dorchester, East Boston, Roxbury, South Boston and South End (City of Boston, 2016). The analysis of secondary data from the CRB-report in combination with several site visits in Boston (personal on-site analysis) shed a light on the distinct characteristics and problems of the different areas in Boston.

According to the Climate Ready Boston research, out of all Boston neighborhoods, East Boston is the area that has the most land surface exposed to coastal storms in the coming decades (City of Boston, 2016). This means that in the near future, this area can be seen as most vulnerable to storms and resulting flooding and therefore deserves immediate attention. The report also documented the high vulnerability of residents, critical infrastructure, and community resources in East Boston. These are the main reasons I chose East Boston as the site for my case study. The location of this area is indicated in Figure 4.11. Besides this, I have also seen a lot of opportunities for improvement in this area during my site visits. Driven by gentrification processes, the area undergoes a lot of development, which is not always positive, but it does indicate that the area is ripe for change and investment and that there is room for the type of long-term adaptive plans and designs that I advocate for in this thesis.

Figure 4.11
The location of East Boston

4.1.4 ASSESSING EAST BOSTON'S FUTURE VULNERABILITY

Because of future sea level conditions, East Boston will face increasing threats from flooding. The neighborhood will be extra vulnerable to sea level rise, partly due to its location, but also partly because of the gentrification that is occurring. This is resulting in development of new, large residential buildings along the edges of the waterfront, which are the most flood-prone areas.

The sea level rise (SLR) projections from Figure 4.8 were used to create data sets that could be used for computer-based inundation maps to show which areas will be exposed to flooding in the near term, mid term and long-term. The data sets were used to create three sea level rise maps for East Boston: a map for 23 cm (9 inches) SLR expected in the beginning of the 2030's, a map for 53 cm (21 inches) SLR expected in the beginning of the 2050's, and one for 91 cm (36 inches) SLR expected in the beginning of the 2070s or later. Each of these maps show the water levels for the average monthly high tide, the 10% annual chance storm and the 1% annual chance storm.

The 1% annual chance storm is a storm event leading to flooding, that has a 1% probability of occurring in any given year. It indicates the annual exceedance probability (AEP) and is broadly used term in the United States. Because the 1% AEP flood has a 1 in 100 chance of being equaled or exceeded in any 1 year, and it has an average recurrence interval of 100 years, it can also be referred to as the '100-year flood' (Holmes and Dinicola, 2010)

These maps (Figures 4.12, 4.13, 4.14) are created to assess the areas that could be flooded under different conditions and different timeframes, and show large parts of East Boston under water during the worse case scenarios. The submersion of theses areas would cause problems beyond Boston's current capacity to cope.

Flood pathways

To protect East Boston's exposed areas, it is important to focus on the flood pathways, through which the water can flow over land and inundate larger low-lying areas. Implementation of targeted flood protection systems that block these flood pathways can efficiently and effectively address flood problems. The map (Figure 4.12) shows that around 2030 there are four critical low-lying entry points along the coast that will allow for inland flooding through pathways, if the water in the harbor reaches a high enough level.

First, the southern end of East Boston is exposed, with flooding mainly concentrated in the East Boston Greenway (indicated as GW in Figure 4.12). A large part this greenway lies roughly 60 cm (2 ft.) below the current high tide level. Second, the area south of Bennington Street is exposed by a flood pathway to the west of the area, which will flood the Sumner and the Callahan Tunnel entrances (indicated as TE in Figure 4.12). It is estimated that, because of these entry points, 16 percent of the land area in East Boston may be exposed to low-probability flooding in the near term (City of Boston, 2016). Addressing these locations is therefore critical in preventing large scale flooding in the area.

The percentage of the land area exposed to low-probability flooding events (the 1 percent annual chance event) might increase to almost 50 percent later in the century (City of Boston, 2016). High-tide flooding expected later in the century will use the same flood pathways (Figure 4.14), but will reach much further and the land area exposed to flooding from coastal storms will more than triple as additional entry points for flooding become present. By the end of the century, frequent flooding from high tides will be likely along the East Boston Greenway (City of Boston, 2016).

Figure 4.12
Flood projections for the near term, assuming 9 inches of sea level rise. The darker the colour, the more likely the flooding of the area is: The light blue colour indicates 1% annual chance storm, the darker blue colour indicates 10% annual chance storm and the darkest blue colour indicates flooding at high tide. The locations of flood pathways are indicated with arrows. (created in QGIS, with data from: BostonOpenData, 2017)

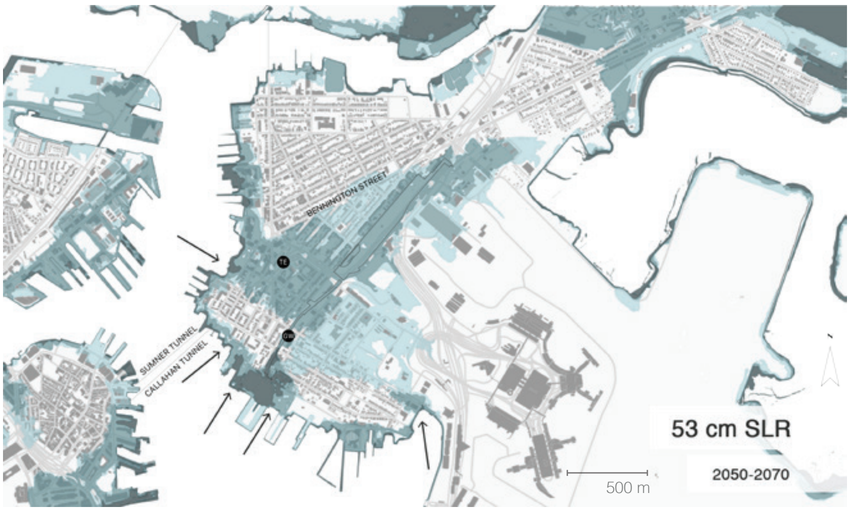


Figure 4.13
Flood projections for the mid term, assuming 21 inches of sea level rise. The darker the colour, the more likely the flooding of the area is: The light blue colour indicates 1% annual chance storm, the darker blue colour indicates 10% annual chance storm and the darkest blue colour indicates flooding at high tide. (created in QGIS, with data from: BostonOpenData, 2017)

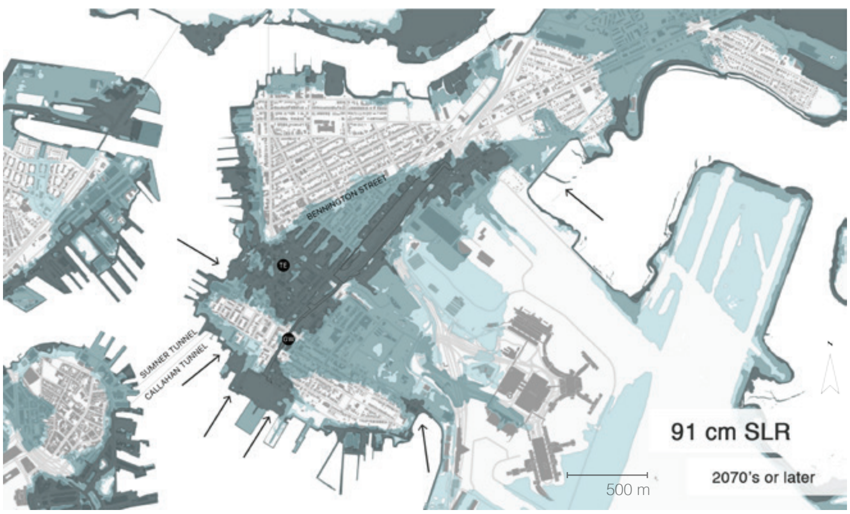


Figure 4.14
Flood projections for the long-term, assuming 36 inches of sea level rise. The darker the color, the more likely the flooding of the area is: The light blue color indicates 1% annual chance storm, the darker blue color indicates 10% annual chance storm and the darkest blue color indicates flooding at high tide. (created in QGIS, with data from: BostonOpenData, 2017)

Figure 4.15
Lewis Street flood pathway in East Boston, in non-flooded state, April 12, 2017

Figure 4.16
Lewis Street flood pathway in East Boston, in flooded state during Nor'easter storm, March 2nd, 2018 (Holt, 2018)

Some of the projected flood pathways are already flooding during extreme weather events. An example is the Lewis Street waterfront, which experienced flooding on March 2nd, 2018, when a Nor'easter hit Boston's coast (see Figures 4.15 and 4.16). This shows that flooding though pathways is not just a future risk and that adaptation is currently already needed in some areas of East Boston.

Vulnerability and exposure of social and built environment

East Boston currently has over 40,500 residents. In the CRB-report it is estimated that, in the near future, around 300 people living in East Boston could be exposed to flooding from high tides (frequent flooding) and 7,020 people could be exposed to flooding from a 100-year-flood (City of Boston, 2016). By the end of the century, these numbers will increase to around 6200 people (flooding from high tide) and 19,070 people (flooding from 100-year-flood). What can be concluded is that not only half of the land area, but also half of East Boston's population will be exposed to flooding in the future (City of Boston, 2016).

An analysis of the amount of residential parcels that will be located within the 100-year floodplain, resulted in the three maps (short-term, mid term, long-term) of Figure 4.17.

Figure 4.17
The residential parcels in East Boston that will be exposed to flooding in the short-term, mid term, and long-term, when a 1% annual chance storm hits.
(created in QGIS, with data from: BostonOpenData, 2017)

Some of these exposed residents are more susceptible to flooding then others. A disproportionate susceptibility of some social groups to the impacts of hazards, including death, injury, loss, or disruption of livelihood is called social vulnerability (City of Boston, 2016? check). The consequences of coastal flooding (and other natural hazards) fall hardest on socially vulnerable groups of citizens, because they don't have much (financial and/or physical) capacity to adapt or recover afterwards, or they are not well informed because of language barriers. Examples of socially vulnerable groups are older adults, children, people of color, people with limited English proficiency, people with low or no incomes, people with disabilities, and people with medical illnesses. Figure 4.18 and 4.19 show the analysis of the percentages of people of East Boston's population that have indications of social vulnerability and where they are located. When looking at the flood projections combined with the social vulnerability maps, it is clear that a lot of the areas where these vulnerable population groups live have chances of flooding, which could lead to devastating consequences.

To reduce these identified vulnerabilities, spatial adaptation of the area is necessary. The next chapter therefore consists of a landscape analysis to obtain a more in-depth understanding of the landscape, which will be used to create an adaptive design.

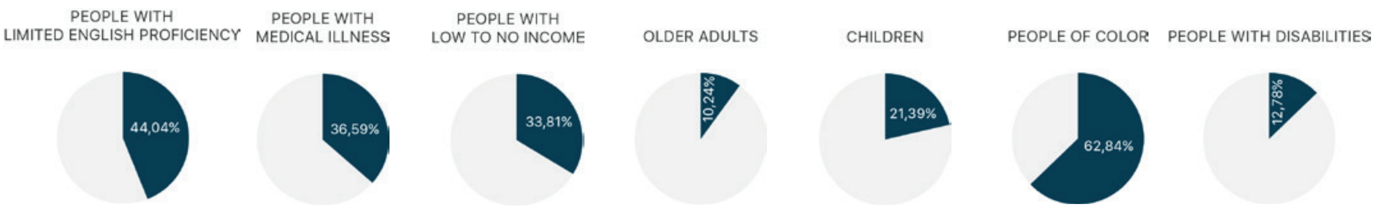


Figure 4.18
Charts showing the percentages of East Boston's population with indications of social vulnerability. (created with data from: BostonOpenData, 2017)

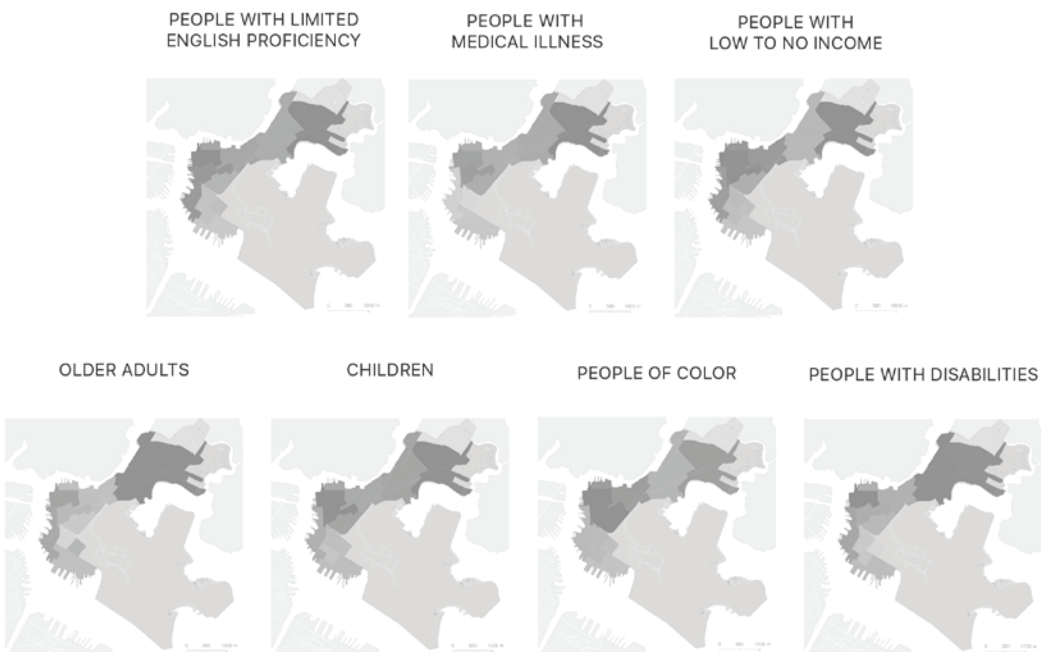


Figure 4.19
Social vulnerability maps showing the amounts of people per sub district. Dark indicates the highest amounts, light indicates the lowest amounts. (created in QGIS, with data from: BostonOpenData, 2017)

4.2 LANDSCAPE ANALYSIS (STEP 2)

Figure 4.20
Aerial view of East Boston, surrounded by water. The airport is visible on the right.
(Cleaveland, 2015)

This section elaborates on the context of East Boston and its physical, historical, social, economic and cultural dimensions to get a good understanding of the landscape as a complex and dynamic socio-cultural construct (within the historical context of the landscape). This step also helps to gain knowledge on spatial problems, constraints and opportunities for adaptation, which can be translated into meaningful design guidelines, that were used for the design of Boston's flood prone areas.

4.2.1 EAST BOSTON SITE ANALYSIS

East Boston (Figure 4.20), located right across the Inner Harbor from Downtown Boston, can be described as a very culturally diverse area, with people of many different races and backgrounds, whose geography, causing it to be surrounded by water, gives the neighborhood a strong identity but at the same time creates a sense of isolation.

History
Before the time Boston started its land reclamation, East Boston consisted of five Islands called Hog Island, Noddle Island, Governor's island, Apple Island and Bird Island which were privately owned islands that were used as a suburb Boston's wealthy residents. Hog Island and Noddle Island were located where the current residential and commercial areas are situated. Governors island, Apple Island and Bird Island were located in the area where Boston's international Airport is built.

In the beginning of the 19th century, the City of Boston experienced a maritime boom. With its waterfront as a home to major shipyards and wharves (including the wharf from which Donald McKay's world-renowned clipper ships sailed), East Boston became known for shipbuilding. This attracted a large number of immigrants from Ireland, Norway, Canada and Portugal, to the area that came to work in the shipbuilding industry, which turned the neighborhood into a culturally diverse, working class neighborhood. This new industry was also one of the causes for the big landfill projects of that century, because it required harbor improvements, and room for more shipping facilities to compete with other port cities.

Figure 4.21
Evolution of Boston from 1630 until 2018
(Based on: Map Works,1999)

However, by the end of the 19th century, the shipbuilding industry declined and East Boston became more known for trade, port activities and other local industries. In the 1920s, Boston Logan International Airport was developed. This caused the local industries to decline in favor of airport-related development. The development of the airport required even more landfilling and therefore the entire area between Noddle island, Bird island and Governors island was filled by 1950.

Current situation
East Boston now has an area of approximately 12,2 km^2, of which a large part is taken up by the airport. The area of the airport is indicated wit the symbol on the map (see Figure 4.22). As a host for Boston's International airport, East Boston functions as the city's main transport hub. This means that accessibility to and from East Boston is very important, in order for the hub to function. East Boston can be accessed via the Callahan, Sumner and Ted Williams Tunnels, a metro line (The Blue Line), ferries (MBTA), and surface roads to the north.

Besides the airport, the largest part of East Boston is still residential area. Currently, the neighborhood houses over 40,500 residents and has a population density of 3262,5 people per km2 (8352 people per square mile). The population has changed a lot during the past centuries, but it can still be characterized as a very diverse community with people from many different backgrounds, of which immigrants from Latin-America and Hispanic-Americans form the largest part.

Figure 4.22
Map indicating Boston Logan international airport

Figure 4.23 Impression of East Boston

From top left, to bottom right:
Construction sites of new development
Large infrastructure
Pier along the Harborwalk
Park with highway above
Densely built areas
Diverse waterfronts

East Boston is one of the few neighborhoods created with a formal plan, which is clearly visible in the grid-structured development (see Figure 4.24), which is in contrast with the rest of the urban form. These grids were developed by the owner of Noddle Island, who founded the East Boston Company, which was the company that became responsible for transforming the island into a residential area. The original plan that was created by this company, divided the island into three areas: Maverick square, Eagle hill and Jeffrey's point. As of today, these areas can still be distinguished (see Figure 4.24).

Figure 4.24
Grid structures in East Boston. The borders of the different sub districts of East Boston are indicated in orange.

4.2.2 SPATIAL PROBLEMS

To be able to create an adaptive design for East Boston, I identified a few spatial problems, constraints and opportunities for adaptation that could be translated into design objectives and design guidelines.

Figure 4.25
An infrastructural barrier (on the left) between Maverick square and Eagle Hill (Google Maps, 2018)

1. Spatial barriers

In some parts of the areas mentioned before, Maverick square, Eagle Hill and Jeffrey's point, spatial barriers obstruct flow through the area, and therefore, the connection between these different communities. Physical barriers, such as highways, railroad tracks, and dead-end streets in the built environment can disconnect urban spaces by, for example, cutting off walking paths and imposing excess walking distance.

An example that obstructs the connectivity of paths and roads is the 1A Highway that crosses East Boston and forms a barrier between parts of Maverick square and Eagle Hill (Figure 2.25).

Figure 4.26 (above)
An unattractive part of the waterfront in East Boston, March 29, 2017

Figure 4.27 (below)
An unattractive part of the waterfront in East Boston, April 12, 2017

Figure 4.28
A part of the waterfront that is inaccessible, March 29, 2017

2. Unattractive waterfronts

The waterfront used to be one of the vital parts of the area, but now that its maritime heydays are over, East Boston has lost a part of its identity. Large parts of the waterfront in East Boston have been neglected and currently lack vitality and attractiveness. For example, some parcels along the waterfront are simply vacant or are used as car parks, which does not contribute to an inviting or attractive waterfront. The current waterfront also offers few possibilities for recreational activity, except from a sailing center and the parks that have playground features and sports facilities. Figures 2.26 and 2.27 show examples of the unattractive parts of the waterfront.

3. Inaccessible waterfronts

Currently, various features separate the neighborhood from the water. Waterfronts are often obstructed by walls, fences or buildings, which form both physical and visual barriers that make a lot of parts of the waterfront inaccessible or invisible. These walls and fences decrease freedom of movement through public space and movement along the waterfront and especially new large housing development projects of multiple storage apartment buildings cause obstruction of views on the waterfront. There are limited possibilities to walk along the waterfront and when pathways along the waterfront are provided, they often stretch a short distance or they are interrupted. An example of an inaccessible waterfront is depicted in Figure 2.28.

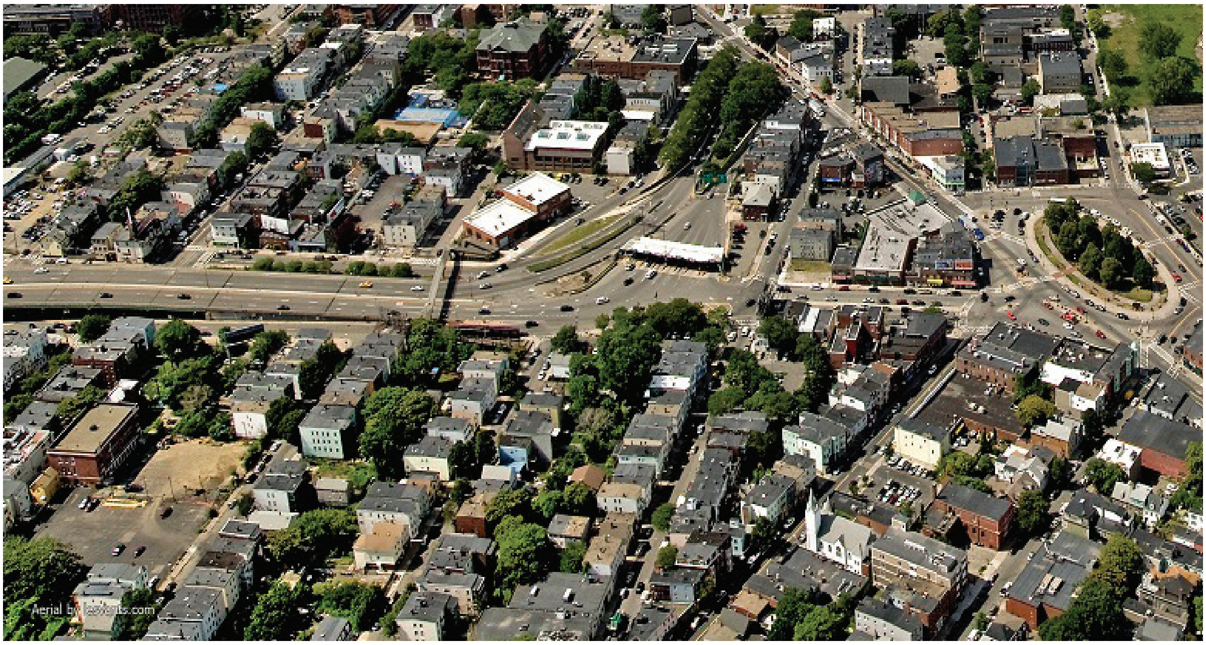


Figure 4.29
Aerial picture showing the densely built area
(Advisors Living, 2015)

4.2.3 SPATIAL CONSTRAINTS FOR ADAPTATION

1. Dense urbanization

Because East Boston is so densely built, there are not many permeable areas. As Spirn (1985) describes, urban areas like this disrupt the natural, hydrologic cycle by prohibiting water from reaching the soil. Besides that, urban wastes introduce pollutants into the flow of water. The densely built area also causes constraints for large scale adaptation measures, because there simply is not a lot of space left. Figure 4.29 shows an aerial view of a densely built part of East Boston.

2. Protection of maritime industry

A constraint for adaptation is the importance of maritime industry in the Boston Harbor. This constraint is presented by the policies, laws and planning measures that are applied in this area. Because of East Boston's location, it was an ideal area for shipbuilding (clipper ships) and other marine industries. Even though a lot of the former industries have left the area, the Commonwealth of Massachusetts has established ten Designated Port Areas (DPAs) to protect these marine industries, of which two are located in East Boston. These DPAs were created to protect and accommodate water-dependent industrial uses within these regulated areas. DPAs have particular physical and operational features important for water-dependent industrial uses and are therefore protected in this way to prevent competition from "non-industrial or nonwater-dependent types of development" (Mass.Gov Energy and Environmental Affairs, 2012). Industries such as commercial fishing, shipping, and other vessel-related marine commercial activities and/or for manufacturing, processing, and production activities that require marine transportation or need large volumes of water for withdrawal or discharge fall under the protection of the DPAs (Mass.Gov Energy and Environmental Affairs, 2012). In order to protect this industry, adaptation measures should not obstruct shipping and other maritime industries. Since maritime industries thrive at sites with well-developed shorelines and deep water channels, certain adaptation measures that are designed in the water are therefore often not the best options for East Boston.

4.2.4 OPPORTUNITIES FOR ADAPTATION

Besides the spatial problems and the constraints for adaptation, there are also a few opportunities for adaptation. This section explains how these opportunities provide possibilities to deal with some of the problems mentioned above.

1. The opportunity to store water

An opportunity in the area in terms of reducing the risk and impact of flooding, could be larger permeable surfaces that are able to catch and store water. However, East Boston is largely built up out of impermeable surfaces, such as concrete and tarmac, consisting of building footprints or paved areas such as streets, sidewalks and parking lots. Because of these surfaces, water can't infiltrate into the soil which causes the water to be channeled straight into drainage systems. These systems can quickly become overwhelmed in storm events and that is when flooding occurs. What is noticeable is that there a only a few green, permeable areas in East Boston (see Figure 4.30).

It is calculated (City of Boston, 2015) that East Boston has 5.33 acres of open space for every 1000 residents, which is below the city average of 7.64 acres. The open areas that are present in East Boston are mostly smaller parks, which are located in different areas of the neighborhood. Besides the smaller parks, the neighborhood includes the East Boston Greenway, Constitution Beach, and Belle Isle Marsh (Figure 4.30). From my analysis I can conclude that the East Boston Greenway provides a big opportunity to store water, because of its location. It is a large connected open area and it's situated in one of the lowest parts of East Boston, which causes water to naturally divert to this site. This visible in Figure 4.31, showing the image of a flooded East Boston Greenway.

From the vulnerability assessment it is clear that the Greenway is part of a flood pathway from which a lot of areas in East Boston can flood. Making sure the water is contained within this area could immediately reduce flood risk in the area.

Besides the opportunity to store water, redesign of this area also can provide additional benefits for the community. The East Boston Greenway (EBG) is a long linear, shared use path that connects several parks and natural areas. The path provides for multiple recreation and transportation possibilities, such as walking, bicycling, skating and people in wheelchairs.

Figure 4.30
Open spaces in East Boston
(created in QGIS, with data from: BostonOpenData, 2014)

The Greenway connects several open spaces in East Boston, including Piers Park, Memorial Stadium, Bremen Street Park, Wood Island Bay Marsh, Belle Isle Marsh and it also allows access to Constitution beach. The linear site is currently 3,2 km (2 miles) long. When completed, the Greenway is expected to be 5.3 km (3.3 miles) in length.

The Greenway is located on the path of a former train line, the Conrail line, which used to run straight through East Boston on a lower lying track. In Figure 4.32, it is visible that this decommissioned part of infrastructure is sunken (deepened) several feet beneath the surrounding areas. Its lowest point has an elevation of 2 ft, while the elevation of the surrounding areas in many places ranges from 8 ft. to 16 ft. (approximately). As the rail line was designed to be closed off from its urban surroundings for safety reasons, the Greenway still only has a few entry points (see Fig 4.33). Creating more accessibility, by connecting more areas and streets to it and adding and more program could enhance the benefits the Greenway provides for the community.

In Figure 4.34 the Greenway is analyzed through sections, which show the lower lying areas where water would naturally divert to.

Figure 4.31
A flooded East Boston Greenway (DiFrisco, 2010)

Figure 4.32
The deepened East Boston Greenway, April 12, 2017

Figure 4.33
The East Boston Greenway and the points from where you can enter it

SECTIONS 1:1000

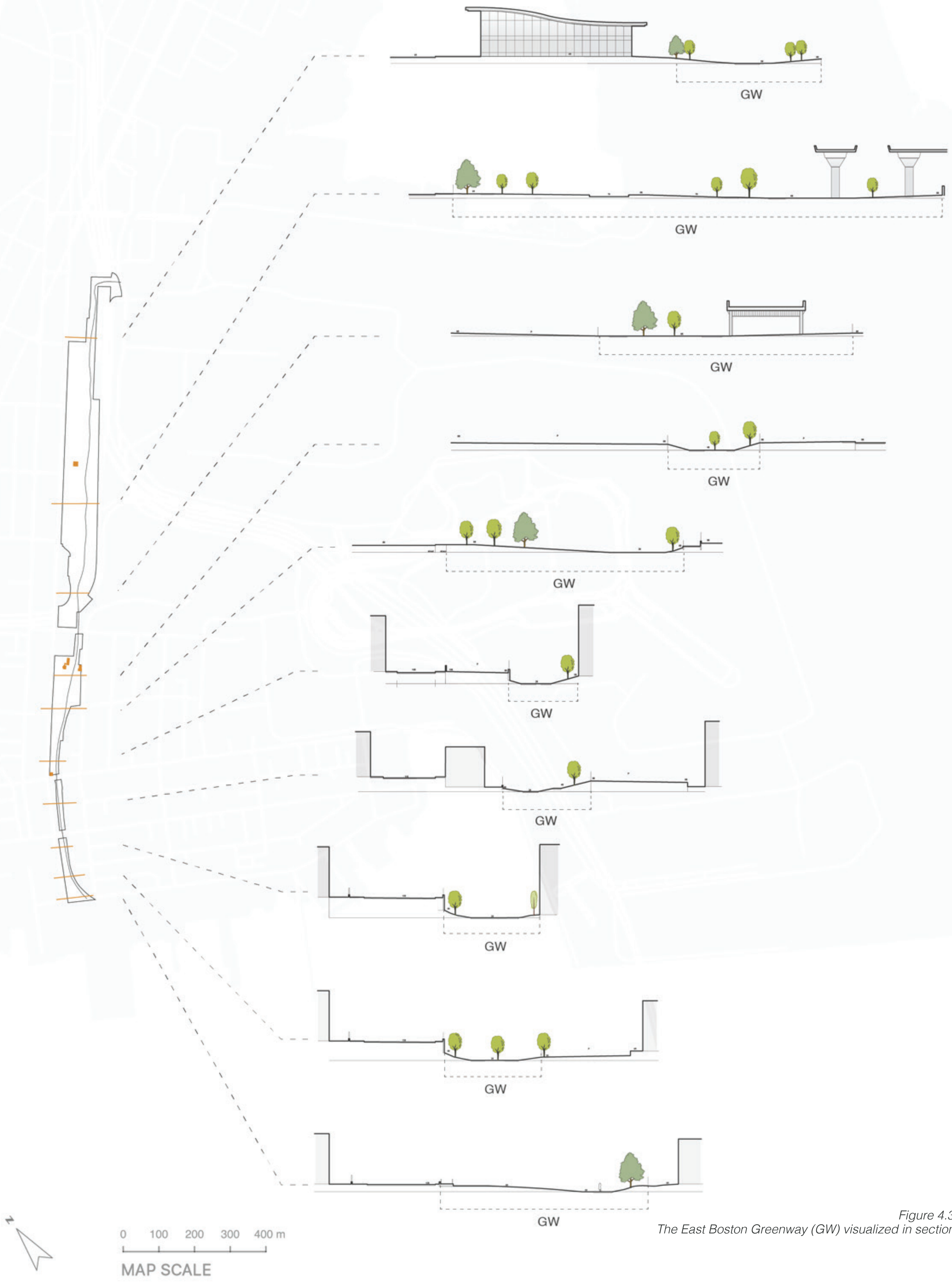


Figure 4.34
The East Boston Greenway (GW) visualized in sections

2. The opportunity to elevate parts of land

In East Boston there are currently a lot of undeveloped parcels along the waterfront. The edges of the neighborhood used to be characterized by the many docks and piers (Figure 4.35), which were very lively and busy parts of the area. Nowadays most of these docks and piers have been removed and the remaining ones often look abandoned and rundown (Figure 4.36). However, some of these former industrial sites are currently being transformed and turned into housing and public space, and more will be developed in the future. An analysis of the yet undeveloped areas in combination with an analysis of critical flood entry points (flood pathways) I could distinguish a few areas that can quite easily be elevated in order to block flood pathways. These are mapped in Figure 4.37. Besides undeveloped parts of land, the map also indicates streets that could possibly be elevated.

Figure 4.35 (above)
Aerial view of North End and East Boston, 1928
(Jones, 1928)

Figure 4.36 (below)
Aerial view of North End and East Boston, 2018
(Apple Maps, 2018)

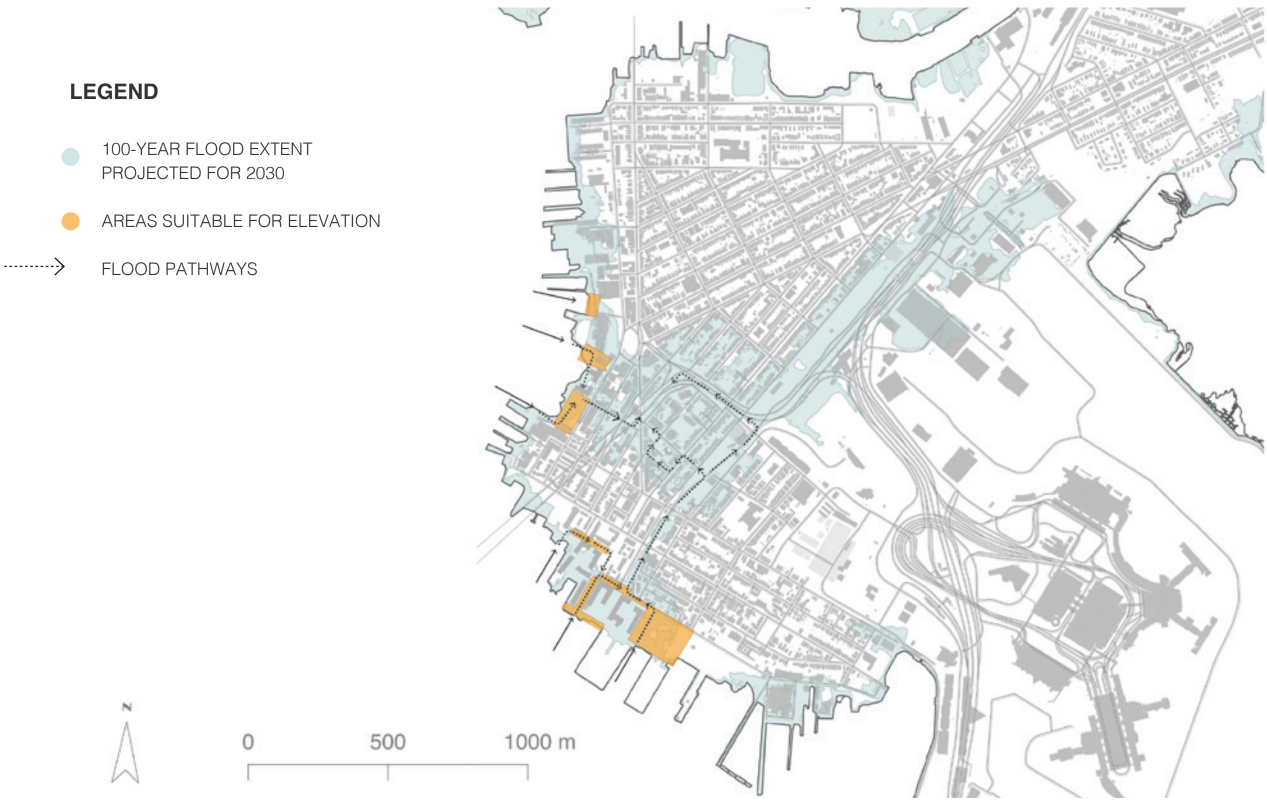


Figure 4.37
Strategic areas for elevation that could
block flood pathways

4.2.5 DESIGN PRINCIPLES AND GUIDELINES

The spatial problems and constraints identified in the previous section are taken a step further for design, by translating them into design principles (sets of generally applicable laws, guidelines, human biases, and design considerations). These principles were in turn translated into design guidelines (practical information on how to implement a design principle). The principles and guidelines are grounded in literature of for example Marcus and Francis (1997) and Gehl (2013). The results are visible in Figure 4.38.

Spatial barriers
Spatial barriers cause disconnected areas. Jane Jacobs (1961) mentions the negative consequences of disconnected areas, as she argues that physical barriers and limited physical access can cause separation and restricted social integration. Connectivity, as a basic principle of urban design, should therefore be improved. Guidelines for design that can improve connection are: new access and connection points, and wayfinding and signage, as this helps for navigation when connection and routing is not straightforward (Lewis & Schwindeller, 2014).

Unattractive waterfronts
Although unattractiveness is a subjective term, there are a few basic principles that define what people perceive as attractive areas. According to Gehl (2013) attractiveness is reached by creating positive sensory experience through for example materialization, fine views and vegetation. Marcus and Francis (1997) speak of visual complexity as a principle to create attractiveness, which is created through a wide variety of forms, colors, textures, sculptures, seating places, nooks and corners, vegetation and changes in level. Another guideline is to add programming, to attract a variety of users and to allow diverse activity to take place (Lewis & Schwindeller, 2014).

Inaccessible waterfronts
To make the waterfront more accessible, principles and guideline for accessibility can be used. A site-specific guideline is to develop more parts of the Harborwalk (Boston Harbor Now, 2017) a more general guideline is to establish (green) links that provide alternative circulation patterns, so there are multiple routes towards one place or area (Lewis & Schwindeller, 2014).

Dense urbanization
The different areas in East Boston are generally dense, with limited private residential outdoor space, such as gardens. The community is therefore dependent on parks. (City of Boston, 2015). Therefore the design principle is to add more green areas and the corresponding guideline is to create a network of green areas. Such a network can create a connection between different neighborhoods and provides access to a large part of open space, without taking up a lot of space within an area itself.

Spatial problems **Constraints for adaptation**		**Design principles**		**Design guidelines**
Spatial barriers	⟶	Connection should be improved	⟶	New access points Wayfinding
Unattractive waterfronts	⟶	Waterfronts should be improved	⟶	Visual complexity Seating areas with fine views Programming Leveled paths
Inaccessible waterfront	⟶	Waterfronts should be accessible	⟶	Harborwalk Green links
Dense urbanization	⟶	More green areas should be provided	⟶	Green network

Figure 4.38
spatial problems, constraints and opportunities for adaptation, turned into design principles and design guidelines

4.3 OBJECTIVES & VISION (STEP 3)

To contribute to a climate ready Boston, the design challenge is to prepare the city for more frequent coastal flooding, while maintaining and possibly even enhancing the welfare of the city. This means there are adaptation objectives as well as city objectives and community objectives that should be taken into account during the design process. To assess these objectives during my research in Boston I have spoken with residents at a community meeting in East Boston, I have spoken with Kannan Thiru (resident & environmental consultant for engaging residents in flood control measures), Manlio Mendez (Resident & Community Organizer) and Phillip Giffee from NOAH (Neighborhoof of Affordable Housing), and I have researched published city documents. The next section explains the outcome of this.

4.3.1 OBJECTIVES FOR CLIMATE ADAPTATION

To reduce the disruptive impacts of natural disaster on the city of Boston, it is important to spatially adapt certain areas in order to protect vulnerable communities and ecosystems regarding both high- and low-probability floods. Therefore, the objective for the adaptive design for Boston is that deaths and injuries should be prevented and damage and disruption during floods should be minimized. These areas should therefore always be protected from a norm frequency of a 1:100 coastal flood event (1 % annual chance flood). Therefore:

- Near-term actions (until around 2030) should protect up to 1:100 coastal flood event with 23 cm (9 inches) of sea level rise.

- Mid term actions (around 2050s) should protect up to the 1:100 coastal flood event with 53 cm (21 inches) of sea level rise.

- Long-term actions (2070s or later) should protect up to the 1:100 coastal flood event with 91 cm (36 inches) of sea level rise.

Conditions where these objectives are no longer met should be avoided. These objectives can therefore also be seen as performance criteria.

4.3.2 ADDITIONAL OBJECTIVES

City objectives
Besides functioning as design for flood risk reduction, the design for the future could also have other co-benefits for East Boston. Therefore I have not only stated objectives for adaptation, but I also researched what the existing objectives of the city are. In Boston, s citywide plan was published, called Imagine Boston 2030 (Imagine Boston 2030, 2017).
In summary, the goals for this plan can be divided in a few topics:

- LIVE: provide quality of life, and ensure affordability.

- WORK: drive economic growth

- ADAPT: provide healthy environments and adapt to climate change

- CONNECT & THRIVE: invest in infrastructure, open space, arts and transit (infrastructure investments) and protect the city's cultural identity and economic vitality.

Community objectives
From a meeting in East Boston (in march, 2017) with Kannan Thiru, Manlio Mendez and Phillip Giffee, who all have close ties to the community, I've learned that many residents are unaware of the risk that their neighborhood is facing. From the meeting it became clear that the community objectives are less focused on climate adaptation and more focused on bringing more housing and other uses to the waterfront of East Boston. Increased use and development of the waterfront is therefore the first community objective. However, this should be done with caution, since the waterfront are the most exposed to flood hazard.

Other objectives were discussed a meeting in East Boston with local residents (April 7th 2017) that informed residents on the research on the risks that the area will be facing and that had as main goal to explore solutions and strategies. Several residents indicated that they want solutions that will protect their safety and their property regarding coastal flooding and indicated that they preferred solutions that had extra benefits for the community. In general, residents were interested in improved mobility, more open space, and better access to the waterfront.

4.3.3 COMBINING OBJECTIVES, ENHANCING IDENTITY

The combination of city and community objectives, led to three additional objectives for design:

- Protect maritime industry
- Connection with water: providing access to the waterfront
- Connection between communities: Develop green networks

By using these objectives as additional objectives for the design, the design can have extra benefits for the city, aside from reducing flood risk. Fulfilling these objectives can help improve the identity of the city, as these objectives help build further on Boston's identity by using what is already there and either protecting or enhancing the characteristics that contribute to the positive identity.

Protecting maritime industry
The location, geomorphology and topography of a city are an integral part of its identity, and therefore it should be embraced and used to benefit from. From research into historical and current spatial characteristics in Boston, I conclude that For Boston, a big part of its identity is its relationship with the water. The water has dictated the location of settlement, it has shaped Boston's contours (elevation) and provided access to global markets since the city's founding. Boston has been known for fishing, trading and shipbuilding for centuries, which also make the water a strong contribution to its welfare. Therefore, focus on protecting maritime industry is chosen as an objective for the design

Connection with water
Besides the fact that it can be used for economic purposes and as a transportation mode, water is also a visual amenity, that fulfills a social function for the city.

By doing site analysis in Boston, I noticed that in some areas, the waterfront is highly embraced and used for recreational purposes, and in other areas the waterfront is isolated, unattractive and polluted. Some areas show (or are starting to show) appreciation for the 'treasure in the backyard': the wharves are being (re)developed and combined with amenities like the aquarium, restaurants, housing, and hotels, to attract people and restore the area's relationship with the water. The Harbor Islands, located along its coast have been rediscovered and are now more accessible and visited more often, and the Central Artery has been replaced with parkland, reconnecting the city and the waterfront. And finally, there's the Harborwalk, along many parts of the waterfront, which offers views of the Boston Harbor.

An actor that plays a role in reconnection with the waterfront, is Boston Harbor Now (before: Boston Harbor Association). This is an organization that has the goal *"to promote a clean, alive, and accessible Boston Harbor through environmental protection programs and harbor activities, as well as providing public access to the water through the Harborwalk"* (Boston Harbor Now, 2017). This Harborwalk was designed to create an uninterrupted walkway along the shoreline of the city to provide people with a place for recreation in the dense city. The Harborwalk is indicated in Figure 4.39.

Connection between communities

Besides the connectivity with the water, a lot of effort is put in to establish connectivity between different areas and neighborhoods. Prioritizing local communities, by building large park systems is a well-known strategy for Boston. Its legacy of parks and park systems is famous all over the world. A quite recent example is a project called 'The Big Dig' where the Central Artery of Boston's infrastructure has been put underground and replaced with parkland. However, the most famous example is Frederick Law Olmsted's design of the Emerald Necklace, in the later 19th century, which is a string of nine connected parks throughout Boston (Figure 4.40). The design for the Emerald Necklace was created to develop interconnected public areas that would provide green, healthy areas for all the citizens of Boston to escape from the pollution, noise and stress of the city.

4.3.4 VISION FOR THE FUTURE: A MULTI-FUNCTIONAL 21ST CENTURY PARK SYSTEM

Combining two recreational concepts: one historical – one present

To create connection between communities and connection with the water, the vision for Boston in 2050 is to combine the two recreational concepts of the Emerald necklace and Boston Harborwalk. This means the Emerald Necklace will be extended all the way towards the water where it will be connected to the Boston Harborwalk. This creates a larger connected network of green areas for nature and recreation and at the same time it functions as a natural coast defense, as it provides a buffer region between the shoreline and the areas where people live. This buffer is important, because the edges of the waterfront will get a lot of exposure to flooding in the future. Leaving room for the Harbor Walk makes the entire edge of the area flexible and adaptable, which provides room for future flood adaptation designs to take place, when new, more precise information has become available.

The combination of the two recreational concepts, by improving urban open spaces and using them to create large networks, will create a park system for the 21st century city, which, as Gehl (2013) mentions, functions as one big meeting place. This park network, accessible to all Bostonians and designed to connect, can be added to Boston's great park legacy.

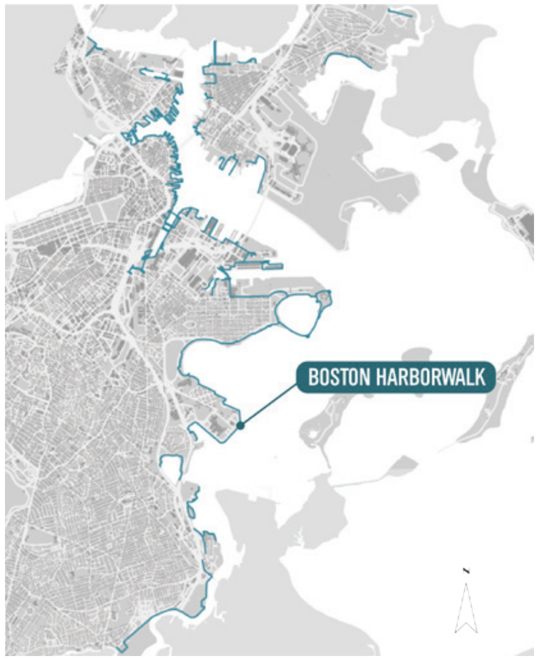


Figure 4.39
The Boston Harborwalk
(created in QGIS, with data from: Boston Harbor Now, 2017)

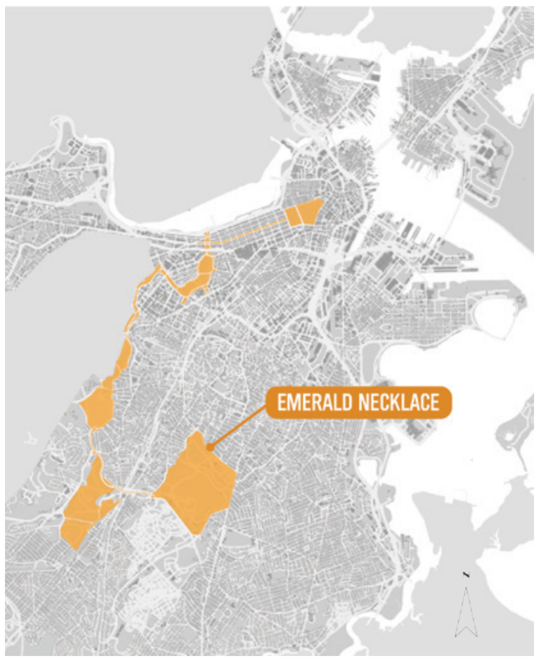


Figure 4.40
The Emerald Necklace
(based on: City of Boston, 2017)

This 21st century park system will make Boston's shoreline and natural areas more accessible and attractive, it will make the water's edge a focus of design and it will make a strong contribution to the identity, vitality, safety and beauty of the city of Boston. The network of parks also adds to another identity of the city, by providing trails and routes for running. Boston is well known for its Marathon and many people in the city run. Creating a continuous path that is runner friendly will provide a lot of people with a safe place to exercise. The concept is visualized in Figure 4.41

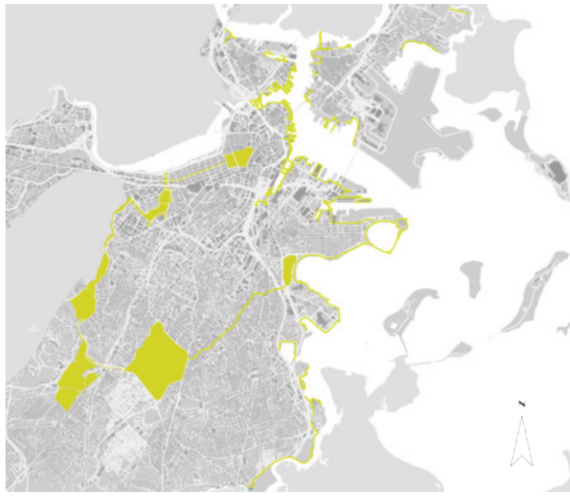


Figure 4.41
The concept for Boston in 2050

4.3.5 THE EAST BOSTON 21ST CENTURY PARK SYSTEM

Translating the vision of a 21st century park system to East Boston, could mean that several missing parts of the Harborwalk will be developed in order to create the interconnected pathway along East Boston's coast that allows access to the waterfront. East Boston's Harborwalk is indicated in Figure 4.42. It is intended to be 9.64 miles long and currently only 3.4 miles are completed (35%), which means there is room for improvement. The interconnected East Boston Harborwalk will also function as a buffer that will be redesigned to protect most low-lying areas from flooding in the case of high water levels. Furthermore, East Boston will have more interconnected open spaces that are safe for walking, bicycling, skating and people in wheelchairs. Existing open spaces will be improved and new areas will be added. Connecting green areas will help to create an urban park system for the 21st century that responds to the needs of the residents. Especially the East Boston greenway and its linear structure, provides the opportunity to connect the different sub districts. The greenway can form a green link that can bring people to and from different areas and it will serve as an area where people can meet.

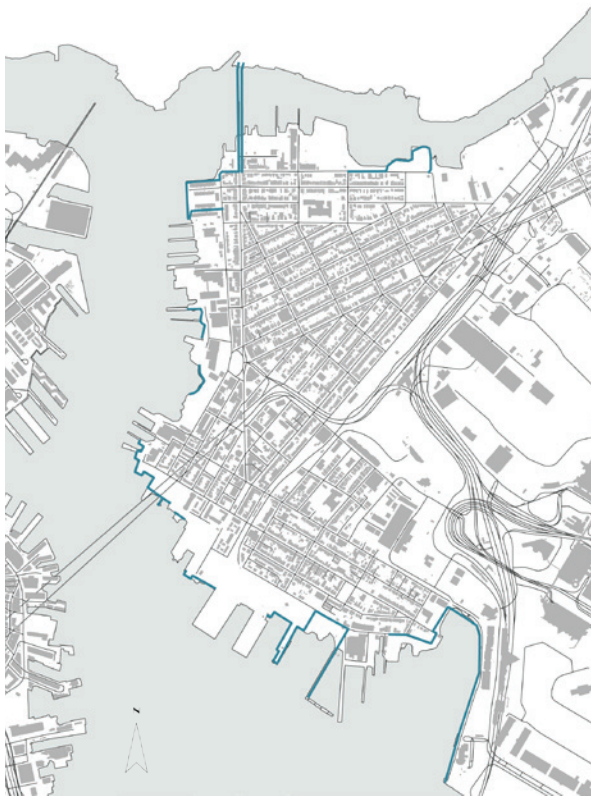


Figure 4.42
The developed parts of the Harborwalk
in East Boston, February 2018

5 DESIGN

(PHASE B)

This chapter consists of the application of phase B of the approach, which is the design phase. This part, consisting of five steps, is solution-oriented and is meant to reduce ontic uncertainty. From here, the approach changes from an exploratory, divergent process into a convergent process, where options are analyzed and evaluated, design choices are made and adaptation measures are designed.

(Advisors Living, 2015)

5.1 PREFERRED ADAPTATION MEASURES (STEP 4)

The first challenge of this convergent phase of the approach is to determine which adaptation measures are most preferable and should be implemented in the area. Therefore the most preferred options are explored.

For the future scenarios, it is clear that East Boston will need measures that enable more resisting capacity along the waterfront. Because Boston is prone to coastal floods that are caused by high tides and storm surges, these measures should be able to break waves and to protect the land from higher water levels. These measures can be combined with measures that accommodate the water when the land floods, such as measures that enable more storage and drainage capacity upon land. The strategies of retreat and accommodate are distinguished by the IPCC CZMS (1990). Because of clear differences between these strategies, distinction between the more resisting and more accommodating measures is made in the sections below.

The measures in this section are derived from a report called Urban Waterfront Adaptive Strategies (NYC Department of City Planning, 2013), which is used as a toolbox to identify a variety of adaptation measures. A subset of these strategies is used in this thesis to identify design measures that could be used along East Boston's waterfront.

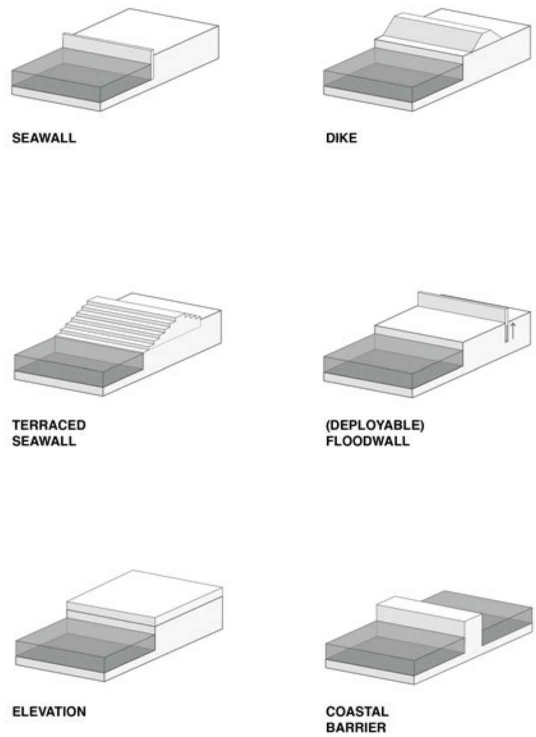


Figure 5.1
Options for grey resisting measures

5.1.1 RESISTING MEASURES

Resisting measures are designed to keep the water out of the area as much as possible by coastal defense systems. Inundation of land is prevented mostly by hard, technological and engineering solutions implementations (grey measures), but also by nature-based or ecosystem-based solutions, forming more natural barriers (green measures).

Grey Measures

Grey measures are physical interventions, construction measures or the use of engineering services to make buildings and infrastructure essential for making society more capable of withstanding extreme events. (EC, 2009). Armoring with hard infrastructure is typically applied where substantial assets are at risk. Grey measures can include seawalls, dikes, terraced seawalls, deployable floodwalls, elevation and large coastal barriers. Especially seawalls are a common form of shore protection in coastal cities.

Seawall/Bulkhead

Seawalls and bulkheads are used for armoring the vulnerable edges that are sensitive to erosion. They brake waves and also prevent flooding from high water levels and storm surges. They should be implemented in places where there is little space along the waterfront.

Terraced seawall

Terraced seawalls should be used when there is enough space along the waterfront. They should be implemented in places along the waterfront with nice views and attractive surroundings, as it provides the additional function as seating area. People would benefit from it most when there are residential areas or cultural and/or recreational amenities around.

(Deployable) floodwall
Floodwalls can be placed along the waterfront or more in-land to protect the areas behind it from flooding. Deployable floodwalls can be implemented in between buildings or walls to temporarily prevent water from entering an area. They should be implemented in places where there is no room for other interventions, or when normal barriers would obstruct views or use of the area. With these temporary walls, an area doesn't have to be altered much, since the wall only has to be deployed in times of flooding.

Dike
Dikes are used to prevent flooding from high water levels and storm surges. They have a pleasant green appearance and can be combined with a path on top that can provide attractive experiences and views. They should be implemented in places where there is a little more space along the waterfront and can be used in green surroundings where a recreational path with a view on the water is desirable.

Land/street elevation
Elevating an entire area of land will protect that area from flooding, as well as the areas behind it. This should be implemented in low-lying areas along the waterfront, especially when important assets are at risk of flooding. Streets and roads can also be elevated, when important evacuation roads tend to flood during flood events.

Large coastal barriers
Large coastal barriers are placed in the water to protect large areas from flooding by storm surge. They consist of dams combined with gates that serve as openings in the barrier. The gates can be closed when it is needed. The entire barrier can close off large waterways by placing the barrier between two shorelines. These barriers can be used when large areas need long-term protection or when areas don't offer much room for other options.

Green measures
Protection through more natural strategies is an alternative to the grey measures. Green measures are ecosystem-based approaches that use the multiple services of nature (EEA, 2013). Examples of these measures are: reinforcing natural defenses such as dunes or wetlands, maintaining and restoring healthy ecosystems, and removing man-made obstacles so that indigenous plant and animal species can move across landscapes (EEA, 2013).

Waterfront park
Waterfront parks are large open spaces on land that are allowed to flood during flood events, as they can quickly recover from flooding. They help protect areas behind it from flooding by storm surge. They should be implemented in places where there is a lot of (open) space, close to dwelling.

Beach and dune nourishments
Nourishments of beaches and dunes improve these natural barriers by increasing their elevation, which will provide a reinforced buffer that protects areas from flooding by storm surge and by breaking waves. These nourishments can be applied where these barriers are already naturally present.

Living shorelines
Living shorelines are a more natural way of shore protection by bank stabilization through plants, soil and revetment structures. They can mainly be used to break waves, but also to protect areas from flooding by storm surge when the soil is elevated. They should be implemented in places that (can) have ecological value and when there is room for it along the coast.

Revetment
Revetments consist of concrete parts or rocks that together form a structure along the coastline. These structures form habitats for sea life and can be used to break waves. As they cannot prevent flooding, this measure is not a sufficient protection measure on its own. They should be implemented in where 'speed bumps' are needed to break waves.

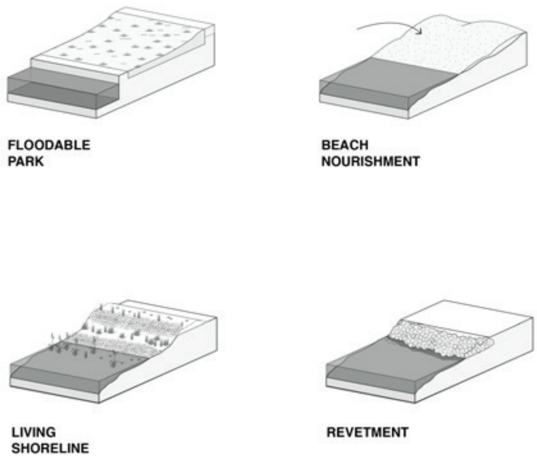


Figure 5.2
Options for green resisting measures

5.1.2 URBAN ACCOMMODATING MEASURES

Urban adaptation also involves making room for water in the city. Besides using resisting measures to keep the water out, Boston can use its open spaces to temporarily accommodate excess flood water, or overtopping. Accommodating measures revolve around slowing the flow of water across the landscape, and storing large volumes of water, once the land floods. This can be done by creating permeability and absorbing areas or by creating hard structures that can withstand flooding. These measures allow human activities and the hazard to coexist. Accommodating measures are often intended to complement traditional, protecting hard measures, such as floodwalls.

Storage
Urban development consists of large amounts of hard, impermeable surfaces that do not allow any water infiltration. Therefore it is necessary to have retention areas that can store larger amounts of water for a longer time during of events of flooding.

Basin
Basins are structures that can hold water so they can be used to create more storage capacity in an area. They keep water into the area and out of the drainage system. This measure should be combined with structures that divert the water into storage area during a flood event, before it reaches built areas. It should be implemented when there are large open places that provide room for storing water above the ground.

Cistern
Cisterns are underground structures that are used to create more storage capacity in an area. They can either be separate structures underground or they can be integrated in buildings, such as parking garages. They should be implemented when there is little to no room for storing water above the ground.

Flood-proofing buildings
Buildings in areas exposed to flooding can be flood-proofed to protect its users or in order to use it in flood defense systems. For the latter implementation, the building should be completely integrated in the flood defense system. They should be implemented when buildings, built in exposed areas, are not well enough protected by protecting waterfront measures.

Drainage
Drainage measures are used to remove water from inundated areas when the storm is over or during low tides. The discharge rate can be enlarged by for example additional pumps and alternative drainage routes, to create a well functioning drainage system.

(Storm)water pump & (Storm)drain
Pumping system are used to discharge water out of an area. Pumping systems should be applied where large amounts of water can’t be removed naturally, because natural flow of water is impossible.

Retreat
Another adaptive measure is to simply retreat. This way the use of structural protection is limited. Development in areas prone to flooding is limited, and buildings and infrastructure are relocated to unexposed areas. Retreating includes withdrawal, relocation or abandonment of built assets that are at risk of coastal flooding.

5.1.3 THE MOST APPLICABLE MEASURES

In this step the measures appropriate for East Boston are identified. To find applicable options, it's important to look at the specific context to select the adaptation measures that are most applicable for the specific location, as not every measure is suitable within the context of East Boston.

For this location, the spatial possibilities, but also the spatial constraints should be kept in mind. For East Boston, applicability (or feasibility) of a measure means that the measure fits within a densely built urban area, where there is little room for big scale interventions. Big scale interventions are therefore less favored. Besides this, it would be beneficial to the community of the adaptation measures would not obstruct the views on the water. Second, one of the city objectives, identified in step 3, is to protect the maritime industry. Therefore, measures should not affect East Boston's maritime industry and interfere with the multiple laws and restrictions on this topic. These laws and restrictions aim to protect the maritime industry, in order to remain a competitive port city. Therefore I evaluated the applicability of the different measures in terms of (1) spatial feasibility and (2) regulatory feasibility concerning harbor activity. Because laws and regulations are involved, the regulatory feasibility outweighs the physical and visual impact in the decision making of applicable measures.

Spatial feasibility is rated according to the visual impacts (low, medium, high impact) of the measures, which are determined by height and location, and physical impacts (low, medium high impact), which are determined by footprint of measures. Regulatory feasibility is rated according to the impact on shipping (low, medium, high impact), which is determined by possible water depth for the measure, and how well the shorelines are developed with a specific measure. In Table 5.1, the outcome of the evaluation of applicability of all the measures in the context of East Boston is shown. The most applicable measures have been selected and these will be used in the design process.

Table 5.1 shows that most of the measures from the literature are applicable for East Boston. However, most of the soft resisting measures are in light grey, meaning they are deemed as not well applicable in the context of East Boston. This is because these measures can obstruct shipping and industry, as maritime industries thrive at sites with well-developed shorelines and deep water channels. Some of the soft measures are therefore not the best options for East Boston. The next step is to determine how high the resisting structures need to be.

Table 5.1.
The outcome of the evaluation of adaptation measures in terms of applicability. The least applicable measures are indicated in light grey. De remaining measures are selected as appropriate for in the context of East Boston.

MEASURES	CRITERIA				NOTES
	Physical Impact	Visual Impact	Impact on shipping/industry	Applicability	Explanatory notes
HARD RESISTANT MEASURES					
Bulkhead/Seawall	low	medium	low	+++	
Terraced seawall	medium	medium	low	++	
Deployable flood wall	low	low	low	+++	
Dike (Levee)	medium	medium	low	++	
Land elevation	high	low	low	++	
Large coastal barriers	high	low	low	++	
SOFT RESISTANT MEASURES					
Beach and dune nourishments	high	medium	low	+	Only where beach/dunes exist
Floodable waterfront park	high	low	low	++	
Revetment	medium	low	medium	+	Can obstruct shipping/industry
Living shorelines	medium	low	medium	+	Can obstruct shipping/industry
ACCOMODATING MEASURES					
Flood-proofing buildings	low	low	low	+++	
Using cisterns/basins for storage	medium	low	low	++	
Increase drainage	low	low	low	+++	
Retreat	high	low	low	+	Hardly any space to relocate to

\+ Lowest level of applicability
\++ Medium level of applicability
\+++ Highest level of applicability

Structure height

Because of its exposure to the combination of sea level rise and storm surge (from extreme storm events), the city of Boston would benefit from raising its resisting structures or adding new ones, such as (terraced) sea walls and dikes. In Boston it is common to determine the height of these flood protection measures by calculating the elevation of possible water levels relative to NAVD'88. NAVD'88 is the North American Vertical Datum of 1988, which is a fixed vertical reference elevation very close to the mean seal level in the Boston Harbor.

For example, Boston's mean elevation of its highest tides is 1,45 m (4.8 feet) relative to NAVD'88, which is written as 1,45 m NAVD or 4.8 ft. NAVD. To protect areas in Boston from a current 1% annual chance storm (100-year flood), flood protection structures should be built up until around 10 ft. NAVD (= highest tide (4.8 ft.) + extreme storm surge (5 ft.)), which is 3 m NAVD. However, flood protection structures often have a lifespan of around 50 years, so they will likely be there up until 2070. Therefore, flood protection structures should be built up until around 13 ft. NAVD, which is 3,96 m NAVD, to protect areas in Boston up to around 2070 from a 1% annual chance storm (100-year coastal flood event), because of an expected 3 feet of sea level rise by then. Figure 5.3 provides a visual explanation of this. When the structures have reached the end of their lifespan, they can be upgraded and elevated to adapt to even higher flood levels.

A design choice can also be to build protective measures less high, and to combine them with other accommodating measures, such as floodable parks, storage basins and in-land deployable floodwalls, which are measures that are also deemed applicable in the context of East Boston. The combination of both resisting structures and accommodating structures is another safe option, that can prevent a situation where East Boston is slowly turned into a bathtub, with walls that keep on rising.

Another option is elevation of land and infrastructure. This measure protects against flooding and at the same time it provides opportunity for new, safer development and improvement of underground infrastructure. By raising the entire land instead of raising walls around the edges, the waterfront will remain more accessible and views on the water will not be blocked. This is however, only possible on large pieces of land that are currently undeveloped.

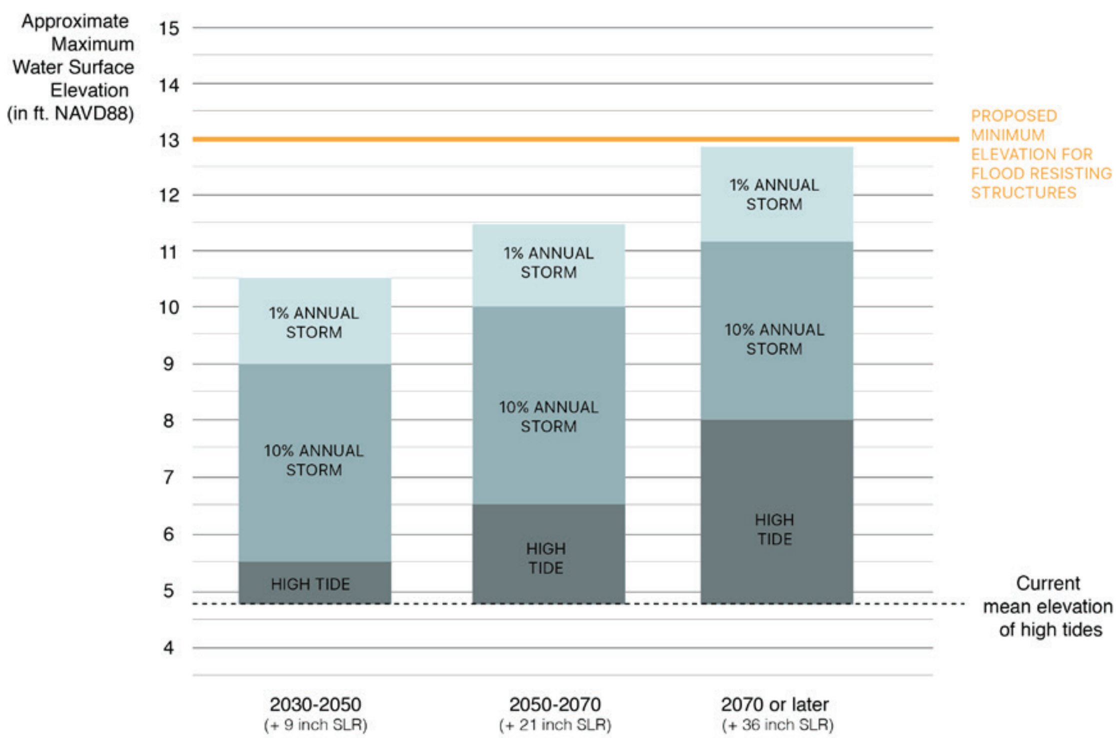


Figure 5.3
Approximate maximum water level elevations according to the CRB-projections and the proposed level of elevation for flood resisting structures
(Based on: City of Boston, 2016)

5.2 EVALUATE (STEP 5)

The previous step helped me to select appropriate measures that would be applicable for East Boston. These measures will be used as input for the pathways map, in order to create a design for East Boston. Because I want to create three different adaptation pathways that are based on the three different strategies that I distinguished in landscape practice: (1) Multifunctional design strategy (MDS), (2) Flexible design strategy (FDS), and (3) Supplementary design strategy (SDS), I need to understand which measure fits with which strategy. Therefore, this next step focuses on evaluating the selected measures according to criteria that fit with these strategies.

For the MFD strategy, the most important criterion is of course the multifunctionality of the measures. When measures have (social or ecological) co-benefits and they add extra value or functions to the specific area, they will score high on multifunctionality. The FDS strategy requires adaptation measures that score high on the criterion of flexibility. Measures with high flexibility are changeable, reversible or temporary. Flexibility of measures is also determined by if they can keep options open for future developments in the area, since a more static measure can still provide the area with a lot of flexibility. For the SDS strategy, the adaptation measures will be rated according to the criterion of scale and lifespan. The measures with a small scale and short lifespan will fit, since this strategy focuses on sequences of multiple measures that together form a bigger system. When a larger amount of measures is applied, they should be of smaller scale in order for the complete design to fit in the urban area. Another way to evaluate ths strategy is to determine if measures are 'stand-alone measures' or if they need additional measures to work well, as the approach does not use stand-alone measures.

The evaluation of the preferred measures according to the criteria mentioned above (multifunctionality, flexibility and scale) is shown in Table 5.2. Besides these criteria, the table also shows the sell-by dates (tipping points) of each measure, to assess the durability of certain measures. Sell-by-dates are the situations in which a particular action is no longer adequate for meeting the objectives (Kwadijk et al. 2010). The objective is to protect the area from a norm frequency of a 1:100 coastal flood event (1 % annual chance flood). Therefore the following performance criteria were established:

- Near-term actions (until around 2030) should protect up to 1:100 coastal flood event with 23 cm (9 inches) of sea level rise.
- Mid term actions (around 2050s) should protect up to the 1:100 coastal flood event with 53 cm (21 inches) of sea level rise.
- Long-term actions (2070s or later) should protect up to the 1:100 coastal flood event with 91 cm (36 inches) of sea level rise.

The tipping points are reached when the measures no longer meet the above mentioned performance criteria. Because of climate uncertainty the dates should be seen as estimates and should only be used for exploration. The sell-by dates are based upon flood projections for 2030, 2050, 2070 and 2100, as provided by the Climate Ready Boston report (City of Boston, 2016).

Table 5.2
The preferred measures, evaluated according to the criteria of multifunctionality, flexibility and scale, combined with their sell-by-dates.

MEASURES	CRITERIA: Multifunctionality	Flexibility	Scale and/or Lifespan	SELL-BY-DATE (years)
Applying large in-sea coastal barriers	-	++	+++	> 2100
Elevation of parts of lands or streets to 13 ft. NAVD88	++	++	++	> 2100
Adding dikes (levees) along coastline +7 ft. above MHW	+++	+	+	2070
Raise seawalls and bulkheads to 11 ft. NAVD88	-	++	+	2030
Adding more permeable, floodable area on shoreline (waterfront park)	+++	++	++	2030
Adding in-land (deployable) flood walls to protect valuable assets	-	+++	-	2050
Flood-proofing buildings	-	++	+	2030
Hard in-land infrastructure to increase storage capacity on land	++	+	++	2050
Increase the discharge capacity by adding pumps etc.	-	+	+	- (insufficient on its own)

+++ Highest level of multifunctionality, flexibility, scale & lifespan
- Lowest level of multifunctionality, flexibility, scale & lifespan

The table shows which measures fit in which strategy:

Multifunctional measures
To evaluate multifunctionality, the measures were scored on: ecological, recreational and economic benefits. The following measures scored the highest:

- Dikes (ecological and recreational benefits)
- Floodable waterfront parks (recreational benefits)
- Terraced seawalls (recreational benefits)
- In-land storage infrastructure (combination with other functions is possible)
- Elevating land and streets (creates opportunity for new land uses)

Flexible measures
To evaluate flexibility, the measures were scored on: changeabilty of the measure (deploying, enlarging etc.), (re)movability, and how well they can ‘keep options open for development’ .The following measures scored the highest:

- Floodable waterfront areas (open areas are easy to change, remove etc.)
- Deployable floodwalls (temporary measure that can be removed)
- Elevating land and streets (keeps options open for development)
- Raise seawalls and bulkheads (relatively easy to replace, remove)

- In-sea coastal barriers (off-land, and therefore keep options open for development on-land.)

Supplementary measures

Supplementary measures were indicated by smaller scale or shorter lifespan measures. The lowest scoring measures, meaning small scale and short lifespan, were preferred. Measures that were not low in scale or timespan, but that should be used in combination with other measures were also added.

- Raise seawalls and bulkheads (raising existing measures has a relatively short lifespan, relatively small scale)
- Elevating land and streets (not stand-alone: should be combined with other measures, because not every part of land can be raised)
- Dikes (not every part in the city can be protected by dikes, often used in combination with other measures)
- Terraced seawalls (not a stand alone measure)
- Deployable floodwalls (very small scale, used in combination with other measures)
- Flood-proofing buildings (as an accommodating measure, this should be used in combination with more resisting measures)

5.3 MAP DIFFERENT PATHWAYS (STEP 6)

Pathways mapping is used as a tool to find the different possible routes to reaching a desired result. The adaptation pathways depict several possible combinations of adaptation actions that are created to accomplish the adaptation objectives within the anticipated timeline.

For the pathways map I used the scenario projections as described in the Climate Ready Boston report. Accordingly, the timeline is set up until 2100, with indications at 2030, 2050 and 2070. The pathways map is visualized in Figure 5.4.

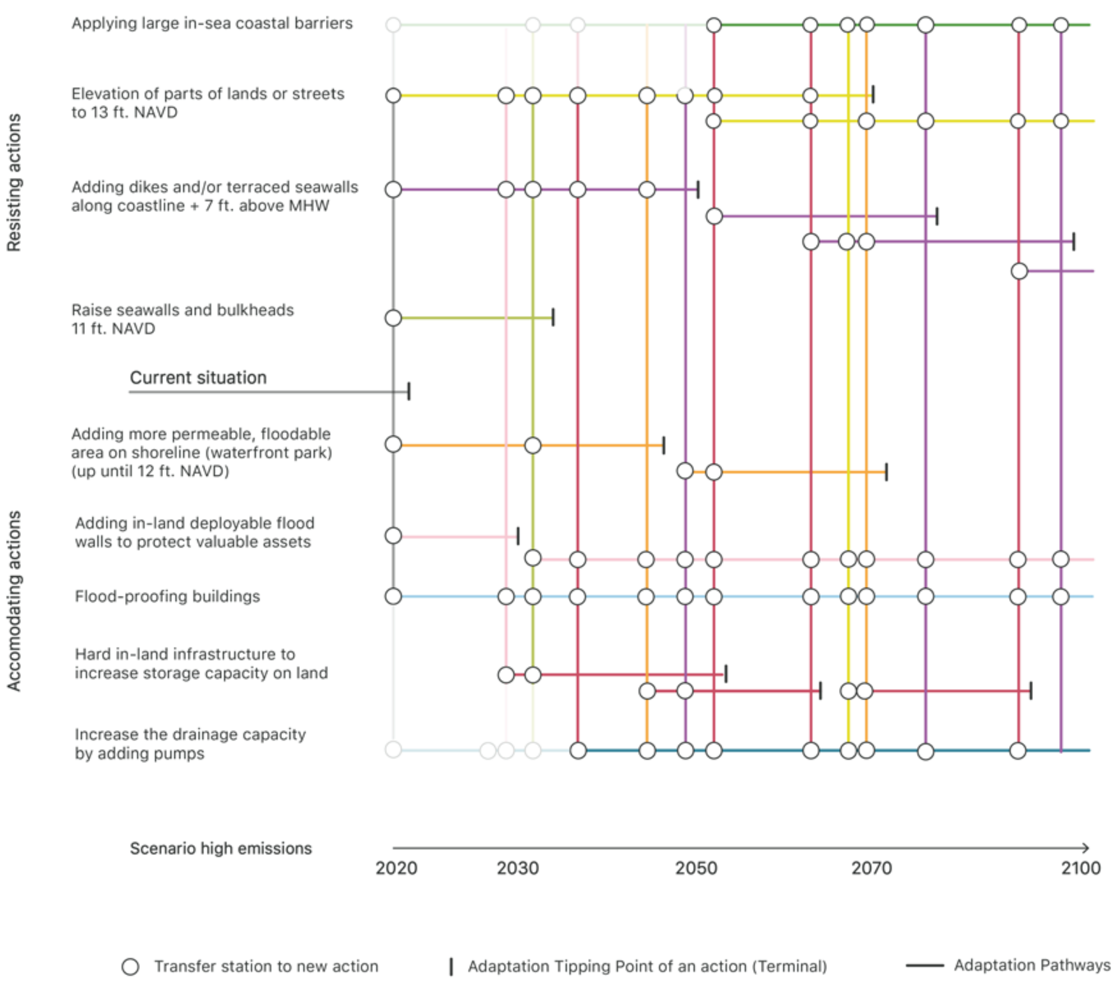


Figure 5.4
The pathways map for East Boston

In the pathways map it is visible that the current situation will fail soon, since overtopping and flooding already happens in some places, at very high tides. This means that the current flood conditions no longer meet the objectives (protection against the 100-year flood), which means a tipping point is reached. It shows that new actions are needed in the short-term. The possible measures that can be implemented are indicated as transfer stations.

The map shows that the pathways can be made by combining two types of actions: resisting and accommodating actions. The resisting actions and the accommodating actions influence each other: When a resisting action is chosen, the addition of storage capacity (as an accommodating action) will have a tipping point far into the future. And of course, the same counts the other way around; when the area is designed to store water, the addition of a resisting action has a tipping point further into the future.

The actions with relevance in the near term are put close to the 'current situation' in the pathways map, because these are actions that will likely be used in the beginning of the sequence of proposed actions. As the CRB-report mentions, adaptation near the low-lying parts of the waterfronts should be addressed earliest. Therefore measures such as raising seawalls and adding dikes and adding permeable/floodable areas are seen as relevant in the near term.

The actions with sell-by-dates far into the future are put on the top and bottom of the pathways map, as these are actions that will probably be used in the end of the pathway-sequence. Some of these measures in the pathways map are only seen as an option in the mid term and long-term part of the time horizon. Examples are land elevation, large coastal barriers and increasing drainage capacity.

Although large in-water coastal barriers would be effective in protecting the neighborhood for the long-term, it is a very expensive strategy, with little co-benefits (not multifunctional) and besides that, they can pose a threat to ecology. They are also quite irreversible which is a reason to only use this strategy when there are no other options and when there is more information available on future situations.

5.4 TEST DIFFERENT PATHWAYS (STEP 7)

In this step, a new way of using the Pathways Mapping tool is explored. Even though it is meant to be used as a policy making and planning tool, it was chosen as a basis for the landscape architectural approach, because it has the potential to be used as a tool for designing. By using spatial adaptation measures, instead of policy measures, in the pathways map, a spatial configuration, using the sequence of measures of a specific pathway, can be made. A pathways map can therefore be used to create and test different designs.

With the help of the constructed pathways map (Figure 5.4), I created and tested different designs according to the three strategies that I distinguished in landscape architectural practice (flexibility, multifunctionality and supplementary). By drawing several pathways for every underlying strategy and testing what they would look like spatially through sketching, I created multiple design concepts that were all different from each other because of these diverse underlying strategies. These spatial concepts were used as feedback on the pathways map and the preferred pathways, which were then altered. This feedback loop was repeated multiple times, creating an iterative process, where the research informed design, and design informed the research.

This eventually resulted in three preferred pathways that could be used for futher, more detailed design. The map with the three pathways; the most promising one for each underlying design strategy, is visible in Figure 5.5.

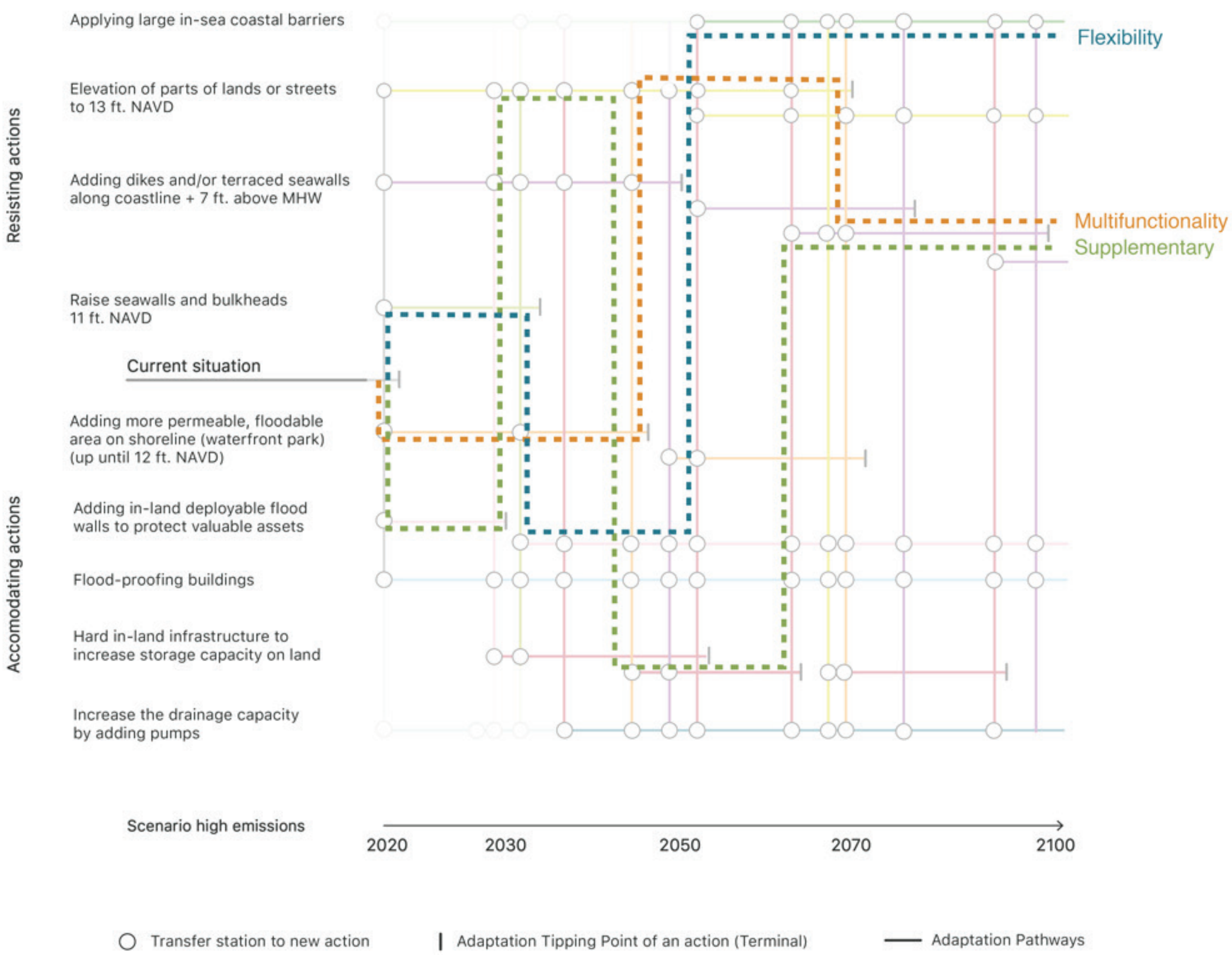


Figure 5.5
The mapped pathways according to the three underlying strategies

Multifunctional pathway

In summary, the multifunctional design strategy focuses on creating a robust, no regret design, that is often overdimensioned, but has multiple co-benefits. The main intervention for the multifunctional pathway is the creation of one robust, green ring of interconnected floodable waterfront parks. A big buffer of multiple green areas will be developed in order to create a sponge effect to hold more water, to provide roughness to break waves and diffuse the power of floodwater, to slow the water down and stop the water from reaching further into the neighborhood. Furhermore it will be multifunctional, as the big, green buffer along the shoreline, which will add to Boston's park and greenway legacy, providing ecological benefits and it will help create a connected Harborwalk. The near term actions consist of creating green floodable areas, the mid term actions focus on creating elevated parks and the long-term action is to create dikes that can protect the area from higher sea levels in combination with storm surges. These dikes also function as elevated paths. Instead of creating a barrier along the waterfront, resisting measures will be placed further in-land. Therefore the waterfront will remains well accessible and views over the water will not be blocked, which will stimulate the public use of the waterfront. In this design, further development of residential buildings along the waterfront will be stopped.

Flexible pathway

The flexibile design strategy used for this pathway consists of interventions that are changeable, upgradable and that keep options open for future developments in the area. In this pathway, near term interventions focus on keeping the water out of exposed areas by raising bulkheads and seawalls that have built-in possibilities for upgrades. These are relatively easy to change and remove and take up little space, so they keep options open for development of the waterfront. To be able to protect critical low-lying areas in the mid term, a flexible measure is to add deployable floodwalls as a secondary barrier of defense during storms. Because they are deployable, they will only be obstructing the area during storms. The rest of the time, they are not visible, which makes them very flexible. For the long-term, large in-sea coastal barriers can be placed. Even though these barriers are not easy to remove or change, they do keep options open for development in the area, because they are located outside of the area.

Supplementary pathway

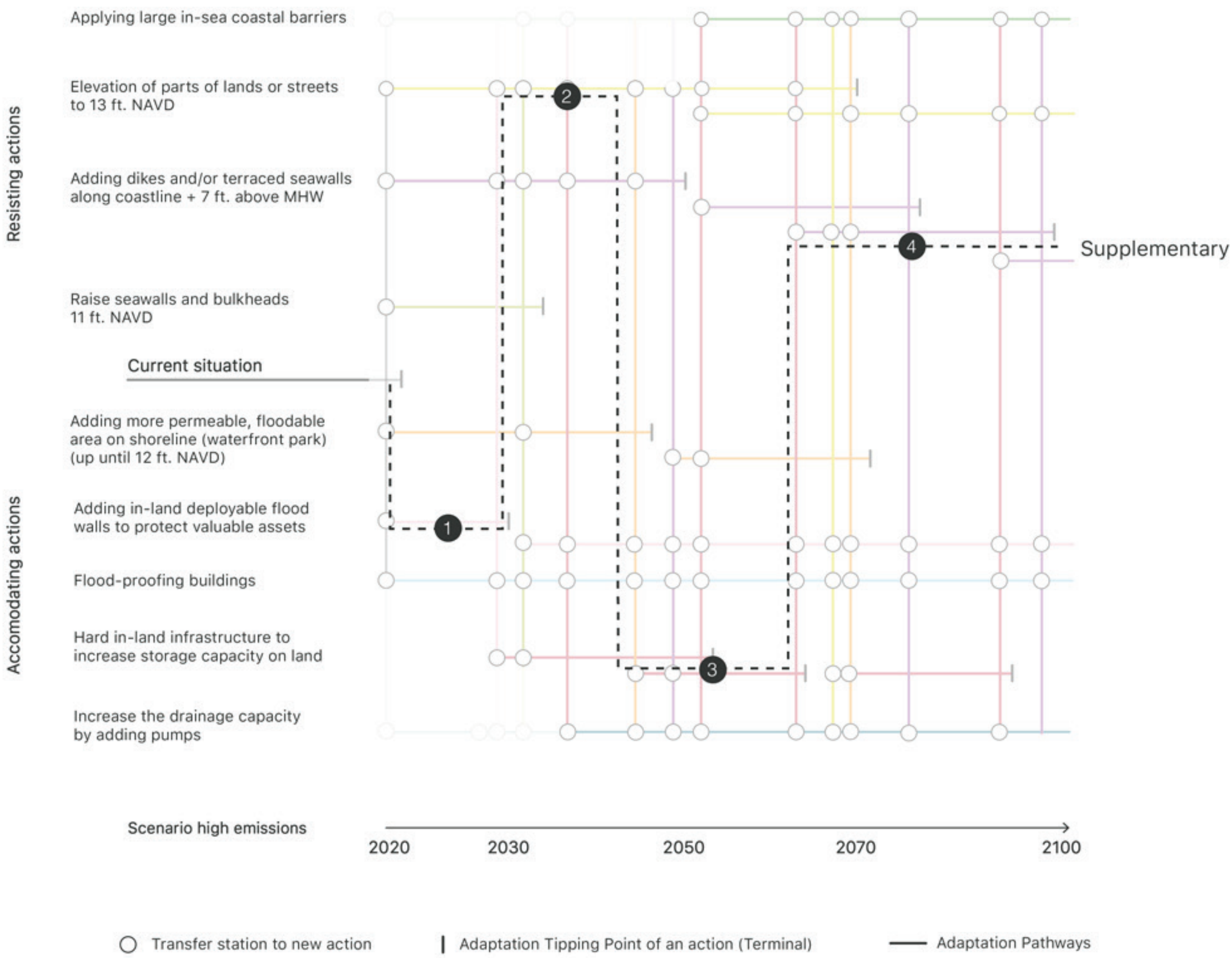
To recapitulate, in the supplementary design strategy, interventions that supplement each other are favored so that they can be added to each other over time to work together as a larger system that can keep growing along with changes in the environment. This pathway therefore focuses on creating multiple interventions that allow for more gradual development of the area instead of abrupt large-scale interventions. The strategy enables on-going urban renewal activity. This pathway therefore has shorter decision timespans, which is visible in the pathways map. Short-term actions involve placing deployable floodwalls and elevating a few critical areas. For mid term sea level rise, exposed areas will be protected by creating areas where overtopping can be stored on land. When the storage capacity limit is reached, in the long-term, the addition of dikes and terraced floodwalls can protect the area from higher sea levels.

The preferred pathway

For this case study, the preferred pathway is the Supplementary pathway, because this pathway is very responsive to change. Taking smaller steps and decisions allows the design to be adapted in the future when new knowledge becomes available. By designing multiple smaller interventions and making sure there is ongoing urban development in East Boston, the area can quickly respond to changes. This is useful for a densely built area that is changing and developing fast. By creating diversity in the measures that are taken, the design also avoids the idea of putting ‘all the eggs in one basket’, because if one part fails, the other solutions will still work. A combination of many different solutions also enhances the capacity to respond to the diversity of risks. Measures will also be taken more spread out over the entire neighborhood. Development throughout the whole neighborhood is more beneficial for the local community than for example only in one spot, as it could help improve different areas.

From conversations with Paul Kirshen (Umass Boston), Robbin Peach (Program Manager of Resiliency at Massachusetts Port Authority), Gretchen Schneider Rabinkin (Architect, background in improving Boston-area neighborhoods) I could conclude that this strategy also fits in the political culture in the USA. In comparison to many other countries, the USA has a more liberal attitude, where too much top down government interference is not appreciated. Smaller steps will likely be more accepted and is less dominant towards residents of the area. Besides that, this strategy is not only beneficial for society but also for governments because it means the plan can be implemented in phases and does not have to be funded in one time, but spread out over multiple years and multiple governments. The supplementary strategy can therefore be used to cater to the needs of both decision makers and residents, and is therefore deemed most feasible in this specific context.

In this case, the supplementary pathway consists of a sequence of four actions over a timespan of 80 years and is depicted in Figure 5.6. This supplementary pathway is used for the final step of the approach, in which the pathway is spatially visualized.



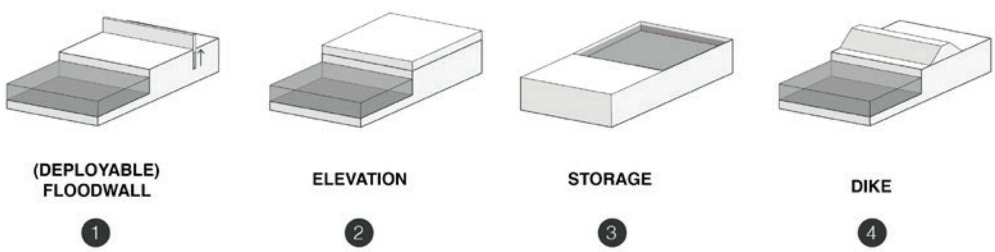


Figure 5.6
The preferred pathway and the sequence of actions

5.5 SPECIFY AN ADAPTIVE DESIGN (STEP 8)

The use of the Pathways Mapping tool resulted in a preferred pathway for East Boston that is based on the supplementary strategy. This final step of the approach builds further onto the previous step by turning the preferred pathway into an adaptive design that serves as a design proposal for the future developments of East Boston.

In order to do this I first created a spatial visualization of the chosen adaptation pathway, that shows the entire sequence of spatial adaptation measures through time. This provides details on which measures should and could be implemented, when they should be implemented, and what they would look like. Besides the visualization of the chosen adaptation pathway, the other possible measures from the pathways map are also visualized to help to keep in mind what options there are with every tipping point.

This sequenced visualization serves as a high level proposal. In the final part of this step this high-level proposal is turned into a detailed design. The design location for East Boston is indicated in Figure 5.7.

A spatial visualization of the adaptation pathway

The proposed actions over a timespan of 80 years are conceptually visualized in Figure 5.8. The pathway visualization shows the phased implementation of sequences of measures from the supplementary pathway. The different phases (numbered) and their adaptation measure are indicated. In this conceptual visualization I integrated adaptation measures with open, public space. This resulted in a combination of actions located both on the shoreline, as well as more in-land. Figure 5.8 does not only show the sequence of proposed actions and their timing, but also their possible alternatives at that point in time, which results in several branches of possibilities. Visualizing a pathway as such is useful for landscape architectural design, because this gives the designer a broad view of the range of options for design. Even though this pathway is currently seen as the best sequence, as it reflects the current understanding of how flood risk in Boston will evolve over time, it doesn't mean that this understanding will be the same in the future. In the future, the predicted scenarios might turn out different than expected, which could for example lead to the decision to take more extreme measures earlier on, or maybe the choice to skip an action of the sequence. The following sections explain the near term actions, mid term actions and long-term options that are presented in the pathway visualization.

5.5.1 NEAR TERM ACTIONS

The near term actions in the pathways map should provide effective flood protection from the 1% annual chance flood with 23 cm (9 inches) of sea level rise, which is expected in the 2030s. Their sell-by date will be around 2040 or 2050.

Deployable floodwalls

The first action consists of applying deployable floodwalls as resisting barriers to stop the flow of water along the identified near-term flood pathways. These temporary floodwalls will primarily be built to prepare for near term flood risks. Closing off flood pathways with these barriers should protect the entrance of the East Boston Greenway, the Sumner and Callahan Tunnels and exposed residential areas. The proposed walls are indicated in the first phase of the chosen pathway, indicated with a (1) in Figure 5.8. The barriers are placed in such a way that the lengths of the walls are minimized, except for one of the walls. This one however, is designed as a multifunctional deployable floodwall that has seating integrated in its structure. Deployable floodwalls are relatively simple solutions that provide early protection and score well in terms of applicability and flexibility. On the longer term, when extra coastal flood protection measures are taken, these walls make coastal flood protection systems redundant, since these measures provide backup protection if other protection measures fail.

Elevated parts

In some areas, critical flood entry points can also be blocked by elevated parts of land along the waterfront. By raising the elevation of entire parts of land, opportunities for safe, new land use are provided. To create additional benefits for the community, these areas can for example be designed as parks that provide green open spaces for recreation and cultural activities. From the landscape analysis in Chapter 4, it could be concluded that there are several areas with yet undeveloped parts of land along the waterfront that could be elevated to block near-term flood pathways.

A few of these areas were selected. The selected areas are added to the sequence in phase 2 of Figure 5.8.

5.5.2 MID TERM ACTIONS

The mid term actions in the pathways map should provide effective flood protection from the 1% annual chance flood with 53 cm (21 inches) of sea level rise, which is expected in the 2050s. Their sell-by date will be around 2070.

Storage of overtopping
Because of the elevated parts of land, most of the water during a 100-year-flood will be kept out of the area. However the water that does enter, will automatically be funneled into the lowest lying areas. Therefore, a new mid-term measure is applied for when the water surpasses the resisting measures and flows into the lowest parts of East Boston. From the analysis, I learned that the greenway is a critical low-lying area, as it can channel a large volume of water into the heart of the area, once flooded. The next measure focuses on being able to store all the water that is funneled into the East Boston greenway, to prevent the greenway from flooding these areas. Therefore, different barriers will be placed along the green way to hold the water and create a basin. The store-phase can be done in multiple different phases, creating a bigger storage area every time, in order to keep the design and outcome adaptable. In Figure 5.8, the storage areas are added to the sequence in phase 3.

5.5.3 LONG-TERM OPTIONS

The long-term options in the pathways map should provide effective flood protection from the 1% annual chance flood with 91 cm (36 inches) of sea level rise, which is expected in the 2070s or later. Their sell-by date is unknown. With this sea level, the projections have shown that additional flood pathways will develop, which also need to be addressed.

Dikes and terraced seawalls
With extra sea level rise in the long-term, the greenway and the elevated parts will likely be insufficient for the protection of surrounding areas. Extra protection will be needed along the waterfront to cope with the height of the storm surges. The final measure is added to the sequence in the pathway visualization in phase 4 (Figure 5.8), which indicate new multi-purpose dikes and sea walls. The construction of resisting seawalls and dikes is a logical step, since they will only be spanning narrow portions of land, but it would protect a substantial area of East Boston from flooding. The dikes and sea walls are designed with an elevation of 7 ft. above the MHW at that point in time, to protect East Boston from a 100-year flood. This height ensures that the design will be effective for a longer period of time. Together with the possibility to store water in the greenway, they are likely to be effective up until 2100. Sometimes space can be too limited for the construction of a dike (for example when there is housing, industrial area or other types of uses). In these cases a seawall can be considered.

Figure 5.7
The specific location for design


2
DIKES / SEA WALLS
3
DIKES / SEA WALLS
CHOSEN PATHWAY
NOW - 2030
2030 - 2045
2045 - 2065
1
(DEPLOYABLE)
FLOODWALLS
2
ELEVATIONS
3
STORAGE
2
FLOODABLE AREA
3
FLOODABLE AREA
NOW
2040
2060

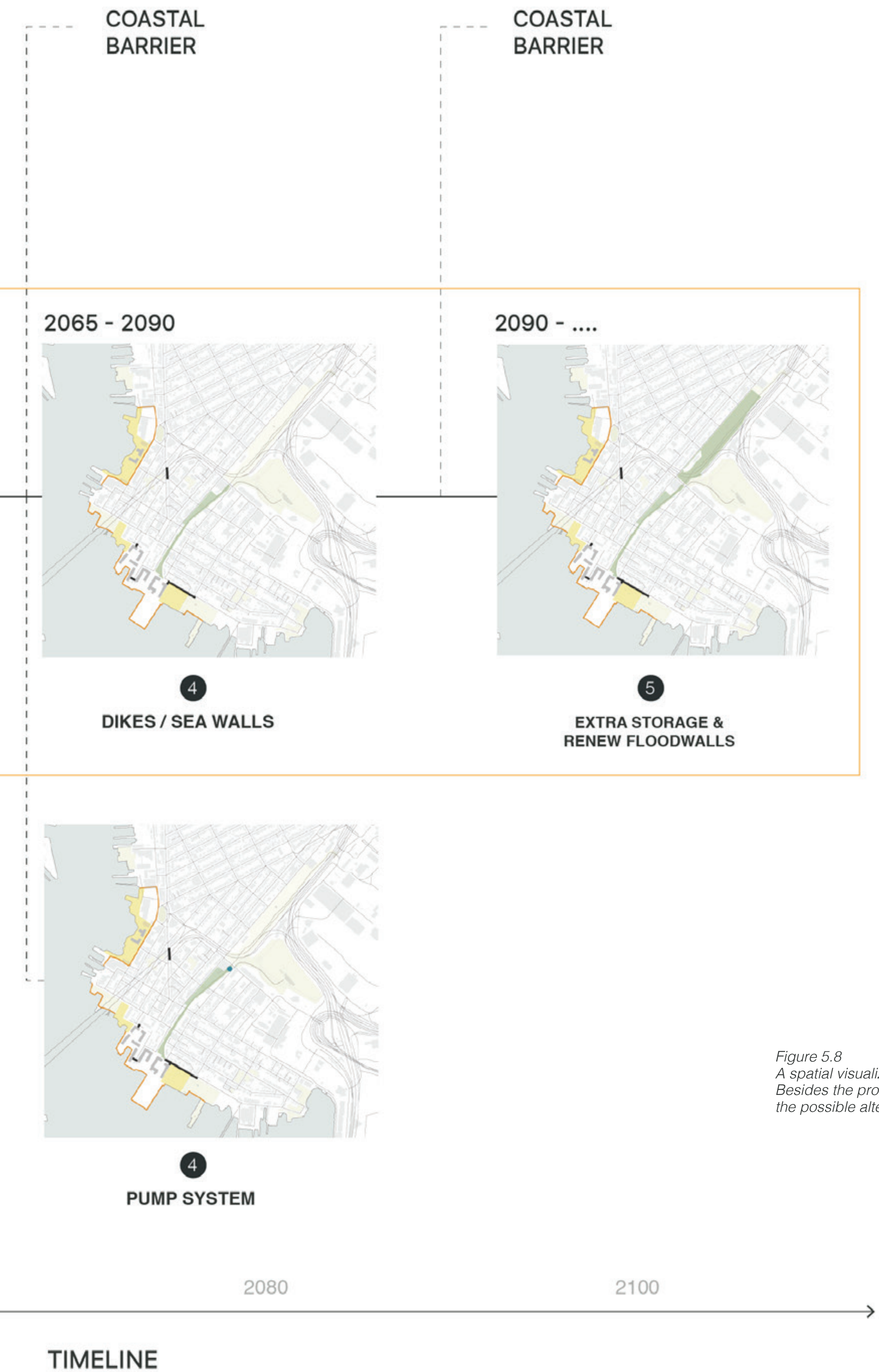


Figure 5.8
A spatial visualization of the chosen pathway. Besides the proposed sequence of actions, the possible alternatives are also visualized.

5.5.4 THE CONCEPT

The goal of the previous section was to spatially visualize the entire sequence of spatial adaptation measures through time, instead of only one final end result. It has shown what the adaptation measures could look like in a site-specific design for Boston. The next section aims to take this design from a high-level proposal to a detailed design by creating a layered and diverse configuration of space that can have multiple benefits for the community.

The purpose of this thesis is to help the city to adapt in order to prepare for the future. Not only by preventing potential damages and helping the city to cope with the uncertain consequences of coastal flooding caused by climate change, but also by taking advantage of opportunities that are presented through new development in the area.

Besides the vulnerability assessment (step 1), the landscape analysis (step 2), and the preferred pathway from pathways map (step 4-7), the design is based on the objectives for Boston, which were determined in Step 3 of the approach, focusing on four main points:

- Protect the city from 100-year-floods
- Protect maritime industry
- Connection with water: providing access to the waterfront
- Connection between communities: linking green area's to develop green networks

These objectives were combined in the vision to create a flood protection system that simultaneously serves as an 'East Boston 21st century park system', which provides protection and connection within the area. This vision was used to create the concept in Figure 5.9.

This concept shows a network of green areas, which provides green neighborhood connections, recreation, waterfront accessibility, and ecological features to improve the public space and expand multiple green areas.

Figure 5.9
The conceptual design for East Boston:
A flood protection system that simultaneously serves as an
East Boston 21st century park system

5.5.5 IMPLEMENTATION OF THE VISION, OBJECTIVES, PRINCIPLES AND GUIDELINES

To fulfill the design objectives, the design is created with the main purpose of reducing vulnerability and exposure to floods, meaning that the performance of the landscape during flood events is most important. Yet, the redesign of the area was done in a way that also makes it attractive in times that there is no threat of flooding, by creating an urban park system. This way the community can benefit from it as well as be protected by it.

To create a design that does not only protect, but also connect, different design principles and guidelines, which were identified in step 2, were used to create a design. The explanation is divided into two parts: East Boston Waterfronts and The East Boston Blueway.

East Boston Waterfronts
As mentioned in step 3, the vision for Boston is to create a large network of urban parks by combining and linking different green areas, such as the Emerald Necklace and the Boston Harbor Walk. This vision has resulted in a design for East Boston's waterfronts that are flood resilient and multi-functional. Different adaptation measures and a few design guidelines, identified in step 2, were used to improve the waterfronts. These are visible in Figure 5.10.

The design will consist of waterfront features such as elevated parcels, dikes (used as elevated pathways) and seawalls, which will provide the bulk of long-term flood protection. The dikes and seawalls do not only function as storm barriers but also as elevated walking paths and seating areas from where people can enjoy the views on the water and Boston's skyline. The sea walls will be terraced, and have an urban look that fits in the industrial identity of the wharves and docks.

The elevated parcels will provide opportunities for safe, new land use and new amenities to activate the waterfront, as the design seeks to connect the city with the water. These parcels for example will provide space for mixed-use development that can help pay for the waterfront transformation. Besides protection from floods, the dikes can be used as parts of the Harborwalk to provide accessibility to the waterfront. The deployable floodwalls that will be constructed as a first action in the near-term, will create a secondary barrier system in the long-term that protects the houses behind the elevated areas and at the same time functions as a funnel that will guide the water into the greenway. The design makes sure that the already existing green, open spaces along the waterfronts will be connected with new green areas and are combined with coastal flood protection measures. This connected green structure will serve as a protection buffer, but at the same time it will also provide social, recreation and ecological functions, reactivating the edges of the area. Accessibility of the waterfront, as one of the major wishes of East Boston's residents, will largely be improved by this design.

Figure 5.10
Five design guidelines used for the waterfront

The East Boston Blueway

By transforming the greenway into a storage basin with a multifunctional character, the East Boston Greenway is turned into the East Boston Blueway. Through design, the goal is not only to store water, but to also change the identity from being a simple, low-lying pathway and establishing the area as an intimate "urban linear park" (Kullmann, 2011). Urban linear parks are public spaces that take people to and from different places, encouraging movement and active use. In this way, they are different from traditional urban parks, that often invite people to rest and stay in one place. In other words, a linear park is a park that guides to different destinations and other parks are the destinations themselves. What is also interesting about linear parks is that they offer users a lot of different views that keep changing every time.

Currently the greenway, has a very sober, monotonous, look. There is a lack of diversity and visual complexity, compared to other linear parks, such as the High Line in New York, the South Bronx Greenway, the 11th Street Bridge Park in Washington, D.C. and La Rambla, Barcelona (Spain).

What makes it extra monotomous is that the Greenway does not offer many views of the surroundings, because of it's lower lying location, which creates a bathtub effect. When you walk along the Greenway, views on the side are often towards walls, so it only provides a far view on the long axis, towards the direction you are walking. By adding more visual complexity, the space will become much more appreciated and used. I used a few design guidelines from Step 2 that were used to turn the Greenway into a more lively and welcoming space (Figure 5.11). The adaptation measure of creating a storage basin was also added to this figure.

First of al, the greenway will be equipped with 'flood proofing' measures, by adding water-resisting walls along the sides. These walls are designed to meet the next point of intervention: leveled pathways. By creating pathways on different levels along the greenway, the pathways provide different views on and past the Greenway. By creating paths on high levels, the paths can also serve as evacuation routes during flooding. No matter in what state the greenway is, the area will always provide a safe route.

The third intervention is the addition of new access points into and over the greenway to apply the principle or connectivity. By creating more entrances, especially from points where people work and live, neighborhood connectivity and accessibility can be improved. By adding crossings, the urban form is connected on both sides of the park. The fourth intervention is the placement of wayfinding elements. By adding signage, people are provided with routes and orientation, giving them a sense of destination and improving user-friendliness of the park. Last but not least, programming, such as playgrounds, art installations and wall paintings, allotment gardens, bike rental services, view points and resting areas are added in order to create attractiveness and recreational opportunities that give people a reason to use the Greenway.

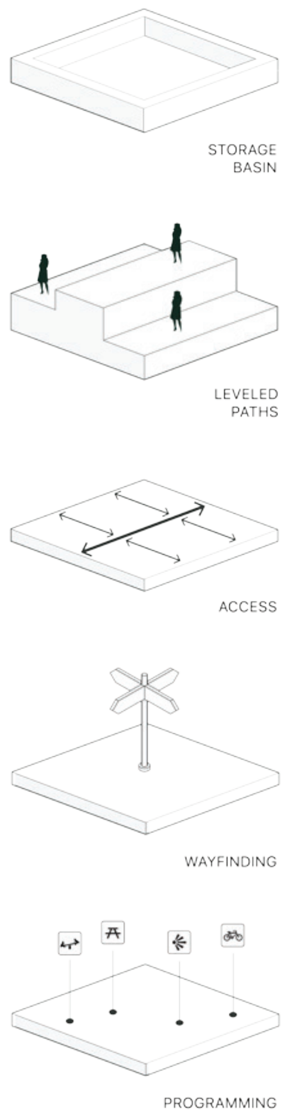


Figure 5.11
Five design guidelines used for the Greenway

5.5.6 VISUALIZATION & DETAIL OF THE POSSIBLE FINAL STATE

In this section, the design in which all the actions of the pathway sequence are implemented, is visualized and explained in detail.

The visualization and detailed explanation can help create an image of what East Boston could look like in the far future. I want to emphasize that the outcomes of this final step of the approach are not meant as a final, static design. The final outcomes should be seen as a proposal that can still be adapted in the future, if needed. This design is therefore an exploration of what the future of East Boston could look like and not the definitive end result. If (and when) the design should be implemented, should depend on the future climate.

With the proposed flood adaptation actions, the physical landscape in East Boston will be prepared to transform into a floodscape from time to time. My definition of a floodscape is:

The visible and material landscape during a flood event in regions affected by flood hazard.

Floodscapes are temporary and dynamic landscapes, as they are only visible during a flood event. To prepare East Boston to turn into a floodscape, the area must be designed to function well in both states; flooded and non-flooded.

East Boston Floodscapes: A design to protect and connect

In the following section, different parts of the design are explained separately, starting with a part of the waterfront and ending more in-land, in the greenway. This way, all the interventions in these parts of the design can be explained more explicitly, giving an idea of the sequential experience that is provided as people traverse the urban park system. The different parts of the design are indicated in Figure 5.12.

Figure 5.12
An overview of the different parts of the design

WATERFRONT PARK EDGE

Figure 5.13
An overview of the waterfront park edge

In this part of the design, a green connection is made from the existing Piers Park (see Figure 5.13) to the East Boston Greenway. A new part of the park is added and provides more room for recreation and large events. Because the park will be situated in an area known for its squares, Maverick square and Central square, another square will be added in this part of the park. This square can be found along the waterfront and can be used as an area where people can gather and meet. Planters combined with seatscapes will be added to provide comfort. The circular shape of a large event space refers to the design of the Piers Park, which has circular elements. The event lawn will be kept open for events such as markets, sports or performances.
Extra parking space will be added, and the park will be enclosed by a multifunctional deployable floodwall with seating integrated in it (Figure 5.13), that helps to funnel the water to the Greenway and keep housing along the park protected. The new part of the park will be elevated in order to block a flood pathway and protect the surrounding areas from sea level rise and storm surge until the mid term. This protection system will be strengthened for the long-term with a walkable dike with an elevation of 13 ft. NAVD88. A lower-lying path right between the dike and the water edge can bring people closer to the water and give them access to floating docks. When the water surpasses the dike, the entire area is designed to funnel the overtopping to the greenway. Therefore, a green link will be made that connects this new part of the park to the greenway to safely guide the water in the right direction. Figure 5.14 and Figure 5.15 show what the design could look like in between 2070 and 2100.

NON-FLOODED

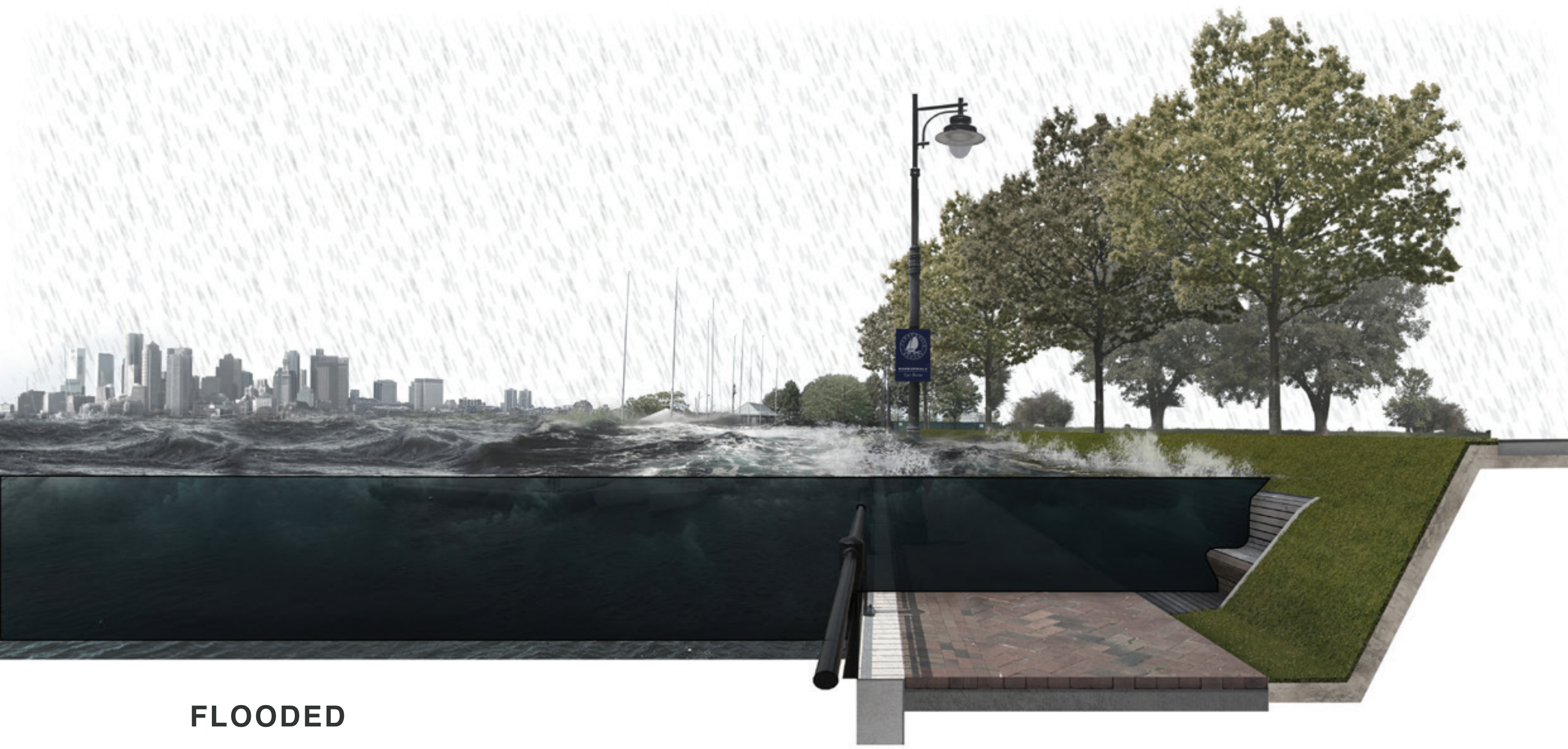


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Figure 5.14
Visualization of the waterfront park edge (A-A')


A
A'
N
0 100 200 300 400 m

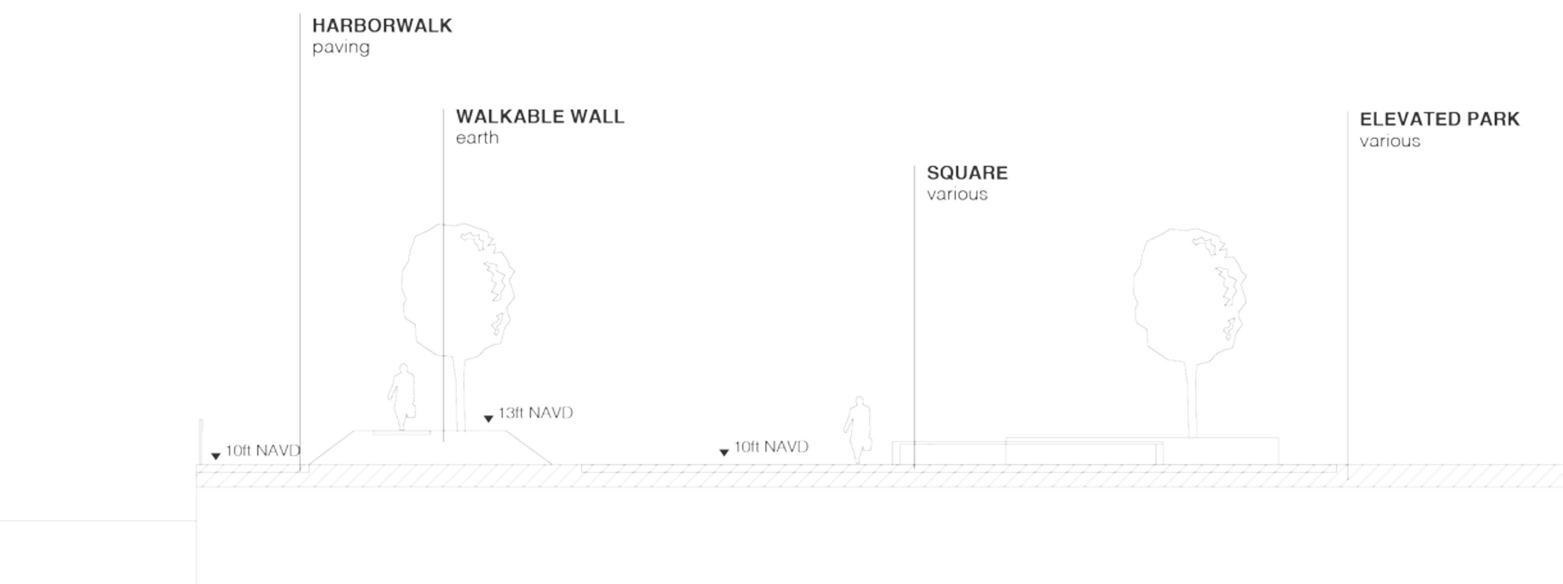

Figure 5.15
Section and materialization of the waterfront park edge (A-A')

GREENWAY ENTRANCE

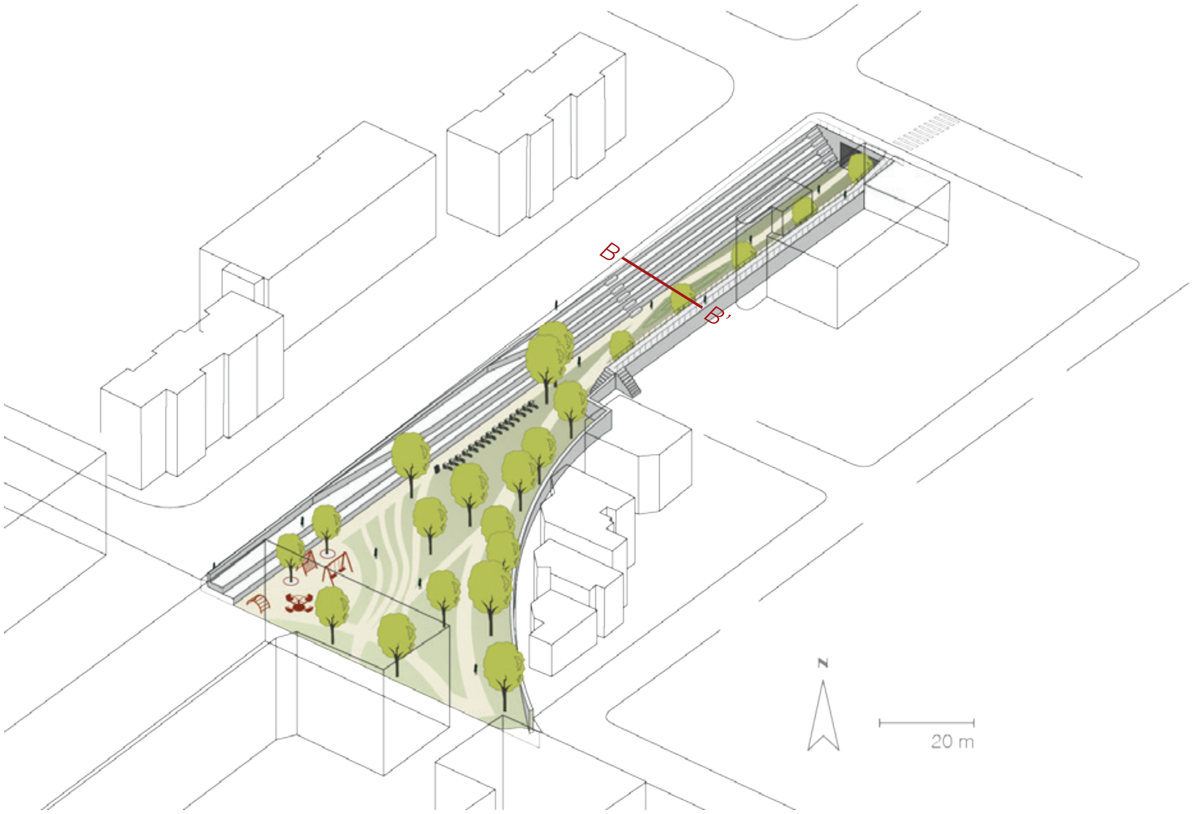

Figure 5.16
An overview of the Greenway Entrance

The greenway, that will be connected to the new part of the Piers park, will get an inviting new park entrance, to attract people into the greenway. The area has a funnel shape that takes you from the street level, down to the lower level of the deepened profile of the greenway (Figure 5.16). Because the greenway is in the middle of different residential areas, this area provides a 'front yard' experience, as it is designed as green social space for interaction and gathering. The greenway will be 'flood-proofed' through the addition of floodwalls to the sides of the greenway. The wall on the northwest side will get a greener look with a terraced wall with vegetation incorporated in it (see Figure 5.17). The terraced wall provides new access points to the greenway and functions as a seating area. The wall on the other side of the greenway will be more simple, but high and two meters broad. These walls serve as leveled walking paths that give people different experiences of the greenway. New possibilities to enter the greenway park increase the accessibility of the park and new features, such as new paths, new seating areas and more vegetation are added to create a qualitative park entrance. By adding a new playground and a bike rental service, new activity and programming are added to attract people to actively use the greenway park. Figure 5.17 and Figure 5.18 show what the design could look like in between 2070 and 2100.

NON-FLOODED

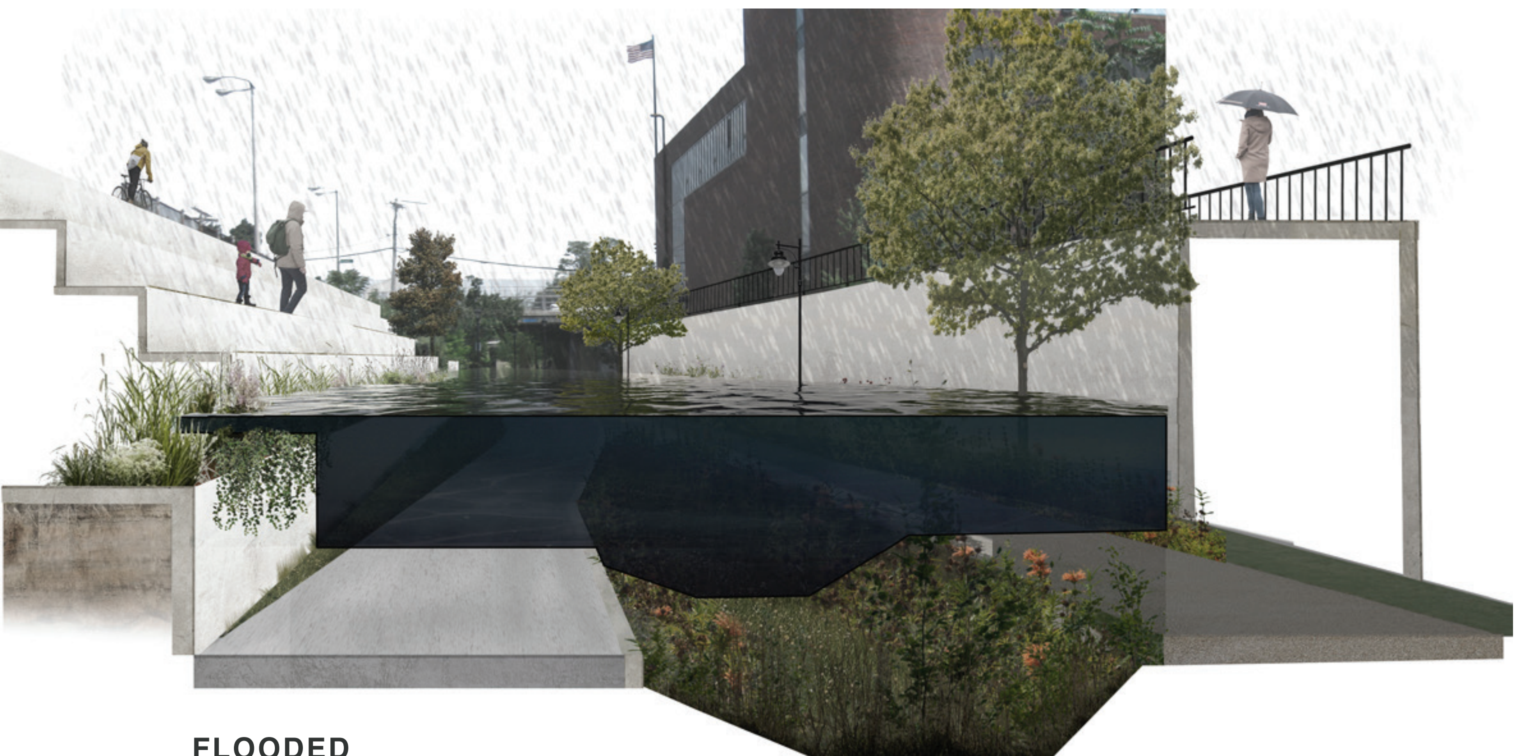

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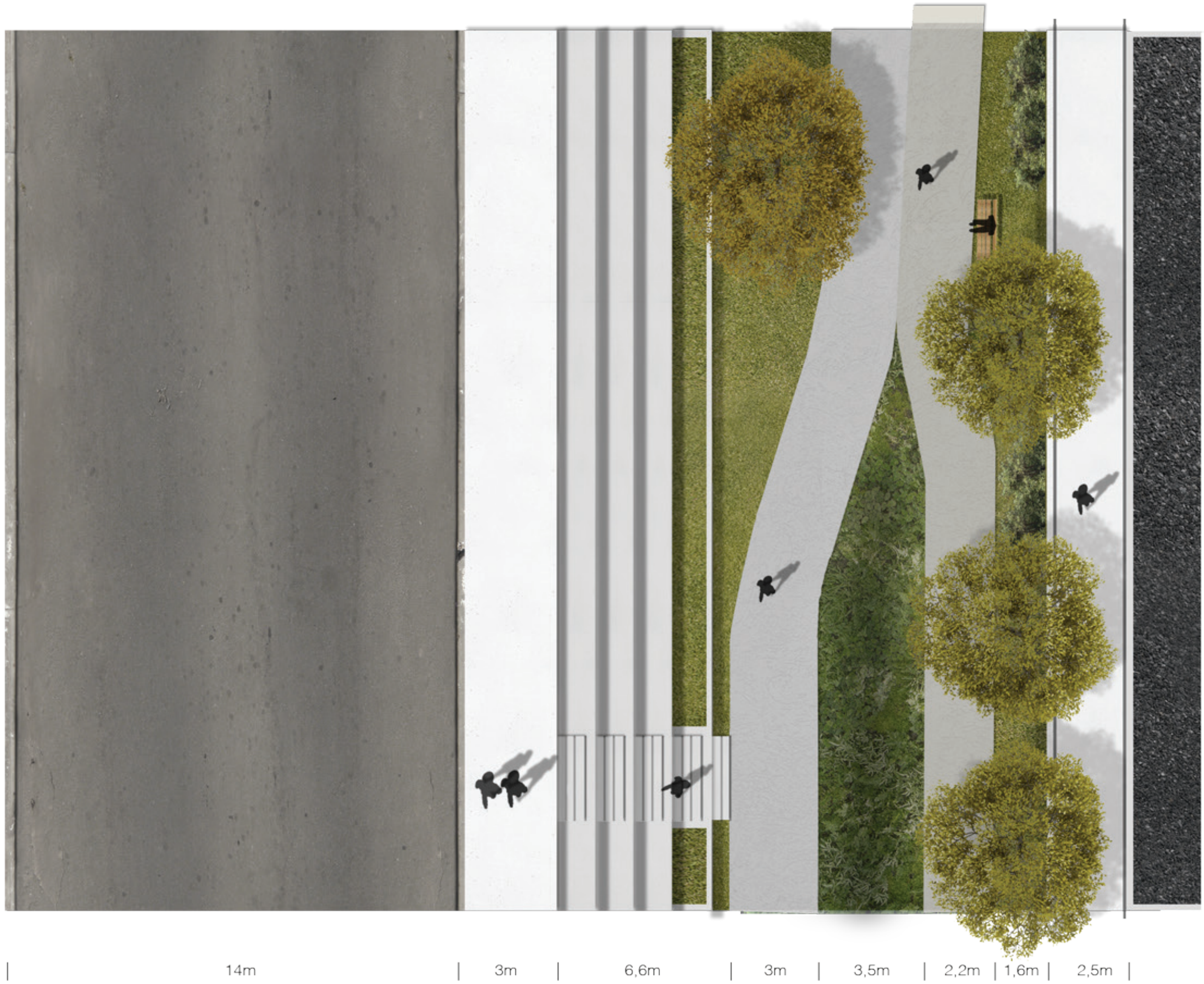
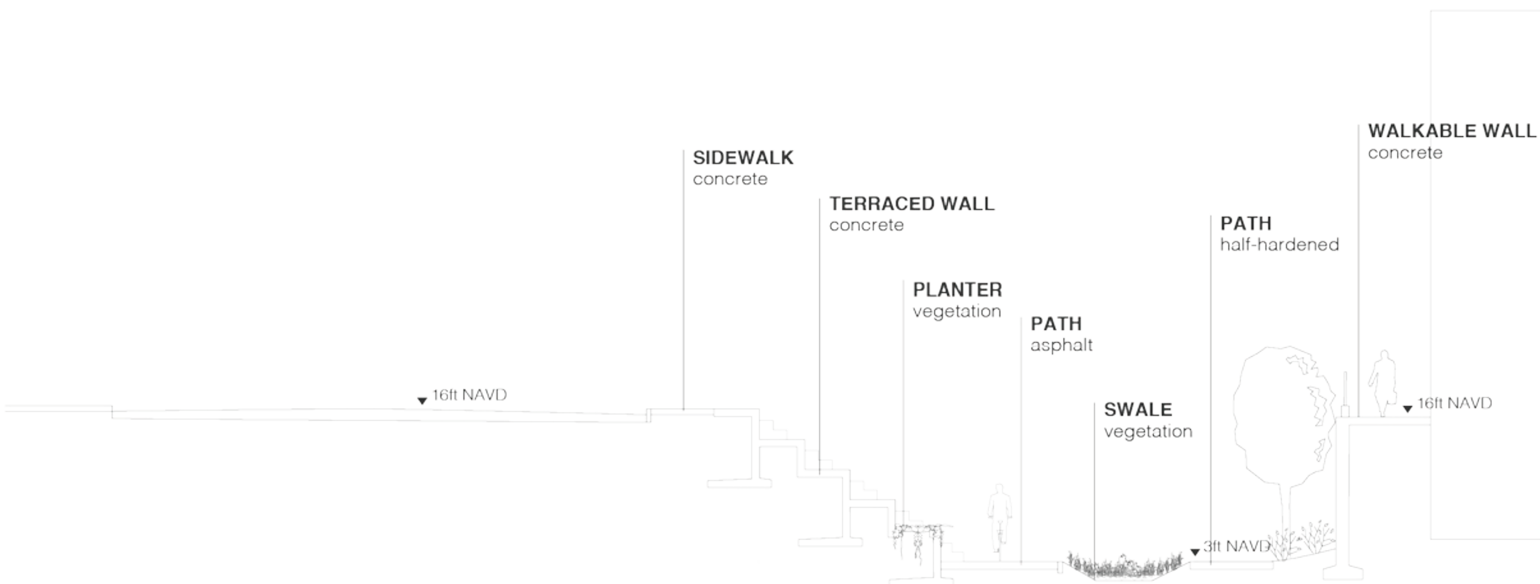
Figure 5.17
Visualization of the Greenway Entrance (B-B')


B
B'
N
0 100 200 300 400 m





SECTION 1:200

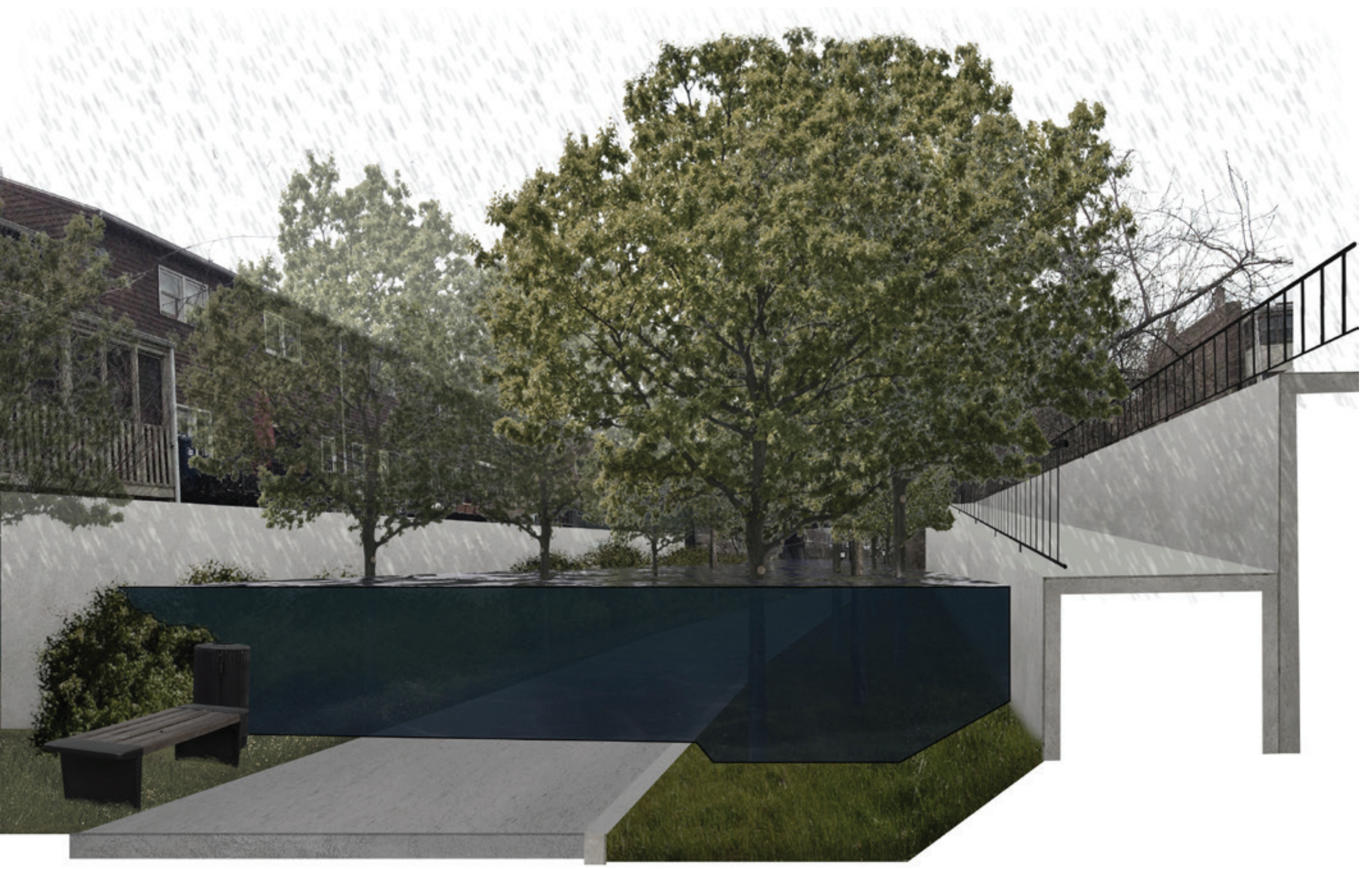
Figure 5.18
Section and materialization of the Greenway Entrance (B-B')

RESIDENTIAL GREENWAY

Figure 5.19
An overview of the Residential part

The next part of the Greenway (Figure 5.19) will provide a passage that leads directly along several housing units on the northwest side. Therefore, the walls on the northwest side will not be walkable in this area. On the other side, the wider wall will be continued and two pedestrian access points from the adjacent areas onto the Greenway will be added on this side. In contrast to the 'front yard' experience in the previous part, this area will provide a 'back yard' experience. This area can give a relief from urban stress and offers relaxation and rest. A more enclosed, forest-like atmosphere will be created in this part, focusing on ecology and providing intimate space. This will be done by using the hardy, seaside tree such as the Thornless Honeylocust and shrubs such as the Bayberry and the Rosa rugosa. The area is made accessible through a ramp, that can be used for wheelchairs, strollers and bikes. Figure 5.20 and Figure 5.21 show what the design could look like in between 2070 and 2100.

NON-FLOODED



FLOODED

Figure 5.20
Visualization of the Residential part (C-C')


C
C′
0 100 200 300 400 m

Figure 5.21
Section and materialization of the Residential part (C-C')

SECTION 1:200

CENTRAL GREENWAY

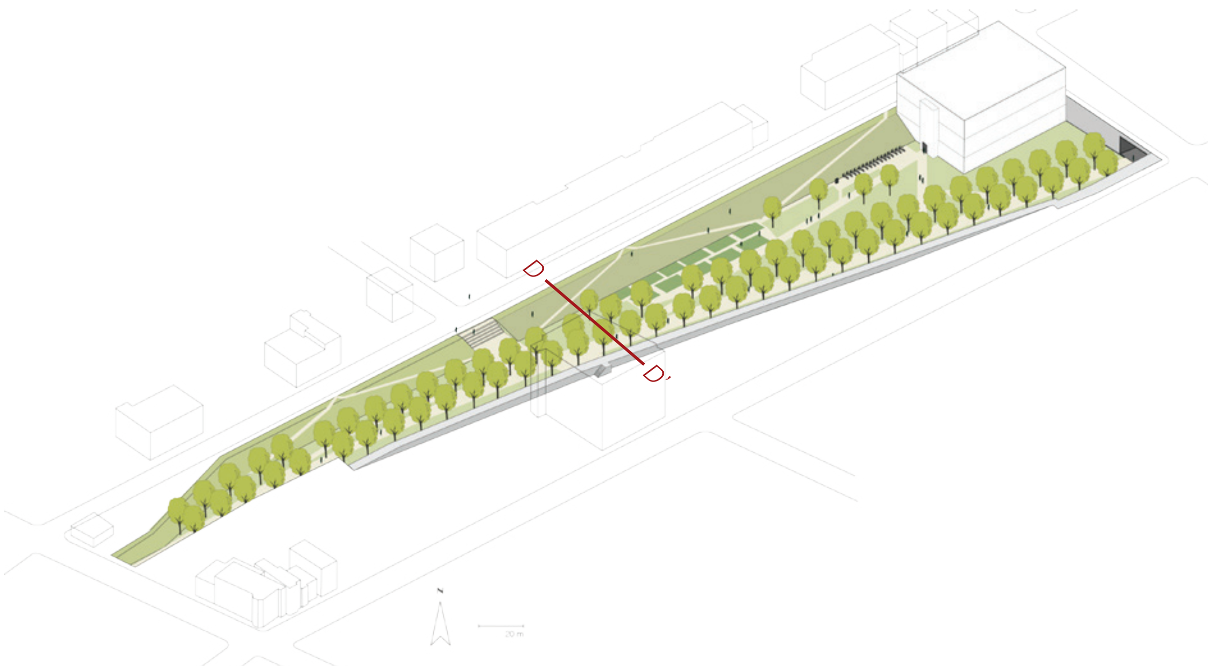


Figure 5.22
An overview of the Central Greenway

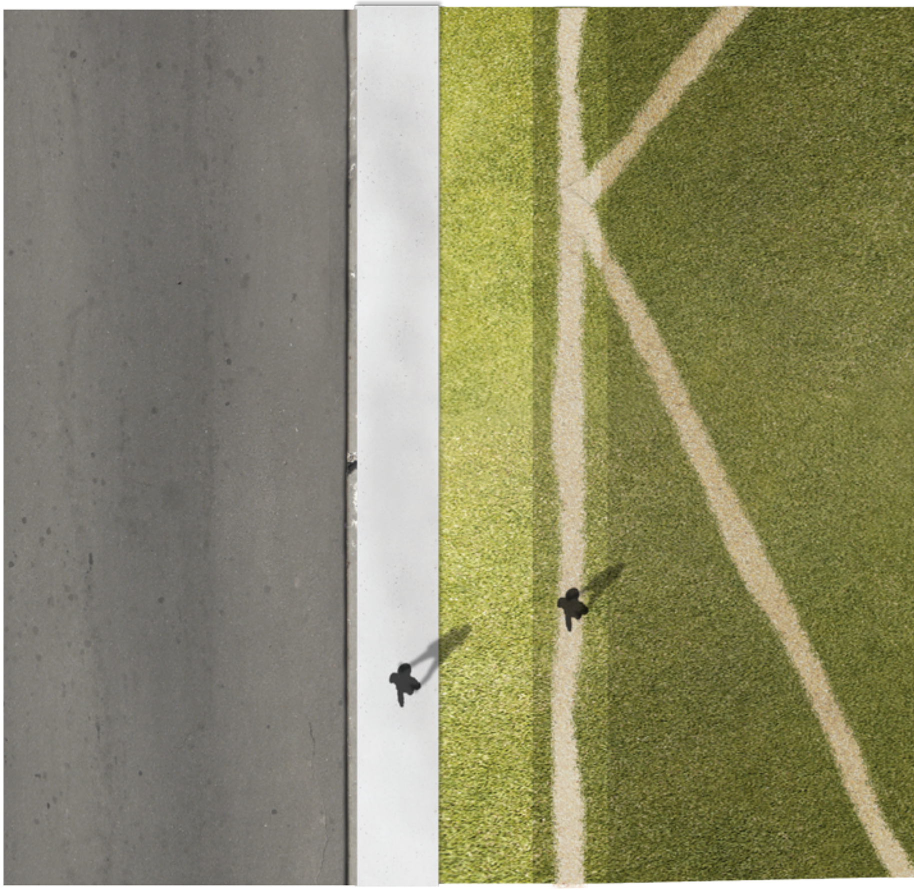
The next link in the continuous park (Figure 5.22) will get a big transformation, as a large area will be added, extending the width of the greenway in this area. Areas that were previously used as parking lots will be added to the greenway park to increasing the storage capacity. In return, a multiple story parking garage, of which the lowest level is floodable, will be built to replace the removed lots. In this part of the park, the northwest side will be waterproofed by a continuous levee and the opposite side will fortified by the wider walkable wall. The levee is an important feature in this part because it will prevent a very large, currently exposed residential area from flooding.

The levee will provide slopes that protect this area, which can also be used as playground and resting areas. New features will be a broad promenade lined with trees and allotment gardens located on a slightly higher level. These allotment gardens will be added to provide a community meeting area and to give people a way to manipulate space to create a sense of ownership and attachment to the park (Marcus and Francis, 1997). New access points will be provided by the slopes of the levee and the parking garage. Figure 5.23 and Figure 5.24 show what the design could look like in between 2070 and 2100.

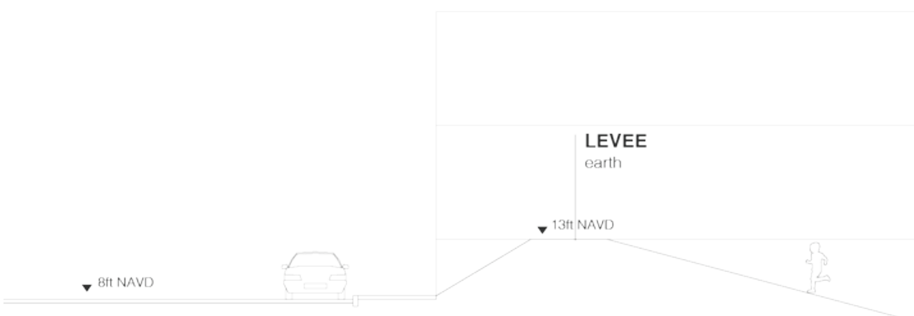
NON-FLOODED

FLOODED

Figure 5.23
Visualization of the
Central Greenway (D-D')



16,5m | 2,2m | 2,5m | 2m | 11,2m



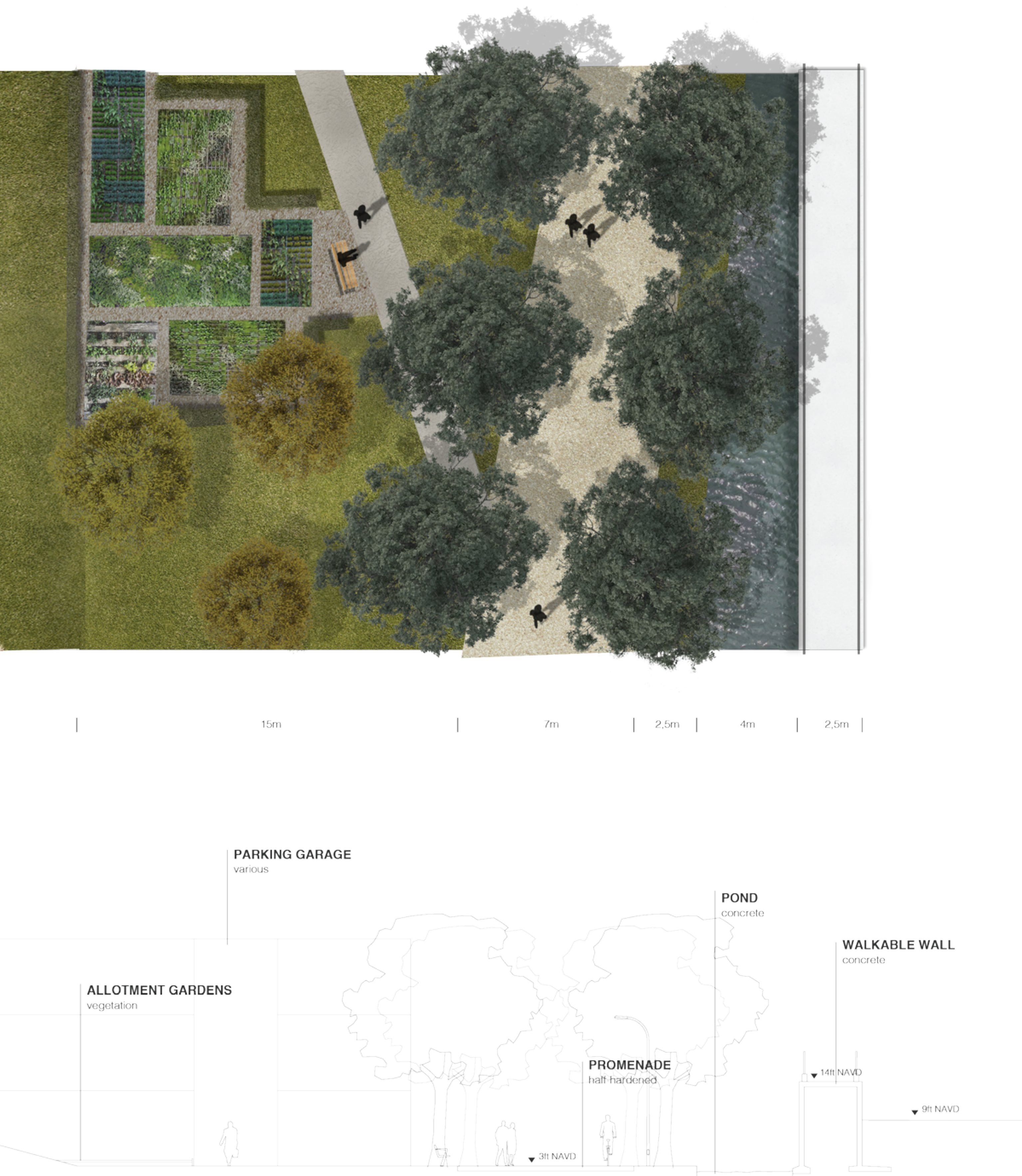


Figure 5.24
Section and materialization
of the Central Greenway
(D-D')

SECTION 1:200

This final step of the approach provided an in-depth explanation and visualization of the design that is created through use of the developed framework for landscape architectural design under uncertainty.

All the parts combined provide a variety of open spaces that together form a flood protection system, which is designed as an urban park system that can be added to Boston's park legacy. The design is created in an attempt to reach the objectives and vision that were created for the area. When all the parts of the design are implemented, the Greenway will therefore serve multiple functions (shown in Figure 5.25). Besides a storage area and a linear park, the greenway can also be seen as a transport hub. Meaning that it is a place where people can change between different transport modes. Besides the existing T-station where people can exit and access the park with the Blue line (metro), a new parking garage and three bike rental stations are added. With the new design of the greenway, it is therefore more easy to get to (and through) the park, and in times of flooding to get away from the area.

Together with the new part of the Piers Park along the waterfront all these pieces together form a system that could be used as an adaptive plan for East Boston, contributing to its climate readiness.

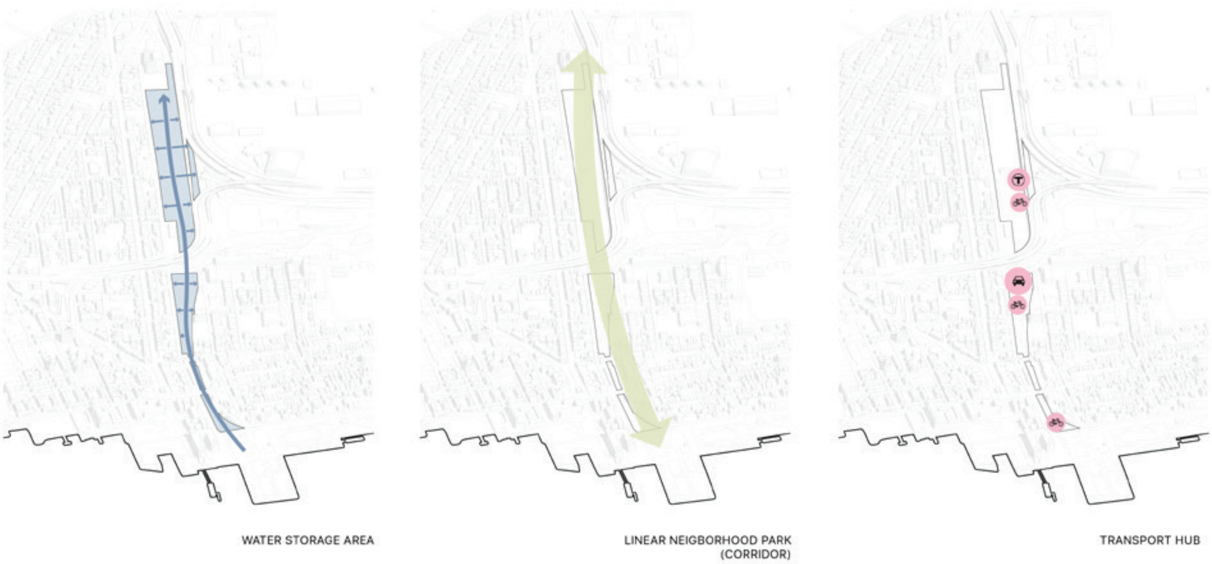


Figure 5.25
An overview of the three main functions of the Greenway

6 CONCLUSIONS & DISCUSSION

(Shutterstock, n.d.)

6.1 CONCLUSIONS

The argument in this thesis was that in order to contribute to flood risk reduction in Boston (and other coastal cities), it is necessary to take into account future uncertainty in the design process, to help avoid maladaptation. Since there is a lack of approaches and tools in the literature that allows landscape architects to do this, the purpose of my research was therefore to investigate how uncertainty can be accounted for in the landscape architectural design of densely urbanized coastal cities, by means of an approach that could be used in the design process.

In this thesis, I contribute to landscape architectural research on flood risk reduction by developing a systematic approach for spatial adaptation that can serve as a tool to assist landscape architectural design under uncertainty. New approaches like this are relevant, because researchers observe a lack of substantial rates of implementation of adaptation actions compared to the substantial efforts and investments in adaptation science (Wise et al, 2014). This lack of action could partially be caused by lacking or underdeveloped design approaches that make landscape architects able to deal with uncertainty.

Furthermore, I have applied the proposed approach, to fulfill the design purpose of my thesis, which was to create a design of an adaptive plan for long-term flood protection of Boston's flood-prone areas that need to be spatially adapted in order to protect it from flooding. The design should contribute to flood risk reduction and develop the city's ability to adapt to coastal flooding caused by climate change. This design purpose was addressed by the following design question:

What landscape architectural design can be created, by means of an adaptive, systematic approach for spatial adaptation that will contribute to flood risk reduction in Boston?

Because I wanted to create this design with the help of the mentioned approach, I first needed to investigate the adaptive systematic approach for landscape architectural design under uncertainty. Therefore, my main research question was:

What is an adaptive, systematic approach for landscape architectural design under uncertainty?

And I stated the following the sub research questions:

- *What is adaptiveness and how is this concept operationalized in landscape architectural practice regarding flood risk reduction?*

- *What are the components of an adaptive systematic approach for landscape architectural design under uncertainty?*

- *What are the specifics of the Bostonian urban landscape in relation to its vulnerability to flood risk?*

To give an answer to the stated research questions, I first conducted a desk study (literature review), which led to understandings of concepts such as flood risk reduction, complexity, uncertainty, unpredictability and adaptation under uncertainty (Chapter 2). Subsequently, I developed and proposed a systematic approach for spatial adaptation in coastal cities that can serve as a tool to assist landscape architectural design under uncertainty (Chapter 3). The approach is based on the concept of adaptiveness, which was first investigated in this chapter through a literature review and through a review of reference project in landscape architectural practice. Furthermore, the approach is based on different components of adaptive approaches in the literature, which I distinguished through a literature review of prevalent approaches in planning and decision making. The approach was created to address two kinds of uncertainty (epistemic uncertainty and ontic uncertainty) and is partially based on the Adaptation Pathways Mapping tool (Haasnoot et al., 2013), which is developed for decision-makers to help map out sequences of actions to develop long-term policy strategies for an uncertain future. I used this tool and turned it into a tool that is also useful for creating spatial designs instead of policies and plans. I then applied the developed design approach in a case study in Boston, in order to create a design for an adaptive plan for long-term flood protection of Boston's flood-prone areas. The case study started with an assessment phase (phase A of the approach), where the vulnerability of the site was assessed, a landscape analysis was conducted, the spatial problems, constraints and opportunities for adaptation were identified and translated into design guidelines, and the objectives and vision were explored (Chapter 4). Finally, I used the Pathways Mapping tool to create a landscape architectural design for the area of East Boston (phase B of the approach) and gave an elaborate explanation of the created design that should contribute to flood risk reduction (Chapter 5). I describe the outcomes of these studies in the following sections.

6.1.1 AN ANSWER TO THE RESEARCH QUESTIONS

It can be concluded that spatial adaptation is important to reduce flood risk in Boston. However, spatial adaptation is challenging for designers because in the present situation, uncertainty regarding future climate conditions increases rapidly with time. Climate parameters that used to be 'known' (or at least were believed to be beyond doubt) have become uncertain and hard to predict and we can't expect climate scientists to provide certain and accurate climate forecasts anymore. In fact, uncertainty in future climate change is so large that it makes many traditional approaches to landscape architectural design of flood-prone areas inadequate. Therefore, I have developed and applied a new approach to provide an integrated framework for addressing uncertainty as part of landscape architectural design that enables all sources of uncertainty to be taken into account in the design process. The landscape architectural framework for adaptation under uncertainty is based on the concept of adaptiveness, which I researched through the question:

What is adaptiveness and how is this concept operationalized in landscape architectural practice regarding flood risk reduction?

In this thesis, I focused on adapting the spatial configuration of a city to climate change and the uncertainties that accompany it. In this context, adaptiveness is defined as being able *"to handle irreducible (ontic) uncertainty about future change"* (Zandvoort, 2017, p.70).

From research on landscape architectural design practice for flood risk reduction by studying reference projects, I can conclude that adaptiveness is operationalized in practice through applying different design strategies in the design process. A strategy consists of *"goals, related measures and one or more development trajectories"* (van Rhee, 2012, p.18). Three strategies that can be distinguished are the Multifunctional design strategy (MDS), Flexible design strategy (FDS) and the Supplementary design strategy (SDS).

These strategies are used in the landscape architectural framework for adaptation under uncertainty. By a literature review on prevalent planning approaches that help account for uncertainty in the decision making process, I was able to answer the question:

What are the components of an adaptive systematic approach for landscape architectural design under uncertainty?

The most prevalent approaches in the literature have a few common components that help with decision making under uncertainty: components that help identifying vulnerabilities, components that help developing objectives, components that help improve foresight, components that help explore options, actions and strategies, and components that help analyze and optimize decisions.

All these components can be used and incorporated in an approach for landscape architectural design under uncertainty. However, the approach should not be limited to these components, as these components only help designers to make decisions. Besides helping to make decisions, the approach should also help to create design. This means additional components are needed. First of all, an important component for a landscape architectural approach is of course the component of the design activity itself. This component also requires a component that helps include local context, through fieldwork, landscape analysis and incorporating local objectives.

The answers to the previous questions helped to answer the main question:

What is an adaptive, systematic approach for landscape architectural design under uncertainty?

The approach called the 'Landscape architectural framework for adaptation under uncertainty' is based on: (1) research on the concept of adaptiveness and adaptive design strategies (2) components of prevalent planning approaches that help account for uncertainty in the decision making process, (3) inclusion of local context, through field work, landscape analysis and incorporating local objectives.

The approach uses the Pathways Mapping tool, which is used in Dynamic adaptive policy pathways (DAPP) explained by Haasnoot et al. (2013), as a basis. This is a tool that helps analyzing and optimizing decisions. This decision-making tool is turned into a tool for landscape architectural design by:

- Replacing the input of policy actions with spatial adaptation measures.
- Selecting pathways according to different underlying design strategies.
- Using the mapped pathways to test different designs and inform design, creating an iterative research through designing process.
- Spatially visualizing the pathways and their sequence of actions.

The approach consists of two phases and eight steps. The first phase is the Assessment phase in which the first three steps are taken: A vulnerability assessment (step 1), a landscape analysis (step 2), creating objectives and a vision (step 3). These steps help to collect information and data to contribute to the reduction of epistemic uncertainty. The next phase is the Design phase, in which the next five steps are taken: selecting preferred adaptation measures (step 4), evaluating adaptation measures (step 5), mapping different adaptation pathways (step 6), testing different adaptation pathways (step 7) and specifying a dynamic adaptive design (step 8). These steps enable designers to deal with ontic uncertainty by anticipating on possible future conditions and finding ways to adapt plans and ideas in a later phase, if the future turns out to be different than expected. The approach therefore addresses two kinds of uncertainty

By developing the approach and by applying it onto a case study in East Boston, I have learned about the strengths and weaknesses of the developed framework. A strength is that the approach offers the designer eight clear steps that give practical guidance in in the difficult process of designing under uncertainty. By using pathways mapping as a tool for design, the approach helps to keep a broad view of all the possible adaptation options and it stimulates designers to look far into the future and think about long-term adaptation options. It helps landscape architects to let go of the idea to create a static and 'optimal' design and to think in adaptation pathways and alternatives instead of single end goals. It helps remind designers to trade 'optimality' for 'adaptiveness' as a priority for the design.

The use of the approach in the case study also revealed some flaws in the framework. A weakness of the approach could be that it sometimes requires the user to make assumptions that are not thoroughly tested. For example, the assessment the sell-by dates of the possible adaptation measures were determined using expert judgment and model results from previous studies (e.g. the CRB-report), but determining the sell-by dates through computational exploration would probably be more effective and reliable.

Furthermore, this case study could be executed effectively because in Boston there was already a lot of data on climate, flooding and vulnerabilities available that could be used as input to create an informed design. However, the framework does not specify, how the vulnerability can be assessed if there is little to no data available on these topics.

What are the specifics of the Bostonian urban landscape in relation to its vulnerability to flood risk?

The area of East Boston is subjected to a few processes, which have defined its vulnerability. Most dominant in this is the process of sea level rise, but besides that, the processes that have contributed are its historical land fillings and the densification in population and built-up area. Gentrification processes speed up this densification and cause development in parts of the area previously left unused for residential purposes. Most of the development happens on the waterfronts, which are the lowest-lying, and therefore the most exposed areas. Another contribution to East Boston's vulnerability are a few flood pathways, with critical low-lying entry points along the coast, through which the water can flow over land and inundate larger low-lying areas. Lastly, the vulnerability of the area is increased by the composition of the population, which consists of large groups of older adults, children, people of color, people with limited English proficiency, people with low or no incomes, people with disabilities, and people with medical illnesses. These groups are called social vulnerability groups.

To reduce these vulnerabilities, East Boston needs to be spatially adapted. However, adaptation of the area is constrained by dense urbanization and little possibility for development in the water. Nevertheless, there are also opportunities for adaptation, such as the opportunity to store water, to elevate parts of land and to add protective measures along the waterfront. Through adaptation of the area, other problems like the lack of attractiveness and accessibility of the waterfront could also be dealt with in order to create additional benefits for the area.

6.1.2 THE ESSENCE OF THE DESIGN

A case study as research through designing (RTD) method was used to test the approach in practice and create a design for East Boston in order to reduce its vulnerability and exposure to flooding.

Besides the vulnerability assessment (step 1), the landscape analysis (step 2), and the preferred pathway from pathways map (step 4-7), the design is based on the objectives for Boston, which were determined in step three of the approach, focusing on four main points:

- Protect the city from 100-year-floods
- Protect maritime industry
- Connection with water: providing access to the waterfront
- Connection between communities: linking green areas to develop green networks

These objectives were combined in the vision to create a flood protection system that simultaneously serves as an 'East Boston 21st century park system', which provides protection and connection within the area.

Protection from flooding was reached by designing spatial adaptation measures according to an adaptation pathway that was created with the help of the Pathways Mapping tool. The chosen adaptation pathway fits with a supplementary design strategy that is used to create an adaptive design that keeps climate uncertainty into account. The strategy is to create a sequence of multiple smaller scale adaptation measures to explore the opportunity to gradually adapt densely-built urban areas to flooding using on-going urban development. The ongoing development, instead of one large-scale, static adaptation measure, creates the ability to quickly respond to changes. By creating diversity in the adaptation measures that are designed, the design also avoids the idea of putting 'all the eggs in one basket', because if one part fails, the other adaptation measures will still work. It also enhances the capacity to respond to the diversity of risks. Protection of the area was ensured by both urban waterfront protective measures as well as accommodating measures that provide safety when protective barriers are overtopped and water inundates areas behind the barriers. This means measures are designed more spread out over the entire neighborhood, which is beneficial for the local community as it could help improve different areas. The adaptation objective was that vulnerable areas in Boston should always be protected from a norm frequency of a 1:100 coastal flood event (1 % annual chance flood), taking into account sea level rise projections. It can be concluded that the design is created to be responsive to its dynamic environment and adaptable to maintain its functionality, whatever the circumstances are.

Connection was reached by designing interconnected green areas along the waterfront and by redesigning and improving a linear urban park that connects several areas. These design choices were based on the objective that the design should also provide other co-benefits for East Boston. This led to a design in which missing parts of the Harborwalk are developed in order to contribute to an interconnected pathway along East Boston's coast that allows access to the waterfront. Furthermore, the design consists of more interconnected open spaces that are safe for walking, bicycling, skating and people in wheelchairs. Connecting green areas helps to create an urban park system for the 21st century that responds to the needs of the residents. Green infrastructure investments also offer a host of environmental benefits, including: water quality, water efficiency and air quality.

This design is an exploration of what the future of East Boston could look like and not the definitive end result. The final outcomes should be seen as a likely sequence that can still be adapted in the future, if that is deemed necessary.

6.2 DISCUSSION

6.2.1 MAIN CONTRIBUTIONS

This thesis was written to contribute to landscape architecture research and practice, and to society in general. The main contributions of this thesis are threefold:

1) A contribution to a Climate Ready Boston

In Boston, the so-far taken scientific effort to assess the city's climate vulnerability has not automatically led to adaptation action. In response to this I have built on the research done by the Climate Ready Boston initiative by using the vulnerability assessment of the Climate Ready Boston report (City of Boston, 2016), and taking it one step further by creating a site-specific design for East Boston that takes into account climate uncertainty.

This design for Boston explores different adaptation measures that can lead to the reduction of flood risk in the area. It provides knowledge on how a supplementary strategy can be used to cater to the needs of both decision makers and residents. It visualizes what the area could look like flooded and non-flooded and it provides knowledge on how a sequence of flood protection measures can lead to additional benefits for the community. The design was created with a tool, which resulted in a design based on a preferred adaptation pathway and based on the scenarios from the CRB-report, but that there are many adaptation pathways and options for the future, which can still be pursued if the future turns out to be different then expected.

2) An approach to help deal with two types of uncertainty in landscape architectural design

I developed this spatial urban design, with the help of a newly developed adaptive systematic approach for landscape architectural design. The approach, which was developed in this thesis, is based on the growing consensus that new approaches are needed to address uncertainty and the challenge it creates for landscape architects to design climate adaptation measures.
In general, the design approach offers guidance and structure in the landscape architectural design process and it is created with the attempt to create designs that account for ontic uncertainty and epistemic uncertainty. The approach was developed through research on adaptiveness, research on landscape architectural practice and literature reviews of prevalent planning approaches that help account for uncertainty in the decision making process. This resulted in a stepwise approach called a landscape architectural framework for adaptation under uncertainty.
The approach can be used to create adaptive spatial designs that reduce flood risk in coastal cities. It first focuses on closing knowledge gaps by identifying and understanding current and future climate change vulnerabilities and landscape characteristics of a specific place, and is then followed by a more solution-oriented focus on designing vulnerability centered adaptation measures with the help of Pathways Mapping (Haasnoot et al., 2013).

3) A translation of an existing planning tool into a tool for landscape architecture

Within the developed approach, I used an existing tool called Pathways Mapping. This tool was partially developed by Haasnoot et al. (2013) and is originally created as a planning tool. I translated this existing planning tool into a tool for landscape architecture, so it could be used to create adaptive designs instead of policies and plans.
The tool was translated into a tool for landscape architectural design by adding spatial adaptation measures instead of these policy actions. Adaptation pathways have to be selected according to underlying design strategies distinguished in landscape architectural practice, instead of different stakeholder perspectives. The tool is used for testing different designs in iterative manner and results in not only a pathways map with preferred adaptation pathways, but also a visualization of the entire sequence of spatial adaptation measures through time.
Translating the tool was important because, landscape architects don't have a lot of tools for design under uncertainty yet and this tool has proven to be beneficial in planning and decision-making practice. By transforming it, I made it useful for landscape architecture as well.

6.2.2 METHODOLOGICAL REFLECTION

Besides proposing a systematic approach and investigating it further by testing it on a case study in Boston to create an informed design, the greater purpose of this research was to contribute to helping the wider global community of coastal cities in trying to address the challenge of adapting to an uncertain future climate. To draw conclusions on whether the approach is worthy of replication or broader dissemination, I reflect on the reliability, internal validity and external validity of the research.

Reliability
In this thesis, reliability is ensured in several ways. Firstly, the reliability of the development of the approach is ensured through documentation of the sources used to collect data, and the procedures and methods that were used to collect and analyze data that were used for construction of the framework. Secondly, the reliability of the case study is ensured through documentation of the steps taken, the decisions made within the steps, and the outcomes of the design process. Lastly, reliability is ensured by documenting the collected raw data, such as GIS maps, pictures and notes of conversations. These actions should enable replication of the research, however complete reliability can never be ensured, because of my personal, subjective interpretations caused by my experiences, social environment and background.

Even though the design was created according to a stepwise approach that was partially created according to established tools and components, design is never a completely rational decision. It can be limited by certain bias that may have affected how I have stated the problems, constraints and opportunities, how I have selected the data to be studied, and the way I have chosen to represent the design. Design includes intuition and personal preferences. These can be important, determining aspects, which are hard to overcome.

Internal validity
Firstly, internal validity throughout the thesis is ensured through triangulation by using multiple methods to answer the same research question. My research design foresees the triangulation of different methods and techniques for collecting information; by using qualitative approaches with subject-focused instruments (conversations with designers, developers, researchers, users and non-users), researcher-completed study of local databases (containing existing, secondary data, collected by someone other than the researcher) and observations (descriptions, pictures), so mixed methods are used to ensure objectivity.

Secondly, the internal validity of the developed approach is ensured by incorporating components in the approach that are used in existing approaches that are well established and have already proven to be efficient. An example is the pathways mapping tool that has already been used in multiple case studies.
Thirdly, the case study research itself comprises validation of the framework, as it resulted in an adaptive design for Boston. The design creates ongoing development and improvement of the area, providing the ability to be responsive to its dynamic environment and adaptable to maintain its functionality. This way, the design accounts for uncertainty, which is what developed approach was intended to do.

However, there were a few limitations that possibly had an impact on the quality of my findings and the ability to effectively answer my research questions.

- Starting Point: Currently there is not an agreed approach for landscape architecture, and there is not much literature on how uncertainty can be accounted for in landscape architecture. For my research, I was therefore sometimes limited in sources and therefore I used an exploratory research design, where I had to sometimes rely on literature from other fields of expertise or conduct my own research.

- Data: For the landscape analysis I have used the most recent data I could find, but some of the available data from databases could be a little outdated and therefore it could be that the collected data does not entirely represent the most recent situation.

- Time: The time available to investigate the research problem, the different concepts that were used as a basis and the time to develop and test the approach onto the case study of East Boston were of course limited. This of course affected some conclusions and research decisions that were made.

External validity
A reason to assume that the results of study are somewhat generalizable is because Boston is considered to be a 'paradigmatic case' in this thesis. As is explained in this thesis, the case of Boston is a good prototype of a densely urbanized coastal city that has a high vulnerability and exposure to flood risk. In the future this exposure and vulnerability will increase, because the hazard increases and because these cities are under pressure to expand and build on lands previously left unoccupied because of their low-lying locations. This expansion pressure in Boston represents a situation that has general relevance for many coastal cities. By selecting this prototypical case, the conclusions of the research may also be relevant for the design of other flood risk reduction designs in other densely built coastal cities.

As a conclusion to this methodological reflection, the results of this thesis indicate that the approach could be worthy of replication or broader dissemination, helping the wider global community of coastal cities in trying to address the challenge of adapting to an uncertain future climate. However, more research the application of the approach is necessary. I reflect upon this in the recommendations of the next section.

6.3 REFLECTION AND RECOMMENDATIONS

This report provides insight and advice into reducing vulnerability and exposure to flooding in the area of East Boston in the future, by creating an adaptive design that takes uncertainty into account. I enjoyed working in a new design environment, gaining new knowledge on a relevant emerging topic in landscape architecture, and I hope I have contributed to a more Climate Ready Boston. Secondly, I hope it provides a useful framework for landscape architecture that can be used as a stepwise approach for making smart design choices that generate adaptive plans.

Personal lesson
Personally, I have learned that protecting densely built coastal cities is a long-term, ongoing process of assessing risks, developing and evaluating alternatives, and implementing adaptive strategies, but most of all it is about knowing how to deal with uncertainty. Uncertainty is often taken as an excuse for inaction, but this thesis shows that accurate and precise predictions are not a pre-requisite for adaptation and decision-making. I therefore learned that uncertainty can never be taken as an excuse for inaction. I would like to argue that our present and future environments should be designed in ways that they becomes as adaptable as possible, since we don't know which future scenarios will come our way. I have learned that long-term thinking in this sense is very important, because future uncertainties need to be incorporated into our current planning and design. I argue that adaptive design under climate uncertainty must become a matter of course in spatial (re)development.

My thesis in relation to the wider context
The topics of complexity, climate uncertainty, adaptive approaches and design were chosen for their relevance in the larger social and scientific realm. Climate uncertainty is an issue that is increasing with time, so for long-term adaptation and preparedness, new solutions are very relevant and desirable. It has become clear that designing under uncertainty is a challenge for landscape architects that has not been addressed much in their own field, while uncertainty in future climate change is so large that it makes many traditional approaches to landscape architectural design of flood-prone areas inadequate.

Dealing with uncertainty in the design process by shifting the focus from creating optimal designs to creating adaptive designs, will create more sustainable designs that provide the designed area with the capacity to respond to unprecedented and unexpected future circumstances in order to maintain a safe level of protection. I would like to see my thesis as inspiration for a new way of assessing and designing flood-prone areas that need to be spatially adapted in order to protect it from flooding. I want to inspire a shift in the way flood risk reduction designs are created and start a discussion on what would be the best way to do this. Hopefully the three main contributions of this thesis can help doing this.

In general, I think this thesis shows that research in landscape architecture could play an important role in (flood) risk reduction. Through design for spatial adaptation of vulnerable and exposed areas, risk can be reduced and the impacts of hazards including death, injury, loss, or disruption of livelihood can be prevented. This prevention can be called pre-disaster design, which I think is becoming a very relevant field of research, due to rapid climate change.

Recommendations and possible topics for future research

This thesis could lead to more general insights into how the flood risk of densely urbanized coastal areas could be reduced, which could lead to other approaches to be developed. Additional research is required to further develop the application and operationalization of adaptiveness in landscape architecture. The conclusions from this case study could also be relevant for other coastal cities, but additional research on the developed approach is necessary to further substantiate the results from the case study. Therefore, I would recommend the approach to be tested to other case studies on densely urbanized coastal areas to find out its general applicability. This can help to draw conclusions on handling uncertainty through use of adaptive approaches in the design process.

A topic for future research could therefore be to test the approach in other case studies. Another topic for research is to develop alternative approaches to deal with uncertainty in the design process. My exploration of an approach for landscape architectural design under uncertainty is just one example of what new ways of creating adaptive designs could be like. Research on other approaches could for example look into incorporating participatory processes into the process of designing under uncertainty, since different perspectives from different stakeholder could have a big influence on the final outcome of an approach.

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