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CLIMATE ADAPTATION AND URBAN RESILIENCE

Identifying barriers and drivers in sustainable stormwater management implementation

ROBIN NOORDHOEK
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UNIVERSITY OF TWENTE. ARCADIS Design & Consultancy for natural and built assets

Climate adaptation and urban resilience

Identifying barriers and drivers in sustainable stormwater management implementation

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ABSTRACT

The world is urbanizing at a rapid rate. The effects of climate change pose some serious challenges for many cities. One of the major risks of climate change for the built environment is expected to be the increase in extreme weather events. Cities are already vulnerable to extreme rainfall due to the dominance of impervious surfaces. These impermeable surfaces (such as roads, roofs, etc.) are less capable of absorbing rainfall and therefore increase the intensity of rainfall runoff. As rainfall is expected to become more intense for many urban areas around the world, the risk and consequences of pluvial flooding are expected to increase. This makes sustainable stormwater management an increasingly urgent topic for many cities.

Climate adaptation is shifting from a phase of awareness to the development of actual strategies, plans and projects in societies. However, many cities struggle to successfully implement measures that make their urban areas more resilient to pluvial flooding. Although interventions to overcome implementation barriers at the local level are recommended by most studies from a theoretical point of view, scientific literature describing successful interventions in practice is scarce. This research aims to contribute to bridging this gap by assessing a number of successful adaptation programmes to provide municipalities with practical advice on how to develop an adaptation strategy that is tailored to their city's specific characteristics to enable successful implementation.

A literature study was carried out that summarised barriers and drivers for successful implementation of stormwater management measures. Seven key aspects for successful policy development were found. Also, three main categories of barriers and drivers in sustainable stormwater management implementation were distinguished: information, resources and institutional arrangements. The combination of these key aspects, barriers and drivers was used for an in-depth analysis of three real-life cases.

Three cities that have been relatively successful in developing and implementing their adaptation programmes were assessed: Rotterdam, Amsterdam and Hoboken. It was found that these cities adhered to most of the drivers for success identified by literature, as well as some additional aspects that contributed to their success. The municipalities also made use of a number of tools that can be used to improve implementation of plans to make cities more resilient. The results of the three case studies were validated by semi-structured interviews with key players from each city.

The theoretical and empirical patterns were compared using a pattern matching technique. This led to the identification of a number of matches and mismatches between theory and practice. Afterwards, it was analysed why certain elements of the climate adaptation practice deviated from theory. Together with the information collected on adaptation drivers, this led to recommendations on how to align theory and practice. These findings served as 'building blocks' towards a roadmap for climate resilient cities.

Aligning theory and practice has implications for both climate adaptation literature, as well as the current practice in cities. Certain real-life best practices found during the case studies are under-exposed in scientific literature. On the other hand, the cities could improve their planning and implementation efficiency by following certain best practices from theory. Recommendations are put forward that explore ways in which theory and practice could be changed to improve the implementation of sustainable stormwater management principles. This could provide additional guidance to cities that wish to make their city more resilient to pluvial flooding or develop their own adaptation strategy.

PREFACE

This report is the result of my thesis research to conclude my master's degree in Construction Management and Engineering at the University of Twente. Over the past months, I have worked eagerly on this research topic from both Amsterdam and New York.

Presenting this report marks the end of a personal era, my life as a student. It will also mark the start of a new one, the working life of a graduated engineer. I have thoroughly enjoyed my time as a student at the University of Twente. I met lots of interesting, wonderful and amazing people and made friends for life. I would like to thank all of them for making my years as a student a great and unforgettable journey.

The report in front of you could not have been there without the help of a number of people. First of all, I would like to thank the members of my graduation committee - Robin de Graaf, Marcela Brugnach, Bram Entrop and Jeroen Rijsdijk – for their guidance, feedback and for granting me the chance to carry out this intriguing research. I also want to thank all employees at Arcadis that made my internship such an educational and enjoyable time, as well as everyone involved in the 'research and education program in urban resilience' at both the University of Twente and Stevens Institute of Technology. Last but not least, I would like to thank all interviewees for their constructive input.

I hope you enjoy reading my thesis!

Robin Noordhoek

Amsterdam, October 2017

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GLOSSARY

Blue-green infrastructure	A collective term for sustainable green and blue infrastructure that utilises underlying ecosystem functions to deliver multiple benefits, for example: cooling via evapotranspiration, water storage for heavy rainfall events, discharge peak attenuation, seasonal water storage, and groundwater recharge.
Climate adaptation	Courses of action designed to reduce the vulnerability of populations, assets, and operations to climate-related risk
Climate mitigation	Courses of action designed to reduce human impact on global warming and climate change
Critical infrastructure	A term used by governments to describe assets that are essential for the functioning of their society and economy
Pluvial flooding	Floods caused by (excessive amounts of) rainfall
Resilience	The capability of a system for prepare for, respond to, and recover from significant threats with minimum disruption
Stormwater	Surface runoff from rain and storm events that enter the drainage system
Urban area	Inner city plus surrounding areas with continuous built-up surfaces
Urban Heat Island	An urban area having higher average temperature than its surroundings due to greater absorption, retention, and generation of heat by its built environment and human activity

ABBREVIATIONS

ACT	Adapting to Climate Change in Time, an EU-funded network to help municipalities to adapt to climate change
IPCC	Intergovernmental Panel on Climate Change
LID	Low Impact Development
SuDS	Sustainable Drainage Systems
UKCIP	United Kingdom Climate Impacts Programme
WSUD	Water-Sensitive Urban Design

1 INTRODUCTION

This chapter serves as an introduction to the research topic and the research design. It highlights several recent developments that have led to the need for further research in the field of climate adaptation and urban resilience. After this, a summary of the research methodology is presented.

1.1 Background

The world is urbanizing at a rapid rate. Currently, half of the world's population is living in urban areas, and this figure is expected to increase to 66 percent by 2050 (United Nations, 2014). The effects of climate change pose some serious challenges for many cities. The expected impacts of climate change are sea level rise, an increase in air temperature and more extreme weather events (IPCC, 2013). These impacts can increase the risk of flooding, heat stress and drought in cities.

One of the major risks of climate change on the built environment is expected to be the increase in extreme weather events (Hunt & Watkiss, 2011). Cities are already vulnerable to extreme rainfall due to the dominance of impervious surfaces. These impermeable surfaces (such as roads, roofs, etc.) are less capable of absorbing rainfall and therefore increase the intensity of rainfall runoff. As rainfall becomes more intense, surface runoff levels can exceed the capacity of stormwater entry points or cause sewer overflows in combined sewer systems. This can cause street flooding, nuisance, damage, health risks, and moreover also increases the cost of meeting related regulatory requirements. Urban (pluvial) flooding thus has several negative consequences, especially regarding citizen-wellbeing and financial impacts. Besides water management problems, impermeable surfaces and climate change also contribute to other climate-related problems such as the urban heat island effect, which means that urban areas can become significantly warmer that its surrounding areas due to human activities (Hunt & Watkiss, 2011).

Given these trends, pluvial flooding is likely to increase in both occurrence and intensity for many cities around the world (Hunt & Watkiss, 2011). Therefore, drainage and stormwater systems need to be improved to counteract the effects caused by urbanisation and climate change. Over the years, a lot of research on ways to use retention and infiltration of urban water to make cities more resilient has been presented. Studies show that extreme precipitation cannot be dealt with efficiently through conventional sewage systems alone, but that other approaches should be considered as well (Ahiablame, Engel, & Chaubey, 2012). This includes using the outdoor public space for water storage during extreme rainfall events. All of this implies that the outdoor public space should be designed in such a way that it has a beneficial impact on retention and infiltration capacities, calling for a more holistic approach to urban water management by integrating the entire water cycle into the urban design process. This includes promoting local stormwater retention and infiltration measures, reuse, and blue-green infrastructures (Wong, 2006).

Over the last couple of years, a lot of research has been carried out on sustainable stormwater management measures. It has become clear to many local governments around the world that climate adaptation can help to alleviate (future) problems regarding urban water management and related fields. Theoretical ideas about ways in which this could be achieved are abundant. However, local governments struggle to put these theories into practice and lack guidance in developing concrete climate adaptation plans that cater to their area's specific characteristics. Moreover, actual implementation of measures remains troublesome (Aylett, 2015).

This gap between theory and practice is problematic for local governments. Many cities are willing to adapt their surroundings to climate change. They often use the available guidance materials to do so. However, the available literature is not well aligned with the characteristics of actual projects carried out in urban areas. In general, cities need more information in three stages of the process to align theory and practice better: 1) knowledge about local effects of climate change and suitable solutions, 2) setting clear (future-proof) goals that are effective and feasible and 3) knowledge about how to successfully implement their plans (Tyler & Moench, 2012). This research contributes to the domain of climate adaptation by proposing recommendations on aligning theory and practice, improving the ability of local governments to develop solutions that are tailored to their specific characteristics.

1.2 Research methodology

In order to contribute to enhancing urban resilience, this research attempts to provide local governments with support in developing and implementing their adaptation plans. The method to achieve this is briefly elaborated in the research questions and strategy below.

1.2.1 Research objective

The objective of the research is to show how local governments can make their public space more resilient by developing a roadmap that clarifies how they can successfully implement sustainable stormwater management measures. This includes identifying barriers and drivers to climate adaptation from literature, expert consultation, and case studies. Then, recommendations are made on how to align theory and practice in sustainable stormwater management implementation. The roadmap is designed it such a way that it can be used by (small) municipalities that face the challenge of moving from abstract ambitions to concrete solutions.

1.2.2 Research questions

The main research question and corresponding sub-questions are provided below:

Which steps can municipalities undertake to successfully implement sustainable stormwater management measures?

1. Which barriers and drivers to successful implementation of sustainable stormwater management measures can be identified from literature?
    a. According to literature, which barriers to successful implementation of sustainable urban stormwater management design principles can be identified?
    b. According to literature, which drivers for successful implementation of sustainable urban stormwater management design principles can be identified?
    c. Which of the identified factors are expected to significantly influence the ability of local governments to formulate and substantiate their climate adaptation programmes?

2. Which barriers and drivers to successful implementation of sustainable stormwater management measures can be identified from practice?
    a. Which urban water or urban development programmes are regarded as best practices of climate adaptation, and why?
    b. What were the main drivers for success in these programmes?
    c. Which aspects of their approach can be helpful for other municipalities that wish to improve their climate resilience?

3. To what extent do measures from literature and practice regarding sustainable stormwater management align?
    a. Which aspects of sustainable stormwater management can be found in both theory and practice?
    b. Which characteristics of real-life best practices do not align with theory?
    c. What can be done to bridge possible gaps between theory and practice?

1.2.3 Research design

In order to achieve the research objective and answer the research questions, a strategy has been devised. A brief overview of the research design is given below and is visualised in Figure 1 on the next page.

Step 1: Identify barriers and drivers from literature

Through literature analysis, the most important barriers and drivers to municipal climate adaptation are distinguished. With the help of experts from Arcadis, the most important barriers and drivers to implementation of sustainable stormwater management measures in the Netherlands will be selected. The findings serve as the foundation for the development of a draft framework that describes the main barriers and drivers from a theoretical point of view.

Step 2: Analyse best practices

Identification of drivers for implementation is done through studying 'best practices'. Case studies are the most logical way to conduct this research given the small domain, selective sample and qualitative nature of the information available (Verschuren & Doorewaard, 2010). For the case studies, a comprehensive document study is carried out, which will then be validated with at least one key player per city. These key figures played a central role in the development and implementation of the plans. More information on the exact content studied per case, as well as a list of interviewees can be found in Appendix B. The interview framework can be found in Appendix D.

The case studies analyse why certain leading cities are regarded as best practices regarding sustainable stormwater management. Then, the cities' efforts to become more resilient to climate change are compared to the main barriers and drivers identified from theory. An attempt will be made to support empirical observations with scientific literature if additional characteristics are found. In this way, best practices from both theory and practice can be combined.

Step 3: Aligning theory and practice

The final research question aims to assess how well current adaptation literature aligns with actual plans and projects implemented at municipalities that are regarded as frontrunners in the field of climate adaptation.

Pattern matching is used to compare theoretical patterns (found in literature) and empirical patterns (found in the case studies). Pattern matching concerns comparing two patterns in order to determine whether they match or not. Testing consists of matching an 'observed pattern' with an 'expected pattern' and deciding whether these patterns match. Pattern matching, especially when combined with systems thinking, is recommended as a strategy for qualitative analysis of case studies (Yin, 2003; Hak & Dul, 2009; Cao, 2007; de Graaf & Dewulf, 2010).

For possible mismatches between theory and practice that were found during the pattern matching analysis, recommendations are proposed on how to bridge this gap. Findings from both literature and the case studies will be used to present possible solutions. This leads to recommendations that describe the implications for 1) the three cities examined, 2) scientific literature and 3) other cities that aspire to develop an adaptation strategy. Further research could then focus on validating these recommendations together with a number of parties involved.

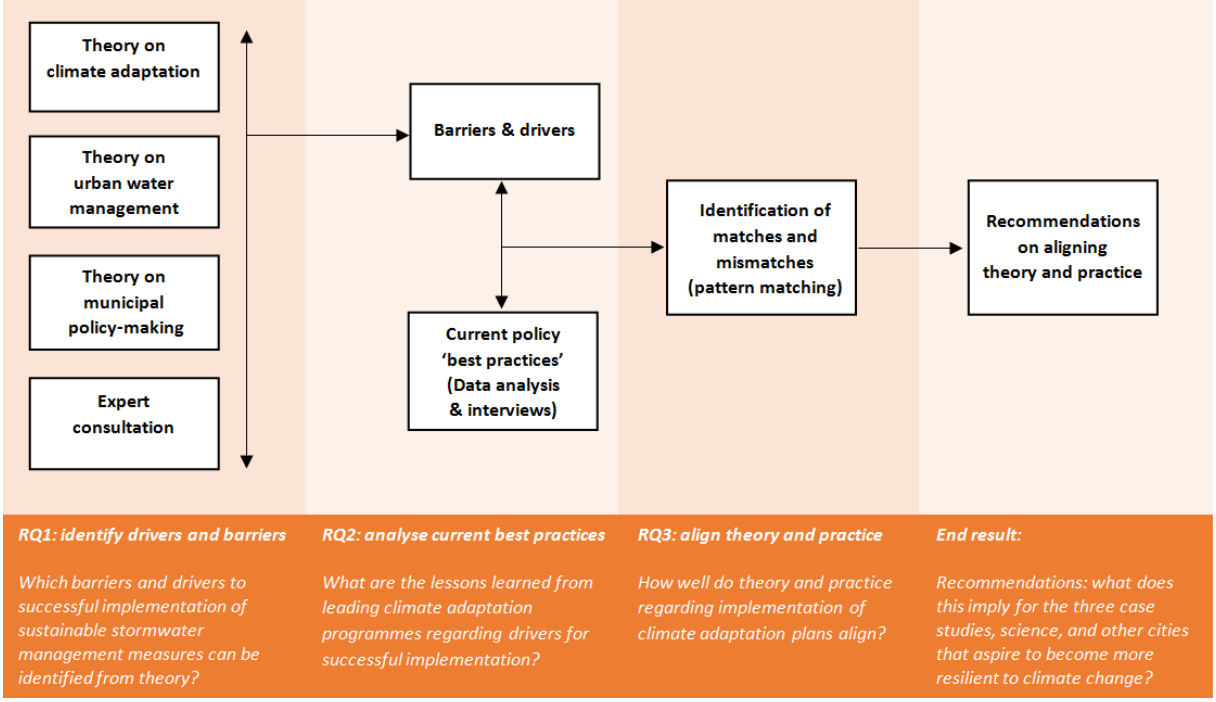

Figure 1: Main questions in relation to the research model, derived from Verschuren & Doorewaard (2010)

2 THE CLIMATE RESILIENT CITY

This chapter outlines the terminology used in this report and describes the challenges of the climate resilient city. First, insights into climate adaptation and resilience approaches are given. After this, the main barriers and opportunities of these approaches are discussed, focusing on sustainable stormwater management. When linked to urban planning processes, this leads to a number of criteria municipalities should consider while developing resilience-related policies.

2.1 Impacts of climate change on cities

There is mounting international concern about how to address the implications of climate change for urban areas. It is important to note that climate resilience is more specific than urban resilience in general, as it focuses on adapting the built environment to shifting climate extremes.

Over the last 100 years, global warming of the Earth's surface temperature by approximately 0.75 ºC has been observed. This trend is expected to continue if emissions of greenhouse gases are not decreased drastically (IPCC, 2013). The effects of global warming are location-based and its main challenges vary per area. This advocates for a bottom-up approach per area, contrasting with the top-down approach of climate mitigation. This means that possible solutions to make cities more resilient to extreme weather depend heavily on local characteristics, and thus can be different for every city.

The two main urban challenges associated with adapting to climate change are water management issues and heat stress (Runhaar et al., 2012). The Dutch Delta Program distinguishes four domains that play a role in making cities more resilient to extreme weather: 1) Urban Water, 2) Nature & Environment, 3) Urban Planning and 4) Infrastructure. These domains are all interconnected, thus advocating for an integrated approach. This report focuses on climate resilience from a stormwater management perspective, but connections with the other disciplines mentioned are acknowledged and briefly cited.

For the Netherlands, climate change will likely mean that temperatures will rise and the total amount of precipitation will increase. Major expected implications for urban areas are the increase of both extreme temperatures and extreme rainfall events (Netherlands Environmental Assessment Agency, 2015). This is shown in Table 1.

Table 1: Climate change projections for the Netherlands

	1981-2010	Projections for 2050
Yearly average amount of rainfall	851 mm	Between +2% and +5%
Yearly average maximum amount of rainfall per hour	15 mm	Between +12% and +25%
Average temperature	10.1 ºC	Between +1.0 ºC and +2.3 ^{0}C
Average hottest day of the year	32.0 ºC	Between +1.0 ºC and +3.8 ºC

Estimates for the end of the century show even bigger changes. For example, the same report also expects extreme rainfall quantities to increase with 10-60% by 2100. This shows that climate resilience is not some sort of 'end goal' that can be reached, but should be viewed as a continuous process that deals with lots of variables and uncertainties.

This means that a climate resilient city recognises the possible (and uncertain) impacts of climate change, and has effectively responded to the challenges that come along with it. This allows for robust protection and quick recovery after extreme events, minimising the negative impacts to people and the built environment.

2.2 Design approaches for climate proof cities

To counteract the impacts of climate change on cities, various approaches have been developed. The paragraphs below provide an overview of the most mentioned concepts, measures and policies in literature.

Sustainable (storm)water management approaches are being developed on a global scale, using slightly varying typology and scope (Fletcher, et al., 2015). One of the more well-known approaches is Low Impact Development (LID). LID is a term frequently used in Canada and the US. Similar practices are also described under the terms Sustainable Drainage Systems (SuDS) in the United Kingdom and Water-Sensitive Urban Design (WSUD) in Australia. Initiatives such as the Climate Proof City (CPC2050) in the Netherlands and the Sponge City program in China are building upon this knowledge on stormwater management. In this report, all these approaches will be referred to as climate adaptation approaches. These approaches, such as LID, SuDS and WSUD, CPC2050 and the Sponge City program adhere to the following principles among others (Ahiablame, Engel, & Chaubey, 2012):

- Integrate stormwater management strategies into the early stages of site planning and design;
- Manage stormwater as close to the source as possible with distributed micro-scale practices;
- Promote environmentally sensitive design;
- Promote natural water features and natural hydrologic functions to create a hydrologic multifunctional landscape;
- Focus on prevention rather than mitigation and remediation;
- Reduce costs for the construction and maintenance of stormwater infrastructure;
- Empower communities for environmental protection through public education and participation.

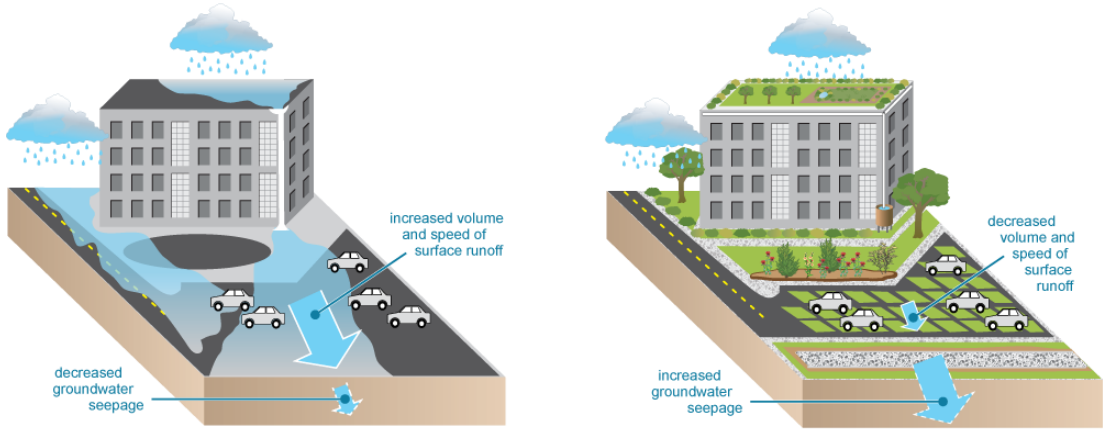

Figure 2: Example of climate resilient design (source: CACBTF, 2013)

While mostly focusing on flow control, these water management measures can deliver multiple benefits when combined with green infrastructure. Examples include beneficial effects to water quality and heat mitigation. These combinations are referred to as co-called ‘blue-green infrastructure’ (Thorne, Lawson, Ozawa, Hamlin, & Smith, 2015).

Ideas about various ways to make cities more climate resilient using the concepts described above are abundant. Numerous technical solutions have been developed that follow the principles described above, such as green roofs, permeable pavements, bioretention systems, rainwater tanks, swales, infiltration systems, etc. (Melbourne Water, 2005). Projects at the interface of climate adaptation, urban water management and urban planning are often collected and recorded in national repositories to inspire and inform other stakeholders. Examples of such repositories are UKCIP (UK), WSUD (AUS) and Kennisportaal Ruimtelijke Adaptatie (NL).

2.3 Policy approaches for climate proof cities

As various design approaches have been developed, municipalities need to ensure that they have the knowledge, skills and resources to implement related policies. An overview of efforts on all scales is presented below.

2.3.1 International and national efforts

The European Union strives towards national adaptation strategies for each of its member states (European Environment Agency, 2014). In the Netherlands, several guidelines and policies to make cities more climate resilient have been published during recent years. Between 2010 and 2014, the Climate Proof Cities (CPC) research program was established and carried out. The program has contributed to the knowledge on assessing vulnerability of cities, on adaptation options and their effectiveness, and on governance of adaptation. Also, guidance models for resilient landscape design were presented, as well as the 'Ambition Climate Proof City 2050', which envisions how Dutch municipalities can incorporate climate resilience into urban planning and design (Albers et al., 2015).

The next step towards implementing climate proof measures was the development of the National Adaptation Strategy (NAS), which was presented recently. This document describes the consequences of climate change and possible solutions (Ministry of Infrastructure and the Environment, 2016). The national adaptation strategy will be incorporated in the Delta Plan on Spatial Adaptation, which is a component of the Delta Programme 2018. The Delta Programme also states that by 2020 every municipality in the Netherlands should take climate adaptation into account in future planning and maintenance policies (Ministry of Infrastructure and the Environment, 2016). However, explicit guidance for municipalities on how to embed climate proof measures appears to be lacking or insufficient at this moment. Therefore, this requires further attention (Albers et al., 2015).

2.3.2 Local organisational approaches: dedicated vs. mainstreaming

While a lot of research has been done on establishing dedicated 'climate departments' within municipalities to promote implementation, empirical evidence suggests that in practice adaptation objectives need to be aligned with other disciplines (Uittenbroek, Janssen-Jansen, & Runhaar, 2013). Therefore, two different approaches to implementation of climate adaptation measures can be distinguished: a 'dedicated' and a 'mainstreaming' approach.

According to Uittenbroek et al. (2013), the *dedicated* approach focuses on the development of a new dedicated policy domain within the municipal organisation. Climate proofing the built environment is its main objective, and conformance to adaptation norms is the main criterion to assess policy outcomes in this approach. The majority of currently available adaptation guidelines underline this approach.

On the other hand, the *mainstreaming* approach attempts to embed climate proofing into other policy domains. This means that adaptation then will become one of the objectives within this domain, promoting integrated urban design solutions. This acknowledges the dynamic nature of municipal policy-making and would imply a more performance-driven approach.

2.3.3 Current state of affairs in the Netherlands

A recent survey among 85 Dutch municipalities provides insight into the uptake of climate adaptation on a local scale. While urban flooding was recognised as a climate-related risk by the vast majority of respondents (84%), awareness about other themes such as heat and drought was significantly lower (resp. 40% and 26%). Of all municipalities interviewed, 81% indicated that they were taking measures to adapt to climate change. However, only 42% of the respondents have actually embedded climate adaptation into their policies (Klimaatverbond Nederland, 2015). As these percentages don't say anything about the way in which adaptation is embedded, it is likely that the number of municipalities

that are able to successfully implement measures is even lower. Hoppe et al. (2014) underwrites this, and concludes that climate change adaptation is often not considered to be an important municipal policy issue due to a lack of urgency and incentives. Therefore, the degree of implementation of plans is relatively low in the long term. Often, adaptation measures are only implemented when they provide broader societal benefit, especially when they relate to other objectives from more established policy domains.

To some extent, the uptake of climate adaptation by municipalities can be described using the same terminology as the 'product adoption life cycle'. This concept distinguishes five groups of adopters: 1) innovators, 2) early adopters, 3) early majority, 4) late majority and 5) laggards. The gap between the first two groups and the (early) majority is a well-known problem in a number of disciplines (Moore, 2014) and can also be distinguished in the municipal uptake of climate adaptation. While leading cities such as Rotterdam and Amsterdam can be considered innovators (or in an international context at least early adopters), the target group for the end result of this research is the vast majority of municipalities that make up the other groups.

2.4 Overview of general challenges and opportunities

While the understanding of the impacts of climate change and possible design solutions have become clearer, the availability of practical guidance has not kept pace. Research findings suggest that more information on climate change impacts and adaptation possibilities does not necessary lead to more adaptation actions. Merely disseminating information does not ensure that action is undertaken to deal with the challenges (European Environment Agency, 2014).

The barriers also have a physical aspect. As the effects of climate adaptation differ on a local scale, it is up to local governments for formulate climate adaptation measures that fit the characteristics of their area. The biggest challenge for increasing resilience lies in existing cities, as the infrastructure, the urban design and the buildings themselves limit the number of possible adaptation measures (Albers et al., 2015). Numerous examples of climate adaptation actions are available, but the decision-making behind the implementation of these measures remains blurry. There is a lack of guidance for municipalities in determining what the best course of action is that caters to their specific needs and wishes (Measham et al., 2011).

Due to this lack of guidance, resilience-related themes are often not processed into concrete municipal urban projects. As a result, resilience is rarely represented in key municipal urban design principles or planning policies. Municipalities have difficulty translating the resilience challenge into output demands for projects, let alone outcome demands (Albers et al., 2015).

"The biggest challenge for increasing resilience lies in existing cities, as the infrastructure, the urban design and the buildings themselves limit the number of possible adaptation measures."

While some local governments are actively working on adaptation plans, others are falling behind due to a number of reasons. Aylett (2015) surveyed 264 municipalities worldwide and found several barriers against actively adapting the built environment to climate change. Through semi-structured interviews with water experts in the Netherlands, four main barriers were identified (de Graaff, 2011):

1) unfamiliarity with climate adaptation;
2) underestimation of the challenge ahead;
3) uncertainty regarding future scenarios;
4) unattractiveness of short-term investments.

Unfamiliarity with climate adaptation can be countered by awareness campaigns and using (online) platforms to share knowledge about adaptation actions, such as the repositories mentioned in Section 2.2. The second and third point indicate that municipalities require insight into the long-term effects and uncertainties of climate change on urban (water) resilience. Adaptation becomes more attractive when the extent of the challenge becomes clear and when it is shown how uncertainties can be dealt with in a sensible and cost-effective way. As indicated by the fourth barrier, it needs to become clear for policy

makers if (and how) adapting their city to climate change can be attractive in terms of costs. To do so, long-term benefits of investments, as well as insight into other benefits (ecological, recreational, aesthetic, etc.) of climate adaptation measures need to be known and shown. The most promising way to overcome the barriers mentioned seems to be the integrated approach to stormwater resilience as described in Section 2.2. (Stahre & Geldof, 2003). It is widely accepted that this interplay with other disciplines can lead to solutions with maximum added value and widespread acceptance (Vogel & Henstra, 2015). This so-called 'mainstreaming' of climate adaptation is also promising because it attempts to actively connect adaptation between policy fields, and thus is expected to stimulate the effectiveness of policy-making through combining objectives, efficient use of human and financial resources and safeguarding long-term investments (Uittenbroek, Janssen-Jansen, & Runhaar, 2013).

According to Dupuis & Biesbroek (2013), adaptation policies should be both *intentional* and *substantial*. While a minority of Dutch municipalities have purposefully designed or changed policies to manage the impacts of climate change (intentionality), this still does not mean that the policy has actually contributed to making cities more resilient to climate change (substantiality). This is schematised in Figure 3.

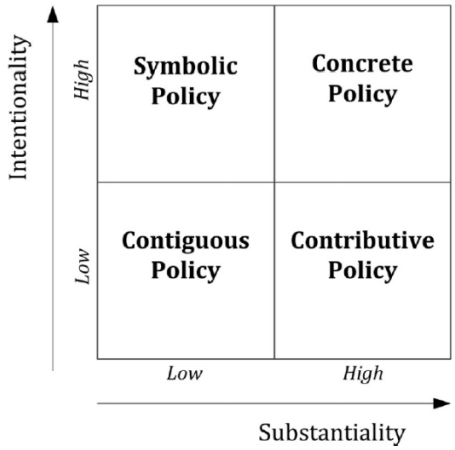

Figure 3: How to develop concrete adaptation policies, instead of symbolic ones? Substantiating adaptation policies seems to be a major challenge for many municipalities (Dupuis & Biesbroek, 2013).

Empirical evidence shows that in order to enhance the chances of successful implementation of adaptation measures, solutions should be sought that integrate the adaptation objectives into existing policy domains. While efforts have been made to analyse this phenomenon, it is still unclear for most municipalities how to progress from visions and ambitions to actual, concrete action regarding climate adaptation (Uittenbroek, Janssen-Jansen, & Runhaar, 2013). Therefore, this chapter distillates the expertise of municipal 'adaptation frontrunners' to lessons that can be applied to municipalities that struggle with this issue.

Finally, stormwater issues also provide opportunities in terms of stakeholder involvement and community engagement (Derkzen, van Teeffelen, & Verburg, 2017). Contrary to mitigation, climate adaptation is focused at a relatively small scale so its benefits are perceived directly by stakeholders at a local level. This improves the attractiveness of the participatory process, showing potential for active stakeholder participation (Snover, et al., 2007).

2.5 Urban planning processes & decision-making

Urban planning and climate adaptation are intertwined. Therefore, it is important to consider the characteristics of urban planning when investigating the development of climate adaptation policies. Many scholars have conceptualised municipal policy processes. A common disaggregation splits the

policy process into five conceptual stages: *agenda setting*, in which problems are formulated, brought to the attention of all parties involved and are prioritised for action; *policy formulation*, whereby possible solutions are designed and a course of action is recommended; *decision-making*, which involves the selection of a policy option; *implementation*, where policies are put into force and *evaluation*, which refers to monitoring the output and performance, and adjusting the policy over time if necessary (Jann & Wegrich, 2007).

The classification as described above provides a good overview of the policy process, but it artificially portrays the process as orderly and sequential. In reality, actors enter and exit at various stages of the process, and the elements of policy-making often occur concurrently rather than consecutively. Therefore, Wu et al. (2010) reframed these five stages as seven 'general policy-making functions' and illustrated the skills and tasks necessary for each function. This approach is preferred for this research as it is more suited for a comparative analysis of local adaptation activities. Vogel & Henstra (2015) analyse the seven functions, drawing on previous adaptation efforts. The overview in Table 2 is derived from their analysis, combined with general recommendations from the European guidelines for adaptation to climate change for municipalities (ACT, 2013). These 'core adaptation characteristics' are used as the foundation for the analysis of barriers and bridges in Paragraph 2.6 and the comparative analysis of the cases analysed. This is summarised in Appendix B.

Table 2: 'General policy-making functions' and their core characteristics (derived from Vogel & Henstra, 2015 & ACT 2013)

Policy-making function	#	*Core adaptation characteristics*
1. Setting the agenda	1a	Establish a project leader or representative
	1b	Bring the issue to the attention of the public
	1c	Create a sense of urgency
	1d	Make use of "policy windows"
2. Framing the problem	2a	Choose between hazard-, risk-, vulnerability-. and resilience-based approaches
	2b	Ensure (political) commitment by linking the issue to tangible, everyday problems
3. Engaging stakeholders and the public	3a	Analyse and involve stakeholders
	3b	Promote citizen participation through public-private partnerships
	3c	Set up a communication strategy
4. Setting priorities	4a	Define scope and time horizon
	4b	Establish a baseline and assess future projections (climate-related and socio-economic)
	4c	Analyse local impacts of climate change
	4d	Analyse adaptive capacity
	4e	Map potential adaptation actions and their requirements
	4f	Prioritise actions
5. Formulating policy options	5a	Establish vision and guiding principles
	5b	Collect and organise relevant information on adaptation options
	5c	Set goals, objectives, and targets
	5d	Generate and detail policy options
	5e	Identify instruments, resources and agents required
6. Generating political support	6a	Recognise, incorporate, and demonstrate co-benefits
	6b	Select preferred alternative using decision-making tools
	6c	Ensure political leadership and commitment to secure financial and organisational resources
	6d	Gain public interest by stressing (co-)benefits of adapting
7. Policy integration	7a	Implement policies and actions
	7b	Mainstreaming (incl. institutional/organisational provisions)
	7c	Establish tools and strategies to integrate adaptation into decision-making processes and allocation of funds
	7d	Set up monitoring and evaluation framework

2.6 Barriers & drivers in implementing adaptation measures

Adaptation to climate change is shifting from a phase of awareness to the construction of actual strategies and plans in societies. According to Mimura et al. (2014), information about setting up successful climate adaptation policies is abundant, but its availability is fragmented. Over the years, a lot of research has been done on the effectiveness of adaptation measures and identification of barriers

for implementation of these measures. However, to date this does not seem to have provided sufficient guidance, given the limited uptake of climate adaptation in municipal policies and projects (Hoppe, van den Berg, & Coenen, 2014).

Nevertheless, there is a lot of information available that enables setting up a list of barriers and drivers to climate adaptation. An overview of the barriers and drivers mentioned (in both guidelines and scientific research) is given below. To distinguish the patterns regarding municipal implementation, the classification of barriers as defined by Measham et al. (2011) is used, as it specifically targets municipal implementation of climate adaptation. Three core mechanisms that impede implementation of adaptation measures are defined: acquire sufficient information to make well-informed decisions ('information'), secure the resources necessary ('resources') and facilitate a broadly supported, integral approach ('institutional arrangements'). An overview of barriers and drivers listed in scientific research and stormwater adaptation guidelines is given below, using the classification of Measham et al. (2011). The most important takeaways (the bold text below) will then be used in the pattern matching in section 3.2, connecting theory to three case studies that were carried out.

1. Information

Gathering and spreading information is the first step towards **creating awareness and a sense of urgency**. A growing body of literature highlights the importance of effective communication of climate change information to increase awareness and understanding, provide continuity, and constructively engage policy-makers, stakeholders, and the public (Moser & Ekstrom, 2010; Lee & Yigitcanlar, 2010). According to Runhaar et al. (2012), addressing the issue is more effective if the positive aspects of adapting are stressed. People are more willing to collaborate if they have incentives for, or get direct benefits from participating. Improving resilience and liveability should be the main themes instead of climate change, as there is a group of people that does not believe or perceive climate change to be a problem.

When setting up an adaptation strategy, municipalities must first **gain an understanding of the possible local impacts of climate change and possible solutions**. Furthermore, municipalities must have access to information pertaining to their vulnerability to climate impacts in order to define realistic and relevant goals. This should allow them to **select and prioritise adaptation actions**. If municipalities lack insight in this when defining their goals and strategies, they might encounter unexpected barriers during the implementation of their measures. One way to improve insight is by participating is knowledge networks (Moser & Ekstrom, 2010). Furthermore, this information should be tailored to politicians, planners, and managers, and at a relevant scale and timeframe for taking action. Scenario-based projections should be used due to the lack of certainty regarding climate and social-economic forecasts (Measham et al., 2011).

Information about the progress and effectiveness of the plans and their implementation needs to be collected and analysed. Therefore, **mechanisms that allow for monitoring and periodic evaluation need to be in place** (Moser & Ekstrom, 2010).

2. Resources

A major challenge in terms of resources is to **build adaptive capacity among municipal staff**. According to the definition of Runhaar et al. (2012), this includes knowledge, awareness, and time, as well as the ability to integrate the work of all relevant municipal departments, which is important in this cross-sectoral issue. In order to do so, it is advised to define a climate change adaptation team that is responsible for accomplishing adaptation objectives (ACT, 2013).

Inadequate resources are often the first response practitioners give when asked why they have not yet begun adaptation planning (Moser & Ekstrom, 2010; Aylett, 2015). Measham et al. (2011), states that resources should be allocated in such a way that effective life-cycle planning and long-term issues are given attention. Aylett (2015) found that the lack of funding for implementation is at least partly caused by the fact that most municipalities need to allocate money from existing budgets. **The chances of getting political and financial support can drastically improve if the issue is explicitly connected to the positive effects of adapting in the short term** (ACT, 2013).

Implementation of measures should be tailored to its environment. Therefore, it is important to **connect with inhabitants and other stakeholders**. When effectively using this network knowledge, experience and additional funding from these parties can be used to smoothen the implementation process (ACT, 2013).

3. Institutional arrangements

Institutional arrangements are interpreted as (in)formal regimes and coalitions for collective action and inter-agent coordination, ranging from public-private cooperation and contracting schemes to organizational networking and policy arrangements (Geels, 2004). Policy frameworks in which the municipality operates should facilitate an integrated approach to the problem (Measham et al., 2011). However, this is often not the case. Aylett (2015) highlights a number of challenges linked to institutional arrangements. The most important ones are lack of jurisdiction over key policy areas, difficulties in collaboration between municipal departments, and competing priorities within the organisation. In order to successfully implement multi-sectoral measures, cross-level relationships need to be established and maintained (Moser & Ekstrom, 2010). Using the knowledge of existing innovative knowledge networks is another option (Runhaar et al., 2012). The main rationale for considering adaptation measures seems to be to link their benefits to other, more popular and tangible subjects such as environmental and spatial quality. As many actors on a local level still are not aware of the urgency of climate change problems, re-framing the issue might prove to be more effective in enhancing the chances of successful implementation of building and street-scale measures. According to Brugnach et al. (2008) this promotes thinking towards a new vision of the problem, possibly allowing different relations and solutions to emerge through reflection, dialog, and negotiation. In terms of reframing the issue to gain momentum in the political arena, the following stimuli should be considered: getting the image of an early adapter, becoming more attractive to businesses, and climate proofing the built environment during restructuring plans and public pressure (Runhaar et al., 2012).

When **developing goals and objectives**, involving important stakeholders through local initiatives or industry partnerships enhances the chances of successful implementation (Lee & Yigitcanlar, 2010). Therefore, a good **stakeholder analysis** needs to be carried out in the early stages of the process. Afterwards, concrete provisions regarding communication and collaboration can be made. This promotes engaging the community in climate resilient planning (Tyler & Moench, 2012).

Leadership is another important organisational mechanism. Leaders who demonstrate high skills levels and strong qualities of integrity tend to be more trusted by participants and perceived as legitimate (Moser & Ekstrom, 2010). **Appointing one clear leader** of the project is one step towards overcoming institutional fragmentation as the leader is the connecting element in organising and assigning responsibilities (Runhaar et al., 2012).

Internal communication and collaboration provisions need to be established. Tools and strategies for mainstreaming need to be established and used to promote implementation of measures for cross-sectoral issues (ACT, 2013; Lee & Yigitcanlar, 2010).

Summary

The mechanisms as described above are used as an a priori framework of analysis for studying the case studies and best practices regarding municipal climate adaptation. In Chapter 3 and 4 these mechanisms will be referred to as ‘theoretical patterns’. The findings of the case studies will be discussed in Chapter 3.

2.7 Knowledge co-production

Looking at the barriers and drivers for successful implementation of sustainable stormwater management measures, it can be seen that aligning theory and practice plays an important role. Aligning what we know with what we do is one of the major challenges of contemporary water governance. Solving current water problems transcends the decision-making power and resources of any single actor and requires coordinated actions among a diversity of actors from different organizational levels and sectors (Brugnach, 2017). This calls for the co-production of knowledge among these actors.

It is important to keep in mind that the processes concerning knowledge creation are not top-down, nor do they revolve around one right way to deal with the issue of climate resilience. In fact, knowledge production is a circular and cooperative process that should acknowledge that there are multiple ways of knowing. Armitage et al. (2011) define this knowledge co-production as “the process of bringing a plurality of knowledge sources and types together, promoting a more inclusive way of generating relevant, robust and actionable knowledge”. Knowledge co-production is an iterative process that can happen though coordinated action among stakeholders who engage in some form of collaboration to create the knowledge that is ready to be translated into action. A visualization of this circular, iterative process is shown in Figure 4.

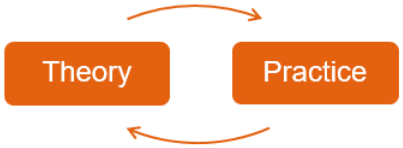

Figure 4: Knowledge co-production

When co-producing knowledge, ambiguity plays a key role. Ambiguity refers to the degree of confusion that exists among a group of actors regarding what the problem or issue is (Weick, 1995). Ambiguity potentially stands for both a source of creativity and a source of conflict, since the presence of multiple ways of knowing may be a source of inspiration and innovations for developing solutions, bringing new elements to the decision space, triggering new thoughts, and developing new synergies among people. Hajer (1995) argues that a certain degree of ambiguity or openness to multiple interpretations is needed for a disparate group of actors to find solutions in ways that are meaningful for all of them, and differences can facilitate actors to engage in a joint initiative and co-create a solution. While it may often be hidden in assumptions, making collective decisions always entails handling differences. Ambiguity is unavoidable, and to the extent that it is not conflicting, it is a desirable component of multi-actor settings (Brugnach & Ingram, 2012).

Divergent ways of knowing can still yield organised collective action when the interaction frames (i.e. communication behaviours actors use) are sufficiently aligned. This requires the capacity to establish collaborative links among different networks of actors, empowerment efforts and mechanisms that restore power balances among actors (e.g. legal support, access to information, capacity building) together with the continuous reflection on the rules of participation (Brugnach, 2017).

Although interventions to overcome barriers to climate adaptation are recommended by most studies, empirical studies on interventions are scarce (Biesbroek, 2013). Experience with the integration of stakeholder knowledge and scientific knowledge in urban climate adaptation is still limited. There appears to be a lack of system-wide reflection on and learning from case studies. This results in fragmented knowledge on successful adaptation approaches, hindering the up-scaling and application of local best practices (Groot, 2015). In the next chapter, an analysis of several case studies is presented in order to address this issue.

3 CLIMATE RESILIENCE IN PRACTICE: CASE STUDIES

Which municipalities are leading the way when it comes to climate resilience, and do their efforts correspond with the existing body of literature on adaptation? These questions are discussed in this chapter. Therefore, this chapter distillates the expertise and experience of municipal 'adaptation frontrunners' into empirical patterns. A number of real-world best practices are presented, which are then compared to the theoretical patterns derived from literature.

3.1 Implementation of resilience measures: best practices

What can we learn from successful adaptation projects? In order to determine which cities could be seen as leaders in the field of sustainable urban water management, the Sustainable Cities Water Index (Arcadis, 2016) was used. While many rankings for resilient cities exist, this is the most comprehensive city index available (as it analyses the biggest number of cities worldwide) that focuses on sustainable water management. The index ranks 50 cities worldwide based on the way they deal with urban water challenges. Both Amsterdam and Rotterdam score very well in this ranking, especially in the water resilience sub-ranking (respectively #2 and #1). Hoboken, New Jersey is added as a third case study, due to the fact that the Greater New York area experienced substantial flooding during an extreme weather event (Hurricane Sandy), and has been planning to improve its resilience through innovative and well-documented schemes such as the Rebuild By Design competition and Rockefeller's 100 Resilient Cities Campaign. This led to Hoboken being selected as 'Role Model for Resilience'[1] by the United Nations, as one of only two US cities.

Rotterdam, Amsterdam and Hoboken can be seen as best practices and were further examined in order to determine which factors contributed to their top positions. This was done by reconstructing an 'adaptation timeline' of the city in question using the available documentation. This timeline was then verified and supplemented by key figures from within the corresponding municipal organisations. All of this is summarised in short background narratives per city, which can be found below. A full list of documents and people consulted is given in Appendix B.

3.1.1 Rotterdam

The city of Rotterdam was one of the first European cities to acknowledge the need to account for adaptation to climate change. Situated in a delta area below sea level, the city has long been aware of its vulnerability to both coastal and river floods. After heavy rainfall events in 1999 and 2001, it became clear that the city also needed to improve its resilience to pluvial flooding. This put stormwater management on the agenda. Rotterdam soon realised that the success of its stormwater management policy depended heavily on its integration with other fields, such as climate change adaptation, spatial planning, and cooperation with its citizens. Climate change was seen not only as a threat, but also as an opportunity to improve the city and its image (Municipality of Rotterdam, 2007).

The municipal administration has played an active role in setting things in motion, for example by working on a water-driven vision of the city for the Architecture Biennale in 2005, and starting the Rotterdam Climate Proof programme in 2008. The city saw the programme as a way to improve its image, and to present itself as a good example of a sustainable delta city. After years of pilots, research, etc. this led to the presentation of the comprehensive Rotterdam Adaptation Strategy (and a revised version of the cities' *Waterplan)* in 2013, linking climate change with heat mitigation, (storm)water management, and liveability whilst also accounting for implementation, monitoring and financing (Municipality of Rotterdam, 2013; Rotterdam Climate Initiative, 2013a).

[1] https://nextcity.org/daily/entry/hoboken-flooding-strategy-makes-role-model-city

3.1.2 Amsterdam

While already highlighting the economic and aesthetic importance of water in the *Waterplan* of 2001, it took Amsterdam until 2014 to present a comprehensive stormwater management plan. The first document to incorporate climate adaptation was presented in 2010 and focused on flood safety and the water system as a whole. Cloudbursts in 2012 and 2014 raised awareness of the need for action in the field of pluvial flood prevention. The ´Amsterdam Rainproof´ programme was set up and gained momentum during this time, presenting its first comprehensive stormwater management programme in 2014 (Amsterdam Rainproof, 2014). This programme also recognises and identifies cross-over benefits (heat stress mitigation, liveability), though its current focus is on stormwater management. This relatively narrow scope is intentional: by focusing on rainwater the programme's initiatives were expected to be more visible, realistic, and feasible. A broader adaptation document is currently being developed and is expected to be presented in 2018.

3.1.3 Hoboken

Hoboken, New Jersey is a city in the Greater New York area with a population of around 50,000 people. It is a very densely populated urban area with more than 15,000 inhabitants/km^2. Consequently, 90% of the city's land area consists of impervious surfaces such as buildings and roads (Bykowski, 2013). In 2004, the 'City of Hoboken Master Plan' was Hoboken's first document specifically addressing resilience in relating to pluvial flooding. It mentions the implementation of green infrastructure as a desirable goal for the city to deal with the problems caused by the high degree of impermeability (Hoboken Planning Board, 2004).

However, it took a natural disaster to accelerate Hoboken's efforts to improve resilience. In 2012, Hurricane Sandy inundated 80% of the city and severely disrupted everyday life. As this was caused by both pluvial and coastal flooding, the event served as a catalyst to come up with more ambitious green infrastructure plans, combined with new coastal defence measures. After Hurricane Sandy, Hoboken entered New York's resilience-oriented design competition 'Rebuild by Design' in June 2014. The competition resulted in a comprehensive water management strategy named 'Resist, Delay, Store, Discharge' (OMA, 2014). Among measures like hard infrastructure for coastal defense (resist) or water pumps for better drainage (discharge), the plan suggests green urban infrastructure to slow down stormwater runoff and store excess rainwater. Therefore, Hoboken's 'Green Infrastructure Strategic Plan' builds upon this broader strategy and falls within the strategic aspects of 'delay' and 'store' of the Rebuild by Design project. The plans were worked out further in Hoboken's 'Green Infrastructure Strategic Plan' (Together North Jersey, 2013) and a feasibility study (Dewberry, 2017). Currently, the city is revising its Master Plan, consulting a wide array of inhabitants and private parties in the process[2].

[2] More information on the current state of affairs can be found on http://hobokennj.gov/masterplan/

3.2 Theoretical patterns vs. empirical patterns

In this research, pattern-matching is used to compare the theories about successful implementation of climate adaptation measures to what has actually been done in practice in successful projects.

The pattern analysis is divided into three main themes: information, resources, and institutional arrangements. This is in line with the categorisation as previously presented in Section 2.6. An overview on the background and the main characteristics of the approaches of the cities examined has been provided in Section 3.1. From this, together with the interviews and document studies, the empirical pattern is derived. The findings are summarised in tables. For readability purposes, only a selection of relevant quotes related to the three main themes is presented.

3.2.1 Empirical pattern 1: information

In both Rotterdam and Amsterdam, there have been extensive awareness campaigns, though using different methods. The municipal administration of Rotterdam has played an active role in creating awareness and kick-starting their resilience projects, for example by working on a water-driven vision of the city for the Architecture Biennale in 2005, and starting the Rotterdam Climate Proof programme in 2008. In order to raise awareness and achieve widespread adoption of adaptation actions, the city of Amsterdam intends to facilitate stakeholders in 'rainproofing' their surroundings though the Amsterdam Rainproof platform. On this platform, inhabitants can find information regarding exposure, vulnerability and ways of adapting their surroundings to climate change. Also, the programme partners with the private sector to improve visibility, for example through garden centres and neighbourhood meetings. In New York, it took a natural disaster (Hurricane Sandy) for people to become aware of the urgency of the issue. Afterwards, the municipal administration made adaptation one of its top priorities, which is reflected in the amount of attention the resilience issues get when new projects are announced and constructed.

Rotterdam gathers and shares knowledge together with other cities in the C40 Connecting Delta Cities program, the Rotterdam Centre for Resilient Delta Cities, the 100 Resilient Cities initiative and the Dutch Climate Adaptation City Deal. Amsterdam is focusing more on internal networks and tries to bring the right people within the municipal organisation together to exchange knowledge. Hoboken gathers and shares its experiences and knowledge within a number of programmes, such as Rebuild by Design and the 100 Resilient Cities program.

All cities have conducted major efforts to investigate and visualise the effects of climate change on (storm)water management and flood safety. This includes connecting climate projections and socio-economic trends as well as identification and mapping of vulnerable places. Rotterdam acknowledges that the best adaptation solution can vary per neighbourhood. Therefore, it has set up a list of standardised measures that describe the general direction in which solutions should be sought per neighbourhood, but leaves room for the exact interpretation on a local scale. In order to select the solution that fits a neighbourhood´s problem best, a wide array of tools is available, such as a climate atlas, adaptation toolbox, cost-benefit analysis tools and a climate game that visualises the impacts of possible solutions (Rotterdam Climate Initiative, 2013a). Amsterdam is doing the same, but currently only focuses on rainwater as solving this problem is expected to be more visible, realistic, and feasible and thus created a better start of the project. Hoboken has mapped its exposure and sensitivity to extreme weather events. After this, a number of promising solutions was proposed and prioritisation was done using several criteria, such as (cost-)effectiveness, feasibility and social impact.

All cities have made arrangements regarding monitoring and evaluation of adaptation projects and policies. At the moment, Amsterdam uses mainly output-indicators to do so, while Rotterdam has developed both process- and output-related indicators. Hoboken is still in its early stages of implementing solutions, but is busy establishing output-based indicators. A summary of the findings from the case studies in relation to the theoretical patterns as described in the previous chapter can be seen in Table 3 on the next page. This is supplemented with quotes from interviews and the document study.

Table 3: Patterns compared: information

Theoretical pattern	Empirical pattern	Examples[3]	Match?
Raise awareness through a public campaign.	Awareness was created not only through campaigns, but also after flooding took place.	"Participating in the Architecture Biennale in 2005 proved a key activity in informing and motivating people about climate change adaptation." (R) "We utilised the flood events of 2012 and 2014 as starting point of our story. These events will occur more often if we don't take action." (A) "While Hurricane Sandy mainly caused flooding because water from the Hudson River entered the city, it definitely made people realise that our city is vulnerable to weather extremes and that something needs to happen." (H)	Yes, furthermore flood events are as utilised as extra opportunity to raise awareness.
Gather knowledge about (projected) climate change impacts and available solutions. Collaborate within established innovative networks.	Knowledge about impacts and solutions is gathered through internal and external networks. Collaboration takes place within established innovative networks.	"We are member of a large number of innovative networks. That helps us to gather the information we need." (R) "We try to co-create with stakeholders to make use of all knowledge available. We also learned a lot from Copenhagen's approach during a visit." (A) "The Rebuild by Design competition helped us to establish a framework about what we need to know, and where we can get that information." (H)	Yes
Assess exposure, sensitivity, and adaptive capacity to prioritise the most important impacts. Set up a decision-making framework to select and prioritise adaptation actions.	Extensive assessment of exposure and sensitivity has taken place. Adaptive capacity focuses on physical aspects, but not on governance. This impairs the implementation decision-making process.	"After conducting a stress test we know exactly what the vulnerable places in the city are, now and in the future. We did not consider governance." (R) "We have mapped exposure and sensitivity for flood 'hotspots'. We also identified which parts of our internal and external network we need to involve to deal with those areas." (A) "There is never enough funding to build what we need to build. It's a matter of prioritsing." (H) "We're using a multiple-criteria analysis to select and prioritise actions. Due to the limited amount of money we plan on implementing the things that are most cost-effective and feasible in terms of permits." (H)	Partly, governance is under-exposed when assessing adaptive capacity.
Design a monitoring and evaluation framework that uses both process-based and outcome-based indicators. Periodically review and update the plans.	Outcome-based indicators are often used, municipalities struggle to formulate process-based indicators or use them only implicitly. Periodical review takes place.	"The programme is evaluated yearly, by looking at whether we're on schedule with implementation and costs." (R) "We have a monthly evaluation meeting in which we discuss all aspects of monitoring and evaluation. Formally though, we only use output-indicators at the moment." (A) "Most of our projects are yet to be implemented. Therefore, we're still busy developing and evaluation system. However, we do think about maintenance costs, etc." (H)	Partly, municipalities succeed in setting up output-based indicators. Defining outcome- and process-based indicators proves to be more difficult.

[3] R = Rotterdam, A = Amsterdam, H = Hoboken

3.2.2 Empirical pattern 2: resources

The cities investigated used a variety of methods to build organisational capacity. Rotterdam for example made use of a relatively top-down, centralised strategy. For many years, the Rotterdam Climate Initiative was responsible for all resilience-related activities and had the manpower and budget to do so. This included in-house development of risk- and vulnerability analyses and adaptation options. Amsterdam on the other hand attempts to build organisational capacity by mainstreaming its work on climate adaptation. The city acknowledges that a great number of departments are working on their own projects, but actively tries to connect these efforts until collaboration becomes the new culture/habit within all departments. The city of Hoboken is not actively assessing vulnerability, risk and adaptation options on its own, but outsources most of the work through local initiatives such as Together North Jersey and Rebuild by Design. The city is actively cooperating with these organisations, but is not the key player.

All cities ensured political and financial resources in a different way, with varying degrees of success. Rotterdam saw the programme as a way to improve its image, and to present itself as a good example of a sustainable delta city. A number of iconic projects contributed to the cities' progressive image, while their visibility also improved public awareness of the issues at the same time. Landmark local adaptation projects include the floating water pavilion, multifunctional flood protection, the water plaza, and water storages underneath the central station and the Museum Park Garage. Amsterdam developed a comprehensive strategy to implement climate adaptation into existing policy domains (referred to as 'mainstreaming'). This way, major additional investments are avoided, as money should be allocated from existing budgets. Hoboken on the other hand, like most other U.S. municipalities, has limited financial manoeuvring room. Therefore, the city relied on federal and state funds directly related to rebuilding the city after Hurricane Sandy. However, the city attempts to rebuild in such a way, that resilience gets a prominent place in the new plans. Furthermore, the city relies on a number of public-private partnerships to finance its plans. Political commitment was secured through urgency after Hurricane Sandy and a strong focus on liveability, however this might change when a new mayor is elected in November 2017.

In executing its strategy, Rotterdam is actively collaborating with all stakeholders involved. Plans on how to share adaptation knowledge within the governmental bodies is documented. Also, the municipality actively tries to inform inhabitants and local businesses about the challenges regarding climate change and water nuisance. It is stressed that adaptation first of all is a responsibility of the plot owner. The municipality promotes climate adaptation measures among inhabitants by providing them with information about the benefits of adapting, as well as financial incentives for some measures (such as green roofs). Amsterdam uses other innovative approaches to water resilience. For example, a water label for buildings, the 'water-neutral building envelope' and rainwater-related tax incentives are currently being developed and investigated (Amsterdam Rainproof, 2014). Hoboken is involving private parties through its design competition, Rebuild by Design. Also, the city has recognised that using publicly owned land for adaptation purposes is the most effective and feasible solution in the short term. As the city's climate adaptation plans are currently still being developed, the focus of the municipality is currently on these kind of solutions to set an example to its citizens and raise awareness.

Table 4: Patterns compared: resources

Theoretical pattern	Empirical pattern	Examples	Match?
Build organisational capacity to assess vulnerability, risk, and adaptation options by appointing a dedicated municipal adaptation team or department.	Building organisation capacity can take place through setting up one specialised municipal department, but also through smart internal and external networks.	"For many years, the Rotterdam Climate Initiative was responsible for all adaptation-related activities and research." (R) "Knowledge is scattered throughout the municipal organisation. Rainproof tries to connect all relevant disciplines, but is not supposed to play a central role in the long term." (A) "We partnered with a number of organisations and networks that carried out the majority of the assessments." (H)	No. Municipalities can also succeed through 'mainstreaming' or by engaging external parties.
Ensure political commitment and financial resources by addressing the urgency and the positive effects of adapting on the short term.	Awareness and sense of urgency are key to maintaining political commitment and allocation of financial resources. Co-benefits are stressed to make the issue tangible.	"Our participation in the Architecture Biennale definitely opened up everyone's mind about the urgency and possibilities of adapting our city to climate change." (R) "We ensure commitment by providing added value to the city without much additional costs." (A) "In the planning stages, the city emphasized the project's co-benefits, such as improved accessibility and quality of public spaces, to gain support." (H)	Yes, with focus on stressing local co-benefits
Facilitate implementation by involving private parties to gain access to money and experience	Different approaches. Rotterdam and Hoboken have a history of implementing mainly large-scale, centralised solutions. Amsterdam co-designs with private parties and stimulates them to invest.	"Implementation is often easier if it concerns our own assets, such as the public space. Of course, we do try to involve other parties if possible." (R) "We try to facilitate implementation by making adaptation a standardised part of the city's urban design activities. On a local scale, we then try to pick the best solution together with stakeholders." (A) We spend a lot of time engaging our public and trying to work with them to foster a collaborative design process in all planning of large capital projects. However, it has been hard to activate local businesses to invest voluntarily." (H) "At the moment, we focus on implementing measures on publicly owned land and eminent domain. Otherwise it would become too complex." (H)	Partly, municipalities prefer implementing measures in the public space, as it minimises the complexity of implementation, but this also limits cooperation

3.2.3 Empirical pattern 3: institutional arrangements

One of the findings from literature is that most successful climate adaptation plans have a strong adaptation advocate, leading the transformative process. In the case of Rotterdam, the newly formed Rotterdam Climate Initiative (RCI) proved to be the centre point of adaptation activities. According to one interviewee '(...) everyone knew to turn to the RCI if they needed information on climate adaptation or mitigation.' Besides this, Rotterdam's mayor and several other political head figures have shown strong support for the adaptation strategy. In Amsterdam, Amsterdam Rainproof is clearly leading the adaptation efforts. However, since this organisation is intended to be of temporary nature, it is up for debate whether there will be one clear person or organisation taking the lead in the future. In Hoboken, two clear leaders can be distinguished. The city's mayor has been a strong advocate for climate adaptation, which has gradually trickled down to all relevant municipal organisations. On the other hand, Rebuild by Design remained the gathering point for all knowledge, ideas and plans regarding climate resilience.

In terms of setting time- and location-dependant objectives, Rotterdam's adaptation strategy for stormwater differentiates between five different 'layers' of action with different importance and priority. The strategy aims to make the city resilient to a 1/100-year rainfall event, but also acknowledges the uncertainties that come with these kinds of predictions. Therefore, the city has committed itself to comply with the standard (less ambitious) national norms[4], and then focus their efforts on the areas that 1) have the highest urgency and 2) are promising in terms of creating added value (Rotterdam Climate Initiative, 2013b). Therefore, Rotterdam's adaptation strategy can be regarded as more effect-oriented rather than norm-oriented. Amsterdam intends to design its public space in such a way that it can handle a rain event of 60 mm/hr, of which the first 20 mm will be conveyed trough conventional systems (which is the standard capacity of Dutch sewerage systems). The remaining two thirds will be stored temporarily in either public or private space, depending on the location and options. It should also be noted that the city has a radically different definition of the word 'rainproof' compared to most other cities. Loosely translated: 'You are rainproof when you are aware of the consequences and opportunities of dealing with rainwater. It is up to you whether to undertake action or do nothing. In the latter case, you accept the consequences." (Amsterdam Rainproof, 2014). Hoboken has not yet set clear time- and location-dependant objectives, as this will likely depend on the amount of funding the city will receive. At the moment, the city experiences pluvial floods and combined sewer overflows multiple times per year. Based on local characteristics, the city has already made an inventory of which solutions will fit which areas of the city. This is based on a number of spatial characteristics, such as building density, soil characteristics and flood risk.

In executing its strategy, Rotterdam is actively collaborating with all stakeholders involved. Plans on how to share adaptation knowledge within the governmental bodies is documented. Also, the municipality actively tries to inform inhabitants and local businesses about the challenges regarding climate change and water nuisance. It is stressed that adaptation first of all is a responsibility of the plot owner. The municipality promotes climate adaptation measures among inhabitants by providing them with information about the benefits of adapting, as well as financial incentives for some measures (such as green roofs). In order to achieve widespread adoption of adaptation actions, the city of Amsterdam intends to facilitate stakeholders in 'rainproofing' their surroundings through the Amsterdam Rainproof platform. Similar to established practices (such as Low Impact Development) this approach focuses on local, street-scale solutions. The main way to engage inhabitants is through the Rainproof Platform which, by providing data and information on stormwater issues, is intended to inspire stakeholders and co-produce measures with them (Locher & Dekker, 2016). To ensure the uptake of this bottom-up approach, a comprehensive communication- and participation strategy has been set up. Hoboken is currently mainly focusing on climate adaptation in the public space, minimising the interactions required with other stakeholders. However, the city has acknowledges that in the long run it needs to involve private parties as well. The city is currently looking at the possibility of changing zoning regulations, rainwater-based tax incentives and changing the building code.

[4] This is a downpour that is expected to occur once in every two years (T = 2). In the Netherlands, storm sewers are generally designed to convey 60 or 90 l/s/ha (i.e. 21.6 mm/h or 32.4 mm/h). They should be able to deal with a T = 2 downpour without resulting in water nuisance. Water nuisance or flooding occurs respectively during T = 10–25 and T = 50 downpours.

Following Rebuild by Design's approach, Hoboken´s communication and collaboration strategies are accounted for, but details on when and with whom are yet to be established.

Integration of adaptation activities within municipal departments is a topic that is stressed by al interviewees. However, specific tools and strategies to do so are not always available or in place. Rotterdam has ran a pilot with a tool that 'scans' whether the adaptive capacity of certain municipal departments is big enough when it comes to climate change. Also, the city uses a 'climate game' to show the need for collaboration. However, this game is mainly focused on involving inhabitants. A comprehensive strategy however, is lacking. Amsterdam on the other hand has set up a detailed strategy on how to integrate adaptation into all relevant municipal departments and has a number of tools to achieve this 'mainstreaming'. Amsterdam Rainproof has mapped all relevant activities within its network that play a role in climate adaptation, and has identified key players to collaborate with in each of these domains. Hoboken has not actively worked in integrating its efforts yet. On a municipal level, most of the work is done at the city planning department, they cooperate with other departments if necessary. Hoboken is not actively developing tools or strategies themselves, but appears to rely on Rebuild by Design to do so.

Table 5: Patterns compared: institutional arrangements

Theoretical pattern	Empirical pattern	Examples	Match?
Establish one clear team leader who connects all parties necessary.	One clear team leader who connects all parties necessary was established.	"Everybody knew to turn to the RCI if they needed information on climate adaptation or mitigation." (R) "Our most important task is to create a network of people working on climate adaptation." (A) "Our mayor has been a big advocate for climate adaptation from the beginning." (H)	Yes
Set clear goals, objectives, and targets, incorporating time and location. Develop them jointly with key stakeholders.	Goals, objectives, and targets are set, yet sometimes somewhat vaguely formulated. All cities prefer effect-oriented rather than normative approaches. Joint development of goals with external stakeholders does not take place.	"When developing our goals and targets, we did not involve external stakeholders yet. Involving them this soon would make things only more complicated." (R) "Although we try to avoid using normative targets, we set the limit at 60mm/hr to give engineers something to work with." (A) "There is no one-size-fits-it-all strategy for how we vision, design, build our projects. This differs from location to location due to spatial characteristics and the preferences of the people involved." (H)	Partly, joint development with stakeholders rarely takes place in practice.
Explicitly investigate stakeholders and state with whom, when, and how to communicate and collaborate.	Detailed stakeholder analyses take place. Detailed communication plans are in place, but participation receives less attention in one case.	"We conduct stakeholder analyses for each project, but in practice we prefer informing stakeholders instead of co-designing." (R) "Besides our communication strategy, we also offer collaborative working sessions for most projects." (A) "We invite encourage inhabitants and local businesses to provide us with input and feedback during community meetings." (H) "(…) and I think public engagement has changed, a lot of the stakeholder engagement has changed, frankly through the dedicated efforts by the RBD project and several other large capital planning project that were undertaken." (H)	Yes, although cities have trouble differentiating between informing, consultation, partnerships and co-design (Arnstein Gap).
Establish tools and strategies for the integration of adaptation activities within municipal departments	Integration of adaptation activities depends on the way the programme is organised (centralised vs. network).	"Strategies? Not that I know of. We do use tools and a climate game to show the need for collaboration." (R) "We have a detailed strategy for internal mainstreaming of climate adaptation. This is necessary, because knowledge about climate adaptation is scattered throughout the organisation." (A)	Partly, depends on the way the programme is organised (centralised vs. network approach).

3.3 Pattern matching conclusions

Pattern matching proved useful to unravel differences between theory and practice in climate adaptation. When comparing best practices from theory and practice, a number of similarities and differences can be identified. The highlights of this comparison are summarised below. After this, the differences between the cities themselves will be discussed briefly. The results of this chapter will then serve as the starting point for aligning theory and practice, which will be elaborated in Chapter 4.

In Table 6, an overview of the pattern matching results is presented. It can be seen that every category has both matches and (partial) mismatches. These will be explained in more detail below.

Table 6: Overview of matches, partial matches and mismatches between theory and practice

Match?	Category	Theoretical pattern
Yes	Information	- Raise awareness through a public campaign. - Gather knowledge about (projected) climate change impacts and available solutions. Collaborate within established innovative networks.
	Resources	- Ensure political commitment and financial resources by addressing the urgency and the positive effects of adapting on the short term.
	Institutional arrangements	- Establish one clear team leader who connects all parties necessary.
Partly	Information	- Assess exposure, sensitivity, and adaptive capacity to prioritise the most important impacts. Set up a decision-making framework to select and prioritise adaptation actions. - Design a monitoring and evaluation framework that uses both process-based and outcome-based indicators. Periodically review and update the plans.
	Resources	- Facilitate implementation by involving private parties to gain access to money and experience.
	Institutional arrangements	- Set clear goals, objectives, and targets, incorporating time and location. Develop them jointly with key stakeholders. - Explicitly investigate stakeholders and state with whom, when, and how to communicate and collaborate. - Establish tools and strategies for the integration of adaptation activities within municipal departments.
No	Resources	- Build organisational capacity to assess vulnerability, risk, and adaptation options by appointing a dedicated municipal adaptation team or department.

3.3.1 Summarized pattern matching results: matches

The matches from the pattern matching analysis can be regarded as best practices underlined by both theory and practice, and should therefore be utilised by other cities who wish to become more climate resilient.

All of the cases showed successful attempts to raise public awareness. Recent flood events were utilised as extra opportunity to raise awareness. This seems to be particularly effective when coupled with personal stories of inhabitants that experienced the flooding. Activation of citizens proved to be most effective when awareness campaigns were coupled to everyday concerns of inhabitants, for example by coupling them to liveability issues. This is in line with theory (O'Neill & Nicholson-Cole, 2009).

All cities analysed also made extensive efforts to gather knowledge about projected climate change impacts and possible solutions. This knowledge was gathered through both internal and external networks. For all cities, it proved successful to collaborate within innovative knowledge networks, sharing knowledge and experiences with other cities and private parties.

When ensuring (political) commitment, all sources interviewed have indicated that stressing financial benefits of adapting in the short term are important, but that the most important factor for achieving commitment appears to be to stress co-benefits of adapting. This makes the issue tangible to people that would otherwise be reluctant to participate in resilience-related projects.

All cases had a clear project leader who, according to the interviewees, attributed to the success of each city. This leader (which can be an organisation or person) proved to be a key connecting element in bringing all relevant stakeholders together.

3.3.2 Summarized pattern matching results: partial matches

A number of partial matches were found during the pattern matching. This means that while the approach of the cities adhered to theory to some extent, further improvements or development needs to take place to fully match theory and practice. This can be achieved through either adjusting theory or practice.

When assessing adaptive capacity, the cities investigated have a tendency to focus on physical aspects. However, as it is more difficult to assess governance aspects as well, this aspect is often under-exposed. This impairs the decision-making process when actions need to be selected and prioritised, as it is now unknown whether the municipal organisation itself is currently aware of the importance of the issue and is capable of changing its routines.

In setting up a monitoring and evaluation framework, scientific literature recommends that both process-based and outcome-based indicators should be used. All municipalities are capable of setting up output-based indicators on their own, however they struggle to set up the other indicators on their own.

When looking at facilitating implementation, in reality municipalities often first turn to adapting spaces they own themselves. However, this also drastically limits cooperation opportunities. Although co-designing with inhabitants and other private parties is a relatively slow and complex process, it is advised that municipalities should not wait too long before also utilising this possibility to implement stormwater management projects, as this approach takes root slowly.

Tools and strategies to integrate adaptation activities within all relevant parts of the municipal organisation highly depend on the way the programme is organised. Amsterdam, using a network approach, has extensively worked on this issue. Rotterdam and Hoboken have focused less on this issue, as their way of organising adaptation (resp. specialised department and external design competition) makes integration a less critical issue.

While agreeing with the main features of the analysis and engagement of stakeholders for resilience projects, there appears to be room for improvement. Although recommended in adaptation literature, joint development and active citizen participation in the design and development process not always takes place in practice. However, there appears to be a lot of information available on these subjects in a number of networks and organisations that aid municipalities in setting up adaptation strategies. In involving stakeholders, some cities seem to have trouble differentiating between informing, consultation, partnerships and co-design. This is often referred to as the so-called ‘Arnstein Gap’ (Arnstein, 1969; Wilker, Rusche, & Rymsa-Fitschen, 2016).

3.3.3 Summarized pattern matching results: mismatches

For one pattern, a mismatch between theory and practice was found. Building organisational capacity to assess vulnerability, risk, and adaptation options takes place, but this does not necessarily have to take place within one specialised municipal department, as theory suggests. In most available handbooks and guidelines, it is advised to set up a dedicated municipal department for climate adaptation and mitigation. However, reality appears to be different. Cities like Amsterdam and Hoboken do not have a dedicated municipal department, but still succeed in building organisational capacity through ‘mainstreaming’ and smart use of external networks.

4 ALIGNING THEORY AND PRACTICE

As concluded in the previous chapter, theory and practice for implementation of climate adaptation measures do not fully correspond in over half of the patterns identified. Aligning theory and practice has implications for climate adaptation theory, as well as for the three case studies and all other cities attempting to put theory into practice. The implications will be discussed in this chapter. In the end, preliminary recommendations on how to align theory and practice are presented. The findings from this research were then used during the development of a roadmap for climate resilient cities. This process is schematised in Figure 5.

Figure 5: from pattern matching to recommendations and roadmap

4.1 Analysis of matches, partial matches and mismatches

First, an overview of matches will be given. After this, the mismatches between theory and practice are analysed and explained.

4.1.1 Matches: what went well?

First of all, when comparing theory and practice, it should be noted that all of the cities that were analysed adhered to the majority of best practices identified from theory. This can also be seen in Appendix B. A number of highlights regarding matching patterns are provided below.

Match?	Category	Theoretical pattern
Yes	Information	- Raise awareness through a public campaign. - Gather knowledge about (projected) climate change impacts and available solutions. Collaborate within established innovative networks.
	Resources	- Ensure political commitment and financial resources by addressing the urgency and the positive effects of adapting in the short term.
	Institutional arrangements	- Establish one clear team leader who connects all parties necessary.

Given the fact that these patterns were found in both theory and practice, it could be argued that these patterns are ‘best practices’ when it comes to climate adaptation. Below, more detailed information for all best practices is given.

- *Raise awareness through a public campaign.*

All cities examined focus their communication on the broader benefits of adapting (more green space in the city, more attractive for businesses and higher educated people, improved public spaces, etc.). In order to gain awareness and acceptance, they all focus their stories on liveability rather than flood risk reduction. Rotterdam is a good example of this, by giving people an idea of the possibilities of what the city could look like in 2035, through their design of ‘Rotterdam Water City’ for the Architecture Biennale. The benefits of adapting to climate change in the short term are stressed in a visual way that is easy to understand for many people.

Also, examples of recent floods are used to further improve the sense of urgency and willingness to act among inhabitants. It is stressed that these events will occur more often, or will be more severe, if no action is undertaken.

In most cases, a communication strategy was not formally set up. However, in practice all of the cities found ways to communicate the importance of the issue successfully through a multitude of channels such as an online platforms, social media, community meetings, etc. These practices became routine activities for the municipal employees involved.

- *Gather knowledge about (projected) climate change impacts and available solutions. Collaborate within established innovative networks.*

The solutions of Rotterdam, Amsterdam and Hoboken are all more effect-oriented rather than norm-oriented. This means that the approaches focus on efficient use of resources, rather than focusing on flooding norms.

Rotterdam and Hoboken make use of a standardised set of preferred solutions per type of neighbourhood. Also, Rotterdam and Amsterdam have both incorporated elements of sustainable stormwater management into their urban design manuals, making it a standard aspect when redesigning the public space. Hoboken has not yet formally done this, but has explicitly made sustainable stormwater management a priority in all of its current redevelopment activities.

All three cities, especially Rotterdam and Hoboken, cooperate within specialised knowledge networks to collect and share knowledge about best practices. Examples include the C40 Connecting Delta Cities program, the Rotterdam Centre for Resilient Delta Cities, the Dutch Climate Adaptation City Deal, the 100 Resilient Cities initiative and Rebuild by Design.

- *Ensure political commitment and financial resources by addressing the urgency and the positive effects of adapting in the short term.*

All cities recognise climate adaptation as a shared responsibility between public and private actors. Furthermore, all cities focus on no-regret and low-regret measures in the short term. In addition to this, Amsterdam actively intends to spread the ‘rainproof’ way of thinking among its citizens (stressing their own responsibility and the positive side-effects of adapting) and civil servants (stressing the need for collaboration within the organisation).

- *Establish one clear team leader who connects all parties necessary.*

All cases had a clear project leader who, according to the interviewees, attributed to the success of each city. This leader (which can be an organisation or person) proved to be a key connecting element in bringing all relevant stakeholders together.

4.1.2 Partial matches: what could be improved?

While the three cities examined have achieved more resilient urban planning, there is room for improvement. As was concluded from the pattern matching analysis, a number of patterns only aligned partially. These partial matches are analysed in this chapter. Table 7 on the next page shows the partial matches found between theory and practice. This section also suggests ways to further improve on these points.

The three cases all have been successful in making their city more resilient. However, they sometimes used ways to achieve this that differed from each other, or even from theory. For some of these points cities have proved to be successful despite not sticking to adaption theory. An overview of the main differences between the approaches is shown in Appendix B.

Table 7: Overview of partial matches between theory and practice

Match?	Category	Theoretical pattern
Partly	Information	- Assess exposure, sensitivity, and adaptive capacity to prioritise the most important impacts. Set up a decision-making framework to select and prioritise adaptation actions. - Design a monitoring and evaluation framework that uses both process-based and outcome-based indicators. Periodically review and update the plans.
	Resources	- Facilitate implementation by involving private parties to gain access to money and experience.
	Institutional arrangements	- Set clear goals, objectives, and targets, incorporating time and location. Develop them jointly with key stakeholders. - Establish tools and strategies for the integration of adaptation activities within municipal departments.

In order to gain a better understanding of how to align climate adaptation theory and practice, the mismatches that were found during the pattern matching are analysed. In general, it could be argued that there are two ways to close the gap between theory and practice:

I. By refining theory to better match reality.
II. By adjusting the strategies of cities in order to match the current paradigm.

For each mismatch, explanations on why practice deviated from theory, accompanied with suggestions on ways to overcome this, are presented below.

- *Assess exposure, sensitivity, and adaptive capacity to prioritise the most important impacts. Set up a decision-making framework to select and prioritise adaptation actions.*

All three cities have a wide array of tools and guidelines at their disposal that improve the decision-making capability regarding implementation of measures.

When assessing adaptive capacity, the cities investigated have a tendency to focus on physical aspects. However, as it is more difficult to assess governance aspects as well, this aspect is often under-exposed. This impairs the decision-making process when actions need to be selected and prioritised, as it is now unknown whether the municipal organisation itself is currently aware of the importance of the issue and is capable of changing its routines.

Cities that did not invest in assessing adaptive capacity of the organisation itself omitted this because they were either not aware of either the existence or the importance of this step (for example stating that ‘everyone within the organisation is already aware of the problem’ and that therefore they skipped this part of the assessment).

The cities did not explicitly choose between hazard/risk/vulnerability/resilience-based approaches, simply because in practice there is not enough budget to fully fund any of those approaches. Cities solved this by focusing on prioritising their most important goals. This was then implemented in decision-making tools or in local policy or design manuals.

In order to gain a better understanding of their own organisational adaptive capacity, cities should first of all invest in tools that help them to gain insight into the current state of affairs on this topic. A number of tools has already been developed to do so. A good example of this is the TURAS ‘stress test’, which was used as a pilot in Rotterdam.

- *Design a monitoring and evaluation framework that uses both process-based and outcome-based indicators. Periodically review and update the plans.*

When setting up a monitoring and evaluation framework, scientific literature recommends that both process-based and outcome-based indicators should be used. All municipalities are capable of setting up output-based indicators on their own, however they struggle to set up the other indicators. This is

something where the currently available literature on adaptation falls short in providing guidance. In order to improve this, climate adaptation theory should focus more on providing policy-makers with tangible examples of process-based indicators, as well as support in developing these indicators.

- *Facilitate implementation by involving private parties to gain access to money and experience.*

When looking at facilitating implementation, in reality municipalities often first turn to adapting spaces they own themselves. However, this also drastically limits cooperation opportunities. Although co-development with inhabitants and other private parties is a relatively slow and complex process, it is advised that municipalities should not wait too long before also utilising this possibility to implement stormwater management projects, as this approach takes root slowly.

While literature generally advocates for a bottom-up approach of the resilience issue, the three successful cases do not all agree with this statement. The Municipality of Rotterdam used a relatively top-down approach to develop and implement its adaptation strategy. Amsterdam is using a bottom-up approach in which it intends to co-design together with inhabitants. Hoboken appears to be somewhere in between, selecting a number of preferred alternatives before consulting inhabitants. The more top-down oriented approaches proved to be successful because they appear to have engaged stakeholders and the public in a different way. Rotterdam used iconic, highly visible projects (such as the Architecture Biennale and the water squares) to promote the benefits of adapting. Hoboken has engaged with its community through extensive field trips and community meetings with the parties selected in the design competition. However, in both cases big, public projects proved to be a catalyst of all the other activities, by setting an example, creating awareness of the problem through permanent visibility and by improving the image of the city.

Adaptation literature should acknowledge that successful implementation of adaptation plans depends on the goals of the strategy as well and local characteristics. Therefore, while this often advocates for a bottom-up approach, other ways to achieve this are also possible.

- *Set clear goals, objectives, and targets, incorporating time and location. Develop them jointly with key stakeholders.*

A lot of room for improvement can be found in analysing and involving stakeholders for resilience projects. Joint development and active participation not always take place in practice. Some cities seem to have trouble differentiating between informing, consultation, partnerships and co-design when it comes to the development of these plans. This can be perceived as a knowledge issue. However, there appears to be a lot of information available on these subjects in a number of networks and organisations that aid municipalities in setting up adaptation strategies, as well as in scientific literature. Therefore, the municipalities investigated should follow the available literature on this topic in order to improve their development process.

In defining the time horizon of their programmes, both Amsterdam and Hoboken try to avoid using long-term deadlines. This means that they do have deadlines in the short term for carrying out certain projects, but they do plan not focus on certain safety norms, thresholds and deadlines in the future. In general, their goal could be described as becoming ‘more resilient’. Climate resilient planning should become a standard part of their vision and activities in the future. Amsterdam refers to this as ‘the rainproof way of thinking’. The city acknowledges that adapting is long-term work and focuses therefore on 1) adapting the ‘weak spots’ in the city in the short term and 2) establish a ‘rainproof way of thinking’ for all future maintenance, rehabilitation and development activities.

- *Establish tools and strategies for the integration of adaptation activities within municipal departments.*

Tools and strategies to integrate adaptation activities within all relevant parts of the municipal organisation highly depend on the way the programme is organised. Amsterdam, using a network approach, has extensively worked on this issue. Rotterdam and Hoboken have focused less on this issue, as their way of organising adaptation (resp. specialised department and external design competition) makes integration a less critical issue.

4.1.3 Mismatches: what didn't work?

Table 8 shows the mismatch that was found between theory and practice. This section will analyse why the mismatch occurred and what could be done to overcome this.

Table 8: Overview of (partial) mismatches between theory and practice

Match?	Category		Theoretical pattern
No	Resources	-	Build organisational capacity to assess vulnerability, risk, and adaptation options by appointing a dedicated municipal adaptation team or department.

- Build organisational capacity to assess vulnerability, risk, and adaptation options by appointing a dedicated municipal adaptation team or department.

In most available handbooks and guidelines, it is advised to set up a dedicated municipal department for climate adaptation and mitigation. However, reality appears to be different. Cities like Amsterdam and Hoboken do not have a dedicated municipal department, but according to the interviewees still succeeded in building organisational capacity through 'mainstreaming' and smart use of external networks. While this is already advocated by a number of scholars (Uittenbroek, Janssen-Jansen, & Runhaar, 2013), not all adaptation guidelines acknowledge this yet. An example of this deviation from theory is Hoboken, as the city has outsourced many of its activities to private parties and the Rebuild by Design competition. However, this has not led to a decrease in focus on the subject. Simply by making climate resilience one of the key points in allocating funds and granting construction projects it has gained significant momentum. However, this approach depends on a strong adaptation advocate within the municipal organisation. In this case, both the mayor and city planning board took on this role.

It can be concluded that building organisational capacity to assess vulnerability, risk and adaptation options can be done in other ways than suggested in the majority of literature, for example through mainstreaming and smart use of external networks.

4.2 Implications of aligning theory and practice

After identifying and analysing the mismatches between theory and practice, actions can be recommended to bridge this gap. These recommendations acknowledge that improving the implementation of climate adaptation practices is a shared responsibility between science and practice. The implications for the cities examined, other cities and climate adaptation theory will be discussed below. Recommendations will be made on actions to align theory and practice in these fields. Further research is needed to assess whether these actions have indeed been successful in aligning theory and practice. Also, including a bigger number of cases and/or interviews could possibly also bring to light additional patterns that need to be incorporated in the implications described in this section.

Section 4.1 described the gaps between theory and practice, and made suggestions on how to overcome these gaps based on the information gathered during the literature analysis and case studies. These suggestions are incorporated in the implications for practice (section 4.2.1) and theory (section 4.2.2) below.

4.2.1 Implications for climate adaptation practice

Aligning theory and practice has its implications on the way climate adaptation and stormwater management should be carried out in practice. This is true not only for the three selected cases, but also for other cities that are working on climate resilience. Based on the findings of this research, three main implications can be identified:

I. Cities should focus more on paradigm changes, rather than meeting flooding standards

In making their city more resilient to pluvial flooding, municipalities have the tendency to focus on meeting regulatory standards and norms. However, while this approach might provide a solution in the short term, it is advised to rather focus on changing the way of thinking and working of both municipal employees and citizens to ensure improving resilience in the long term. This entails that this new way of thinking should be formally embedded in all relevant standard procedures for future development. While this already is happening in Amsterdam, other cities like Rotterdam and Hoboken should focus more on this shift if they truly aspire to become a resilient city, not just one that meets regulations. A lot of research has been carried out on how these paradigm changes could be achieved, which can be found in the works of Ferguson et al. (2013) and Davoudi et al. (2013), among others.

II. When assessing adaptive capacity, governance deserves a more prominent role

All cities that were analysed understood the need of assessing vulnerability and adaptive capacity in order to develop solutions that would suit their problems. However, when assessing adaptive capacity, municipalities often seem to think that this only encompasses the built environment. This appeared to be the case in Hoboken. However, governance is also a very important aspect of adaptive capacity since adapting the built environment to climate change also requires changes in the organisation and the governance approaches that are used. Therefore, besides the physical component, it is argued that the governance component is also key in successfully assessing adaptive capacity (Engle, 2011). In order to address adaptive capacity in terms of governance, a variety of readily available tools and strategies can be used. This includes for example strategies as proposed by Quay (2010) the TURAS (EU-supported framework for policy transition strategies) tools used by Rotterdam.

III. Improve citizen engagement

Although all case studies made attempts to engage citizens when implementing adaptation projects, there appears to be a lot of room for improvement. While there is an abundance of theory available on citizen engagement in similar projects, municipalities do not seem to be aware of this and all improvise or develop their own ways of collaborating with stakeholders. In order to improve the efficiency and effectiveness of engagement, it is advised to use established approaches as developed by their respective higher levels of government or as established within knowledge networks. The general picture is that citizens are willing to support (or be involved in) climate adaptation as long as its solutions are multifunctional, i.e., also benefits them in another way (recreation, aesthetics, costs). It is advised for cities to generate public support not only by making people aware of climate change impacts but also by providing information on the multiple benefits of adapting, and to tailor the choice of solutions to local preferences (Derkzen, van Teeffelen, & Verburg, 2017).

Tailoring solutions to local preferences calls for the co-production of adaptation knowledge. As successful implementation of adaptation measures is so complex, it requires more than just scientific knowledge. Stakeholder knowledge should also be utilised as it is trans-disciplinary and contains tacit knowledge. Utilising this specific type of knowledge in iterative development processes adds value to projects and improves the chances of successful implementation (Geldof, 2011).

Also, literature suggests that citizens and other stakeholder should also be involved in earlier stages of the project, such as the development of adaptation strategies. Understanding the different dimensions that shape preferences for climate adaptation measures help urban planners identify more effective policy responses, thus effectively reducing impacts of climate change in cities. According to research, in general stakeholders would prefer up to two levels more involvement on the Arnstein ladder of participation than currently applied in adaptation projects (Wilker, Rusche, & Rymsa-Fitschen, 2016). In this way, there are more opportunities to deal with ambiguity in the development process, as well as opportunities to provide added value to projects and increase participation.

4.2.2 Implications for climate adaptation theory

Aligning theory and practice also has its implications on climate adaptation and stormwater management theory. This encompasses scientific literature, as well as guidelines that have been published to support municipalities in becoming more resilient. Based on the findings of this research, three main implications for theory can be identified:

I. Acknowledge that there are different ways of engagement for different adaptation strategies

From theory, it can be concluded that there are a great number of ways to involve stakeholders in climate adaptation. Bottom-up approaches to do so are advocated by the vast majority of scientific literature. However, other approaches that can contribute to awareness and engagement are only seldom represented in literature. In practice, a number of more top-down actions can be distinguished that have been identified as drivers for awareness and engagement. These actions include highly visible projects such as Rotterdam's water squares and the Rebuild by Design competition that gained significant coverage in the media and improve awareness as well as the image of climate adaptation in general. Although these solutions do not change the current paradigm of resilient design as most of the actions can be regarded as one-offs, they do have contributed to improving engagement in the short term. Therefore, although these actions might be regarded as less desirable from a theoretical point of view, literature should acknowledge that their short-term effects can contribute substantially to securing long-term resources and priority among stakeholders.

II. Use context-specific characteristics to develop tailor-made solutions

Furthermore, the cases have highlighted that approaches that are regarded as successful can still vary to some extent between one another. This is mainly due to the differences between cities. These differences can be physical, but also in terms of history, culture, organisation and politics. The failure to consider these contexts of knowledge exchange can result in the promotion of benefits while failing to adequately address adverse consequences (Williams & Hardison, 2013). In order to develop solutions that fit local characteristics well, it is advised to take all these aspects into account. However, current guidelines do not seem to leave enough room for this. Therefore, literature should be more flexible in suggesting fitting and feasible solutions by acknowledging the context-specificity of local climate adaptation.

III. Provide more guidance in developing outcome-related adaptation indicators for municipalities

Resilience is not some sort of 'end goal' that can be reached but should be viewed as a continuous process that deals with lots of variables and uncertainties. Therefore, it is important to set up adequate monitoring and evaluation systems. Scientific literature recommends that both process-based and outcome-based indicators should be used in evaluation and monitoring (ACT, 2013; Davoudi, Crawford, & Mehmood, 2013). However, municipalities have trouble differentiating between output- and outcome-related indicators. This is something where the currently available literature on adaptation falls short in providing guidance. Therefore, guidelines should focus more on helping municipalities to develop these kind of indicators.

4.3 Towards a roadmap for climate resilient cities

In order to synthesise the findings from this research into workable advice for municipalities, two further steps were undertaken. First, workshops were organised with municipalities and water authorities to find a suitable way of representing the climate adaptation process. Secondly, the implications for practice (as discussed in Section 4.2.1) were further developed into tangible recommendations, which were used during the development of a roadmap for climate resilient cities. Both activities are discussed in more detail below.

4.3.1 Developing of a roadmap for climate resilient cities

The implications of aligning theory and practice in climate adaptation have shown that there is room for improvement in daily practice at municipalities. The implications for practice from Section 4.2.1 can therefore be synthesised into 'building blocks' towards a roadmap. This roadmap could provide municipalities with guidance on what they can do to become more resilient and, more importantly, what they *should* do to become more resilient, thus reducing the gap between theory and practice.

In order to make such a roadmap a useful tool for municipalities that aspire to become more resilient to pluvial flooding, a number of workshops were organised. These workshops revolved around conceptualising the climate adaptation process and describing the barriers encountered for every part of the process. This project was commissioned by STOWA (organisation for regional water management in the Netherlands) and RIONED (umbrella organisation for urban water and sewage in the Netherlands).

The following parties participated in these workshops:

- 3 municipalities
- 4 water authorities
- Representatives from STOWA and RIONED

More details on participants can be found in Appendix C. During the workshops, several points were designated as key issues by the participants:

- All of the participants experienced a gap between policy development and implementation.
- Determining the goals and thresholds related to flooding (and resilience in general) proved troublesome in practice.
- All of the parties acknowledged that more guidance on organisational embedding of climate adaptation is needed.
- The participants of the workshop were not sure if the way they currently engaged with private actors (and citizens in particular) was the most effective approach. They indicated the need for additional guidance on how to develop solutions that would be widely supported.

Regarding the conceptualisation of the climate adaptation process, the participating local authorities proposed to use an 8-step, cyclical process-based approach. They argued this was how their development process could be characterised best. The eight steps roughly match the five steps of Jann & Wegrich (2007) as described in Section 2.5, with three steps (policy formulation, decision-making and evaluation) being split into multiple parts due to their complexity. An impression of the 8-step model of the roadmap can be seen in Figure 6 on the next page.

The roadmap distinguishes two cycles: a strategic cycle in which policy development takes place, and an operational cycle that takes into account the actual implementation or construction of adaptive measures. The participants of the workshops indicated that the connection between these two cycles proved problematic in their current day-to-day routines. The roadmap that was developed incorporates loops to connect strategic (policy development) and operational (implementation) aspects.

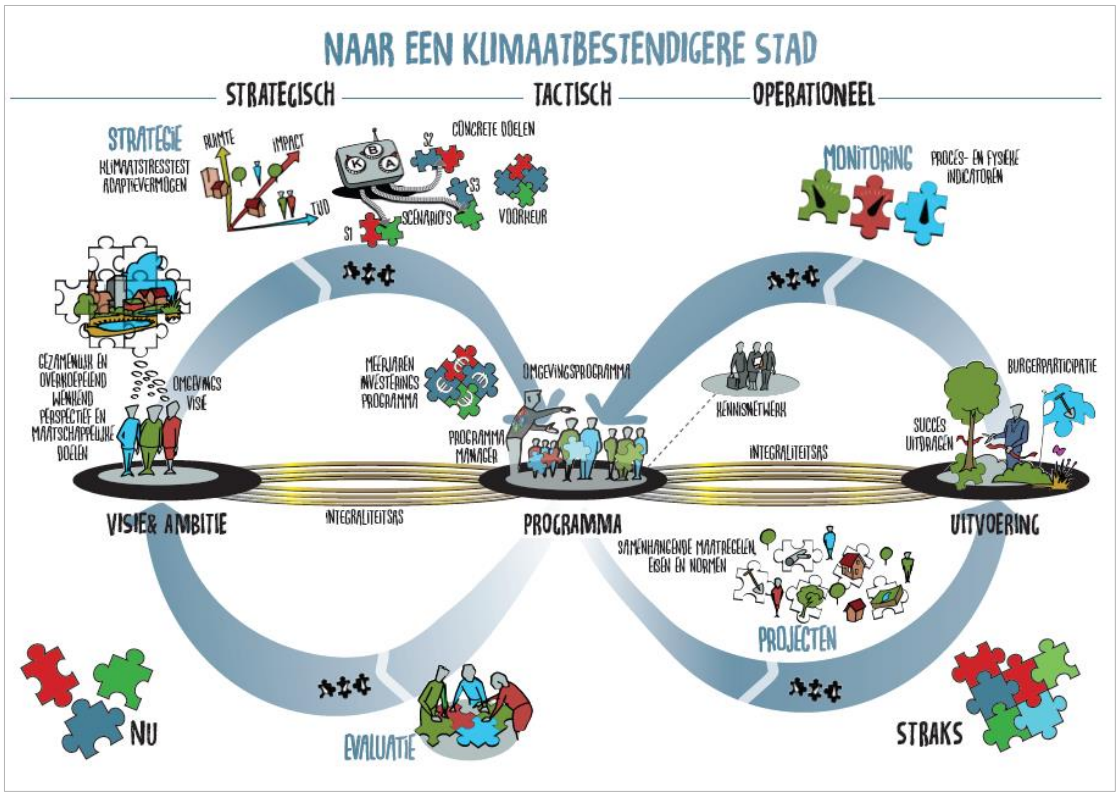

Figure 6: towards a roadmap for climate resilience: draft visualisation of possible steps

Each step of the roadmap revolves around a number of questions that need to be addressed when setting up climate adaption plans. It is intended that the roadmap then guides the user to helpful sources and approaches for every step of the process. During the development of the roadmap, the implications for theory and practice as presented in this report were addressed and incorporated. The development of the roadmap is currently in its final stages. After further validation together with municipalities and water authorities, it is intended that this roadmap will serve as a tool for policy-makers when setting up local plans related to climate adaptation, stormwater management, and resilience.

This is necessary, since the Dutch government has released its first ever *Deltaplan Ruimtelijke Adaptatie* in September 2017. In it, a number of policy measures to ensure climate resilient urban design are announced. One of these measures is that by 2020 all municipalities should have formally made climate adaptation part of their policies and activities (Ministry of Infrastructure and the Environment, 2017). Therefore, after further development and validation, the roadmap could support municipalities in accelerating their efforts with regard to the new Deltaplan.

4.3.2 Recommendations for the roadmap

In order to provide input for the workshops, action points for municipalities, referred to as 'building blocks' during the workshops, were set up based on this research. Therefore, this section synthesises the findings from literature, best practices and experts into building blocks that can be used by municipalities when defining their climate adaptation or stormwater management policies. The case studies serve as input for the building blocks of the roadmap in the following ways:

- The cases show that for some aspects of resilient city development, (scientific) literature is available, but is not yet utilised by municipalities. The recommendations presented should improve implementation and applicability of theory.
- Common 'best practices' found in the case studies are theoretically underpinned and are added as building blocks for the roadmap.

A summary of this is presented below, along the lines of the three implications for climate adaptation practice, as presented in Section 4.2.1.

I. Cities should focus more on paradigm changes, rather than meeting flooding standards

- In 2021, the new Environment and Planning Act (in Dutch: *Omgevingswet*) will come in to force, compelling municipalities to set up an integrated vision on future (urban) planning. Combining this with the challenges in the field of climate adaptation provides municipalities with the opportunity to efficiently join forces with water authorities and other actors to come up with integrated long-term solutions.
- Subdivide the 'container concept' of climate adaptation into a broad spectrum of societal challenges and goals, e.g. liveability, economic development, health, safety, sustainability. Focus on which processes need to change in order to achieve resilience in the long term, rather than focusing on regulatory requirements. Identify the added value of climate adaptation for each of the categories.

II. When assessing adaptive capacity, governance deserves a more prominent role

- The adaptive capacity of an organisation increases as its initiatives are coupled to local initiatives and projects in other policy domains. Therefore, it is important to conduct a thorough stakeholder analysis, and couple this to a suitable collaboration strategy. This analysis should not be limited to external parties, but should also focus on the municipal organisation itself.
- Adaptive capacity is also relates to the amount of knowledge within an organisation. Therefore it is important to build capacity through both allocating staff specifically to resilience issues, and through capacity building by training and education of employees.

III. Improve citizen engagement

- The level of stakeholder participation intended should match with the participation technique used. The implementation of an inappropriate degree of involvement may result in conferring an inappropriate level of power to a stakeholder and in a non-suitable participation technique. Levels include: information, consultation, collaboration, co-design and empowerment. Every level has its own recommended engagement methods. Proactive and well-defined approaches are more likely to influence policy than reactive and ill-suited participation strategies.
- Distinguish between policy participation (participation in policy development) and social participation (encouraging people to take action themselves). Both require different ways (and timing) of interaction.
- It is essential to understand that participation is context-driven: cultural, political and historical context have important consequences for the choice and success of a participation strategy. Local knowledge of the environmental conditions of the place and perceptions of them, (e.g. residents' associations) can enhance understandings of ecosystem services and benefits. Adopting such participatory approaches that encourage using this local 'expert knowledge' can lead to the delivery of more tailor-made policy outcomes, improving implementation chances due to more added value and improved acceptance and justification.
- Online design and communication platforms can be used to further improve awareness and participation. Geographic information systems have the potential to show the impacts of climate change, while examples of successful resilient design can be collected to inspire inhabitants to take action themselves.

These action points mentioned can be seen as 'building blocks' towards aligning theory and practice. The building blocks were then incorporated into the roadmap that was developed for STOWA and RIONED, together with advice on where to find more information on the subjects. This research contributed to the development of the roadmap by providing input on ways to improve the implementation efforts of municipalities along the lines of the recommendations made in this section. The roadmap itself was then further validated and developed in workshops with a wide variety of actors, led by employees of Arcadis.

5 CONCLUSION & RECOMMENDATIONS

This chapter discusses the final conclusions of the research. After this, a number of recommendations for further research are presented.

5.1 Discussion and limitations

In the end, this research provided a good understanding of why certain cities were successful in their adaptation efforts, and proved to be helpful in aligning climate adaptation theory and practice. The report as a whole shows promising prospects for implementing resilience measures in Dutch cities and around the world. However, as with every research, several remarks regarding the validity of the research need to be made.

First of all, the amount of in-depth case studies conducted for this research is relatively small. An extensive document study was conducted for only three cities. Besides this, the cases were selected on the availability of data, contacts and language in which the background documents were written. In order to improve the validity of this part of the research, more cities need to be added to the analysis. Also, more interviews per case study could be conducted to improve the validity of the document study.

In the case of the Hoboken case study, it could be argued that this analysis is outside the research scope because of two reasons: 1) because it is not located in the Netherlands and 2) because the majority of Hoboken's plans have not been implemented yet. However, the case provides this research with valuable insights from an innovative and leading design competition from overseas, which made part of Hoboken's approach a valuable addition to the other the case studies conducted.

The experts that were contacted for the validation of the research were selected based on contacts within the network of the writer and Arcadis. It should be noted that the amount of interviews conducted to date is relatively small. In order to further improve and validate this research, a larger and more heterogeneous sample of experts can be consulted. This might arguably also bring to light additional gaps or similarities between theory and practice.

5.2 Conclusion

First, the sub questions are discussed. After this, the main research question is discussed.

1. *Which barriers and drivers to successful implementation of sustainable stormwater management measures can be identified from literature?*

A large number of barriers and drivers to successful implementation have been identified from literature. The barriers and drivers can be divided into three main categories: information, resources and institutional arrangements. *Information* deals with raising awareness, gathering knowledge about current and future climate projections, as well as local risk and vulnerability. Access to information about suitable adaptation options and their effectiveness also play an important role. Setting up a monitoring and evaluation framework to gather all information necessary regarding progress and effectives is also often mentioned as both a barrier and driver for successful implementation, as it improves the learning capacity of the organisation. *Resources* comprises money (funding, public-private partnerships, etc.) and organisational capacity. *Institutional arrangements* are important because certain aspects, such as stakeholder management, integration of activities within the organisation, and setting up objectives and targets greatly affect the chance of success when setting up and implementing resilience policies.

2. *What are the lessons learned from leading climate adaptation programmes regarding drivers for successful implementation?*

The climate adaptation programmes of three leading cities were analysed: Rotterdam, Amsterdam and Hoboken. A wide array of drivers for success could be distinguished. These include widespread awareness and sense of urgency, effect-oriented approaches and focusing on co-benefits of adapting. Most of the lessons learned from the case studies were in keeping with theory. It was found that both top-down and bottom-up approaches (or a mix of both) can be successful, this is however highly

dependent on local circumstances. Therefore, to facilitate successful implementation the climate adaptation programme of a city should be carefully tailored to its characteristics. The cities investigated have a wide array of tools and approaches at their disposal that can be used to make urban areas more resilient to extreme rainfall.

3. *To what extent do theory and practice regarding sustainable stormwater management align?*

When comparing theory and practice, it should be noted that all of the cities that were analysed adhered to the majority of best practices identified from theory to some extent. In order to gain a better understanding of how to further align climate adaptation theory and practice, the mismatches that were found during the pattern analysis were analysed. The recommendations following this analysis have implications for the cities examined, other cities and climate adaptation theory. Recommendations were made on possible actions to align theory and practice in these fields.

The conclusions of the sub questions above contribute to answering the main research question:

> *Which steps can municipalities undertake to successfully implement sustainable stormwater management measures?*

A large number of actions to successfully implement sustainable stormwater management measures have been identified from both literature and the case studies. First of all, it is important to distinguish the different approaches to reduce flooding. Secondly, the approach chosen should match local characteristics. To ensure this, enough information and resources need to be available and institutional arrangements need to be accounted for. A number of mismatches between theory and practice for these three main categories were found. In order to improve successful implementation of sustainable stormwater management measures, a number of recommendations were made to align theory and practice. These include three main takeaways for cities: 1) focus on paradigm changes instead of meeting regulatory standards, 2) assess governance as part of the adaptive capacity analysis and 3) improve citizen engagement. Main steps for theory include acknowledging the context-specificity of climate adaptation to ensure efficient engagement and strategy development, and providing more guidance for municipalities in developing outcome-related adaptation indicators. So, in order to successfully align theory and practice, there are both challenges for science and local governments that need to be overcome. The challenges and recommendations that apply to municipalities were then incorporated into a roadmap for climate resilient cities which is currently being developed.

5.3 Recommendations

There are several recommendations for further research on this topic. They include recommendations for future case analysis as well as advice for the appliance of the lessons learned to similar urban areas and challenges.

In order to improve the validity of this research, it could be argued that more case studies of successful adaptation programmes are desirable, as well as a more heterogeneous and bigger sample of experts for the validation of the results.

Also, further research on a number of aspects that contribute to successful implementation of climate adaptation measures should be carried out to develop a more complete tool to aid municipalities. This research could focus on one of the three main barriers and drivers, and include an analysis of for example financing options, possible policy instruments or more detailed projections of flood vulnerability.

Another interesting option for further research is to continue following the process of policy development using the recommendations made. After certain programmes have been carried out, the entire process (from development to implementation and assessment of effectiveness) could be evaluated. This could possibly bring to light further recommendations on aligning theory and practice for policy-makers.

REFERENCES

ACT. (2013). *Planning for Adaptation to Climate Change; Guidelines for Municipalities.* Brussels: European Commission, LIFE Program on Environmental Policy and Governance.

Adger, W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B., & Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity. In IPCC, *Climate Change 2007: Impacts, Adaptation and Vulnerability; contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change* (pp. 717-743). Cambridge, UK: Cambridge University Press.

Ahiablame, L. M., Engel, B. A., & Chaubey, I. (2012). Effectiveness of Low Impact Development Practices: Literature Review and Suggestions for Future Research. *Water, Air & Soil Pollution*, 223:4253–4273.

Albers et al. (2015). Overview of challenges and achievements in the climate adaptation of cities and in the Climate Proof Cities program. *Building and Environment*, 1-10.

Amsterdam Rainproof. (2014). *Programmaplan Amsterdam Rainproof.* Amsterdam: Waternet.

Arcadis. (2016). *Resilient Cities Water Index.* Amsterdam: Arcadis.

Armitage, D. B.-S. (2011). Co-management and the co-production of knowledge: learning to adapt in Canada's Arctic. *Global Environmental Change*, 21(3), 995-1004.

Arnstein, S. R. (1969). A Ladder of Citizen Participation. *Journal of the American Institute of Planners*, 35(4): 216-224.

Aylett, A. (2015). Institutionalizing the urban governance of climate change adaptation: Results of an international survey. *Urban Climate*, 14: 4-16.

Biesbroek, G., Termeer, C., Klostermann, J., & Kabat, P. (2011). Barriers to climate change adaptation. *Climate Law*, 181-199.

Brugnach, M. (2017). The Space in Between; Where Multiple Ways of Knowing in Water Management Meet. *Journal of the Southwest*, 59(1): 34-59.

Brugnach, M., & Ingram, H. (2012). Ambiguity: the challenge of knowing and deciding together. *Environmental Science & Policy*, 15(1): 60-71.

Brugnach, M., Dewulf, A., Pahl-Wostl, C., & Taillieu, T. (2008). Toward a Relational Concept of Uncertainty: about Knowing Too Little, Knowing Too Differently, and Accepting Not to Know. *Ecology and Society*, 13(2): 30.

Bykowski, J. J. (2013). *Historic Waters: Re-imaging Hoboken's Engineered Landscape.* New Brunswick, NJ: Rutgers University.

Cao, G. (2007). The Pattern-matching Role of Systems Thinking in Improving Research Trustworthiness. *Systemic Practice and Action Research*, 20(6): 441-453.

Davoudi, S., Crawford, J., & Mehmood, A. (2013). *Planning for climate change; strategies for mitigations and adaptation for spatial planners.* London: Earthscan.

de Graaf, R., & Dewulf, G. (2010). Applying the lessons of strategic urban planning learned in the developing world to the Netherlands; a case study of three industrial area development projects. *Habitat International*, 34: 471-477.

de Graaff, R. J. (2011). *Omgevingsanalyse Sturing Nieuwbouw en Herstructurering.* Leiden: ORG-ID.

Derkzen, M. L., van Teeffelen, A. J., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences? *Landscape and Urban Planning*, 157: 106-130.

Dewberry. (2017). *Rebuild by Design - Hudson River Project Feasibility Study.* Trenton, NJ: State of New Jersey Department of Environmental Protection.

Dupuis, J., & Biesbroek, R. (2013). Comparing apples and oranges: The dependent variable problem in comparing and evaluating climate change adaptation policies. *Global Environmental Change*, 1476 - 1487.

Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change*, 21(2): 647-656.

European Environment Agency. (2014). *National Adaptation Policy Processes in European Countries.* Luxemburg: Publications Office of the European Union.

Ferguson, B. C., Frantzeskaki, N., & Brown, R. R. (2013). A strategic program for transitioning to a Water Sensitive City. *Landscape and Urban Planning*, 117: 32-45.

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., . . . Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12(7): 525-542.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6): 897-920.

Geldof, G. D. (2011). The importance of tacit knowledge for urban water management. *12th International Conference on Urban Drainage*, 1-8.

Groot, A. (2015). Integration in urban climate adaptation: Lessons from Rotterdam on integration between scientific disciplines and integration between scientific and stakeholder knowledge. *Building and Environment*, 83: 177-188.

Hajer, M. (1995). *The politics of environmental discourse: ecological modernization and the policy process.* Oxford: Clarendon Press.

Hak, T., & Dul, J. (2009). Pattern Matching. In A. J. Mills, G. Durepos, & E. Wiebe, *Encyclopedia of Case Study Research.* Thousand Oaks, CA: Sage.

Hoboken Planning Board. (2004). *City of Hoboken Master Plan.*

Hoppe, T., van den Berg, M., & Coenen, F. H. (2014). Reflections on the uptake of climate change policies by local governments: facing the challenges of mitigation and adaptation. *Energy, Sustainability aadn Society*, 4(8): 1-16.

Hunt, A., & Watkiss, P. (2011). Climate change impacts and adaptation in cities: a review of the literature. *Climatic Change*, 104:13–49.

IPCC. (2013). Summary for Policymakers. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Jann, W., & Wegrich, K. (2007). Theory of the policy cycle. In F. Fischer, G. Miller, & M. Sidney, *handbook of public policy analysis; theory, politics and methods* (pp. 43-62). CRC Press: Boca Raton, FL.

Klimaatverbond Nederland. (2015). *Voetje voor voetje; op weg naar een klimaatbestendig Nederland.* Arnhem: Klimaatverbond Nederland.

Lee, S., & Yigitcanlar, T. (2010). Sustainable stormwater management; water sensitive urban design perceptions, drivers and barriers. In S. Lee, & T. Yigitcanlar, *Rethinking Sustainable Development; Urban Management, Engineering, and Design* (pp. 26-37). Hershey, PA: IGI Global.

Locher, L., & Dekker, G. (2016). De stadsbrede economische illustratie Amsterdam. *Water Governance*, 18-28.

Measham, T. G., Preston, B. L., Smith, T. F., Brooke, C., Gorddard, R., Withycombe, G., & Morrisson, C. (2011). Adapting to climate change through local municipal planning: barriers and challenges. *Mitigation and Adaptation Strategies for Global Change*, 16: 889-909.

Melbourne Water. (2005). *WSUD Engineering Procedures; stormwater.* Collingwood: CSIRO.

Mimura, N., Pulwarty, R., Duc, D., Elshinnawy, I., Redsteer, M., Huang, H., . . . Sanchez Rodriguez, R. (2014). Adaptation planning and implementation. In IPCC, *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 869-898). Cambridge, United Kingdom and New York, USA: Cambridge University Press.

Ministry of Infrastructure and the Environment. (2016). *Delta Programme 2017; work on the Delta.* The Hague: Ministry of Infrastructure and the Environment & Ministry of Economic Affairs.

Ministry of Infrastructure and the Environment. (2016). *Nationale klimaatadaptatie-strategie 2016 (NAS).* The Hague: Ministry of Infrastructure and the Environment.

Ministry of Infrastructure and the Environment. (2017). *Deltaplan Ruimtelijke Adaptatie; maatregelen on Nederland klimaatbestendig en waterrobuust in te richten.* The Hague: Ministry of Infrastructure and the Environment.

Moore, G. A. (2014). *Crossing the Chasm, Marketing and Selling High-Tech Products to Mainstream Customers (revised edition).* New York: HarperCollins Publishers.

Moser, S., & Ekstrom, J. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences of the United States of America*, 107(51): 22026-22031.

Municipality of Rotterdam. (2007). *Waterplan 2; werken aan water voor een aantrekkelijke stad.* Rotterdam: Thieme Mediacentre.

Municipality of Rotterdam. (2013). *Herijking Waterplan 2; werken aan water voor een aantrekkelijke en klimaatbestendige stad.* Rotterdam: Veenman+.

Netherlands Environmental Assessment Agency. (2015). *Klimaatverandering; samenvatting van het vijfde IPCC-assessment en een vertaling naar Nederland.* Den Haag: OBT.

OMA. (2014). *Resist, Delay, Store, Discharge; a comprehensive urban water strategy.* New York: Rebuild by Design.

O'Neill, S., & Nicholson-Cole, S. (2009). "Fear won't do it"; Promoting Positive Engagment With Climate Change Through Visual and Iconic Representations. *Science Communication*, 30(3): 355-379.

Quay, R. (2010). Anticipatory governance; a tool for climate change adaptation. *Journal of the American Planning Association*, 76(4): 496-511.

Rotterdam Climate Initiative. (2013a). *Rotterdam Climate Change Adaptation Strategy.* Rotterdam: Gemeente Rotterdam.

Rotterdam Climate Initiative. (2013b). *Rotterdamse adaptatiestrategie; themarapport stedelijk watersysteem.* Rotterdam: Gemeente Rotterdam.

Runhaar, H., Mees, H., Wardekker, A., van der Sluijs, J., & Driessen, P. P. (2012). Adaptation to climate change-related risks in Dutch urban areas: stimuli and barriers. *Regional Environmental Change*, 12: 777-790.

Snover, A. K., Whitely Binder, L. C., Kay, J., Sims, R., Lopez, J., Wilmott, E., . . . Strickler, A. (2007). *Preparing for climate change; a guidebook for local, regional and state governments.* Oakland, CA: ICLEI.

Stahre, P., & Geldof, G. D. (2003). *New Approach to Sustainable Stormwater Planning.* Malmö: International Green Roof Institute.

Stuurgroep Deltaprogramma Nieuwbouw en Herstructurering. (2013). *Manifest Klimaatbestendige Stad; nu bouwen aan de stad van de toekomst.* The Hague: Ministry of Infrastructure and the Environment.

Thorne, C., Lawson, E., Ozawa, C., Hamlin, S., & Smith, L. (2015). Overcoming uncertainty and barriers to adoption of Blue-Green Infrastructure for urban flood risk management. *Journal of flood risk management*, 1-13.

Together North Jersey. (2013). *Hoboken Green Infrastructure Strategic Plan.*

Tyler, S., & Moench, M. (2012). A framework for urban climate resilience. *Climate and Development*, 4(4): 311-326.

Uittenbroek, C. (2014). *How mainstream is mainstreaming? The integration of climate adaptation into urban policy.* Utrecht: Utrecht University, Faculty of Geosciences.

Uittenbroek, C. J., Janssen-Jansen, L. B., & Runhaar, H. A. (2013). Mainstreaming climate adaptation into urban planning: overcoming barriers, seizing opportunities and evaluating the results in two Dutch case studies. *Regional Environmental Change*, 399-411.

United Nations. (2014). *World Urbanization Prospects: The 2014 revision.* New York: United Nations.

Verschuren, P., & Doorewaard, H. (2010). *Designing a Research Project.* The Hague: Eleven International Publishing.

Vogel, B., & Henstra, D. (2015). Studying local climate adaptation: A heuristic research framework for comparative policy analysis. *Global Environmental Change*, 31: 110-120.

Weick, K. (1995). *Sensemaking in organizations.* Thoasand Oaks, CA: Sage.

Wilker, J., Rusche, K., & Rymsa-Fitschen, C. (2016). Improving Participation in Green Infrastructure Planning. *Planning Practice & Research*, 31(3): 229-249.

Williams, T., & Hardison, P. (2013). Culture, law, risk and governance: contexts of traditional knowledge in climate change adaptation. *Climatic Change*, 20(3): 531-544.

Wong, T. H. (2006). Water sensitive urban design - the journey thus far. *Australian Journal of Water Resources*, 10(3), 213-222.

Wu, X., Ramesh, M., Howlett, M., & Fritzen, S. (2010). *The Public Policy Primer; Managing the Policy Process.* Routledge: London/New York.

Yin, R. (2003). *Case study research: Design and methods.* Thousand Oaks, CA: Sage Publications.

Zhou, Q. (2014). A review of sustainable urban drainage systems considering the climate change and urbanization impacts. *Water*, 6: 976-992.

APPENDICES

[Confidential]