Towards the Rainproof-city:

Amplifying the implementation of nature-based solutions for urban drainage in Amsterdam

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Preface

Fulfilling my personal goal of pursuing a Master's degree in Spatial Planning in the Netherlands and the consequent completion of this final research would not have been possible without the unlimited support of my partner in all dimensions of life. Bas, I am deeply grateful to you. Your friendship and advice, Zelina, Amanda, and Aline, have also been fundamental to keep me on track and not let me give up in the face of the many challenges I encountered, so thank you very much. Finally, I humbly praise my parents, who always encouraged me to be curious and open, to continue asking hard questions, and to persist in my learning endeavors.

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Abstract

Cities increasingly face climate-related challenges that require adaptation planning to build urban resilience. In the Netherlands, the risks of flooding caused by extreme rainfall events are a major threat to urban areas, demanding targeted interventions from the planning actors that mitigate such risks. The city of Amsterdam is investing in policies and plans to be a climate-resilient city by 2050, giving a good example of what can be done. A core adaptation strategy in the city is the implementation of *rainproofing* measures to create a 'sponge' effect, absorbing rainwater locally and reducing run-offs. However, the city is still in the early stages of realizing this urban-drainage transformation and needs to implement more projects that contribute to fulfilling the *Rainproof* goal. This research contributes to achieving the transformation of local urban drainage by investigating the use of *Nature-based Solutions* (NBS) as an effective adaptation planning strategy against downpours. Furthermore, it approaches NBS planning from a *blue and green infrastructure* (BGI) perspective for the value of its networked character and the ability to create a hybrid drainage system with the traditional drainage infrastructure. Nature-based solutions can be a valuable component for *sustainable urban drainage systems* (SUDS) given their multifunctionality and range of benefits to people and ecosystems, which exceed improving the local drainage.

Amsterdam is the single case study and the main unit of analysis of this research, and two NBS projects are the embedded sub-units of analysis. This study followed a qualitative research strategy, using a multi-method research design to fulfill two objectives: **(1)** to identify opportunities and challenges for the implementation of NBS for urban drainage in Amsterdam and **(2)** to explore processes that amplify the implementation of NBS for urban drainage in Amsterdam. The main research question that drives the research is: ***How can the implementation of nature-based solutions for urban drainage be amplified in Amsterdam?***

Framing NBS as sustainability initiatives and proposing their implementation as urban experiments, this research sits at the interface of urban planning, ecological sustainability, water management, and transitions studies. Besides, it applies sustainability transformations theory in the analysis of existing NBS experiments in Amsterdam, proposing a tailored and targeted use of amplification mechanisms to increase NBS implementation, contributing to the Rainproof-city.

Key-words: Nature-based Solutions, Urban drainage, Experimentation, Sustainability transformation, Amplification

Table of Contents

List of Tables

List of Figures

1. Introduction

1.1. Background

Extreme climate events such as intense heat waves, droughts, and flash-floods resulting from climate change threaten human health, well-being, biodiversity, and ecosystems, putting communities and the environment at risk around the world. They also damage the urban infrastructure**,** costing an average of twelve billion Euros per year in the EU alone (Carter et al., 2015; European Commission, 2021). All levels of power must take action to tackle the urban challenges posed by climate change: from global to local. Yet, climate adaptation planning is most likely to take place at the local scale, as the city is the predominant level of urban and infrastructure planning (Hurlimann & March, 2012; Mimura et al., 2014; Otto-Zimmermann & Balbo, 2012; Wamsler et al., 2014). Adaptation planning requires urban planners to find solutions that make cities resilient, so that urban systems and communities can withstand stresses and move forward without greater damages (Blakely, 2007; IPCC, 2007; Kabisch et al., 2016; Mimura et al., 2014)**.**

Over the last two decades, European policymakers have built strategies to address climate change, framing climate adaptation as an integral part of sustainable economic and urban development in European agendas. The Paris Agreement (2016) and the European Green Deal (2020) are the best examples of far-reaching E.U. policies including climate adaptation objectives. This year (2021), the E.U. Adaptation Strategy from 2013 was updated to *"make adaptation smarter, swifter and more systemic, and to step up international action on adaptation to climate change"* (European Commission, 2021, p. 4). The Strategy understands that enabling climate adaptation helps achieving the ambitious goal of a climate-resilient European Union by 2050 (Carter et al., 2015; European Commission, 2021; Faivre et al., 2017). This Adaptation Strategy was translated into national policies and cascaded down into municipal goals for local planning and development (Carter, 2011). In the Netherlands, the Municipality of Amsterdam launched a Climate Adaptation Strategy in 2020, understanding that *"adapting the environment to climate change is inevitable"* (Gemeente Amsterdam, 2021a).

Although climate adaptation planning is gaining space, it is unclear how it looks in practice, as there is no single approach to its implementation and adaptive projects must be context-dependent (Emilsson & Sang, 2017; Morchain, 2018). Furthermore, Otto-Zimmerman (2012) argues that to achieve urban resilience future risks must be taken into account in urban development and urban infrastructure systems should be planned to answer to long-term needs, increasing urban sustainability. But, how to forecast future risks and plan for the unknown remains a great puzzle for urban planners. Urban experiments with sustainability initiatives are one possible strategy to build adaptation in practice, which support and enable large transformations from sociotechnical to socio-ecological-technical systems, as required in climate adaptation (Bulkeley & Castán Broto, 2013; Frantzeskaki, Castán Broto, et al., 2017; Pereira et al., 2015; van der Jagt et al., 2020b).

Against this context, Nature-based Solutions (NBS) propose using nature as a provider of Ecosystem Services (ES) to address the urban and societal challenges of climate change, increasing the resilience and sustainability of cities and their infrastructure systems (Cohen-Shacham et al., 2016; Eggermont et al., 2015; Faivre et al., 2017; Frantzeskaki et al., 2019; Gómez-Baggethun et al., 2013; Kabisch et al., 2016). Recently, the term NBS got substantial attention for its apparent simplicity and the range of co-benefits it entails (Cohen-Shacham et al., 2019). In Europe, the term grew after being adopted by the European Commission in climate adaptation and environmental policies (Eggermont et al., 2015; Faivre et al., 2017). The latest EU Adaptation Strategy claims that "*Implementing nature-based solutions on a larger scale would increase climate resilience and contribute to multiple Green Deal objectives*" (European Commission, 2021, p. 11). Moreover, the research of NBS is promoted by the large-scale program 'Horizon 2020 framework for research and innovation of nature-based solutions in Europe' (Faivre et al., 2017; Maes & Jacobs, 2015).

NBS can materialize in different projects and this research focuses on NBS for urban drainage as a component of sustainable urban drainage systems (SUDS). The rainwater drainage matter is extremely relevant in the Netherlands, the place where this research takes place. For centuries, the country has protected its cities from water-related risks, due to the country's delta location and the large share of territory below or at sea level (de Vries & Wolsink, 2009; Terpstra & Gutteling, 2008). The situation has worsened with the current climate crisis and extreme weather events such as increased droughts and downpours are the biggest climate threat to Dutch cities, especially when combined with densifying urban centers and extensive soil sealing (Davis & Naumann, 2017; de Vries & Wolsink, 2009). Recently, the south region of the Netherlands faced a dramatic situation when 150 mm of rain - a quarter of the annual precipitation - fell in 48 hours causing huge damages and demanding the complete evacuation of some villages (July 2021) (Schuttenhelm, 2021).

Albert et al. (2019), however, make a critical consideration about the requirements for the successful uptake of NBS in practice, saying that "*proposed actions should be realizable and thus necessarily require viable governance or business models for implementation"*, adding that "*as long no such implementation concepts can be offered, suitable actions remain propositions, but cannot qualify as solutions"* (Albert et al., 2019, p. 15). Therefore, finding ways to expand NBS implementation and reducing the barriers encountered, are central in this study. Ultimately, the ability of Amsterdam to systematically implement NBS projects, mainstreaming them into planning, will determine its success in becoming resilient and climate-proof (Frantzeskaki et al., 2020; Wamsler et al., 2020). Lastly, empirical research on how cities are experimenting with NBS to tackle climate-related challenges helps to uncover ways to reduce existing barriers and find useful mechanisms to amplify implementation (Albert et al., 2019; Frantzeskaki et al., 2019; Nesshöver et al., 2017).

1.2. Problem Statement

The implementation of nature-based solutions needs to be amplified in urban areas to support climate adaptation goals (Kabisch et al., 2016; Wamsler et al., 2020). However, NBS and similar solutions are not yet mainstreamed into local spatial planning practices (Frantzeskaki et al., 2019; Wamsler et al., 2020) and the implementation of new blue and green infrastructure (BGI) projects for urban drainage is slower than expected (Connop et al., 2016; Marlow et al., 2013; Suleiman, 2021). This is also true for Dutch cities, where urban nature and NBS are not a direct priority of urban development policies and plans (van der Jagt et al., 2020). The upcoming national planning regulation (*Omgevingswet*) shall partially address this problem with a holistic approach to planning, merging laws and regulations for housing, roads, the environment, nature, and water. Nonetheless, how to turn policy goals into implemented projects will remain a challenge to Dutch municipalities, the main actor in local urban development.

Against this context, the city of Amsterdam is working to become climate-proof and especially rain-proof by 2050, aligning with national concerns with disrupted rainfall patterns (van Weeren et al., 2018). The Amsterdam Rainproof website states that *"We have to deal with extreme rainfall more often. That makes our city vulnerable. Due to increasing building and paving, the rainwater can no longer be drained. This leads to growing nuisance and damage, also in your neighborhood"* (Amsterdam Rainproof, 2021a). Nonetheless, the systematic implementation of NBS as part of a blue and green infrastructure system is not yet in place, and conventional gray infrastructure still dominates rainwater drainage systems. Hence, the main research problem identified is the gap between Amsterdam's ambitious plans of being a climate-adapted and rainproof-city by 2050 and the quantity of NBS projects implemented that contribute to fulfilling this goal. The desire to bridge this gap and amplify the implementation of NBS motivates this study and finds an echo in the literature, which argues NBS implementation needs to be expanded to make a meaningful contribution to climate adaptation (Faivre et al., 2017; Maes & Jacobs, 2015; Nesshöver et al., 2017).

To build the analytical framework of this research, I frame NBS as 'sustainability initiatives', which are *"potential local solutions to sustainability problems with global relevance"* (Lam et al., 2020, p. 3). This reinforces the argument that NBS projects support sustainable transformations and - *if systematically implemented* - contribute to climate adaptation (Frantzeskaki, Borgström, et al., 2017; Frantzeskaki et al., 2019). Therefore, the analysis wears the lenses of 'amplification processes', understood as the set of available processes to increase the impact of sustainability initiatives, such as NBS (Gorissen et al., 2018; Lam et al., 2020; Riddell & Moore, 2015). The *amplification* concept is theoretically forged in the fields of transitions and sustainability transformations and based upon mechanisms to grow, flourish, and mainstream sustainable urban experiments proposed by these fields (Gorissen et al., 2018; Hermans et al., 2016; Lam et al., 2020; Olsson et al., 2017). The *'amplification framework'* applied as the analytical framework was proposed in a comprehensive work by Lam et al. (2020). This framework captures and synthesizes relevant mechanisms from six other sustainability transformations' frameworks. The value of the amplification framework lies in its integrative and applied character. The integration aspect is the result of the common language created for the wide spectrum of existing transformation mechanisms. The applied character is due to the potential of the proposed mechanisms to create transformative change, keeping the focus on practical aspects rather than on abstract systems' conceptualization (Lam et al., 2020). As the amplification framework was recently published and has not been applied as analytical lenses in (published) empirical research yet, this research is also a novel scientific contribution.

1.3. Research Objectives and Questions

The main research goal is to explore how the implementation of NBS for urban drainage can be amplified in Amsterdam, contributing to the desired rainproof city. For that, I analyze the implementation of existing NBS for urban drainage through the lenses of amplification processes. The objectives of the present research are twofold:

1. **To identify opportunities and challenges for the implementation of NBS for urban drainage in Amsterdam.**
2. **To explore processes that amplify the implementation of NBS for urban drainage in Amsterdam.**

To fulfill these research objectives, the main research question asked is:

<u>How can the implementation of nature-based solutions for urban drainage be amplified in Amsterdam?</u>

To answer this question, I first need to know the predominant approach to planning and implementing urban drainage systems in Amsterdam. Identifying the prevailing drainage system will expose the current regime that the amplification of NBS is challenging. The first sub-question is:

a. What is the predominant urban drainage approach in the city?

After determining the predominant approach, I must uncover which mechanisms (i.e. policies, strategies, plans, and regulations) foster the planning and implementation of NBS for drainage in Amsterdam. This will reveal the context of NBS implementation and show how existing mechanisms help to amplify it. Therefore, the second sub-question is:

b. Which mechanisms enable the implementation of NBS for urban drainage in the city?

Next, analyzing cases of NBS for urban drainage in the city should reveal why NBS were chosen instead of the conventional approach for those projects, and how their implementation process unfolded. This will give insights into the motivation for experimenting with sustainability initiatives in Amsterdam. Consequently, the third sub-question is:

c. Why and how NBS for urban drainage were implemented in the city?

Finally, the enablers and obstacles for the implementation of urban drainage NBS in the city will emerge. The analysis of these elements will show which of them activate or slow down the amplification processes of NBS, deriving suggestions on how to reduce amplification obstacles. The fourth and last sub-question is:

d. ***What supports or hinders the implementation of NBS for urban drainage in the city?***

Answering these sub-questions should provide a reasoned and accurate understanding of how the implementation of NBS for urban drainage can be amplified in Amsterdam.

1.4. Case Selection

The Netherlands is a global reference in best practices for water management and urban planning, stemming from the country's long-standing tradition in both fields. The ability to protect its citizens and land from water damage is part of the Dutch planning culture, and the know-how produced here is recognized by international researchers and practitioners (de Vries & Wolsink, 2009).

The city of Amsterdam was chosen to illustrate the current implementation status of nature-based solutions for rainwater drainage within the Dutch context. Amsterdam's selection has four main reasons: First, Amsterdam is the capital and most populated city in the Netherlands, being densely urbanized and integrating the large metropolitan region of the Randstad. As a consequence, the city concentrates typical urban challenges related to urban drainage, such as high surface-sealing, lack of open green areas for rainwater infiltration and storage, and outdated infrastructure systems.

Second, the city promotes sustainable solutions to water management and the use of blue-green infrastructure in its urban planning agenda. In 2020 an ambitious Climate Adaptation Strategy was launched to achieve a fully climate-adapted Amsterdam by 2050 (Gemeente Amsterdam, 2021b). Rainwater drainage is central in this Strategy and making Amsterdam 'rainproof' is the main climate-related goal of the Municipality together with the Water Boards and the water company Waternet. This ambition started with Waternet, which set the Amsterdam Rainproof Initiative in 2014 to serve as a knowledge center on how the city can adapt and become resilient to increased downpours (Amsterdam Rainproof, 2018). The example of the newly passed Rainwater Ordinance (*Hemmelwaterverordening*) in the city demonstrates how the Rainproof principle works in practice. This regulation requires all new buildings in Amsterdam to include a rainwater storage system.

Third, the city has recently implemented remarkable NBS pilot projects for urban drainage. While other Dutch cities have also used natural projects to tackle urban drainage, such as bioswales (*wadi's*) or parks designed for temporary water retention, these elements were conceived as independent, low-impact, and mono-functional drainage elements (i.e. wadi's) or exceptional projects (i.e. water parks). Therefore, Amsterdam distinguishes itself for experimenting with NBS for urban drainage and integrating projects to the conventional drainage system in a scalable way, looking at the city as a whole. Furthermore, they are broadening the scope of monofunctional blue-green infrastructure and promoting NBS implementation for its multi-functionality and benefits to the population (van der Jagt et al., 2020b).

The two projects selected for analysis have distinct planning and implementation processes, serving as much-needed examples for future NBS projects in Amsterdam - and other municipalities - that help to advance the implementation of NBS (Kabisch et al., 2016). Fourth and lastly, the way these solutions are designed to fit the tightly-woven urban fabric of the city and connect with the gray infrastructure drainage system of the city serves as a good example for the amplification of NBS for urban drainage in dense urban areas.

1.5. Societal Relevance

The increasing risk of flooding caused by extreme precipitation is a major climate-related challenge faced by Dutch cities, together with drought caused by higher temperatures and the threats of a sea-level rise (KNMI, 2014). A report from 2019 on extreme precipitation by the Dutch Meteorological Institute (KNMI) concludes that there was an increase of 5 to 30% in precipitation extremes over the last 50 to 100 years, and the amount of average rainfall in a year has increased by 26% between 1910 and 2013 in the Netherlands (aan de Brugh, 2021; van Weeren et al., 2018). The KNMI report adds that an extreme rainfall of 58 millimeters per hour, which has a local probability of once every 100 years, occurs almost every year somewhere in the country, showing that 'rare extremes' are much more common than statistics suggest (van der Aa, 2020; van Weeren et al., 2018).

In 2020, Interpolis (the largest non-life insurer in the country) shared that in the first half of the year 6,472 reports of damages caused by rain, snow, or meltwater were made country-wide. In contrast, the number of reports made in the same period in 2017 was 3,651, an increase of more than 70% (van der Aa, 2020). While this can be caused by multiple factors, Youri van der Avoird from Interpolis stated that *"We can at least conclude that people are experiencing more flooding due to extreme rainfall"* (van der Aa, 2020). Additionally, the Dutch Association of Insurers forecasts that extreme weather scenarios caused by climate change cost insurers more than 250 million euros a year. And, a large share of this amount goes to paying damages to houses, vehicles, and other goods caused by rainwater (van der Aa, 2020).

In light of this scenario, strengthening urban rainwater drainage is fundamental to address the risks of floods faced by Amsterdam and many other Dutch cities. Cities play a crucial role in this task and must take a proactive attitude to adapt their environment and infrastructure systems to climate risks, otherwise, their vulnerability will only increase (Kabisch et al., 2016; Mimura et al., 2014; Wamsler et al., 2020). This research contributes to the science and practice of climate adaptation planning, exploring how Amsterdam can expand the use of NBS to reduce their vulnerability to downpours and become climate-adapted. I argue that a valuable strategy is to experiment with sustainability initiatives (i.e. NBS), building knowledge and expanding these solutions so that they become mainstreamed into planning (Frantzeskaki, Borgström, et al., 2017). Urban experiments with NBS, if amplified, can contribute to the city's desire to become climate- and rain-proof by 2050.

1.6. Scientific Relevance

Scientific research on climate adaptation has discussed concepts, strategies, and adaptation plans but knowledge on implementation is still limited (Mimura et al., 2014). Besides, literature on its implementation mainly focuses on limiting aspects for mainstreaming adaptation planning (Kabisch et al., 2016; Mimura et al., 2014). The proposition of using NBS as an adaptation strategy is still being unbundled by research, which aims at revealing processes that help to mainstream NBS implementation into planning and practice (Bush & Doyon, 2019; Frantzeskaki et al., 2019; Nesshöver et al., 2017; Wamsler et al., 2020).

This research contributes to this academic discussion by **(i)** approaching nature-based solutions from a blue and green infrastructure planning perspective (Connop et al., 2016; Raymond et al., 2017), **(ii)** expanding research on NBS implementation through urban experiments (Albert et al., 2019; Frantzeskaki et al., 2019), **(iii)** applying sustainability transformations' theory to explore how to increase the impact of NBS (Frantzeskaki, Castán Broto, et al., 2017; Pereira et al., 2015; van der Jagt et al., 2020b; Wamsler et al., 2020), and **(iv)** using the Typology of Amplification Processes by Lam et al. (2020) as the analytical framework. The typology is a practice-oriented trans-disciplinary framework that coordinates a wide range of transformative processes (Lam et al., 2020), here used to explore how to expand the implementation of NBS. With this approach the research moves past the phase of identifying challenges and obstacles for NBS implementation, to generate practical knowledge on helpful mechanisms that expand NBS implementation and foster mainstreaming (Wamsler et al., 2020).

1.7. Report Structure

This report is structured in six chapters:

Chapter 1 introduced the research problem; stated the research goal, objectives, main question, and sub-questions; justified the case study selection; provided the societal and scientific relevance of the topic; and will close with an outline of the research structure and the connections it makes (Figure 1).

Chapter 2 provides the theoretical background and framework, organized in four blocks. The first block briefly sets the context of climate adaptation planning in the Netherlands. The second block introduces the conceptual framework, reviewing the central concepts of nature-based solutions (NBS), sustainable urban drainage systems (SUDS), and blue and green infrastructure (BGI), and pinning their relevance within the research context. The third block zooms into the implementation process of NBS, unbundling the research problem and proposing an NBS implementation framework to be used in the empirical analysis. The fourth block introduces the analytical background and framework, explaining the amplification framework and its theoretical background and proposing its application to the analysis of NBS implementation.

Chapter 3 details the research methodological approach, justifying the research design and describing the methods for data collection, processing, and analysis. The research quality criteria are also laid down, followed by the role of the researcher, research limitations, and ethical considerations.

Chapter 4 presents the results from the empirical research, divided into four blocks. Block one and two address the city-level questions, block three scrutinizes the two selected NBS projects, and block four wraps the enablers and barriers for NBS implementation on both city and project levels from the previous blocks.

Chapter 5 critically discusses the results through the lenses of amplification, and the sub-questions are thoroughly answered one by one. Recommendations on how to amplify NBS implementation are also provided in this chapter.

Chapter 6 brings the research to a conclusion, recapping the main findings of the discussion section and answering the main research question. The significance and implications of the findings are discussed, followed by a reflection on the research contribution to the field. Finally, I reflect upon the research limitations and propose relevant research questions that emerged through this study for further research.

1.8. Thesis Outline

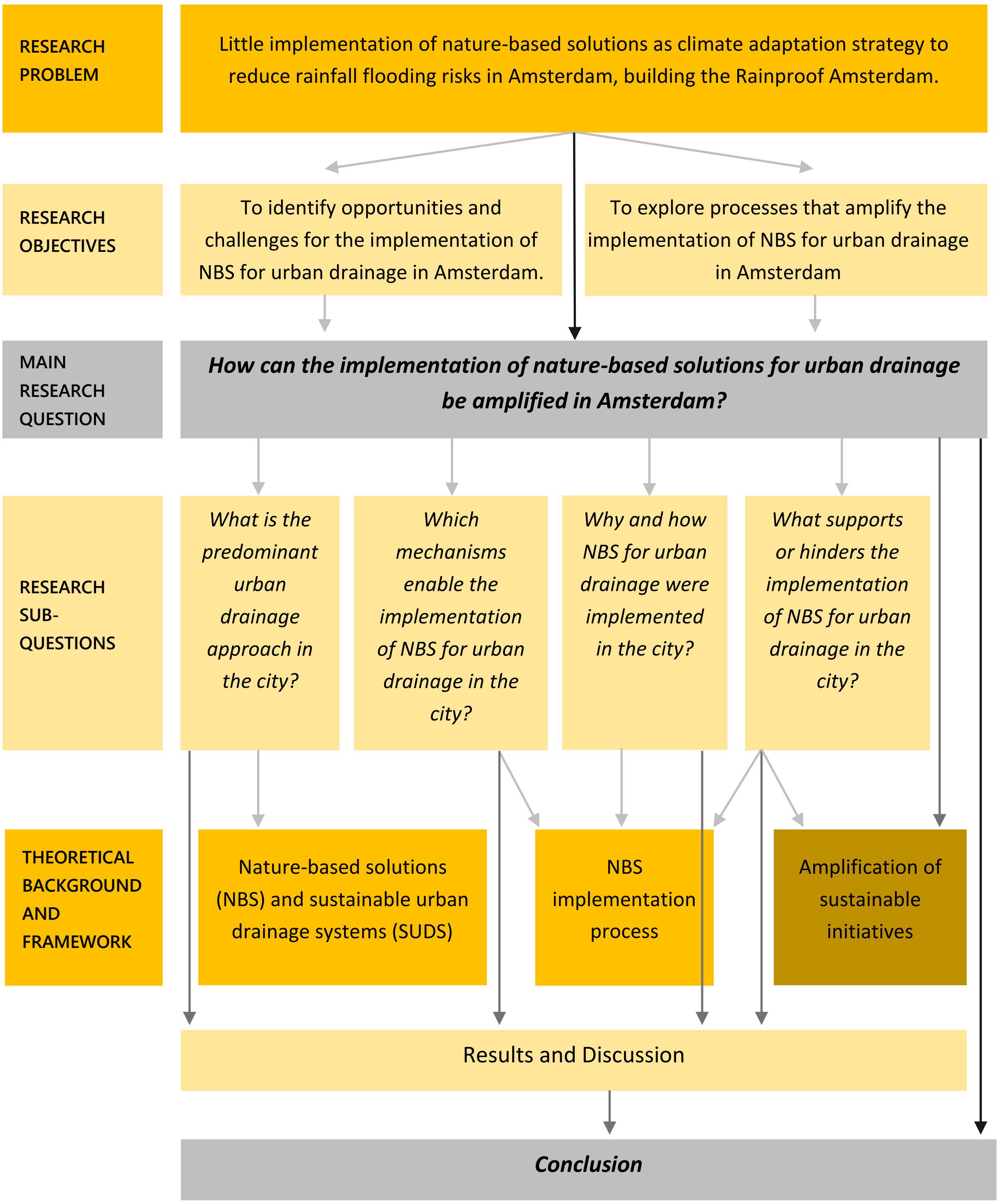


Figure 1: Thesis outline.

2. Theoretical Background and Framework

2.1. Climate Adaptation Planning in the Netherlands

Planning for climate adaptation entails making adjustments to natural or human systems to achieve a state of resilience and less vulnerability to climate change, often with incentives implemented through policy (Carter et al., 2015; IPCC, 2007; Leichenko, 2011). Spatial planning plays a role in creating conditions to incorporate climate change adaptation into local development plans, policies, and the built environment, through infrastructure investments (Wamsler et al., 2014).

Climate adaptive solutions that reduce the risks of drought and floods are on the Dutch planning agenda. The large city of Rotterdam developed a Resilience Strategy that helps to adapt to climate change with programs such as ‘Water sensitive Rotterdam’ (Gemeente Rotterdam, 2016). Additionally, many Dutch municipalities are in the process of writing their Environmental Vision (Omgevingsvisie) to comply with the new national planning regulation (*Omgevingswet*). This new law will merge the regulations for housing, roads, the environment, nature, and water, coming into effect in 2022.

The country traditionally relies on dykes and polders to protect itself from increases in rivers and ocean levels (Terpstra & Gutteling, 2008; van de Ven et al., 2011). However, protection from downpours and extreme rainfall requires a different approach, such as creating a system to slow down the rainwater runoff and increases local infiltration and retention of water (Davis & Naumann, 2017; Suleiman, 2021). One solution in this direction is the use of bioretention systems to collect, store and filter the water before it infiltrates the soil. Another solution is bioswales, which slow down water flow, remove larger pollutant parts, and support biodiversity (Davis & Naumann, 2017). These two solutions are types of NBS for urban drainage, as the ones addressed in this research.

If considered a synonym for blue and green infrastructure (BGI) (Connop et al., 2016), NBS are an alternative to traditional gray infrastructure and are considered as more sustainable, resilient, and positive to the environment (Davies & Lafortezza, 2019). Because of its characteristics, NBS for urban drainage demands a different approach to designing, planning, and implementing drainage systems, being a valuable component of a resilient drainage system (Suleiman, 2021). But what exactly classifies as NBS and how can it be planned in the context of urban drainage? This is explained in the coming sections, demonstrating how nature-based solutions can be applied in the context of urban drainage to create a blue and green infrastructure network that protects the city against heavy rainfall.

2.2. Nature-based Solutions (NBS) and Sustainable Urban Drainage Systems (SUDS)

2.2.1. NBS: an umbrella-term

In the last two decades, scholars from the field of urban ecology, environmental science, resilience, and sustainability proposed a range of concepts describing the use of nature in urban environments as providers of ecosystem services (ES). Ecosystem services are benefits that natural ecosystems provide to people and societies, such as food and water provisioning, climate regulation, recreation opportunities, and soil formation, among many others (Grimm & Schindler, 2018; Millennium Ecosystem Assessment, 2005). They help creating urban resilience and bring additional benefits to the well-being of people (Chong, 2014; Emilsson & Sang, 2017; Gill et al., 2007; Gómez-Baggethun et al., 2013).

Regarding how nature is conceptualized in sustainable development and urban resilience studies, Nesshöver et al. (2017) provide an overview of the six most used concepts in the current literature (Table 1).

These concepts are divided into 'problem-solving techniques' and 'approaches to management' (Nesshöver et al., 2017, p. 1218). The authors place these concepts under the umbrella term nature-based solutions, explaining that NBS entails both similar solutions (in the case of EE, BGI) or shares principles and outputs (in the case of EbA, ES, NC) with the related concepts. Cohen-Shacham et al. (2019) and Pauleit et al. (2017), corroborate the idea of NBS as an umbrella-term covering a variety of ecosystem-based approaches, although, the concepts placed under this umbrella vary slightly per author and field. The use of NBS by municipalities as an approach to management is desirable because of its systemic view. However, this is not a reality in most cities, and NBS are mainly conceived as a problem-solving technique. In Amsterdam, existing NBS for urban drainage were implemented as punctual interventions to solve rainwater bottlenecks. Therefore in this research, I focus on the implementation of NBS as components of a BGI, that complement the traditional drainage infrastructure system.

Nature-based solutions (NBS) an umbrella term:	
Application context	**Concepts included**
Problem-solving techniques: *specific interventions that apply nature to solve urban problems*	ecological engineering (EE) and blue and green infrastructure (BGI)
Approaches to management: *consider not only the problem to be addressed but also the strategy to be used and its socioeconomic implications.*	ecosystem-based adaptation (EbA), ecosystem-services framework (ES), and natural capital (NC)

Table 1: Most used concepts for nature's use in urban development (Adapted from Nesshöver et al., 2017).

This research adopts the widely used definition of NBS by the European Commission as *"solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience"* (European Commission, 2015, p. 4). This definition is relevant in the European context, relates NBS to the three pillars of sustainability, and mentions its contribution to building resilience. Moreover, it has a broad take on which solutions classify as NBS while clearly stating that nature supports or inspires them. Finally, although the 'cost-effective' aspect is not always present in other academic definitions, it is relevant if we consider that costs are an important factor in the implementation of NBS (Sarabi et al., 2019).

Although the above definition by the E.C. is not universal, most authors agree that NBS entails a broad scope of initiatives and projects using nature and natural elements in both urban and non-urban environments and scale (Eggermont et al., 2015; Kabisch et al., 2016). Different NBS address different challenges, such as planting trees to filter the air and reduce heat stress or using bioswales to improve rainwater drainage systems (Haase, 2017). Furthermore, they can vary from a single house (i.e. private green roofs) to a large river (i.e. natural water buffers as the Room for the River project in Nijmegen, NL). Nesshöver (2017) explains that besides linking nature to positive outcomes for society, *"NBS will always be intervening in complex socio-ecological systems"* (Nesshöver et al., 2017, p. 1220). Therefore, addressing urban challenges with NBS conciliates the ecological aspects of ecosystem-based approaches with social and economic factors and benefits (Raymond et al., 2017) that are equally important.

2.2.2. Types of NBS

Eggermont et al. (2015) classify NBS in 3 types, depending on three variants: (i) the level and type of engineering of biodiversity/ecosystems, (ii) the number of ecosystem services to be delivered and stakeholders involved, (iii) the likely level of maximization of the delivery of targeted ecosystem services. Figure 2 shows how these factors delimit the 3 types of NBS proposed. Type 3 best represents the work of urban planners because it concerns the design and management of new ecosystems, requiring more human intervention and the development of new areas that deliver the desired ES at optimal conditions. Moreover, the authors state that Type 3 is relatable to concepts such as blue and green infrastructure, linking disciplines like engineering, urban planning, landscape architecture, and biodiversity conservation. Examples of projects in this category are green walls to reduce rainwater runoff and constructed wetlands to regulate ground- and surface water flows (Haase, 2017).

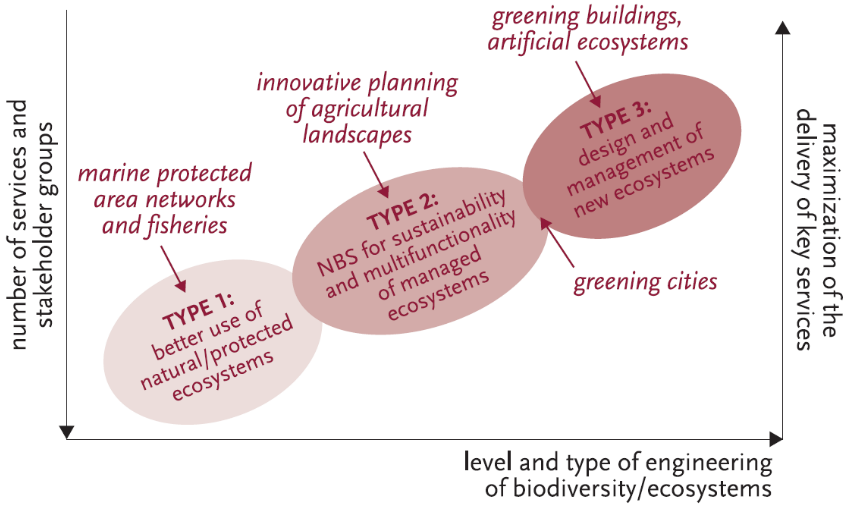


Figure 2: The three types of NBS based on the level of engineering of biodiversity and ecosystems delimited by Eggermont et al. (2015).

This research focuses on nature-based solutions of the 'Type 3' proposed in the typology because this type of NBS is particularly important in urban areas, which have to conciliate existing gray infrastructure with sustainable development. Dense urban centers like Amsterdam, for example, have limited open space to implement NBS. Developing projects in existing areas demand commitment to these solutions and requires investments in research and experiments to uncover the most adequate solutions. To have a larger impact on urban drainage, NBS projects cannot be implemented isolated but need to be conceived in collaboration with other NBS and the underground drainage system. The question that emerges is how to plan NBS to achieve this interconnectivity of infrastructure.

2.2.3. Planning NBS as blue and green infrastructure (BGI)

Planning NBS in the context of infrastructure entails stopping relying solely on conventional, mono-functional, and gray infrastructure, to having diverse, multifunctional, and flexible systems that incorporate blue and green infrastructure (Bai et al., 2018; Connop et al., 2016; Raymond et al., 2017; Zhou, 2014). BGI provides benefits to people and biodiversity such as improving air quality and reducing pollution, preventing extreme temperatures, and creating habitats for wildlife through the creation of more green areas in the city (Connop et al., 2016; Gill et al., 2007). When considered a synonym for blue and green infrastructure (BGI), NBS can substitute, enhance or support the functioning of traditional gray infrastructures (Connop et al., 2016; Depietri & McPhearson, 2017). This becomes visible in the definition for blue and green infrastructure:

> *"Green infrastructure is a strategically planned network of natural and semi-natural areas, incorporating green spaces, or blue if aquatic ecosystems are concerned, and other physical features. In the context of water, BGI is a strategically planned network of high-quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity"* (Brears, 2018, p. 9)

The intention of developing urban nature while providing ES and protecting biodiversity visible in this definition is similar to that of NBS. An important aspect of the BGI definition is the 'planned network' characteristic, which relates to the networked character of most infrastructure systems. When planning NBS to improve urban drainage systems, it is important to deliver solutions which benefits exceed their physical location. Kabisch et al. (2016) explain that "*strategic planning of green infrastructure will be instrumental to avoid piecemeal approaches and instead to integrate NbS into a multifunctional and connected system of green and blue spaces in the city*". By approaching NBS planning from an infrastructure point of view, cities can systematically include nature in urban development, integrating blue and green infrastructure to existing gray infrastructure systems (Davies & Lafortezza, 2019; Depietri & McPhearson, 2017). Furthermore, including NBS in urban infrastructure policies and plans will increase implementation and amplify this type of solution, resulting in greater contribution from NBS projects.

Nonetheless, blue and green infrastructure cannot replace gray infrastructures entirely, as they are deeply rooted in urban planning practices and continue to play an important role in modern cities'. Therefore, hybrid systems are proposed, which combine gray and blue-green infrastructure to improve the performance of drainage systems (Davies & Lafortezza, 2019; Davis & Naumann, 2017; Depietri & McPhearson, 2017). Finally, authors from the environmental sciences emphasize that for nature to deliver ES and contribute as expected for climate adaptation, the biological and environmental conditions need to be researched and understood, and the effectiveness of new projects assessed from the macro perspective (Depietri & McPhearson, 2017; Eggermont et al., 2015; Nesshöver et al., 2017). In the context of urban drainage, gray and green infrastructure have distinct characteristics, and the implementation of NBS contributes to creating a sustainable urban drainage system (SUDS), as explained next.

2.2.4. Building SUDS with NBS for urban drainage

Traditional rainwater drainage systems are designed to remove rainwater that falls in urban areas as fast as possible discharging it in rivers or nearby water bodies (Brears, 2018; Zhou, 2014). The components of such a system are what literature calls gray infrastructure because of its engineered and manufactured characteristics and consist of concrete and plastic drainpipes, curb inlets, manholes, minor channels, roadside ditches, and culverts (Brears, 2018; Davis & Naumann, 2017). The main downsides of this traditional approach are the mono-functional character and silo thinking of planning actors. Moreover, underground infrastructure for drainage has high sunk costs with construction, maintenance, and repair (Davis & Naumann, 2017). Suleiman (2021, p. 1) highlights the following water challenges associated with traditional drainage infrastructure: *"deteriorating water quality, the alteration of water cycles and drying up of water sources, decreasing water availability, ecosystem degradation and climate change impacts (in terms of heavy rains, floods, droughts), and socioeconomic consequences"*. Furthermore, gray infrastructure is expected to be insufficient to drain peak water flows and prevent floods (Davis & Naumann, 2017; Zhou, 2014), considering its dimensions are based on historical data of rainfall patterns, which became less predictable with climate change (Brears, 2018). Therefore, combining BGI with existing or new gray infrastructure is desirable to restore and improve urban drainage (Depietri & McPhearson, 2017). This reduces the risks posed by extreme rainfall and drought periods and creates a more natural environment in cities wherein water can be retained, filtered, absorbed through infiltration and slowly drained away, contributing to a healthier environment and biodiversity (Davis & Naumann, 2017; Zhou, 2014). In practice, this happens by strengthening underground piping network that are prone to overflowing with above-ground green ducts (i.e. bioswale), which allow rainwater to be partially absorbed by the soil or retain a percentage of the water for future use (Brears, 2018; Marlow et al., 2013).

A range of concepts describe more integrated and natural approaches to urban water management, as Low Impact Development (LID), Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Design (WSUD), and Integrated Urban Water Management (IUWM) (Fletcher et al., 2015). The term sustainable urban drainage systems (SUDS) is particularly adopted with a close meaning of nature-based solutions (Davis & Naumann, 2017). Despite the terminology used, there are three main benefits of using blue-green over gray infrastructure for water management: "*(1) a more 'natural' water cycle; (2) enhanced water security through local source diversification and (3) resource efficiency"* (Marlow et al., 2013, p. 7152)**.** Notwithstanding the existing concepts, I refer to projects using nature and natural elements (i.e. living organisms, plants, earth, clay, rocks) combined with technological parts to improve urban drainage as 'NBS for urban drainage'. Doing so, I highlight the problem-solving aspect of NBS and its broader contribution to climate adaptation and resilience.

The main benefits of NBS for urban drainage are an improved water cycle, increased water retention and infiltration, and controlled surface run-off. (Raymond et al., 2017). Moreover, the provision of social benefits associated with human contact with nature and green spaces, such as better health, is another quality of NBS projects (Kabisch et al., 2016; Sarabi et al., 2019). Beyond the direct benefits, the additional quality of NBS is the potential to bring stakeholders together and initiate social innovation, producing broader socioeconomic benefits (Sarabi et al., 2019). This is important because municipalities as Amsterdam depend on partnerships with a range of stakeholders (i.e. universities, private companies) to research and invest in innovations on public and private projects. The smart grid of blue-green roofs being constructed in the city that is analyzed in the Results section is an example of partnerships and innovation with NBS. Therefore, the systematic planning of NBS addresses multiple urban challenges, creating sustainable socio-economic practices that can be incorporated into spatial planning (Raymond et al., 2017). NBS for urban drainage adds to the environmental, biological, and ecological aspects of SUDS. Nonetheless, BGI and SUDS literature contributes to operationalizing the implementation of NBS for urban drainage. The next section covers the components that can be implemented through NBS to build a blue and green network of rainwater drainage.

2.2.5. Drainage components of blue and green infrastructure

When it comes down to real-life projects of NBS for urban drainage, the BGI components listed by Brears (2018) give a good overview of the different types of nature-based projects that exist. He divides BGI into two types: (1) natural water features and (2) man-made water features, each comprising a range of BGI components (Table 2). Natural features are those wherein rainwater is stored and absorbed gradually through the surface without the aid of technology or manufactured components, while man-made ones are those where the rainwater is collected, transported, filtered, stored, or absorbed with the help of artificial or man-made elements.

BGI Components available for NBS projects:	
(1) Natural water features	• **Stormwater detention or retention systems** *Detention or retention basins, bio-retention basins or swales, capture runoff from buildings and roadways, interrupting traditional urban stormwater pathways at locations upstream from stormwater sewer inlets.* • **Riparian buffers** • **Restored waterways** • **Constructed wetlands** • **Pond, rivers, lakes** • **Wetlands**
(2) Man-made water features	• **Green buildings systems** *Green roofs, blue roofs, disconnected downspouts, and rain barrels, and rainwater harvesting;* • **streets** *Buffer Vegetation and Lawns, Stormwater Planters, Stormwater Bump-Outs, Stormwater Tree Trenches, Pervious Pavement and Depaving, Gravel Trenches, Detention Tanks/Underground Systems, Green Parking Spaces;* • **Places** *Urban Forests and Vegetation, Parks and Open Spaces, Multifunctional Public Facilities*

Table 2: Two types of water features and their components (adapted from Brears, 2017).

There is great overlap in the functions and benefits of components from both groups, and Brears (2018, p. 43) argues that SUDS are more effective when the different BGI elements work together complementing each other, as the sum of all parts makes the system multifunctional, increasing urban resilience. However, cities are just recently experimenting with planning and implementing NBS and such experiments tend to be single projects, which lack adequate monitoring and evaluating processes (Raymond et al., 2017). Therefore scaling up these experiments into a functioning network of interconnected BGI is a major challenge to creating effective SUDS.

From an urban planning perspective, some drainage components from Table 2 are more suitable to dense urban environments as in Amsterdam, given they require less space to be implemented and can be more easily amplified. Large detention or retention basins (i.e. water squares, swales), for example, demand a lot of space and do not fit easily into a built-up area. Likewise, constructing wetlands, parks, urban forests, and ponds require relatively large space available, which is scarce in urban spaces (Figure 3). On the contrary, solutions that can be incorporated into the urban fabric such as small bio-swales and all man-made features belonging to the categories 'green-building systems' and 'streets' can be easier replicated in the city in the development of new urban areas or adjusting to the available spaces (Figure 4). Taking this into account, I focus on NBS that encompass the second group of solutions, for understanding that they have more potential to be amplified in the urban environment and create a network of NBS that impact urban drainage systems. Despite the valuable contribution offered by NBS to urban drainage, there are still challenges that slow down their implementation. The challenges arise in large part from the contrasting points between gray and green infrastructure, which are explained next.

Figure 3: A bio-retention swales (wadi) in Hanover, Germany, covers a large surface area and is harder to fit in denser urban areas. (Atelier Dreiseitl)

Figure 4: A new stormwater planter in Amsterdam, the Netherlands fits between the sidewalk and the housing blocks in the dense area of Zuidas (Amsterdam Zuidas).

2.2.6. The complexity of NBS in comparison to gray infrastructure

Obstacles for the uptake and expansion of the SUDS approach to rainwater management are identified in the literature and are in large part a consequence of the lack of reliable data and evidence from existing systems to support investments in BGI components. This results in a lack of exemplary cases to learn from regarding costs, performance, and maintenance requirements, especially in comparison to traditional gray infrastructure (Davis & Naumann, 2017). A similar challenge is faced in the scaling-up of NBS, and understanding the differences between traditional systems and NBS is important to overcome the obstacles on the way to NBS amplification.

The multi-functionality of NBS is the core difference between NBS planning in comparison to traditional mono-functional infrastructures (Kabisch et al., 2016; van der Jagt et al., 2020b). While multifunctional projects require transdisciplinary collaboration between stakeholders from social, political, ecological, and technical spheres, the operational mode of local governments tends to be heavily siloed (Frantzeskaki et al., 2019; Nesshöver et al., 2017; Wamsler et al., 2020). This results in inadequate institutional structures to develop NBS, which leads to gaps in knowledge and a lack of appropriate tools to initiate and implement NBS projects (Frantzeskaki et al., 2020; Kabisch et al., 2016).

The cost-benefit of NBS also contrasts with traditional infrastructures. Benefits provided by NBS are considered to outweigh their costs of implementation and NBS can be more cost-effective than engineered solutions to address less extreme climate events, such as some urban flooding episodes (Kabisch et al., 2016; Seddon et al., 2020). However how to assess the cost-effectiveness of NBS and compare the benefits of multi-dimensional against mono-functional solutions is not clear yet (Seddon et al., 2020). Furthermore, long-term functionality and provision of ecosystem services by NBS are difficult to ensure, conferring an apparent uncertainty to NBS projects (Kabisch et al., 2016; Seddon et al., 2020). The same argument is made about SUDS which are site-specific with the "*levels of effectiveness, fulfillment of associated land requirements, costs, and benefits varying greatly from case to case"* (Davis & Naumann, 2017, p. 131). These uncertainties about costs and benefits make NBS more complex and challenging to public authorities, who may lack the capacity to plan and adapt to changing circumstances. Table 3 provides an overview of the main differences between gray and green drainage systems based on the reviewed literature.

Comparison of traditional gray drainage infrastructure Vs. sustainable urban drainage systems (SUDS):	
Traditional drainage infrastructure systems	**Sustainable urban drainage systems (SUSD)**
Treat rainwater like waste, an undesirable resource (Zhou, 2014).	Treat rainwater like a valuable resource (Marlow et al., 2013).
The goal is to remove rainwater that falls in urban areas as fast as possible and discharge it into water bodies (Brears, 2018; Zhou, 2014).	The goal is to increase local retention and infiltration of water, reducing runoffs and managing water where it falls, improving the 'natural' water cycle (Davis & Naumann, 2017; Marlow et al., 2013).
Mono-functional, designed by engineers applying technical knowledge and manufactured parts (Davis & Naumann, 2017; Fletcher et al., 2015).	Multi-functional, designed by a multidisciplinary team using nature (plants, living organisms) or natural elements (earth, rocks) (Davis & Naumann, 2017).
Predictable functionality in the long term (Seddon et al., 2020).	Unsure long-term functionality and provision of ES (Seddon et al., 2020).
High sunk costs in construction, maintenance, and repairs (Davis & Naumann, 2017).	Lower construction costs than underground infrastructure, unsure maintenance, and repair costs (Davis & Naumann, 2017).
Provide no additional value to citizens beyond drainage function (Davis & Naumann, 2017).	Provide many ES generating additional value to citizens (Davis & Naumann, 2017; Fletcher et al., 2015).
Effective but rigid system. The predetermined capacity is difficult to expand (Brears, 2018).	Effective and flexible system, the capacity can be regulated and modified and it is easier to expand (Brears, 2018).
Negative consequences are: deteriorating water quality, alteration of water cycles and drying up of water sources, decreasing water availability, ecosystem degradation and climate change impacts (in terms of heavy rains, floods, droughts), and socioeconomic consequences (Davis & Naumann, 2017; Suleiman, 2021).	Qualities are: Increase water availability for diverse uses and wildlife and serve as a reservoir for dry periods. Increase biodiversity and quality of ecosystems by creating new places for natural life in the city. Reduce the effects of climate change (Davis & Naumann, 2017; Marlow et al., 2013; Zhou, 2014).

Table 3: Traditional gray drainage infrastructure Vs. sustainable urban drainage systems (SUDS)

As Table 3 shows, the differences between NBS for urban drainage and gray infrastructure systems are related to the different systems they belong to. Traditional drainage infrastructure belongs to a large socio-technical system, consequently suffering from great path-dependencies and institutional and technological lock-ins. Additionally, such path-dependencies form a barrier to the adoption of new, more sustainable technologies. (Bulkeley et al., 2014; Marlow et al., 2013; Suleiman, 2021). NBS, on the other hand, are considered socio-ecological systems (SE's) (Raymond et al., 2017), or socio-ecological-technical systems (SET's) (van der Jagt et al., 2020b). The SET’s perspective is more accurate because it includes the three dimensions that interact in urban systems, driving urban systems’ dynamics (Depietri & McPhearson, 2017). Marlow et al. (2013, p. 2) argue that promoting SUDS fosters *“experimentation and infrastructure diversification”* but conclude that SUDS “*remain a niche innovation from the perspective of broader infrastructure provision”*.

Given the fundamental differences between both systems, it is not surprising that the effective implementation of NBS in cities is not yet common practice, progressing slowly (European Commission, 2021; Wamsler et al., 2020), with van der Jagt et al. (2020b) calling their diffusion ‘patchy at best’. In this research, I apply knowledge from different research fields (socio-technical and socio-ecological systems, and social innovation) to propose ways of achieving a sustainability transformation towards NBS. Before explaining how the implementation of NBS can be amplified, the research problem of a lack of NBS implementation is explained, followed by a working definition of the ‘NBS implementation process’ to be used in the analysis of this study.

2.3. NBS Implementation Process

The lack of NBS implementation in practice is a large obstacle to achieving the benefits offered by this solution. This issue configures the research problem identified by this research and is discussed in this chapter from a theoretical perspective. Scrutinizing the main research problem, and proposing a working definition to the NBS implementation process (which is not directly available in the literature) are the main goals of this chapter. Finally, I suggest an experimental approach to NBS implementation, in line with the most recent discussions on the topic.

2.3.1. Climate-proofing cities require expanding NBS implementation

Despite literature recognizing the advantages of using nature in urban development projects as a strategy to climate-adaptive cities, NBS (and other ecosystem-based approaches) still face many challenges. These challenges are due to the novelty of NBS and differences in planning from traditional infrastructure systems (as explained in section 2.2.6). Consequently, the implementation of new BGI projects is slower than expected in terms of impact and benefits (Connop et al., 2016; Marlow et al., 2013; Suleiman, 2021). Additionally, Nesshöver et al. (2017) argue that the transdisciplinary science required to implement NBS is not yet in place. Hence, there is a clear need to scale-up the implementation of NBS projects in urban areas to fulfill its expected contribution to climate adaptation (European Commission, 2021; Frantzeskaki et al., 2020; Kabisch et al., 2016; van der Jagt et al., 2020b). This desire is translated into international projects like Connecting Nature, funded by the European Commission's Horizon 2020 Program, which mission is to *"support the transition of cities from innovating and implementing NBS at a demonstration scale, to widespread roll-out"* (Frantzeskaki et al., 2020, p. 3).

One important consideration about the requirements for the successful uptake of NBS in practice is made by Albert et al. (2019, p. 15), who explains that "*proposed actions should be realizable and thus necessarily require viable governance or business models for implementation",* adding that "*as long no such implementation concepts can be offered, suitable actions remain propositions, but cannot qualify as solutions"*. Therefore, this research concerns specifically with challenges faced in the implementation phase of NBS by the cities, or 'how plans are turned into realities on the ground' (Davies et al., 2015). It is the effective implementation of projects that ultimately determines the success of a city becoming resilient and climate-proof, as desired by Amsterdam. To achieve effective implementation, it is crucial to have a clear picture of the implementation phases of NBS projects and how they can be verified in practice, this is proposed in the next section.

2.3.2. Defining the implementation process of NBS

What exactly the implementation phase of urban projects entails is an open discussion which scope diverges among authors and researchers. Besides, each ecosystem-based project has particular characteristics that may require a different implementation process. This research understands the implementation phase as *"how planning and governance arrangements aim at impacts in real life",* following a report on urban green infrastructure (UGI) planning and implementation in Europe by Davies et al. (2015, p. 15). The report proposes four dimensions in the implementation process of BGI: (i) programs and projects, (ii) the deployment of funding, (iii) action planning, (iv) monitoring and evaluation. These dimensions are interconnected and dependent, as one influences the existence and performance of the other. Furthermore, an important contribution to defining the implementation process of NBS by Raymond et al. (2017) presents a framework for the assessment of the co-benefit of NBS. In his work, he identified seven steps (or demonstration phases) for the successful implementation of NBS, linking these steps with innovation opportunities for the upscaling of solutions.

In this research, I use the implementation dimensions for UGI by Davies et al. (2015) for the implementation of NBS, given the similarities between BGI and NBS projects (as explained in section 2.2.3). Additionally, I correlate these dimensions to the seven steps of successful NBS implementation by Raymond et al. (2017). Some of the steps fit more than one dimension, and step 4 - 'implement NBS' - is here understood as the actual deployment of actions or the physical construction of solutions and projects. Finally, I translate the implementation steps into indicators that allow identifying if a dimension is present in the implementation of an NBS project. This approach was used to operationalize the NBS implementation process, allowing each of the dimensions to be verified in the empirical research. Table 4 shows the relation between the two implementation perspectives and the indicators defined for each dimension.

Implementation of nature-based solutions - dimensions and indicators:			
Dimensions of implementation *(Davies et al., 2015)*	What the dimension entails *(adapted from Davies et al., 2015)*	Seven stages for successful NBS implementation *(by Raymond et al., 2017)*	Indicators of the dimension *(one or more should be present for each dimension)*
A) Programs and projects:	▪ The existence of programs and/or projects in the city that enable the implementation of a particular solution. ▪ The longevity of interventions - as the benefits accruing will normally increase with time. ▪ Dedicated human resources such as a project team *(optional).*	1) Identify a problem or opportunity that allows the use of NBS. 5) Frequently engage stakeholders and communicate co-benefits	- Initiatives and programs promoting NBS in the city. - NBS is proposed as a solution for a clear problem or opportunity.
B) Deployment of funding:	▪ Availability of resources to implement desired solutions. ▪ Variety of funding sources *(not only direct support but also creative use of the planning system to 'lever in' private sector contributions as help-in-kind such as labor supplied by volunteers or corporate social responsibility programs)*.	2) Select and assess NBS and related actions 4) Implement NBS 5) Frequently engage stakeholders and communicate co-benefits	- Designated funding for NBS implementation. - Subsidies for NBS implementation. - Partnerships to implement the project. - Maintenance and repair funding.
C) Action planning:	▪ An agreement of what will be done and how - based on a predefined strategy. ▪ A plan of action, steering arrangements, accountability to local representatives and politicians. ▪ Partnerships creation and long-term maintenance.	2) Select and assess NBS and related actions 3) Design NBS implementation processes 4) Implement NBS 5) Frequently engage stakeholders and communicate co-benefits	- Using NBS to address a specific problem (a project). - Partnerships are created to implement the project. - Action plan laying project steps; executed and completed.
D) Monitoring and evaluation:	▪ Programs or procedures for monitoring and evaluating the performance of implemented solutions. ▪ Regular reporting and reviews. ▪ Ability to alter course if new mechanisms become available which supersede existing ones.	5) Frequently engage stakeholders and communicate co-benefits 7) monitor and evaluate co-benefits	- Monitoring and performance evaluation of the project. - Assessment and report of project benefits. - Reflection process on the project, and adjustments for future projects *(when needed)*.

Table 4: Implementation of NBS: dimensions and indicators.

2.3.3. Barriers and enablers for NBS implementation

Recent literature has critically assessed the effectiveness of NBS implementation across many European cities, uncovering a variety of challenges faced by local authorities for the uptake of NBS planning and implementation, preventing the consequent mainstreaming (systematic integration) of NBS into policy, planning, and practice (Frantzeskaki et al., 2020; Kabisch et al., 2016; Nesshöver et al., 2017; van der Jagt et al., 2020; Wamsler et al., 2020). One recurring argument is that knowledge gaps of local administration and practitioners slow down the implementation of NBS projects, and Kabisch et al. (2016) identify four areas where knowledge gaps impact the effectiveness of NBS. One of these areas is implementation and the authors explain that among other things, legal instruments and requirements for implementing NBS may be unknown to urban planners and administrators.

The literature presents a wide range of challenges to the successful upscale of NBS implementation. A systematic literature review from Sarabi et al. (2019) identified the main barriers and enablers for the successful uptake and implementation of NBS, from 41 relevant articles on the topic. These challenges and enablers are summarized in Table 5 and were related to the dimensions of the implementation process (Table 4). These barriers and enablers are used in the empirical analysis to determine how much they impact the implementation of NBS in Amsterdam.

Main barriers and enablers for the successful implementation and uptake of NBS:				
Main barriers and implementation dimension(s) they impact most	**A)**	**B)**	**C)**	**D)**
Path dependency (resistance to change inside organizations) *(socio-institutional barrier)*	X	X	X	X
Inadequate regulations (prevailing regulations are for gray infrastructure; lack of law enforcement) *(socio-institutional barrier)*	X		X	
Institutional fragmentation (sectorial silos, unclear responsibilities) *(socio-institutional barrier)*			X	X
Inadequate financial resources (funding opportunities; time-span) *(socio-institutional barrier)*		X		
Lack of information (knowledge) and uncertainty regarding implementation process and effectiveness of the solutions *(socio-institutional and biophysical barrier)*	X		X	
Limited land and time availability (NBS tend to require more space than gray infra; space is scarce in the inner city; require long-term collaboration) (*biophysical barrier)*		X	X	
Main Enablers and implementation dimension(s) they impact most	**A)**	**B)**	**C)**	**D)**
Partnerships among stakeholders *(socio-institutional enabler)*	X	X	X	X
Economic instruments *(socio-institutional enabler)*		X		
Plans, acts, and legislations *(socio-institutional enabler)*	X			
Open innovation and experimentation *(socio-institutional and biophysical enabler)*	X		X	X
Knowledge sharing mechanisms and technologies *(socio-institutional enabler)*	X		X	
Education and training *(socio-institutional enabler)*			X	
Effective monitoring and valuation systems for implementation process and benefit *(socio-institutional and biophysical enabler)*				X
Combining NBS with other urban elements and gray infrastructures *(biophysical enabler)*			X	

Table 5: Main NBS barriers and enablers (adapted from Sarabi et al., 2019).

2.3.4. *Achieving NBS implementation through urban experimentation*

Considering the need to upscale the implementation of NBS and the challenges for its mainstreaming in planning practices, this research focuses on how the implementation of NBS can be amplified. Bridging this gap reflects the broader desire identified in the literature to increase the use and impact of NBS, particularly in the European context (Faivre et al., 2017; Frantzeskaki et al., 2020; Maes & Jacobs, 2015; Nesshöver et al., 2017).

Two main formal institutional enablers that help amplifying NBS implementation, are 'economic instruments' and 'plans, acts and legislations'. However, Bulkeley & Castán Broto (2013, p. 361) identified significant institutional capacity and political-economic obstacles for municipalities to adopt a "*comprehensive and planned approach to climate governance*". Therefore, an alternative strategy for effective implementation is through open innovation and experimentation with sustainability initiatives (Sarabi et al., 2019). Bulkeley et al. (2014) explain that experimentations are 'open-ended processes where different actors attempt to legitimize their proposals and projects', such as NBS. In this regard, the value of experimentations is in the concrete implementation of projects with 'unknown impacts', creating valuable evidence and relevant data to be used in assessing the success of an NBS project and adjusting the design, implementation, and maintenance of future projects, in an incremental way (Frantzeskaki, Castán Broto, et al., 2017; Frantzeskaki et al., 2019).

Raymond et al. (2017) explain that the upscale of NBS occur when the 'demonstration phase' showcase 'innovative solutions' which may become 'mainstreamed solutions'. The authors say that for that to happen, NBS first needs to be implemented - as experiments - and evaluated to reach a 'transfer and upscale' point wherein they are seen as an innovation worth scaling up. Experimental projects generate knowledge and expertise, which can be used to integrate NBS into planning practices (Frantzeskaki, Castán Broto, et al., 2017; Frantzeskaki et al., 2019; Raymond et al., 2017). Additionally, Pereira et al. (2015, p. 6027) evaluate that systemic transformations in the dominant regime require transformative changes. The authors add that *"such systemic transformations necessitate experimentation in public arenas of exchange and a deepening of processes that can widen multi-stakeholder learning"*.

Literature deems experiments equally important for sustainable urban drainage systems, seeing it as a way to gain empirical knowledge of innovative drainage components, like the ones studied in this research (Marlow et al., 2013). In fact, such experiments are already happening, with the strong support given to NBS leading to many demonstration projects. In Europe, organized urban living labs (ULL) have been one way of experimenting with NBS (Sarabi et al., 2019). An example of an experiment that led to an innovative drainage solution is the 'blue and green roof system' known as 'Polder Roof'. This innovation is a technological solution for smart rainwater storage developed by a company from Amsterdam. Given the value of experimenting with NBS to boost implementation, fostering sustainability transformations, this research analyzes the implementation process of two existing NBS urban experiments for urban drainage in Amsterdam. The analysis demonstrates whether and how the amplification processes introduced in the next section can be activated to expand the impact of NBS in the city, and eventually mainstream it.

2.4. Amplification of Sustainable Initiatives

2.4.1. Expanding NBS implementation through sustainability transformations

The previous sub-chapter explained the challenges of upscaling the implementation of NBS, which prevents the mainstreaming of these solutions and proposed experimentation as a valuable approach to foster implementation (Frantzeskaki et al., 2019). However, to have a large-scale impact NBS need to move past the experimental stage to integrate the repertoire of urban planners and developers, becoming an embedded practice of urban development. To achieve this, NBS initiatives can make use of amplification processes developed to support sustainability transformations. An extensive review and discussion of the literature on sustainability transformations is beyond the scope of this research, and other authors provide great coverage of this topic (see Gorissen et al., 2018; Hermans et al., 2016; Olsson et al., 2017). In this chapter, I lay the theoretical foundation of the amplification framework and next, explain the framework in detail. The main goal of this chapter is to introduce and unbundle the analytical framework that is used in the interpretation of the result of the empirical research.

Just recently authors started analyzing how to overcome obstacles of NBS implementation to achieve transformative change, which is 'change that goes beyond incremental improvements' (Bennett et al., 2016) through transitions' theory (see Frantzeskaki, Castán Broto, et al., 2017). Davies & Lafortezza (2019) propose a transitional path to break the path-dependencies of gray infrastructure, while van der Jagt et al. (2020b) developed a Nature-Based Innovation System (NBIS) framework adapted from the Technological Innovation System (TIS) framework. The transitions lenses were also used earlier to analyze concepts similar to NBS such as ecosystem-based adaptation (EbA) (in Wamsler et al., 2014). The gap between NBS and transitions literature may result from NBS being often perceived as an 'addition' to existing approaches, or it may be due to transitions originally concerning socio-technical systems (ST's), while NBS add the dimension of 'ecology' (SET's) (van der Jagt et al., 2020b). Nonetheless, Pereira et al. (2015, p. 6028) explain that to achieve sustainable development and improve societal wellbeing *"invariably require both disruptive innovations and systemic transformations that address the root causes of these issues in the dominant social norms, behaviors and practices*". Against that background, the theory on sustainability transitions helps to understand how blue and green infrastructure can enter the current regime, dominated by gray infrastructures (Jagt et al., 2020).

Transitions' theory complements studies on sustainability transformations, which focus on the changes and innovations needed to challenge the current situation, fostering more sustainable practices within socio-ecological systems (SE's) (Gorissen et al., 2018; Hermans et al., 2016; Olsson et al., 2017). Grin et al. (2010) understand that such "*radical transformations towards a sustainable society serve as a response to a number of persistent problems confronting contemporary modern societies*". In this study, I refer to the collective changes delivered by NBS as sustainability transformations, in the broader sense of *"fundamental changes of interactions and feedbacks in, for example, social-ecological or socio-technical systems"* as done by Lam et al. (2020)

2.4.2. Analytical framework: foundations of the amplification framework

Different research areas have addressed the matter of sustainability transformations since the turn of the century. These researches share a common motivation of finding ways of creating environmental, social, and technical changes towards a more sustainable future (Feola, 2015). In that regard, some studies introduced frameworks aimed at expanding the impact of sustainability initiatives, such as Moore et al. (2015), Bennett et al. (2016), and Gorissen et al. (2018). However, a variety of processes have been introduced by these frameworks, resulting in a heterogeneous conceptualization of mechanisms to scale sustainable practices (Lam et al., 2020; Loorbach et al., 2017).

In a recent publication, Lam et al. (2020) combined different mechanisms from existing frameworks into one integrative typology, building a 'typology of amplification processes'. The authors analyzed key studies from three different research areas (resilience, social innovation, and sustainability transitions), selecting the most relevant frameworks to create the amplification framework. Amplification processes are hereby understood as *"diverse actions deployed by sustainability initiatives together with other actors (e.g., from government, business, or society) to purposively increase their transformative impact (e.g., initiating a new initiative in another city)"* (Lam et al., 2020, p. 3). The value of this typology lies in its integrative and applied character. The integration aspect results from the creation of a common language for the broad spectrum of existing mechanisms. The applied character is due to the potential application of the mechanisms selected to create transformative change. Hence, I understand that the amplification typology provides practical processes to increase the amount and impact of NBS in cities.

The amplification typology included only frameworks that support transformative which is the desired outcome of sustainability initiatives as NBS. This also prevents the typology of suffering from vagueness, pointed by Feola (2015) as a risk when developing useful mechanisms for transformational change. Lam et al. (2020) also avoid using the term 'scaling' arguing that the word has a connotation of moving upwards or downwards through 'levels' or 'scales' (Hermans et al., 2016) but to *increase impact* does not always require changes in levels of action. This becomes visible in the Results section wherein different amplification processes are identified, not all including a change in levels. By operationalizing the amplification processes and applying the typology as an analytical framework to the implementation of NBS this study uncovers the available mechanisms to increase the impact of NBS projects for urban drainage, building a rainproof city.

The amplification typology used in the analysis of this study was developed drawing from 6 relevant sustainability transformations framework, from different research areas. Despite addressing different systems, these research areas overlap and at times draw from each other (as in Hermans et al., 2016). Many authors have explored their differences and commonalities (see Feola, 2015; Horcea-Milcu et al., 2020; Loorbach et al., 2017; Pereira et al., 2015). The complete overview of the frameworks used in the amplification typology and their theoretical background, reference authors, and processes are in Appendix A.

To build the typology, 'identification, comparison, and aggregation' of existing mechanisms were done (Lam et al., 2020). In the comparison step, it was evinced that only the framework of acceleration mechanisms from Gorissen et al. (2018) concerned with increasing the *speed* of initiatives, and most frameworks considered impacting higher institutional levels (scaling-up) an important amplification mechanism (Lam et al., 2020). Finally, eight amplification processes were selected to summarize the mechanisms into three main categories. The three amplification categories are 'within, out, and beyond', and these are explained in the next section. Appendix B shows the final typology from Lam et al. (2020).

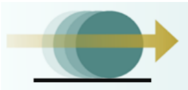
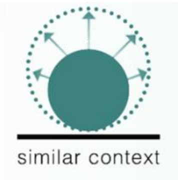
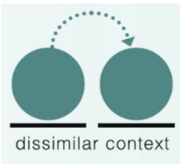
2.4.3. Analysis criteria

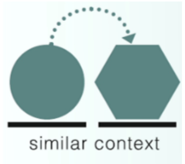
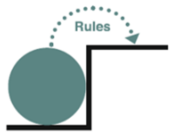
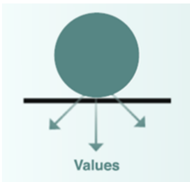
It is worth mentioning that the amplification typology used in the analysis is recent and has not been used in (published) empirical research yet. Additionally, this framework is not tailored for NBS, so I had to develop criteria to apply the mechanisms to the topic of NBS for urban drainage. Table 6 gives the full overview of the categories and processes used to analyze the amplification of NBS for urban drainage in Amsterdam, according to the criteria explained in this section and the indicators introduced in the table. Finally, an example of each process is provided, illustrating how each process manifests in practice.

Amplifying within refers to processes aimed at 'stabilizing' and 'accelerating' the impact of initiatives, and it is not much explored in the literature (Lam et al., 2020). For the implementation of NBS for urban drainage, amplifying within consists of consolidating a pilot project or experiment into the repertoire of solutions used by the city and partners in urban drainage projects. *Stabilizing* means an NBS experiment for urban drainage is considered a successful innovation and becomes a permanent solution, used regularly in drainage projects. *Speeding up* means that the implementation process of NBS optimized and becomes more efficient, creating impact faster than in the early stages.

Amplifying out refers to the impact range and amount of initiatives, meaning more people and places are affected. This category sub-divides into processes that amplify initiatives that are either ‘dependent’ or ‘independent’ from the original initiative in ‘similar’ or ‘dissimilar’ contexts (Lam et al., 2020). Most of the processes in the underlying literature belong to this category. In this research, *amplifying out* entails an increase in the amount and coverage of NBS projects (i.e. more surfaces covered with NBS). When innovative NBS projects multiply in the city or when initiatives add features to their NBS repertoire, a *growing* process is activated. If an initiative creates new ways (capabilities) to increase the impact of their solutions, they are also *growing*. When NBS initiatives are implemented in different contexts (either socioeconomic, technological, legal, or ecological, for example) they activate a *replicating* process. Replication happens when initiatives bring their solution to different cities or countries that have distinct water regulations or climate conditions, for example. *Transferring* and *spreading* processes can happen within and outwards of the city. In *transferring,* the knowledge, technology, or experience of an initiative with an NBS is shared with other actors, who are independent of the original initiative and will implement a similar solution in their own (similar) context. In *spreading*, the core principles of a solution disseminate and loosely inspire variations of the original project in places with different contexts. *Spreading* happens, for example, if the principles of storing rainwater in roofs would inspire projects that store rainwater in parking lots, which have different requirements and characteristics.

Amplifying beyond represents the latest paradigm in transitions literature, and concerns with how initiatives create impact, proposing processes to change institutional structures, values, or mindsets (Lam et al., 2020). *Amplifying beyond* the implementation of NBS for urban drainage means the ‘rules of the game’ have changed as a result of deeper changes in values and beliefs by the actors involved in the process. The *scaling-up* process is represented by a pilot or experiment with NBS becoming embedded into governmental practices or inspiring new regulations. Finally, in the *scaling deep* process, the values and perception towards rainwater change, and the actors involved in the implementation of drainage systems no longer see rainwater as a problem, but as a solution or a source of innovation and investment opportunities.

Analytical Framework: The amplification processes and their application to the implementation of nature-based solutions for urban drainage				
A) Category	**B) Amplification process**	**C) Definition of the process (by Lam et al., 2020)**	**D) How it applies for the implementation of NBS for urban drainage:**	**E) Example of process in existing sustainability initiatives aimed at urban drainage:**
Amplifying within Doing the same initiative longer or faster	Stabilizing 	*"To strengthen and more deeply embed initiatives in their context, making them more resilient to up-coming challenges and ensuring they last longer"*	• The duration of the experiment is extended. • Funding for the experiment is extended. • The experiment is monitored and evaluated. • The experiment is embedded in local practices.	**Rainproof Initiative.** *With this initiative, the city of Amsterdam creates opportunities for individuals and businesses to take action to increase urban rainwater resilience by sharing knowledge and creating an organized movement to implement initiatives to store and drain rainwater locally.*
	Speeding up 	*"To increase the pace by which initiatives create impact or are brought to fruition"*	• Shorter iterations when implementing similar projects[1]. • The efficiency of project[1] implementation is increased. • More or new knowledge facilitates implementation.	**Subsidy to blue-green roofs in Amsterdam**. *Aim to increase the pace of citizens adhering to it, making the impact of the implementation of this solution be felt faster.*
amplifying out Doing the same or a similar initiative in a similar or dissimilar context	Growing 	*"The expansion of the impact range"* • **dependent initiative** • **similar context**	• The same project[1] is implemented more times in the same context[2] by the same initiative. • Experiment copied to a place with a similar context[2]. • New features are added to the project[1], increasing its impact.	**RESILIO program**. *The goal is to implement 10.000m2 of green roofs in Amsterdam. After a successful pilot, several partners came together to create a larger network of blue and green roofs in the city of Amsterdam, growing the impact of this solution on urban drainage.*
	Replicating 	*"The copying of an initiative to a dissimilar context"* • **dependent initiative** • **dissimilar context**	• The same project[1] is implemented in a different context[2] by the same initiative. • An experiment is adapted and implemented in a different context[2] by the same initiative.	**Polder Roof system**. *Invented by MetroPolder business in Amsterdam, the system (technology) was implemented in other countries (different contexts) such as Italy and the USA under the coordination of MetroPolder.*

	Transferring 	*"Implementing a similar but independent initiative in a different place, adapted to the new but similar local context"* • **independent initiative** • **similar context**	• Know-how is transferred to actors who implement an inspired project[1] in a similar context[2]. • Experiment informs independent initiatives who implement an inspired project[1] in a place with similar context[2].	**RESILIO program.** *The project is sharing the knowledge and expertise obtained during the program with other cities across NL and EU (this is part of the condition for getting EU funding).*
	Spreading 	*"Disseminating core principles and approaches to other places with a dissimilar context"* • **independent initiative** • **dissimilar context**	• The principles and approach of a project[1] are borrowed by actors to implement a variation of the experiment adapted to their context[2]. • A new project is inspired by an experiment elsewhere (with a different context[2]).	**"Water Squares" across Dutch cities.** *This is now a diffused practice and while the projects vary quite a lot, they have the same principle of storing water in urban areas to release the drainage system.*
amplifying beyond Changing rules and values	Scaling up 	*"processes that aim to impact higher institutional levels by changing the rules or logic of incumbent regimes"*	• The experiment is uptaken by the municipality and embedded in the local set of rules and practices. • A project[1] results in new regulations, policies, or institutions which incorporate its principles and values.	**Water storage ordinance in Amsterdam**. *The new regulation dictates that all new buildings need to store water in their lot and release in a controlled way.* **Groenebook – Pucinnimethod**. *Defines the standards for the planning of green spaces in Amsterdam.*
	Scaling deep 	*"We derived scaling deep from processes that address the change of values and mindsets"*	• A project[1] changes how people perceive a problem, or how the problem is framed. • Rainwater is perceived not as a problem but as a resource and opportunity for innovation/investment. ** Does not apply directly to the 'implementation process', which is either a **result** of scaling deep or **will activate** this process after experiments are implemented.*	**Rainproof Initiative.** *Created to change the perception of people about water, from being a nuisance to being a resource. The mission of the initiative is to engage people, through various ways, to implement local solutions to increase retention and local use of rainwater.*

project[1]: here understood as the pilot or experiment with NBS. It can be for example a smart blue-green roof system, a natural solution to purify rainwater, or bioswales.

context[2]: meaning similar socioeconomic, technological, legal, ecological conditions. Examples of similar context: same locality, cities in the same country, location with similar drainage conditions, or legislation. Example of different context: another country, different climate conditions, varying building legislation, etc.

Table 6: Analytical framework.

3. Methodology

3.1. Research Paradigm

The methodological approach detailed in this chapter was designed to answer how amplification processes can increase the impact of NBS in the urban drainage system of Amsterdam. The interpretivist epistemology and constructionist ontology followed by this research assume social reality to be constructed, and the implications for the research process are detailed next (Bryman, 2016). Additionally, the research design shows how the chosen methods allow answering the research main and sub-questions, fulfilling the research's main goal and objectives, and answering the main research question *"How can the implementation of nature-based solutions (NBS) for urban drainage be amplified in Amsterdam?"*

The main research goal and research objectives that guided this methodology are recapped below, followed by the research paradigm. Next, other aspects of the methodological approach are explained.

Research Goal: Explore how the implementation of NBS for urban drainage can be amplified in Amsterdam, contributing to the desired rainproof city.

Objective 1: To identify opportunities and challenges for the implementation of NBS for urban drainage in Amsterdam.

Objective 2: To explore processes that amplify the implementation of NBS for urban drainage in Amsterdam.

Figure 5: Main research goal and research objectives.

The epistemological view of this research is interpretivism because the topics of climate change adaptation, urban resilience, and sustainability transitions that sustain this research are only meaningful within a given sociological and cultural context, and not externally to human experience (Bryman, 2016). Interpretivism recognizes that a different logic applies to people and social structures than to natural sciences objects. Hence, research procedures should consider the subjective meaning of social action (Bryman, 2016). Furthermore, urban planning is largely based on normative knowledge and a highly contextual set of beliefs and values, creating an imagined ideal of the urban environment (Rydin, 2007).

The ontological position of this research is constructionist, as the underlying theoretical body belongs to a constructed social reality in constant revision by internal social actors (Bryman, 2016). The research is based on two main theories. First, theory on the implementation of ecosystem-based approaches (i.e. NBS and BGI was considered. Pauleit et al. (2017) say that ecosystem-based approaches focus on human interests and benefits, and have a problem-focused character requiring inter- and transdisciplinary research. Second, the theory on sustainability transformations was applied. Sustainability transformations' theory is the base of the amplification framework proposed by Lam et al. (2020) and used as analytical lenses in this research.

A multi-method qualitative research strategy was chosen to answer the research questions, deriving from the epistemological and ontological positions. A qualitative approach focuses on words rather than on numbers and quantifications (Bryman, 2016). Therefore, I analyzed the narratives of actors who engage in the implementation process of NBS in Amsterdam to identify NBS implementation challenges and explore adequate amplification processes. A similar strategy was used in Frantzeskaki (2019) Frantzeskaki et al. (2020), and Wamsler et al. (2020) to uncover the state of NBS across cities. Finally, the theory-development in this research is abductive. Hence, the research moved back and forth between theory and observations of reality.

3.2. Research Design

To investigate the central topic of NBS for urban drainage, this research adopts an embedded single-case design, as proposed by Yin (2018). Figure 6 summarizes the layers of the case study. It is important to notice that the city is at the same time the case and the main unit of analysis.

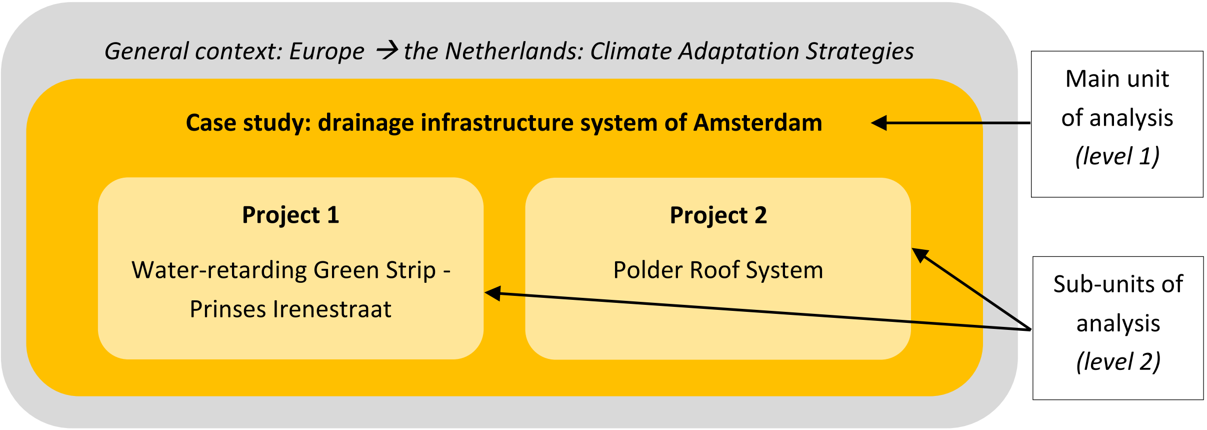


Figure 6: General context, main unit, and sub-units of analysis of the research.

Bryman (2016) says case studies provide an in-depth examination of the object of interest, and according to Yin (2018), three overarching criteria justify the use of a case study as a research design, all of which apply to this research:

i. *"your main research questions are "how" or "why" questions,*
ii. *you have little or no control over behavioral events, and*
iii. *your focus of study is a contemporary (as opposed to entirely historical) phenomenon;"*

The city is the scale of the case selection, as case studies at this level allow cities to learn from each other on how to address common challenges of urban areas, such as climate change and climate adaptation planning. Frantzeskaki et al. (2020) explain that case studies are useful to research new urban planning approaches (i.e. NBS) and the context-dependent knowledge they generate, provide a deeper understanding of the processes and actors involved.

The city of Amsterdam delimits the single-case study, and the case is bounded to the urban drainage infrastructure system of the city, which is the main unit of analysis. A single-case design was chosen for considering that the selected case is a critical one. Flyvbjerg (2006, p. 229) explains that critical cases have *"strategic importance in relation to the general problem".* The Case Selection section in the introduction explains the relevance of Amsterdam and its 'rainproof' efforts within urban drainage. Therefore, the city is considered the 'most likely' (Flyvbjerg, 2006) to have an advanced implementation of NBS for urban drainage in the Netherlands.

The selection of the case study was limited to a city within the Netherlands for various reasons:

- The Netherlands is particularly threatened by the risk of flooding given its flat morphology and its large territory below or at sea level (Brinkhuis-Jak et al., 2004).
- The country has a strong tradition in water management and exports solutions to other countries. Therefore, it is expected that the latest solutions in rainwater management can be found in the country.
- The research is being conducted from the Netherlands, resulting in facilitated access to experts and needed information to support the research here than in other countries, increasing the chances of completing the research scope within the time limit.

Furthermore, the research design is embedded because the case entails units of analysis at different levels (Yin, 2018). The first level is the drainage infrastructure system of the whole city, and the second level is made by the two selected NBS projects, which are also the subunits of analysis. These projects are located within the Municipality of Amsterdam and their selection was limited to NBS implemented as part of either a municipal initiative or a public-private partnership. This delimitation is because all water management systems in the Netherlands are governmental responsibility, being provided as a public service. Therefore, NBS projects that address urban drainage as part of a blue and green drainage infrastructure system are either direct responsibility or coordinated by the Municipality.

The entry point to select the studied city was the Urban Nature Atlas by Naturvation, a catalog containing 1000 cases of NBS across 100 cities in 24 European countries, developed under the European Commission research project Horizon. The online Atlas is the most comprehensive database of European NBS, providing a detailed overview of each project with the same format of data classification, which allows for comparisons between projects. Browsing the available NBS and verifying them against practical requirements for completing the research (i.e. availability of online content given Covid-19 restrictions, ability to map and reach stakeholders virtually, and applicability of findings) a suitable case was selected to fulfill the research objectives.

The Urban Nature Atlas features 30 projects within the Netherlands, in 3 main Dutch cities (Amsterdam, Den Haag, and Utrecht). From those, 19 projects target "*climate action for adaptation, resilience and mitigation*" and 20 target *"water management",* with an almost complete overlap (only 2 projects of water management do not address climate adaptation). The projects were reviewed individually based on four criteria used to filter the most relevant cases:

i. The project targets both 'climate adaptation' and 'water management'.
ii. Water management objectives are central to the project. This is verified in two ways (1) verifying if the "Urban Setting" indicates "green areas for water management" and (2) reading the "objectives" section of the project, searching for terms such as "water retention", "stormwater storage", "sustainable drainage systems", "urban drainage" or similar.
iii. The project was not carried exclusively by non-governmental actors. These represent private initiatives or citizens-led projects that are not embedded in the municipal planning strategy. The research focuses on projects implemented as part of broader urban adaptation plans for rainwater management, requiring some level of governmental participation.
iv. The project is not for coastal protection, a park, or a unique facility type (i.e. sports center) because of their exceptional character and/or limitations for amplification.

This filtering identified six suitable projects, two in Utrecht and four in Amsterdam. Amsterdam had the most projects identified and, during the analysis, the city stood out for its Rainproof Initiative, a governmental-led network that enables the implementation of rainproof drainage projects. Therefore, the city was chosen as the location of the case study, and two different projects were selected as subunits of analysis.

3.2.1. Project: Water-retarding Green Strip - Prinses Irenestraat

The newly completed 'water-retarding green strip' project at the Prinses Irenestraat is the first sub-unit of analysis. This project was selected for its novelty, biophysical characteristics, and implementation process. The pilot that inspired this project, is in the Urban Nature Atlas (Figure 7), being the first of its kind in Amsterdam. The pilot is a narrower stormwater planter that extends for one block on Zuidelijk Wandelweg Street at the Zuidas district. During the preliminary investigation, I learned about a second, larger project under construction at Prises Irenestraat, following the experience obtained with the first one (Figure 8). This newer project is located nearby its precursor in Zuidas and it was conceived by the same team with adjustments based on the first experience. Therefore, I chose to analyze the newer and larger green strip project at Prinses Irenestraat, which is more complex and demonstrates how the initial pilot has amplified into a larger project.

Figure 7: The original Green Strip project that features the Urban Nature Atlas, located at the Zuidelijke Wandelweg street, Zuidas, Amsterdam (Amsterdam Zuidas).

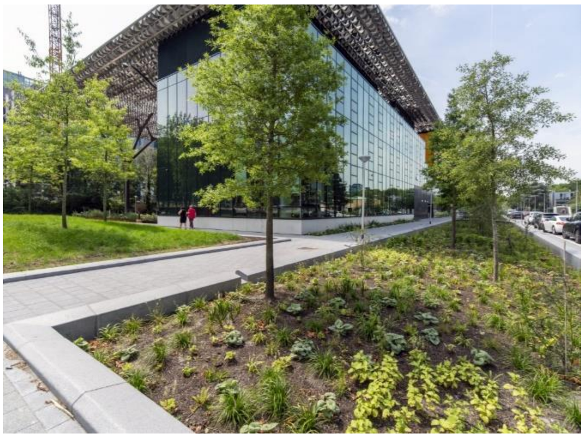


Figure 8: The second Green Strip project, analyzed in this research, located at Prinses Irenestraat, Zuidas, Amsterdam (Amsterdam Zuidas).

3.2.2. Project: Polder Roof System

The first 'polder roof system' (Polderdak) of the world was developed and implemented in Amsterdam in 2013 (Figure 9), also in the Zuidas district, and it is the second sub-unit of analysis. This innovative micro water management experiment started the implementation of blue-green roofs in the city (and beyond). Consequently, a large European-funded program emerged – RESILIO – aiming at realizing 10.000m^2 of smart blue-green roofs in the city (Figure 10). The polder roof differs from traditional green roofs because of its water storage capability and automation aspects. It *"combines multiple benefits including the heat stress reduction, noise reduction, sustainable energy provision, biodiversity, food production, and climate change adaptation"* (NATURVATION, 2020). Hence, the case's relevance is not limited to the first Polderdak but extends to the new rainwater management paradigm and technology introduced by it. The analysis focuses on the polder roof solution, considering both the first project "Polderdak" featured in the Urban Nature Atlas, and also the program RESILIO, which is a direct consequence of this innovation and an example of amplification in real life.

Figure 9: The first Polder Roof just after completion in 2013 (Merlijn Michon).

Figure 10: A citizens' event on a RESILIO blue-green roof in Amsterdam (Leon Kapetas, UIA).

3.3. Data Collection, Processing, and Analysis

In summary, the methods used for collecting data were:

- Research, selection, and qualitative analysis of relevant documents.
- Qualitative semi-structured interviewing.

By using two or more different sources of data it is possible to triangulate the information and increase the credibility of the evidence provided (Bowen, 2009). Table 7 gives an overview of the methods of data collection and how they relate to the research sub-questions:

Units of analysis and data collection method:			
Unit of Analysis	**Research sub-questions and main question**	**Data collection method**	**Example of interview question**
City-level (Main unit)	**SQ1:** What is the predominant urban drainage approach in the city?	• Documentation from municipality and water agency. • Interview(s) with employee(s) from the water agency.	*"Inside Waternet, do you have enough people thinking about nature-based solutions when you start new projects for urban drainage? Do you think the aspects you mentioned about blue and green infrastructure are considered or is this still a bit utopic for the institution?"* (question to interviewee #3, Advisor for Climate Adaptation at Waternet)
	SQ2: Which mechanisms enable the implementation of NBS for urban drainage in the city?	• Documentation, policies, and strategies from the municipality. • Official websites; • Interviews with employees from the municipality.	*"How do the policies for climate adaptation and 'green' in the city actually result in new projects and their implementation?"* (question to interviewee #4, Policy advisor at the Municipality Amsterdam)
Project-level (Sub-unit)	**SQ3:** Why and how NBS for urban drainage were implemented in the city?	• Interviews with stakeholders. • Project documents and web pages.	*"Zuidas has many 'green projects', like the one at the* Van der Boechorststraat *or the 'Groenestrook' at* Prinses Irenestraat. *What motivated the implementation of these green projects in Zuidas?"* (question to interviewee #1, Senior Designer for the Zuidas district of Municipality Amsterdam)
	SQ4: What supports or hinders the implementation of NBS for urban drainage in the city?	• Interviews with stakeholders.	*"What do you consider obstacles still existing to increase green roofs in the cities? Are there still obstacles to have more projects like this?"* (question to interviewee #6, Manager at Dakdokters)
City and project level	**RQ:** How can the implementation of nature-based solutions for urban drainage be amplified in Amsterdam?	• Combination of the methods and outcomes of the sub-questions.	*"Do you think that a project as these 'urban wadis' changed the perception of people or companies about drainage? Did it create some awareness or have an educational purpose?"* (question to interviewee #10, Sewerage specialist at Waternet)

Table 7: Data-collection methods per research question.

Amsterdam has several official documents (i.e. plans and strategies) as well as websites providing extensive information on the topics of sustainable development, climate adaptation, and rain-proofing the city to be analyzed. These resources were of great value in the data collection phase. The main documents used as data sources in the analysis step are listed in Table 8:

Analyzed documents:			
Title	Produced by	Year	Overview
1. Strategie Klimaatadaptatie Amsterdam (Climate Adaptation Strategy)	Gemeente Amsterdam	2020	Set the strategy of the Municipality of Amsterdam and partner institutions to achieve a climate-resilient city by 2050.
2. Uitvoeringsagenda Klimaatadaptatie (Climate Adaptation Agenda)	Gemeente Amsterdam	2021	Action plan for the implementation of the climate adaptation strategy up to 2030.
3. Amsterdam Rainproof	Amsterdam Rainproof Initiative	2018	Covers the first 4 years of the initiative, with many articles on why and how the program was developed, which are the participant actors, what projects exist, and what are the solutions available to make the city rain-proof.
4. Regenbestendige Gebiedsontwikkeling (Rainproof Area Development)	Gemeente Amsterdam, Waternet, and Rainproof Initiative	2019	This study translates the sometimes abstract objectives from relevant policy (such as the Amsterdam Municipal Sewerage Plan 2016-2021) into recommendations and a technical/substantive action perspective.
5. Gemeentelijk Rioleringsplan Amsterdam 2016-2021 (Municipal Sewerage Plan Amsterdam 2016 – 2021)	Waternet	2015	This Plan describes the water management objectives of Amsterdam and explains how water tasks will be fulfilled by Waternet, the municipal water agency in the coming period.
6. Groenvisie 2020 – 2050 (Green Vision 2020-2050)	Gemeente Amsterdam	2020	The vision of the Municipality of Amsterdam for the role of nature and greenery in the city, as part of the new Environmental Vision (Omgevingsvisie) for 2050.
7. Een groene zoom voor de hoogstedelijke Zuidas in Amsterdam (A green border for the metropolitan Zuidas in Amsterdam)	Magazine "Green" – Year 75, Issue 9, p. 16-19	2019	Article about the water retention strip at the Prinses Irenestraat explaining the project and the development context, with an interview from the responsible architect Ton Muller.
8. Structuurvisie Amsterdam 2040 (structural Vision Amsterdam 2040)	Gemeente Amsterdam	2011	The complete vision of the Municipality for its social, economic, and infrastructure development until the year 2040. *(Only the parts related to urban drainage and water were considered);*

Table 8: Documents analyzed in the empirical research.

Documents can be very comprehensive and contain large amounts of carefully organized and selected information, being a source of facts and figures produced without the researcher's intervention (Bowen, 2009). They also often have the input of experts who are out of reach for interviewing. Merriam (1988, p.118 as cited in Bowen, 2009) explains that *"documents of all types can help the researcher uncover meaning, develop understanding, and discover insights relevant to the research problem".* It must be observed however that the information provided in documents is static and may not represent reality, or provide a partial picture of the matter (Atkinson and Coffey, 1997 in Bowen, 2009). Therefore, apart from using documents, I conducted semi-structured in-depth interviews with relevant actors who could validate and confirm the information obtained in documents and give additional information, providing alternative perspectives to what is documented. The documents were processed in three steps: scanning, selection of relevant parts, and translation. As most documents are in Dutch, I first scanned them to identify relevant information. Next, the relevant sections were translated with an online tool. A new document was created with the English text and used in the analysis. If the document was in English, the same initial scan was done, and the relevant text was used directly in the analysis.

Furthermore, websites are a new format of documentation that can be used in research, classifying as 'virtual documents' according to Bryman (2016). I used official websites as a supporting source of information when information was not found on reports or publications. The two main websites used are from the Municipality of Amsterdam (www.amsterdam.nl) which contains condensed information about the city's policies, plans, regulations, useful maps and images, and from Rainproof Initiative (www.rainproof.nl) which is a knowledge center with measures to improve urban drainage, including a list of exemplary projects as well as the stakeholders involved. Whenever information was retrieved from websites, this is visible in the reference.

To deepen the knowledge and capture the constructed reality of the actors involved in the process, I conducted in-depth semi-structured interviews. The selection of interviewees included a variety of job titles, organizations, and roles. Most participants work for the Municipality and the subsidiary water agency Waternet, given the role of the public administration in the urban drainage. To identify and contact potential interviewees I used the following strategy: a) search for relevant names in documents and publications related to the topic; b) Perform a search on LinkedIn to confirm the credentials; c) contact person via LinkedIn; d) Use LinkedIn for a 'snowballing' method to identify and contact relevant people. A parallel strategy was to use the snowballing method with the people I interviewed.

The interviews were conducted via video call and over the phone because of the Covid-19 pandemic's restrictions to face-to-face interaction. This type of interview may suffer limitations such as the risk of technical problems (i.e. bad internet connection) that may cause the interview to be unclear and difficult to understand, as pointed by Bryman (2016). Potential limitations were considered and addressed in advance, and no restricting technical difficulty was experienced. Besides, video call interviewing has advantages that benefit this research, namely the ability to record and transcribe and the facility to find a slot in a busy agenda. An interview guide tailoring the topics and questions to the interviewee's role was used in all interviews. Table 9 lists the people who react to the initial contact for an interview and their relevance to the research. It also provides details for each interview.

Interviews' participants and details:				
N.	**Organization and occupation**	**Type of knowledge**	**Source of contact and contact mode**	**Interviewed, date, and duration**
1	**Gemeente Amsterdam:** **Senior Designer** of public space at the "Spatial Design and Sustainability" dept.	*Works in the Zuidas development team and participated in the project of Prises Irenestraat. Knows about the collaboration between the Gemeente and Waternet.*	• LinkedIn contact. • LinkedIn message, e-mail, video-call.	**Yes** 16/04/2021 50 minutes
X	**Gemeente Amsterdam:** **Chief Designer** of public space at the "Spatial Design and Sustainability" dept.	*Works in the dedicated development team for Zuidas, participated in the project of Prises Irenestraat, and contributes to the Green Vision and Puccini Green standards.*	• Recommendation from the previous respondent. • E-mail.	**No** - *After the recommendation two e-mails were sent without reaction.*
2	**Waternet:** **Project Leader** and consultant at Waternet and member of Rainproof Initiative	*Member at the Rainproof Initiative as a consultant from Waternet knows how drainage projects are implemented, and ongoing measures to make sewerage systems resilient and the city rainproof.*	• Recommendation from a contact in the organization. • E-mail, video-call.	**Yes** 07/5/2021 60 minutes
3	**Waternet:** **Advisor for Climate Adaptation** at Waternet and member of Rainproof Initiative.	*Knowledgeable about Waternet climate adaptation strategy. Active in many Rainproof projects in Amsterdam, including RESILIO program and the Prinses Irenestraat.*	• Recommendation from the previous respondent. • Phone call, video-call.	**Yes** 25/5/2021 53 minutes
4	**Gemeente Amsterdam:** **Policy Advisor** for sustainability at "Spatial Design and Sustainability".	*Work in the development of sustainability policies, such as the latest Climate Adaptation Strategy and Agenda, and the Green Vision. Experience with the RESILIO program and green roofs.*	• LinkedIn contact. • LinkedIn message, e-mail, video-call.	**Yes** 19/5/2021 53 minutes
X	**Rooftop Revolution:** **Director** at Rooftop Revolution. *(NGO in consultancy and development of green roofs).*	*Participated in many green-roof projects in Amsterdam and the RESILIO program. Knowledgeable of enablers and obstacles of green roofs implementation in the city.*	• Recommendation from the previous respondent. • E-mail.	***No*** - *After recommendation and e-mail exchange, no further reaction.*
5	**Gemeente Amsterdam:** **Senior Designer** of public space at the "Spatial Design and Sustainability" dept.	*Experience designing public spaces. Knowledgeable on how NBS is being integrated into the city of Amsterdam, the enablers and challenges for that.*	• Recommendation from a contact in the organization. • E-mail, video-call.	**Yes** 26/5/2021 37 minutes
6	**Dakdokters:** **Manager** and Project Advisor at the Dakdokters. *(Company specialized in green and blue-green roofs).*	*Experience with the development and implementation of green-roof projects. Knowledge about the system's evolution in Amsterdam.*	• LinkedIn contact. • Linkedin message, e-mail, phone call.	**Yes** 31/5/2021 20 minutes

7	**MetroPolder:** **Project Manager** at MetroPolder (*Company specialized in smart water storage facilities-Polder Roof)*	*Works expanding the Polder Roofs beyond the Netherlands, and partnership with other cities and businesses. Knowledge of polder roofs' implementation and RESILIO.*	• LinkedIn contact. • Linkedin message, e-mail, video-call.	**Yes** 1/6/2021 41 minutes
8	**Researcher:** **Dr. Lam**. Member of the research project on amplification mechanisms, literature that informed the analysis of this research.	*Dr. David Lam is a Director at Leuphana University Lüneburg, Germany, and the main author of the framework used as the analytical framework. He has deep knowledge of amplification theory, processes, and framework.*	• LinkedIn contact. • Linkedin message, e-mail, video-call.	**Yes** 8/6/2021 30 minutes
9	**Rooftop Revolution:** **Green Roofs Consultant** for Rooftop Revolution *(NGO in consultancy and development of green roofs).*	*Consultant for green roofs implementation in partnership with a Dutch Municipality. Knowledgeable of the challenges to introducing and scaling green roofs at a new location.*	• LinkedIn contact. • Linkedin message, e-mail, video-call.	**Yes** 10/06/2021 34 minutes
10	**Waternet:** **Asset Manager and Sewerage specialist** at Waternet.	*Vast experience in the sewerage department. Knowledgeable on systems' requirements, challenges, and evolution and the implementation of urban "wadis", including Prinses Irenestraat.*	• LinkedIn contact. • Linkedin message, e-mail, video-call.	**Yes** 17/06/2021 42 minutes
X	**Gemeente Amsterdam, Zuidas:** **Project Manager** at Zuidas division of the Municipality.	*Member of the Green Program at Zuidas, knowledgeable on how the implementation of NBS and sustainability initiatives in Zuidas.*	• LinkedIn contact. • Linkedin message.	**No** - *No availability within interview schedule*

Table 9: Research participants and interviews' details.

All interviews were conducted remotely and recorded, with verbal agreement from the interviewee. After being recorded, the interviews were transcribed with the support of software that converts speech to text. In this stage, information considered out of the research topics was filtered out to create a synthetic final transcript without changing the meaning of the responses. The final transcripts were then used in the analysis. When reporting the findings, the quotations are presented in the formal language, meaning that the literal words of the respondents were adjusted for the sake of clarity and comprehension.

The last step consisted of the data analysis, which used a combination of qualitative content analysis and thematic analysis as strategy, as explained in Bowen (2009). Bryman (2016) says that qualitative content analysis is the most used approach to qualitative analysis of documents, while thematic analysis is a very common approach to qualitative data analysis such as interviews but it does not have a 'distinct cluster of techniques'. In my analysis, interview transcripts were considered as a document together with the written documents.

The analysis was done in five steps, based on Bryman (2016), Bowen (2009), and Wamsler et al. (2020): (1) the development of a coding scheme using themes to reflect the main concepts used in the theoretical and analytical framework, (2) multiple readings of each document to identify potentially-relevant extracts, (3) coding of the text using the pre-defined themes, (4) analysis of the coded text and themes, also cross-referencing the themes, to identify patterns, (5) condensation of main findings per theme creating a database of extracts used to write the main findings.

The pre-defined themes for coding and analysis were based on the main topics from the theoretical and analytical framework and divided into three main themes that were subdivided into categories and several sub-themes, included in Appendix C.

3.4. Research Quality Criteria

According to Bryman (2016) *reliability, replicability* and *validity* are the main criteria for the quality evaluation of a research design. However, these criteria are mainly connected to quantitative research and refer to an accurate measurement of concepts, so the results can be repeated and the study replicated. In qualitative research, achieving consistency in concept measures is not so simple because there is much 'subjective judgment' in activities like coding of interviews and content analysis (Bryman, 2016). Considering the differences between quantitative and qualitative research, Lincoln and Guba (1985) emphasize, in their reference work Naturalistic Inquiry, that the criteria used for assessing the world from a realistic (positivist, quantitative) perspective are not applicable when a naturalistic (interpretivist, qualitative) approach is taken. They propose the use of four other criteria to evaluate the trustworthiness of interpretivist research, which were considered in this study:

- **Truth value** *(instead of internal validity)* - means the research is credible and that the multiple constructions of reality are adequately represented by the research (Lincoln & Guba, 1985). In this research, I achieve truth value by explicating the careful processes that led to the results, as well as by providing the coding themes and sub-themes (Appendix C) and the full transcripts of the interviews (Appendix D), which can be re-interpreted by the reader. Moreover, I tried to ensure a critical selection of interview participants and, whenever possible, I triangulated important information between interviews and documents, to strengthen the credibility of the research.
- **Applicability** *(instead of external validity)* - means that a 'working hypothesis' may be abstracted from the completed research which may be transferable to other contexts empirically (Lincoln & Guba, 1985). A direct transfer of results from a research done in one context to another (or from one city to another) is not possible, precisely because the contexts vary and only the original context is known by the researcher. Lincoln and Guba (1985, p. 298) say that to achieve potential applicability the researcher is responsible for *"providing sufficient descriptive data to make such similarity judgments possible"* by the part who may want to apply the findings. I seek to achieve applicability by providing the conditions (context) in which the results emerged and by explicitly relating the conclusions to the context and results from the case study.
- **Consistency** *(instead of reliability and replication)* - is based on the notion that the object being studied is 'ephemeral and changing' and can only be 'so much' reliable (or at least partially unreliable) (Lincoln & Guba, 1985). Therefore, contrary to traditional replication objectives, it accepts that there is no *"tangible and unchanging 'out there' that can serve as a benchmark"* (Lincoln & Guba, 1985, p. 299). While the replication of a subjective and interpretive study is unlikely to yield the same results again, this research was careful in documenting the main steps of data selection and analysis to increase the overall trustworthiness of the results.
- **Neutrality** *(instead of objectivism)* **-** means that the research is concerned with the quality of the data obtained, rather than with how objective or value-free it is (as this is not possible in an interpretivist approach). Therefore, the goal of this research was to collect data that is confirmable, factual, and reliable, leading to trustworthy results instead of unreliable and biased results (Lincoln & Guba, 1985).

3.5. Role of the Researcher and Biases

My role in this study was to scrutinize the implementation process of NBS for urban drainage in Amsterdam. Following an interpretivist epistemology, my data and reality interpretation are the product of my position and perspective towards the research problem. To credibly portray the current situation, I interviewed people who directly participate in NBS implementation processes, hearing their perspectives. I also read the most available documents on the topic possible. Nonetheless, the presence of unavoidable, unconscious biases from my culture in the conduction of the study, interpretation of the results, and writing of the conclusion should be noted.

As a foreign researcher in the Netherlands, the Dutch context of urban planning is external to my personal planning experience, which is forged in the Global-south. I strive to 'stick to the data' and be neutral on my judgments, but as explained by Lincoln and Guba (1985) and Bryman (2016) this is never fully possible in social research. Exercising self-awareness and self-reflection is the best one can do to minimize the influence of its own biases (Bryman, 2016). Finally, my 'normative knowledge' (Rydin, 2007) on what characterizes an 'ideal' planning scenario unavoidably reflects in all steps of the research to a certain degree.

3.6. Research Limitations

Two major limitations were faced in all research steps: time restrictions and the covid-19 pandemic. Time limitation was a challenge to be overcome, avoiding risking poor conduction of the research or incomplete results. The limitations of the ongoing Covid-19 pandemic are exceptional to this time in life, having many direct and indirect consequences to everyday, academic, and research life. The interviews and interactions, including with colleagues and the supervisor, had to take place exclusively online. While this brings advantages, as increased availability and facilitated recording of meetings (Bryman, 2016), it interferes with the quality of interactions. Research indicates that online communication lacks the 'nonverbal and environmental cues' from face-to-face ones, (Sproull and Kiesler, 1985, as cited in Okdie et al., 2011) reducing the likeability of the interaction partner, for example (Okdie et al., 2011). As the pandemic is a new and unique situation, its impacts on research are not well-understood and it is hard to say how much it affected the research output.

A third possible limitation is the interviews not being held in the respondent's native and working language. This may cause slight changes in the conceptual context and meaning of what is being expressed, because of the personal translation process (Squires, 2009). Open and clear communication was sustained and questions and answers were repeated and rephrased during interviews if they were not clear, to align the understanding of the researcher as much as possible with the information transmitted by the interviewee.

3.7. Ethics

The research was conducted honestly and scrupulously. Throughout the process and especially in the contact with interviewees, I was clear about the contact reasons, how and why the person was selected, how the data would be used, and the purpose and objectives of the interview. Moreover, the name and identification of participants remained private, and numeric codes were used to preserve their anonymity.

Integrity and transparency drove the research process, even if the outcome of the analysis could result contrary to my expectations due to unanticipated or unknown reasons. Furthermore, I am fully accountable for all the research steps, including the data collection, data analysis, and writing of the final report, and I ensure that no step of the process was misconducted. Finally, I declare having no conflicting interests or personal relationships that influenced the work reported in this research.

4. Results

Amsterdam is the capital city of the Netherlands, with around 870.000 inhabitants, the city is a dense urban center and a European hub of transport, tourism, culture, education, shopping, and more. As with all Dutch cities, Amsterdam is vulnerable to climate change. Given its geographic and morphologic conditions, the city is threatened by floods caused by the ocean, surrounding lakes, or intense rain. With that in mind, the Municipality recently launched a Climate Adaptation Strategy (Gemeente Amsterdam, 2020a) and a complementary Agenda for its implementation (Gemeente Amsterdam, 2021d). This policy is a consequence of the increased awareness of the local government about climate-related challenges to the city. Downpour events are already an issue in the Netherlands, and on June, 19th (2021) an impressive 80mm of rain fell in 90 minutes in the city of Alkmaar (next to Amsterdam). Usually, such a precipitation volume accounts for the entire month of June (Kersten, 2021).

Chapter 2 explained how NBS alleviates the impact of extreme weather events such as downpours in urban areas. When conceived as part of a green infrastructure network to complement grey infrastructure systems, NBS can be embedded in urban planning and development activities. (Depietri & McPhearson, 2017). However, there are obstacles to mainstreaming NBS into planning and practice (Wamsler et al., 2020). Against this background, the first objective of the empirical research was to identify opportunities and challenges in the implementation of NBS for urban drainage to reduce flooding risks in Amsterdam. The second objective was to uncover how the contribution of NBS to reduce flooding risks in Amsterdam can be amplified. The analyzed interviews and documents informed the following results. With the results, I demonstrate what Amsterdam is already doing to become rainproof, and the enablers and barriers to the implementation of NBS projects for urban drainage in the city.

4.1. Urban Drainage and Climate Change in Amsterdam

The collection and processing of rainwater runoff is a legal responsibility of the municipality of Amsterdam (Waternet, 2015, p. 7). The Municipality of Amsterdam and the Amstel, Gooi, and Vecht Water Board (AGV) mandate that Waternet, the municipal water agency, is responsible for the drainage system.

The main drainage policy in Amsterdam is the “Gemeentelijk Rioleringsplan Amsterdam 2016 – 2021” (GRPA) *(Municipal Sewerage Plan Amsterdam 2016 – 2021)* from 2015, and Waternet is writing a new plan for the upcoming six years to replace this one that expires soon (Respondent #2). The goals, objectives, and actions needed for the development, management, and maintenance of a quality sewerage system in the city are included in the sewerage plan.

The analysis of the GRPA and the interviews show that the current drainage system is based on gray infrastructure. This is not surprising, considering that underground systems are the most widely-used solution for urban rainwater drainage in developed cities around the world. The GRPA (Waternet, 2015, p. 17) says that in Amsterdam *“all streets and squares are equipped with gullies (wells) and other water inlets so that the rainwater does not remain in the street”*. In 2015, the rainwater sewerage network was 1.697 kilometers long and since 1923, wastewater and rainwater have been collected separately (25% of the system is mixed). The sewerage plan also forecasts the expansion of the underground sewerage to new areas and the replacement of damaged pipes and gullies, allocating a budget for these tasks (Waternet, 2015).

One of the primary goals of the water agency is to fulfill the ‘dry feet’ objective, meaning the city must protect its inhabitants and infrastructure against damages caused by rainwater. The GRPA (2015) acknowledges that increases in extreme rainfall events caused by climate change, combined with a densifying city, will make the urban space more vulnerable to such damages. Additionally, it states that the underground infrastructure will be insufficient to process heavy rainfall amounts, similar to argued by (Davis & Naumann, 2017). Finally, it proposes changes to the current drainage system, recommending that surface areas should be used to collect, process, and discharge excess rainwater, creating a hybrid system (Waternet, 2015), as proposed in the literature (Davies & Lafortezza, 2019; Davis & Naumann, 2017; Depietri & McPhearson, 2017). Hence, the current Sewerage Plan introduces the 'Rainproof' principle into local policies and makes it an official municipal goal. It also claims that all actors of the city must collaborate to achieve this rainproof state and endorses the 'Rainproof Initiative' as responsible for managing this network of actors and pushing this goal forward. The document states that:

> *"The Amsterdam Rainproof program motivates, informs, and activates residents, entrepreneurs, civil servants, and knowledge workers to work rainwater-proof when changing roofs, streets, gardens, parks, and squares. **The basic principle is that targeted, small-scale, intricate, and cost-effective measures will make the city more resistant to rainwater and at the same time more attractive and liveable**. No expensive large-scale monofunctional solutions, but with smart adjustments that increase the sponge effect of the city. The principles and actions from the Amsterdam Rainproof program are anchored in this Municipal Sewerage Plan."*
>
> GEMEENTELIJK RIOLERINGSPLAN AMSTERDAM 2016 – 2021: WATERNET, 2015, P. 8

The 'large-scale monofunctional solutions' mentioned in the GRPA are typical of gray infrastructure (Davis & Naumann, 2017), while the 'targeted, small-scale, intricate, and cost-effective measures' are associated with the components of BGI, as proposed by Brears (2018). Furthermore, the 'attractiveness' and 'liveability' expected from these drainage solutions are characteristics of NBS (Emilsson & Sang, 2017). However, the GRPA does not explicitly recommend the use of NBS to rainproof the city.

A bold ambition for the rainwater volume the city should resist is set in the GRPA. The goal was by 2020 to resist a shower of 60mm per hour without damage to property and infrastructure. This is an increase of 200% to the previous target of 20mm (in 2015), and it was "*seen as a feasible, realistic ambition and at the same time sharp enough to offer the city adequate protection against flooding."* (Gemeente Amsterdam & Waternet, 2019, p. 13; Respondent #2; Respondent #10). The policy also specifies that the existing underground system remains accountable for 20mm, with the remaining 40mm being temporarily stored in 'public and private spaces'. Finally, the GRPA proposes a 'sponge effect' in which the rainwater infiltrates the soil where it falls, rather than being transported away, restoring natural water cycles (Waternet, 2015, p. 23; Respondent #3). The use of NBS is promoted with the sponge effect, which is relatable to sustainable urban drainage systems (Suleiman, 2021; Zhou, 2014).

The Sewerage Plan (2015) proposed significant changes in the drainage system of the city. However, these changes do not represent the replacement of the traditional approach based on gray infrastructure. The underground system must and will continue to exist. But, additional solutions are needed to address extreme rainfall events expected in the city that are not supported by the underground system (Respondent #1, Respondent #2, Respondent #3, Respondent #5, Respondent #7, Respondent #10). When asked if there is a transition process from grey to green infrastructure, a respondent explained:

> *"It is not a transition of grey traditional infrastructure to green infrastructure, it's more an addition because grey infrastructure is still the basis of urban drainage. We use the standard - that's used all around the Netherlands - that with the grey infrastructure for drainage you should process 20 millimeters of rainwater in an hour, and this is still the case. We still design our grey infrastructure in that way."*
>
> RESPONDENT #2: PROJECT LEADER, WATERNET, 2021.

When questioned about why current drainage projects use NBS, two respondents from Waternet explained that it is not always possible to expand the underground sewerage system, and that comes with very high costs. They added that Waternet looked for solutions in different places, and arrived at the idea to work with natural drainage at the surface drainage, capturing rainwater in the public space (Respondent #2, Respondent #10). As a consequence, a shift in responsibilities for urban drainage happened in the city. While this task is officially Waternet responsibility, the design, implementation, management, and maintenance of the public space is the responsibility of the Municipality (Respondent #2, Respondent #3). The department "Spatial Planning and Sustainability" is in charge of designing the public space (Respondent #5, Respondent #10).

New 'rainproof' drainage projects were implemented in public areas since the introduction of the GRPA, wherein Waternet and the Municipality worked together. Still, there is a blurred line over the responsibilities of new surface drainage solutions. The interviewees reflected on the uncertainty and difficulty perceived on this issue on both sides. Two respondents from Waternet said surface drainage projects are challenging to implement because the public space is not their responsibility, and the public designers need to be aware of 'rainproof' requirements (Respondent #2, Respondent #3). A designer from the municipality said that climate adaptation requires the combination of under and above-ground solutions, which are complex and raise new questions about who is responsible for costs and maintenance (Respondent #5).

In sum, the current Sewerage Plan introduced in 2015 states that excess rainwater should be temporarily stored in public and private spaces, but does not define what solutions should be used. It gives indications, saying solutions should make the city more 'attractive' and 'liveable'. The GRPA (2015) also explains the direct relation of rainwater and groundwater, adding that rainwater should be infiltrated in a 'sponge effect', contributing to groundwater levels and quality. Finally, public and private urban areas are considered to offer opportunities to use water-storage solutions to *"prevent flooding, replenish groundwater shortages, and greening and cooling the city"* (Waternet, 2015, p. 21). This is the only reference the document makes to using nature as a solution (through greening).

4.2. Mechanisms for NBS Implementation

Since the publishing of the Sewerage Plan in 2015, many mechanisms were created in the city that enables the implementation of NBS for urban drainage. Legal mechanisms are policies, strategies, plans, and regulations that provide legal-institutional conditions for the implementation of NBS. In Amsterdam, policies for urban development, greening, and adaptation enable NBS implementation and recent regulations push this implementation further (Respondent #4).

The second group of mechanisms derives from two dimensions of the implementation process defined in Table 4. These dimensions are 'programs and projects' and 'deployment of funding', and they also enable the implementation of NBS for urban drainage. The dimensions 'action planning' and 'monitoring and evaluation' do not provide enabling mechanisms because they concern the actual implementation phase of NBS.

4.2.1. Legal instruments

Three main municipal policies, two relevant regulations, and one district greening plan support the development of NBS for urban drainage (Table 10). The "Structural Vision Amsterdam 2040" from 2011 (Gemeente Amsterdam, 2011) is the main policy for the spatial development of the city, serving as a basis for all following spatial plans. Creating a sustainable city is a core goal, and the vision states *"[An] absolute condition for the future-proofing of Amsterdam concerns intensive care for the living environment in the city. For a sustainable city, we must anticipate climate change"* (Gemeente Amsterdam, 2011, p. 8). The Vision also considers climate change and the risk of flooding serious threats that must be addressed within urban development. Additionally, the Vision shows a concern with providing high-quality green spaces to the citizens. Having greenery and water features throughout the city is considered essential, and the Vision sees urban nature as a multi-functional provider of multiple ecosystem services, as in NBS (Eggermont et al., 2015; Emilsson & Sang, 2017). A resulting action-point connecting the topics of nature and water is *"More attention to designing with water in public space for quality of life, water storage, and use."* (Gemeente Amsterdam, 2011, p. 135).

In 2020 the government launched a Green Vision for the next 30 years (Gemeente Amsterdam, 2020b), an outcome of the central role given to urban greenery and water in the city. The Vision places green as a priority for the upcoming urban development and densification, explaining how Amsterdam can increase the quantity and quality of blue and green areas. The central message of the Green Vision is to "*develop green space in the city with a focus on health, nature, climate adaptation and social well-being."*(Gemeente Amsterdam, 2020b, p. 23). Figure 11 shows the intention of creating a 'coherent green network' throughout the city. According to Brears (2018), a central characteristic of blue and green infrastructure is this 'planned network' aspect.

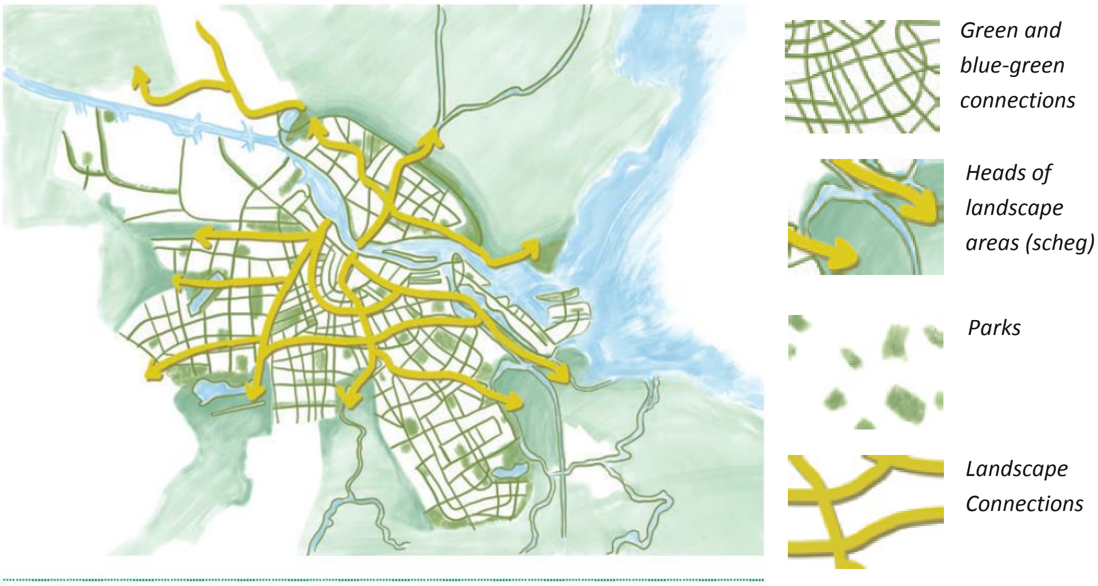


Figure 11: Vision Map for 2050 (Gemeente Amsterdam, Green Vision, 2020, p.23).

The principles and themes proposed by the Green Vision are closely related to nature-based solutions. The policy emphasizes how nature can provide ecosystem services, supporting urban cooling, flood resistance, biodiversity, leisure activities, social well-being, and more (Gemeente Amsterdam, 2020, p. 16, 26, 33). One of the four principles of the vision specifically addresses the use of nature in drainage, stating:

> ***Principle 2: We provide green that contributes to various tasks***
>
> *Where necessary, we add greenery to increase rain resistance in gardens, on roofs, along streets (in lowered plant areas), and in parks. Water retention is a way to have enough water available for plant growth during drought. During heat waves, the presence of water is crucial for evaporation and therefore cooling of the environment. A soil with a good structure and composition is also essential for this.*
>
> GREEN VISION 2020-2050: GEMEENTE AMSTERDAM, 2020, P. 33

This principle shows how the city envisions using NBS for surface drainage and all man-made water features proposed by Brears (2018) (see Table 2) are mentioned as rainproofing projects: 'green buildings systems' (in roofs), 'streets' (along streets), and 'places' (parks). The water stored in natural areas is also wanted to reduce the urban heat island effect and improve the soil, benefits of NBS. When explaining how the policy will turn into projects, a respondent explained the "Green and Healthy City" team is creating a program to start implementing projects that bring the vision to life (Respondent #4).

Furthermore, an important idea introduced by the Green Vision and mentioned in the interviews is the concept of *'green, unless'*. This idea means that *"streets and squares become green, unless other functions make this impossible, turning the vision of public space around"* (Gemeente Amsterdam, 2020b, p. 37). The respondents see this principle as the latest paradigm for the design of public spaces in Amsterdam. (Respondent #4, Respondent #5, respondent #10). Nonetheless, to implement this idea challenges as removing internal silos between departments and developing a new working mentality need to be overcome, explained a respondent from the Municipality (Respondent #4).

The third policy that enables NBS for urban drainage in the city is the Climate Adaptation Strategy from 2020. The Strategy says climate-adaptive projects must be the 'new normal', strengthening Amsterdam's ambitions to be a climate-proof city by 2050. The Strategy says that rainproof design must be embedded in urban development *"with all physical changes in the city - roof, garden, park, street, sewerage, and square - rain resistance is the standard."* (Gemeente Amsterdam, 2020a, p. 15). It also promotes the expansion of the Rainproof network and highlights the need to *"stimulating private individuals, housing corporations and companies to retain rainwater on their own property, such as softening and greening"* (2020a, p. 15).

Regarding pilot projects for urban drainage, the Strategy argues that *"To be better prepared for climate change, it is necessary to scale up and standardize existing successful (pilot) activities and to start new, innovative initiatives."* (2020, p. 4-5), similar to what propose Bulkeley (2014) and Fratzeskaki et al. (2017). The Climate Adaptation Agenda, launched in April 2021, complement the Adaptation Strategy. The Agenda is a catalog of ongoing initiatives, projects, and legislation that support climate adaptation in the city. It also proposes actions that should be implemented for flooding, heat, and drought, stating who is responsible for the action and the time frame.

During the research, I identified other plans that foster NBS in specific areas of the city, as the "Plan for a green Zuidas" (Gemeente Amsterdam, 2017). This district plan is more detailed than city-level plans, containing specific projects and the action plan for their implementation. The Green Plan (2017) gave a clear nature-focus to the different actors working in the Zuidas area, including projects of 'water retention green strips' as the one analyzed. A public designer that works in the Zuidas district team explained that the area is of national relevance and densely build. They said the district is transitioning from commercial to mixed-use, and it should become a liveable area for families, with green spaces. Finally, they explained a multi-disciplinary team of over 100 people works to develop the area and implement the Green Plan (Respondent #1).

Two regulations emerged as central enablers of NBS for urban drainage in the city, the "Puccini Method – Green Book" *(Puccinimethode - Handboek Groen)* and the new "Water Ordinance" (*Hemmelwaterverordening*). The Green Book provides the standards for designing public green areas in the city and it followed the Red Book, which lays the standards for grey (or *red*) public spaces. A designer for the public space explained that regulations do not align seamlessly among themselves, and the Puccini Red does not consider adaptation measures, for example, being inconsistent with newer regulations and hindering implementation (Respondent #5).

A project leader from Waternet who works in the Rainproof Initiative said that the Green Book influences the implementation of the rainproof principle because it determines the solutions available for the public space. They explained that if a measure (i.e. permeable pavement) is not included in the Book, it cannot be used in the public space (Respondent #2). Therefore, the Green Book systematizes the use of nature and facilitates access to knowledge, but it can be an obstacle when the rules do not represent the best solution available for urban greening.

Finally, most interviewees considered the newly passed Water Ordinance (*Hemmelwaterverordening*) an important regulation that changes the dynamics of rainwater drainage in the city, particularly in the private sphere. The law, from 2021, *"regulates an obligation for new buildings, and for existing buildings that are* *radically renovated, to store at least 60 liters of rainwater per m² and to store this rainwater over the following 60 hours to drain."* (Amsterdam Rainproof, 2021b).

Respondents from Waternet and MetroPolder explained that the new Water Ordinance influences the demand for blue-green roofs because it makes building owners responsible for processing rainwater that falls on their plots. They also explained how the Water Ordinance derived from a *scaling-up* process, caused by the embedding of existing solutions into regulation, and a *scaling deep* process emerged from a change in mentality around rainwater and the need of mainstreaming climate adaptation. (Respondent #3, Respondent #7, Respondent #10). One respondent added that the law reduces the pressure on the underground drainage system and transfers part of the drainage responsibility to users, creating awareness of flooding risks (Respondent #10).

Considering the legal mechanisms that support NBS development in the city, I asked a designer of the public space if they perceive any resistance to developing NBS at the Municipality. They explained that among the designers there is not much resistance, but perhaps a lack of information or knowledge on the topic, a problem also identified by Frantzeskaki et al. (2020) and Kabisch et al. (2016). Moreover, they said that the interest in NBS is changing and new generations are more open to it. Finally, they explain some colleagues are more enthusiastic and open to experimenting with new solutions, influencing others. (Respondent #5). Wamsler et al. (2020) argue that 'individual champions' are largely responsible for NBS implementation when mainstreaming mechanisms are not available, but it seems they also play an important role inside large organizations, where not all employees are as enthusiasts about sustainability transformations, and the champions pave the way ahead.

4.2.2. Programs and projects

An extreme rainfall event in Copenhagen in 2013, alerted Amsterdam for increased flooding risks. As a response, Waternet in collaboration with the Gemeente Amsterdam launched the Amsterdam Rainproof Initiative in 2014 (Amsterdam Rainproof, 2018; Respondent #2). The initiative is an 'independent brand', despite being managed by public organizations, this reduces resistance and makes it more flexible to dialogue with all actors in the city (Amsterdam Rainproof, 2018; Respondent #2). Amsterdam Rainproof mapped rainwater bottlenecks in the city, identifying priority areas and needed actions (Figure 12). It also supports projects that solve these bottlenecks, and since its start, it has contributed to the implementation of numerous projects in public and private areas. For that, a broad range of actors from the public and private spheres work in close collaboration, through a network approach (Gemeente Amsterdam, 2020; Respondent #2, Respondent #3, Respondent #5).

Amsterdam Rainproof is a knowledge hub that makes good solutions visible, sparking innovation in the city (and beyond) and amplifying out NBS drainage projects and other solutions (Gemeente Amsterdam, 2020; Respondent #1, Respondent #2, Respondent #10). The initiative promotes NBS to create the sponge effect, sharing a broad range of NBS projects in their online 'measures toolbox'. A designer for the public space explained the Rainproof platform helps them to browse existing projects in the city and find good ideas to *replicate*. It also helps citizens to learn what can be done in their plots, increasing permeability and resilience (Respondent #1). A project leader at Waternet believes the initiative also emphasizes the importance of green infrastructure in the city*, scaling* NBS *deep* (Respondent #2).

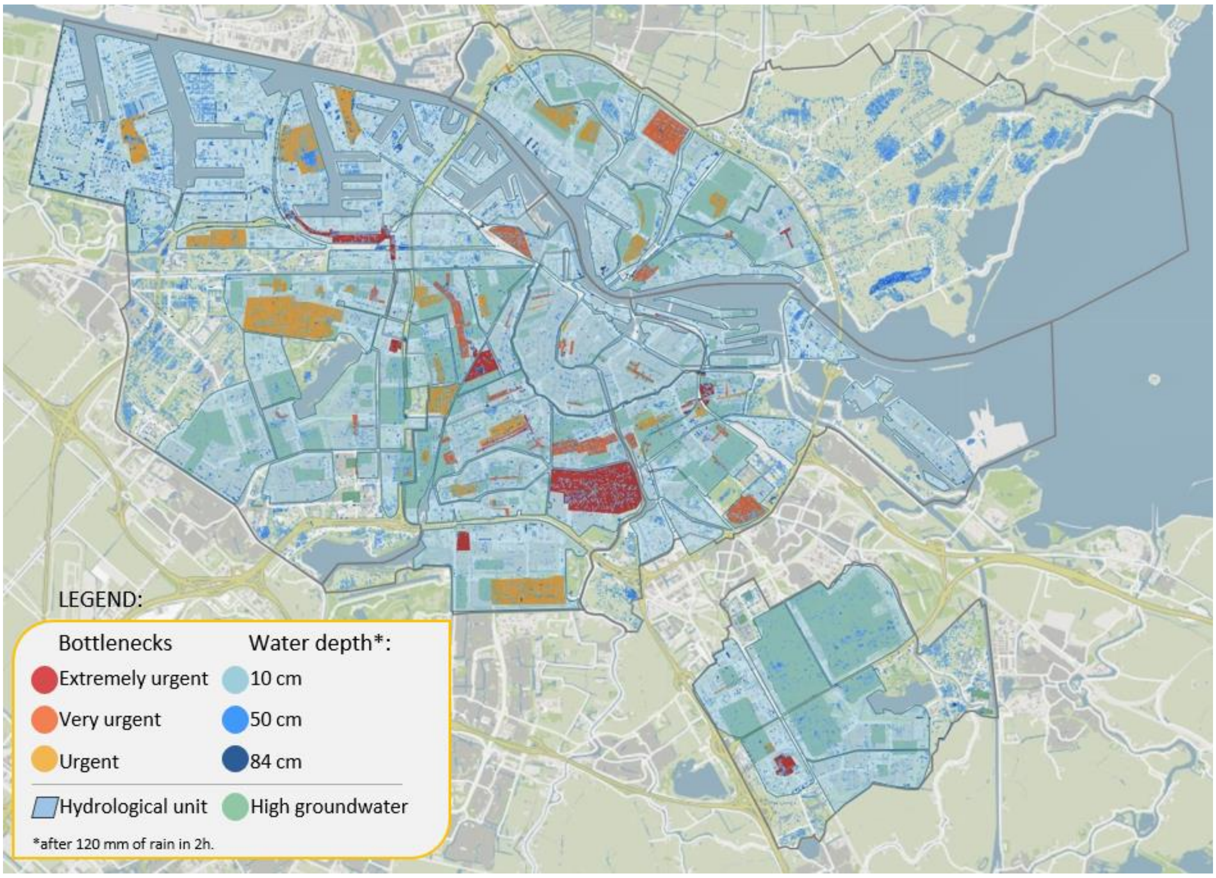


Figure 12: Amsterdam Rainproof bottlenecks map (Municipality of Amsterdam, 2021).

Most interviewees considered that Amsterdam Rainproof amplifies the implementation of NBS *within, out, and beyond*. This emerged, for example, when the enabling, supporting, and coordinating role of the initiative was mentioned. Amsterdam Rainproof also participated in the two analyzed projects. When talking about the green strip at Prinses Irenestraat, a respondent explained how the project helped to *scale up* and *deep* the rainproof principle, embedding it into new drainage plans:

> *"In the start, everyone said, "Rainproof, ah, it won't be necessary, it won't happen, it will cost too much, there won't be enough space" and all the clichés. We had to do it and let people see it can work, how it looks... It looks amazing, at least it looks better than it was. I won't say this is "THE solution", but "a solution". In almost every project we are working on now, there is always the question "what are we going to do about the Rainproof?" Six years ago that wasn't the case. I think in the last two years...Eventually [Rainproof] is now embedded in every project, always the question "Are there any Rainproof measures necessary?" will be raised."*

RESPONDENT #10: SEWERAGE SPECIALIST, WATERNET, 2021

Making rainproof a standard for urban development is still a challenge, as explained by a member of the initiative from Waternet. The management of the combined gray and green infrastructure system by Waternet and the Municipality is not optimal. The interviewees think that is because the two separate organizations collaborate but are not one team, creating a barrier to further *scaling up* the rainproof principle in the local urban planning activities (Respondent #2). Two respondents added to that, arguing that collaboration between departments and institutions is still lacking. (Respondent #2, Respondent #3).

The project RESILIO was initiated in 2018 aiming at implementing 10.000m^2 of smart blue-green roofs in Amsterdam (Respondent #3). The project was developed in a partnership between Waternet, the Municipality, research institutions, housing corporations, and private companies (Resilio Journal N°1, Kapetas, 2020). Blue roofs add a water-storage layer under a green roof. The smart component allows holding the water and releasing it into the drainage system when necessary, through automation (Respondent #7). The water in the roof is used as a thermal insulator for the building, to irrigate vegetation, and for evaporation reducing urban heating (Kapetas, 2020, Respondent #7).

The EU program "Urban Innovative Actions" (UIA) - the urban lab of the European Union - awarded 4.8 million Euros for research, pilots, and subsidies of this new experimental drainage solution in the city (Kapetas, 2020). The respondents considered this funding paramount to *stabilize* and *grow* the innovative project of blue-green roofs in the city, which already existed before RESILIO but lacked resources to amplify implementation (Respondent #3, Respondent #4, Respondent #7). The blue-green roofs implemented through RESILIO are on top of private property, and a large share of them are planned on top of social housing buildings owned by the housing corporations that helped set up the project. Yet, the public administration has a stake in their implementation, as it alleviates rainwater runoff into the public sewerage system (Respondent #3, Respondent #4, Respondent #7). The timeframe of the project was initially three years, but, because of delays, it has been extended another 6 months, until 2022 (Kapetas, 2021). When I asked a project member of RESILIO if the target would be met at the end of the period, they replied that the target is not the main concern but amplifying the solution of smart blue-green roofs:

> *"To me, the 10.000m2 is not relevant. It is about the implementation of the DSS (decision support system), to create awareness about blue-green roofs, a climate-adaptive solution on the roof landscape, it's so much more. (…) We are not there yet, I guess we will overshoot a bit because although the housing corporations are slowing down and having difficulties realizing the roofs, the private subsidiary scheme we developed is going much better. (…) And personally, I don't care too much if it will be 10.000 precisely, a little bit less, or much more, which I think will eventually turn out. It's about stepping up. It is part of the whole scaling up the program because we won't stop if we are finished, we go further."*
>
> RESPONDENT #3: ADVISOR FOR CLIMATE ADAPTATION, WATERNET, 2021

The Zuidas Green Business Club (GBC Zuidas) started in 2011 as an independent foundation, by ABN-AMRO, ORAM, Zuidas (Municipality), and others. Now, more than 55 members work together to bring sustainable projects to life, achieving concrete results in the Zuidas district. The members operate in the area and have the joint ambition of making Zuidas the most sustainable and liveable living and working area in the Netherlands (GBC Zuidas, 2021b). GBC Zuidas, through their 'Water & Green' group, was one of the main partners in the development and implementation of the first Polder Roof ever made, the Polderdak Zuidas on top of the "Old School", together with Waternet and Amsterdam (GBC, 2020). In section 4.3.2 the Polderdak project is analyzed, demonstrating how public-private partnerships like GBC Zuidas enable the implementation of NBS.

In 2021, the initiative launched its Ambition Statement for 2021-2025 and the most significant goal in the Water theme is to install by 2025 at least 25,000 m2 of water-storing green roofs on top of local buildings (GBC Zuidas, 2021a). A respondent from Waternet, who is also a member of the GBC Zuidas, explained how the organization supports the amplification of NBS. According to them, the organization embraces the NBS philosophy to create a new roofscape in the area, becoming part of a broader NBS community in the city. Hence, GBC Zuidas helps *to stabilize* and *grow* sustainable initiatives, while creating spin-offs to other domains of urban development (Respondent #3).

4.2.3. Funding and resources

The last enabling mechanisms belong to the 'deployment of funding' dimension, verified by 'designated funding, subsidies, and partnerships that increase resources to implement NBS' (Table 4). All three indicators were verified in Amsterdam, and are briefly explained below.

Subsidies are the most important financial mechanism enabling private NBS implementation in the city. Two similar subsidies exist; one for green roofs and another for blue-green roofs. The subsidy for green roofs is an ongoing scheme started in 2010 that subsidies up to 50% of new private green roofs to a maximum of €50,000 (Gemeente Amsterdam, 2021c). In contrast, the blue-green roof scheme is time-bounded to the duration of RESILIO, as the funding for this subsidy is connected to the EU financing project. This subsidy covers up to 75% of eligible costs of polder-roof projects, to a maximum of €150.000, and has stricter guidelines than green roofs (Gemeente Amsterdam, 2021c).

Most respondents considered the subsidies an efficient tool to amplify NBS projects. Two respondents commented that blue-green roofs' subsidy should continue after RESILIO finishes, being embedded in the city regulations (an example of stabilizing). This is an outcome of RESILIO's success and the desire to continue amplifying within and out the polder roof system, building climate adaptation (Respondent #3, Respondent #4).

The policies analyzed in section 4.2.1 indicate how the projects they propose can be funded. For example, the Green Vision proposes to 'set up a city-wide investment program for the development and management of green spaces'. The Vision also states that 'structural financing' should be found for the development, management, and maintenance of urban nature. Furthermore, it affirms that if resources remain the same not all ambitions of the Vision can be realized. The Green Vision and other policies state that a dedicated budget is needed to develop green and rainproof projects, and the city gives some guidelines on where the needed resources will come from. The Climate Adaptation Agenda also provides insights into how adaptation projects are being funded, and how the municipality allocates the available budget. For example, the Agenda states that 10% of Amsterdam's annual maintenance budget for public space and landscaping is used to test and implement innovative solutions within maintenance to make the city resistant to climate change (Gemeente Amsterdam, 2021d). Furthermore, it says that, as new data on the costs of climate adaptation is generated, extra funding will be requested from the city conservation fund. The budget is also expected to originate from national programs such as the National Delta Fund and internationally from various European subsidy schemes. Finally, the Adaptation Agenda says that the costs of climate-proofing the city are also expected to have financial consequences for residents, businesses, and other stakeholders, evincing the role of private actors in amplifying NBS for urban drainage change (Gemeente Amsterdam, 2021d). A remark made by the municipality in the Agenda shows the attempt of *scaling deep* a new perspective on rainwater management that results from climate change needs, saying that *"The costs of making and keeping our city climate-adaptive are high. They will only increase in the coming years. On the other hand, the costs of damage that arise if we do nothing will be many times higher."* change (Gemeente Amsterdam, 2021d, p. 54). This perspective positions NBS as necessary, despite the costs they may have, arguing that not using them will have an even higher cost.

Partnerships are also activated in the city to increase resources for the implementation of NBS projects, especially in private plots. As private parties want to invest in sustainable projects (i.e. GBC Zuidas) or innovative ideas (i.e. Polder Roof System), they look for municipal sponsorship and make connections with other partners that can bring in resources for NBS implementation. The case of blue-green roofs in the city is a good example of how different actors (i.e. Municipality, housing corporations, and research institutes) benefit from partnerships to optimize and speed up the implementation of NBS projects.

Mechanisms that enable NBS implementation:			
Type:	Name:	Scale:	How does it enable NBS for urban drainage:
Legal instruments	Sewerage Plan 2016-2021 (2015)	City-level	**Indirectly**. *Propose a sponge effect and rainproofing the city.*
	Structural Vision 2040 (2011)	City-level	**Directly**. *Prioritize urban water and greenery for the sustainable development of the city.*
	Green Vision 2020-2050 (2020)	City-level	**Directly**. *Promotes NBS in the city and recommends using nature to reduce risks of flooding.*
	Climate Adaptation Strategy (2020) and Climate Adaptation Agenda (2021)	City-level	**Directly**. *Sets the goal of a climate-proof Amsterdam by 2050.*
	Plan for a green Zuidas (2017)	District-level	**Directly**. *Includes specific NBS projects for the Zuidas area.*
	Puccini Method – Green Book	City-level	**Directly**. *Guidelines for green areas in the public space.*
	Water Ordinance – *"Hemmelwaterver-ordening"* (2021)	City-level	**Indirectly**. *Requires new private buildings to store water.*
Programs and Projects	Amsterdam Rainproof Initiative	City-level	**Directly**. *Manages a network of actors, provides knowledge, and makes connections to foster the implementation of rainproof projects.*
	RESILIO	City-level	**Directly**. *Aims at implementing 10.000m2 of smart blue-green roofs in Amsterdam.*
	Green Business Club Zuidas (GBC Zuidas)	District-level	**Indirectly**. *Aims at implementing sustainable projects in the Zuidas district.*
Funding and Resources	Green and blue-green roofs subsidy	City-level	**Directly**. *The subsidy is a direct enabler of NBS for urban drainage.*
	Policies financing schemes	City-level	**Directly**. *Financing schemes proposed by policies are an enabler of NBS implementation.*
	Partnerships	City and District levels	**Directly**. *Public-private partnerships are indispensable for the implementation of many NBS projects in the city.*

Table 10: Mechanisms that enable NBS implementation.

4.3. Existing NBS for Urban Drainage in Amsterdam

Existing projects demonstrate how the mechanisms just explained result in the implementation of NBS. The Methodology chapter explains how and why the two cases analyzed in this section were selected. Both projects are in the Zuidas district, an important business center in the Netherlands and an increasingly dense residential area (Amsterdam Rainproof, 2018; Respondent #1). The implementation of large-scale sustainable projects in the area is the work of many partners, as the Zuidas team and GBC Zuidas. The Green Plan for Zuidas also drives NBS implementation in the area. This research reveals why urban experiments with NBS were chosen instead of a traditional approach for the selected cases and how their implementation unfolded. In this section, following a brief description of each project, I analyze their implementation process regarding the dimensions of implementation and their indicators proposed in Table 4. Table 11 provides a summary of which indicators were verified for each dimension (section 4.3.3).

4.3.1. Water-retarding Green Strip – Prinses Irenestraat

The 'water-retarding green strip' at Prinses Irenestraat is a 'stormwater planter' (Brears, 2018), consisting of a green ditch that temporarily stores rainwater, absorbing it into the soil through drainage layers of sand and gravel. An overflowing system drains excess rainwater into the street sewerage (Figure 13) (Moerkamp, 2019). This NBS project is a designed new ecosystem with a high level of engineering, belonging to the 'type 3' of NBS proposed by Eggermont et al. (2015) (Figure 2). In the Netherlands, this type of solution is often called an *(urban)-wadi* (bioswale), and the term was used interchangeably with 'green strip' by the interviewees and from here on. This drainage component retains and absorbs up to 95 m^3 of rainwater locally and, having appropriate plants, provides a range of ecosystem services, such as urban cooling and habitat for insects (Moerkamp, 2019). This project was the second of its type in the city, following a smaller pilot implemented in Zuidelijk Wandelweg (Respondent #1, Respondent #3, Respondent #10). Its first phase was completed in June 2019 being 100m long and 7m wide. When fully finished in 2024, the green strip will be 500m long (Moerkamp, 2019; Respondent #3).

Figure 13: Project sign of the Green Strip at Prinses Irenestraat (Zuidas and Amsterdam Rainproof).

a. Programs and projects

A public designer who worked on the project said an NBS was selected for *"sustainability, greenery, ecological reasons, rainwater, and to make the city rain-proof"*. They also confirmed that Amsterdam Rainproof supported and gave visibility to the project (Moerkamp, 2019; Respondent #1, Respondent #3). An employee from Waternet who works at the Rainproof initiative explained the decisions about this project were a 'matchmaking' between the underground sewerage team from Waternet and the Zuidas designers. Additionally, he explained that they helped to develop this drainage component, which he calls a 'technical wadi', and he sees it as part of a 'beautiful and functional system in the making' (Respondent #3). The head designer and landscape architect Ton Muller explained the motivation for the project, highlighting its multifunctionality:

> *"The Prinses Irenestraat forms an important green link between the Schinkel area in the west and the Amstel area in the east. At the same time, the street on the south side forms the entrance to Zuidas and on the east side the entrance to Beatrix Park. We want to accentuate those connections through greening. But there is another reason: we are creating a zone that contributes to making Zuidas "rainproof", an important municipal ambition. With the green strip, we kill several birds with one stone: we create high-quality greenery in a very metropolitan area, we increase the amenity value, we offer a habitat for plants and animals and we contribute to the water-resistance of Zuidas."*
>
> TON MULLER, IN VAKBLAD GROEN (MOERKAMP, 2019)

Furthermore, the 'Vision Zuidas 2030' includes the development of a 'green border' to mark the division of two districts at the Prinses Irenestraat. This Vision gives a direction for planners and designers working on Zuidas and influenced the development of the water-retarding green strip (Moerkamp, 2019). Finally, the Plan for a Green Zuidas (2017) promoted this as one of three exemplary integral design projects to be implemented in the District.

In terms of solving a clear urban problem through NBS implementation, interviews revealed a rainwater bottleneck was identified in the area in simulations run by Waternet and Amsterdam Rainproof. Moreover, the area has flooded before, damaging homes and temporarily closing the nearby train station (Moerkamp, 2019; Respondent #1). Furthermore, with the major transformations planned at the Zuidas Station area, local drainage became an eminent problem. Hence, this NBS emerged as a solution to alleviate the excessive rainwater runoff in this location (Respondent #10). The project was built upon the first water-infiltration strip piloted in the Zuidelijk Wandelweg but it covers a larger area than the former, displaying more types of vegetation. A respondent said the concern with extreme rainfall and the *deep scaling* of rainproof values influenced the implementation of this NBS, demonstrating the activation of amplification processes (Respondent #1).

A sewerage specialist from Waternet explained this NBS was conceived as a 'problem-solving technique' (Nesshöver et al., 2017) to address the limitations of the traditional infrastructure of the 'Zuidasdok' project. According to them, this project will place a section of the highway that cuts the area underground, increasing the need for drainage capacity. They also explained this engineering challenge could not be solved solely with underground infrastructure. So, the idea to create a hybrid system using multifunctional green infrastructure emerged, and it was coupled with the desire to improve urban greenery in the area (Respondent #10). In conclusion, the implementation of the green strip derives from the aim to reduce the local rainwater bottleneck together with a program that fosters NBS and urban projects for greening the area.

b. Deployment of funding

The Prinses Irenestraat received funding from a ten-million euros budget made available in 2018 by the city council to implement the Plan for a Green Zuidas. The plan aimed at developing quality greenery in the District and focused on multifunctional projects that are 'valuable for people, plants and animals' (Moerkamp, 2019). The project is a public work and was financed and implemented by the municipality, partnerships were not used to increase resources for implementation. One respondent from Waternet explained that in the early projects of green infrastructure, Waternet financially contributed to the Municipality, as the city had no budget for such projects at the time (Respondent #10). It is not clear if the Prinses Irenestraat received support from Waternet, considering the municipal budget mentioned earlier for the Green Zuidas.

Another important funding aspect of urban projects is maintenance costs. This is especially important for NBS, which requires regular maintenance of the plants and other natural elements to keep delivering the planned ecosystem services. When asked if the maintenance costs of the green strip were accounted for, the designer from the municipality explained that every phase of the project is checked together with the Maintenance Department (Verkeer and Openbareruimte) who needs to assess its feasibility and give the green light for the project to go through. Additionally, the costs of green projects do not stop prevent their implementation, but rather make the designers look for better solutions that require last maintenance. As an example, grass fields need to be mowed every two weeks, while the green strip need to be cleaned and repaired around four times a year (Respondent #1)

Figure 14: 3D of the green strip project (Amsterdam Zuidas).

Figure 15: Project under construction January 2019 (Marcel Steinbach).

Figure 16: Completed project (Amsterdam Rainproof).

c. Action planning

In the action planning phase plans and designs are turned into projects on the ground. I identified four indicators for this dimension, but the most important one is 'the action plan is executed and completed', representing the actual implementation of the project.

The 'programs and projects' dimension was fulfilled by the decision to use green infrastructure to strengthen the drainage network of the area. The reasons for using this drainage component were twofold. First, the solution was copied from a pilot project implemented in the vicinities in 2016. Since then, there was a desire to grow that solution, creating a model for the rest of the city (Respondent #1, Respondent #3, Respondent #10). Second, the solution was considered the most adequate for this location, given its small size and urban character, fitting with the business character of Zuidas (Figure 14) (Respondent #1).

When asked about what other projects inspired this type of solution, a sewerage specialist from Waternet told that:

"This solution is general knowledge, but they did it in Copenhagen, also in Portland in the US... and we were looking for possible solutions. In Rotterdam, there was also a big Water Square, (Benthemplein) and that was one alternative. But it needs a lot of space and I think it's hot and maybe ugly. We were looking for some small solutions, we don't have so much space. I think we just find it on the Internet, maybe it's a little bit easy (laughing)."

RESPONDENT #10: SEWERAGE SPECIALIST, WATERNET, 2021

For the indicator 'partnerships for the implementation', the project development was a partnership between the Municipality Zuidas planning team and Waternet, which combined their expertise to develop this project (Respondent #1, Respondent #10). As previously explained, the shift of responsibilities for urban drainage from Waternet to the municipality is recent, and knowledge collaboration is needed. Besides, an external company was used for consultancy about the groundwater level and the constructors were hired through a tender process (Respondent #1).

Finally, two indicators are coupled together, 'an action plan lay the steps to complete the project' and 'the action plan is executed and completed'. The first one was implicit in the articles and interviews that talked about the project. An action plan is a normal document in any urban project, and especially in such an experimental project, it was essential. The drawing at the beginning of this section (Figure 13) was shared by one of the interviewees and shows the project technical plan. Regarding execution and completion, the project has two stages. The first phase of the project (100m) was successfully built and completed in 2019 (Figure 15 and Figure 16). However, the full plan is 500m and the next phases are not started yet. Nonetheless, the interviewees were certain that the rest will be implemented, as it is part of the Zuidas Green Plan and the first phase is a successful, exemplary project.

d. Monitoring and evaluating

The monitoring and performance evaluation of the project was briefly discussed in the interviews. A respondent explained how the monitoring of the first pilot led to adjustments in this second project:

"In the beginning, in the other project (Zuidelijk Wandelweg), we had the idea that the ground would be a very wet soil all year, so we really had to find plants that were swamp or wet resistant, but now we know that is exactly the opposite, you need plants that are resistant to very dry soil. (…) This is a shadow area, and not all plants can grow well in the shadow, so that was also a puzzle you cannot have too many flowers, but we try to make it colorful in every season"

RESPONDENT #1: SENIOR DESIGNER, MUNICIPALITY AMSTERDAM, 2021

It is not clear if this project underwent any water stress test, but one respondent mentioned such test was done for similar projects recently implemented in the city. When asked if the urban wadi is now a diffused solution in Amsterdam, they said this NBS is indeed normal now, but in the beginning, it was an experiment with surface drainage. Furthermore, they added the best-monitored wadi is in Betondorp (in the Watergraafsmeer, Amsterdam East) and its drainage performance is excellent. (Respondent #10).

The assessment and report of the project's benefits have two sides. On one hand, the drainage benefits were promoted beforehand, to create awareness and enthusiasm about it (Amsterdam Zuidas, 2019; Gemeente Amsterdam, 2017; Moerkamp, 2019). The finished project was shared in websites and magazines, becoming a model for the rest of the city and even other cities, who reached Amsterdam to learn more about it, activating *transferring* processes (Respondent #1, Respondent #10). On the other hand, no information was found about the post-assessment of the completed project. One respondent mentioned that the drainage purpose of the project was fulfilled but did not give details on how effective it is (Respondent #1). The outcome of the other benefits (ES) expected to be provided by the project is not mentioned anywhere.

The reflection on the project process and adjustments for future ones were verified in this project, activating *growing* mechanisms. Because of its novelty, many lessons were drawn from it (Respondent #1, Respondent #10). A respondent said knowledge on soil and plants that improve the drainage obtained with the two experimental projects in Zuidas led to the growth of this solution throughout the city. They understand that the technique for this NBS is now known, although there is uncertainty on how it will look in 10 years. Furthermore, four neighborhoods that will be renovated within 10 years in the area 'Middenmeer Noord' will receive one or two new urban wadis like this. (Respondent #10)

4.3.2. Polder Roof System

The Polderdak is the first Polder Roof ever made (Stolp, 2015). The innovative pilot experiment was implemented in 2013 to test the capabilities of this micro water management system, a solution for rainwater storage and controlled flow release (Figure 17) (NATURVATION, 2020). The Polderdak was implemented on the roof of the Old School building in Zuidas district used as a business incubator. In an unusual process the whole system, including its vegetation, was moved to the roof of the Food Bank building in 2019, to spare the roof from renovations done at the Old School. The original Polderdak had 1200 m^2 and a minimum water-storage capacity of 84 m^3 (Stolp, 2015). The Polder Roofs is a smart blue-green component and it is a completely demountable system made of crates that store water under a sedum layer (Figure 18). Therefore it is possible to grow crops on top of the system, combine them with solar panels, make recreational spaces, provide habitats for insects and other small animals, reduce the thermal load on the building, and other ecosystem services characteristics of blue-green NBS (NATURVATION, 2020). Hence, this project is also a 'type 3' of NBS, for the same reasons as Prinses Irenestraat (4.3.1.). The RESILIO program, an EU-funded program to implement 10.000m^2 of smart blue-green roofs in the city using the same technology as the pioneer Polderdak derived from this innovation (Kapetas, 2020). When researching the Polderdak project, most interviewees made direct connections between the Polderdak and RESILIO, which is considered a model program to increase rainwater storage in the city. Therefore, the Polderdak and RESILIO are discussed in this analysis, as representatives of the Polder Roof System.

Figure 17: Green roof with Polder Roof (MetroPolder).

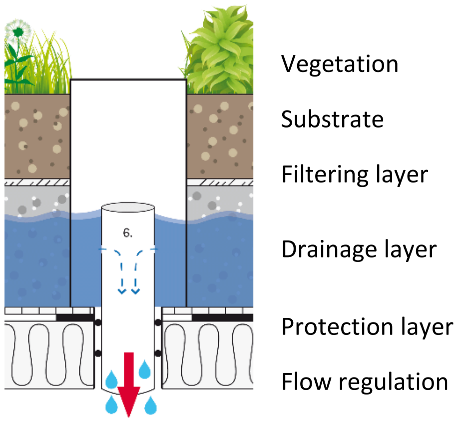


Figure 18: Schematic section of Polder Roof (Optigroen).

a. Programs and projects

The first Polder Roof is an innovative automated micro water management system. The project came out before Amsterdam Rainproof, and it was the product of a partnership between the GBC Zuidas, Amsterdam Zuidas (Municipality), Waternet, and the company De Dakdokters, who invented the system (Kapetas, 2020; Respondent #3, Respondent #6, Respondent #7). As a pioneer, the Polderdak started a new initiative in the city, developing the micro water management approach on roofs to address downpours and sewerage overload.

The Polder Roof originated from dialogues between Waternet and Dakdokters, who had the ambition to make green roofs also 'blue', contributing to climate adaptation (Respondent #3). Waternet then provided rainwater-capacity indicators to configure the 'blue roof', to which Dakdokters presented the simple idea of storing the water in crates under a green roof. The enthusiasm with this solution made Waternet add it to its research program on micro water management, developing the control valve system, activating *growing* mechanisms. Finally, since the project was invented in 2013 many work lines and people were attracted to the philosophy of micro water management on blue-green roofs, *stabilizing* it (Respondent #3).

Following the success of this innovation, the company Dakdokters split into two and while the new company MetroPolder owns and develops the technology, the Dakdokters remains the projects' developer, another indication of the *growing* process. Both companies belong to the same owners, working in close collaboration (Respondent #6, Respondent #7). A project manager at MetroPolder explained that when the system was created in 2013, no one had a use for it yet. But, the excitement with the idea led to new projects, *stabilizing* the innovation. Later, Waternet started looking into ways to *scale up* the solution to make it a requirement in new building developments, increasing its impact in the city (Respondent #7).

Regarding the role of partnerships, a synergy between actors enabled the first polder roof. Besides the commercial interests of Dakdokters, Amsterdam wanted to be a front-runner in green technologies and water management, showcasing what is possible in the field (Respondent #7), and GBC Zuidas was looking for projects to support (Respondent #3). The technical success of the pilot project and the support of strategic actors (especially Waternet) made the system gain momentum, *stabilizing*, and pushed the submission of the RESILIO program, *growing* the initiative (Respondent #7). A respondent explained how RESILIO amplifies the polder roof solution in the city, activating the *stabilizing* and *growing* mechanisms:

> *"The RESILIO Project is a collaboration of different companies and the city of Amsterdam on how we could scale up polder roofs, or blue-green roofs, and what could their impact be. So if you tailor blue-green roofs to a specific neighborhood for flood buffering, or heat buffering, or water reuse, can you create a benefit with multiple roofs instead of an individual roof in a building? It's a case study of expanding the roofs within the city."*
>
> RESPONDENT #7: PROJECT MANAGER, METROPOLDER, 2021

In conclusion, this NBS derived from a search for alternatives to expand green-roof systems, store rainwater, and alleviate the sewerage system. The solution was invented by a private company, but it originated from connections with Waternet to improve the water retention capacity of green roofs. Finally, public and private parties were engaged in the implementation process, establishing lasting partnerships that led to a new program at the city level that enables the implementation of this NBS.

b. Deployment of funding

As the Polderdak was the first polder roof, there was no existing funding or subsidies for it. However, Waternet was willing to invest in testing this new solution, considering its benefits for the urban drainage. Who paid for each part of the project was not mentioned in the interviews, but the Urban Nature Atlas states that its financing came from the 'public local authority's budget' and non-financial contributions were unknown (NATURVATION, 2020). Regarding subsidies, it is remarkable that the micro water management system introduced by the Polderdak led to the creation of a subsidy scheme for smart blue-green roofs (RESILIO), *stabilizing*, *speeding up,* and *growing* the solution (Kapetas, 2020). A respondent from MetroPolder (which invented the system) explains that RESILIO goes beyond the polder roof system itself, focusing on the 'smart' component of blue-green roofs and the controlled-flow release. They added that a developer can use the water-storage system they want, including the polder roof, but this is not a requirement of the program (Respondent #7).

In terms of partnerships to increase implementation resources, this project was the collaboration of many parties, as explained in the 'programs and projects' section. RESILIO in turn is a larger program, with partners from different areas, such as research institutes and housing corporations (Table 11). These actors have different stakes in the project, but a shared desire of creating a new *roofscape* in the city that contributes to micro water management, reduction of flood risks, and climate adaptation (Kapetas, 2020; Respondent #3, Respondent #7). One of the biggest challenges to the uptake of the system mentioned in the interviews is to create a compelling business case. A respondent explained how the challenge of assessing the 'soft' values of NBS hinders investments in such a project:

> *"So the transformation of the existing roof landscape is a challenge, but doable, although the discussions about the business case keep going on. In the end, who's going to pay for it? (…) we have to find means to value the soft values of these developments because that's always the challenge, what are the gains? Well, like in a lot of nature-based solutions, a lot of the gains are not easily quantifiable in Euros but can be done. (…) it's more about finding the guts to put the soft values into policy, into a societal challenge that we have to face and not the fight 'who's going to pay for it? What's going to bring me and how am I going to benefit from it?' This is a very traditional classic neo-liberal individual approach. If it doesn't do anything for me, I'm not going to pay for it."*

RESPONDENT #3: ADVISOR FOR CLIMATE ADAPTATION, WATERNET, 2021

c. Action planning

The decision to use roofs in urban drainage was largely influenced by the Daktokters, who initiated the project. The company had experience in green roofs and developed the 'crate and valve system' that makes the polder system. In RESILIO, an important partnership was established between the program and housing corporations so that 80% of the new roofs would be on top of social housing buildings (Respondent #3). This is a good strategy to increase awareness on NBS and amplify implementation (*stabilizing*), as explained by one respondent:

> *"A project like RESILIO helps the housing corporations to think 'oh, yeah, green is also very important and it can also be a solution for the energy transition'. Or, they realize that you can combine the green roof and solar panels. I think it was very good to work with the social housing corporations to get them involved with greening the city, instead of only putting solar panels on the roofs."*

RESPONDENT #4: POLICY ADVISOR, MUNICIPALITY AMSTERDAM, 2021

The implementation of the Polderdak was completed twice: at its original location on top of the Old School and at its new location on top of the Food Bank. Both times, implementation was conducted by the Dakdokters. For RESILIO, the implementation is ongoing, as the total amount of blue-green roofs is the sum of many individual projects. Regarding the projects with housing corporations, the RESILIO report says:

"The procurement of most roofs has been successfully completed, the construction of 5 out of the 8 roofs has started, and one has already been completed. Some technical challenges have surfaced but the project is developing contingency plans to resolve them. The engagement plan has been executed and amended accordingly to deal with corona-related restrictions. Scientific observations point to the expected results, although longer observation records are needed. Finally, a Cost-Benefit Analysis is being developed to support the business case for upscaling; moreover, possible business and governance models are being explored."

RESILIO JOURNAL N^{O}2, FEBRUARY 2021 (KAPETAS, 2021)

Moreover, the part of the program targeting private users has subsidized the construction of 2.000m2 of private smart blue-green roofs in the city so far (Respondent #3, Kapetas, 2021).

d. Monitoring and evaluating

The monitoring and performance evaluation of innovative solutions as the Polderdak is essential to demonstrate if its objectives were achieved and what can be improved. The pilot of the Polderdak led to ongoing studies and research on the performance and capabilities of blue-green roofs, amplifying the solution through *growing* (Kapetas, 2021). The volume of rainwater stored, the plants and species that can grow on top, the insulation capability, the combination with other technologies like solar panels, and more are some aspects being studied for *growing* the impact of blue-green roofs, by the Project Smartroof 2.0 for example. Furthermore, the costs and business case are also under research, as seen in the citation above from the Resilio Journal N^{o}2. Because RESILIO is financed by the EU (Urban Innovative Actions) monitoring and evaluation are mandatory requisites of the project and are being conducted by the parties involved (Kapetas, 2020; Respondent #4). Regarding the indicator 'assessment and report of project benefits', this step is very important for the dissemination and acceptance of this new drainage system (Respondent #7). RESILIO aims to report back to other Dutch and European cities about the experiences in Amsterdam, sharing knowledge and opening space for the consolidation of this NBS for micro water management, which activates the *transferring* and *replicating* mechanisms (Respondent #3, Respondent #4, Respondent #7). A respondent involved with RESILIO explained that *transferring* this knowledge can also be challenging, as other cities need to learn and adapt the solutions to their own context:

"One of the challenges in RESILIO is the dissemination of the developed knowledge. We are also working, for instance, to share our findings with other European cities during Amsterdam International Water Week, so they can address, or fight their challenge for themselves. Everybody understands the principle of blue-green solutions, nature-based solutions. And we hope we can convince them that the decision support system (DSS) with micro water management underneath can enhance the quality of these systems."

RESPONDENT #3: ADVISOR FOR CLIMATE ADAPTATION, WATERNET, 2021

Reflecting on the implementation process of this NBS to adjust the solution for future projects is essential for its success. As with other innovations, amplification is an iterative process, and every new project creates learning opportunities. A respondent, reflecting on the learning curve of this system, said that creating a pilot is easy but the challenge is its *stabilization* (Respondent #3). Lastly, a respondent from MetroPolder said the company is already looking ahead into the next generation of polder roofs, how to expand its functionalities, capacity, and contribution to cities, by for example providing drinking water from rainwater (Respondent #7).

4.3.3. Overview of the implementation process: Green Strip and Polder Roof System

Implementation process: Green strip and Polder Roof System			
	Indicator	**How it was verified for the green strip at Prinses Irenestraat**	**How it was verified for the Polder Roof System – Polderdak and RESILIO**
Programs and projects	Initiatives and programs promote NBS in the city:	• *Amsterdam Rainproof Initiative;* • *Vision Zuidas 2030;* • *Plan for a Green Zuidas (2017);*	• *Polderdak: Innovative project, not part of an existing program;* • *RESILIO: resulted from the success of the Polderdak (scaled up this NBS);*
	NBS is a solution for a clear problem or opportunity:	• *Rainwater bottleneck in the area and flood events;* • *Zuidasdok project;* • *Construction of a new building;*	• *Increased rainfall and flooding risks led to this innovation;* • *The company that invented the system already worked with green roofs;*
Deployment of funding	Funding designated for NBS implementation:	• *€10 million for the Green Zuidas plan;*	• *Polderdak: funded by the local authority;* • *RESILIO: funded by the EU (4.8 million Euros);*
	Subsidies for NBS implementation:	• *Not identified;*	• *Not identified for the Polderdak;* • *RESILIO: is a subsidy program for this type of NBS;*
	Partnerships increase resources for NBS implementation:	• *Not identified;*	• *Polderdak: GBC Zuidas, Amsterdam Zuidas, (Municipality), Waternet, and De Dakdokters;* • *RESILIO: Municipality Amsterdam, Waternet, MetroPolder Company, Rooftop Revolution, HvA, VU, Stadgenoot, the Alliantie, and De Key;*
	Funding for maintenance and repair:	• *The maintenance team approved the project;* • *It is part of municipal assets;*	• *Polderdak: Not identified/discussed in interviews;* • *Within RESILIO maintenance of blue-green roofs is the responsibility of buildings' owners;*
Action planning	NBS addresses a specific problem:	• *A larger version of a pilot green strip;* • *Adequate for its small size and urban character;*	• *Polderdak: Rainwater retention, drainage, and discharge;* • *RESILIO: aims specifically at smart blue-green roofs;*
	Partnerships for implementation:	• *Municipality (Zuidas district) planning team and Waternet;*	• *Polderdak and RESILIO results from public-private partnerships;*
	The action plan lays project steps; it is executed and completed.	• *An action plan is implicit;* • *The 1st phase was completed in 2019 (20% of total);*	• *Polderdak: implemented twice in different locations (2013/19);* • *RESILIO: in progress. ±2000m2 of private roofs are completed.*
Monitoring & valuation	Monitoring and performance evaluation of the project:	• *The performance of a previous project led to adjust in this one;* • *Monitoring green infrastructure is normal in Amsterdam;*	• *Polderdak and RESILIO are monitored to improve the system;* • *Research programs originated from it - Project Smartroof 2.0;*
	Assessment and report of project benefits.	• *Partially confirmed. Benefits were mainly communicated before the project implementation.*	• *Confirmed. Important for the dissemination and demand for this new drainage system;* • *Polderdak and RESILIO reported the project benefits to increase its visibility and create a business case;*
	Reflection process and adjustments for future projects.	• *This step was essential to expand this solution to other parts of the city.*	• *This step was essential to expand this solution to other parts of the city and beyond Amsterdam.*

Table 11: Overview of the implementation process.

4.4. Enablers and Barriers for the Implementation of NBS for Urban Drainage

In Amsterdam, NBS implementation has been supported by plans to complement the city's gray infrastructure with a green infrastructure network, as demonstrated by the cases. The two projects and the reviewed mechanisms expose the opportunities and challenges in the implementation of NBS in Amsterdam, fulfilling the first objective of this study. Uncovering these aspects provide insights into how NBS projects for urban drainage can be amplified in Amsterdam. Amplification processes will be easier activated when facilitated by the enabling factors, overcoming the barriers that slow down implementation. In this section, I analyze barriers and enablers found in Amsterdam in relation to the ones identified by the literature, as detailed in Table 5.

4.4.1. Path dependency and innovation

Implementation of NBS for urban drainage is hindered, in multiple dimensions, by path dependencies (Marlow et al., 2013; Zhou, 2014). In Amsterdam, the underground drainage system creates strong path dependencies, given the extensive size, lifetime, and sunk costs of such a system, as pointed by Davis & Naumann (2017). Additionally, knowledge and available resources from Waternet and the Municipality are intertwined with the existing technology employed in the underground system. Yet, the 'lock-in' effect of the traditional system (Marlow et al., 2013) is not so restrictive because of a paradigmatic shift in the perception of rainwater by the city. Since 2014 with the creation of Amsterdam Rainproof and the introduction of the new Sewerage Plan (2015), the city is changing the narrative around rainwater, to create a 'rainproofing' mentality in both public and private parties. The interviews confirmed the valuable role of Amsterdam Rainproof making the rainproof principle the 'new normal' in urban projects, which directly supports the amplification of existing initiatives. The initiative helped blue-green roofs to *grow* and have also *transferred* and *spread* knowledge on NBS for drainage from Amsterdam to other European cities. A respondent from Waternet explained how his work is to create this shift in perspective, embedding climate adaptation and rainproofing into urban development:

> *"I work on this new awareness and the perspective we have to develop regarding climate adaptation. The growing awareness that water is not a facilitating function in the spatial field, but a basic, or steering asset, that helps us make right choices in the development of our city."*
>
> RESPONDENT #3: ADVISOR FOR CLIMATE ADAPTATION, WATERNET, 2021

Bulkely & Castán Broto (2013) argue that openness to innovation and experimentation reduces the impact of path dependencies. Amsterdam is an enthusiast of experimentation in the urban realm and is considered an innovative and front-runner city in sustainability and greening projects (Respondent #4, Respondent #5, Respondent #7). An advisor for climate adaptation from Waternet reflected on how innovative projects challenge the status quo, saying that having a new idea is simple, but implementing it into the organizations and environment is harder (Respondent #3). At the same time, a project manager from MetroPolder praised Waternet for staying close to innovation and supporting new solutions, fostering experimental projects. They added that people with vision and enthusiasm about new drainage solutions at Waternet foster new experiments in the field (Respondent #7). Nonetheless, the respondents said the polder roof system took almost five years to turn from an experiment with few customers into a commercial solution with market demand, which is just starting. In part, this is because a new mentality must be created around this micro water management solution, and investors, developers, building owners, and architects have to embed this new solution into their planning repertoire (Respondent #3, Respondent #7).

In sum, although path dependencies from traditional infrastructure are unavoidable, the proactivity of the city for proposing a new approach to drainage, supporting innovation, and asking for sustainable solutions have amplified the implementation of NBS, especially *within* and *beyond*.

4.4.2. Adequacy of policies, plans, and regulations

As described in section 4.2, Amsterdam has a recent but robust set of policies, strategies, plans, and regulations that foster the implementation of NBS. A supportive legal framework is decisive for the implementation and amplification of nature-based solutions. Such a framework should explicit the intention of using NBS in urban projects and have a multidimensional and interdisciplinary approach, as the Green Vision does. Furthermore, city-level documents like the Climate Adaptation Strategy have a top-down influence on the local mindset on NBS and facilitate its implementation by the public sector. But policies alone do not ensure implementation, and action plans and resources are needed to create real impact (Respondent #4). Finally, laws are the most effective legal mechanism to *stabilize* and *speed up* initiatives by the private sector, such as done by the new Water Ordinance. There are, however, limitations to how much legislation enables the implementation of NBS in Amsterdam. The guidelines for the design of public space (Puccini method – Red Book and Green Book) are not aligned, for example, leading to conflicts and restrictions to what can be done in projects. The Green Book also restricts the possibilities of public NBS projects, because it is a static document while NBS have requirements that are context-dependent, varying from case to case (Davis & Naumann, 2017).

4.4.3. Economic instruments and resources

Resources for the implementation of NBS in Amsterdam are limited and must be invested according to priorities and the plans on the city's agenda, making the financial aspects challenging in the implementation of new projects in the city, as seen in Kabisch et al. (2016) and Wamsler et al. (2020). Three main aspects about the funding of projects in the city stood out from the interviews: effective subsidies, robust municipal capacity, and a weak business case. The subsidies for green projects, especially blue and green roofs, were considered a strong enabler and amplifier of NBS by the private sphere, as investors, developers, and citizens take advantage of available subsidies to implement more sustainable projects. A respondent confirmed that the award of almost five million Euros by the EU allowed the 'further scale-up of the blue-green roof philosophy' (Respondent #3).

Creating an attractive business case for NBS remains one of the larger obstacles for its amplification, and according to Frantzeskaki et al. (2020), this is a 'know unknown' challenge to most cities, especially in the ambit of NBS for urban drainage systems. The respondents explained that the valuation of NBS projects and quantification of ES is not easily done, but people want to see the return in their investments, weakening the interest of investors (Respondent #1, Respondent #2, Respondent #3, Respondent #7, Respondent #9). A project manager at MetroPolder explained the implications of not having a solid business case for blue-green roofs:

> *"Until you have a functioning blue-green roof system at scale, the price is paid individually, but the benefit is for the city. The city requires water storage from new buildings because they get a benefit from having nature-based solutions in the city. Amsterdam is doing a great job with RESILIO, offering subsidies to push people in that direction, but until the city has looked at how much water we have managed, how much we have saved and put a value on that rainwater, and the value on water stored on a roof to make that real to a developer, there's always an incentive for them to pay the least or build a solar panel that pays them back or another solution that is more immediate in terms of return."*
>
> RESPONDENT #7: PROJECT MANAGER, METROPOLDER, 2021

Frantzeskaki et al. (2020, p. 8) argue that reducing this obstacle requires *"accelerate institutional and governance innovations that support systemic evidence of the multiple benefits of NBS and mainstream them as social, economic, environmental and business solutions for sustainable and resilient cities."*.

Lastly, the robust human and financial capacity of the Municipality facilitates the funding of NBS projects for the public space. Besides, respondents from the Municipality agreed that the costs of green infrastructure are often inferior to that of grey infrastructure (Kabisch et al., 2016; Seddon et al., 2020). However, uncertainties about the long-term costs of these projects (i.e. for maintenance), and implementation responsibilities over surface drainage projects between Waternet and the Municipality are still obstacles that slow down the implementation of NBS for urban drainage (Respondent #1, Respondent #5). Still, interviewees believe the Municipality Amsterdam has more resources than most Dutch cities, which allows the city to invest more in green infrastructure, amplifying NBS (Respondent #2, Respondent #10). Finally, the human resources of the Municipality are also significant, with a rich body of professionals from various fields working together to enable projects of NBS for urban drainage, such as ecologists and landscape designers. This is considered an asset of the city by interviewees, but they say collaboration among professionals still needs to improve for the amplification of NBS projects in the city (Respondent #3, Respondent #4, Respondent #5).

4.4.4. Partnerships and institutional fragmentation

Strong partnerships amplify the implementation of NBS for urban drainage, and this is visible with RESILIO (4.2.2), which *stabilized* and *grew* smart blue-green roofs in Amsterdam (Respondent #6, Respondent #7). RESILIO expanded the blue-green roofscape in Amsterdam, and new companies started operating in this field, implementing more projects (Respondent #4, Respondent #7). A challenge faced by RESILIO in the implementation of blue-green roofs in Zuidas is reaching the owners of the buildings, which are often large corporations and investors located outside the city, without interest in the local context and development (Respondent #4).

In innovative and experimental projects, partnerships help to create the multidisciplinary team needed for NBS implementation, and this is also true in Amsterdam (Frantzeskaki et al., 2020). Public-private partnerships foster the implementation of urban projects, and both Amsterdam Rainproof and Rooftop Revolution enable new partnerships between the two sectors in the city. Amsterdam Rainproof activates a network of actors to seize opportunities for new drainage and NBS projects. Rooftop Revolution is an NGO operating mainly in Amsterdam with consultancy for green and blue-green roofs, guiding individuals to obtain a subsidy, also amplifying NBS implementation (Respondent #4).

However, the public sector also suffers from institutional fragmentation, a common barrier in NBS implementation (Frantzeskaki et al., 2019; Nesshöver et al., 2017; Wamsler et al., 2020). One on hand, respondents said the Municipality is a large institution with good capacity, where specialized teams collaborate in green infrastructure projects (Respondent #1, Respondent #2, Respondent #4). On the other hand, respondents from the Municipality consider the organization very complex, which creates silos and makes collaboration among and within departments sub-optimal. Additionally, all respondents from Waternet and the Municipality said there is friction between the organizations because, although being partners, they do not follow central coordination and do not have uniform working procedures (Respondent #1, Respondent #2, Respondent #3, Respondent #4).

When talking about the shift in responsibilities for urban drainage introduced by NBS, a public designer understands that changes need to happen in higher levels, *scaling up* the processes to improve the system:

> *"It is about working together and not so much about splitting up the costs. It is about getting one system, and that makes it complex. And it's good to change on a larger scale because a lot of people are busy with a lot of different projects and everybody has to deal with the same questions. But there have to be changes on the higher level, then it gets easier to work. Otherwise, everybody has to do these discussions with Waternet and the Municipality again."*

RESPONDENT #5: SENIOR DESIGNER, MUNICIPALITY AMSTERDAM, 2021

4.4.5. Knowledge and information

Knowledge and information are far-reaching enablers of NBS implementation, however, local actors often lack 'systems' thinking' and 'solution-oriented thinking' knowledge required to amplify implementation (Frantzeskaki et al., 2020; Kabisch et al., 2016; Nesshöver et al., 2017). In Amsterdam, creating and spreading knowledge is partially a goal present in NBS implementation. Most respondents mentioned that the Rainproof network helps *to stabilize* and *speed up* NBS implementation, by sharing information, enabling partnerships, and making projects visible. Amsterdam Rainproof and RESILIO are sources of technical and socio-economic knowledge on green infrastructure projects for urban drainage. However, the ecological aspects of sustainable urban drainage systems are not as communicated and are often placed as secondary targets of drainage NBS projects.

The respondents agree that knowledge on climate adaptation is embedded in the urban agenda and that NBS are seen as useful to achieve the desired sustainable transformation on urban drainage systems. An advisor from Waternet explained how the knowledge obtained with the polder roof system activated the *growing* mechanism, amplifying the implementation of micro water management solutions within the city. They said the success of the system impulsion a demand for information, amplifying out the implementation to other cities in the Netherlands and abroad (Respondent #3). Nonetheless, another respondent from Waternet said that mainstreaming climate adaptation is still a challenge because it requires great changes in the current ways of thinking and doing, and they explain:

> *"One of the huge challenges of climate adaptation is that you don't want it to be something that comes always at the end of the design, like, "oh, yeah, we need to do something about climate adaptation too" you want it to be as common or as regular as traffic safety or green. If you want to develop or redevelop the public space you need to ensure some green areas because that's just policy in Amsterdam, so that's very common. But climate adaptation is a new thing, so mainstreaming it is a big challenge in public organizations."*
>
> RESPONDENT #2: PROJECT LEADER, WATERNET, 2021

In conclusion, Amsterdam is actively working to develop knowledge in different aspects of urban drainage and nature-based solutions. They invest in ongoing research, partnerships with education institutions, web pages that share detailed solutions, partnerships with organizations as GBC Zuidas, working with consultancy firms, and more. This is a 'targeted stakeholder collaboration' strategy and is effective to address knowledge and capacity limitations (Wamsler et al., 2020). However, the respondents consider that 'rainproofing' is still a new concept and existing projects are recent innovations limited to a niche. Therefore, they agree time is needed to stabilize, solidify and amplify these NBS into local urban development (Respondent #2, Respondent #3, Respondent #7, Respondent #10).

4.4.6. Biophysical aspects

Obstacles related to limited (physical) space and time in the implementation of NBS were little discussed in the interviews. One aspect regarding the green strip at Prinses Irenestraat mentioned was the design principle of creating an urban wadi, which would be suitable for the large scale and density of the project location (Respondent #1). The policies also demonstrated that a dense city like Amsterdam (for Dutch standards) envisions the integration of nature into the city urban fabric through a connected and widespread blue and green infrastructure network. Although not explicitly mentioned in the interviews, the use of blue-green roofs in urban drainage seems logical in a city where extensive sealed surfaces magnify the rainwater runoff. Therefore, combining NBS with other urban elements and gray infrastructure is an enabler (and an objective) of NBS implementation in the city, as widely recommended by the literature (Davies & Lafortezza, 2019; Davis & Naumann, 2017; Depietri & McPhearson, 2017; Suleiman, 2021; Zhou, 2014).

The ecological and biological aspects of NBS for urban drainage are still being developed in Amsterdam. The two green strip projects (at Zuidelijk Wandelweg and Prinses Irenestraat) served as experiments of what plants' species and soil composition are better to perform the quickest drainage possible. An interviewee from Waternet added that newer projects of water-retarding strips built in the Rivierbuurt are lush, green, and biodiverse and perform the drainage very well because the municipality 'has learned the technique for it' (Respondent #10). However, a senior designer who worked on the projects at Zuidas said that there is not a formula for replicating the same nature-based solution everywhere:

"I get the question from other cities and other people in Amsterdam asking 'hey can you send me the book and the list of plants, so we can use it?' and I say 'no wait, it is not like that'".

RESPONDENT #1: SENIOR DESIGNER, MUNICIPALITY AMSTERDAM, 2021

Besides that, the interviews evinced that the ecological aspects of NBS are usually centralized in one person, which for both the green strip and the polder roof is a landscape designer. When asked about the participation of biologists or environmentalists in the projects, the respondents said this did not happen (Respondent #1, Respondent #6). As the literature argues, the bio-ecological aspects of NBS matter, as they determine the ecosystem services (benefits) provided, and the consequent sustainability of the project (Connop et al., 2016; Wamsler et al., 2020). However, the lack of interdisciplinarity seen in research is also observed in practice, reducing the success of NBS in fulfilling adaptation planning goals.

4.4.7. Monitoring and valuation systems

The effective monitoring and valuation system for the implementation of NBS projects contributes to the amplification of NBS (Kabisch et al., 2016). However, this remains a challenge for NBS, considering that it is difficult to determine which indicators to use for measurements. In Amsterdam, the monitoring and valuation strategies vary from project to project.

On one hand, public projects use pre-allocated resources based on the policies and plans of the city, demanding fewer valuation systems to justify their implementation. Projects like urban wadis implemented in the city already proved effective for flood reduction, and monitoring is done by Waternet only in the case they want to do additional rainwater stress tests.

On the other hand, private or semi-private projects like the polder roof depend on monitoring and valuation to demonstrate their effectiveness and increase the acceptance of the offered solution by potential customers. The interviews showed that this acceptance and the consequent demand for the polder roof system have increased, making the company expand businesses beyond Amsterdam, *replicating* the solution in other contexts. Nonetheless, respondents from MetroPolder and Rooftop Revolution said the business case for Polder Roofs is not strong enough, slowing down the amplification of this type of NBS (Respondent #7, Respondent #9).

4.4.8. Overview of enablers and barriers for NBS implementation

Enablers and barriers for the implementation of NBS in Amsterdam	
Barrier	**Impact and summary**
Path dependencies from grey infrastructure:	**Large**. *However, a recent paradigm change in rainwater management in the city towards micro water management solutions weakens the impact of path dependencies.*
Inadequate regulations:	**Small**. *Some regulations do not support climate adaptation goals or are conflicting. The current GRPA does not make explicit reference to using NBS for urban drainage.*
Inadequate resources:	**Medium**. *Resources are always limited. Amsterdam invests in NBS but the business case of some projects is weak. An unclear valuation system for NBS makes it harder.*
Institutional fragmentation:	**Medium**. *Silos inside the Municipality and misalignments with Waternet are obstacles for NBS implementation. The collaboration among the two is improving gradually.*
Lack of information (knowledge) and uncertainty about NBS implementation and effectiveness:	**Small**. *Many mechanisms provide information and share knowledge on NBS projects. Mainstreaming of innovative solutions takes time and is an ongoing process. The long-term contribution and functioning of NBS are unknown, as most implemented projects are recent (10 years or less).*
Limited land and time:	**Medium**. *The urban and dense character of Amsterdam demands compact solutions (i.e. green strip). This is not the main obstacle for NBS implementation in the city.*
Enabler	**Impact and summary**
Openness to innovation:	**Large**. *Amsterdam is an innovative front-runner city in sustainability projects.*
Regulations:	**Large**. *Amsterdam has a robust set of policies, strategies, plans, and regulations that enable the implementation of NBS.*
Economic instruments:	**Medium**. *Subsidies for blue-green roofs enable the implementation of NBS by private actors. The Municipality has the funds to plan and implement NBS in the public space.*
Partnerships:	**Large**. *Through the network of Amsterdam Rainproof, public-private partnerships enable the implementation of NBS, especially in private plots. Waternet and the Municipality dominate the development of new projects in the public space.*
Knowledge-sharing mechanisms and technology:	**Medium**. *Amsterdam Rainproof and RESILIO invest in research and generate technical and socio-economic knowledge on green infrastructure projects for urban drainage.*
Combining NBS with gray infrastructures	**Large**. *The combination of NBS with other urban elements and gray infrastructure is a necessity and a clear objective of the Municipality, given its spatial characteristics.*
Monitoring and valuation systems:	**Medium**. *The monitoring and valuation of NBS are harder and less common than that of grey infrastructures. Projects that require private investments are more monitored and valuated than public ones to develop a compelling business case.*

Table 12: Overview of enablers and barriers for NBS implementation.

5. Discussion

In this chapter, I reflect on and discuss the main findings of the empirical study, connecting them to the Theoretical Background and Framework. These findings support a critical reflection on how amplification processes have been activated to expand the implementation of NBS for urban drainage in Amsterdam.

5.1. Amsterdam: Shifting the Urban Drainage Paradigm

The Results section demonstrated that the current drainage system in Amsterdam relies heavily on the underground gray infrastructure system. An extensive drainage network covers the city, with huge sunk costs typical of gray infrastructure (Davis & Naumann, 2017). While the traditional infrastructure is the main solution for urban drainage, over the last decade, Waternet developed a new mindset around combining gray with blue-green infrastructure into a hybrid system.

Since 2014, Waternet works to make 'rainproof' the standard for urban drainage projects. The inclusion of the 'rainproof' and 'sponge city' principles by the Sewerage Plan in 2015 is a milestone and the start of this paradigmatic shift in how urban drainage is planned in the city. This new mindset emerged after severe downpour events that caused much damage, inflicting huge costs to insurance companies and the local government. Moreover, the 'rainproof' mindset was reinforced by a sense of urgency stemming from the most recent climate scenarios. The Amsterdam Rainproof initiative is a successful example of how this shift in approach happens in reality. Although the initiative operates independently, its roots in the public administration are determinant for its success, since its goals are aligned with urban development objectives and municipal legal responsibilities, such as ensuring the 'dry feet' of citizens. Therefore, the success of rainproofing efforts is a direct consequence of the leading role that the public administration took in this process.

Planning the rainproof city created favorable conditions for the amplification of NBS, especially when combined with the ambitions of the local government to develop a greener, liveable, natural, and sustainable city, as stated in the Sewerage Plan, Structural Vision, and Green Vision, for example. Additionally, Amsterdam Rainproof has a large impact in the public sphere, as the drainage of public areas is a municipal responsibility. Introducing and coordinating the private sector into this mindset shift has proven more complex, as interests and concerns regarding rainwater are not aligned between public and private parties. Moreover, the latter is primarily concerned with commercial feasibility and the profit of projects, rather than fulfilling policy goals.

In conclusion, Waternet and Amsterdam Rainproof activated the *scaling deep* process by introducing a new mindset and values around rainwater, sending a centralized and top-down message to mobilize public and private stakeholders into implementing new solutions for urban drainage, particularly nature-based solutions. The Rainproof initiative also contributed to *stabilizing* and *speeding up* the implementation of NBS projects that deliver a more sustainable urban drainage system, amplifying NBS *within*. Still, the reach and impact of the initiative are small in comparison to the complete drainage system of the city, and amplifying *out* mechanisms can be activated to *grow* NBS impact within Amsterdam. Nonetheless, the most important contribution of the program is the consolidation of a new, aligned mentality around rainwater in the city, which started being seen as an asset that must be treated carefully instead of drained away. I consider *'scaling deep'* the most important process to achieve transformative change in urban drainage, because it sparks change from within, affecting institutional structures, values, and mindsets (Lam et al., 2020). Without a change in values and beliefs, there is no incentive for systematic investments into experiments that enable sustainability transformations. Finally, changing the 'rules of the game' for urban drainage is only possible if the actors who play the 'game' are on board, as in the case of Waternet and the Municipality.

5.2. Amplifying NBS Implementation: the Crucial Role of Enabling Mechanisms

The Results section scrutinized how enabling mechanisms for NBS implementation contributed to the implementation of new drainage projects in Amsterdam. Three sets of mechanisms are active in the city; (i) legal instruments, (ii) programs and projects, and (iii) funding and resources. The research revealed that all three must be in place for the amplification of NBS projects, as they reinforce each other. These finding are supported by Frantzeskaki et al. (2020) and Kabisch et al. (2016).

The drainage context is rather homogeneous in Amsterdam, in terms of regulations, climate conditions, and socio-economic aspects. Therefore, the analyzed enablers mainly amplify implementation *within* and *beyond* and activate the *growing* mechanism of amplifying *out*. The main takeaways from the analysis of the mechanisms are as follows:

e. Policies stabilize the implementation of NBS, but regulations speed up and grow initiatives:

The 'sponge effect' and the 'rainproof' principles introduced by the GRPA, next to the goal of standing a rainfall of 60mm/h, were important legal changes that amplified the implementation of NBS for urban drainage activating *scaling up* and *scaling deep* mechanisms. These changes - in particular the new drainage capacity - are decisive because Waternet must meet its targets. Therefore, changes in the drainage regulation amplify NBS initiatives in the city *within*, fostering innovation and culminating in new projects. An example of this process is the evolution of the polder roof system, an innovative system that is now implemented on top of many buildings in the city.

While the sewerage plan *enables* NBS it does enforce this solution in new projects. In that sense, other policies in the city complement the sewerage plan, specifically the Green Vision and the Adaptation Strategy, which make the explicit connection between increasing the drainage capacity of the city to prevent flooding and the use of NBS, *scaling up* its implementation. The Adaptation Strategy also links climate adaptation with urban experiments, saying they need to be *upscaled* and mainstreamed to have a greater impact (as argued in section 2.3.4), pushing amplification.

The nature-inclusive legal framework of Amsterdam creates a favorable environment for experimenting with NBS, especially by the public administration since public projects tend to follow local development policies rather than commercial goals, resulting in implementation and *scaling deep* of the NBS ideals. However, binding regulations are needed to *speed up* and *grow* public and private initiatives for NBS. The examples of the new Water Ordinance (*hemmelwaterverordening*) and the 'Puccini - Green Book' evinced how laws amplify implementation. These two binding regulations enforce the use of NBS in both private and public spheres respectively. The Water Ordinance increased the demand for drainage NBS (i.e.blue-green roofs) in private projects, and it is expected to continue *speeding up* implementation. Furthermore, this regulation made the collaboration of the private sector to urban drainage official, setting clear expectations and targets. At the same time, the subsidy scheme for blue-green roofs is the government's contribution to *stabilizing* this new regulation.

In sum, policies and regulations are an effective strategy to mainstream the implementation of NBS (Wamsler et al., 2017). However, they must remain flexible not to hinder innovation with rigid and inadequate requirements. Furthermore, while blue-green roofs are an effective alternative for rainwater storage, not all roofs are suitable for this solution and older buildings often have insufficient structural resistance. Therefore, the government must broaden its legal instruments, providing alternatives for the implementation of NBS for urban drainage by private actors. A suggestion for new developments is using a Green Point System, already used in cities like Malmo, Sweden, where constructions score points for a list of sustainable solutions, and a certain amount of points is required for a project's approval.

f. Programs, partnerships, and resources are crucial to amplifying NBS implementation:

As expected, enabling mechanisms belonging to the first two dimensions of implementation (programs and funding) have an important role in urban experimentation, *stabilizing*, and *speeding up* NBS initiatives. The case of Amsterdam shows that programs create a common goal and partnerships fulfill them. Furthermore, programs and projects enable action plans and mobilize resources for the implementation process. The innovative polder roof system, for example, resulted in a strategic partnership to launch the RESILIO program, which amplifies blue-green roofs *within* and *beyond*. Bottom-up, grassroots movements are increasingly a source of innovation and dissemination of urban planning solutions, however, urban drainage is controlled by local authorities who mostly drive urban experiments in this field. For example, Waternet was involved in all NBS for urban drainage found during the research. This is a reflex of water management tasks being centralized by the government in the Netherlands, the municipality's responsibility of providing and maintaining the drainage infrastructure, and the 'common good' provided by drainage systems.

Through Amsterdam Rainproof, Waternet amplified the implementation of drainage NBS *within*, *out*, and *beyond*, sharing knowledge, facilitating partnerships, and activating resources by working the link between public and private organizations. On one hand, the long-standing partnership between Waternet and the Municipality *stabilizes* the implementation of NBS in public areas, as existing experiments such as the green stip becomes slowly embedded into local practices. On the other hand, actors like the Green Business Club Zuidas and local housing corporations support the *stabilization* of NBS in private projects, investing or using subsidies to implement sustainable solutions and green infrastructure. Moreover, public initiatives *grow* and *transfer* initiatives, while private ones *grow* and *replicate* them. *Spreading* is not deliberately activated, but it is a consequence of successful experiments that *inspire* independent initiatives in other locations.

While there are a couple of successful initiatives enabling NBS in the city at the moment, they are mainly top-down and governmental-led, aimed at projects for the public spaces and private roofs. Hence, there is definitively room for new initiatives focusing on solutions that broaden the scope of NBS (*growing* process), and also for bottom-up and grassroots initiatives, which strengthen the social inclusion and environmental justice of NBS (see: Nesshöver et al., 2017; Raymond et al., 2017; Wamsler et al., 2020)

Interestingly, the implementation of NBS shifted part of the responsibilities over drainage projects from Waternet to the Municipality, which is responsible for projects on the surface (in the public space). This has not prevented the implementation of experimental NBS projects, as the two organizations collaborate on them, but has certainly slowed it down. Respondents confirmed teamwork and communication between both parties can improve, as well as the delimitation of a clear division of responsibilities over NBS projects.

Funding proved to be a crucial enabler for NBS amplification. The subsidy provided via RESILIO, for example, boosted the demand for the polder roof technology, and *stabilized* and *speeded up* the implementation of blue-green infrastructure by private parties. Amsterdam indeed had to co-finance the EU investment, which required local resources being available for that, but the large sum accessed with the program would be beyond the city's capacity. Therefore, national and international funding schemes are an important source of resources to amplify NBS. Nonetheless, having NBS innovation and pilot project implemented was decisive to let the city enroll in the funding program. In conclusion, more resources are needed to further amplify NBS, especially *within*, as investments in innovation allow urban experiments to reach the 'transfer and upscale' point, in which they may become mainstream solutions (Raymond et al., 2017). Besides, specific budget allocation for NBS projects and resources for long-term funding by the Municipality are needed to amplify sustainability initiatives in the city, mainstreaming them into urban planning practices.

In that regard, the Climate Adaptation strategy states that *"In the coming years, the municipality will continue to actively seek co-financing from (municipal) programs or third parties. There are also many opportunities for innovative collaborations. We are currently working with a temporary program to stimulate* *climate adaptation through projects and activities. Ultimately, it should become part of our daily work."* Finally, although the budget for green projects in Amsterdam is not at risk and, on the contrary, it seems to be increasing, it is important to make supporting economic instruments official, including clear targets for NBS implementation. This will *scale up* experimentation with NBS initiatives, and lead to the embedding of experimental solutions into local practices.

5.3. Amplifying NBS Implementation: Public and Private Initiatives Contribute Differently

The two analyzed projects have distinct characteristics and implementation processes. Yet, their analysis provided insights on what motivates NBS implementation in the city, and how it takes place. Knowing what enabled existing projects helps to answer how they can be amplified.

The analysis revealed that the main purpose of implementing NBS for urban drainage in Amsterdam is to address the limitations of the traditional drainage infrastructure network. However, public and private initiatives have different approaches and strategies for developing new projects. Public projects dominate the blue and green infrastructure network for urban drainage, which is not surprising given the centralized role of the government in drainage tasks. Public NBS projects are implemented primarily to solve the rainwater bottlenecks (mapped by Waternet) and gray-infrastructure physical limitations. And, also due to local policies to expand urban nature, the 'rainproof' mentality, and the socio-economic importance of the area they are located. In the private sector, the implementation of NBS is often motivated by commercial interests, allied with the belief that the private sector can be a source of climate adaptation projects while generating economic and socio-ecological benefits. Therefore, public projects are primarily socio- and technically-driven while private ones are mainly economically driven. Hence, while the amplification of public-implemented projects depends on the contribution they make to urban planning goals, the amplification of private ones requires a compelling business case. Finally, public and private projects contribute to stabilizing NBS. Three main takeaways on the expansion of NBS implementation emerged from the case study:

a. Experimentation with NBS effectively amplifies implementation:

The case study demonstrated that Amsterdam is open to innovation and experimentation with NBS for urban drainage, confirming that experimentation is an effective strategy for the successful implementation of NBS (Albert et al., 2019; Frantzeskaki, Castán Broto, et al., 2017; Frantzeskaki et al., 2019). The city invested in experimental NBS projects for considering that a hybrid system can improve urban drainage, reducing rainwater bottlenecks, and building a climate-resilient city. Furthermore, the implementation of NBS pilots increased knowledge on the solutions, incorporating it in subsequent projects. This shows that experimental projects helped overcoming the issue of a lack of exemplary cases to learn from, improving SUDS explained by Davis & Naumann (2017). These experiments led to more and better projects (*growing process*), and in the uptake and inclusion of these solutions in the urban repertoire (*stabilizing process*), reinforcing the argument that experimental projects foster implementation and NBS mainstreaming (Albert et al., 2019; Frantzeskaki et al., 2019; Raymond et al., 2017).

Furthermore, both public and private experiments activated amplification processes. The Green Strip advanced experimentation with the water-retardant planters on sidewalks, *stabilizing* the solution. Although partially completed, the project is a success and the solution has *grown* within the city. Besides, external parties (i.e. other municipalities) contacted the municipality, interested in the *transfer* of this NBS. The Polderdak in turn introduced an innovation in micro water management. The project was the first of its type and the engagement of multiple partners together with its technological achievement led to successive projects in and out of Amsterdam, *stabilizing, speeding up, growing, replicating, and scaling up* this NBS. Nonetheless, the most important amplification mechanism for the implementation of both NBS was the *scaling deep* of the 'rainproof' and 'sponge city' principles, as explained in 5.1.

b. The private sector activates different amplification processes than the public:

With Amsterdam Rainproof, Waternet aimed to include the private sector in the development of the blue and green drainage infrastructure. Since Amsterdam is a densely built city, developing drainage NBS in private areas is a strategy to increase the SUDS network. Sustainable drainage projects implemented by private actors can be permeable gardens or residential rainwater storage systems, as the polder roof for example. An important result of including building owners in urban drainage tasks is that the government creates awareness and shares the responsibility for flooding damage risks with them. Although convincing the average citizen to improve their plot's drainage is challenging, the economic interest of commercial systems pushes the private sector to amplify the implementation of NBS (*speeding up, growing, and replicating*). Moreover, the *scaling up* of innovative solutions into local rules (i.e. Water Ordinance) results in the *speeding up* and *growing* of NBS projects. *Speeding up* is particularly important because it creates impact faster and in climate adaptation, time is a pressing matter. Nonetheless, more enabling mechanisms like regulations, policies, or partnerships are still needed to amplify private experiments *within* and *out*.

The Polderdak case showed that the Dakdokters' ambition of providing a new service, combined with support from partners interested in investing in sustainable solutions, resulted in the implementation of thousands of square meters of blue-green roofs on top of private buildings in Amsterdam. The creation of RESILIO to subsidize this NBS increased the demand for the polder roof, *speeding up* implementation. Additionally, because MetroPolder (the company that developed the system) is private, having commercial interests, they *amplified out (i.e. growing, replicating)* the implementation of NBS through entrepreneurship. Hence, they actively seek potential customers in the Netherlands and other countries, demonstrating the capabilities of the system, advertising its economic value, and gradually expanding their portfolio of smart blue-green roofs. After successful pilots in Amsterdam, the company implemented projects in Belgium, Italy, and more recently in the United States. In Italy, the projects were adapted to the local context, which has a warmer and drier climate than the Netherlands. The company is using the experience from the Italian projects to develop roofs in Spain and South Africa, *replicating* the solution in different environments. Finally, the company works in partnership with the public sector and research institutes to continuously improve the smart blue-green roofs, adding valuable functionalities and making their product more relevant to the final user (*growing* process). In sum, involving the private sector in urban drainage is a form of activating different amplification processes that can complement and intensify those activated by the public sector.

c. Amplifying NBS improves ecosystem services' provision:

The cases showed that when a sustainable initiative is amplified, it tends to refine and improve the solution introduced by the initial experiment. For the amplification of NBS, this means that subsequent projects may provide more or better ecosystem services, improving their ecological functions. When the Municipality implemented the green strip at Prinses Irenestraat, they *grew* the first pilot from Zuidelijk Wandelweg. The second project is larger, the soil and drainage capacity are improved, and more species of plants - *including some trees* - were added to the solution. The interviews confirmed that this second project drains better but also remains greener through the seasons, providing more ecosystem services such as heat reduction through evapotranspiration. Following the green strip at Prinses Irenestraat, other urban wadi projects were implemented in the city, which applied the knowledge obtained in the previous ones. These more recent urban wadis broadened the scope of this NBS, with more varieties of flora and the combination with underground worms' culture, for example. The *growing* process of the green strip shows how amplification impacts both the quantity and the quality of NBS, increasing the multifunctionality and biodiversity of NBS (Connop et al., 2016).

Regarding the polder roof system, continuous improvement and research have *grown* this NBS. Polder roofs implemented after the Polderdak have, for example, different types of plants species, thicker substrate, combination with solar panels, leisure areas, etc. Each of these elements enriches the provision of ecosystem services by the system. Recently, research on the insulation capacity of polder roofs, as well as on possible vegetation that grows on them (i.e. vegetables and small trees) are examples of how activating the *growing* mechanism pushes innovation further.

In conclusion, amplification and innovation walk together, as the reproduction of existing solutions creates knowledge and insights on how to improve them. In the literature, this finds an echo in the seven stages of successful implementation proposed by Raymond et al. (2017). According to the authors, when an NBS is in the 'demonstration phase', teams can learn with the experiment, monitoring and evaluating the co-benefits. In this phase, the NBS may be 'upscaled' for being a valuable innovative solution that, if mainstreamed, leads to sustainability transformations (Raymond et al., 2017).

5.4. Reducing the Obstacles for NBS Amplification

Section 4.4 detailed the enablers and barriers of NBS implementation in Amsterdam, explaining how they affect implementation. Previous research on NBS has uncovered a variety of obstacles to the upscale and mainstreaming of NBS, affecting the three dimensions of this socio-ecological-technical system. These obstacles were observed in Amsterdam with different intensities, and in this section, we analyze the three main cross-cutting challenges that slow down the amplification of NBS implementation, and possibilities to reduce them.

a. Unifying the gray and blue-green infrastructure into one system:

The first cross-cutting challenge to amplifying the implementation of NBS for urban drainage is unifying the gray and blue-green infrastructure components into a cohesive drainage system. As explained before, the use of NBS in the city has partially shifted responsibilities for urban drainage. While the traditional underground drainage infrastructure is fully under Waternet responsibility, surface blue-green drainage components are the responsibility of the municipal 'Spatial Planning and Sustainability' department. With this shift, there are uncertainties over the planning, design, implementation, financing, maintenance, and monitoring aspects of NBS, slowing down implementation. Furthermore, internal silos and institutional fragmentation on both organizations add to this challenge, as observed in Wamsler et al. (2020), hindering the *speeding up* of initiatives. However, simply splitting the work and allocating tasks for each organization is not enough to unlock amplification, as it will reinforce fragmented and sectorized ways of working.

As indicated by one interviewee (Respondent #5, p.64) *one* cohesive drainage system is needed in the city, instead of two separate ones, coordinated by two individual authorities. To achieve this cohesive system, the organizations need to work *even closer* together, not only exchanging information or in occasional collaboration, but with shared priorities for new drainage projects and standardized operational procedures followed by the two sides. They also need to share the action plan and results of implemented projects, including costs and performance indicators, to allow comparisons between gray and blue-green components. Furthermore, they must set clear guidelines for testing the drainage capacity of a given urban area to assess the capacity of gray and blue-green infrastructure combined, to affirm if a rainwater bottleneck is solved.

Finally, while the Municipality has expertise in urban planning, landscape design, ecology, biology, and more, Waternet is specialized in urban drainage and retains know-how on technical and engineering aspects of the drainage system. These disciplines must work together in interdisciplinary teams to build an effective sustainable urban drainage system. This reflects the argument that NBS projects require the 'alteration of internal cooperation structures' (Wamsler et al., 2020) and the improvement of cross-sectoral and interdisciplinary collaboration to overcome 'governance gaps' identified in NBS planning and implementation

(Albert et al., 2019; Davies & Lafortezza, 2019; Frantzeskaki et al., 2020; Nesshöver et al., 2017). The improvement in collaboration between the Municipality and Waternet *stabilize* and *speed up* experimentation, allowing innovative solutions to move from niche to regime (Loorbach et al., 2017). Although this collaboration is not easy to achieve because both the municipality and Waternet are complex and rigid institutions, which creates resistance to change, institutional transformation is a must to achieve the desired sustainability transformations (Loorbach et al., 2017).

b. Generating knowledge to amplify NBS:

Having adequate knowledge to execute the sustainability transformation of urban drainage systems is the second cross-cutting challenge to amplifying the implementation of NBS. Amsterdam demonstrates awareness of climate adaptation needs and the relation of NBS with rainproof and resilient cities, as seen in the Structural Vision 2040 and the Adaptation Strategy. However, there are knowledge gaps that still need to be filled for the upscaling and mainstreaming of NBS in the city. Particularly, knowledge on the full extent of NBS benefits, as it increases the acceptance and usage of NBS (as seen in Albert et al., 2019; Frantzeskaki et al., 2020; Nesshöver et al., 2017; Raymond et al., 2017).

While a few pilot projects have activated the *growing* mechanism in the city, the results showed that NBS for urban drainage is still a niche. Moreover, each new project raises questions on the appropriate technical solution, how to implement it, which flora species to use, how much rainwater the system retains and absorbs, etc. Frantzeskaki et al. (2020) and Albert et al. (2019) identify these doubts as *'systems' knowledge'* needed for advancing NBS. This refers to knowing the multiple benefits of NBS, as well as their complexity. In Amsterdam, increasing knowledge on sustainable urban drainage systems will let the designers of the public space make better-informed decisions on which NBS to use, and the biophysical aspects to consider in each project (Frantzeskaki et al., 2020). Furthermore, the ecosystem services generated by NBS, and the ones desired in a given project should be better understood (Albert et al., 2019). Increasing systems' knowledge should unlock the amplification of NBS by generating new experiments, and *growing* existing solutions.

One way to increase systems' knowledge is through the systematic monitoring of implemented projects (Frantzeskaki et al., 2020). However, monitoring the performance of NBS has proven a complex task, in part because it requires the measurement of ecosystem services (Kabisch et al., 2016). Unclear metrics and indicators for measuring and valuating natural elements, especially when compared with well-understood grey infrastructure, make effective monitoring a challenge (Nesshöver et al., 2017). Furthermore, Small et al. (2017) explain that the word 'value' is associated with monetary aspects, but much of ES value is non-monetary, such as ecological and socio-cultural values. Due to the non-monetary values of NBS being often too indirect and complex, they can be extremely difficult to assess (Small et al., 2017).

The two analyzed projects focused on monitoring the drainage capacity because this is their main function. But more dimensions should be included in the monitoring, such as the ecological and social ones, to learn, for example, what species they attract and how people experience them. The effective monitoring of NBS projects and the communication of their benefits hold the capacity to attract investments, amplifying the solution *within* and *out* (Frantzeskaki et al., 2020; Raymond et al., 2017). Therefore, developing methods to collect empirical evidence of the performance of drainage NBS projects in the city is an important way to increase systems' knowledge and *grow* existing solutions.

c. Determining the cost-benefit of NBS:

As briefly touched upon in the previous paragraphs, the third and last cross-cutting challenge for amplifying NBS implementation is assessing the cost-benefit of projects. Although NBS are portrayed as positive and desirable, their implementation will invariably depend on investments from public and private actors, which are widely evidence-based. The public sector is not commercially oriented and prioritizes socio-technical aspects of projects. However, they still rely on a limited budget for project implementation, and uncertainties about the NBS costs and benefits lead to more 'conventional' solutions with known outcomes being adopted, slowing down NBS amplification. This rationale grows in the private sector, which is economically driven and depends on profitable business models to operate. Frantzeskaki et al. (2020, p. 6) affirm that *"The lack of data and examples on effectiveness and value for money hinder persuading decision-makers to invest in NBS."*

On one hand, the city of Amsterdam is creating a new narrative that places rainwater as a valuable resource that benefits different aspects of the urban environment such as ground-water levels and green-space provision, in line with the ecological and socio-cultural values proposed by Small et al. (2017). The *scaling deep* of the 'rainproof' principle plays an important role in strengthening the 'underlying values' of ecosystem services (Small et al., 2017). With this approach, NBS for urban drainage become of 'no regret' as their contribution exceeds urban drainage, tackling municipal goals of urban greening, social well-being, liveable neighborhoods, etc.

On the other hand, knowing the strong and weak points of implemented projects allows the *stabilizing* and *growing* of experimental solutions, strengthening their business case. Once again, improving the monitoring of NBS projects to include non-monetary aspects in the evaluation, should favor their business case. Furthermore, the assessment of non-monetary benefits could potentially translate into some type of monetary value to developers and actors that invest in NBS, giving them commercial incentives to use NBS, amplifying it within and beyond.

6. Conclusion

This study set out to explore how to expand the implementation of NBS, contributing to climate- and rain-proofing Amsterdam. It did so through the lenses of sustainability transformations theory, applying the *amplification framework* proposed by Lam et al. (2020). The research followed an embedded single-case design, wherein the drainage infrastructure system of Amsterdam was the case and main unit of analysis. Two NBS projects, one implemented by a public and the other by a private initiative, were the sub-units of analysis. The research had two main objectives:

1. To identify opportunities and challenges for the implementation of NBS for urban drainage in Amsterdam.

2. To explore processes that amplify the implementation of NBS for urban drainage in Amsterdam.

The central points from each of the sub-questions are summarized below and support answering the main research question:

First, I sought to confirm the prevailing drainage system in Amsterdam, which configures the socio-technical regime (Loorbach et al., 2017). The case study confirmed that the traditional gray infrastructure is the dominant urban development approach towards drainage systems. However, it also revealed that the urban drainage paradigm is shifting, with the introduction of the 'rainproof mindset', which *scaled deep* NBS principles and values. This paradigmatic shift enabled a niche of innovation and experimentation with NBS into the city (Loorbach et al., 2017). Consequently, amplification processes were activated, as urban experimentation is an effective strategy to increase implementation (Frantzeskaki, Castán Broto, et al., 2017; Frantzeskaki et al., 2019).

Second, I scrutinized the local mechanisms that promote the implementation of NBS for urban drainage, revealing how they culminated in existing projects in the city. The results evinced three sets of mechanisms that interact and enhance each other: legal instruments, programs and projects, and funding and resources. Furthermore, all three mechanisms stimulated amplification processes for NBS implementation. Finally, consistent funding of experimentation and innovation was revealed to be crucial to *stabilize* NBS experiments, so they can reach a 'transfer and upscale' point and amplify into a mainstream solution (Raymond et al., 2017).

Third, narrowing down to the project level, I uncovered the motivation and implementation process of existing urban experiments with NBS for urban drainage. The analysis of a public and a private project showed that these experiments were driven by different aspects (socio-technical or economic). Yet, both benefited from the rainproof mindset's *scaling deep* and impacted the ecological dimension. Furthermore, engaging the private sector proved challenging but rewarding, as it approaches innovation differently than the public sector, activating distinct amplification processes.

Fourth, the supporting factors that enable the amplification of NBS implementation and the obstacles that slow it down were identified and analyzed. Three cross-cutting challenges stood out, and suggestions on how to reduce their weight on amplification were made. The first challenge is unifying the gray and blue-green infrastructure components into a cohesive drainage system. The second challenge is generating systems' knowledge on the full extent of NBS benefits, to increase the usage and diffusion of NBS (Frantzeskaki et al., 2020). This is a difficult endeavor because it includes measuring and valuating ecosystem services, a known obstacle for NBS advancement (Kabisch et al., 2016; Nesshöver et al., 2017; Small et al., 2017). The third and last challenge is to increase data and evidence on NBS cost-benefits. Two solutions were proposed to reduce the influence of these challenges: (1) To improve cross-sectoral and interdisciplinary collaboration, reducing silos and institutional fragmentation and creating a favorable context for innovative solutions to move from niche to regime (Albert et al., 2019; Frantzeskaki et al., 2020; Loorbach et al., 2017; Nesshöver et al., 2017). (2) To implement systematic monitoring of projects and the communication of their benefits, strengthening their business case and attracting investments (Frantzeskaki et al., 2020; Raymond et al., 2017).

The main research question was ***"How can the implementation of nature-based solutions (NBS) for urban drainage be amplified in Amsterdam?"*** The central findings of this explorative study are:

- ***Changes in values and principles around rainwater management are largely responsible for the amplification of NBS implementation.*** Therefore, it is fundamental to continue *scaling deep* the 'rainproof mindset' in the city, consolidating this principle that activates amplification processes. Reinforcing the micro water management and NBS approach fosters new programs, projects, and funding. Consequently, more experimentation with NBS can take place. Then, these experiments are *stabilized* through programs, projects, and funding, becoming embedded in local practices and rules.
- ***Removing organizational silos and increasing cross-sectoral cooperation and interdisciplinary planning stabilizes and speeds up implementation.*** The reduction of institutional fragmentation provides structure, cohesion, and a support system to organizations, making NBS implementation more efficient. Additionally, defining clear responsibilities over each of the dimensions of NBS implementation also increases institutional efficiency, *speeding up* and *growing* implementation.
- ***Dedicated and systematic funding of NBS projects increases experimentation, amplifying implementation.*** Funding schemes exclusively for NBS *stabilize* and *speed up* implementation. This is because resources for research and development (R&D) and the optimization of processes make implementation more efficient. Furthermore, investments in systematic monitoring, research, and development enact a *growing* process of NBS, with the expansion of the impact range and the provision of enhanced ecosystem services. When initiatives activate *growing* processes they may come up with new experiments, which enter the cycle of *stabilization* and *speeding up* again.
- ***An outcome of amplifying within successful experimentation is the scaling up of initiatives.*** This entails the experiments being taken up by the authorities to become embedded in local rules and practices or even the creation of new regulations, policies, or institutions. *Scaling up* contributes to the *speed up* and *growing* of implementation, encouraging new businesses in the field, generating investment in innovation, and the continuous development of NBS.
- ***Consolidating urban experiments with stabilizing and scaling up mechanisms supports their amplification outwards, especially by replicating and transferring.*** When innovation is embedded in local practices and seen as valuable, its *replication* in dissimilar contexts may happen, especially if driven by commercial interests. If the innovative know-how belongs to public organizations (i.e. Municipality Amsterdam), they are more likely to be *transferred* to other independent actors that can adopt the solution (i.e. city to city). The *spreading* of NBS for urban drainage happens spontaneously when solutions are considered valuable and worthy of being copied by other parties. Both *transferring* and *spreading* benefit from knowledge-sharing platforms like the Amsterdam Rainproof.

The lenses of sustainability transformations proved useful in exploring how the implementation of NBS for urban drainage can be amplified in Amsterdam. Using the amplification framework proposed by Lam et al. (2020) helped operationalizing mechanisms of transformative change from different research areas into an analytical framework on the current state of NBS implementation in Amsterdam, exploring amplification possibilities. The activation of the various amplification processes happens in the background of everyday urban planning and practice. Surfacing their contribution and influence gives tools to purposefully shape the desired transformation towards a rainproof city. The findings above also reinforced the value of urban experiments to realize sustainability transformations (Frantzeskaki, Castán Broto, et al., 2017), informing Amsterdam about successful actions and the ones still needed to keep expanding the quality and coverage of NBS for urban drainage. If the implementation of NBS experiments is amplified, the blue and green infrastructure network that supports the traditional drainage infrastructure can be built, increasing urban resilience and achieving the desired Rainproof Amsterdam.

This research contributed to the planning and urban sustainability fields in three ways:

First, proposing a functional implementation framework for NBS based on four dimensions and defining indicators for their validation in practice, building upon the work of Davies et al. (2015) and Raymond et al. (2017). Furthermore, it connects these dimensions with the main barriers and enablers of NBS implementation found across a rich body of literature and condensed by Sarabi et al. (2019), which allows targeting solutions to the implementation obstacles identified in the empirical research.

Second, approaching the implementation of NBS from an urban experiment's perspective and analyzing their contribution to sustainability transformations. While this approach is not novel, NBS research using the lenses of urban experimentation is recent and limited (Frantzeskaki, Castán Broto, et al., 2017; Xie & Bulkeley, 2020) and cities benefit from additional empirical research demonstrating the contribution of NBS experiments as a driver for transformations, pushing implementation further (Albert et al., 2019; Frantzeskaki et al., 2019).

Third, using the amplification framework from Lam et al. (2020) as analytical lenses in the empirical research, making a novel contribution to sustainability transitions' studies. The amplification framework integrates existing processes from six other frameworks found in sustainability transformations' research, creating a cohesive and transdisciplinary typology (Lam et al., 2020). The authors expected the framework could be used to assist initiatives striving to achieve sustainability transitions in practice, and that was achieved in this research, which proposes ways to increase NBS's transformative impact on Amsterdam's urban drainage system.

The research did not come without limitations, which are addressed next. Regarding the research design, only two projects were used in the analysis of NBS implementation, being restricted to the Zuidas district, an important and wealthy neighborhood. The selection of the projects was careful to include relevant cases at the local level, and the analysis took a step back to have a broader view of the implementation process. Still, the selection of other or more diverse projects (i.e. located in other neighborhoods) could have yield slightly different outcomes. To reduce the impact of this limitation, the interviews included questions on the implementation of NBS at the city level, but oftentimes the respondents focused their answers on the Zuidas area, as that is their main area of action.

Regarding the selection of interview participants, the methods used for their recruiting were limited to online search and communication, since I do not have a network in the city of Amsterdam. Therefore, I had to rely on online tools - LinkedIn messaging and e-mailing - to recruit participants. The results could be biased on the perceptions of people that are more active on social networks and who reacted to my messages, who are likely more engaged with the research topic. Individuals that do not identify their job position on Linkedin or that did not react to my contact stayed out of reach. To work around this pre-considered bias, I tried to use the snowballing method with participants to identify potential respondents out of my reach. However, only 3 out of 10 interviewees were recruited this way, so the bias should be considered when reading the results. Finally, I do not consider this to weaken the research outcomes, given its interpretivist epistemological approach.

Lastly, I am conscious that my choices for the theoretical framework and analysis have forefronted some aspects of nature-based solutions, while the concept requires a holistic and multi-dimensional approach (Kabisch et al., 2016; Nesshöver et al., 2017). Due to the research focus laying on transformative change and amplification processes, I emphasized the technical and socio-institutional aspects of NBS implementation while the ecological aspects remained secondary. This was a conscious decision for conciseness and time's sake. However, it reinforces the critique often made to NBS research from the planning field, which fails to integrate the ecological and biodiversity indicators in the assessment of NBS projects (Albert et al., 2019; Bush & Doyon, 2019; Nesshöver et al., 2017).

While the research goals and objectives have been fulfilled, new questions emerged during this study, creating opportunities for further research to deepens the knowledge on the research topics. One of these opportunities is to investigate each of the amplification processes more thoroughly to understand how they can be purposefully activated, and to what extent they influence the implementation process. Potential research questions are, for example, '*how can the Municipality transfer the knowledge obtained with NBS pilot projects to citizens?*' And, *'how do the different transferring strategies increase the impact of NBS?*'

Additionally, the main findings have briefly touched upon the interactions and influence of one mechanism with the others. Further research could focus on these interactions to determine *if there is a better order to activate amplification mechanisms, achieving greater transformative impact*. Finally, another opportunity is to research how the amplification of NBS happens on private projects without governmental partnerships. This research intentionally selected projects with the participation of the local authority, for understanding their centralizing role in urban drainage. Yet, the interviewees and documentation highlighted the need of including private areas and homeowners in the effort of creating a 'sponge effect' in the city. Hence, the question of '*how the amplification of NBS for urban drainage affects private projects and contributes to expanding the urban blue and green infrastructure network?*' remains.

References

aan de Brugh, M. (2021, July 15). *Nederland krijgt vaker te maken met extreme regenval* [Digital Newspaper]. NRC. https://www.nrc.nl/nieuws/2021/07/15/nederland-krijgt-vaker-te-maken-met-extreme-regenval-a4051140

Albert, C., Schröter, B., Haase, D., Brillinger, M., Henze, J., Herrmann, S., Gottwald, S., Guerrero, P., Nicolas, C., & Matzdorf, B. (2019). Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? *Landscape and Urban Planning*, *182*, 12–21. https://doi.org/10.1016/j.landurbplan.2018.10.003

Amsterdam Rainproof. (2018). *Magazine Amsterdam Rainproof*. https://www.rainproof.nl/sites/default/files/rainproof-magazine-engels.pdf

Amsterdam Rainproof. (2021a). *Wat is Rainproof?* [Institutional]. Amsterdam Rainproof. https://www.rainproof.nl/wat-is-rainproof

Amsterdam Rainproof. (2021b, April 30). *Hemelwaterverordening* [Institutional]. Amsterdam Rainproof. https://www.rainproof.nl/hemelwaterverordening

Amsterdam Zuidas. (2019, February 6). *Prinses Irenestraat krijgt 'groene gracht'*. Zuidas. https://zuidas.nl/blog/2019/02/06/prinses-irenestraat-krijgt-groene-gracht/

Bai, X., Elmqvist, T., Frantzeskaki, N., McPhearson, T., Simon, D., Maddox, D., Watkins, M., Romero-Lankao, P., Parnell, S., Griffith, C., & Roberts, D. (2018). Synthesis—New Integrated Urban Knowledge for the Cities We Want. In T. Elmqvist, X. Bai, N. Frantzeskaki, C. Griffith, D. Maddox, T. McPhearson, S. Parnell, P. Romero-Lankao, D. Simon, & M. Watkins (Eds.), *Urban Planet: Knowledge towards Sustainable Cities* (pp. 462–482). Cambridge University Press. https://doi.org/10.1017/9781316647554.055

Bennett, E. M., Solan, M., Biggs, R., McPhearson, T., Norström, A. V., Olsson, P., Pereira, L., Peterson, G. D., Raudsepp-Hearne, C., Biermann, F., Carpenter, S. R., Ellis, E. C., Hichert, T., Galaz, V., Lahsen, M., Milkoreit, M., Martin López, B., Nicholas, K. A., Preiser, R., … Xu, J. (2016). Bright spots: Seeds of a good Anthropocene. *Frontiers in Ecology and the Environment*, *14*(8), 441–448. https://doi.org/10.1002/fee.1309

Blakely, E. J. (2007). *Urban planning for climate change* (Working Paper WP07EB1; p. 29). Lincoln Institute of Land Policy. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.452.2918&rep=rep1&type=pdf

Bowen, G. A. (2009). Document Analysis as a Qualitative Research Method. *Qualitative Research Journal*, *9*(2), 27–40. https://doi.org/10.3316/QRJ0902027

Brears, R. C. (2018). *Blue and Green Cities: The Role of Blue-Green Infrastructure in Managing Urban Water Resources*. Palgrave Macmillan. https://doi.org/10.1057/978-1-137-59258-3

Brinkhuis-Jak, M., Holterman, S. R., Kok, M., & Jonkman, S. N. (2004). Cost benefit analysis and flood damage mitigation in the Netherlands. *Heron*, *49*(1), 8.

Bryman, A. (2016). *Social Research Methods* (5th ed.). Oxford University Press.

Bulkeley, H., & Castán Broto, V. (2013). Government by experiment? Global cities and the governing of climate change. *Transactions of the Institute of British Geographers*, *38*(3), 361–375. https://doi.org/10.1111/j.1475-5661.2012.00535.x

Bulkeley, H., Castán Broto, V., & Maassen, A. (2014). Low-carbon Transitions and the Reconfiguration of Urban Infrastructure. *Urban Studies*, *51*(7), 1471–1486. https://doi.org/10.1177/0042098013500089

Bush, J., & Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities*, *95*, 1–8. https://doi.org/10.1016/j.cities.2019.102483

Carter, J. G. (2011). Climate change adaptation in European cities. *Current Opinion in Environmental Sustainability*, *3*(3), 193–198. https://doi.org/10.1016/j.cosust.2010.12.015

Carter, J. G., Cavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). Climate change and the city: Building capacity for urban adaptation. *Progress in Planning*, *95*, 1–66. https://doi.org/10.1016/j.progress.2013.08.001

Chong, J. (2014). Ecosystem-based approaches to climate change adaptation: Progress and challenges. *International Environmental Agreements: Politics, Law and Economics*, *14*(4), 391–405. https://doi.org/10.1007/s10784-014-9242-9

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C. R., Renaud, F. G., Welling, R., & Walters, G. (2019). Core principles for successfully implementing and upscaling Nature-based Solutions. *Environmental Science & Policy*, *98*, 20–29. https://doi.org/10.1016/j.envsci.2019.04.014

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (Eds.). (2016). *Nature-based solutions to address global societal challenges*. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Connop, S., Vandergert, P., Eisenberg, B., Collier, M. J., Nash, C., Clough, J., & Newport, D. (2016). Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. *Environmental Science & Policy*, *62*, 99–111. https://doi.org/10.1016/j.envsci.2016.01.013

Davies, C., Hansen, R., Rall, E., Pauleit, S., Lafortezza, R., De Bellis, Y., Santos, A., & Tosics, I. (2015). *Green Infrastructure Planning and Implementation: The status of European green space planning and implementation based on an analysis of selected European city-regions* (Technical Report No. WP5; p. 134). http://rgdoi.net/10.13140/RG.2.1.1723.0888

Davies, C., & Lafortezza, R. (2019). Transitional path to the adoption of nature-based solutions. *Land Use Policy*, *80*, 406–409. https://doi.org/10.1016/j.landusepol.2018.09.020

Davis, M., & Naumann, S. (2017). Making the Case for Sustainable Urban Drainage Systems as a Nature-Based Solution to Urban Flooding. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 123–137). Springer, Cham.

de Vries, J., & Wolsink, M. (2009). Making Space for Water: Spatial Planning and Water Management in the Netherlands. In S. Davoudi, J. Crawford, & A. Mehmood (Eds.), *Planning for Climate Change: Strategies for Mitigation and Adaptation for Spatial Planners* (1st ed., pp. 191–204). Routledge. https://doi-org.proxy.library.uu.nl/10.4324/9781849770156

Depietri, Y., & McPhearson, T. (2017). Integrating the Grey, Green, and Blue in Cities: Nature-Based Solutions for Climate Change Adaptation and Risk Reduction. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 91–109). Springer, Cham.

Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W., & Le Roux, X. (2015). Nature-based Solutions: New Influence for Environmental Management and Research in Europe. *GAIA*, *24*(4), 243–248. https://doi.org/10.14512/gaia.24.4.9

Emilsson, T., & Sang, Å. O. (2017). Impacts of climate change on urban areas and nature-based solutions for adaptation. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 15–27). Springer, Cham.

European Commission. (2015). *Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities* (p. 74). European Union. https://data.europa.eu/doi/10.2777/765301

European Commission. (2021). *Forging a climate-resilient Europe—The new EU Strategy on Adaptation to Climate Change* (p. 23). European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., & Vandewoestijne, S. (2017). Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*, *159*, 509–518. https://doi.org/10.1016/j.envres.2017.08.032

Feola, G. (2015). Societal transformation in response to global environmental change: A review of emerging concepts. *Ambio*, *44*, 376–390. https://doi.org/10.1007/s13280-014-0582-z

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & 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. https://doi.org/10.1080/1573062X.2014.916314

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, *12*(2), 219–245. https://doi.org/10.1177/1077800405284363

Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy*, *93*, 101–111. https://doi.org/10.1016/j.envsci.2018.12.033

Frantzeskaki, N., Borgström, S., Egermann, L., & Ehnert, F. (2017). Nature-Based Solutions Accelerating Urban Sustainability Transitions in Cities: Lessons from Dresden, Genk and Stockholm Cities. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 65–88). Springer, Cham.

Frantzeskaki, N., Castán Broto, V., Coenen, L., & Loorbach, D. (2017). Urban Sustainability Transitions: The Dynamics and Opportunities of Sustainability Transitions in Cities. In N. Frantzeskaki, V. Castán Broto, L. Coenen, & D. Loorbach (Eds.), *Urban Sustainability Transitions* (1st ed., pp. 1–19). Routledge. https://doi-org.proxy.library.uu.nl/10.4324/9781315228389

Frantzeskaki, N., McPhearson, T., Collier, M. J., Kendal, D., Bulkeley, H., Dumitru, A., Walsh, C., Noble, K., van Wyk, E., Ordóñez, C., Oke, C., & Pintér, L. (2019). Nature-Based Solutions for Urban Climate Change Adaptation: Linking Science, Policy, and Practice Communities for Evidence-Based Decision-Making. *BioScience*, *69*, 455–466. https://doi.org/10.1093/biosci/biz042

Frantzeskaki, N., Vandergert, P., Connop, S., Schipper, K., Zwierzchowska, I., Collier, M., & Lodder, M. (2020). Examining the policy needs for implementing nature-based solutions in cities: Findings from city-wide transdisciplinary experiences in Glasgow (UK), Genk (Belgium) and Poznań (Poland). *Land Use Policy*, *96*, 1–9. https://doi.org/10.1016/j.landusepol.2020.104688

GBC. (2020). *Parkdak Zuidas: 25.000 m2 in 2020* [Institutional]. Green Business Club Kennisbank. https://greenbusinessclub.nl/kennisbank/projecten/25-000-m2-parkdak-in-zuidas-in-2020/

GBC Zuidas. (2021a). *GBC Zuidas Ambitieverklaring 2021-2025*. https://greenbusinessclub.nl/zuidas/wp-content/uploads/sites/6/2021/03/GBC-Zuidas-Ambitieverklaring-2021-2025-1.pdf

GBC Zuidas. (2021b). *Green Business Club Zuidas—About us* [Institutional]. Green Business Club. https://greenbusinessclub.nl/zuidas/over-ons/

Geels, F. W., & Schot, J. (2010). The Dynamics of Transitions: A Socio-Technical Perspective. In J. Grin, J. Rotmans, & J. Schot (Eds.), *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change* (1st ed.). Routledge.

Gemeente Amsterdam. (2011). *Structuurvisie Amsterdam 2040—Economisch sterk en duurzaam*. https://assets.amsterdam.nl/publish/pages/867639/structuurvisie_amsterdam_2040_2011.pdf

Gemeente Amsterdam. (2017). *Plan voor een groene Zuidas*. https://www.must.nl/wp-content/uploads/2019/03/Plan-voor-een-groene-Zuidas-raadsdocument.pdf

Gemeente Amsterdam. (2020a). *Strategie Klimaatadaptatie Amsterdam*. https://www.omgevingsweb.nl/wp-content/uploads/po-assets/301953.pdf

Gemeente Amsterdam. (2020b). *Groenvisie 2020-2050—Een leefbare stad voor mens en dier*. https://www.amsterdam.nl/wonen-leefomgeving/duurzaam-amsterdam/publicaties-duurzaam-groen/groenvisie-2050-leefbare-stad-mens-dier/?PagClsIdt=15556562#PagCls_15556562

Gemeente Amsterdam. (2021a). *Duurzaam ontwikkelen* [Institutional]. Gemeente Amsterdam; Gemeente Amsterdam. https://duurzaamontwikkelen.amsterdam/klimaatadaptatie/

Gemeente Amsterdam. (2021b). *Samen aan de slag voor een klimaatbestendig Amsterdam* [Institutional]. Amsterdam.nl; Gemeente Amsterdam. https://www.amsterdam.nl/bestuur-organisatie/volg-beleid/coalitieakkoord-uitvoeringsagenda/gezonde-duurzame-stad/samen-slag-klimaatbestendig-amsterdam/

Gemeente Amsterdam. (2021c). *Subsidie Groen in Amsterdam* [Institutional]. Gemeente Amsterdam. https://www.amsterdam.nl/veelgevraagd/?productid=%7B11F1610B-B76A-4051-8A8A-44BFE27F8DF6%7D

Gemeente Amsterdam. (2021d). *Uitvoeringsagenda Klimaatadaptatie*. https://www.amsterdam.nl/bestuur-organisatie/volg-beleid/coalitieakkoord-uitvoeringsagenda/gezonde-duurzame-stad/samen-slag-klimaatbestendig-amsterdam/

Gemeente Rotterdam. (2016). *Rotterdam Resilience Strategy: Abstract*. https://s3.eu-central-1.amazonaws.com/storage.resilientrotterdam.nl/uploads/2016/05/09115549/Abstract-Rotterdam-Resilient-Strategy.pdf

Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting Cities for Climate Change: The Role of the Green Infrastructure. *Built Environment*, *33*(1), 115–133. https://doi.org/10.2148/benv.33.1.115

Gómez-Baggethun, E., Gren, Å., Barton, D. N., Langemeyer, J., McPhearson, T., O'Farrell, P., Andersson, E., Hamstead, Z., & Kremer, P. (2013). Urban Ecosystem Services. In T. Elmqvist, M. Fragkias, J. Goodness, B. Güneralp, P. J. Marcotullio, R. I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K. C. Seto, & C. Wilkinson (Eds.), *Urbanization, biodiversity and ecosystem services: Challenges and opportunities* (pp. 175–251). Springer. https://link-springer-com.proxy.library.uu.nl/book/10.1007/978-94-007-7088-1

Gorissen, L., Spira, F., Meynaerts, E., Valkering, P., & Frantzeskaki, N. (2018). Moving towards systemic change? Investigating acceleration dynamics of urban sustainability transitions in the Belgian City of Genk. *Journal of Cleaner Production*, *173*, 171–185. https://doi.org/10.1016/j.jclepro.2016.12.052

Grimm, N. B., & Schindler, S. (2018). Nature of Cities and Nature in Cities—Prospects for Conservation and Design of Urban Nature in Human Habitat. In S. Lele, E. S. Brondizio, J. Byrne, G. M. Mace, & J. Martinez-Alier (Eds.), *Rethinking Environmentalism: Linking Justice, Sustainability, and Diversity* (Vol. 23, pp. 99–125). MIT Press. https://doi.org/10.7551/mitpress/11961.001.0001

Haase, D. (2017). Nature-Based Solutions and Climate Change – Four Shades of Green. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 111–121). Springer, Cham.

Hermans, F., Roep, D., & Klerkx, L. (2016). Scale dynamics of grassroots innovations through parallel pathways of transformative change. *Ecological Economics*, *130*, 285–295. https://doi.org/10.1016/j.ecolecon.2016.07.011

Horcea-Milcu, A.-I., Martín-López, B., Lam, D. P. M., & Lang, D. J. (2020). Research pathways to foster transformation: Linking sustainability science and social-ecological systems research. *Ecology and Society*, *25*(1), 13. https://doi.org/10.5751/ES-11332-250113

Hurlimann, A. C., & March, A. P. (2012). The role of spatial planning in adapting to climate change. *WIREs Clim Change*, *3*(5), 477–488. https://doi.org/10.1002/wcc.183

IPCC. (2007). *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 104). IPCC. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., & Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: Perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society*, *21*(2), 39. https://doi.org/10.5751/ES-08373-210239

Kapetas, L. (2020). *The RESILIO project: Journal N° 1* (p. 17). UIA - Urban Innovative Actions. https://www.uia-initiative.eu/sites/default/files/2020-06/Amsterdam_Resilio_Journal%201.pdf

Kapetas, L. (2021). *RESILIO's Journal #2: From planning to development* (p. 5). UIA - Urban Innovative Actions. https://www.uia-initiative.eu/en/news/resilios-journal-2-planning-development-6

Kersten, A. (2021, June 19). *Extreme weersomstandigheden: 'Zoveel regen in zo'n korte tijd komt bijna nooit voor'* [Digital Newspaper]. NH Nieuws. https://www.nhnieuws.nl/nieuws/287634/extreme-weersomstandigheden-zoveel-regen-in-zon-korte-tijd-komt-bijna-nooit-voor

KNMI. (2014). *Climate scenarios—Pictures of the future* [Institutional]. KNMI Projects. https://www.knmiprojects.nl/projects/climate-scenarios

Lam, D. P. M., Martín-López, B., Wiek, A., Bennett, E. M., Frantzeskaki, N., Horcea-Milcu, A. I., & Lang, D. J. (2020). Scaling the impact of sustainability initiatives: A typology of amplification processes. *Urban Transformations*, *2*, 1–24. https://doi.org/10.1186/s42854-020-00007-9

Leichenko, R. (2011). Climate change and urban resilience. *Current Opinion in Environmental Sustainability*, *3*, 164–168. https://doi.org/10.1016/j.cosust.2010.12.014

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. SAGE.

Loorbach, D., Frantzeskaki, N., & Avelino, F. (2017). Sustainability Transitions Research: Transforming Science and Practice for Societal Change. *Annual Review of Environment and Resources*, *42*(1), 599–626. https://doi.org/10.1146/annurev-environ-102014-021340

Maes, J., & Jacobs, S. (2015). Nature-Based Solutions for Europe's Sustainable Development: Europe's sustainable development. *Conservation Letters*, *10*(1), 121–124. https://doi.org/10.1111/conl.12216

Marlow, D. R., Moglia, M., Cook, S., & Beale, D. J. (2013). Towards sustainable urban water management: A critical reassessment. *Water Research*, *47*(20), 7150–7161. https://doi.org/10.1016/j.watres.2013.07.046

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis* (p. 155). Island Press. https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Mimura, N., Pulwarty, R. S., Elshinnawy, I., Redsteer, M. H., Huang, H. Q., Nkem, J. N., Rodriguez, R. A. S., Moss, R., Vergara, W., Darby, L. S., & Duc, D. M. (2014). Adaptation planning and implementation. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White, *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 University Press.

Moerkamp, J. (2019). Een groene zoom voor de hoog-stedelijke Zuidas in Amsterdam. *Vakblad Groen*, *75*(9), 16–19.

Moore, M.-L., Riddell, D., & Vocisano, D. (2015). Scaling out, scaling up, scaling deep: Strategies of non-profits in advancing systemic social innovation. *Journal of Corporate Citizenship*, *58*, 67–84.

Morchain, D. (2018). Rethinking the framing of climate change adaptation: Knowledge, power, and politics. In S. Klepp & L. Chavez-Rodriguez, *A Critical Approach to Climate Change Adaptation: Discourses, Policies, and Practices* (pp. 55–73). Routledge. https://library.oapen.org/handle/20.500.12657/27355

NATURVATION. (2020). *Polder Roof Zuidas*. URBAN NATURE ATLAS. https://una.city/nbs/amsterdam/polder-roof-zuidas

Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Külvik, M., Rey, F., van Dijk, J., Vistad, O. I., Wilkinson, M. E., & Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of The Total Environment*, *579*, 1215–1227. https://doi.org/10.1016/j.scitotenv.2016.11.106

Okdie, B. M., Guadagno, R. E., Bernieri, F. J., Geers, A. L., & Mclarney-Vesotski, A. R. (2011). Getting to know you: Face-to-face versus online interactions. *Computers in Human Behavior*, *27*(1), 153–159. https://doi.org/10.1016/j.chb.2010.07.017

Olsson, P., Moore, M.-L., Westley, F. R., & McCarthy, D. D. P. (2017). The concept of the Anthropocene as a game-changer: A new context for social innovation and transformations to sustainability. *Ecology and Society*, *22*(2), 31. https://doi.org/10.5751/ES-09310-220231

Otto-Zimmermann, K., & Balbo, A. (2012). The Global Adaptation Community Expands Its Scope. In K. Otto-Zimmermann (Ed.), *Resilient Cities 2: Cities and Adaptation to Climate Change – Proceedings of the Global Forum 2011* (Vol. 2, pp. 3–8). Springer. https://doi.org/10.1007/978-94-007-4223-9

Pauleit, S., Zölch, T., Hansen, R., Randrup, T. B., & van den Bosch, C. K. (2017). Nature-Based Solutions and Climate Change – Four Shades of Green. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 29–49). Springer, Cham.

Pereira, L., Karpouzoglou, T., Doshi, S., & Frantzeskaki, N. (2015). Organising a Safe Space for Navigating Social-Ecological Transformations to Sustainability. *International Journal of Environmental Research and Public Health*, *12*(6), 6027–6044. https://doi.org/10.3390/ijerph120606027

Raymond, C., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D., & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy*, *77*, 15–24. https://doi.org/10.1016/j.envsci.2017.07.008

Riddell, D., & Moore, M. (2015). *Scaling out, scaling up, scaling deep: Advancing Systemic Social Innovation and the Learning Processes to Support it* (p. 36). J.W. McConnell Family Foundation. https://mcconnellfoundation.ca/wp-content/uploads/2017/08/ScalingOut_Nov27A_AV_BrandedBleed.pdf

Rydin, Y. (2007). Re-Examining the Role of Knowledge Within Planning Theory. *Planning Theory*, *6*(1), 52–68. https://doi.org/10.1177/1473095207075161

Sarabi, S. E., Han, Q., Romme, A. G., De Vries, B., & Wendling, L. (2019). Key Enablers of and Barriers to the Uptake and Implementation of Nature-Based Solutions in Urban Settings: A Review. *Resources*, *8*(3), 121. https://doi.org/10.3390/resources8030121

Schuttenhelm, R. (2021, July 28). *Klimaatverandering maakte extreme neerslag Limburg heftiger* [Digital Newspaper]. NU.nl. https://www.nu.nl/klimaat/6146588/klimaatverandering-maakte-extreme-neerslag-limburg-heftiger.html

Seddon, N., Chausson, A., Berry, P., Girardin, C., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Phil. Trans. R. Soc. B*, *375*(1794), 12. https://doi.org/10.1098/rstb.2019.0120

Small, N., Munday, M., & Durance, I. (2017). The challenge of valuing ecosystem services that have no material benefits. *Global Environmental Change*, *44*, 57–67. https://doi.org/10.1016/j.gloenvcha.2017.03.005

Squires, A. (2009). Methodological challenges in cross-language qualitative research: A research review. *International Journal of Nursing Studies*, *46*(2), 277–287. https://doi.org/10.1016/j.ijnurstu.2008.08.006

Stolp, S. (2015, January 14). *Het Polderdak* [Institutional]. Amsterdam Rainproof. https://www.rainproof.nl/het-polderdak

Suleiman, L. (2021). Blue green infrastructure, from niche to mainstream: Challenges and opportunities for planning in Stockholm. *Technological Forecasting and Social Change*, *166*, 12. https://doi.org/10.1016/j.techfore.2020.120528

Terpstra, T., & Gutteling, J. M. (2008). Households' Perceived Responsibilities in Flood Risk Management in The Netherlands. *International Journal of Water Resources Development*, *24*(4), 555–565. https://doi.org/10.1080/07900620801923385

van de Ven, F. H. M., Gersonius, B., Graaf, R., Luijendijk, E., & Zevenbergen, C. (2011). Creating water robust urban environments in the Netherlands: Linking spatial planning, design and asset management using a three-step approach: Creating water robust urban environments. *Journal of Flood Risk Management*, *4*, 273–280. https://doi.org/10.1111/j.1753-318X.2011.01109.x van der Aa, E. (2020, July 7). *Steeds meer schade door extreme neerslag: 'Vaker verrast door hoosbuien'* [Digital Newspaper]. Het Parool. https://www.parool.nl/gs-b2eaf67a

van der Jagt, A., Raven, R., Dorst, H., & Runhaar, H. (2020b). Nature-based innovation systems. *Environmental Innovation and Societal Transitions*, *35*, 202–216. https://doi.org/10.1016/j.eist.2019.09.005

van der Jagt, A., Toxopeus, H., Tozer, L., Dorst, H., Runhaar, H., & Bulkeley, H. (2020). *Greening European Cities: Accelerating the uptake of Urban Nature-Based Solutions* (Deliverable 5.8.; p. 54). NATURVATION. https://naturvation.eu/system/files/greeningeuropeancities_accelerating_the_uptake_of_urban_nbs_final.pdf

van Weeren, B.-J., Beersma, J., Peerdeman, K., Hakvoort, H., & Talsma, M. (2018). *Overal in Nederland, nu én in de toekomst: Een actueel beeld van de kans op extreme neerslag*. Stichting Toegepast Onderzoek Waterbeheer STOWA. https://library.wur.nl/WebQuery/hydrotheek/2283059

Wamsler, C., Luederitz, C., & Brink, E. (2014). Local levers for change: Mainstreaming ecosystem-based adaptation into municipal planning to foster sustainability transitions. *Global Environmental Change*, *29*, 189–201. https://doi.org/10.1016/j.gloenvcha.2014.09.008

Wamsler, C., Pauleit, S., Zölch, T., Schetke, S., & Mascarenhas, A. (2017). Mainstreaming Nature-Based Solutions for Climate Change Adaptation in Urban Governance and Planning. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 257–273). Springer, Cham.

Wamsler, C., Wickenberg, B., Hanson, H., Alkan Olsson, J., Stålhammar, S., Björn, H., Falck, H., Gerell, D., Oskarsson, T., Simonsson, E., Torffvit, F., & Zelmerlow, F. (2020). Environmental and climate policy integration: Targeted strategies for overcoming barriers to nature-based solutions and climate change adaptation. *Journal of Cleaner Production*, *247*, 119154. https://doi.org/10.1016/j.jclepro.2019.119154

Waternet. (2015). *Gemeentelijk Rioleringsplan (2016-2021)*. Waternet. https://www.waternet.nl/siteassets/ons-water/gemeentelijk-rioleringsplan-amsterdam-2016-2021.pdf

Xie, L., & Bulkeley, H. (2020). Nature-based solutions for urban biodiversity governance. *Environmental Science & Policy*, *110*, 77–87. https://doi.org/10.1016/j.envsci.2020.04.002

Yin, R. K. (2018). *Case Study Research and Applications: Design and Methods* (6th ed.). SAGE.

Zhou, Q. (2014). A Review of Sustainable Urban Drainage Systems Considering the Climate Change and Urbanization Impacts. *Water*, *6*(4), 976–992. https://doi.org/10.3390/w6040976

Appendices

Appendix A

Framework / Reference author(s)	**Theoretical background / Reference authors(s)**	**Amplification purpose**	**Processes utilized in the framework**	**Amplification typology category**
Framework: **Strategies for social innovation** Author: Moore et al. 2015	Social innovations research Author: Westley et al. 2006	To achieve systemic impacts and large systems change (Moore et al. 2015, p.3 and 6).	*Scaling up* - "Impacting laws And policy"	Scaling up
			Scaling out - "Impacting greater numbers"	Replicating / Spreading
			Scaling deep - "Impacting cultural roots"	Scaling deep
			Cross-cutting – *"*Impacting across disciplines"	*not considered
Framework**: Seeds of a good Anthropocene** Author: Bennett et al. 2016	Social-ecological transformations research Author: Gunderson and Holling 2002	To have transformative impacts beyond initial localities and sectors (Bennett et al. 2016, p. 443).	*Scale up* – "to grow, to involve more people and places"	Stabilizing / growing
			Scale out – "to reproduce in different places"	Replicating
			Scale deep – "to change underlying values to inspire people to live in a different way"	Scaling deep
Framework: **Scale dynamics** Author: Hermans et al. 2016	Social-ecological transformations research and socio-technical transitions research Author: Gunderson and Holling 2002; Grin et al. 2010	To enact transformative change across scales and have a wider impact beyond the people directly involved in their initial development. (Hermans et al. 2016, p. 285).	*Upscaling* – "identifying opportunities and barriers within institutional structures to properly embed an innovation"	Scaling up
			Outscaling – "to replicate and disseminate programs, products, ideas or innovative approaches in order to affect more people or to cover a larger geographical area"	Growing / Replicating
Framework: **Acceleration mechanisms** Authors: Gorissen et al. 2018; Ehnert et al. 2018	socio-technical transitions research Author: Grin et al. 2010	To accelerate (increase the speed of change) of sustainability transitions in city-regions through transition initiatives (Gorissen et al. 2018, p. 173).	*Upscaling* – "the growth of members, supporters or users of a single transition initiative in order to spread these new ways of TDO (think, doing, organizing)"	Speeding up / stabilizing / growing
			Replicating – "take up of new ways of DTO of one transition initiative by another transition initiative or different actors in order to spread out these new ways"	Speeding up / Transferring / spreading
			Embedding – "the alignment of old and new ways of DTO in order to integrate them into city-regional governance patterns."	Speeding up/Scaling up (yellow and blue)

			Partnering – "pooling and/or complementing of resources, competences, and capacities in order to exploit synergies to support and ensure the continuity of the new ways of DTO".	*not considered
			Instrumentalizing – "tapping into and capitalizing on opportunities provided by the multi-level governance context of the city-region in order to strengthen new ways of DTO locally."	*not considered
Framework: **Transition management** Authors: Rotmans and Loorbach 2008; Frantzeskaki et al. 2018	socio-technical transitions research Author: Grin et al. 2010	To make a potentially large innovative contribution to a transition process (Loorbach 2010, p. 176).	*Scaling up* – "apply a successful experiment at a higher scale level"	Scaling up
			Broadening – "To repeat and link an experiment in a different context"	Replicating / Transferring / Spreading
			Deepening – "To learn as much as possible from a transition experiment within a specific context"	Scaling deep
Framework: **Strategic niche management** Authors: Naber et al. 2017	socio-technical transitions research Author: Grin et al. 2010	To scale-up and diffuse innovative solutions in order to increase the potential of the niche to influence the current regime and eventually achieve a transition." (Naber et al. 2017, p. 344).	*Transformation* – "To transform means that the experiment shapes wider institutional change in theregime selection environment""	Scaling up
			Replication – "To replicate means that the main concept of the experiment is replicated in other locations or contexts"	Transferring / Spreading
			Growing – "To grow means that the experiment continues and more actors participate, or the scale at which technologies are used increases"	Stabilizing / growing
			Accumulation – "To accumulate means that the "experiments are linked to other initiatives""	*not considered
*not considered because it does not focus specifically on increasing impact				

Table 13: Frameworks that compose the amplification typology.

adapted from Lam et al. (2020). Overview of the 6 frameworks used to compose the typology of amplification processes, the main authors responsible for the framework, the theoretical background of the framework, the purpose of the processes identified in each framework to increase the impact of sustainability initiatives, the specific processes proposed by the framework with a brief description and finally the corresponding process in the new typology of amplification processes proposed by Lam et al. (2020).

Appendix B

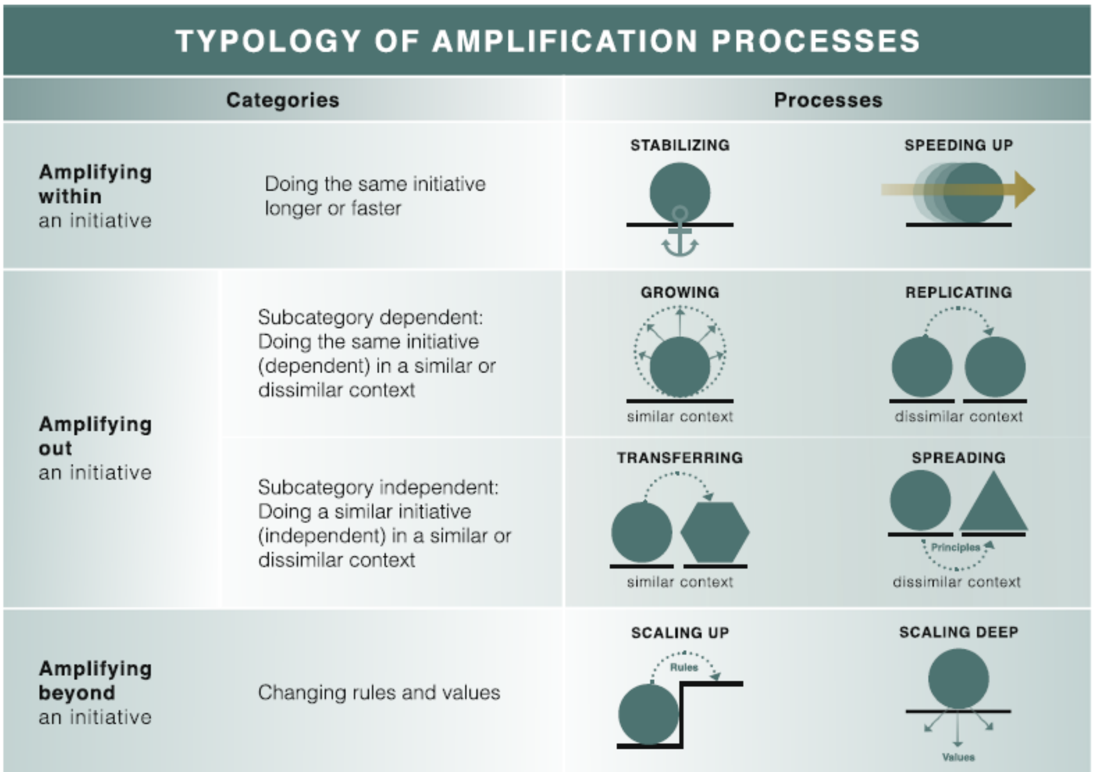


Fig. 2 Illustration of the eight amplification processes grouped into three categories. Note that there is no vertical correspondence between the eight illustrations intended

Figure 19: Typology of Amplification Process by Lam et al. (2020).

Appendix C

Coding Themes and sub-themes		
Main theme:	Categories:	Sub-themes:
Drainage System City Level	**Traditional drainage approach**	• Qualities • Limitations • Other
	NBS approach	• Qualities • Limitations • Other
Implementation Process Project Level	**Green Strip - Prinses Ireenestraat**	• Requirements and process • Enablers / Supporting conditions • Obstacles / Hindering conditions • Other
	Polder Roof System - Polderdak	• Requirements and process • Enablers / Supporting conditions • Obstacles / Hindering conditions • Other
Amplification City & Project Level	**Amplify within**	• Stabilizing • Speeding up
	Amplify out	• Growing • Replicating • Transferring • Spreading
	Amplify beyond	• Scaling up • Scaling deep

Table 14: Coding themes and sub-themes for analysis.

Appendix D

This appendix consists of the full transcript of the interviews, and it is provided as a separate file for privacy reasons.

Utrecht, August 04, 2021