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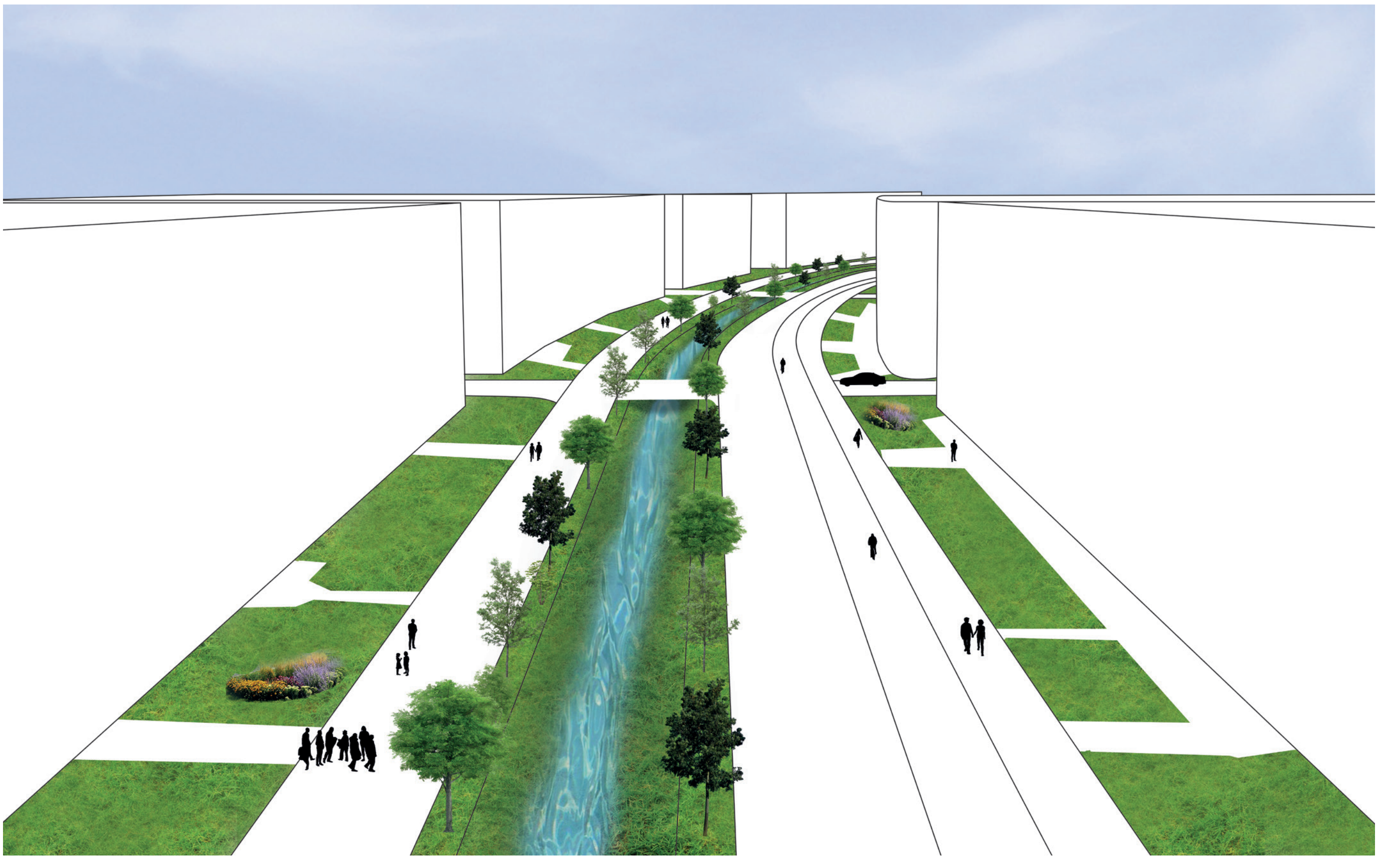

Ecosystem Services for Stormwater Management in Dense City Areas

Master's thesis in Industrial Ecology

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Department of Space, Earth and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

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Cover: Vision of blue-green solutions for stormwater management in Linnégatan, Gothenburg, as developed in this thesis.

ABSTRACT

With the current trend of densification of cities and the threats of pollution and increasing precipitation due to climate change, stormwater management is becoming increasingly important. Traditionally, this has been done through leading the stormwater in mixed sewage pipes to a wastewater treatment plant, or in separate pipes directly to a water recipient. The consequences of these approaches can be combined sewage overflows when the pipe capacity is reached, or that water recipients are polluted by untreated stormwater. Therefore, stormwater best management practices recommend solutions using soil infiltration and plant mechanisms as alternatives. By adding values like biodiversity and human well-being, such ecosystem service-based solutions provide a multifunctional use of space that is highly relevant for dense city areas.

This master's thesis applies a broad perspective on the issue of implementing ecosystem service-based solutions for stormwater management in Gothenburg, focusing on an existing, dense city area. Three research questions were asked:

- Which solutions exist that could be suitable?
- How can space be found to implement them?
- What are the main barriers for implementation?

The research was done in the form of a case study in Linnéstaden, Gothenburg. Drawing on backcasting methodology, explorative interviews and a workshop with researchers and professionals in stormwater management from the public and private sectors were held. The findings were then used to produce a vision for transformation of the case study area and to recommend which barriers to address in moving forward.

The study shows that there are many solutions, such as rain gardens and grass infiltration, already existing that could be tested in Gothenburg. In the developed vision, these solutions are used for stormwater treatment and flow control together with a resurfaced creek in the middle of the street. A major finding is that the solutions should be considered as part of a complex system where existing infrastructure, topography, municipal responsibilities and many more parameters are included. Such a holistic perspective will be a key to maximizing the efficiency and acceptance of ecosystem service-based solutions. Finding the space required to place those solutions is a matter of restructuring streets in a more integrative way. Today, large areas are used for traffic and parking, which limits the freedom of action for other services. Three main themes are presented as the main gaps to address to overcome the barriers. *Legitimacy* refers to convincing all the stakeholders that stormwater is an urgent problem. It is identified that more *research* is still needed about the economical aspect of ecosystem services and local stormwater impact. Lastly, the city of Gothenburg would benefit from a *structure* that redefines responsibilities and facilitate interaction between stakeholders.

KEYWORDS: Stormwater management, ecosystem services, green infrastructure, sustainability, climate adaptation, blue-green solutions, densification

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This thesis was also made possible by the openness and enthusiasm of our interviewees and workshop participants. Their willingness to give us their valuable time to share their views and knowledge was essential, and we owe them thanks for that.

Finally, we would like to thank our respective partners, families and friends for sticking with us through the whole process. Their patience in listening to complaints and accomplishments, and their reminders of what truly matters in life, is what enabled us to get this far.

Amanda Arnö and Cédric Pellegrini, June 2017

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1 Introduction

This master's thesis was written within the Challenge Lab at Chalmers University of Technology. It is a platform for master's thesis students of different backgrounds in which they collaborate to solve complex sustainability problems in the Gothenburg region. The Challenge Lab students are educated to become change agents for sustainability, inviting them to discover their strengths and values. As a part of this process, the students organize dialogues with a wide range of actors working in the region to explore possible thesis topics. Based on such dialogues and further research, the present authors identified stormwater as an important sustainability challenge for Gothenburg. The city is on the verge of an extensive densification development and has inherent difficulties in its soils, topography and historical pollution. Using ecosystem service-based solutions was identified as an opportunity to address this challenge because of the interest showed by relevant actors, an important part of the Challenge Lab approach, and their potential for multifunctionality.

Stormwater is defined by Cettner (2012) as "rainfall that runs off pervious and impervious surfaces such as rooftops and parking lots in urban areas", but runoff from roads is also included in the concept. In cities, impervious surfaces limit ground infiltration which increases surface runoff. Other services originally provided by plants are also lost, such as shading, evapotranspiration, soil infiltration, rainwater storage and stormwater delay (Gill et al, 2007; Murase & Liptan, 2002). As a result, the amount of stormwater is significantly increased (Murase & Liptan, 2002), and the concentration of pollutants in stormwater increases, which impairs water quality (Weiss et al, 2008). In urban areas, increased water quantities cause more erosion and risks of flooding (Booth et al, 2002). The flooding risk is due to an overload of the drainage system, when the pipe capacity is no longer enough (Schmitt et al, 2004).

Urbanization is also an important source of contaminants. Urban stormwater contains many pollutants, including nitrogen, phosphorus, lead, zinc, cadmium, copper, pathogens, suspended particles, salts and organic pollutants such as petroleum hydrocarbons (Weiss et al, 2008). The impact of such pollutants has been widely studied (Sadeghpour et al, 2017; Valtanen, 2014; Viera et al, 2013) and pose several sanitation and environmental impacts. More recently, studies have highlighted the presence and lack of knowledge about micro- and nanoparticles in stormwater (Lopez, 2015; Bisiaux et al, 2011; Keller et al, 2010). Organic pollutants emitted by traffic have also been given attention as they are persistent in the environment, highly toxic, and present in many different varieties (Markiewicz et al, 2017; Björklund, 2011).

On a long-term perspective, the quantity of stormwater is expected to increase due to climate change. Past trends and future projections point at increased global temperatures and rain falls (IPCC, 2008). Due to these increases, urban stormwater is likely to negatively impact water bodies as more pollutants will be transported to recipients (Weiss et al, 2008). In countries like Denmark and Sweden, 100-year events are already becoming more frequent, which results in significant damage and cost (Christian, 2017; Climate-ADAPT, 2014). In Gothenburg, the precipitation is expected to increase by 30 % by 2100, and the flow rate in streams by 50 % during winters (Lind & Kjellström, 2012). Climate change is also predicted to raise sea levels and increase the risk of heat waves in Gothenburg (Lind & Kjellström, 2012).

These challenges have caught the international community's attention. The United Nations published a list of 17 goals in 2015, from which four goals directly relate to stormwater management (UN, 2015):

Goal 3. Ensure healthy lives and promote well-being for all at all ages. The third goal is particularly relevant for stormwater as water can be a carrier of diseases and pollutants. Ensuring proper stormwater management is a critical parameter into building a safe and healthy environment in a sustainable future.

Goal 6. Ensure availability and sustainable management of water and sanitation for all. The sixth goal also deals with water quality but promote smart uses of water, as well as protection of natural environments that provide ecosystem services.

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. The ninth goal states that infrastructures in society should be retrofitted to meet the sustainable requirements. It also promotes cross-disciplinary ownership of challenges which involves fostering of research and projects.

Goal 13. Take urgent action to combat climate change and its impacts. The thirteenth goal as developed by the UN clearly states: "Integrate climate change measures into national policies, strategies and planning" (UN, 2015). As stated earlier, climate change is expected to modify precipitation patterns around the world, which has to be taken into account by the different actors.

The 16 Swedish environmental goals (see Naturvårdsverket, 2017) include three that are directly related to water quality and one concerning the toxicity of the environment. Using ecosystem service-based solutions for stormwater management could also contribute to the two goals concerning biodiversity, and to the one concerning the built environment as they can enhance amenity.

In this thesis, ecosystem service-based solutions for stormwater management are defined as any solution that makes use of the biological services of ground infiltration, evapotranspiration, soil anchoring and shading. Ecosystem service-based solutions are typically used because of their multifunctional nature. In cities, this type of green infrastructure has been shown to support biodiversity, alleviate heat island effects, and generally improve life quality for the population (Gill et al, 2007; Keely et al, 2013). Studies also show that ecosystem service-based solutions have effectively removed pollutants (Ali et al, 2013; Arthur et al, 2005; Ghosh & Singh, 2005), and controlled stormwater flows (Pennino et al, 2016). Ecosystem services for stormwater have been implemented in several cities in North America, northern Europe and Australia. Notable examples are Portland in Oregon, USA, with an extensive strategy implemented in the 1990's (Water environment research foundation, 2009), and Malmö in Sweden, where a system approach was applied to manage sewage overflow in the early 2000's (Klimatanpassningsportalen, 2016).

As mentioned above, the focus in this thesis is on Gothenburg, which is a city in the western part of Sweden with around 550 000 inhabitants. It is built on mostly impermeable soils, with a challenging topography of steep hills combined with flat areas along the Göta river (City of Gothenburg, 2017). The city also has a combined stormwater and sewage system in many parts and an industrial history that caused contamination. Therefore, stormwater is an important issue in the current densification plans. In the area, several recent projects indicate that there is interest in this issue. These projects include a strategic plan for cloudburst management (Göteborg stadsbyggnadskontoret, 2017), a toolbox for stormwater planning (Climate-KIC, 2016), and the ambitious goal of being the world's best city when it rains in 2021 (Göteborgs stad, 2017). There are also projects around ecosystem services for stormwater in new areas (e.g. Göteborgs stad, 2015; Klimatanpassningsportalen, 2017), and as retrofits in less dense areas. However, less attention has been given to investigate the possibilities of implementing them in the dense parts of the existing city, and the implementation is generally slow. A previous master's thesis at the University of Gothenburg conducted a literature study on how to solve these implementation problems, and indicated aspects to consider (Lindh, 2013).

This master's thesis applies a holistic perspective on the issue of implementing ecosystem service-based solutions for stormwater management in Gothenburg, focusing on an existing, dense city area. It seeks to give insight into which types of solutions are suitable, where they can be placed, and what barriers and drivers there are for implementation. The main research question is: ***How can ecosystem services for stormwater management be included in an existing, dense city area?*** The research was done in the form of a case study in the district of Linnéstaden in Gothenburg. In this context, the following sub-questions are answered:

- What types of ecosystem service-based solutions for stormwater exist that could be suitable for the case study area?
- How can space for these solutions be found in the case study area?
- What are the main barriers for implementation?

To help anchor the results in the city, relevant actors in stormwater management from academia and the public and private sectors were involved. An important focus of this thesis is the multifunctionality of solutions. Therefore, it does not cover sustainable stormwater systems not based on ecosystem services, such as permeable pavements and underground sedimentation solutions. Because of the holistic nature of the study, in-depth technical investigations were not conducted.

1.1 How to read this thesis

This thesis is divided in two parts. In chapter 2, the question formation work done in the first phase of the Challenge Lab is presented. The chapter introduces the theories and methods used within the Challenge Lab, as well as presenting the results from this process. In the following chapters, the second part of the thesis containing the main research is presented. The theory chapter contains a literature review of research in sustainable stormwater management, and ecosystem services for stormwater. It also gives a background for the case study. Chapters 4 and 5 contain the methods and results and discussion of the main study, as well as concluding discussions of methods in both phases.

2 Challenge Lab: Phase 1

The transition to sustainability is expected to be complex and difficult. Many different actors with different agendas have to work together to make it happen. Senge, Hamilton and Kania (2015) argue for a systemic leadership based on trust-building and collaboration in this situation. Such leadership can give space for people to achieve the change themselves, and thus avoid resistance to a top-down approach. The Challenge Lab, in which this thesis was written, is inspired by these concepts. It is an initiative at Chalmers University of Technology that empowers students to become system leaders and change agents for sustainability transitions.

In the Challenge Lab, the students are required to design their own research question. This research question is expected to improve the sustainability of the chosen area. To achieve this, the Challenge Lab offers its students tools to develop themselves and their understanding of sustainability transitions. The master's theses are then written in two phases: one where the participants work together to identify sustainability challenges, and one where the students address selected challenges in pairs. In this chapter, phase one of the master's thesis is introduced. First, the background and principles of the Challenge Lab is presented. The following sections include theories and methods relevant for the first phase of the thesis. The result section then describes the process of finding challenges and developing a research question, followed by a discussion of the phase one process.

2.1 The Challenge Lab

The Challenge Lab was initiated by Chalmers, in a project led by John Holmberg in 2011 (Holmberg, 2014). One of the motivational factors for developing the Challenge Lab was to break down walls and boundaries to tackle complex problems related to sustainability. This idea was first addressed by Chalmers' initiative Areas of advance. The Areas of Advance is a challenge-driven organization that invites all departments and disciplines to communicate and work together toward sustainability. The Areas of advance was designed to be the missing link within the knowledge triangle: academia, education and innovation (Areas of advance, 2016).

The Challenge Lab's approach to problems is also based on the triple helix framework used by Chalmers. This framework is inspired from the triple helix developed by Etzkowitz and Leydesdorff (1995). The modified framework used by Chalmers comprises academia, society and business, as well as education and innovation. If the area of advance is the missing link in the knowledge triangle, the Challenge Lab students connect the whole triple helix by bringing knowledge to society and business (Holmberg, 2014). Figure 1 shows the triple helix and the knowledge triangle as it is used by Challenge Lab.

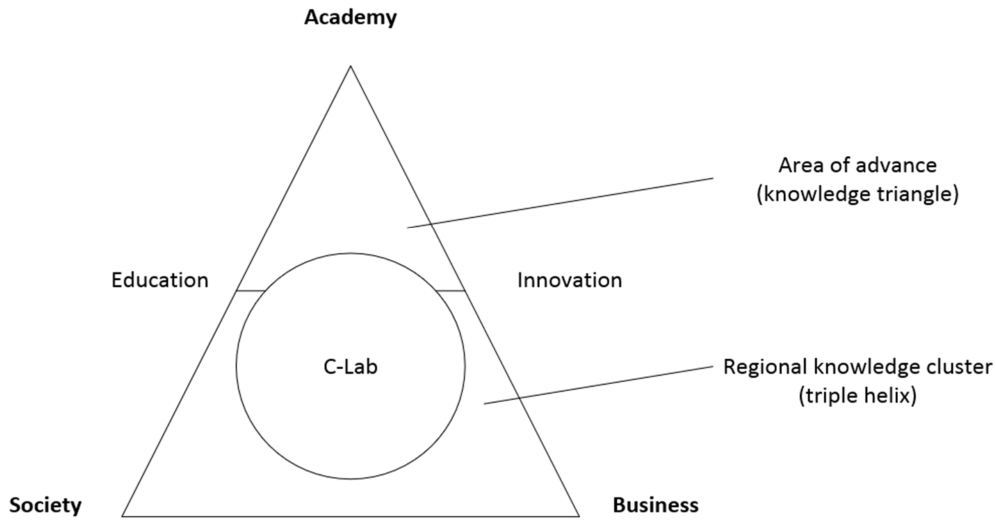

Figure 1. The triple helix and the knowledge triangle. Adapted from Holmberg (2014).

The approach used to connect the triple helix parts is to provide a neutral ground to deal with complex socio-technical problems that require interaction between all stakeholders (Holmberg, 2014). To achieve that, a central concept is to create space for students to become change agents in society. As Holmberg describes, the students are challenging and non-threatening at the same time, giving them unique possibilities to make change happen. According to Holmberg, the strength of the change agent is to be able to approach stakeholders without any organization tag, therefore not representing a competitor on the market.

To further promote collaboration between disciplines, the Challenge Lab invites a heterogenous group of students to come together and reflect on the problems society is facing today and will be facing in the future. The heterogeneity of the group is an important aspect as the overarching idea is to apply many different competences and interests to complex problems (Holmberg, 2014). In 2017, 16 students from ten master's programs and ten countries wrote their master theses in the Challenge Lab.

2.2 Theory

In this section, theories relevant for phase 1 of the thesis are presented. Backcasting, leverage points and multi-level perspectives are the three main theories used in the Challenge Lab. These theories aid the Challenge Lab students in developing a holistic perspective on complex problems.

2.2.1 Backcasting

Backcasting was first introduced in the energy field as an alternative to traditional forecasting (Robinson, 1982). The main characteristic of the approach is that focus is not on how to adapt to a likely future, but on how the most desirable future can be attained. In that way, strategies are designed "backwards", from the future to the present. A general method for sustainability backcasting was first developed by Robinson (1990). In his paper, Robinson argued that the existing forecasting approaches were insufficient in the face of the long-term environmental challenges. Similarly, Dreborg (1998, p. 816) concluded that backcasting is particularly useful when:

- *"the problem to be studied is complex, ...*
- *there is a need for major change, ...*
- *dominant trends are part of the problem, ...*
- *the problem to a great extent is a matter of externalities, …*
- *the scope is wide enough and the time horizon long enough to leave considerable room for deliberate choice ..."*

Therefore, it is not surprising that the main use of backcasting has been in sustainability challenges. Although being used for similar purposes, backcasting studies and practice are very diverse. For instance, the vision of the future could be developed by experts, or be left as a democratic process involving stakeholders or citizens (Vergragt & Quist, 2011). The term is also sometimes used to describe a single step in a methodology, and sometimes for the methodology itself. In the 1990's, a method for sustainability backcasting in organizations was developed for the non-profit organization The Natural Step (Holmberg, 1998). Its four steps, shown in Figure 2, are:

1. Defining criteria for sustainability
2. Describing the current situation, in relation to the criteria for sustainability
3. Envisioning the future
4. Finding strategies for sustainability

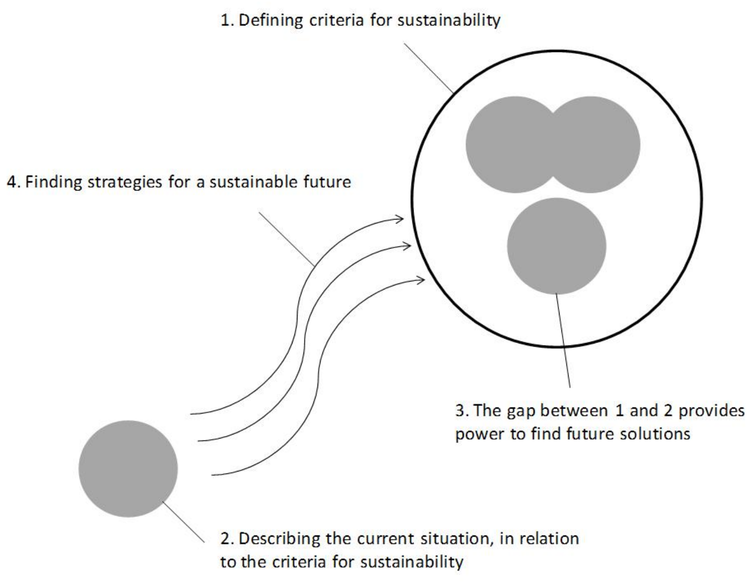

Figure 2. Four steps of backcasting. Adapted from Holmberg (1998).

The criteria defined in the first step are meant to work as a shared mental framework for conducting the remaining steps. They should be non-prescriptive, valid at various scales, and thinking upstream in causal chains (Holmberg & Robèrt, 2000). They should also be worded as simply as possible, without losing content.

2.2.2 Leverage points

Leverage points are defined by Meadows (1997) as places in a complex system that can be pushed to create a shift in the whole system. According to Meadows, the leverage points have different effect depending on how high up in the system that they act. She presents a scale of nine levels of leverage points, where level one is the highest and most effective (Meadows, 1997, pp. 78-79):

"9. Numbers (subsidies, taxes, standards).
8. Material stocks and flows.
7. Regulating negative feedback loops.
6. Driving positive feedback loops.
5. Information flows.
4. The rules of the system (incentives, punishment, constraints).
3. The power of self-organization.
2. The goals of the system.
1. The mindset or paradigm out of which the goals, rules, feedback structure arise."

2.2.3 Multi-level perspective

Multi-level perspective (MLP) is used in transition studies to understand complex system innovations and socio-technical changes. The theory identifies three levels in which socio-technical change can occur (Geels, 2004):

- The niche (micro level), where radical innovations first appear in specific markets. Here, changes can happen quickly, and innovations can be prepared for scaling up.
- The regime (meso level), where the currently dominating technologies, infrastructure and principles exist. Change tends to be slower and more incremental in nature.
- The landscape (macro level) refers to larger societal and environmental structures that no individual can affect. Here, global parameters such as culture, globalization and environmental problems belong. Change at this level is very slow due to its large-scale parameters.

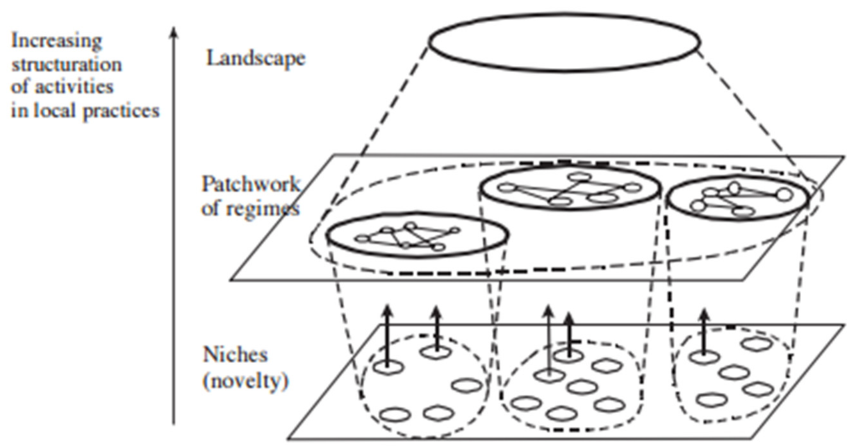

Figure 3. The three levels of the socio-technical system. Figure from Geels (2004).

The levels are related through a "nested hierarchy", where the niches are inside the regime, and the regime is inside the landscape (Geels, 2004, p.684). Therefore, none of the levels are independent, and even the flexible niches are affected by the regime and landscape. This relationship is illustrated in Figure 3.

Geels and Schot (2007) developed a typology of transition pathways that describes how the multi-level system could be changed. Four possible pathways were identified:

> P1. Transitional pathway: moderate pressure from the landscape level together with *undeveloped* niches, causes gradual change of the regime.
> P2. De-alignment and re-alignment: divergent landscape developments pull the regime apart, and leave room for embryonic niche developments. Eventually, one becomes dominant and forms the new regime.
> P3. Technological substitution: pressure from the landscape level together with *developed* niche technology, causes the regime to be replaced by the new niche development.
> P4. Reconfiguration pathway: symbiotic innovations are added to the regime, subsequently triggering further development.

The authors point out that in the event of disruptive landscape changes, the transition is likely to adopt a sequence of pathways, from transformation to reconfiguration and possibly substitution or de-alignment and re-alignment.

2.3 Method

As mentioned above, the Challenge Lab addressed sustainability challenges by creating space for students to become change agents in society. It applies a holistic perspective to sustainability, providing the participants with both inside-out and outside-in tools. The tools given to the participants in the inside-out perspective aim at helping them understand their own strengths, values and visions as well as the interactions between actors in the system. For the outside-in perspective, the tools aim at helping understand the nature and requirements of sustainability transitions (Holmberg, 2014).

The inside-out perspective is informed by theories on self-determination and dialogic leadership (Ryan & Deci, 2006; Isaacs, 1999). In the first week of the Challenge Lab phase 1, a self-leadership workshop was held. During this workshop, deep listening, strengths balancing and value identification exercises were done in order to help the participants become better change agents. The openness between students in the exercises aided the building of trust within the group. The inside-out perspective was also applied throughout the following steps of the process, particularly in the dialogues described in section 4.2.1.

For the outside-in perspective, a central part of this Challenge Lab thesis was the use of backcasting from principles, applying the general framework described by Holmberg (1998) (see section 3.1). The process was divided in two phases. In phase 1, step one and two of the backcasting process were used to find relevant a research question. Step three and four were then addressed in phase 2, which in itself was similar to a conventional thesis. Methods related to phase 2 are presented in chapter 4.

2.3.1 Backcasting step one

As described above, the aim of backcasting step one is to identify criteria for a sustainable future. In this thesis, the criteria were identified by a series of workshops. A sustainability framework describing four dimensions of sustainability was used to aid the criteria development (Figure 4). In this framework, ecological sustainability is seen as the foundation on which the other dimensions stand. The economical and societal dimensions carry the fourth dimension: human well-being.

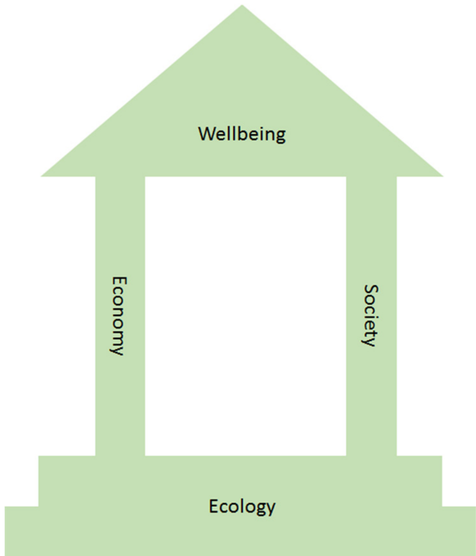

Figure 4. The four dimensions of sustainability used in the Challenge Lab.

First, the Challenge Lab students divided in four groups, each focusing on one of the sustainability dimensions. Then, the preliminary criteria developed were brought up for discussion in the whole group. The criteria were determined to be finished when consensus was reached. To be able to achieve this common framework within the time constraints, an approach of making the wording more general was used whenever strong disagreements occurred. An important input into this process was the inside-out perspective tools described above.

2.3.2 Backcasting step two

During step two, gaps between today's situation and the defined criteria for the future were identified. These were formulated as challenges for a sustainable future. For this purpose, information was gathered both with research on the internet and scientific databases, and with three stakeholder dialogues arranged around three pre-set themes: mobility, urban future, and circular products and services. Step two was then concluded by a process of narrowing down, finding research questions and splitting the group into thesis pairs. The dialogue methods and narrowing down process are described more thoroughly below.

2.3.2.1 Stakeholder dialogues

Before each dialogue, the students prepared discussion topics by mapping the challenges found so far in the system. The purpose of the stakeholder dialogues was to refine this map, and find where there was energy in the system that could be utilized as leverage points.

The stakeholder dialogues were performed in a closed fishbowl format, inspired by the method described in Priles (1993). For this purpose, two concentric circles of chairs were set up. The main discussion took place in the inner circle, while the outer circle acted as observers. After some time of discussion on the set topic, the moderator gave the word to the outer circle, for reflections and questions. Then, a concluding discussion about the outer circle comments took place in the inner circle.

The stakeholders were placed in the inner circle, together with three to four discussing students and two student moderators. The remaining Challenge Lab students took seats in the outer circle. For each dialogue, different stakeholders relevant for the different themes were present. They represented academia, the public and private sectors, and NGOs.

2.3.2.2 Narrowing down

During this stage, the Challenge Lab students divided according to interest, and did additional research on the identified challenges. The goal was to find clear research questions and divide the group into thesis pairs. Within each challenge, leverage points were identified. An important criterion for a leverage point in the Challenge Lab was that there was interest from professionals or activity already happening in the area. The participants then applied their own motivations, strengths and values onto the leverage points, resulting in thesis topics and research questions. In this way, the theses within the Challenge Lab were created with both an outside-in and an inside-out perspective.

2.4 Results

In this section, the results of phase one are presented. The first subsection includes the criteria developed in backcasting step one. The second subsection is divided in stages, where results from the dialogues and narrowing down process are presented.

2.4.1 Defining criteria for sustainability

The following criteria were developed for the four dimensions of sustainability described in 3.1.

Ecological criteria
Substance** emission:
• Nature is not subject to systematically increasing concentrations of substances.

Substance extraction:
• Substances are not extracted in a way it disturbs the balance of natural cycles.

Ecosystem balance:
• Exist in harmony as one system, enabling ecosystem services and biodiversity.
*** A species of matter of definite chemical composition*

Adopted and inspired by Holmberg et al. (1996), Holmberg and Robèrt (2000), UN (2015) and the criteria of Challenge Lab 2016.

Societal criteria
A sustainable society is a system of individuals built upon the following criteria:

• Empowerment
• Equity & Justice
• Trust (such as between individuals, transparency)

• System for well-being (maintain access to food, medical service, support & safety)
• Openness to Development and Novelty

Adopted and inspired by Raworth (2012), Pisano (2012), UN (2015) and the criteria of Challenge Lab 2016.

Economical criteria
The economic system is an instrument that enables the other criteria, to be met efficiently and effective in such a way that:

• Resources* are used indefinitely non-depleting.
• It ensures a fair distribution of resources*.
• It is resilient to disturbance and disruption and is flexible enough to adapt to changing conditions.
• It facilitates transparency and trust.
** Resources include natural and man-made.*

Adopted and inspired by Sen (1985), Anand & Sen (2000), Simmie & Martin (2010), UN (2015) and the criteria of Challenge Lab 2016.

Wellbeing criteria
• Everyone should have the right to human basic needs (subsistence, protection), such as health, security, food, water, sanitation, recreation, shelter, energy.
• Human life should fulfil psychological needs, such as affection, understanding, participation, idleness, creation, identity.
• Everyone should have the equal opportunity and freedom.
  • to choose or to opt out
  • to express one's identity
  • to define and pursue their own goals, objectives and commitment without limiting others' freedom or harming others

Adopted and inspired by Rawls (1971), International Wellbeing Group (2013), Cruz (2009), UN (2015) and the criteria of Challenge Lab 2016.

2.4.2 Describe present situation in relation to the criteria for sustainability

The process of this step can roughly be divided into two parts: one where the whole group worked together (up until the dialogues), and one where the group members were working on different challenges. Therefore, this section of the results has a slightly unusual layout. In the dialogues subsection, the general results for the Challenge Lab are presented. The specific process of this particular thesis is then explained in the following subsections.

2.4.2.1 Dialogues

The three dialogues and personal research built the group's knowledge about the present situation in the region of Västra Götaland. In this section, the main findings from the dialogues are presented.

The main message to take from the first dialogue about circular products and services is that sustainable circularity is a very complex topic that does not fit the existing system. A successful establishment of sustainable circularity will require a lot of time, discussion and a shift in demand. The role of the students could be to facilitate dialogues between actors of the system and understand the needs for a transition toward a sustainable society.

The second dialogue about urban future revealed many oppositions between stakeholders regarding the meaning of a city, and what challenges density should address. One of the hot topics was regarding the place of nature in a dense city. On one hand, some argued that nature does not fit densification planning, while on the other hand, counter arguments highlighted the importance of green areas to contribute to a sustainable city life and well-being. The dialogue was also the occasion to question the stakeholders about social sustainability. Processes of gentrification and segregation have been important in the city history and is still problem in suburbs such as Angered, Hammarkullen and Bergsjön. Understanding the citizens' needs and their empowerment was widely discussed as a key criterion for a denser city in the future.

The third dialogue about mobility explored quite extensively the place of transportation in our society and the social aspect of it. Mobility as service and multi-modal transportation were discussed as solutions to improve sustainability in the transport sector. The area in Gothenburg called Frihamnen appeared to be a place under investigation as plans are being developed for the area. Minimizing the need for individual car usage is part of the plan but requires discussion and research as interests are conflicting.

2.4.2.2 Challenges and leverage points addressed in this thesis

In this thesis, the challenges of density and nature in the city were connected to that of stormwater management. The leverage point identified to address these was to increase the implementation of ecosystem service-based solutions for stormwater management. As mentioned in the introduction chapter, the City of Gothenburg has recently started initiatives around sustainable stormwater management, and there is an interest in using plant-based and open solutions instead of the conventional pipe system. A previous master's thesis in the Challenge Lab researching bioretention planters also found interest among actors in the area (Cuarán & Lundberg, 2015). Therefore, the ecosystem service-based solutions for stormwater were considered a valid leverage point to explore further in this thesis.

2.4.2.3 Personal perspectives of the authors

Cédric Pellegrini is a French student in the Industrial Ecology master's program at Chalmers. He obtained a Bachelor's degree at Griffith University (Australia) after studying Ecology and Conservation. This interest in biology and natural ecosystem dynamics shaped his belief that society as a whole should cooperate more to facilitate the flow of materials and information, just like nature does. As a Challenge Lab student Cédric aims at deepening his knowledge about ecosystem services and discover ways to implement such solutions into industrial ecosystems.

Amanda Arnö is a Swedish student in the engineering program Architecture and Engineering at Chalmers. Like Cédric, she does her master's in Industrial Ecology. Her main interests are in the sustainability of cities and buildings, and in how space can be more multifunctional to aid this purpose. She believes that the sustainability challenges can be solved through cooperation and dialogue.

When combining these backgrounds and interests, four main perspectives and interests on the leverage point emerged:

- Finding a way to integrate green solutions into cities

- Reduce the contaminant runoff to the river
- Multifunctionality of space
- Engineering and design of concepts

4.4.2.4 Finding the research question

The research question for the thesis was obtained by combining the identified leverage point with the above personal perspectives. The choice was made to focus on transforming a dense city area with little green space and need of stormwater treatment to implement ecosystem service-based solutions. Then, there was both a need for multifunctionality of space, a possibility to reduce river contaminants and an integration of green space in the city. In that way, the outside-in perspective of what is objectively relevant was combined with the inside-out perspective of the present authors' motivations. It was also important to choose a research question that would comply with the sustainability criteria designed in backcasting step one. The research question does that by addressing a leverage point related to several of the nature, social and society criteria. In the end, the research question chosen for the present thesis was: ***How can ecosystem services for stormwater management be included in a dense area?***

To explore the research question, it was decided that studying the area around Linnégatan was relevant as investigations are ongoing at the municipal Department of sustainable waste and water (Kretslopp och Vatten). Also, it is a dense area, it uses a combined sewer system, and it is not adapted for stormwater, which both fits the personal perspectives and the leverage point.

2.5 Discussion

The Challenge Lab wants to be a place for innovation: a place where all expertise can work together and design an ideal future. In order to achieve this goal, the lab relies on the backcasting methodology and sustainable criteria developed by the students themselves. The phase 1 of this master thesis was very academic and utopian in this sense. Carlsson-Kanyama et al (2008) encourages to welcome people from different backgrounds to come up with their needs and expectations for the future. In the Challenge Lab, students from different backgrounds came together to write down criteria for the future. Even though it may seem like it was a wide array of people who sat with their needs and expectations, it still was a group of students only. Out of the five elements of the "triple helix", only academia and education were solicited. From that perspective, the designed criteria are backed up by research but may lack credibility and legitimacy when presented to the public sector, the private sector, innovation entities and the citizens. If backcasting fails at being rallied by all the societal entities, its efficiency to drive change may be impaired.

From a multi-level perspective, the identified leverage points should allow this thesis to facilitate the transition of a niche technology to the regime. The system related to the chosen leverage points can be considered on the verge of such a transition. Relating to the transition typology described by Geels and Schot (2007), ecosystem services for stormwater could act as a symbiotic technology, thereby contributing to a reconfiguration pathway to transition. On Meadows' (1997) scale, this thesis falls under the fourth and fifth levels that are "The rules of the system" and "Information flows". In the established Gothenburg pipe system, bringing in ecosystem service-based solutions could be seen as a disruption. Stakeholders have to face new tasks that challenge the rules. Challenging the rules enough to change them is supposedly difficult but may result in important system change (Meadows, 1997). Disrupting the system also brings in new information to the system. In order for that information to have an influence, big efforts are necessary to make it visible by the different actors (Meadows, 1997).

3 Theory

A theoretical background of stormwater management with ecosystem services is presented in this chapter., as well as a description of the case study area.

3.1 Challenges with stormwater

Urban stormwater has been shown to cause a number of impacts on the environment, such as contamination of water bodies with contaminants coming from impervious surfaces (Heaney & Huber, 1984). As suggested by Murase and Liptan (2002), stormwater appeared when forests were cut down and replaced by impervious surfaces. The modelling exercises presented in Figures 5 and 6 revealed that stormwater is a man-made problem. Figure 5 illustrates the accumulation of water on the ground in relation to rainfall in a forest (blue curve) and in urban area (pink curve). Figure 6 illustrates the water runoff in a forest (blue curve) and in urban area (pink curve). It can be observed that in a native forest, stormwater only appears for a rainfall over 31 mm and peak flows almost never happen. Stormwater quantities increases when soil infiltration is no longer possible because of the surface coverage of impervious materials in urban areas. Such modification of the land surface structure is associated with impacts such as land degradation, floods, habitat degradation, loss of urban aesthetics and additional costs for urban maintenance. In addition, all impact due to increasing amounts of stormwater are expected to get worse as climate change could increase the amount of rainfall (Murase & Liptan, 2002).

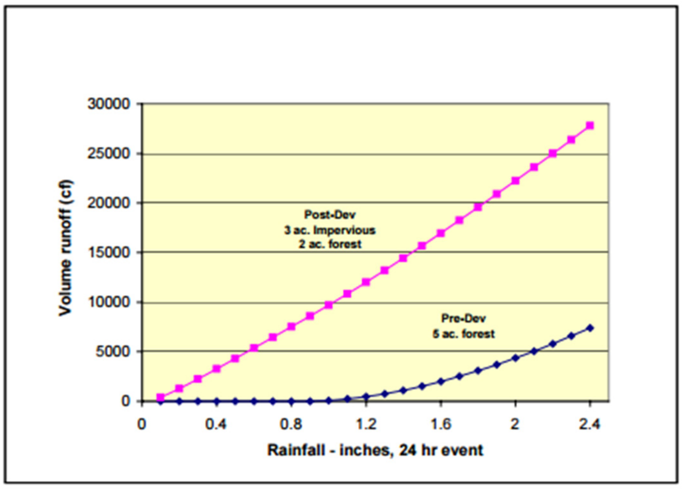

Figure 5.Modelled runoff (cf) in relation to rainfall (inch). The pink curve is the volume runoff post development. The blue curve is the volume runoff pre development (Murase & Liptan, 2002).

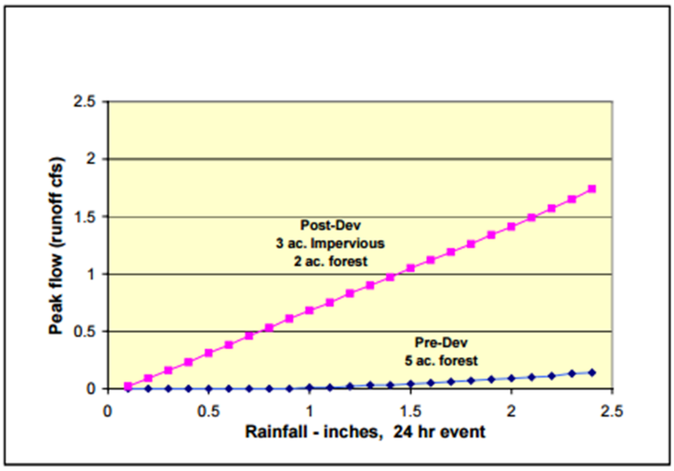

Figure 6.Modelled peak flow (cfs) in relation to rainfall (inch). The pink curve is the peak flow post development. The blue curve is the peak flow pre development (Murase & Liptan, 2002).

Stormwater quality also deserves care as it transports a cocktail of pollutants that can have a negative impact on human health and the environment. A pollutant is defined as a substance that is present in air, water or soil in a higher concentration than it would naturally be (Chiew et al, 1997). Suspended solids (TSS), are solid particles which remains in suspension in water, which contribute to the turbidity reducing the light penetration and aesthetics of the water, and increases the need for filtration. Other pollutants such as metals and organic pollutants can be attached to suspended solids. Metals are common pollutants in urban areas where vehicles emit lead, cadmium, zinc and copper. Metal roofs are also important sources of copper and zinc (Chiew et al, 1997). Organic pollutants such as polycyclic aromatic hydrocarbons (PAH) are primarily emitted by vehicles and traffic infrastructure. They are persistent in the environment and bioaccumulate, with highly negative effects on both humans and the environment (Markiewicz et al, 2017; Björklund, 2011).

3.2 Sustainable stormwater management

Stormwater management has traditionally consisted in safely leading away the water to prevent floods, often using combined sewage systems. In the previous decades, a development has started towards a more integrated planning approach for stormwater (Marsalek & Chocat, 2002; Chocat et al, 2001). In that context, several frameworks and terms are included, ranging from technical labels to holistic planning frameworks. Below, a short overview of terms and frameworks is given, as well as a description of implementation challenges found in literature. For a more comprehensive review, see Schuster et al (2015).

One subset of terms describing sustainable stormwater management simply refer to a group of technical solutions. Some examples are *stormwater best management practice* (BMP), *techniques alternatives* (TA), *stormwater control measures* (SCM) and the Swedish *öppen dagvattenhantering* ("open stormwater management"). These terms all describe stormwater solutions that are decentralized and suggest treatment of water close to the source, and include ground infiltration, ponds or plant-based solutions. Focus is on the type of solution used rather than the overall planning approach. BMP and TA are the oldest of the terms. They have been criticized for focusing too much on the technical requirements, so that non-technical solutions such as source control are not used (Schuster et al, 2015).

In contrast, the holistic planning frameworks generally handle both solution types and planning aspects. The most extensively used planning frameworks for sustainable stormwater management are *low impact development* (LID), *sustainable urban drainage systems* (SUDS) and *water sensitive urban design* (WSUD). LID aims at restoring the pre-development hydrologic conditions of a site using integrated micro solutions such as pervious pavement and bioretention facilities (US Environmental Protection Agency, 2000). Similarly, SUDS operates on the principle of mimicking natural runoff rates using at-source control, pollution prevention, treatment, and surface solutions based on infiltration and evapotranspiration (CIRIA, 2015). WSUD also builds on the same philosophy, but handles all parts of the water cycle (Lloyd et al., 2002). These frameworks thus promote the integration of stormwater solutions into other planning disciplines. They also argue for holistic solutions that consider larger areas. For example, CIRIA (2015) states that their SUDS components are meant to be used in systems and not as individual solutions. A term that is also used in this context is *green infrastructure*, which is used for any green space structure that provides functionality to the city. It is thus a broader concept, not only concerning stormwater. However, it has been used extensively in stormwater management policies, then sometimes called *green stormwater infrastructure* (e.g. Fitzgerald & Laufer, 2016; Dagenais et al, 2016).

Because the above practices are different from conventional solutions, their implementation comes with new challenges. Firstly, they do not work well with the traditional "silo structure" of organizations, where all disciplines are separated. A recent case study on the governance of sustainable stormwater management in Philadelphia found that the new strategy required increased cooperation between municipal departments (Fitzgerald & Laufer, 2016). This finding is supported by earlier case studies from cities in Europe and North America (Nickel et al, 2014; Delshammar et al., 2004; Keely et al, 2013). Secondly, because they are new, there is a lack of knowledge among professionals of both costs and technical details of the solutions to be implemented. These problems can both cause poor installment and make it difficult to argue for implementation (Sharma et al, 2016). Thirdly, there is a need for communication with the public. Keely et al (2013) listed public support, especially for stormwater fees, as an important challenge for implementation. However, Baptiste (2014) indicated that higher environmental knowledge among citizens could increase acceptance. Residents in retrofitted areas also want to give opinions and feedback on the solutions (Sharma et al, 2016; Delshammar et al, 2004).

Assessing the cost of green solutions is the topic of a number of studies. Even though there is a general consensus that such alternatives require high investments and maintenance costs, the added value and benefits strongly support the momentum in favour of green solutions (Liu et al, 2016; Spatari et al, 2011; Niu et al, 2010). The most common benefits mentioned are in relation to energy savings and greenhouse gases emissions (Spatari et al, 2011; Niu et al, 2010). However, quantified benefits related to social or ecological aspects are still absent from the literature and decision makers agenda (Visitacion et al, 2009).

3.3 Ecosystem service-based solutions

In order to solve the problems related to stormwater quality and quantity, ecosystem service based solutions can be used. The following text describes the main characteristics of ecosystem service-based solutions as defined in this thesis. They should be multifunctional, provide ecosystem services and perform stormwater treatment and flow control. This type of solutions treats stormwater through filtration and through phytoremediation, which is described later in this chapter.

3.3.1 Ecosystem services

Ecosystem services refer to all services provided by nature that benefit humans (Jacobs et al, 2013). Bastian et al (2013) suggest three categories of services: provisioning, regulation and socio-cultural. Provisioning services refer to renewable biotic resources provided by nature. It includes clean water, oxygen, wood, food, medicinal resources, also materials for clothing and shelter. Animal excretion, and plant production and decaying matter are also part of provisioning services. Regulation services refer to the interactions of the abiotic factors and living organisms. Those interactions allow for natural processes such as energy transfer and transformation through food chains, biomass, bio-geochemical cycles and all the processes that make life possible on Earth. Socio-cultural services refer to abstract benefits such as well-being, creativity, spiritual values, aesthetic and recreation. Although important in theory, socio-cultural services are difficult to value in terms of money which often leads to a disregard from the decision makers.

In urban area, the high value of ecosystem services is that it increases the multifunctionality of space. One of the solutions to solve the competition for space in urban area is to promote multifunctionality of space (Hasen &Pauleit, 2014; Lovell & Taylor, 2013; Aubrey et al, 2012; Fratini et al, 2012). Multifunctionality is even more important when we talk about green spaces in dense areas, as promoters tend to value green spaces less than buildings (Ba & Moustier 2010). Arguing for ecosystem services may be challenging and lacks quantitative research (Lovell et al, 2013; Aubry et al, 2012; Ba & Moustier, 2010).

3.3.2 Phytoremediation

Plants have an inner capacity to accumulate organic and inorganic compounds in their tissues which can be used to treat stormwater (Ali et al, 2013; Arthur et al, 2005; Ghosh & Singh, 2005). This process is called phytoremediation. This accumulation of compounds into plant tissues is an efficient and cost-effective technology to remediate contaminated soils and water (Ali et al, 2013; Arthur et al, 2005).

The processes accomplished by the plants to phytoremediate their surrounding medium can be grouped into four categories (Arthur et al, 2005):

- Phytofiltration and rhizofiltration
- Phytoextraction and hyperaccumulation
- Phytoimmobilization and phytostabilization
- Phytodegradation and rhizodegradation

Out of these processes, phytofiltration and rhizofiltration are used to treat stormwater (Arthur et al, 2005). Phytoextraction is also extensively studied for removal and recovery of heavy metals in soils and waters (e.g. Ali et al, 2013; Arthur et al, 2005; Chen et al, 2004; Sekhar et al, 2004). These remediation processes use absorption, concentration, and precipitation of pollutants. Therefore, only these three are relevant for the purposes of this thesis.

Using plants can be a very efficient way to filtrate water, but also to stock the contaminants in their tissues. In contaminated lands, studies have shown that heavy metals can be recovered from plants. For instance, Indian sarsaparilla (*Hemidesmusindicus*) was shown to be an efficient and cheap plant to remove and recover lead from wastewater (Sekhar et al, 2004). Arthur et al (2005) showed the properties of Alfalfa in filtrating lead, zinc, copper and PAH. Schulman, Salt, and Raskin (1999) published a research where by selecting certain mutated forms of Indian mustard (*Brassica juncea*), they managed to significantly increase the accumulation capacity of lead and cadmium for this specific plant. The efficiency of phytoremediation relies on the right choice of plants and how adapted they are to the environment utilized. When properly planned, phytoremediation could be an efficient and cheap alternative to heavy metals recovering from soil and water (Ali et al, 2013; Arthur et al, 2005).

3.3.3 Solution types

Many different ecosystem service-based solutions for stormwater have been studied and implemented. Often, they are combined with gravel drains, sedimentation ponds, filter solutions or other types of solutions not based on ecosystem services to form a complete surface stormwater system (e.g. Klimatanpassningsportalen, 2016; Carden & Winter, 2015; Stahre, 2006), as recommended in sustainable stormwater practices (e.g. CIRIA, 2015; Cahill, 2012). In this section, an overview is given of some of the most common types of ecosystem service-based solutions for stormwater.

A simple stormwater solution is to use grass surfaces to filter the water. For example, downspout disconnection consists in letting roof stormwater flow on existing grass (Carmen et al, 2016; Salim et al, 2002). This simple, yet under-estimated method uses natural ground infiltration, which has been shown to reduce stormwater by 34% to 89%, depending on the soil composition and topography (Carmen et al, 2016; Waters et al, 2003). Some of the benefits from downspout disconnections are: water collection to water the grass, using natural infiltration and recharging natural ground water tables (Waters et al, 2003). However, the disconnection should involve a quality check of the building as it may result in basement flooding problems if the walls are not water tight (Salim et al, 2002). Downspout disconnection can be used in conjunction with rain barrels to improve the flow control capacity. This method has been shown to decrease peak stormwater flows and can also form a basis for stormwater harvesting (CIRIA, 2015; Ahiablame et al, 2013). Another solution using the principle of simple grass filtration is filter strips (CIRIA, 2015). They are slightly sloping grass surfaces with engineered soil often placed next to a road to filter the water before it reaches the next stormwater component.

Another common solution type is rain gardens, illustrated in Figure 7. The Pennsylvania Department of Environmental Protection (2006) describes rain gardens as part of best management practices for stormwater. Rain gardens are used to accomplish water quality improvement and water quantity reduction. They use natural services such as ground infiltration, evapotranspiration and evaporation (Pennsylvania Department of Environmental Protection, 2006; CIRIA, 2015). To prevent waterlogging, underdrains are recommended when deep ground infiltration is not possible. Some of the benefits attributed to such practices are: reducing runoff volume, filtering pollutants, recharging groundwater, reducing stormwater temperature impacts, enhancing aesthetics and mimicking ecosystem services such as evapotranspiration and providing habitat for animals (Pennsylvania Department of Environmental Protection, 2006). However, the quality of the water is discussed as the removal of the pollutants depends on the plants present in the garden. Adding a rain garden also tends to be a source of phosphorous emissions to water bodies (Dietz, 2005). Planter boxes are small scale rain gardens designed to accomplish on-site treatment and retention of stormwater (Dietz, 2007; Pennsylvania Department of Environmental Protection, 2006). Because of their limited size and stricter characteristics, they are commonly studied and used for urban areas (e.g. Cuaran & Lundberg, 2015; Dietz, 2007). The benefits from using planter boxes are comparable to those described for rain gardens.

Figure 7. Rain garden in Maplewood, Minnesota. Image credit: raingardens.org.

Finally, swales are V-shaped structures placed along roads and car parks. They can be planted with cut grass or with perennials for a higher treatment effect, then often called bioswales (CIRIA, 2015). The bioswales are similar to rain gardens in their function. The objective is to slow down, limit and treat stormwater (Scharenbroch et al, 2016). Specific designs can be used to safely lead heavy rains to retention areas (McLaughlin, 2012). Swales can be installed on slopes up to 6 %, but check dams need to be installed if they exceed 3 % (CIRIA, 2015). CIRIA also recommends designing bioswales as a series of flat surfaces for maximal biofiltration efficiency.

3.4 Case description

Linnégatan stretches between Linnéplatsen and Järntorget in Gothenburg, a distance of 1,4 kilometers. It is part of a large catchment area including the nature reserve Änggårdsbergen in the south, parts of Slottsskogen in the west and the old city parts of Linnéstaden (including Linnégatan) in the north. The catchment area slopes towards the Göta river in the north. In this area, Linnégatan is particularly interesting because of its history and topographic location. The street is located in the bottom of a valley in which the creek Djupedalsbäcken ran prior to its construction (BRF Linnor, 2017). It is also in an old area with dense city development and little green space. The whole area is built on clay soils which limit infiltration (data from SGU). Figure 8 shows the case boundaries along Linnégatan in the context of its catchment area.

Figure 8. Case study boundaries (red), set approximately one city block around Linnégatan

Linnégatan, as shown in Figure 9, belongs to an old area with high cultural value. Many of the buildings and street characteristics of crossing streets are protected by the municipality (Lönnroth, 1999). Therefore, careful consideration would be needed when retrofitting the area. Most buildings are seven floors high with private courtyards, and residents include housing, restaurants and retail stores. In the south sections of the street, the houses have old front gardens of which some are now occupied by restaurant seating space. The cinema Hagabion in the middle and the cross streets Långgatorna ("the long streets") in the north have active cultural life and are very popular with locals. There is also a strong connection to Slottsskogen in the south, which is a very busy park summertime.

Figure 9. Linnégatan in early spring.

In the case study area, both combined sewage pipes and separate stormwater pipes are installed today. The combined system is more prominent in the lower, north parts with the oldest buildings. Recently, an investigation was done to show how the system in the whole catchment area should be modified to better handle extreme rain events (Stadsbyggnadskontoret Göteborg, 2017). Linnégatan was then recommended as a cloudburst transport route. Retention areas were suggested upstream in Slottsskogen. Such modifications would help avert catastrophic events, but would not solve the pollution problems present for daily stormwater addressed in this thesis.

4 Method

Figure 10 illustrates the thesis process. The second part of this thesis followed two main methods. Firstly, explorative interviews were conducted with professionals in the area to gain an initial understanding of the local situation with stormwater and ecosystem services. The findings from these interviews were then further investigated in a workshop. Lastly, an interview with a municipal park and nature authority was held to have an expert opinion on the results.

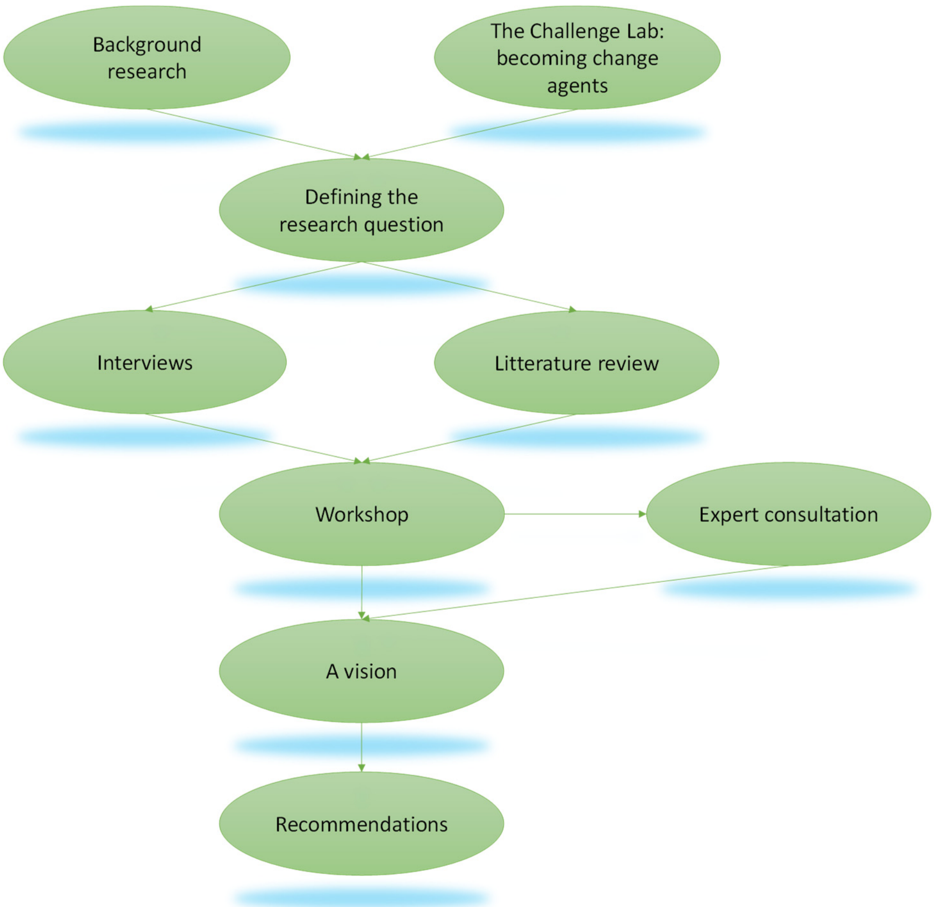

Figure 10. The Ecosystem services for stormwater management thesis work process.

4.1 Explorative interviews

The explorative interviews had two main purposes: 1) to indicate topics to explore in the workshop and 2) to understand the current situation within the field in Gothenburg. Therefore, the format was kept open and with little formal structure. As argued by Gillham (2005), this is a good approach when the interviewee has a more extensive knowledge of the topic than the interviewer, because important aspects could otherwise be missed. The interviews started with an explanation of the thesis research interest, and then the interviewees were allowed to comment and talk freely on the subject. Probing questions were asked to clarify statements and to steer the conversation towards the researched questions, which were:

- How are responsibilities for stormwater management allocated in Gothenburg today?
- What are the main issues with stormwater management in Gothenburg?
- Which ongoing and finished projects around ecosystem service-based stormwater management exist in Gothenburg?

All questions were not explored in all the interviews. Five telephone interviews and four face-to-face interviews were conducted, differing in length between 20 minutes and an hour. The interviewees were professionals working with stormwater, city planning and climate adaptation in Gothenburg. Documentation was done through taking notes.

4.2 Workshop

The explorative interview findings indicated that the problem studied required cooperation between different disciplines to come to a solution. The subsequent workshop was therefore designed to facilitate this type of discussions. Backcasting was chosen for the workshop structure because of its strengths in managing complex sustainability transitions (Dreborg, 1996). The workshop structure was inspired by the backcasting framework developed by Holmberg (1998) and followed four steps:

1. Achieving a common sense of why
2. Defining the current situation
3. Envisioning future solutions
4. Finding strategies for implementation

For a theoretical background of backcasting and an explanation of the Holmberg method, see section 2.1. Step one was addressed through a survey that was sent out to the participants. The results from the survey were presented during the workshop, and the participants had the opportunity to comment. For step two, information gathered from literature and from the previous interviews was presented to the participants to create a common ground. Step three and four were more extensively discussed in the two workshop activities.

4.2.1 Preparatory survey

The preparatory survey was sent out by email to the workshop participants 10 days before the workshop. Two questions were asked:

- Why do you think that it is important to discuss blue-green solutions for stormwater?
- How do you think that blue-green solutions for stormwater could contribute to a sustainable society?

The purpose of these questions was to help the participants think about their reasons for participating in the workshop, and to help them understand why we should take action. Five answers were received. These were compiled and presented in an anonymous list during the workshop.

4.2.2 Workshop activity 1: Exploring the space

The first workshop activity concerned envisioning solutions i.e. step three of the backcasting method, envisioning solutions. It also addressed the research sub-question of how to find space in the case study area. The activity thus had a dual aim: to collect data on possible space-finding solutions and to get the participants into the right mindset for thinking about implementation. To achieve these aims, it was important to design an activity that would help the participants break free of their usual roles. Therefore, a creative activity approach was chosen.

For this activity, the workshop participants were divided in three groups of three. Three in each group was estimated to be adequate to avoid a situation where participants could feel excluded. Care was taken to divide the present competences as evenly as possible in order to maximize the communication between different disciplines. Each group was then assigned an area along Linnégatan to work with. They were provided with a printed plan drawing of their area in A0 format, pictures to help them orient themselves, a booklet with examples of solutions, and different types of pens and post-it notes to draw on. The groups were then given 30 minutes to give suggestions for how to retrofit their area with ecosystem services for stormwater before presenting their results. The presentations were audio recorded for documentation purposes.

The studied areas were chosen based on their diversity: Olivedalsgatan, where Linnégatan has wide-cross streets and buildings with front gardens; Hagabion, where there is a wide, open space; and Långgatorna, where the streets are narrower. Figure 11 shows the areas in their context.

Figure 11. Case areas along Linnégatan studied in the workshop.

4.2.3 Workshop activity 2: Strategies for implementation

The second workshop activity aimed at exploring how to achieve the proposed solutions. For this purpose, the workshop participants were given three post-its each and told to write down the three most important barriers or actions for implementing more ecosystem service-based stormwater solutions in Gothenburg. They were then told to attach the post-its on a timeline from today to 2050 and explain their thoughts to the group. This exercise was used as a basis for a discussion about implementation strategies, moderated by the thesis authors. The activity was documented by audio recording.

4.2.4 Participants

Ten participants were present in the workshop: three water researchers, one architecture researcher, three representatives from the municipal department of sustainable water and waste (Kretslopp och vatten), one representative from the municipal traffic office (Trafikkontoret), and one representative from a private company working with stormwater. Thus, academia and the public and private sectors were represented.

4.3 Expert consultation

To give further input to the case study, an expert in ecosystem service-based solutions from the municipal park and nature administration (Park- och naturförvaltningen) was consulted. The expert was asked to comment on the feasibility, potential and technical limitations of the solutions suggested by the workshop participants in activity 1.

4.4 Data analysis

The data gathered during the interviews and the workshop had to be analyzed and presented in a comprehensive way. The following sections presents the methods used to analyze the data.

4.4.1 Interviews

Because the interviews were done in an initial, explorative phase of the study, only a broad analysis was done. The interview notes were examined and summarized to answer the above questions. The main findings for each question were used as input to the workshop design.

4.4.2 Workshop activity 1

The data from workshop activity 1 consisted in recordings from the presentations and physical material produced by the workshop participants. This data was analyzed through categorizing it under two questions:

- How did the workshop participants find space for their interventions?
- What type of solutions did they use and where?

Other comments made by the workshop participants regarding the activity were also summarized. This material was then used to discuss opportunities for transforming the case study area and design a vision for future changes in its stormwater management.

The aim of the vision design was to illustrate how the case study area could be transformed in a future scenario to increase the stormwater functionality and multifunctionality of space. It was developed based on the results from the workshop, the expert consultation, literature on stormwater management design and the Swedish Transport Administration (Trafikverket) guidelines for street design, VGU.

4.4.3 Workshop activity 2

The data from the second activity of the workshop was analyzed following the six-step method for thematic analysis described by Braun and Clark (2006):

1. Getting to know the data
2. Coding
3. Compiling initial themes
4. Refining themes
5. Defining and naming themes
6. Writing the results

This thematic analysis was chosen because it provided a clear structure and step by step methodology. To minimize the risk of bias, all steps were independently performed by both authors and thereafter compared and synthesized. The first step was aided by a transcription of the recorded data, which was performed by the authors and required an in-depth listening. Further familiarization was achieved during the coding process, in which the transcription was interpreted and labeled. Steps three to five were performed iteratively. Transcription abstracts with similar codes were put together in order to create a list of initial themes. These initial themes were then narrowed down into three main themes, which were defined and named through further iterations. Finally, abstracts from the transcript were chosen and anonymized to illustrate and support the themes. For this step, inspiration was taken from the structure of Fielden et al (2011).

The results from this analysis were used to identify barriers for implementing ecosystem service-based solutions in Linnégatan and make suggestions on how to proceed to overcome them.

5 Results and discussion

This section presents the results from the interviews, the workshop and the expert consultation. The results are then discussed and compared to findings in literature. Based on the results and the discussion, a vision for Linnégatan is suggested as well as recommendations to overcome the barriers.

5.1 Explorative interviews

In this section, the answers on the three main questions asked during the explorative interviews are presented and discussed.

Question 1. How are responsibilities for stormwater management allocated in Gothenburg today?

As it is today, the Department of sustainable waste and water at the municipality of Gothenburg is responsible for planning solutions and maintaining the pipe system. The stormwater contaminants mostly end up in the Göta river or enters the combined pipe system, where the stormwater and sewage water are transported to and treated in the wastewater treatment plant Ryaverket, owned by the municipal company GRYAAB. A combined effort of the Department of sustainable waste and water and GRYAAB is to handle the stormwater volume with wide pipes and a high treatment capacity.

However, responsibilities for stormwater management in Gothenburg is the topic that all interviewees from the municipality identified as lagging behind. Because of a lack of legislation regarding stormwater management, the responsibilities are given to the Department of sustainable waste and water but not the authority to act. The holistic perspective required to solve stormwater issues is gaining attention. Therefore, alternative solutions such as green solutions are being discussed between the water and the park and nature departments. In order to properly plan green solutions, a more significant involvement of all the different municipal departments is suggested.

Question 2. What are the main issues with stormwater management in Gothenburg?

Gothenburg has a wide range of problems from water treatment to organizational structure. Peak rain flows and contaminant runoff are one problem to solve. Peak flows are responsible for over flooding in the wastewater treatment pipe system, which results in sewer overflows with untreated water being emitted to the Göta river. Heavy rainfalls are responsible for basement flooding – for example in Lorensberg in the central part of Gothenburg city.

The main sources of contaminants have been identified to be metal roofs and traffic pollution. Dealing with these sources require cooperation with parties that are not directly responsible for stormwater. Therefore, problems with communication, conflicting priorities and knowledge gaps often occur.

The lack of structure for stormwater management is slowing down the implementation of alternative solutions. Despite a positive interest for green solutions, the lack of guidelines for stormwater treatment creates a very fragmented planning and implementation of solutions where actors lack communication and support. In terms of legitimacy, stormwater management does not have much power in the discussions. The absolute priority today is to build houses, which involves building on virgin land that could otherwise be used to improve stormwater management.

Question 3. Which ongoing and finished projects concerning ecosystem service-based stormwater management exist in Gothenburg?

A joint effort of the water, park and nature, traffic and city planning departments is allowing a number of projects around Gothenburg that are experimenting ecosystem services for stormwater management:

- In Lorensberg (city center), ecosystem services installations are going to be tested to solve basement flooding and enable disconnection of stormwater flows from the combined system.
- Jubileumsparken (Hisingen) is an area about to be built which could potentially innovate with blue-green solutions and get rid of stormwater pipes all together.
- A car park in Kviberg, in the eastern part of Gothenburg city is a test bed for rain gardens and bioswales.
- Structure plans are being presented to develop important dams and retention areas upstream of Kvillebäcken at Hisingen and in Linnéstaden.

In this context, stormwater projects not falling under the definition of ecosystem service-based solutions were also mentioned by some of the interviewees. For example, filters are being installed outside the hospital Sahlgrenska to treat copper pollution, and a system for treating road runoff outside Partihallarna including ponds and filters is under construction. These projects further indicate that there are efforts in sustainable stormwater management in Gothenburg.

It should also be mentioned that many of these projects aim at contributing to make Gothenburg *the best rainy city in the world*. The City of Gothenburg has already joined the 17 principles introduced by the International Water Association (IWA), which should encourage the different departments to consider rainwater more in their agendas. An IWA conference called “Embrace the Water” is hosted by the City of Gothenburg from the 12th to the 14th of June 2017. This conference is expected by the interviewees to strongly highlight the need for additional work on the topic of stormwater, and result in a larger political participation.

Question 4. What special considerations should be taken for ecosystem service-based solutions?

The City of Gothenburg can learn from other cities such as Portland, Vancouver, and Malmö regarding how to plan for ecosystem services for stormwater management. However, Gothenburg has some important considerations to take into account. The first important limit to implementing rain gardens is the fact that most of the city is on clay soil. On one hand, it is an advantage as groundwater is unlikely to be polluted. On the other hand, it is impossible for the city to use ground infiltration to slow down and treat stormwater. A draining system is necessary to avoid flooding of the plants.

Another consideration is that winters are long in Gothenburg. It is estimated that from October to April trees cannot be used for any reduction of stormwater. However, grass deals much better with the climatic conditions and could still provide some services over the winter.

The climate is also expected to bring more rain in the winter in the future. Major rain events could also become more common, which involves a couple of extra considerations when planning for stormwater management.

Lastly, a couple of legislations must be followed when planning for urban retrofitting. For instance, streets must always be accessible for ambulances and firefighters.

5.2 Workshop activity 1

The workshop groups used two main approaches to find space for blue-green stormwater solutions: improving the multifunctionality of existing spaces, and creating new space through reduction of the traffic space. In justifying solutions using the second approach, the participants argued that car traffic will be reduced in the future. This was also pointed out by a participant as being good for the stormwater management situation since it would lower emissions of pollutants. Table 1 lists all space-finding solutions used by the workshop groups.

Table 1. Space-finding strategies used by the workshop participants to transform the case areas.

Improved space multifunctionality	Green walls
	Greenery between existing street trees
	Greenery on tram tracks
	Filtration in existing front gardens
	Cloudburst flow allowed on streets
	Stormwater cassettes under streets
	Move parking underground with a roof garden
Reduced traffic space	Narrow wide streets
	Turn streets into one-way streets
	Turn streets into pedestrian streets
	Merge car lanes with tram lanes
	Remove the tram to open the old stream
	Treatment fountain in an intersection

Beyond their suggestions of solutions for the case areas, the workshop participants made comments regarding the task given and important factors to consider. Regarding the task, one group pointed to the importance of not only looking at separate areas like they had to, but consider the whole catchment area in designing solutions. A participant also commented that the idea held by the present authors that green roofs are not possible in the area was flawed, since green roof projects in Venice have shown that old buildings can be retrofitted with green roofs. Other important factors mentioned were that permeable asphalt might be a problem with plastic pollution, that it is important to keep pedestrian space close to Järntorget, that there needs to be a balance between different types of surfaces in the street space, and that the main challenge was to compete with public transport for space.

In the topmost area, Olivedalsgatan, the responsible group proposed a system of solutions both using existing space and current traffic space (Figure 13). They chose to put the cars together with the tram to make room for an innovative treatment fountain in the intersection and green spaces on the side of the street. This move is illustrated in the figure by the extended green strip on the right side of the street and the blue ovals representing fountains. The fountain was described as combining art with stormwater treatment, and was raised from the ground to prevent children from falling in. This solution in particular was commented on by a workshop participant as providing “a showcase for Gothenburg”. The group also converted the west side of Olivedalsgatan into a pedestrian street to be able to fit more greenery and a “blue solution” resembling a retention pond and a canal. Finally, they removed any copper roofs and used the existing front gardens and green spaces in the courtyards to filter the stormwater.

Figure 12. The workshop group’s suggestion of stormwater solutions in the Olivedalsgatan/Linnégatan case area

The group working with the Hagabion area developed three scenarios, see Figure 13:

1. Move the tram and bring back the river to the surface
2. Gaining more pervious rain surface
3. “Microsurgery” approach, working with the street sections

For the first scenario, the group changed the street section to accommodate for the creek that ran there prior to the street construction in the late 19th century. They considered moving the traffic to one side, and having a pedestrian area closest to the buildings on the east side of Linnégatan. On the sides of the river, there would be bioswales to take care of water pollution. For the second scenario, the group proposed converting the existing parking space into an underground garage with an educational roof garden. They argued that this could also allow for removing some of the street parking, freeing even more space for green solutions. For the final scenario, the main approaches from the group were to use some space from the cross streets, which they thought looked over dimensioned, and to add some green walls on unspecified buildings.

Figure 13. The workshop group's suggestion of stormwater solutions in the Hagabion/Linnégatan case area.

The third case area, Långgatorna, seemed the most challenging to approach. Here, the working group did less invasive measures than the others (Figure 14). They gave the traffic flow in Linnégatan much consideration and did not change the street section. Instead, they proposed installing stormwater cassettes underneath the street to aid the street trees in managing higher water flows. In conjunction with these, they concluded that it is necessary to break up the concrete above them to facilitate infiltration. For the cross streets, Andralånggatan and Tredjelånggatan, the group suggested that the traffic is limited to one-way to make room for green space. It should be noted, however, that these streets are already one-way streets, so that traffic limitation would not be needed. Although they recognized that the buildings are culturally protected, the group suggested that green walls might be possible to use in the courtyards, which are grey today.

Figure 14. The workshop group's suggestion of stormwater solutions in the Långgatorna/Linnégatan case area

5.3 Expert consultation

The stormwater solutions developed in exercise 1 were presented to an expert from the municipal Park and Nature administration. Technical requirements were discussed for the solutions he thought had most potential.

The stormwater cassettes were disliked by the expert as he argued that the eco-friendly versions available are "ugly", and that the other varieties mean putting plastic in the ground. However, he thought that if metallic structures were developed, stormwater cassettes could become a solution to consider.

In general, the expert was strongly in favor of ecosystem service-based solutions. He stressed the following technical aspects to consider for implementation:

- Big stone fractions could be used under parking spaces, pedestrian areas and biking lanes to allow for some water infiltration and storage.
- Trees require a drainage system to not be flooded
- Golden rule of city trees: 30% family, 20% genre, 10% species. High diversity to avoid the spread of diseases.
- Grass is more resistant to winter weather and salt.
- Rain gardens should cover 2–10 %, preferably 4–5 %, of the catchment area to treat.

Digging up the creek was also a highly appreciated idea. Removing or moving the tram clear up space to allow for the creek to flow in Linnégatan. The creek should be made so that the banks are bioswale-like to filter the road runoff.

He also mentioned that maintenance cost should not come early in the discussions. He sees it as a problem that can be solved later in the planning phase.

Lastly, he mentioned public acceptance about removing existing trees. Some trees such as the old linden trees have been present in Gothenburg for over a hundred years. Some people may see in those trees sentimental values that may conflict with tree species diversification plans.

5.4 Evaluation of suggested solutions

In a possible future transformation of the case study area, both the literature (e.g. CIRIA, 2015) and the workshop results indicate that using a holistic approach is preferred. With such an approach, the whole catchment area is considered in dimensioning solutions and choosing appropriate solution types. In the area in question, the ponds in Slottsskogen could be utilized for upstream retention, while solutions in the studied area around Linnégatan focus on treatment and flow delay. This approach is in line with the cloudburst strategy found in the structure plan, in which Linnégatan is used as a water transport route (Stadsbyggnadskontoret Göteborg, 2017). A more detailed investigation, while outside the scope of this thesis, would be valuable for future decisions. A treatment and delay strategy in the area around Linnégatan would work well with the different solutions proposed by the workshop participants. In this section, the proposed solutions are evaluated for multifunctionality and feasibility.

Designed properly, the suggested solutions using ground infiltration and adding plants fit the sustainability criteria specified in Challenge Lab phase 1 (see section 2.4.1). As described in section 3.3, they can prevent pollutants from increasing in the environment, increase the resilience of the system and provide various ecosystem services including those promoting human well-being. In Linnégatan, the most prominent ecosystem services added were regulating services, cultural and amenity services and to some degree habitat services for insects and birds (Lead et al, 2010), as listed in Table 2. Firstly, all stormwater solutions containing plants add the regulatory services of phytoremediation and evapotranspiration (Ali et al, 2013; Arthur et al, 2005; Ghosh & Singh, 2005). In the workshop, rain gardens and grass surfaces in particular were seen as ways to regulate flow and remove pollution. Secondly, cultural and amenity services can be achieved by the suggested educational garden and rain gardens. Such services are described by Lead et al (2010) as "Opportunities for recreation & tourism" and "Information for cognitive development". Thirdly, habitat services for biodiversity can be added through a proper selection of plants in the rain gardens (Pennsylvania Department of Environmental Protection, 2006). As discussed with the expert, the choice of trees and plants can be challenging as people attribute sentimental values to those streets. This claim is supported by Lead et al (2010), who argues that beyond beautification of urban area, green spaces contribute to spiritual experience, recreation, tourism and creativity.

In the workshop, green walls were discussed to increase biodiversity and habitat for wildlife. However, research about the potential of green walls to be integrated into stormwater management is limited. They have mostly been studied for energy savings, which is beyond the scope of this study (e.g. Prodanovic, 2017; Wilkinson & Castiglia Feitosa, 2016). Therefore, green walls were disregarded for the vision. The proposed stormwater cassettes were also disregarded because they do not provide the multifunctionality aimed for in this thesis. Also, as the expert consultation indicated, one of the most common versions is made of plastic, which does not meet the sustainability criteria.

Table 2. Ecosystem services provided by the suggested stormwater solutions in the workshop case areas.

	Regulatory	Cultural & Amenity	Habitat
Rain garden	- Ground infiltration - Phytoremediation - Resilience - Pollination	- Education - Recreation	- Birds - Insects
Trees	- Phytoremediation - Resilience - Pollination - Local climate	- Spiritual - Aesthetics - Education	- Birds - Insects
Grass	- Ground infiltration - Phytoremediation		- Insects
Creek + swale	- Drainage - Ground infiltration - Phytoremediation - Resilience	- Recreation - Spiritual - Aesthetics	- Birds - Insects - Aquatic organisms

Many of the solutions proposed by the workshop participants would require a change in traffic patterns in the area. One-way restrictions and pedestrian street conversions were proposed for the cross streets, and three traffic scenarios can be extrapolated for Linnégatan itself: 1) the traffic space is kept intact, 2) the car and bus traffic is moved to the tram lanes, and 3) the tram is removed from the street. The cross-street solutions and the second scenario for Linnégatan imply that car traffic is reduced to fit in a smaller space. The same is true for the third scenario if the tram is moved to an adjacent street. A reduction is not unlikely considering that the local traffic strategy aims at reducing car transport significantly by 2035 (Göteborgs stad, 2014). However, as the traffic strategy states, measures to improve the mobility for other kinds of traffic would be needed to achieve that. Also, because Linnégatan is an important route for public transport and for ambulances to the Sahlgrenska hospital, any significant changes to Linnégatan would require a traffic investigation for the whole area. Beyond the direct space gains, reducing the car traffic could potentially reduce the need for parking spaces in the area, and decrease pollution as vehicles are one of the major contaminant sources for stormwater. Source control measures of this sort is an important part of sustainable stormwater management frameworks such as SUDS and WSUD (CIRIA, 2015; Lloyd et al, 2002).

The potential stormwater management functionality of the suggested solutions is difficult to estimate accurately without any site measurements or modeling. However, literature indicates that such potential functionality exists. As discussed in section 3.3, studies have shown that rain gardens, swales and downspout disconnection can reduce peak stormwater flows and treat stormwater pollution. Extensive green roofs, as the parking garage roof garden would be an example of, have also been found effective for flow reduction (Czemiel Berndtsson, 2010). However, their potential for street stormwater treatment is not widely studied, likely because green roofs are not typically located on ground level. A reasonable estimate is that the treatment effects could come close to those of rain gardens and grass surfaces if they are properly designed. Stormwater fountains have been used previously in road environments (e.g. Landers, 2010) and could work similarly to stormwater pond solutions.

A rough estimate of the dimensions needed for adequate stormwater treatment can be done through approximate area percentages. As was discussed with the expert, the size of the solutions should represent 2 to 10% of the area to be managed. The City of Gothenburg webpage about rain gardens suggests 5% (Göteborgs stad, 2017a) and bioretention planters designed by Cuaran and Lundberg (2015) in their master's thesis were calculated to cover about 6% of the area. Using these values as a rule of thumb, even the smallest suggested areas are enough for treating at least the stormwater from the streets and roofs in the case study area. Furthermore, since the street is located in the bottom of a valley, the larger area suggestions could be used to treat water from other parts of the catchment area.

5.5 Vision for Linnégatan

Today, Linnégatan is a much-appreciated street and an important transport route between Järntorget and Slottsskogen. Therefore, it was important to design a solution concept that kept the present values as well as added new ones. The final developed vision starts with the concept of making Linnégatan a showcase for Gothenburg, inspired by the great botanist Carl von Linné. Diverse greenery, the sound of water and an educational garden bring new life to the area, connecting strongly to Slottsskogen in the south. As discussed above, the changes made to Linnégatan would also impact other streets, but the details of such impacts and how they could be solved are outside the scope of this thesis.

To make space for the new street design, the tram is moved to the adjacent street ÖvreHusargatan and space for motorized traffic is restricted. With these measures, the characteristics and functionality of Linnégatan changes; it no longer functions as a main public transport route or an ambulance corridor. However, its location in a valley and its many restaurants and shops makes it particularly suitable for stormwater and street life functions, respectively. It also has potential as a green infrastructure route because of its connection to Slottsskogen. Therefore, it is reasonable to redistribute its current functions to other streets in a future restructuring of the area.

Of the solutions suggested in the workshop, opening up the creek triggered most enthusiasm in the consulted expert. It also has the most potential ecosystem services and forms a diverse solution system when combined with other solutions. Therefore, the creek is the central solution concept in the vision. The creek itself works as a stormwater conveyance route in place of the current pipes and provides some buffer capacity for heavy rains. It is complemented by rain gardens and trees in Linnégatan and its cross streets, and downspout disconnection with rain barrels and grass filtration in the houses. As suggested by the workshop participants, the parking space beside Hagabion is also converted into an underground garage with a garden on top. These complementary solutions provide necessary stormwater treatment and flow control. Outside of the case study area, the system could be connected to stormwater treatment and retention facilities in Slottsskogen in the north and the new development Masthuggskajen, close to the river. This system is illustrated in Figure 15.

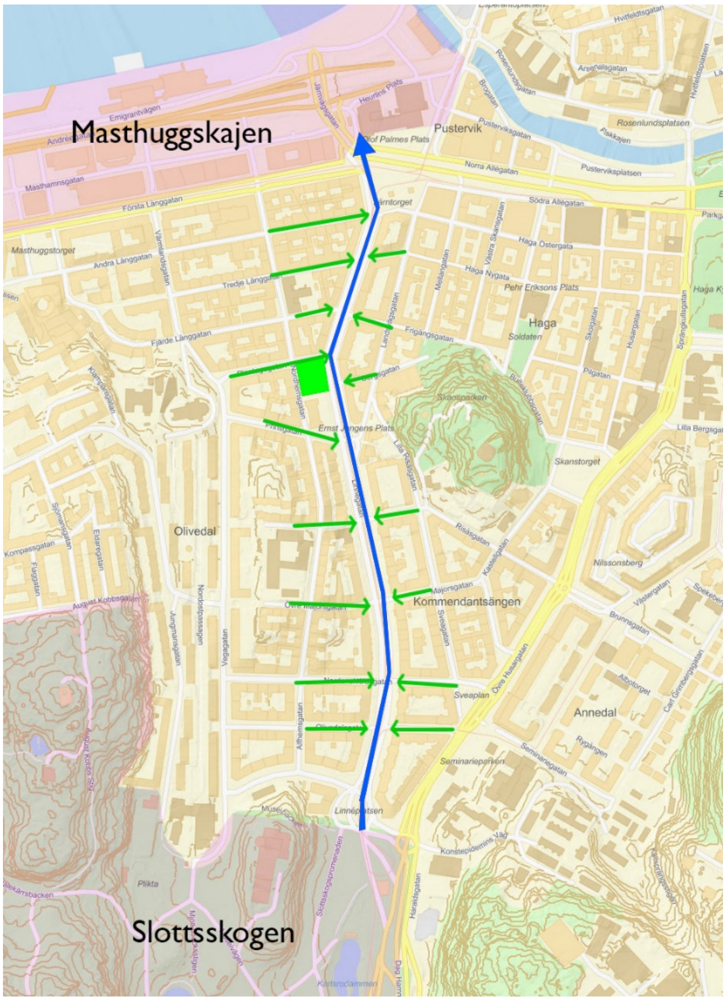

Figure 15. Solution concept for the case study area. The blue arrow represents the creek, the green arrows represent rain gardens for treatment and delay and the green rectangle represents the parking garage roof garden.

5.5.1 Linnégatan

The most extensive changes are done to Linnégatan, as illustrated in Figure 16 and Figure 17. The old creek, Djupedalsbäcken, is resurfaced and used for stormwater conveyance. It is designed with green slopes planted with perennials to increase biodiversity and provide minor treatment of the water. The main stormwater treatment is provided by rain gardens on the sides of the creek. These are planted with trees of various species to increase resilience and biodiversity. With the tram removed, all car and bus traffic flows in two lanes beside the creek, and a two-direction bicycle lane complying with the standards for medium traffic is installed. On the other side of the creek, the pedestrian space is extended and has water access. To be able to cross the river, bridges for pedestrians and motorized traffic have to be fitted at appropriate intervals.

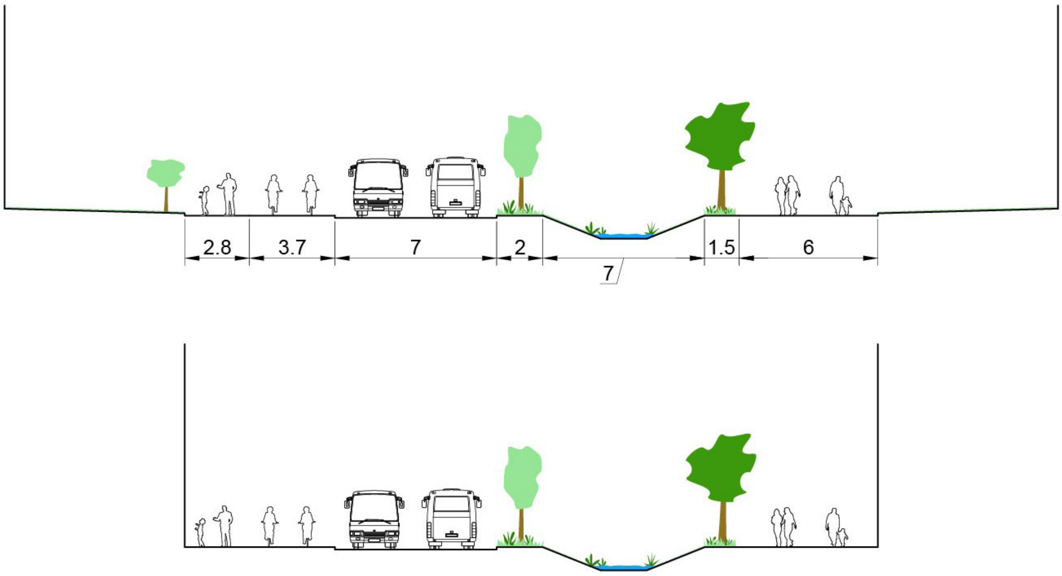

Figure 16. Vision for blue-green stormwater solutions at Linnégatan, illustrated by sections of the street with front gardens (above) and without front gardens. Measures in meters.

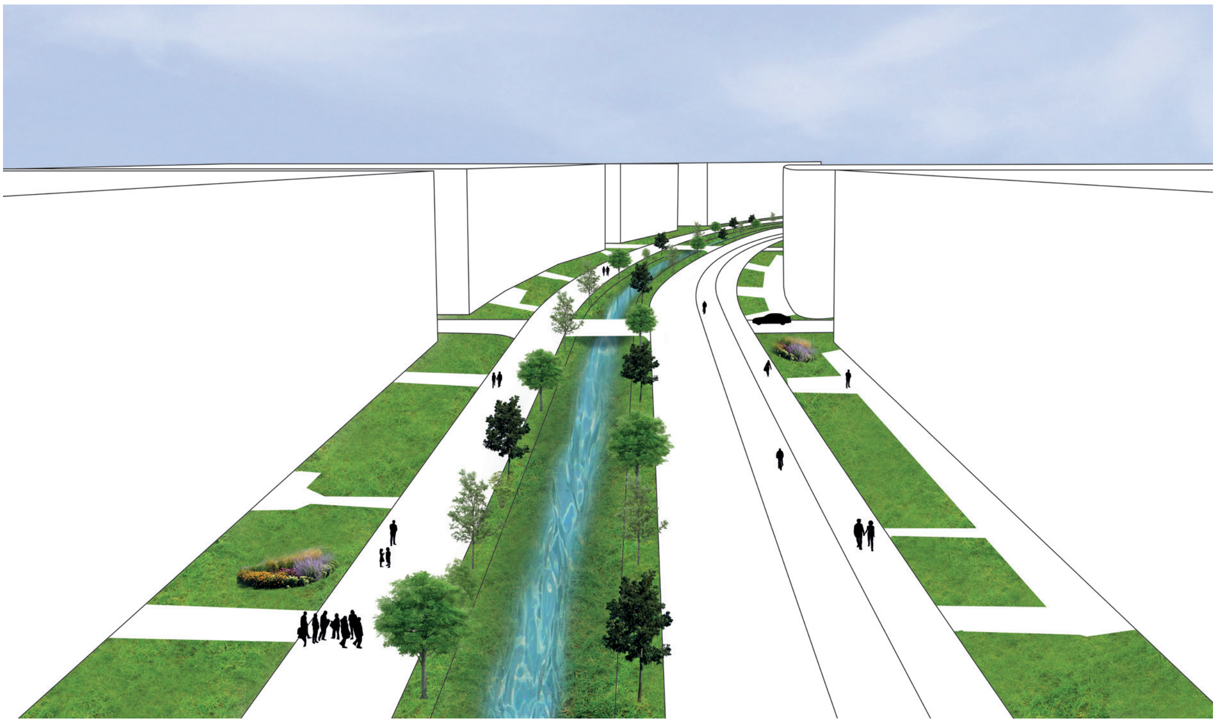

Figure 17. Perspective illustration of the vision for blue-green solutions on Linnégatan.

5.5.2 Narrow cross streets

In the narrower cross streets, space is taken from the street side parking to allow for planter boxes with trees to be installed. If trees with narrow crowns are planted, they can stand four meters from a facade according to VGU. Parking spaces are installed in between planter boxes. The sidewalks are increased to the new-build guidelines of two meters per side. Figure 18 shows an example section of Tredje Långgatan, 12 meters wide.

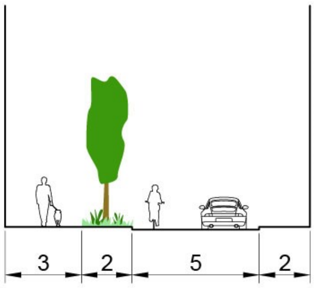

Figure 18. Vision for blue-green stormwater solutions at narrow cross streets, illustrated by a section of Tredje Långgatan. Measures in meters.

5.5.3 Wide cross streets

The wider cross streets are also retrofitted with planter boxes, but with a wider version. Parking spaces are kept on one side of the street and can also be fitted in between planter boxes up to half of the stretch. Even with increased walking space, the streets allow for two trucks and a bicycle to meet. Figure 19 shows an example section of Olivedalsgatan, 18 meters wide.

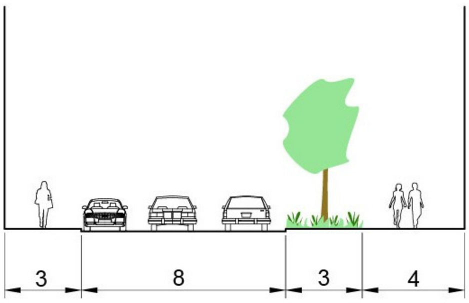

Figure 19. Vision for blue-green stormwater solutions at wider cross streets, illustrated by a section of Olivedalsgatan. Measures in meters.

5.5.4 Front gardens

The existing front gardens are used to disconnect the roof downspouts and filter the water. To further delay heavy flows, rain barrels are installed (as described in section 3.3.3). Because the front gardens are of several different layouts in Linnégatan, specific designs for different locations will have to be done. For example, existing grass lawns can be used as filter strips, and raised front gardens can be fitted with rain gardens. Although downspout disconnection is often reliant on infiltration in the grass, it would work here as sediment filtration and small-scale treatment together with the shallow infiltration possible in the area.

5.5.5 Hagabion parking space

The parking space beside Hagabion is converted into an underground garage, with two storey to also release space in nearby streets. The parking access is placed on the same location as the current entrance. On top of the garage, an extensive green roof is installed. It is designed as a garden to accommodate recreational and educational activities. This space is characterized by a large variety of species to attract insects, boxes in which residents can grow food and seating areas for multiple purposes. The garage access ramp is used as an elevated seating area and as wind protection for plants. A possible layout of this garden is illustrated in Figure 20.

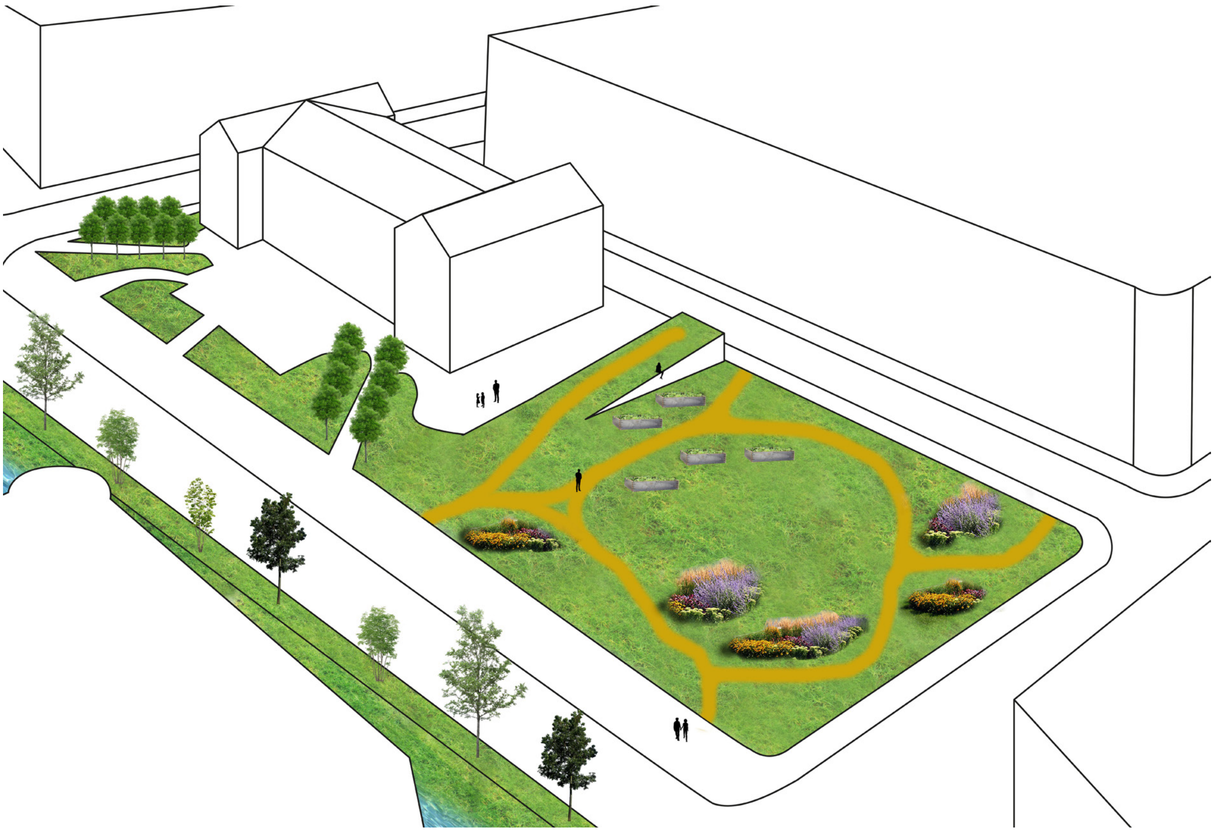

Figure 20. Vision for blue-green stormwater solutions in the area around the Hagabion parking space.

5.6 Workshop activity 2

The second activity brought the participants together to think about barriers in the current system and how to achieve a change in the stormwater management at Linnégatan. In the thematic analysis, three main themes were identified. They were named “Legitimacy”, “Research” and “Structure”. The underlying aspects to those themes may be overlapping across the three categories. However, this should be seen as an illustration of the high degree of complexity of the system where nothing is isolated, but interact and relate to one another. The themes and the links between them are illustrated in Figure 21.

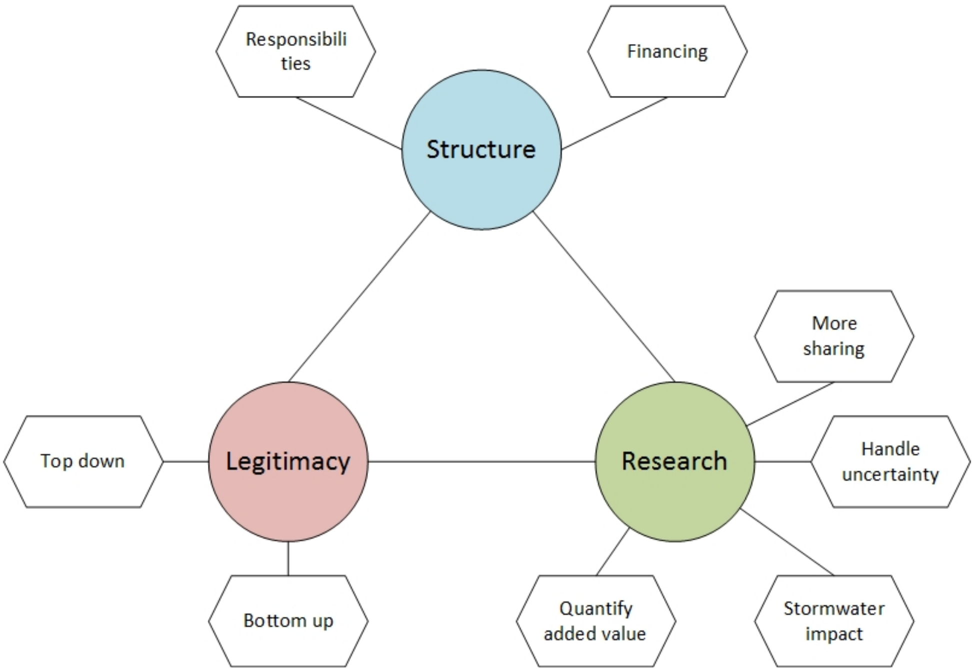

Figure 21. Illustration of the results from the thematic analysis.

The timeline that was provided to the participants helped understand how to prioritize actions. The overall impression was that a lot needs to be done early, as can be seen in Figure 22. A struggle highlighted by the participants is that it can be difficult to place actions on the timeline as they need to be omnipresent in the discussions all along the planning process. For instance, maintenance of green solutions is a topic that was agreed on by all participants; however, there was some discussions about when to tackle maintenance. Some people argued that maintenance should be discussed at the beginning of planning, while others argued that it should be an ongoing discussion during the whole lifecycle of a project.

Figure 22. The participants attached post-it notes with barriers and actions for implementation on a timeline from today to a desired solution approximately 2050.

5.6.1 Legitimacy

Legitimacy is about convincing stakeholders that ecosystem services are important and deserve attention. The legitimacy theme refers to the concern the participants had about introducing a new system of solutions from an acceptance perspective. People have their own lifestyle; they are used to a certain surrounding. Challenging this routine can create conflicts and resistance to change. Also, institutions have budgets and knowledge about a certain set of stormwater solutions. Stormwater needs to gain legitimacy so that the established system will put energy and money into supporting a new system. Two main scenarios were discussed to bring in this legitimacy. The first one consisted in a top down approach, while the second scenario was about a bottom up approach.

The top down approach relies on an intervention from the politicians to achieve regulations, taxes and budget allocation. This could also be referred to as a need for formal legitimacy for stormwater actions. An important factor brought up by a researcher was that stormwater does not have its own legal status today, but is considered to be wastewater. This causes problems when trying to implement stormwater interventions. Moreover, a recurring comment was that a clear political decision is needed to have mandate from the city to start the transition process. A representative from the Department of sustainable waste and water also pointed out the need for educating the decision makers to achieve good stormwater actions.

The bottom up approach consists in educating the public about stormwater solutions to increase acceptance and put green stormwater solutions on the politicians' agenda. As a private company representative said: "We need to start a movement!". This idea gained a lot of momentum in the discussion. However, the difficulties of making people change their habits were also brought up. As the participants discussed, promoting an increase in awareness of climate change and of stormwater consequences could help solving this problem. Increasing the transparency of water flows for this purpose was suggested by a representative from the Department of sustainable waste and water

5.6.2 Research

The participants raised concerns related to the lack of knowledge and research in the field. Firstly, the benefits of ecosystem service-based solutions are difficult to quantify, which results in inaccurate cost-benefit calculations by authorities. Several mentions were made of the importance of researching the additional value of sustainable stormwater management, for example rainwater harvesting and recovery of metals. A general conclusion was that a cost-benefit analysis on green stormwater solutions should be done.

> *"When people are talking about the costs, usually they forget that some costs are saved by implementing blue-green solutions. [...] yes, so one cost is that the wastewater treatment plant will reduce their cost because they will reduce the volume of water that is coming. Another thing that can... so, the values should be monetized somehow, also to make understand the private why do I need to spend more money to make a green roof, because, yeah, you have this energy saving, you are not gonna renovate your roof."*

Researcher

Another issue is that although there is research conducted in different parts of the world, much of the knowledge needed is site specific. For example, measurements of pollutants were discussed. Measurements are necessary for determining real treatment needs, but they are also expensive and not done enough. To keep the cost down, modeling softwares are used to estimate water flow and recipient sensitivity, but the accuracy of such models can be unreliable. Some pollutants are also bioaccumulating, which makes them harmful even in concentrations lower than the detection limits of the measurement methods. Other aspects mentioned were the need for a better understanding of the impacts of stormwater on dense areas and uncertainties of maintenance requirements and costs.

A way of reducing these uncertainties could, as proposed by a researcher, be to introduce better knowledge sharing between cities, for example by benchmarking. Some of the participants also advocated for flexibility in installed solutions to avoid unnecessary costs long-term. The flexibility aspect is important not only because of the problems we know of today. A researcher stressed the possibility of new pollutants emerging that we need to address. The opposite situation of less pollutants could also happen if the sources of pollution are changed.

"And also to, I mean we've been talking a lot about reducing the cars. Maybe we build a lot of expensive solutions, and then we don't have any cars so we don't have so much pollutants. We should think flexible and we should think long-term."

Department of sustainable waste and water representative

5.6.3 Structure

New solutions require a new organizational structure in responsibilities and financing, both in the planning, investment and maintenance stages. There was a general agreement that there is a need for a specific structure for stormwater management. It requires a holistic approach which means that all the city departments and many different expertise should be involved. The need for a specific group also originates from the unclear responsibility among departments today. Both who should do something and how to acquire space for solutions was discussed.

"The first one I wrote was the responsibility. Then I'm talking about the... cause already today there's there are a lot of people that wants to do these things but nobody starts cause everybody's like, oh, maybe someone else will do it, so we need to clear this out and... and we were working with that and I think that needs to be done very early here."

Department of sustainable waste and water representative

"I think it's important to have a group that sort of … maybe a group within the municipality that work together on stormwater. Not having stormwater in different departments."

Researcher

A structure specific to stormwater should also consider the funding and where to get the money from. There were many discussions about the financing of green solutions. A municipal water authority summarized the unanswered questions: "What should be done on the water tax? And on the regular tax? And what should be done on a municipal level? And national level?" These questions illustrate the high complexity of transitioning to a new stormwater management system, and echo back to the need of a high diversity of stakeholders to work together on different levels.

5.7 Discussion for activity 2

As mentioned in section 3.2, the need for acceptance from the public and the decision makers, for additional knowledge and for a different organizational structure have all been found in previous studies. More specific suggestions made by the workshop participants, such as quantifying additional value, have also been discussed previously (cf. Sharma et al, 2016; Keely et al, 2013). Therefore, the key results from workshop activity 2 support the current research, and indicate that the city of Gothenburg has similar challenges in implementing ecosystem service-based solutions for stormwater as other cities. Below, the three themes found in this thesis are discussed in the context of possible future strategies.

5.7.1 Legitimacy in Linnégatan

The discussed approaches for building legitimacy in Linnégatan were characterized by raising awareness among the inhabitants and convincing decision makers that this problem deserves attention. Both in the top-down and bottom-up scenarios, the point was to bring stakeholders with divergent interests together to agree on a common project. Such approach is argued by Sarasini et al (2016) as an efficient way to build legitimacy.

Today, stormwater is an invisible aspect of people's surrounding as it disappears in the pipe system. Therefore, displaying information about stormwater in key areas could raise awareness about stormwater and environmental impacts. Such initiatives could contribute to making sense of why we should deal with this problem. Building transparency around stormwater to create legitimacy is an approach described by Sarasini et al (2016) and Morsing & Schultz (2006). However, focusing on 'sense giving' requires a lot of accurate communication. The accuracy and the transparency of the discourse are key aspects of such communication as too much transparency or too much simplification can seem suspicious, resulting in undesirable consequences (Curtin & Meijer, 2006; Morsing & Schultz, 2006). In a top-down scenario, building legitimacy was also discussed as politicians and decision makers may have other priorities today. Applying the same concept of transparency to serve legitimacy could contribute in reaching those who have power to initiate change in Linnégatan.

5.7.2 Solving the research gap

It was discussed that the lack of research, especially measuring contaminant concentrations, was due to lack of funding. Instead, the professionals are limited to use models that have questionable accuracy. Because funding often comes with priorities from the decision makers, this indicates that the research problem is closely related to the legitimacy theme. There are research initiatives in other cities in the world. For example, facilities for stormwater have been established in Oregon and Vancouver (University of British Columbia, 2017; Benton County and OSU, 2015). However, this knowledge is not easily available for the stormwater professionals because of the little communication between cities and countries. A possible approach to address this problem is the benchmarking initiative suggested in the workshop, since that could gather global knowledge about solutions. The spreading of such knowledge is being worked on at Chalmers where a digital platform is designed to solve this communication problem (Climate-KIC, 2016).

Some of the knowledge needed is site-specific and difficult to obtain from studies done in other places (Draper et al, 2000). Literature suggests that establishing a structure for iterative learning is valuable for such local knowledge building in stormwater management (Chini et al, 2017; Water environment research foundation, 2009). As was found in the interviews, the municipality already has pilot projects for evaluation which could be a good structure to build on for this purpose.

If pilot projects can help recognize the values of ecosystem services-based solutions, then the city managed to complete the first step suggested by the TEEB (the Economics of Ecosystems & Biodiversity, 2017). The TEEB developed a three-tiered approach to make ecosystem services values visible to all the stakeholders. This approach suggests ways to quantify in monetary terms the values added by ecosystem services. TEEB argues this approach facilitates the dialogue with decision makers.

5.7.3 Structure

The idea of an interdepartmental stormwater group is not new. For example, it has been successfully implemented in Portland (Water environment research foundation, 2009). Cross-departmental collaboration with climate mitigation was also rated as a good approach in an international survey among 350 member cities of Local Governments for Sustainability (ICLEI) (Aylett, as cited in Fitzgerald & Laufer, 2016). This structure could also help achieving the legitimacy of stormwater management that is needed, since it would increase communication, collaboration and transparency.

5.8 Discussion for methods

The methods and outcomes of this thesis were influenced by the Challenge Lab process. Inspiration was taken from the explorative approach used in the question finding phase, and from the Challenge Lab purpose of bringing stakeholders together. These were important factors in the choice of interviews and a workshop as the main methods in this thesis. Also, because the authors personally conducted the interviews and workshop, their acquired change agent mindset likely helped the participants in questioning the current system and thinking more freely. Below, important factors in the methods are discussed, as well as limitations to the study.

Although the explorative interviews were not recorded and the questions quite open, a large amount of data was collected, which allowed for a solid background research about the gaps in today’s situation. If data were missing, reconnection with the interviewees completed the thesis content. The collected data of the interviews was presented as an introduction in the workshop where all the participants agreed on the findings. This indicates that no major aspects were missed due to the documentation method.

On the overall, the workshop provided answers to the workshop questions and received very good feedback from the participants. However, the spatial limitations imposed in the workshop was frustrating for some participants as they had the feeling that it was lacking holistic perspective, and that working with retention projects upstream could have helped envisioning more efficient solutions. An important achievement of this workshop was to bring together municipal representatives of different departments and private actors, which was positively commented upon by the participants. The workshop brought together the triple helix described in section 2.1. However, all the participants were somehow involved in water discussions in their work, which makes it somehow biased. Referring to the legitimacy theme, the workshop could have positively benefited from a wider range of perspectives. More private companies, housing companies and politicians could have brought different views and opinions.

Because of the broad perspective of the study, the vision developed is limited and would need additional research before implementation. If the cost dimension was taken into account, factors such as investment costs and maintenance requirements would have had to be considered in the solutions. However, as the workshop indicated, the main values added by the proposed solutions are not economic and such considerations may not give a fair result. A more extensive traffic investigation may also have changed the outcome. For example, suitable bus stop locations would need investigating. Finally, some important site-specific information was absent from the case study, such as the volume of water to treat and the concentrations of contaminants in stormwater. As discussed previously, this knowledge needs further research and relies mostly on model estimations today. In summary, the vision provides indications of where to focus the future investigations rather than a complete suggestion.

6 Conclusions

This thesis has investigated the implementation of ecosystem service-based solutions for stormwater management in Linnéstaden, Gothenburg. In order to answer the research question, the authors explored the types of solutions that could be implemented, how space could be found in a dense city where space is expensive and rare, and what barriers are slowing down the implementation.

The study shows that there are many solutions already existing that could be tested in Gothenburg such as rain gardens and grass infiltration. A major finding is that the solutions should be considered as part of a complex system where additional parameters including existing infrastructure, topography, municipal responsibilities and many more should be considered. Such a holistic perspective will be a key to maximizing the efficiency and acceptance of ecosystem service-based solutions. Finding the space required to place those solutions is a matter of restructuring streets in a more integrative way. Today, large areas are used for traffic and parking, which limits the freedom of action for other services. Three main themes were presented as the main gaps to address in order to overcome the barriers. *Legitimacy* refers to convincing all the stakeholders that stormwater is an urgent problem. It was identified that more *research* is still needed about the economical aspect of ecosystem services and local stormwater impact. Lastly the city of Gothenburg will benefit from a *structure* that redefines responsibilities and facilitate interaction between stakeholders.

These findings have significant implications for the understanding of how sustainable transitions can operate at a municipal level. This thesis will serve as a base for future studies that aim at implementing sustainable solutions that are likely to challenge the existing physical infrastructure and division of tasks between departments.

The following recommendations for future research are made based on the findings in this thesis:

- More site-specific research: measurements, multi criteria risk analyses, risk analyses
- Cost-benefit analysis of ecosystem service-based solutions for stormwater
- Broader geographical limitations
- Repeat the workshop with more diversified participants
- Investigate the potential of green roofs and green walls for stormwater
- Investigate the feasibility of traffic changes to make space for stormwater solutions

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