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Author: Marita Helland and

Tiril Hole Mohr

(signature author)

(signature author)

Course coordinator: Daniela Müller-Eie

Supervisor(s): David Chapman

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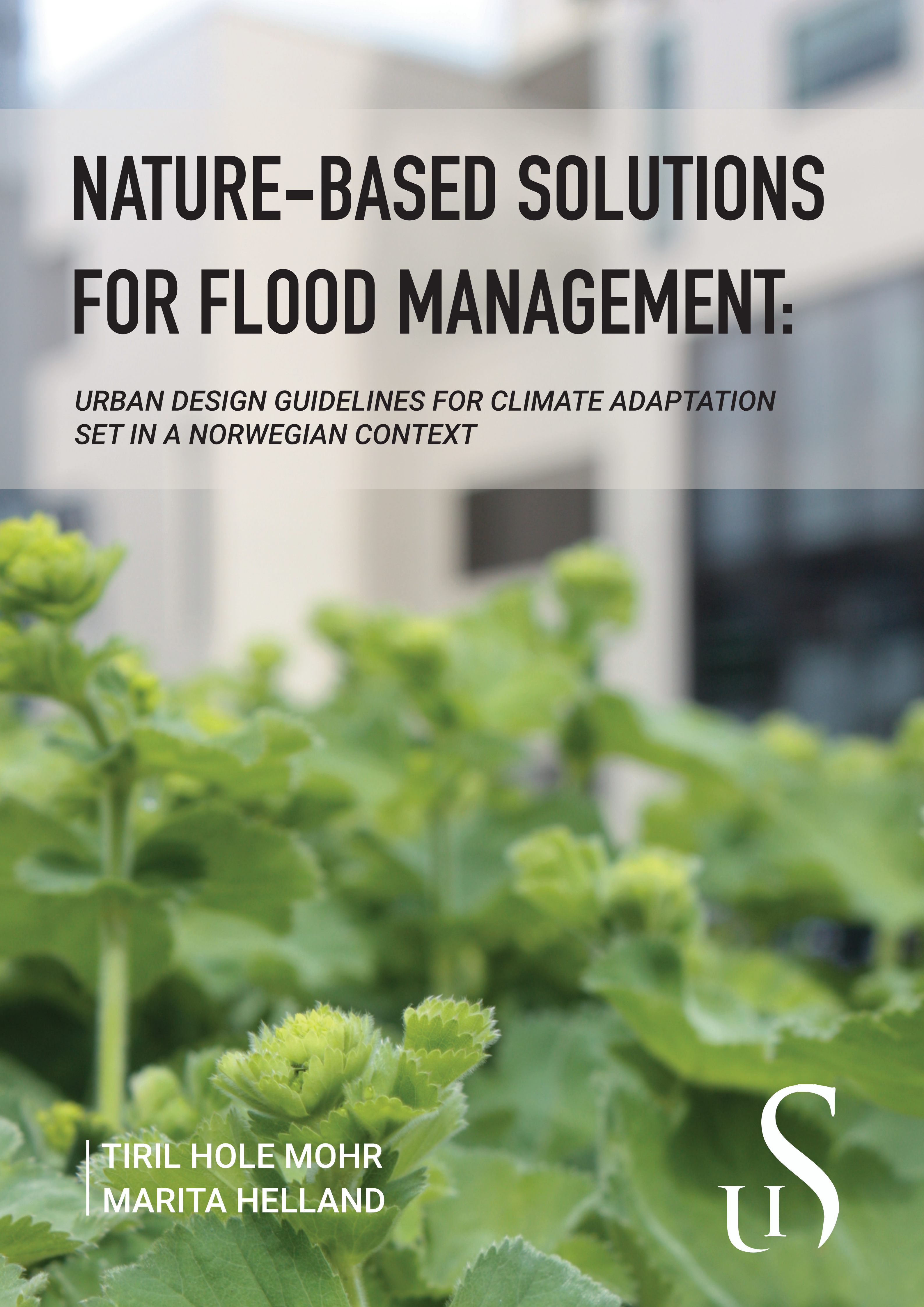
NATURE-BASED SOLUTIONS FOR FLOOD MANAGEMENT:

URBAN DESIGN GUIDELINES FOR CLIMATE ADAPTATION SET IN A NORWEGIAN CONTEXT



TIRIL HOLE MOHR
MARITA HELLAND

Master thesis, Spring 2022

Department of Safety, Economics and Planning

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PREFACE

This thesis marks the end of a two-year master's program in "City and Regional Planning" under the Department of Safety, Economics, and Planning at the University of Stavanger. The thesis makes up the subject BYGMAS-1 and accounts for 30 credit points.

The authors share a common interest in topics related to how cities can be designed in a more climate considerate and sustainable manner to meet the challenges of tomorrow. Among several of the interesting courses we attended at the UiS, our professors encouraged the students to solve challenges in urban settings with elements that can provide additional benefits to the area. The relevant climate impact for our local context is extreme weather with vast amounts of precipitation. When we became familiar with nature-based solutions such as flooding prevention measures, we were fascinated by their advantages and potential. One of the authors had an internship at the company COWI Stavanger through the university. There she became acquainted with the cloud burst plan for Stavanger, which is still in the making, and how the private and public sector currently addresses the topic of stormwater.

Working with the thesis and this broad and complex topic has been insightful and educational. We found it especially interesting talking to local municipalities about the progress and challenges they encounter in their work with climate adaptation.

We want to thank our supervisor David Chapman, for his guidance and honest feedback. Further, the authors would like to thank all the representatives from local municipalities who attended the interviews and provided us with great, elaborative answers to let us take up some of their time and give great responses to the interview.

We would also like to thank Håvard, Anita and Josh for constructive criticism and feedback during the writing process. Finally, we would like to thank our spouse/partner, family, friends, and fellow students for engaging and motivating us during our time at the University of Stavanger.

Stavanger, June 2022

ABSTRACT

Nature-based solutions (NBS) have gained attention in the past decade as a way to adapt urban environments to the changing climate. However, the progress of implementing these solutions is considered to be slow. A reason for this may be due to unstructured and scattered information. Therefore, this thesis aimed to create urban design guidelines with nature-based solutions for climate adaptation in urban projects in a Norwegian context.

Several qualitative methods were used to achieve the aim. Initially, necessary knowledge regarding feasible solutions and a suitable urban framework was collected through a literature search. Then interviews were conducted with local planners to understand challenges on the relevant scale, and case studies were reviewed to learn from previous projects. Finally, the findings were systemised and illustrated in a simple format.

The result of this work is a design guideline that provides recommendations for the use of nature-based solutions for local water management caused by pluvial flooding for different landscapes pattern. The design guidelines are directed to planners in a Norwegian context and can be used as a guide for several zones characterised by various landscape forms and urban intensity.

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1

INTRODUCTION

CHAPTER ONE

INTRODUCTION

There are many notable effects and complications that will arise from climate change. From health issues and socio-economic inequality, to limited access to certain necessities, loss of biodiversity and conflicts and refugees (IPCC, 2022). Furthermore, it is important to be aware of the risks of damage to nature and urban elements as we continue into the future.

As of today, over half of the world's population live in cities, but by 2050 this number is expected to increase dramatically by 2.5 billion people. This increase would result in 68% of the worldwide population living in cities (UN, 2018). These developments strongly imply further urbanisation of a much large scale, The consequences of this urbanisation are many, notably an increase of hard imperious surfaces – which is shown to disturb the natural water balance by reducing natural infiltration, leading to increases of runoff (Ødegaard, 2012, Pochodyla et al., 2021; Zavenbergen et al., 2010). Incidentally this large-scale urbanisation is considered to be the main driver, along with climate change, to urban flooding challenges.

Over the last decade, the reduction of climate gas emissions has increasingly been implemented into the planning process. There appears to be a broad knowledge base among academics and planners on reducing climate gas emissions. However, there seems to be less attention brought to climate adaptation over the same period. The lack of attention toward adaptation is especially true for planners, who find themselves overwhelmed by new research and literature and convey that they lack the resources to absorb the information. Urban planning can be viewed as a collaborative multi-disciplinary process, with many involved actors and specialists from various fields (Kashef, 2007, p.28). Not everyone within this collaboration has an overview of recent technology, and knowledge must be communicated efficiently. Climate adaptation and nature-based solutions are topics that have gained more attention in the academic field. In scientific literature the topics become more apparent in the past decade. This is also reflected in UNs SDGs.

The UN has developed The Sustainable Development Goals (SDGs) as part of their strategy to meet coming challenges and ensure a sustainable future. SDG number 11 addresses sustainable cities and communities and emphasises that further urbanisation will cause challenges and create opportunities. Opportunities include better use of resources in urban settings with attention to climate adaptation. For example, water in urban areas could pose a threat resulting in disaster, or be used as a resource.

Nature-based solutions (NBS) and *blue-green infrastructure (BGI)* are emerging water management concepts that aim to create resilient cities by using water as a resource. Conventional water management strategies also referred to as grey measures, are based on guiding water swiftly away from the city by using underground pipes and tubes. Much of this infrastructure is outdated and not dimensioned for the forecasted change in weather patterns. NBS and BGI, on the other hand, aim to deal with the excess to water locally by introducing vegetation and concepts inspired by natural processes and phenomena. This approach has many co-benefits, including ecological, social, environmental, and economical; on the other hand, it also has some challenges related to implementation (Pochodyla et al., 2021; Tomasi et al., 2021; Vojinovic et al., 2021). NBS is also considered more adaptive than conventional methods (Voskamp & Van de Ven, 2015; Faivre et al., 2018; Kuller et al., 2019). Traditional methods for water management in Norway are to guide water into enclosed pipe systems. This strategy's main issue is the rigidness of the systems (Ødegaard, 2014, p.344). It is a system that lacks adaptability. The expected changes will challenge the system's capacity; therefore, it is essential to plan for robust systems capable of the change and effectively managing surface water (Norsk Vann, 2022).

Urban design is about considering the totality of the physical environment and is essentially the art of making places for people (Monighan, 2016, p. 4). City planning aims to resolve problems within cities and urban areas; simultaneously. They seek to improve overall quality. One of the main challenges in Norwegian cities is flood-related. Flood challenges can be solved by using NBS (NOU 2015:16). At the same time, the cities can become greener, which can help create more resilient urban areas since NBS is adaptive (Voskamp and Van de Ven2015; Faivre et al., 2018; Kuller et al.2, 019). They are relevant on different scales and will give co-benefits on various levels

To create and achieve holistic design, specific NBS interventions and measures should be evaluated based on their appropriateness according to the given place's uses and characteristics. An urban framework categorises various locations based on urban form and patterns.

1.1 AIMS AND OBJECTIVES

Damage to urban elements caused by weather events resulting from climate change is likely to continue. Therefore, the UN has included sustainable and resilient cities as SDG number 11, stating that some climate-related challenges can be resolved by holistic urban design in the city and regional planning. A prerequisite for this is that the actors involved in urban planning processes are familiar with appropriate solutions relevant to the given urban setting. This thesis aims to create design guidelines for urban projects to improve the knowledgebase and communication of available NBS concerning pluvial flooding in a Norwegian context. These guidelines intend to provide the municipalities with a user-friendly tool that can be used internally within municipalities and externally by other stakeholders.

The main research question and sub-questions are as follows:

How to create urban design guidelines with nature-based solutions for climate adaptation in a Norwegian context?

- What barriers do the local authorities encounter in their work with pluvial flood prevention and climate adaptation? Do they have the necessary means?

- Could the Rural to Urban Transect be used as a framework for design guidelines in urban projects in a Norwegian context?

The aim is achieved by compiling knowledge of climate adaptation related to pluvial flooding in the field of urban planning, reviewing relevant NBSs, presenting an urban design framework, and identifying possibilities and barriers that local authorities encounter in the climate adaption process and learning outcomes from case-studies. Based on this, a design guideline is created, reducing the knowledge gap, and facilitating more effective implementation of appropriate measures for a given urban and landscape pattern.

	Knowledge	Methods
1	*Compile knowledge regarding urban hydrology and nature-based solutions*	*Literature search*
2	*Present an urban framework that can be used to systemize knowledge of available nature-based solutions*	*Literature search*
3	*Gain an understanding of limitations regarding climate adaptation and NBS encountered on a local level of government*	*Semi-structured interviews*
4	*Explore case studies relevant to NBS and urban hydrology on different scales and rural-urban degree*	*Case-studies*

Fig 1. Knowledge and methods.

Choice of Scale

This thesis includes several levels of urban scales, ranging from micro to macro. It is necessary to explore several scales to understand the impact and scope of different solutions singularly and provide a comprehensive recommendation. Micro is the single measure, meso is the measures seen about each other, and macro is the sum of the measures seen in the transect. "The mesoscale does not focus on providing too much detail to the urban planner and decision-makers." (Zund, 2016). The macro-scale of urban planning is based on planning, zoning, and infrastructure networks (Australian Sustainable Built Environment Council, 2015) and is, therefore, quite relevant for the work of this thesis.

Fig 2. NBS interventions on different scales.

1.2 STRUCTURE

The thesis is divided into eight chapters. Chapter one consists of the introduction. The methodology of the thesis is presented in chapter two. Chapters three, four and five constitute the data collection of the thesis, which addresses the research questions and knowledge aim. The following chapter is the discussion. Here, the results and main findings from the previous chapters are discussed and evaluated and form the basis of the proposal. The proposal, which is the urban design guidelines, constitutes chapter seven. The final chapter consists of the overall conclusion.

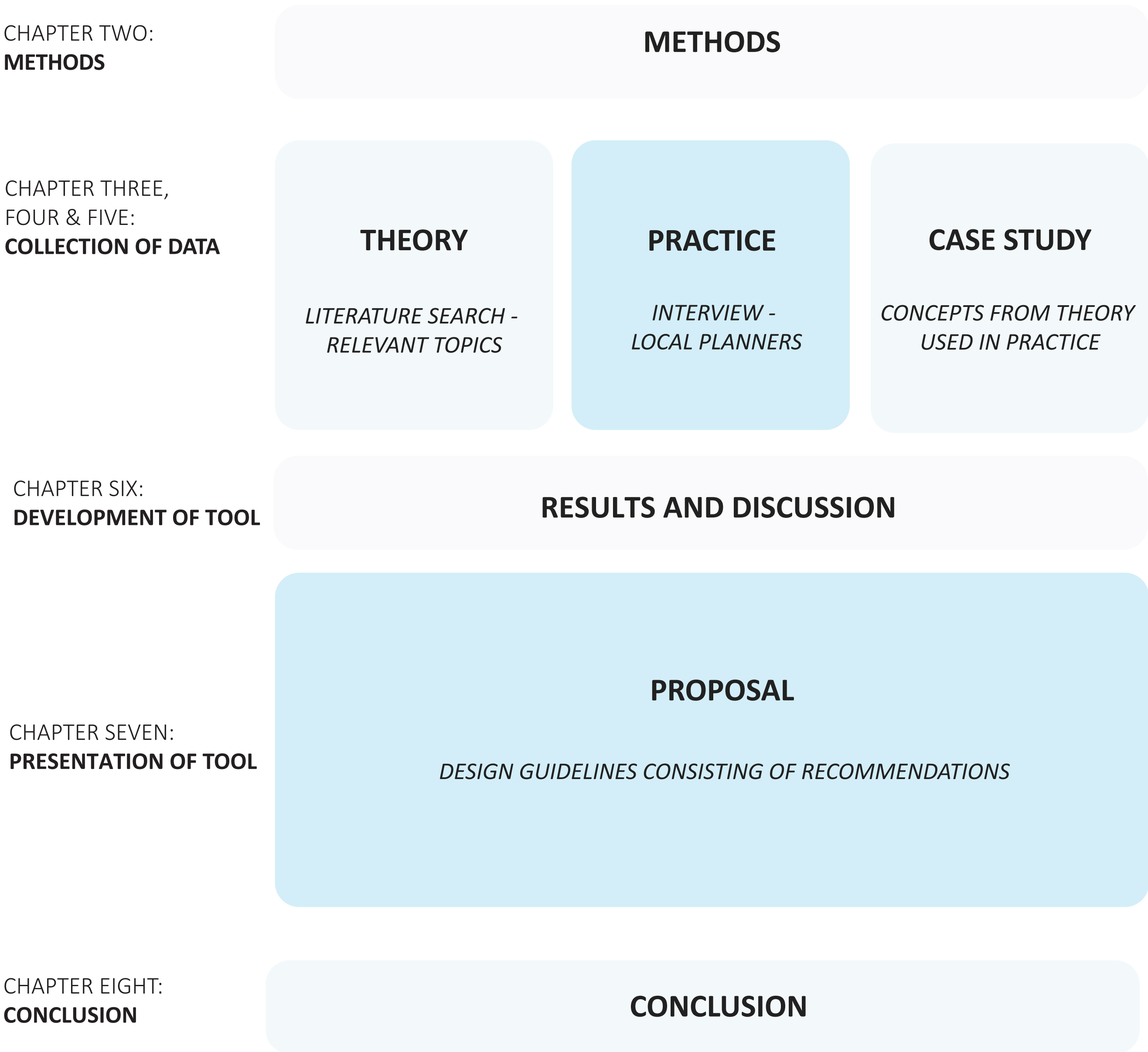


Fig 3. Structure of the thesis.

2

METHODOLOGY

CHAPTER TWO

METHODOLOGY

This chapter describes the mixed methods used to obtain the research aim and the associated knowledge aim. The knowledge aim requires different approaches to be answered and, therefore, other methods. Mixed methods can help provide a clearer picture “by representing research methods that involve qualitative and quantitative methods in the same study” (Leech and Onwuegbuzie, 2008, cited from Cameron, 2014). The following chapter will present a general description of the different methods and how they are applied. In addition, a description of the data sources and gathering the data.

The purpose of the knowledge aim is to achieve the thesis’ overall research question. Qualitative methods were selected as the methodology to achieve the aim. According to Dalland (2011), qualitative methods utilise data based on meanings, knowledge, and problems set in real life. The first two knowledge aims is gathering current information about existing concepts. Reaching the aim of the two is done through literature searches. Interviews are a qualitative method conducted in this thesis and are used to achieve knowledge aim three. The participants have been encouraged to elaborate on their experiences in the real world. The case study aims to answer knowledge aim four by understanding how concepts function in praxis.

2.1. DATA AND DATA SOURCES

The data used in this thesis is a combination of open access data, which is research data that is publicly available for anyone to download and use (York University, n.d.). Data includes local data and primary data. Local data used in this thesis have been collected from official local governments, including plans, strategies, and archives. Primary data, which is data collected by researchers directly from a source, are in this thesis gathered from site visits and interviews (Formplus, 2021). Scientific literature or the scientific knowledge base represents the individual “end product” of scientific research; new research builds on the previous research from the field. “The scientific knowledge is often divided into two basic categories” (Humboldt, 2022). Primary and secondary literature. Primary is reports of the results of original scientific research, while secondary is publications that synthesise and condenses knowledge on specific topics. Both forms of literature can be found in this thesis (Humboldt, 2022).

2.2. LITERATURE SEARCH

A literature search is an academic method that includes "research, reading, analysing, evaluation and summarising scholarly literature about a specific topic" (Auria Library, 2021). The intention of applying this method is to learn about the history and nature of the topic and identify different opinions, research gaps, and problems. A well-conducted review as a research method provides a firm foundation for creating a knowledge base (Auria Library, 2021). An initial literature search was conducted early to create a sound knowledge base for this thesis. Based on the preliminary findings, the snowball method was further applied. This systematic search aimed to understand the topic (climate adaptation and nature-based solutions), collect knowledge from a scientific perspective, and ensure that this information was up to date. Specific solutions and general strategies regarding climate solutions in an urban context were explored. The literature search formed the base to set the scope and framework for the thesis. The snowball method was included to give a search targeted toward information and relevant knowledge that would justify the aim of the thesis.

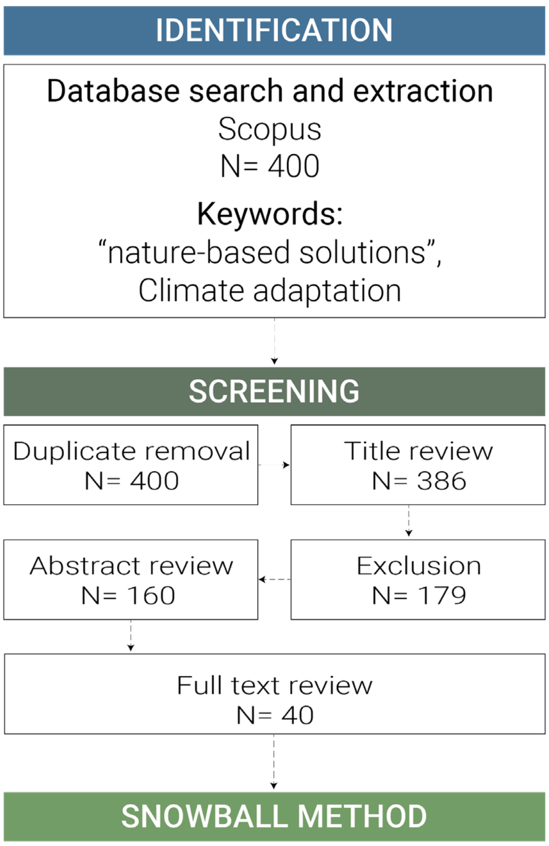


Fig 4. Method of systematic literature search

The initial search and many of the following searches were conducted through Scopus's online database. Scopus is a database that links scholarly literature across various disciplines and contains peer-reviewed literature such as articles, book chapters, books, and reports (Elsevier, 2022). The initial search was based on two main keywords: "climate adaptation" and "nature-based solutions." Other filters in this search include; the time interval 2010-2022; 2010 was chosen as the start year due to the Copenhagen Agreement of December 2009, an agreement that shed light on climate adaptation. The order of the initial literature search was; firstly, the articles or books were chosen based on the apparent relevancy of the title. Secondly, abstracts for the selected papers were read. Finally, the pieces with the most relevant abstracts were studied. The chosen database gives an option to sort the search results by several options; the options selected were sorting the search results by "Cited by (highest)" and "Relevance." The first five pages of each search result for each keyword and the two sorting options were conducted as described above. In total, 400 articles were collected and evaluated in this initial search. After the initial search, the snowball method was applied. The snowball method finds literature "...by using a key document on your subject as a starting point" (Breda University, 2022). Then, the bibliography of the key document was used to find other relevant titles on the subject. The initial literature search has been a base for the snowball method (Breda University, 2022). Relevant keywords were used in Scopus to dive deeper into the topic for the additional literature. The search was done by adding details to the filter function of the search engine, such as: “water management,” “rain garden,” “green roofs,” “green walls,” and “plants,”. Searches outside of Scopus were also carried out. Especially documents published by the EU, UN, and the Norwegian government. The snowball method was included to give a search targeted toward knowledge that would justify the aim of the thesis. Using systematic, structured search as the initial approach and following up with the snowball method enable the following searches to be more effective because the methods complement each other. One of the relevant themes within urban planning found during the literature search was urban coding and the rural to urban transect. These themes have been used for the further work of the thesis

2.3. INTERVIEW

The intention of using interviews as a method for this thesis is to understand how local governments take on climate adaptation challenges and how they include this thematic in their work. Another relevant perspective for the overall aim was to understand if the municipalities had sufficient knowledge and resources about climate adaptation and available solutions and find out if there were any tools or support they felt were missing. The most appropriate method of achieving this was conducting interviews with relevant people in the municipalities.

Research Design

Semi-structured interviews with officials working with climate adaptation in various municipalities were held. An interview is a qualitative research method that involves asking respondents questions to gather information about the research subject. Interview questions can be open-ended- or closed-ended, which encourages the participants to provide valid data valuable to the research (Formplus. 2021b). Semi-structured interviews have a premediated set of questions. This approach was selected instead of structured interviews because it allows the interviewer to explore other aspects of the interview. An interview guide has been the base for the interview questions (appendix).

Participants

A total of eight interviews were conducted. Seven of these were with municipalities, while the final interview was with the County Municipality. The officials from the municipalities were contacted based on available information on the employees responsible for climate, climate adaptation, or water management on their official webpage. They could freely choose who from the organisation would participate in the interview. The selection of respondents was primarily based on whom the municipalities themselves had indicated as responsible for or involved in climate adaptation. The municipalities that attended the interview consisted of 1-2 officials, mainly from the planning department (different kinds of positions:

ranging from spatial/city planners, managers, risk management, and engineers). We also contacted KS – The Norwegian Association of Local and Regional Authorities, to provide relevant information.

Approach and Questions

The interviews were conducted in spring 2022. One week before the interviews, the participants received an interview guide, including the questions and sub-questions. The interviews were semi-structured, meaning the questions were determined in advance, and the respondents were encouraged to speak freely about the subject. The respondents were asked to briefly answer the first section of questions and elaborate on sections 2 and 3. The interviews were held in Norwegian so the respondents could answer in their professional and native language and avoid linguistic barriers. The duration of the interviews varied from 30 minutes to one hour. Three interviews were held digitally via video call, while the remaining were conducted physically as face-to-face interviews. Both variants were interviewer-administered, and the phrasing used was open-ended questions. An open-ended question is a type of question that does not limit the respondent to a set of answers (Formplus, 2022).

The three main sections of the interview were:

1. Main challenges regarding climate and climate adaptation
2. How they work in terms of obtaining new knowledge
3. Factors that would improve their work

The questions have a broad and open formulation to give the respondents space to emphasise their experiences and struggles related to the topic. This type of question can be referred to as free-formed questions, which provide the interviewee with the liberty to express knowledge, experience, and thoughts. The setup is used to understand and map the methods the municipalities use in the climate adaptation work, the organisation of the municipalities, and what challenges they face in their work. The questions gave an initial frame for the interviews; however, each semi-structured interview was unique in how follow-up questions could be presented related to the respondents' answers. Including the interview questions in the appendix and the main theme/questions below. Audio recordings were used during the interviews, a data-gathering tool that collects information during an interview by recording the conversation. This technique is often used during face-to-face interviews to capture the interview objects' responses accurately. The recorded information is extracted and transcribed for data categorisation and data analysis (Formplus, 2022). After the interviews were transcribed and the information extracted.

2.4. CASE-STUDIES

Like the purpose of conducting interviews, case study as a method was included in this thesis to study how theory functions in praxis. A case study is also a qualitative research approach. It consists of a detailed search of a subject. More specifically, a descriptive case study was conducted to investigate the cause of real-life occurrences (Formplus, 2021b). In this thesis, multiple case studies were included to compare several aspects of findings from the literature search. The cases were strategically selected based on climatic similarities with the Southwest coast of Norway but also built environment and landscape typology. The chosen cases have different solutions and urban intensity. The cases included are to represent various measures and landscape zones.

2.4. PROPOSAL

Information gathered from the literature search, interviews, and case studies is presented in a new structure for this thesis's proposal. In the first section of the proposal, specific NBS interventions proposed in the theory chapter were evaluated based on their suitability for the different transect zones. The transect zones were adjusted from the original zones also presented in the theory chapter to the context of Jæren. The NBS interventions were then rated from "Not appropriate" to "Very suitable," based on an assessment with knowledge from the Three Step Strategy, the specific solutions, and the co-benefits of NBS. This rating provides the basis of a system/matrix of suggested interventions for each T-zone, the current characteristics of the different zones, and how they can be improved by implementing the given interventions. Lastly, a proposed layout for this information was made to illustrate the potential format and use.

2.5. LIMITATIONS

Language: A barrier met in this thesis is the language of the resources. In the literature search the authors have been restricted by their language knowledge, this has resulted in a knowledgebase that contains mostly of English and Scandinavian sources. This omits research written in other languages and can therefore affect the outcome of the literature search. The outcome is based on mostly western sources, ideally the authors would have liked to have a knowledge base with sources from other parts of the world as well.

Access: During the literature search some of the search result was not fully available, this resulted in some papers being discharged based on the access.

Number of participations: There were held eight interviews with 1-2 representatives, this makes for a fairly small number of participants, ideally more interviews could have been conducted to gain a larger number of participants to support the findings.

3

THEORY

CHAPTER THREE

THEORY

This chapter contains the information obtained from the literature search. It consists of a general review of climate adaptation in relation to urban planning is presented in 3.1. In the second part, 3.2, several aspects of urban hydrology are reviewed, including flooding, how the water balance changes accordingly to the urban degree, and Norway's common water management strategy. The theme of subchapter 3.3 is NBS. Here, interpretations and definitions of the concept are presented, along with challenges, benefits and specific solutions. Subchapter 3.4 constitutes the urban framework, The Transect, a branch within New Urbanism, and its common applications.

3.1 CLIMATE ADAPTATION

Climate adaptation is a relatively new topic in the academic field. It relates to new challenges that have been based on predictions with varying uncertainty and affect many different fields. This section aims to understand climate adaptation related to urban hydrology and current mitigation strategies.

Effects of Climate Change

According to the IPCC, the effects of climate change are comprehensive. They will include limited access to necessities, health issues, socio-economic inequality, conflicts and refugees, loss of biodiversity, and damage to nature, property, and infrastructure (United Nations, 2021.). It is also predicted to cause mixed precipitation and more extreme weather events, which can cause challenges related to flooding, landslides, bushfires, and draught. Miljødirektoratet describes climate adaptation as understanding the consequences of the changing climate and executing measures that, on the one side, can mitigate or reduces damage caused by a changing climate but also make the most of the possibilities these changes might inherit (Miljødirektoratet, 2022.).

Progress in Academia

As figure 5 shows, there has been an increasing trend for the topics: nature-based solutions and climate adaptation. Research with 'nature-based solutions' as a keyword has been published with exponential growth during the last five years, while the keyword 'climate adaptation' has had steady growth from 2010-to 2020, with a noticeable rise in 2021. The article's scope and scale vary from natural habitats protection and restoration to smart engineering solutions combined with natural elements for dense urban areas.

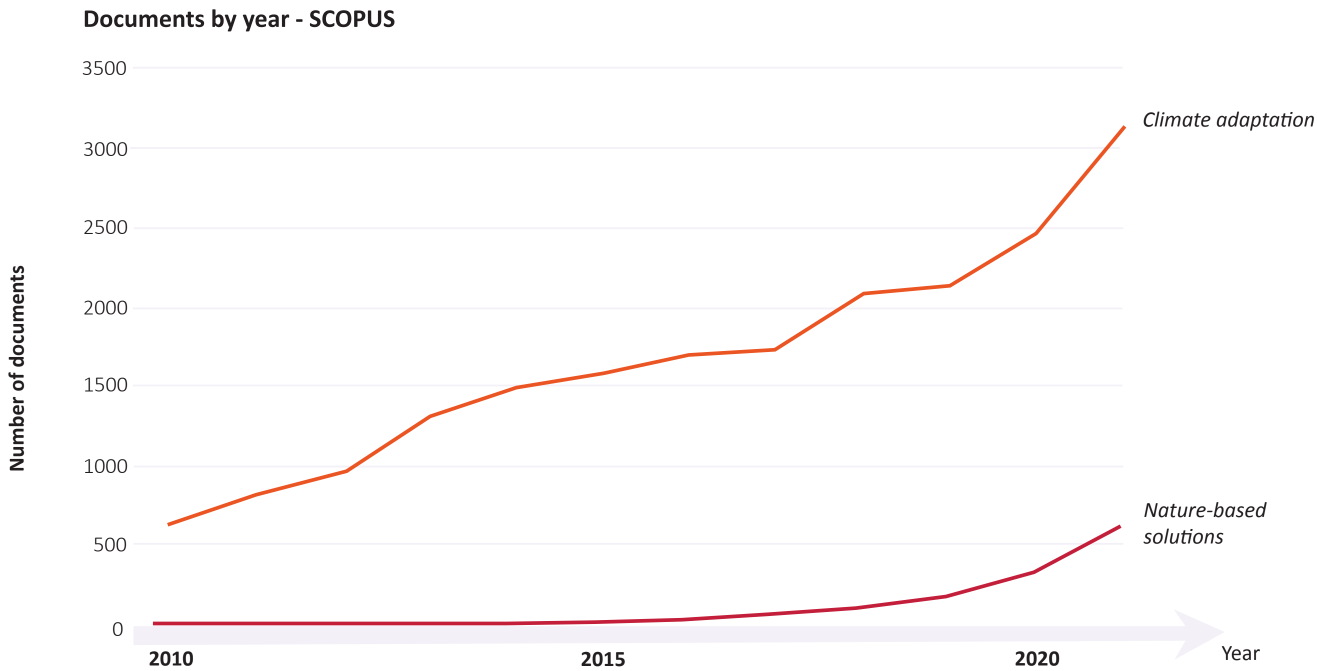


Fig 5. Results from the initial literature search. Documents published on SCOPUS from 2010-2020 with the keywords 'nature-based solutions' and 'climate adaptation'.

Climate Adaptation in Urban Planning

Climate change studies have appeared more prominently in urban planning literature in the last decade; most of the studies addressed climate change mitigation rather than adaptation (Dhar & Khirfan, 2016). The aim of adaptation studies "dealt with governance, social learning, and vulnerability assessments, while paying little attention to physical planning and urban design intervention" (Dhar & Khirfan, 2016). Climate changes impact physical systems, and adaptation to future impacts is needed.

Many existing cities experience challenges related to climate change seeing that infrastructure is under-dimensioned, with outdated systems or structures built for other conditions Ødegaard (2014) and Zevenbergen et al. (2010) emphasise that it is not sufficient to consider yesterday's or even today's conditions in renewal and upgrading the urban fabric to achieve sustainable climate adaptation. The planning should be based on the dynamic changes for the upcoming 100 years, not on the previous planning mindset that assumes the world is static and that the building and site last forever. Further, adaptation should become an integrated part of the planning process in urban renewal schemes and life cycle analysis (Zevenbergen et al., 2010, p.15). Findings from Amundsen, Berglund & Westskogh suggest that on the local scale, they "often invested in measures related to extreme precipitation and flooding than in measures for securing buildings and infrastructure against climate change»(2010). The focus has been on the challenges we face today, while it will be important to address the challenges that will come and adapt to them. With climate change comes a demand for proactive adaptation. (Amundsen, Berglund & Westskogh (2010), Zevenbergen et al, 2010).

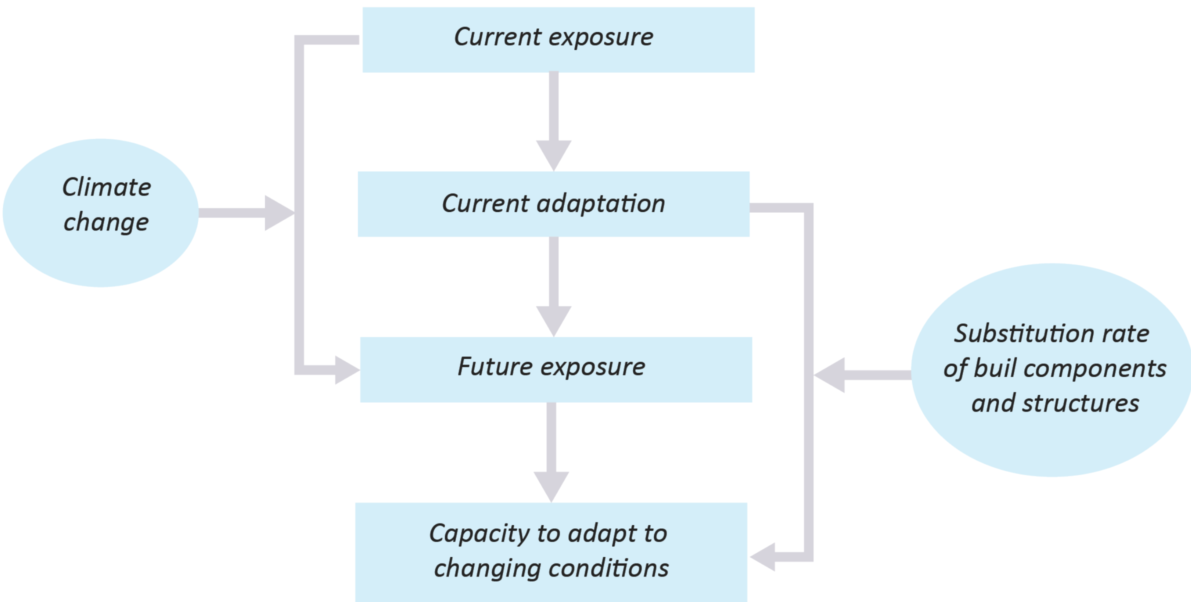


Fig 6. Climate adaptation- a dynamic process. Modified from Zevenbergen et al. (2010) p.16.

Climate Risk

Climate change affects society and ecosystems, both directly and indirectly. The consequences of the changes are dependent on the vulnerability of those affected and can exacerbate existing vulnerabilities. In general, the main aim of climate adaptation is to reduce the negative consequences of climate change and utilise positive aspects. Future consequences and their severity will depend on how well-prepared society is. Compared to other parts of the world, Norway has the opportunity to be well prepared and adapt to climate changes. Climate change is not equally distributed and will not be fair (Miljødirektoratet, 2021).

Adaptation in human systems prepares the systems for the actual or expected climate and its effects to moderate the harmful effects or take advantage of profitable opportunities. In natural systems, the process is related to preparing the system for the actual climate and its impact (IPCC, 2012).

Climate risk includes acute or physical threats, such as droughts, floods, extreme precipitation, and wildfires. Chronic risks include rising temperatures, the expansion of pests and diseases, and an accelerating loss of biodiversity. Climate risk regards the physical consequences of climate change and its effect on nature and society (NOU 2018:17).

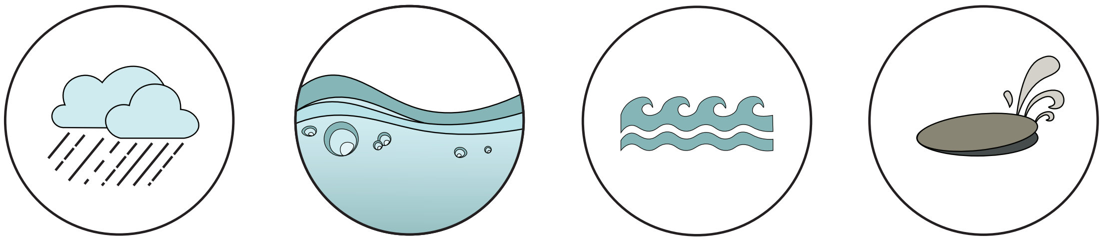
3.2 URBAN HYDROLOGY

Damage in urban settings caused by water occurs when the amount of water exceeds the capacity limit, including the rates of infiltration and engineered drainage. Sometimes this is a flooding situation, which is when an overflow of a significant amount of water rises beyond its regular limits (Zurich, 2020).

The term *runoff* refers to the water remaining on the surface after precipitation or snow melting. Runoff can flow from streets, roads, roofs, or other surfaces (Ødegaard, 2014, p.290). Runoff is not only a flooding-related problem since it can also contain chemical pollutants, pathogens, and heavy metals (Pochodyla et al., 2021; Ødegaard, 2014).

Flood Types

To mitigate the threats of flooding, it is helpful to consider the various kinds of flooding, their causation, and their impact. The most common flooding types in Norway are rainfall, snow melting, and coastal activity. They are induced by various sources or a combination of water. *Pluvial flooding* is a collective term for flooding caused by heavy precipitation exceeding natural and engineered drainage systems (Rosenzweig et al., 2018). Most of the Norwegian water network originates from 1971 to 2000, but approximately a quarter is from before 1971 and needs upgrading (OVAL, 2022). *Fluvial flooding* relates to water in movement, such as overflowing rivers (Store Norske Leksikon, 2021). *Coastal flooding* occurs when the coastal land is inundated by seawater. The flooding incidents in urban areas mentioned above can result in *sewer flooding.* This type of flood can be hazardous and costly, and extensive to recover from. Figure 7 compares the four kinds of flooding.



	Pluvial Flooding	Fluvial Flooding	Coastal Flooding	Sewer Flooding
Characteristics	Relates to flooding caused by **rainfall.** Excessive surface water.	Relates to **moving water**, primarily rivers. River overflow.	Coastal land flooded by **seawater.**	Overflow of water from drainage and **sewerage** system
Causation	Heavy rainfall, and or prolonged precipitation. 1. Urban flooding – low infiltration, drainage system not capable of absorbing water. 2. Flash flooding – extreme amounts of rain, often sudden and unexpected. 3. Groundwater flooding – Underground or natural water levels rise and reach surface.	Snow melting, high rainfall spill, prolonged periods of rainfall.	Heavy storms, extreme weather result in high tide.	Caused by other kinds of flooding events. Overwhelmed capacity of drainage system or clogging/blockage/ damage/ poor maintained/ outdated. Water from sewage flooding is often polluted and very hazardous. Very expensive to recover.
Related terms	*- Surface water flooding* *- Urban flooding* *- Flash flooding* *- Groundwater flooding* *- Storm water flooding*	*- River flooding*	*- Storm surge* *- Tidal flooding*	

Fig 7. The table summarises the diverse types of flooding, their causations, and related terms.

Flood Drivers

In Northern Europe, climate change will likely lead to an increase in the intensity and frequency of extreme weather events (UN, 2021; NOU 2015:16). These include cloudbursts; considerable amounts of rainfall occurring within a brief period. This, along with rapid urbanisation and deforestation, will pose a significant threat to urban water management. Research shows that urban areas are more vulnerable than natural and rural areas (Scharf & Kraus, 2019).

Figure 8 illustrates the predicted effects of climate change on runoff intensity. The runoff intensity of natural, rural, and suburban areas will likely slightly or partially increase with impacts due to climate change. In contrast, urban areas will experience a

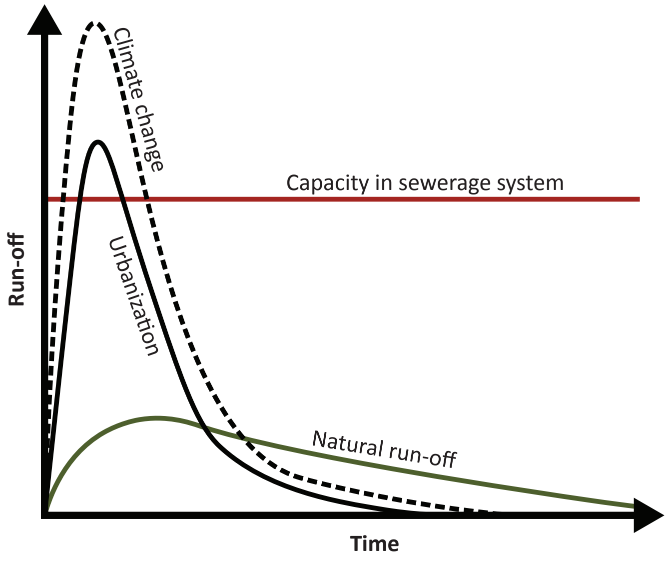


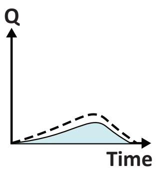
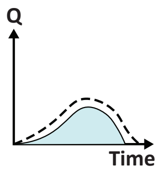
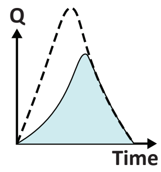
Fig 8. The graph illustrates the relationship between urbanisation, the impact of climate change, and runoff caused by heavy precipitation. Translated from Bergen municipality (Bergen Kommune, 2019). The capacity of the current sewage system is already congested with an increasing degree of urbanisation. Effects of climate change, in addition to urbanisation, are projected to burst the capacity.

significant increment in runoff intensity (SINTEF, 2012). Encroachment on nature, including urbanisation and deforestation, affects the water cycle and balance. Removing natural elements like vegetation that absorb water and surfaces that provide high water infiltration while substituting them with low permeable (hard covers) results in low infiltration, low evaporation, and increased runoff (Tollan, 2020). This combination creates optimal conditions for flooding, which is of high socioeconomic significance for cities and towns (NOU 2015:16, p. 30).

The hydrological cycle and water balance are affected by the permeability of the surfaces (Pochodyla et al., 2021; NOU 2015:16). The hydrological cycle consists of several processes; deep and shallow infiltration, evapotranspiration, precipitation, and runoff. In urban settings, the traditional and general water management strategy has been to guide the water as swiftly as possible out of the city in enclosed pipe systems (Ødegaard, 2014, p.344). This strategy aims to create suitable urban environments protected against flooding incidents. The main issue with this strategy is that the pipe systems are often under-dimensioned, leading to sewer flooding. As figure 8 illustrates, the impact of urbanisation on the runoff intensity has already exceeded the sewage capacity. Add to that the impact of climate change, and the current sewage capacity is exceeded even further.

According to Zevenberg et al. (2010), cities that consist of 75-100% impermeable surfaces experience low infiltration, whereas 10% is shallow infiltration and 5 % is deep infiltration. As a result, much of the water that would naturally infiltrate into the ground remains on the surface. In these cities, the runoff and access water are managed by pipes in the sewage system (Ødegaard, 2014, p.344). Due to the use of impermeable surfaces, runoff increases from 10% in areas with natural ground cover to 20-30% in rural and sub-urban areas. In urban areas, the runoff increases to 55% (Zevenberg et al., 2010). The surface affects the process of evapotranspiration, where less water is converted into water vapour, from 40% in areas with natural ground cover to 30% in urban areas (Pochodyla et al., 2021).

Along with the threat of flooding, the increasing use of impervious surfaces leads to a danger of pollution and hazardous substances. In addition to sewer flooding, the reason for this is that dangerous substances are usually absorbed with infiltration and naturally purified. Now, these are collected and transmitted to natural habitats such as streams, rivers, or the ocean during rain (Pochodyla et al., 2021; Ødegaard, 2014). This poses a severe threat to the ecological environment.

	Rural	Sub-Urban	Urban
Landscape			
Runoff intensity Q = *Runoff intensity* - - - = *Predicted runoff intensity*			
Surface permability	***High***		***Low***

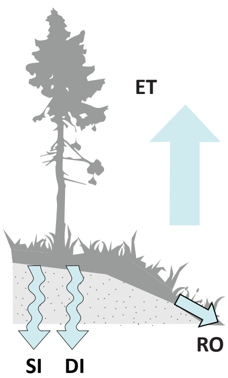
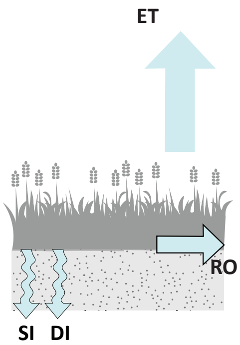
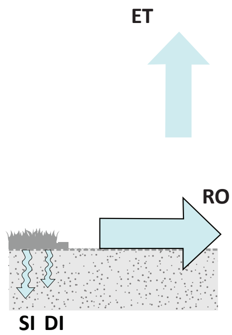
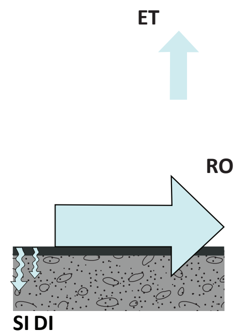
Water balance				
Impervious surface	***Natural cover***	***10-20%***	***35-50%***	***75-100%***
Runoff (RO)	10%	20%	30%	55%
Shallow infiltration (SI)	25%	21%	20%	10%
Deep infiltration (DI)	25%	21%	15%	5%
Evapotranspiration (ET)	40%	38%	35%	30%

Fig 9. Relationship between changing urban degree with increasing impervious surfaces and water balance. Modified from SINTEF (2012) and Zevenbergen et al (2010) p.99.

Water Management in Norway

Miljødirektoratet, *The Norwegian Environment Agency*, is responsibile for communicating knowledge and provide advice on matters related to climate and the environment. When deciding on a strategy for mitigating threats of pluvial flooding, they recommend studying the entire drainage basin simultaneously; this is because the outcome will depend on local characteristics of several factors, including topography, anthropogenic interventions, geological conditions, and how the area is expected to be affected by climate change (Miljødirektoratet, 2021).

According to Ødegaard (2014), a holistic urban water management approach should consider:

- *Safety of the citizens*
- *Avoid flood-related damage by securing percolation patterns*
- *Avoid built development of areas exposed to flood risks*
- *Ensure water quality from runoff*
- *Reduce overflow from the sewage system*
- *Protect existing urban vegetation*
- *Avoid using enclosed systems for streams and natural water flow, focusing on the sustainable design of open systems.*

Local runoff management (LOD) is the current approach in Norway (Ødegaard, 2014, p.344). This is in contrast to the traditional method of guiding the water as swiftly away as possible in pipes, the local approach seeks to let the water find its natural paths and balance. The natural hydrological pattern includes infiltration and natural flood paths such as streams and dams. This approach inherits other possibilities; water elements can be utilised in creating attractive and pleasant spaces, creating the foundation for a better living environment (Ødegaard, 2014, p.344).

Ødegaard (2014) emphasises that water management planners must be aware of the desired outcomes when deciding which measures are appropriate for the given context. He provides the following examples:

- *Avoid overloading the sewage and drainage systems.*
- *Avoid local flooding.*
- *Mitigation of eroding threats and landslides.*
- *Improvement of water quality in the recipient.*
- *Establishment of natural elements in neighbourhoods.*
- *Facilitate natural habitats for birds and animals.*

From an economic perspective, local open solutions could be desirable considering the age and state of the current sewage system and the cost related to upgrading this infrastructure to meet the demands of today and the future (Ødegaard, 2014).

3.3. NATURE-BASED SOLUTIONS (NBS)

Since the turn of the millennium, there has been increased attention to studying different concepts that address the maintenance, enhancement, and restoration of biodiversity and ecosystems; one of these is NBS (Kabisch et al., 2016). Within an urban environment, blue-green spaces provide benefits regarding biodiversity and environmental, social, and economic benefits. NBS is often presented as a part of the solution for climate adaptation, especially in cases related to hydrology. As mentioned in the previous section, nature's solutions can regulate the natural water balance. In this section, various definitions of the concept are presented, the effect this concept can have on an urban environment, and specific examples of such solutions given in recent research.

Terminology

Based on the initial literature search, it was clear that there has been a rapid development in technologies and applications around NBS. However, not all agree upon a uniform definition. Researchers and official publications operate with various meanings, depending on the solutions degree of engineering or their ability to provide societal or ecosystem services. The consensus is that NBS are a concept that works toward addressing multiple concerns simultaneously. According to Balian et al. (2014), NBS can be characterised as "[...] the use of nature in tackling challenges such as climate change, food security, water resources, or disaster risk management, encompassing a wider definition of how to converse and use biodiversity sustainably" (Balian et al., 2014:5, p.2). Davies and Lafortezza's (2019) definition opens for a more human-designed and modified use of biological concepts, where the solutions can be inspired by, supported, or copied from nature. Many agree upon the general conditions that NBS should help society address various challenges regarding ecological, environmental, social, and economic concerns (European Commission, 2015).

There are concepts with similarities to NBS, but that may have a slightly different meaning. According to Pochodyla et al. (2021), *blue-green infrastructures* (BGI) follow the benefits created by nature as NBS. However, NBS is more oriented toward natural elements and improving the biodiversity of ecosystems, while BGI, on the other hand, is based on innovative solutions created with engineering structures (Pochodyla et al., 2021). BGI, also called 'local solutions,' integrates hydrological solutions and local measures to enhance water management and landscape values for more climate-resilient and liveable cities (Nesshöver et al., 2017). BGI includes vegetation-based urban design, green infrastructure (GI), water-based solutions, and blue infrastructure (BI).

Grey infrastructure refers to the more traditional approaches to water management. Grey infrastructures may complement green infrastructures in helping develop climate resilience. Infiltration is typically low in cities where grey infrastructure is the primary space component.

Ecosystem-based Adaptation (EbA) is another concept that shares many features with NBS and is considered a type of NBS. EbA focuses on protecting, restoring, and sustainably managing ecosystems to help humanity adapt to climate change. Ecological engineering is another term relating to technologies developed to solve urban challenges based on natural elements (Magnussen et al., 2017).

In the report, “Naturbaserte løsninger for klimatilpasning” translates to “Nature-based solutions for climate adaptation” (2017), commissioned by the Miljødirektoratet, a broad definition of NBS is used:

- *Solutions that use or restore exciting nature types or ecosystems.*
- *Solutions that are based on nature (including semi-natural solutions).*
- *Solutions are often characterised as blue-green infrastructure and involve “nature mimicking” to some degree. E.g., construction of runoff dams and bioswales or ditches.*

Translated from (Magnussen et al., 2017, p.8)

This thesis has made a conscious choice to use the definition presented in the report “Nature-based solutions for climate adaptation” (2017). This definition allows the concepts of BGI and EbA to be included within the collective concept of NBS. This interpretation contains several aspects of the topic, which opens for various NBS interventions and will be used in the following.

NBS Strategies

NBS can be used to restore the natural water balance structure in urban areas (Pochodyla et al., 2021; NOU2015:16). According to Pochodyla et al. (2021), a place with a 75-100% impervious surface can, by introducing BGI, reduce runoff from 55% to 15%. This is mainly due to the increased shallow infiltration that BGI provides. This is illustrated in figure 10 and 11.

Before NBS

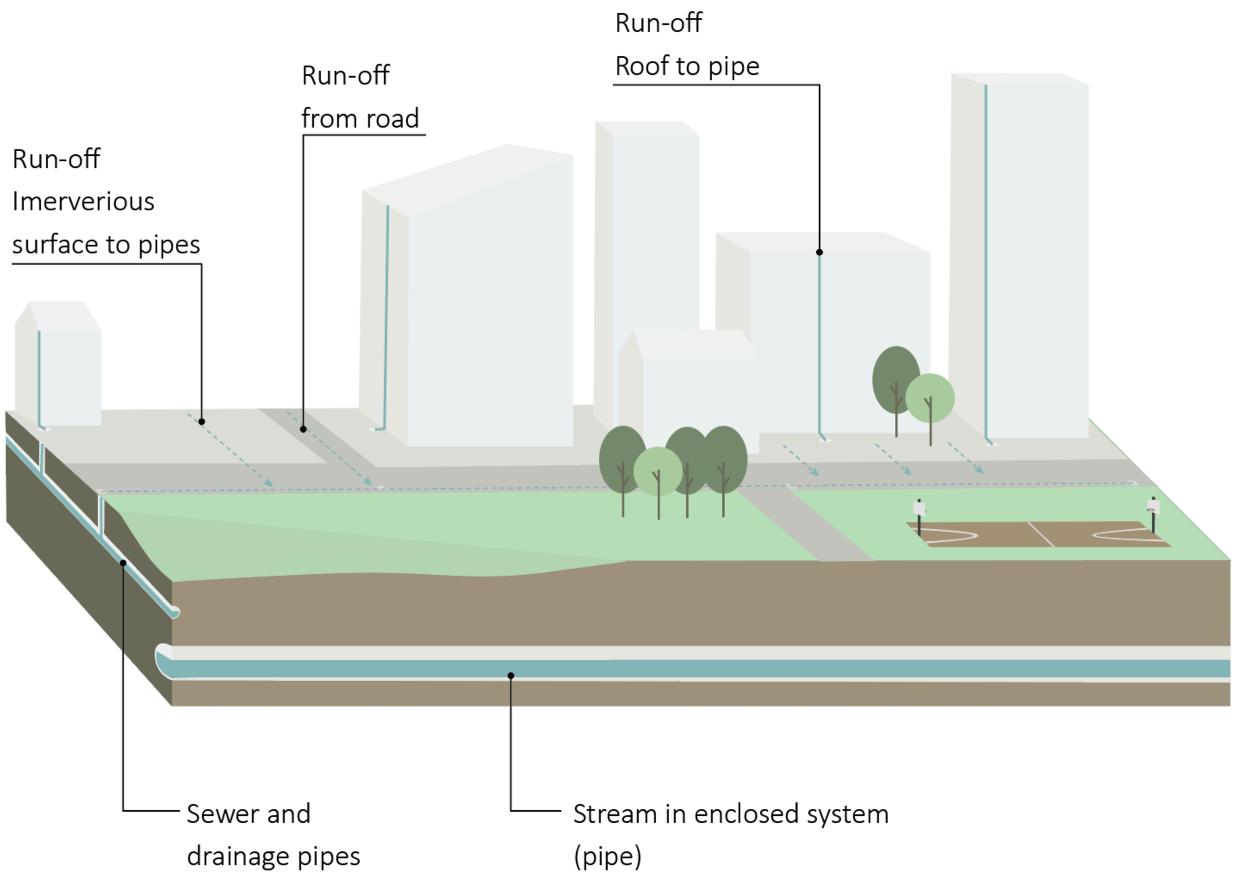
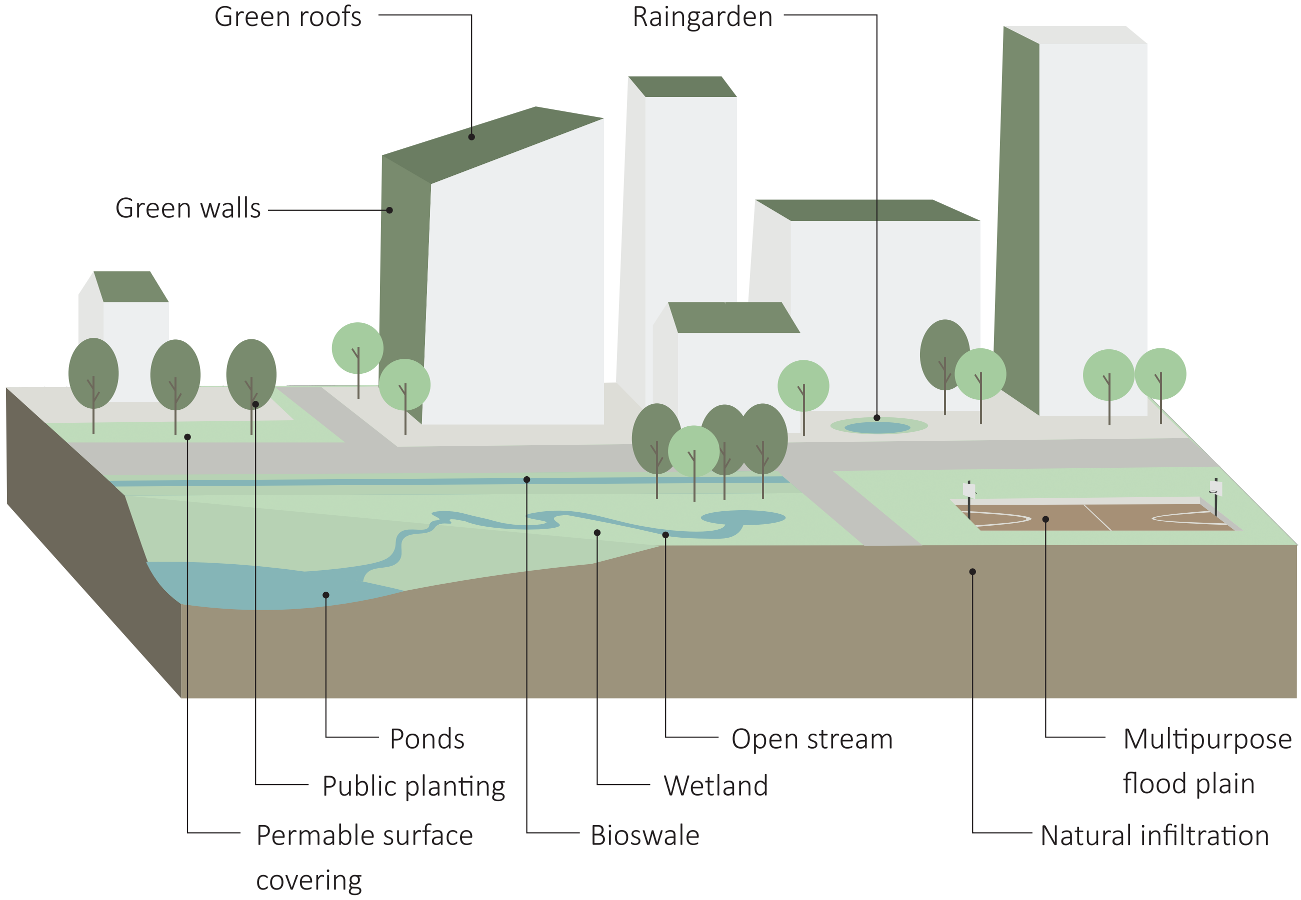


Fig 10. Conventional water management (Before). Modified from NOU 2015:16 p.66

After NBS



	Before	*After*
Impervious surface	***75-100%***	***75-100%***
Runoff	**55%**	**15%**
Shallow infiltration	**10%**	**45%**
Deep infiltration	**5%**	**5%**
Evapotranspiration	**30%**	**35%**

Fig 11. The figure illustrates how specific NBS can be integrated as runoff management measures (After). The table shows NBSs' gathered effect on the water balance in an urban environment without the use of NBS (Before) and after they have been implemented (After). Modified from NOU 2015:16 p.66 and Pochodyla et al. (2021).

Three-Step Strategy

Miljødirektoratet recommends using the Three-Step Strategy (Tre-leddstategi) as a planning tool. As the name suggests, this strategy is based on three concepts for reducing, delaying, and guiding runoff, resulting in less critical water masses that directly threaten the urban environment. When choosing the most effective measure or combination of measures, it is essential to evaluate local characteristics and the intensity and volume of precipitation.

This strategy aims to create a resilient urban living environment, unburden the existing sewage – and drainage system, and adequately secure the pathways to the recipient (NOU 2015:16, p.67). Firstly, the water should, if possible, be managed locally by infiltration and percolation. Private properties with gardens containing runoff measures are an example of local water management mentioned in the NOU 2015:16. The access water is guided to more extensive retention facilities, such as basins, ponds or Bioretention facilities, often a hybrid solution. A hybrid solution is a combination of NBS-derived technology combined with engineering solutions. In periods with intense precipitation, the hydraulic capacity of these facilities could be exceeded. Then the proposed solution is to divert the runoff along a secure pathway to a recipient.

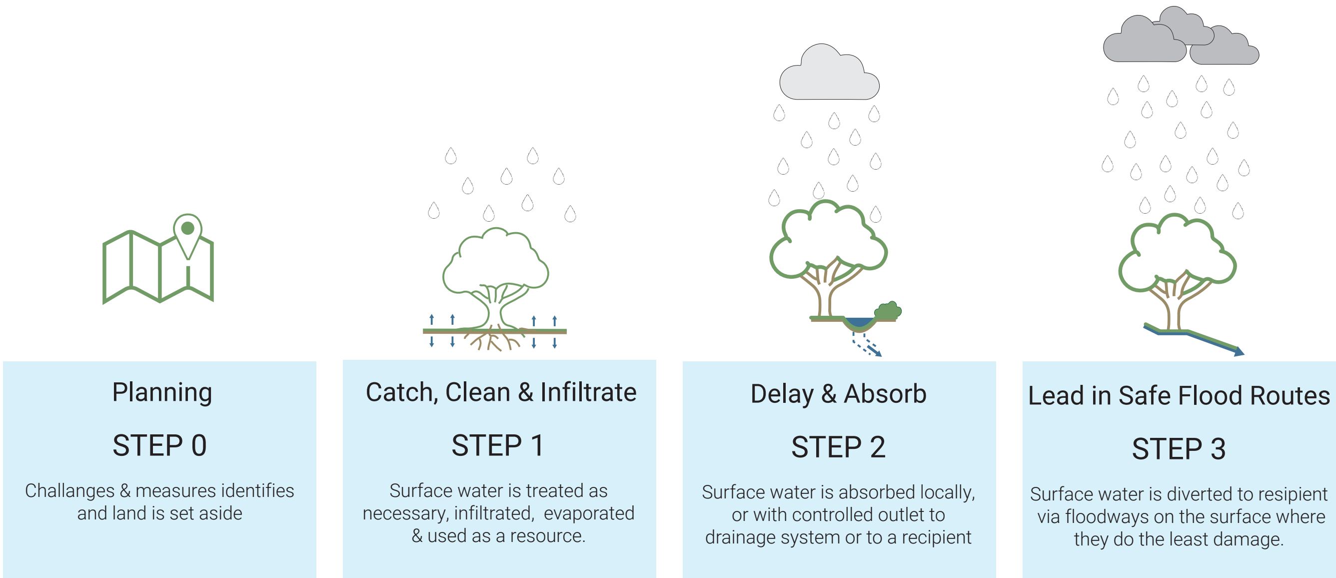


Fig 12. Three-Step Strategy with NBS. Modified from Miljødirektoratet (2021).

STEP 0: Planning

Developing the Three-Step Strategy includes a step 0 based on early planning. Here, the step identifies challenges and viable solutions and sets aside an area necessary for the following steps. Developing plans that include equipped and well-measured solutions and strategies for runoff makes it possible to avoid damages. Having plans for where the excess water is supposed to go is crucial. It is essential to keep in mind that not all measures work under different circumstances; it is, therefore, necessary to consider local premises when planning (Lier Kommune, 2019).

STEP 1: Infiltration

The aim of step 1 is to delay runoff by managing it locally. This is done by infiltration, which is a process where water from the surface penetrates vertically into the soil (Ødegaard, 2014, p.44). When the intensity of the precipitation reaches a certain threshold, where the ground's ability to absorb the water is exceeded, it can result in a flood. Step 1 is therefore used during minor amounts of rainfall. The with-holding of water or infiltration can be achieved by utilising green structures; this is especially important in urban areas with a high degree of impervious surfaces. Examples of measures implemented in step 1 are permeable surfaces, vegetation, and bioswales.

STEP 2: Delaying

This step is used for more significant amounts of rainfall. Here, the excess runoff from step 1 is guided into open facilities that can slow and delay the runoff (Ødegaard, 2014, p 353). Examples of measures that can be implemented in step 2 are; open water surfaces, such as ponds, bioswales, closed retention ponds, retention facilities and basins; basins are a hybrid solution (Ødegaard, 2014).

STEP 3: Runoff to the recipient

Some events have such a large rain volume that the capacity of the regular system is overrun. In step 3, the excess runoff from step 2 is directed into secure floodways and leads to a recipient or other areas adapted to withstand flooding and excess surface water (Ødegaard, 2014, 353). Examples of measures that can be implemented for the third step are safe, planned and engineered floodways and the bodies of water used as recipients. A floodway is a clearly defined canal or an area meant to lead water flow in terrain from urban areas. A floodway is established when the drainage system can no longer divert the entire inflow, and the flood peaks are thus shifted to the terrain surface. When developing new areas, it should always be investigated where there are streams, ditches, or other water courses in the site to be used to divert surface water (Ødegaard, 2014, p. 314).

Fig 13. Three-Step Strategy description.

Blue-Green Factor

Blue Green factor (BGF) is a tool used to ensure the water management, vegetation, and biodiversity in development projects; it is a necessary standard used in Norwegian planning and climate adaptation. Applying a standard for BGF can ensure an excellent outdoor space and a focus on climate adaptation in the development process. The standard includes requirements set to provide a minimum connection to water management and vegetation regarding the current legislation and guidelines (NS 3845, 2020).

The purpose is to motivate the developer to preserve and increase the use of different blue-green qualities in outdoor spaces. The method uses the German model “Biotopflächenfaktor “as a base on how one can calculate green attributes (Oslo & Bærum kommune, 2014).

The blue-green factor can contribute toward:
• *Reducing damages from heavy rainfall.*
• *Sustainable surface water management.*
• *Promote ecological and aesthetic qualities.*
• *Develop the soil, bettering microclimate, water, and air quality.*
• *Facilitate better outdoor spaces.*

Fig 14. Contributions from blue-green factor.

Challenges of NBS

Although NBS is an increasing topic in academia, NBS is applied at a slow pace (Vojinovic et al., 2021). One of the barriers to NBS implementation is that they require new interdisciplinary approaches; another is the knowledge gap of the available technology and how to integrate them successfully (Tomasi et al., 2021; Vojinovic et al., 2021). The effect of NBS is debated within the academic field. In most of the literature studied for this thesis, the researchers advocated for NBS. However, a few were critical. The criticism mainly focuses on NBS lacking documented effects compared to conventional hard-engineering systems and solutions. The advocate’s main focus was on NBS multifunctional services, in contrast to the traditional solutions and grey infrastructure (NBS services include; carbon storage, biodiversity, ecosystem regeneration, aesthetic features, mental well-being, community engagement, food production through urban farming, pollution, and purification of water, air, soil, among others). Another concern mentioned was the NBS’s vulnerability to change in climate, as it will be affected by the same factors they hope to mitigate (Ossola et al., 2021).

Benefits of NBS

NBS provide many co-benefits in addition to flooding mitigation. Miljødirektoratet encourages planners and developers to consider using NBS in projects with flood-related challenges due to its many advantages. The co-benefits mentioned by Miljødirektoratet (2022) and Scott and Lennon (2016) are listed in figure 15.

- **Recreational possibilities.** NBS can provide attractive places for people to stay.
- Physical and mental **health benefits**. Blue-green elements have been shown to have a calming effect, reducing stress,s and the areas with NBS can be used for physical activity.
- **Aesthetical value**, strengthen **cultural heritage** and create **place identity**. Blue-green elements are generally considered to provide aesthetical value. Protecting and reintroducing elements from the cultural landscape can support the cultural heritage and local identity.
- **Education** and **cognitive development** can be achieved with NBS by facilitating learning, explo ration, and play.
- **CO2 capture** and **storage** by utilising the plants' ability to convert C02 and sunlight to O2 by photosynthesis.
- Other local **micro-climate** effects; include mitigation of other climate-related challenges such as wind and sun exposure, retaining stable temperature conditions (both isolation heating and cooling effect)
- Reduction of **noise pollution**. Blue and green elements absorb and reflect vibrations in the air.
- Improve **air quality**. Plants can bind air-borne particles and cleanse the air while producing oxygen. This can reduce the incidence of respiratory diseases.
- **Biological diversity**. NBS create habitats for animals. Also, nature holds an intrinsic value. They are creating optimal living conditions for pollinators by using vegetation. Birds and animals contribute to seed dispersal, which is essential to maintaining biodiversity.
- If collected, the source of **clean water** can be utilised, for instance, to use in urban farming.
- The **cleansing** effect of polluted surface water runoff. Particles from road traffic can be infiltrat ed and absorbed by soil and vegetation.

Fig 15. Co-benefits mentioned by Miljødirektoratet and Scott & Lennon. (Miljødirektoratet, 2019; Scott & Lennon, 2016).

Urban Scale

Scott and Lennon (2016) also mention the NBS's ability to be applied to an urban scale and the range of scalar interventions they can provide. They range from designing ecological networks on a city scale to local urban parks with multifunctional purposes, including cooling and flooding alleviation services, and even to a micro-scale with streetscapes designed to retain rainwater (Scott & Lennon, 2016, p.268).

Types of NBS

There is a wide variety of NBS; some central aspects and measures will be presented. To understand the impact of NBS on a larger scale, it is essential to explore the main measures on a micro-scale. The measures presented in this subchapter are primarily on a smaller scale, and all the steps within the Three-Step Strategy are represented. Some interventions function as several steps, while others can have only one purpose: to infiltrate, as a collector, or guide the water masses away to a recipient.

Eco-Roofs

The traditional roof, or "black roof," has its sole purpose of providing shelter, while eco-roofs are established to achieve additional environmental and sustainability aims. Eco-roofs can provide other measures such as water conservation, cooling, and electricity savings, protecting biodiversity by providing habitat for wildlife, storm-water run-off, water quality management, and carbon absorption. An eco-roof is used to collect and retain stormwater within the Three-Step Strategy. There are three main types of eco-roofs: green roofs, which are vegetated; blue roofs, where the aim is regarded toward water management; and white roofs, where the focus is on cooling (Foster et al., 2011). This section focuses on blue- and green roofs, which are the most relevant to the Norwegian context.

Green Roofs

Green roofs are vegetated roofs; they can be either wholly or partially covered with plants or trees. Green roofs include different layers such as waterproof membrane, root barrier, drainage layer, substrate, and plant elements (Pochodyla et al., 2021). Based on the thickness of the layers and vegetation chosen, there may be a need to structurally reinforce buildings when establishing green roofs to support the added weight (Foster et al., 2011). Green or vegetated roofs are divided into three main categories depending on their structural composition and maintenance requirements (Calheiros & Stefanakis, 2021). These categories are intensive-semi-intensive and extensive green roofs.

There are different benefits to the distinct types of eco-roofs. Green roofs can reduce annual stormwater run-off by 50-60% on average- this includes peak runoff (Columbia university, 2007). In most developed cities, roofs make up 40-50% of all impervious surfaces (Calheiros & Stefanakis, 2021). Calheiros and Stefanakis (2021) emphasise the green roof's role as a solution to the limitation of

Green roof construction

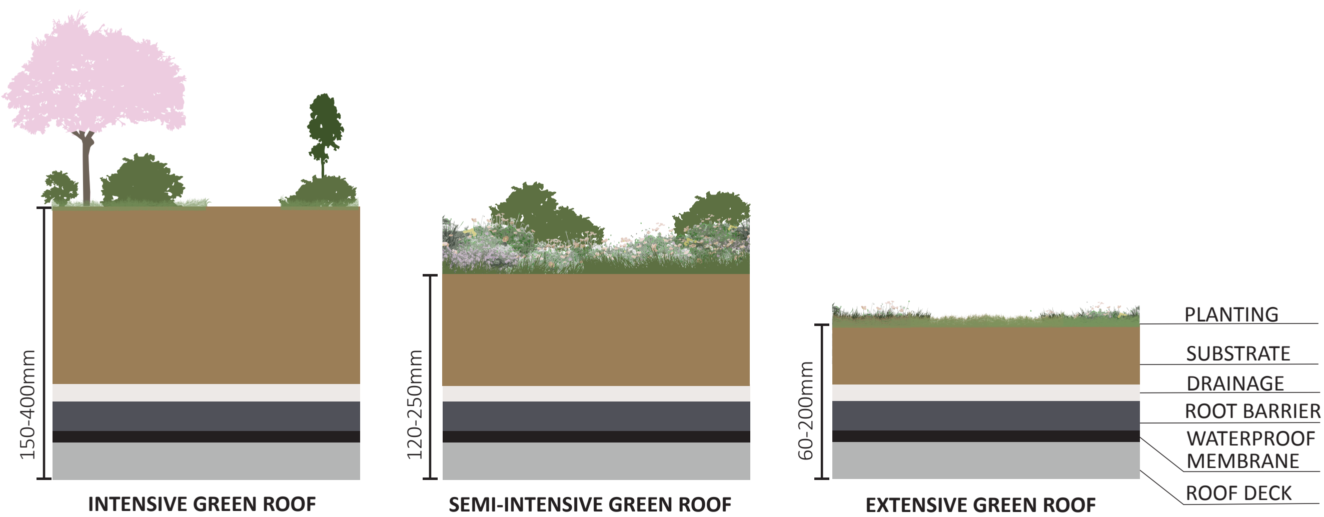


Fig 16. Construction of green roof types (not to scale). Modified from Pochodyla et al. (2021)

available space within the city and the many problems related to this, such as water management. Green roofs can also filter air pollutants, including particulate matter (PM) and gaseous pollutants such as nitrogen oxide, sulphur dioxide, carbon monoxide, and ground-level ozone (Foster et al, 2011, p. 7). One of the main challenges linked to implementing (retrofitting) green roofs is that not all types of roofs are suitable for this construction, such as historical buildings (Calheiros & Stefanakis, 2021).

Intensive green roofs include a variety of plants and uses. Therefore, it requires a thick substrate layer to support the vegetation and use. Within the vegetation suggested for intensive roofs, a wide variety of plant species; trees, shrubs, and perennials. It consists of layers measuring 150-400 mm and weighing 180-500 kg/m2 (Pochodyla et al., 2021). This type requires high maintenance, like a regular garden, in terms of fertilisation, irrigation, and plant accommodation (Calheiros & Stefanakis, 2021). Intensive green roofs can serve many functions, including leisure areas and a social meeting place.

Semi-intensive green roofs have a plant selection that mainly contains small plants such as digestive plants, herbs, and shrubs and therefore requires a moderate thickness of the substrate. The thickness of the substrate layer measures 120-250 mm, and this type weighs around 120-200 kg/m2 (Pochodyla et al., 2021). Semi-intensive green roofs are used mainly for esthetical purposes and can be applied on renovated roofs. It is possible to open this type of roof for public access and establish gardens. The required maintenance is lower than the intensive green roofs. Nevertheless, it should be looked after regularly (Calheiros & Stefanakis, 2021).

Extensive green roofs are the thinnest of the main green roof types. The plants selected for this type of roof have shallow root systems and consist of variations of moss, herbs, and sedum; it also includes grass, which is a favoured choice. There is less variety of species for this roof design than intensive and semi-intensive roofs. However, their biodiversity is often greater than intensive roofs. The substrate has a thickness of 60-200 mm and weighs 60-150 kg/m2 (Pochodyla et al., 2021). It can be installed on steep roofs and in places with restricted access. The vegetation should not be stepped on unless it is for maintenance. The required maintenance and cost implementation and maintenance are low compared to the other types of green roofs (Calheiros & Stefanakis, 2021).

Multipurpose green roofs

The top layer of these green roofs can have several designs depending on their intended purpose. Some examples of this are bio-solar, productive-biodiverse-, and blue-green roofs.

Bio-solar are vegetated roofs in combination with photovoltaic panels. The achieved outcome is generated renewable energy and facilities for creating an ecosystem. The vegetation also has positive performance benefits for the panels (Calheiros & Stefanakis, 2021). A comparative case study conducted by Wooster et al. (2021), comparing bio-solar and conventional solar roofs, proved that green roofs have ecological significance by attracting and supporting fauna in urban areas. This research demonstrates the potential of creating a biologically diverse city by widespread adaptation of green roofs while simultaneously generating renewable energy.

Productive roofs are rooftops used for urban agriculture (Calheiros & Stefanakis, 2021).

Biodiverse roof the main intention of this roof type is to promote biodiversity in terms of both fauna and flora. The species are carefully selected to achieve the goal, with adapted substrate thicknesses and additional structural elements to create an optimal micro-climate (Calheiros & Stefanakis, 2021).

Blue-Green Roofs

According to Busker et al. (2021), conventional green roofs have received criticism regarding their water buffer capacity during extreme precipitation. Their article suggests this problem can be resolved by adding an extra blue water retention layer underneath the standard green layer. This reservoir can store stormwater that infiltrates through the green layer and can provide the vegetation in the green layer with water through the capillary effect. A smart blue-green roof can be regulated by an automated valve that can be opened to drain in cases when extreme rainfall is expected based on weather forecasts (Busker et al., 2021). In the research done by Busker et al. (2021), it was reported that this model of blue-green roofs could capture 70-97% of the rainfall in cases with extreme precipitation, which is over 20mm per hour, in contrast to green roofs with extra water retention (12%) and regular blue roofs without smart system (59%). The smart blue-green roofs performed better than the others in terms of evapotranspiration. On a scorching summer day, blue-green roofs had evapotranspiration of 70%, while conventional green roofs had 30%.

Blue-green roof construction

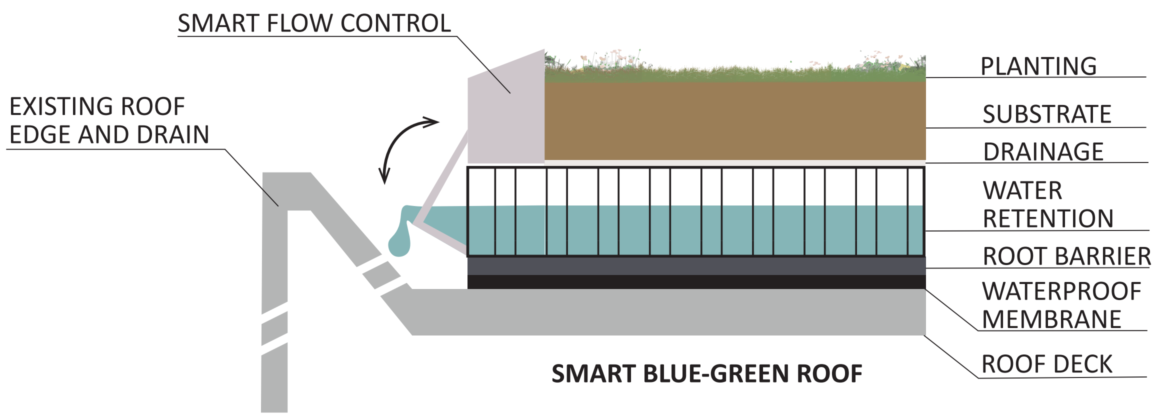


Fig 17. Construction of a smart blue-green roof (not to scale). The top layers are similar to conventional green roofs; the water retention layer is standard in most blue roofs, while the smart flow control based on weather forecasts makes this type of smart. The valve opens when extreme rainfall is expected and allows some water to flow into the drainage system. Modified from Busker et al (2021).

Vertical Greening Systems

Vegetated walls are in academia, often called *vertical greening systems* (VGS) and are defined as living vertical gardens that are self-sufficient (Perez et al., 2019). In the Three-Step Strategy, the VGS is primarily used to retain stormwater but can also be used to infiltrate, depending on the system's construction. VGS can be categorised by the system's structure and selected growing method. The main category is living walls, also referred to as 'green walls;' the other type is the traditional 'green facades' (Coma et al., 2017; Radic et al., 2019). Like Eco roofs, green walls can create habitats, increase biodiversity, and retain surface water.

A living wall, the first category, is a wall installed with panel modules with a growing medium, and the roots are not in direct contact with the ground (Radic et al., 2019). This category can be further divided based on their technical design and growing medium, such as planter boxes, felt layers, foam substrate, and mineral wool layers (Pochodyła et al., 2021). Plant species used in living walls or green walls can be types that naturally would not grow on a vertical surface.

Green façades, the other primary type of VGS, green facades, are walls that are covered with climbing plants with roots based directly in the ground soil (Perez et al., 2019). This vegetation can either grow directly on the façade or be supported by additional structures (Pochodyła et al., 2021). A challenge with this type of facade is that the roots might affect the foundation of the building.

Fig 18. Different types of VGS. Modified from Pochodyla et al. (2021)

Ground Covering

This section includes NBS interventions that are placed on the ground level. This includes permeable pavements, rain gardens, bioswales, and rain barrels. Combined, they serve each step of the Three-Step Strategy. Some interventions can be used for several steps. Permeable pavement is mainly used for infiltration. Rain gardens and rain barrels serve as collection and retention systems (and infiltration), and bioswales can be used for all steps, including flood paths.

Permeable Surface

In an urban settlement, natural land covers such as grass and forests are often replaced with impervious surfaces; these can be roads, streets, and parking lots made by using asphalt, concrete, or stone, e.g., this can give increased runoff because of loss of water retaining from the soil and vegetation. Increased runoff can make for floods, erosion damage, degrading habitat, and diminished groundwater recharge. *Permeable pavement* is a porous urban surface composed of open-pore paves, concrete, or asphalt with an underlying stone reservoir. It catches surface runoff and stores it in a pool, then slowly allows it to infiltrate into the soil below or discharge via a drain tile (Ødegaard, 2014, (Upper Midwest Water Science Center (UMWSC), 2019).

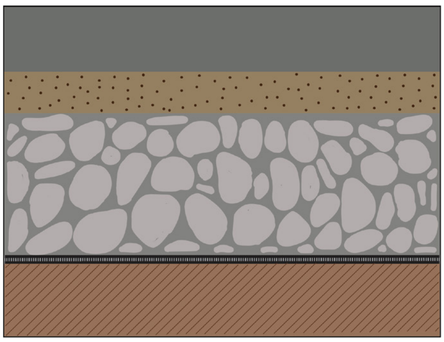


Fig 19. Permeable surface. Modified from Ødegaard (2014)

There are several potential benefits; permeable pavements can help re-establish a more natural hydrologic balance and reduce runoff. It can reduce the concentration of some pollutants. Colder weather can also reduce the need to apply road salt for de-icing (UMWSC, 2019).

Porous covers and surfaces are built with a base of coarse material that water can seep through easily. It is possible to establish porous asphalt pavements or gravel surfaces; the easiest way to establish porous surfaces is to note the surface material too tightly. Solutions with porous surfaces are suitable in areas with permeable spoil; clay is not appropriate. It is built atop of. Porous asphalt should not be implemented in areas with substantial amounts of traffic, the most ideal in areas with little traffic (Ødegaard, 2014, p. 357).

Raingardens

Raingardens, also called bioretention facilities, are landscape sites designed to reduce the flow rate and pollution load of runoff from impervious urban areas. Raingardens contain plants that retain stormwater; they also filter pollution from urban runoff. Hence it can improve water quality in surrounding bodies of water. It is also aesthetic and encourages biodiversity (Groundwater foundation, 2022).

A study by Richards et al. (2015) showed that the given vegetable rain garden reduced the frequency and volume of the runoff by over 90% (rain garden-sized 7.5% of its catchment area). The vegetable rain gardens performed similarly to the control gardens in terms of yield. This research demonstrates the potential of excessive stormwater runoff to urban food production.

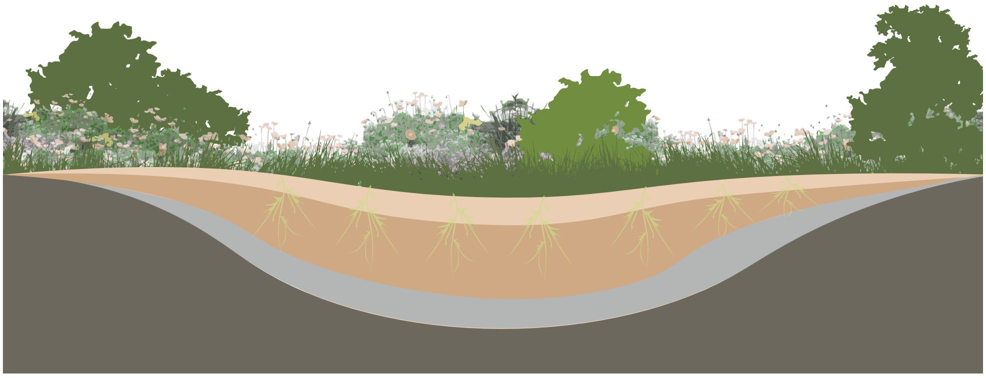


Fig 20. General concept of a natural designed raingarden. Modified from Pochodyla et al. (2021)

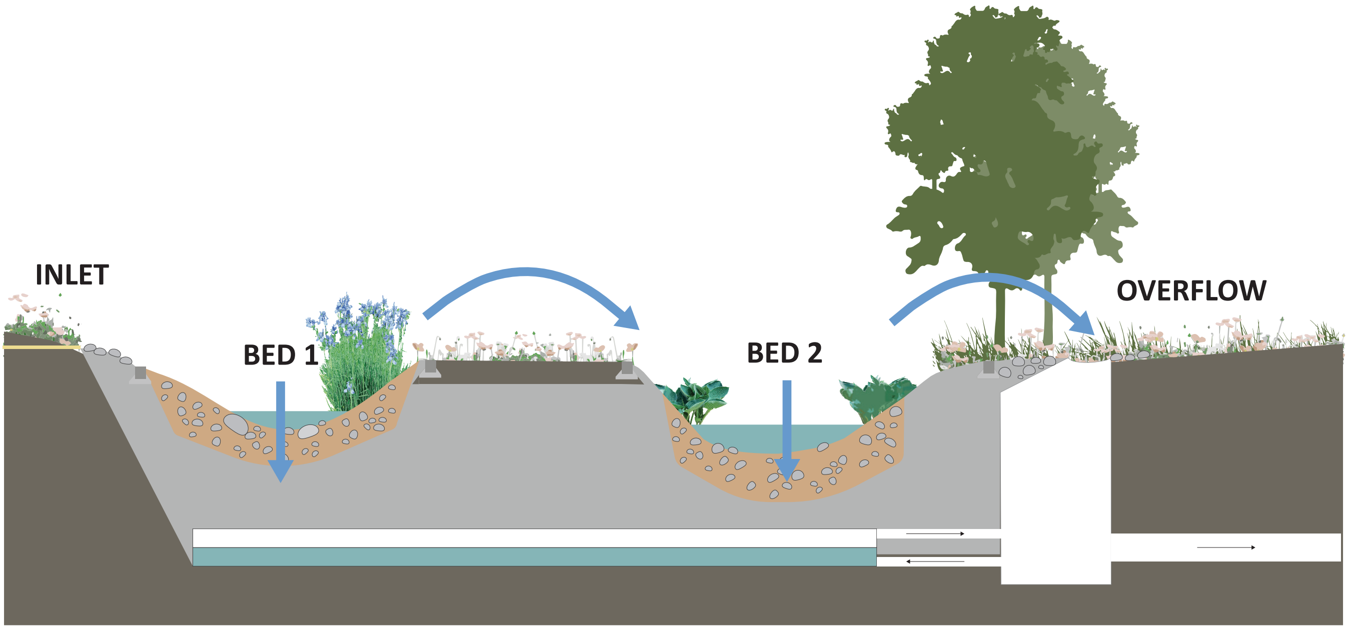


Fig 21. Concept of a hybrid raingarden with technical solutions. Modified from French et al. (2020)

Downspout disconnection and rain-barrels
This is a method for collecting rainwater and is done by disconnecting downspouts from buildings (both official and private) that previously directed water into the existing stormwater management system. Excess water could lead to overwhelmed systems during heavy or extreme rainfall. Instead of leading the excess water into stormwater systems, the downspouts can be reconnected to a collection of slow dispersion systems; this can be a rain garden for slow dispersion or a cistern for storage. Storing or distributing the water at the site can reduce the load on existing systems (Foster et al., 2011).

Urban street trees
Urban trees are trees found in parks, streets, and public spaces in urban areas (Oslo kommune, 2014). Urban trees are a low-tech solution that helps regulate the air temperature and water balance (Miljødirektoratet 2022). The water can be retained and later evaporated through the leaves by guiding runoff from impervious surfaces such as roofs to the tree's root zone. On a warm day, a large deciduous tree can transpire 200-400 litres per day, while conifers transpirate half as much under the same conditions (Oslo Kommune, 2014). In an interview conducted by Miljødirektoratet, the landscape architect Aanderaa emphasised the importance of urban trees in urban flood management. She states that much water can be retained through the roots, but trees with crowns of 10 meters in diameter in full bloom can absorb 1000 litres per day only in the foliage. Meaning this water will not reach the ground at all. Another benefit mentioned is that the tree's root system processes the soil with its roots. Hence, it becomes porous and infiltrates more significant amounts of water than denser soil. Further, she recommends combining several types and species to utilise their unique qualities (Miljødirektoratet, 2022).

Fig 22. Urban tree, Ruten Sandnes.

Bio-swales

Bio-swales are constructed vegetation channels designed to lead stormwater runoff and remove pollution; they can also be used as a floodway. They are vegetated and shallow and treat the first flush or the most polluted volume of water resulting from a storm event. They are an effective type of green infrastructure. By using native vegetation in bioswales, there is potential for greater wildlife habitats—increasing biodiversity (National Association of City Transportation Officials, 2022). The channels have an even fall (***self-fall***); the collected water is delayed, infiltrated, and undergoes some purification before being transported further downstream. They are best suited for smaller drainage basins (<2 ha) (Ødegaard, 2014).

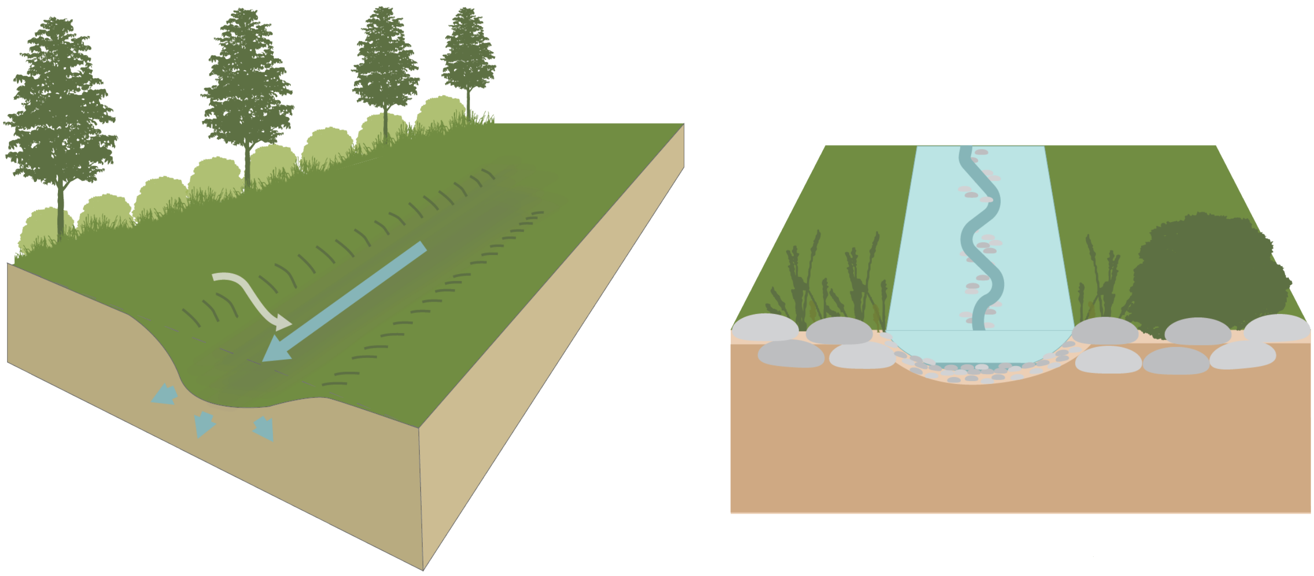


Fig 23. Bioswales

Other

Other NBS for improving water balance are restoring natural streams and wetlands and preserving hydrological patterns (Duany et al., 2010). Gardens that are not public are mentioned as other crucial factors in the built environment to sustain a sound water balance (Miljødirektoratet, 2022; Sweco, 2020). Using infrastructure such as roads and pathways that follow the existing percolation patterns are other methods that are not directly nature-based but can be included in the definition of NBS when combined with green elements.

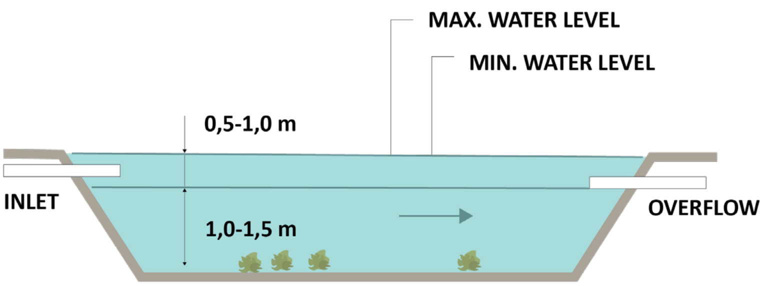
Diversion pond

It is possible to slow down the surface water runoff using a diversion pond, a permanent water surface. The dam's design will vary depending on local conditions, and it requires regular drift and maintenance. The design should include a bottom valve to simplify maintenance work (Ødegaard, 2014). Another benefit of the diversion pond is that it can be used as a purification pond. To be a purification pond, it is essential to have an adequate pool volume, dry and infiltration. The dry volume is the most important in the purification process. Nevertheless, the balance/interaction between the volumes contributes to a favourable result (Ødegaard, 2014, p. 363).

Private Gardens

The report NOU 2015:16 regarding runoff in cities and towns mentions private gardens as an initiative to manage stormwater and runoff locally. The NBS holds the potential of being a key element in the first step of the Three-step strategy, which is to infiltrate water into the ground soil. The report also mentions several countries' authority to take action. In England, for instance, the authorities have the opportunity to ban impervious surfaces in front gardens as a part of the flooding strategy.

Climate strategist and adviser Kongsvik Aall from the consultant firm Sweco is interviewed in the podcast series "Urban Insight" on how to tackle cloud bursts and urban flooding. Kongsvik Aall is asked what the "man on the street" can do to mitigate pluvial flooding. He believes the most effective action is preserving or establishing our private garden. Done by keeping the grass lawn or other natural elements and vegetation and avoiding converting the plot into hard surfaces. Further, he says the actions of one person are almost insignificant in the big picture, but the sum of all private plots has an enormous impact (Sweco, 2020).



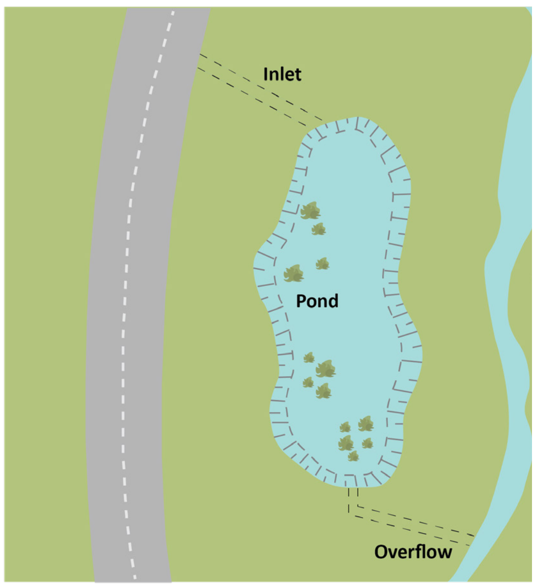


Fig 24. Diversion pond with cleansing elements. Modified from Ødegaard (2014).

Potential of Infrastructure (roads, green structures, sports facilities)

As a result of expected climate changes, the increase in flood sizes will lead to even more significant challenges with traditional permanent types of measures. When extreme cases occur, it will be essential to establish safe flood routes. Within surface water management, there is potential for utilising the road network. Infrastructure continues structure provides the opportunities to use the network to divert extreme rain on the surface. Here you can think about the design of the profile, but it is also essential to preserve the function of the road; the process should not be compromised to be used as a flood route (Oslo Kommune, 2016). This has been included under NBS based on its relevance in the Three-step strategy for step three; depending on the variety, it can be seen as a hybrid or blue-green structure (e.g. using the road network as a floodway in combination with a green structure).

Designing a safe flood route in the street can be done using transverse falls, curbs, ditches, green structures, speed bumps, and similar surface objects. Here it is essential to calculate the catchment area of the flood route in each project. The design should provide sufficient capacity for floodwater at the same time as requirements for water level, and water speed is met. The water must be led safely to the nearest recipient and not cause personal injury or damage to the surroundings. There are diverse ways to use an infrastructure network as a flood route. (Oslo Kommune, 2016).

One-side fall: Here, the road is designed with the possibility of diversion on the surface; with a small floodway, rainwater will be led open along the curb. This presupposes room for the water where it is shown to the nearest recipient; it can be a green structure or a body of water (Oslo Kommune, 2016).

V-profile: Having a transverse fall so that the water can flow in the middle of the road.

V-profile with green structure: A transverse fall with a green design in the middle of the road has a higher flood capacity than streets with a roof slope than a one-sided slope (Oslo Kommune, 2016).

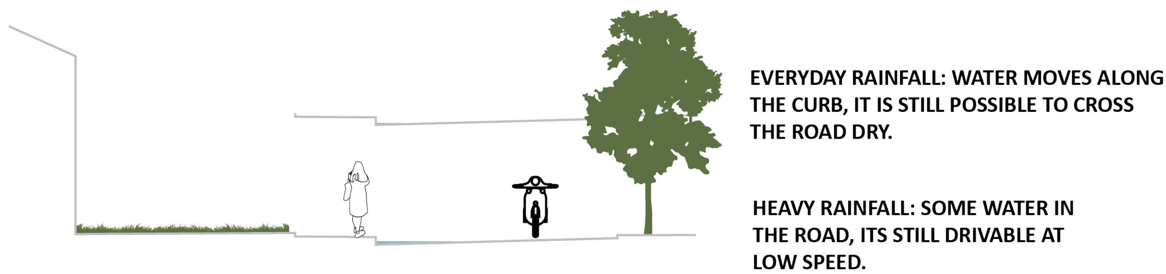


Fig 25. One-sided fall. Modified from Oslo Kommune (2016).

Fig 26. V-profile. Modified from Oslo Kommune (2016).

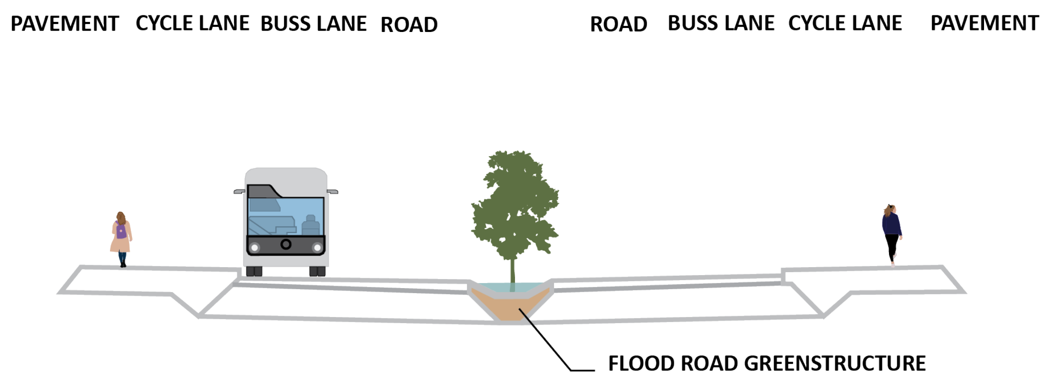


Fig 27. V-profile with green structure. Modified from Oslo Kommune (2016).

Stream and river re-opening
In Norway, many watercourses have changed the use of form, development of infrastructure, settlements, and cultivated land close to rivers and in the act of watercourses surrounding it. Placing development close to watercourses entails the risk of erosion and flood damage.

A part of traditional solutions has been to place streams and rivers in pipes. The ecological state of rivers and streams that have been changed can be reduced. Hydromorphological changes are expected in Norway and can negatively affect wildlife and biodiversity by losing different fish species. Changing their habitats and disturbing the shape, bottom condition, and water flow makes other species' spawning and travelling habits plausible. It is causing a reduction or disappearance of the population. Restoring and opening up rivers that have been placed in pipes can provide a better ecological condition and often leads to greater hydrological capacity (Miljødirektoratet, 2018).

Stream and Wetland Restoration
Peatlands or marshes deliver several ecosystem services such as climate regulation and water purification and are the most efficient terrestrial carbon store on planet Earth (Andersen et al., 2016, p.271). There is value in ecosystem services provided in wetlands. They protect and improve water quality, provide fish and wildlife habitats, store floodwaters and maintain surface water flow during dry periods (Miljødirektoratet, 2022). Preservation and restoration of peatlands will not only serve as a climate adaptation measure but are crucial for preventing and reducing further climate change.

Historically marshlands were used as a recourse, by extraction of peat moss, or built up and used for other purposes; one of those was forest productions in the 20th century (Statsforvalteren, 2018). In Norway, wetlands cover 10% of the mainland, and the commonwealth has pointed out the importance of taking care of the marshes to prevent flood damage and preserve the vulnerable (Menon Economics, 2018).

Marsh is a type of wetland that stores substantial amounts of carbon; the Norwegian bogs/marshes hold 5% of the agricultural area's carbon used at 950 million tonnes. Wetlands have a tremendous biological diversity; in Norway, there are at least 400 vascular plants and 300 moss species that live in wetlands, in addition to 3000 species of arthropods. Wetlands are also essential nesting grounds and resting places for many migratory birds (Klima- og Miljødepartementet, 2021). The Norwegian commonwealth is working on slowing down the demolition of wetlands and instead focusing on bettering its condition. One of the measures suggested in the new nature strategy is to have area neutral if built development occurs in wetlands.

Biochar
Biochar is an artificial low-tec product created from biomass waste (from parks and gardens). The end product has a high surface area due to its pore structure, making it a product that can store substantial amounts of water. This attribute is utilised in modern urban vegetation. The biochar positively affects vegetation due to its ability to absorb moisture from heavy rainfalls and gradually release it to the roots when the humidity decreases (Sandnes kommune, 2020). Biochar is effective in areas with varying weather with high precipitation and periods of drought because it can hold water for more extended periods. This is how biochar can be used to handle flooding issues. Biochar is included as an NBS because it is a natural product based on biological processes and reaching its full potential in use with other NBS measures, such as urban street trees.

The benefits of biochar in urban planting:
- No turf
- Better growth conditions
- Result in more hardy plants and faster growth
- Denser tree crowns (shown in a pilot project in Stockholm)
- Reduces the demand for fertiliser, since it can store nutrients in addition to water.
- Light masses provide good drainage and surface water management. In an area with a lot of hard surfaces.
- Carbon storage

Summary

Type	Measure	Three-step strategy 1	2	3	Purification	Recreational/ Community	Microclimate	Noise pollution/ Air quality	Biodiversity
Roofs	*Intensive roofs*	■	■		○	●	●	●	●
	Semi-intensive roofs	■	■		○	●	●	●	●
	Extensive roofs	■	■		○	●	●	●	◐
	Blue-green roofs	■	■		○	●	●	●	◐
Walls	*Living walls with planter box*		■		○	●	●	●	◐
	Living wall with foam substrate or other		■		○	●	●	●	◐
	Green facade	■	■		○	●	●	●	◐
Ground cover	*Permeable pavement*	■	■		○	○	○	○	○
	Raingarden	■	■		●	●	●	●	●
	Downspout disc. and rain-barrel	■	■		○	○	○	○	○
	Bioswale	■	■	■	●	●	●	●	●
	Urban street tree	■	■		◐	●	●	●	●
Other	*Private gardens*	■	■		○	●	●	●	◐
	Ponds		■		●	●	●	●	●
	Infrastructure (road profile)			■	○	○	○	○	○
	Stream re-opening	■	■	■	●	●	●	●	●
	Wetland restoration and protection		■		●	●	●	●	●
	Biochar	■	■		●	○	○	○	○

Fig 28. Summary NBS . Adjusted from NOU 2015:16 (p.68-69) and Time Kommune (2020, p.96)

3.4. THE TRANSECT

Urban planning is a complex field, with many interdisciplinary aspects to consider in order to achieve a holistic and successful result. An approach to obtaining this is integrating system thinking using a design framework based on code or patterns. For decades, practitioners have studied urban patterns and spatial characteristics and sought to systemise the knowledge to create cities of high quality. An urban planning model that has gained attention in the last two decades is Duany Plater-Zyberk & Company's interpretation of the Transect- SmartCode. The Transect is a prism for analysing the degree of urbanity of physical elements (Bohl & Plater-Zyberk, 2006, p.10). This use of the Transect as a design tool enables the establishment of a hierarchy of places based on urban intensity to help guide the rational and organic development of towns, cities, and metropolia (Tagliaventi, 2006, p.46).

Design Coding

Transect urbanism is a form of design or urban code. A code is a form of detailed guidance, it can go further and be more precise than design guidelines, and it can include more requirements, be stricter and more exact. Although not all codes, most are based on premises that specific rules or principles can be applied to the process of making or remaking development. Key components of good urban design are creating a safe, attractive, and designable environment to live, work, and play in (Commission of Architecture & the Built Environment, 2022).

Positive aspects of design codes:

- A code can provide an opportunity for a better re-design or a fresh start. By making the basics clear and understandable, with clear parameters as to what can be done and what should not be.
- The development can be holistic and of good quality to meet the area's needs by having clear parameters.
- It can also prevent bad choices that can detract from the quality of the community and effects such quality of life.

Transect Urbanism

- a normative theory in the field of urban planning

Transect urbanism is part of the Smart Growth Movement, a branch within one of the key postmodern design movements; the New Urbanism (Larice & Macdonald, 2013, p. 263). To enhance the quality of urban life, New Urbanism is based on principles such as mixed-use, mixed housing types, a generally high standard of design, and pedestrian-oriented streets (CNU, 2022). New Urbanism is a response to the Modernist movement. New Urbanism arose due to rapid growth in urban sprawl (a development characterised by single-use and low-density patterns) in post-World War II. The areas of modernistic planning appeared uninviting without comfort and lacked urbanity, aesthetics, and beauty.

According to Bohl & Plater-Zyberk, the planning lacked a "holistic, regional framework based on the character of place" (Bohl & Plater-Zyberk, 2006, p.6). Therefore, many planners and visionaries craved to bring back qualities from cities and towns that had been created during the last centuries: walkable cities based on human-scale and distinct, liveable, memorable communities worth caring about (Congress for the New Urbanism, 2022; Bohl & Plater-Zyberk, 2006, p.5). Some of the most influential urban theorists of New Urbanism were Gordon Cullen, Christopher Alexander and Leon Krier. They all advocated for the qualities found in historic cities with original morphology that had emerged organically. They presented different approaches to describing urban settings, forms, and elements to address this. They all used form-based design before zoning based design. They were concerned about how the place was visually precipitated, which is essential for the place's identity. According to Lewicka, place identity refers to the distinctiveness of a place, including what characteristics the site holds that distinguish it from other locations (Devlin, 2018). Proshansky believes place-identity is complex because it also refers to the dimensions of the individual's identity with the physical environment, resulting in an intricate pattern of both conscious and unconscious feelings, values, ideas, behavioural tendencies, and preferences, among others relevant to the specific environment (Peng et al., 2020).

Gordon Cullen introduced the concept of the *Townscape*, an urban visual analysis of how the city is perceived based on visual impressions and experience (Larice & Macdonald, 2013). He uses serial vision to illustrate the importance of visual variety throughout the townscapes and thinks of it as a journey through sketched viewpoints. He views urban design as the "art of relationship" between physical elements of the urban landscape. The physical elements include elements such as buildings, trees, nature, traffic, and water. Cullen believes good design is when these elements are weaved together such that drama is released. Cullen says cities should be designed from the view of a moving person rather than using a bird's perspective (Larice & Macdonald, 2013). However, an additional orientation map is needed to illustrate the path from where the viewpoints are located for the serial vision approach to function.

Christopher Alexander presented the *Pattern Language* based on practice-based knowledge of how well-designed cities are structured and organised to create beautiful, functional, and meaningful places (Kjærsdam, 2010). The language is a network that consists of sequences of large to small (level) patterns. The larger patterns create the structures, while the smaller ones embellish these structures (Alexander, 1977, p. xviii). This language and design approach intends that relevant patterns can be composed into a unique sequence tailored for the given design project and could be used by anyone.

Leon Krier promotes the importance of community, which was often neglected in modernistic design (Kjærsdam, 2010). Krier is known for using drawings of forms, rhythm, and principles to convey his urban philosophy, how it should be done and what should be avoided. He has also created a illustration which shows the concept of the transect, the natural succession from urban to natural form occurs in the town of Echernach in Luxembourg.

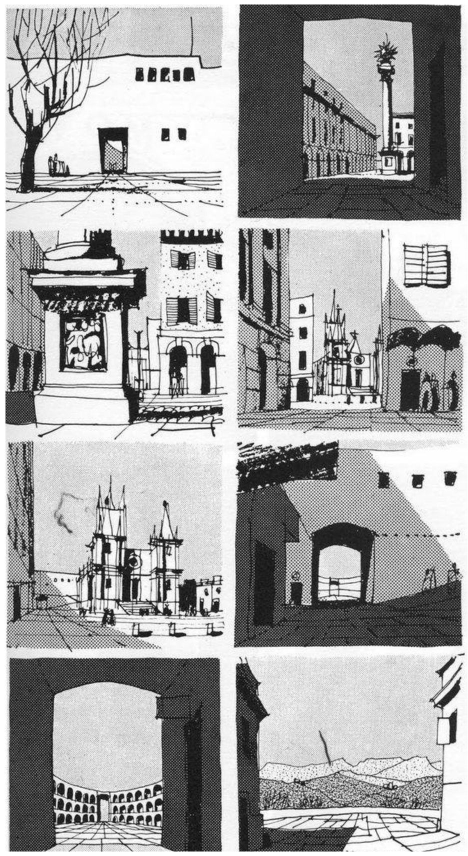


Fig 29. Serial vision illustrated by Gordon Cullen. The visual representation illustrates six viewpoints along the path through the city, with their location shown on the orientation map bellow. (Cullen, 1961)

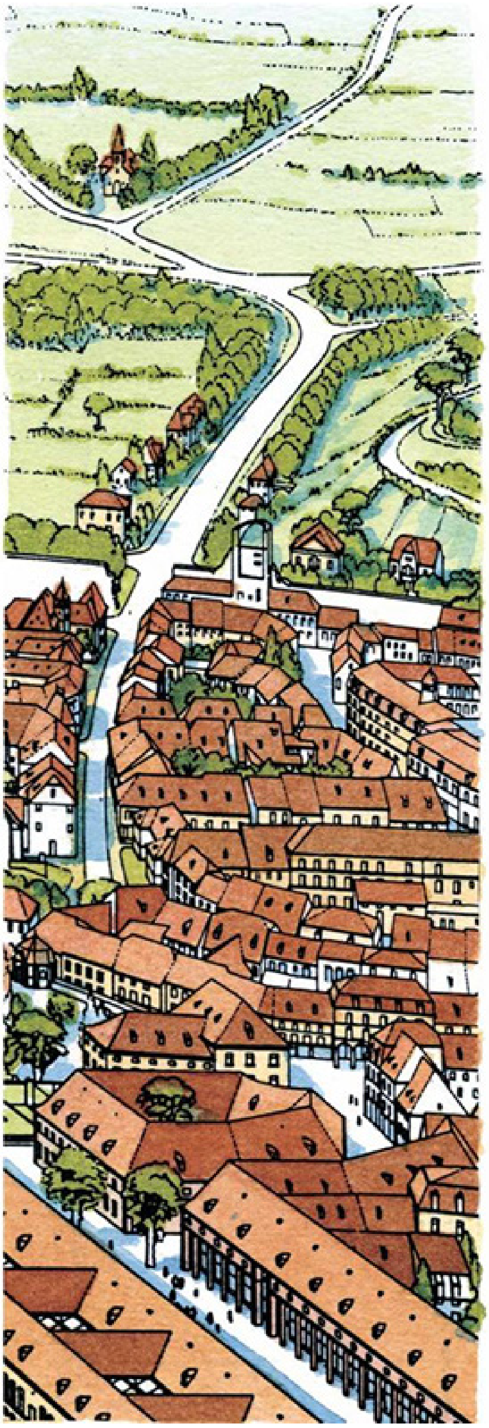


Fig 30. European transect. Early plan of a town in Luxembourg by Leon Krier (Duany et al, 2012).

Years later, Andres Duany incorporated the form-based design approach to the transect framework resulting in the Transect Urbanism. He says the transect allows projecting and analysing urbanism "as a series of symbiotic habitats where the elements in the silos of a dozen specialists could be allocated rationally, rather than undermining or overwhelming each other" (Duany & Falk, 2020, p. 4). Bohl and Plater-Zyberk believe the rural-urban transect could be viewed as a character of place-based normative theory that provides people with a coherent vision of a placemaking in which they can get emotionally invested.

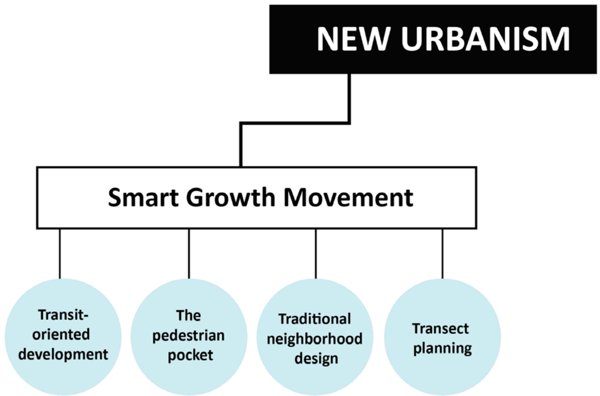


Fig 31. A selection of the hierarchy within the movement of New urbanism. Transect planning is found in the Smart Growth Movement, transit-oriented development, the pedestrian pocket, and traditional neighbourhood design (Larice & Macdonald, 2013, p. 264).

The New Urbanism movement has gained even more followers over the last decades and is now spread worldwide (Larice & Macdonald, 2013, p. 264). Meanwhile, the movements also receive criticism. The criticism is often based on differences in fundamental ideology. Still, the movement has also received scepticism from European planners accusing the theory of being romantic, outdated, and not applicable for a larger scale (Tagliaventi, 2006, p.46). Critics have also been directed to the division of zones in the rural-urban transect model, viewed as one of the model's principal weaknesses since not all types of settlement fit into the given categories. Some argue there are too few zones, while others believe the number of zones is excessive and too specific (Bohl & Plater-Zyberk, 2006, p.11). Tagliaventi argues that Duany's work provides a comprehensive and efficient "operating system" that answers the criticism regarding scale application and the urban balance from natural environments to metropolis. Ideologically motivated critics are often defenders of the adversary: Suburbanism. Suburbanites often advocate for a free-market economy and customers' freedom to decide how and where they wish to live (Larice & Macdonald, 2013, p. 264).

Transect as a Concept

According to Duany Plater-Zyberk & Company, Alexander von Humbolt first described the original concept of a transect in 1790 as a "geographical cross-section of a region used to reveal a sequence of environments." (Duany et al., 2012, p. VI). Initially, this framework was used to analyse natural ecologies by describing varying characteristics of different natural zones such as shores, wetlands, and plains (Duany et al., 2012, p. VI). Using such a system, the user could study the many essential elements for plants and animals to thrive within their habitat or "zone." Later, this concept and principles were applied to a human settlement with the same intention as the original model: to create places with optimal living conditions for the individuals (now: humans) to thrive in symbiotic relationships with their surroundings. Duany emphasises that we humans have different ideas of the perfect place to live; some prefer rural conditions while others seek urban centres. Further, he states that regardless of our preferences, all humans need a system to preserve and create meaningful choices in our habitat (Duany et al., 2012, p. VI).

The Transect is a Design Framework

- Rural-Urban Transect

In literature, the rural- to urban Transect, often called The Transect, is described in many ways. Bohl and Plater-Zyberk describe the Transect as "[...] a taxonomic engine that can place a range of artefacts in a useful order at many levels of design" (Bohl & Plater-Zyberk, 2006, p.6). Put in other words, the Transect is a conceptual framework that provides possibilities for describing characteristics of places that contribute to distinguishing between rural, suburban, and urban (Bohl & Plater-Zyberk, 2006, p.6). By utilising this framework, it is possibly

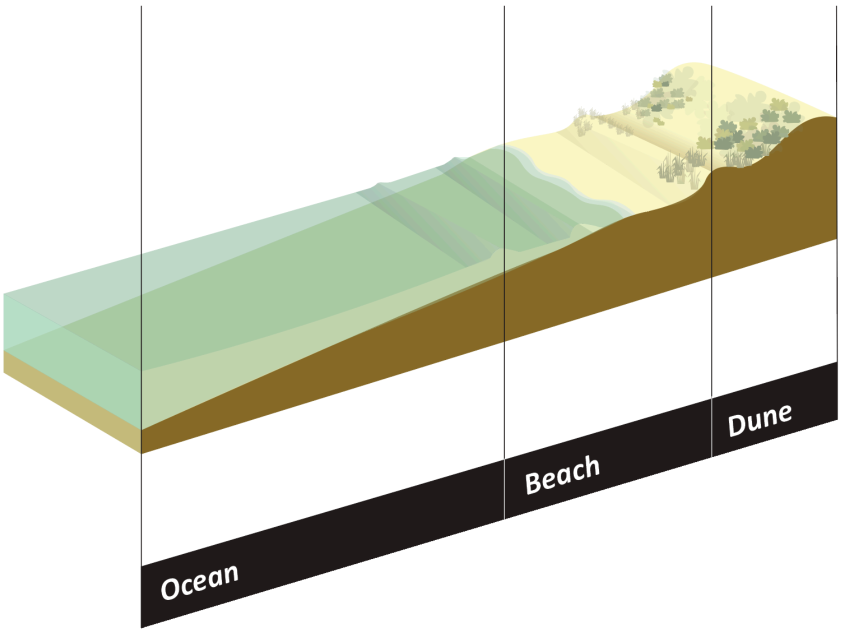


Fig 32. A typical shore at Jæren: Example of a natural transect, where natural landscapes and habitats are divided based on characteristics into different zones. Modified from Duany Plater-Zyberk & Company (Duany & Falk, 2020)

better to understand the qualities and potential of the area. The framework has a form-based design approach rather than the conventional use-based approach (land use, zoning, regulations. This is a tool that strives for development quality (FBCI, 2022). The framework is scalable and can be applied for many levels, ranging from metropolitan scale to a refined scale of architectural detail (Tagliaventi, 2006, p.51). Transect-based modules commissioned by the Center for Applied Transect Studies (CATS), presented on their official webpage, clearly show that the Transect as a design tool can easily be adapted to other aspects of urban design not only from an architectural perspective.

The rural-to-urban Transect is based on a simplified typology where areas are divided into six zones, ranging from rural – to suburban – to urban. The terminology used for the classification of these "transect zones" is the capital letter" T" accompanied by a number representing the urban intensity (1-low, 6-high).

This list of zones varies by their urban degree, not only the level and intensity of physical characteristics but also their social character (Duany et al., 2012, p.VI). Some rural-urban transects operate with six zones and a seventh zone or district referred to as a "Special District." The Special District count typically containsustrial areas or other areas that do not correspond to the t-zones. In addition to the zone's given abbreviation, transects like these are often given an additional descriptive title, which specifies the transect type.

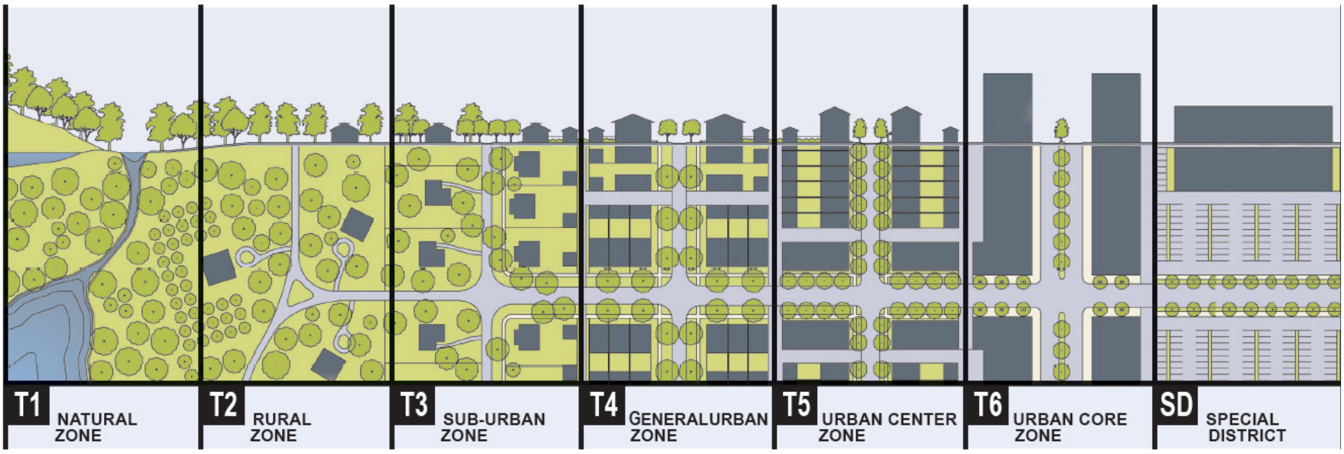


Fig 33. An example of a rural- to urban transect with transect zones, this specific transect is created by Duany Plater-Zyberk & Company (Duany & Falk, 2020, p.19) Duany Plater-Zyberk & Company's interpretation of the Transect the SmartCode is considered the most detailed application of the Transect (Bohl & Plater-Zyberk, 2006, p.10).

T1	**NATURAL ZONE**	*Consists of lands approximating or recerting to a wilderness condition, including lands unsuitable for settlement due to topography, hydrology, or vegetation.*	**General Character**: Natural landscape with some agricultural use. **Typical Building Height**: Not applicable **Type of Civic Space:** Parks, Greenways
T2	**RURAL ZONE**	*Consists of sparsely settled lands in open or cultivated states. These include woodland, agricultural land, grassland, and irrigable desert. Typical buldings are farmhouses, agriculutral buldings, cabins, and villas.*	**General Character**: Primarily agricultural with woodland & wetland scattered buildings **Typical Building Height**: 1- to 2-story with some 3-story. **Type of Civic Space:** Parks, Greenways
T3	**SUB-URBAN ZONE**	*Consists of low-density residential areas, adjacent to higher zones that some mixed use. Home occupations and outbuildings are allowed. Planting is naturalistic and setbacks are relatively deep. Blicks may be larger and t he roads irregular to accommodate natural conditions.*	**General Character**: Lawns, and landscaped yeards surroundings detached single-family houses; pedestrians occasionally **Typical Building Height**: 1- to 2-story with some 3-story. **Type of Civic Space:** Parks, Greenways
T4	**GENERAL URBAN ZONE**	*Consists of a mixed use but primarily residential urban fabric. It may have a wide range of building types: single, side yard, and rowhouses. Setbacks and landscapeing are variable. Streets with curbs and sidewalks define medium-sized blocks.*	**General Character**: Mix of houses, Townhouses & small Apartment buildings, with scattered commercial acticity; balance between landscape and buildings; presence of pedestrians **Typical Building Height**: 2-to 3-story with a few mixed-use buildings **Type of Civic Space:** Squares, Greens
T5	**URBAN CENTER ZONE**	*Consists of higher density mixed used buildings that accommodate retail, offices, rowhouses and apartments. It has a tight network of streets, with wide sidewalks, steady street tree planting and buildings set close to the sidewalks.*	**General Character**: Shops mixed with Townhouses, larger apartments, houses, offices, workplaces and civic buildings; predominantly attatched buildings; trees within the public right-of-way; substantial pedestrian activity. **Typical Building Height**: 3-to 5-story with some variations. **Type of Civic Space:** Parks, Plazas and squares, median landscaping.
T6	**URBAN CORE ZONE**	*Consists of the highest density and height, with the greatest variety of uses, and civic buildings of regional importance. It may have larger blocks; streets have steady street tree planting and buildings are set close to wide sidewalks. Typically, only large towns or cities have an Urban Core Zobe.*	**General Character**: Medium to high-Density mixed-use buildings, entertainment, Civic and cultural uses. Attached buildings forming a continuius street wall; trees within the public right-of-way; highest pedestrian and transit activity. **Typical Building Height**: 4-pluss story with few shorter buildings. **Type of Civic Space:** Parks, Plazas and squares, median landscaping.

Fig 34. Transect zone description and characteristics (Duany et al., 2012, p.SC27).

4

INTERVIEW

CHAPTER FOUR

INTERVIEW

The direct consequences of climate change are felt on the local level. As the lowest level of authority, the municipalities are responsible for implementing climate adaptation measures. There is no " one-solution fits all" type of universal approach. The appropriate adaptation measures to current and expected climate conditions must be selected based on local conditions and context. This chapter aims to understand the current status of implementing climate adaptation as a topic in municipalities in the south-western part of Norway, what kind of tools and resources they lack, and which part of the planning process this tool would be most beneficial.

4.1 BACKGROUND

The Norwegian System

The Norwegian system of government is advanced and mature. The system consists of several levels of government, which play different roles and work with climate-related matters on different scales. According to Miljødirektoratet, the responsibility for climate adaptation lies with the actor whose function or commission is affected by climate change (Miljødirektoratet, 2019). This implies that all actors, not only the government, share this responsibility to some extent. This indefinite distribution of responsibility might result in a more complicated process of coordination and execution of actions. To clarify how the Norwegian system is organized, the main government actors related to climate adaptation are listed in figure 35, including their level of government, role, and responsibility.

Level of Government	Actor	Role and Responsibility
National	Ministry of Climate and Environment	The Ministry has a particular responsibility to facilitate the Government's holistic work regarding climate adaptation (Miljødirektoratet, 2019).
	The Norwegian Environment Agency	Support the Ministry in issues related to climate adaptation and has the responsibility of coordinating national work with this topic (Miljødirektoratet, 2019). This includes: providing a scientific knowledge base and coordinating the holisitc work by, for instance, maintaining the national planning guidelines.
Regional	County Governor	Represents the state on the county level, and functions as an important link between municipalities and the central government authorities (Statsforvalteren, 2013). The County Governor has therefore the responsibility of implementing national policy on a lower level, this is done through guidance, dialogue and supervision with the local authorities (Miljødirektoratet, 2019).
	County Municipality	Coordinates regional planning. Hold the overall responsibility of regional planning and environmental issues and resource management on this level. Create plans with goals, strategies, and guidelines for development within the county (Rogaland fylkeskommune, 2021). Such as climate – and climate adaption plan. The county has a responsibility in the planning guidance towards the municipalities and facilitate for cooperation and knowledge. The county is also responsible for regional development, thus play an important role towards the business in the region and their climate adaptation (Miljødirektoratet, 2019).
Local	Municipality	Role as community developer and land management. Aim to ensure robust and sustainable communities, against direct consequences of climate change (Miljødirektoratet, 2019). PBL §3-1, states that climate considerations must be taken through planning in reducing climate gas emissions and adapt to expected climate change.

Fig 35. The table shows the main official actors in the Norwegian system, what role they have and responsibility.

Local conditions

Jæren is a traditional district located on the south-western coast of Norway. With borders to the North Sea, the weather is characterised by rain showers and incoming winds from the open ocean, resulting in a relatively mild and humid climate (Mayer et al., 2020).

The participating municipalities have spatial and climatic similarities. In a Norwegian context this is considered to be medium to small-sized municipalities in terms of financial resources and geographic extent. They all have either coastal lines or lakes, and water management is an important topic. Many have flat landscapes with agricultural land, with at least one local center with a higher built density. Others have more hilly terrain, where much of the land use is designated for farming purposes.

Fig 36. Geographical location of the respondents. Rogaland county with the district of Jæren.

4.2 RESULTS

Spatial and Climatic Challenges

All the representatives reported that their municipality had observed a distinct change in climate over the past decade. Some referred to specific climate data registration and analysis they had conducted. Others had, in addition, received feedback from farmers about failing crops due to changes in climatic patterns. They have experienced several seasons with changes in precipitation patterns: examples of heavy local rainfall resulting in instant floods, prolonged periods of rain drowning the crops, and seasons with unusually long periods of drought. The agricultural sector has been affected by this, and the officials also mentioned damage to the built environment and infrastructure from extreme weather events. Extreme weather events in this context include storms with extreme precipitation and wind. The municipalities all agreed that change in climate was the cause of these issues.

Another problem derived from this development mentioned was pollution. Runoff and effluent from roads and agricultural land create significant challenges for vulnerable natural and urban areas.

Fig 37. Typical landscapes at Jæren

Status

When asked about how the representatives interpreted the term “climate adaptation,” many found it difficult to give a concise answer. The reasoning for this was believed to be based on the topic’s complexity. Many aspects of the term were discussed, ranging from preventing further climate change and hopefully reversing some of the trends while recognizing the irreversible changes and accepting them by learning to live with them. Not all respondents were familiar with the term and concept of NBS but knew of some of the relevant interventions, such as green roofs.

Some of the respondents went into detail about how they specifically work with climate adaptation. Examples mentioned included: soft mobility and public transportation intensives were mentioned to reduce private car use and climate gas emissions. Another aspect that was brought up as a part of the work with climate adaptation was communication. It was stated that people, in general, lacked awareness of the extent and the severity of the situation and required knowledge to achieve the objective. Plans and strategies were featured as an essential means for some municipalities. An example of this was by using provisions in zoning plans.

In these provisions, a frequently used tool was the blue-green factor, which set a requirement for developers to achieve a given score. Some municipalities experience that this tool is difficult to use for some developers and, therefore, hard to achieve the desired results. Other officials reported that they had no strategy for climate adaptation and NBS. Still, after discussing the topic, they realized they had been working on it for many years, except they had not used this terminology.

Some of the municipalities where the land use is mainly agriculture said they had considered several NBS interventions. They found it inappropriate to use green roofs in rural areas since much land is covered with vegetation. A green roof or a green wall would have minimal impact. Instead, they use dams to collect runoff and purify the water before releasing it into rivers.

Another remark regarding NBS was that certain towns are located above the reserve groundwater reservoir, which is used to serve agricultural purposes in times of drought or if something happens with the district’s primary water source. The municipality that mentioned this consciously avoided using permeable pavement in the specific town because polluted runoff or oil spills from motorized vehicles would cause catastrophic consequences if they were to reach the reservoir. This shows that local knowledge is essential when planning for NBS. Not all interventions are appropriate for allegedly similar contexts.

The majority mentioned that their municipality had allocated considerable investments in upgrading hydrologic infrastructure. Instead of replacing the existing system with new conventional pipes, many respondents said they are looking into alternatives such as re-opening natural streams and other NBSs’. This is done in addition to maintaining existing rivers, ensuring healthy conditions for biological diversity, and avoiding clogging. The topic of flood risk and acceptable risk was also emphasized in this process.

At the time of the interviews, the county municipality had just released a regional plan featuring climate adaptation with recommendations and strategies. All the participants knew this plan, and many said they wished to create a specific climate adaptation plan for their municipality based on guidelines and strategies given in this report. However, due to a lack of resources, some representatives responded that they are unsure if this is feasible to include in their work. For the time being, all municipalities are obliged to have a climate plan on how they intend to reduce climate gas emissions, but there are no requirements for a climate adaptation plan. The majority found the follow-up from the county municipality, NVE, and Miljødirektoratet satisfactory. The follow-up includes awareness of financing programs, relevant research programs, and knowledge-based resources. Most of the represented municipalities have attended relevant seminars and workshops. They point to inter-municipal collaboration and communication with other stakeholders as essential in achieving their goals.

"We must prepare, and adapt to a tougher climate

Direct natural events are easier to decide on

We do not have the capacity (and resources) to go in depth.

The knowledge base is thin

Bring in the local focus

It takes time to involve everyone

From the bottom up

If there is enough money

There is a limit to what you have time to get acquainted with

We miss diversity and examples to take from

Who takes responsibility when the municipality no longer has it?

Measures that have been followed up seem to work

Many people sees green roofs as a cost

Spatial planning is coordination work

See things in context

Competence planning - must be proven so as not to stagnate."

Fig 38. Quotes from the interview

Challenges

There was a varying degree of knowledge and progression when preparing their respective municipality for the effects of climate change. However, the main common challenge the municipalities encountered in their work with climate adaptation and NBS is limited resources. Resources are a compound dilemma. Not all respondents experienced this limitation from the same perspective, but they can all be linked together.

Limited resources include:

Skilled Staff
The municipalities found it hard to attract employees with the necessary skills and knowledge or experienced it as a financial constraint. Few have a designated climate adaptation expert who can grasp “the whole picture,” The technological abilities to operate software and simulations become more demanding. They experience that people with these abilities often choose to work in the private sector.

Financial Prioritization
Lack of economic prioritization includes limited financial means or not being prioritized politically. One of the respondents mentioned lacking knowledge among the politicians and political orientation as a constraint. There were shared opinions about governmental financed support schemes. Some were satisfied with the offerings, while others uttered despair. One municipality pointed out that there has been a shift in responsibility, where official bodies in the past have taken financial responsibility and executed and maintained the installation. Another participant argued for a greater spread of related costs on all levels. The municipalities cannot take on full responsibility for preparing society for the effects of climate change and adaptation.

Time Limitation
Many of the interviewed municipalities are small on a Norwegian scale and experience too large a workload on employees with several responsibilities. This gives little time to attend seminars or other channels of obtaining new knowledge. Most respondents said they felt the available knowledge-based resources and information were sufficient, but they lacked time to get acquainted.

Communication
There is limited capacity to convey knowledge internally within the municipality. One municipality emphasized this as an essential factor in achieving climate adaptation since the topic is interdisciplinary and must be implemented in all processes. Only one of the municipalities answered that they found the internal communication satisfactory. Some of the municipalities worked closely with private landowners. They expressed the need for a tool to make communication with stakeholders more efficient.

Limited Power
Available means for the municipalities include; policies, strategies, guidelines, plans, zoning plans, and provisions. An official pointed at the authority’s available means as a limitation. They cannot “force” developers to choose the most “climate-friendly” solution with these means. They rely on the developer’s level of knowledge and ambitions. Communication becomes, therefore, crucial.

Risk evaluation
Risk evaluation and management was a theme brought up by several of the municipalities. The dilemma of acceptable risk was a key point here, one representative noted that the line must be drawn somewhere, and we must accept some risk or some degree of consequences. But where does that line go?

Economy
Several representatives mentioned the case for economic and financial questions. Perspectives mentioned were regarding funding, who is responsible for financing adaptation measures and maintaining them. The representatives mentioned the theme to different degrees, and important points and perspectives were discussed. Still, it fell outside our scope and is not a focal point in the thesis

or following chapters. The financial aspects should be explored more in further work.

Organizational Structure
Some of the municipalities preferred in-house solutions before involving external consultants. They argued that this gave them better control over the process and outcome. Others found it more convenient to engage external actors due to the internal priorities of resources.

Solutions

The final part of the interview referred to solutions or tools that could assist them in their work regarding this topic. As mentioned, most respondents think the available information is sufficient. The issue is that they lack the resources to keep themselves updated on new technologies and research. One solution mentioned was to introduce an administrative "climate coordinator." Whose task is to coordinate the municipalities' efforts related to climate and see the whole picture the entire time. The smaller municipalities demanded more inter-municipal collaboration, as they think sharing experiences and knowledge can collectively save most of them many resources. These solutions are on an administrative level, not an urban design matter.

Few had a specific answer when asked if they knew of a relevant case study with NBS that could be appropriate for their context. The representatives that knew of a relevant case study mentioned Ruten in Sandnes and Mosvannsparken in Stavanger. Others argued that this was way too resource-demanding for them to consider. So, when asked what they wanted in a potential tool, the majority replied they wanted a simple, concise, user-friendly tool that was intuitive and easy for people with less theoretical understanding to use without problems. It should potentially be used by "the man on the street." One participant suggested mainly using visual communication with many illustrations rather than "heavy text."

Some representatives would like to use this tool for dissemination internally, while others wished to use this in communication externally towards landowners, for instance, to ensure predictability. The tool's content was suggested to be a further elaboration of "ROS-lists" (Risk- and vulnerability analysis tool).

All the respondents agreed that the timing of this tool and considerations in the planning process was crucial. It had to be brought up as early as possible in the process (initial phase). Another suggested it could be used along the process of conducting a site analysis, which could create the foundation and framework for the remaining process. One municipality mentioned that such a tool could also be helpful as a control mechanism in the final phase to check if demands and criteria are met. A fundamental condition brought up is that it must be commonly available, preferably through internet access.

Fig 39. Word cloud from the interview

4.3 CONCLUSION

This interview intended to understand how theoretical knowledge is used by municipalities in a Norwegian context. Due to various challenges, the municipalities have varying progression in implementing climate adaptation measures. Some municipalities have an advanced approach to this topic, while others struggle to keep up with governments' expectations.

Another important aspect of this method was to verify whether there is a demand for a new tool or guideline that could assist them in the process of climate adaptation. Based on the findings in the interview, there was indeed a demand. The municipalities with the most advanced approach were more optimistic about a new tool than the municipalities that lacked an overview of available resources.

All respondents contributed with suggestions on what the tool could contain and how it should be designed. The main requirement was that the tool had to be intuitive to use with an emphasis on usability, and it had to be available and easy to locate. The suggested target audience was not only local official bodies but also private users. The respondents agreed that the tool should be adaptive and flexible, meaning it could be utilized early in the planning process, communication with other stakeholders, and the final planning phase.

5

CASE STUDY

CHAPTER FIVE

CASE STUDY

In this chapter, five case studies are presented. *Case studies* are for the purpose of this thesis projects that have been evaluated or studied by others. This has been included to illustrate the concepts found in the theory chapter and how they are implemented in actual cases. The studies have been chosen based on their relevance to climate adaptation and are located at various levels of the urban scale, from micro to macro. The microscale includes specific solutions, while the macro scale is on a regional level. These projects have also been linked to the different zones found in the rural to urban transect approach.

5.1. WETLAND RESTORATION – YORKSHIRE PEATLAND

Across the British Isles, significant efforts are made to restore natural landscapes that monocultures and urbanisation have repressed. One of these critical natural landscapes is bog- and peatlands. This case study is of the recovered peatland and blanket bog in Yorkshire, England. Blanket bog is a wetland that forms a continuous cover over terrain. It thrives in wetter climatic conditions, either on flat or slightly sloped terrain with ground conditions where the drainage is poor (Yorkshire Peat Partnership, 2022). This bog type is also found in Norway, along the coastal and fjord landscape in Agder to Troms County (Mæhlum, 2020). These landscapes have been drained and modified, and the peat has been harvested for use as fossil fuel (Counsell & Stoneman, 2018, p.65). Blanket bogs are considered an endangered landscape form (Mæhlum, 2020).

Project	Yorkshire Peatland Restoration
Scale	*Micro* ○ ○ ○ ○ ● *Macro*
Urban Degree	*Natural* ● ○ ○ ○ ○ *Urban*
Initiator	Yorkshire Peat Partnership
Date	Ongoing
Relevance	Healthy bog- and peatlands bring many benefits, including carbon storage, biodiversity, and restoring natural water balance and quality (Counsell & Stoneman, 2018, p.65). The Yorkshire Peatlands have been damaged through drainage and peat burning; the project seeks to restore the bog to endure the benefits found in healthy boglands.

Fig 40. Sediment traps created with timber, heather bales, and stone are installed on the gullies (Counsell & Stoneman, 2018, p.66). (Salix, 2022)

Fig 41. After restoration. The photograph shows how well-established measures are in peatland at Garron Plateau (By the newsroom, 2021)

Yorkshire has 70,200 ha of blanket bog, containing 38 million tons of carbon stored in the peat soils (Counsell & Stoneman, 2018, p.65). Due to anthropogenic activity through drainage and peat burning, most of this bog is damaged (Yorkshire Peat Partnership, 2022). Therefore, the bog now emits atmospheric carbon rather than absorbing it. The Yorkshire Peat Partnership is essential for enthusiasts to restore this area to a natural state. According to the organisation, they had in 2020 brought 31,526 ha of bogland into restoration management. They achieved this by blocking 2,100km of eroding grips and gullies and reprofiling 3,250km of hagging and revegetation (Yorkshire Peat Partnership, 2022). The revegetation included over 400 000 sphagnum plugs, cotton grass plugs, and 140 ha of bare peat. The organisation uses remote sensing (satellite monitoring) to survey the peatlands for restoration management. The restoration is not complete, and it is hard to tell how successful it will be and how long it takes to restore. However, if the peatlands are fully restored, they will become a great place of biodiversity and can retain copious amounts of both runoff and carbon.

Learning outcomes

- *Considering long-term, important to consider solutions and there benefits in a long-term perspective.*
- *Improving information access to increase the understanding of the solution and strategy chosen.*
- *It is possible to implement extensive and interdisciplinary projects.*

5.2. RAIN GARDEN - BOLSTAD HAGEN

Located in Bolstadhagen in Drammen is a rain garden consisting of four beds. The rain garden was a pilot project and was fully developed in 2017. The pilot projects were used as a part of the development of Drammen municipality's improved surface water management system. After the rain garden was completed, the municipality collaborated with the Norwegian University of Life Sciences (NMBU) to implement a research project. The project evaluated the functionality of the rain garden during its operation phase to increase knowledge and competence of those types of facilities used for local surface water management and share their experiences. The aim was to investigate the rain gardens:

- Infiltration ability and cleaning ability of the filter medium
- What types of plants are suited for a rain garden, and what species can withstand drought and flooding?
- Salt tolerance in the plants
- What effect does the rain garden have during cold winters with frost?
- What types of attraction value does the rain garden have for this area?

Measurements were made of infiltration capacity, capacity, winter conditions, water quality, and the suitability of the plants (French et al., 2020).

The raingarden is in a schoolyard in Kjøsterud ungdomsskole in the city district Åssiden, Drammen. The maximum water flow for Bolstadhagen was calculated to be 30 l/s, and the storage requirement was estimated to be 308 m^3. Based on recommendations (Paus og Braskerud, 2013), the dimension of a rain garden should be 5-10% of the drainage basin that drains towards the rain garden. Therefore, based on the calculation and recommendations, the rain garden in Bolstadhagen should be more extensive (0,9-1,78Daa) than the set-aside area (0,53Daa); there were also concerns regarding the state of the garden during winter. Based on this, a retention basin under the rain garden was also established; this covered the storage needs

Project	Bolstadhagen
Scale	*Micro* ● ○ ○ ○ ○ *Macro*
Urban Degree	*Natural* ○ ○ ● ○ ○ *Urban*
Initiator	Drammen Municipality
Date	Completed Feburary 2021
Relevance	Bolstadhagen is a hybrid rain garden consisting of four beds that include the principle of rain gardens for the use in surface water management and a technical solution with a Q-bic system designed to store excess surface under the rain garden. The study focuses on the functionality of the rain garden and aims to share the experience of establishing and operating the rain garden for use in local surface water management.

and made it possible to have a smaller rain garden than recommended.

The filter media was recommended to be 40-80cm, with an underlying drainage layer of coarse asses of about 30 cm. Recommended infiltration capacity is 0.1 m/h. The design of the rain garden was based on the recommendations by Paus and Braskerud (French et al., 2020).

The soil used was a mix of mineral soil (sand) mixed in garden/park compost and turf; with added mineral fertiliser; under filter media is a drainage layer and filter cloth with different thicknesses. The drainage layer consisted of gravel fractions (8-12mm); existing masses surrounded this. The rain garden is designed with an inlet and an overflow. This leads water from one rain garden to the next. Under the gardens is a box system (a type of drainage basin) called Q-bic, which is designed to store excess water from the beds under the ground (French et al., 2020).

There were an increase in infiltration from 9cm/h in 2017 to 22cm /h in 2020. There was dicovered a problem with standing water in two of the beds. It probably came from increased particle transport

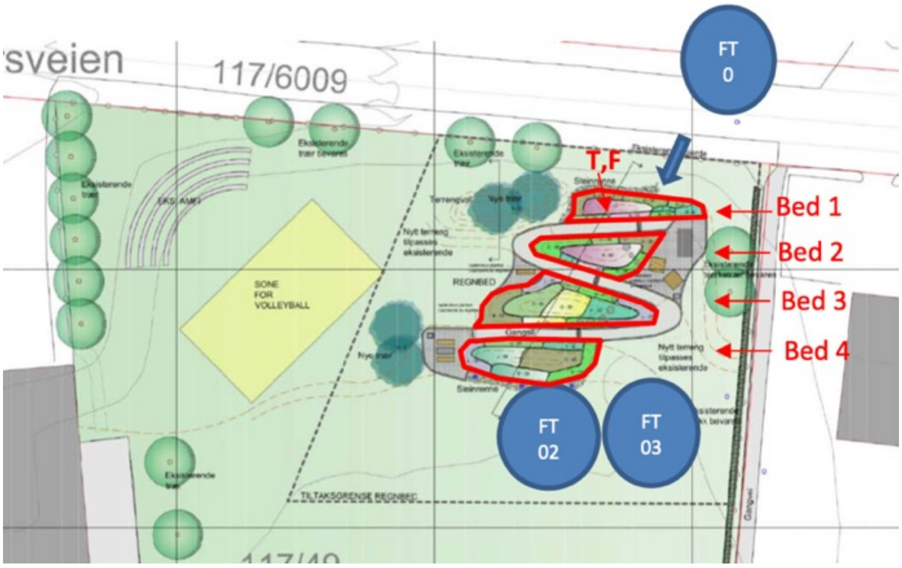


Fig 42. Technical plan for the raingarden (French et al., 2020)

due to a lack of escape from the sand trap. Based on water flow measurements in a utility hole that distributes water into the rain garden via the overflow, during winter 2018, the facility was over-dimensioned. More water was therefore connected in the same year (23.04.18). This increased water flow in the facility and caused water to overflow (singular incidents). Based on better routines, it is still possible to optimise the amount of water for the facility. It might reduce water overflow as there is an unused rain garden /Q-bic reservoir capacity (French et al., 2020).

Based on water analysis, the water within Bolstadhagen has no or low salt concentrations, and in general, there is little contamination in the incoming water to the rain garden. Therefore, there is no leakage of nutrients in the water drained from the rain garden filter material.

It takes some years for new vegetation to establish itself, and local weather conditions in 2018 resulted in poor plant growth that summer. After the first year of life (2017/18), none of the plants had perished, except some that had been trampled. However, after the winter of 2019/20, many of the plants in beds 1 and 2 had suffered permanent damage due to prolonged time standing underwater (French et al., 2020).

Plants and infiltration ability were affected by winter conditions and frost in the ground. Winter 2017/18 was snowy, and ice was observed in the rain garden. This reduced the infiltration ability during the winter and snow melting season. This can cause problems regarding the oxygen availability of plants, and it also postpones the growth season. However, after rainfall in August 2018, the plants were lush and had a high attraction value in the schoolyard.

Learning outcomes

- *Important to learn from implemented project and share the experience, including mistakes.*
- *Pursue finished projects.*
- *Including hybrid solutions can be a favourable.*

Fig 43. Raingarden (French et al., 2020)

5.3. ROOFTOP FARMING - IGA

In Montreal, Canada, a supermarket rooftop has been converted from a regular roof (black roof) into a productive semi-intensive green roof combined with a white roof. The rooftop has utilised SOPRANATURE, a semi-intensive system (Living Architecture Monitor, 2022). The system includes mid-light green roofs with 150 mm to 300 mm of SOPRAFLOR growing media. The plant types established in semi-intensive green roofs are sedum, grass, perennials, shrubs, and edibles. The semi-intensive roofs are preferred for urban rooftop agriculture.

The SOPRANATURE system can absorb, retain and filtrate water, though it still requires frequent irrigation to ensure maximum yields. Establishing a rooftop farm improves stormwater management and helps reduce the risk associated with overflows and floods. The implemented irrigation system considers rain episodes and is triggered as needed to utilise as little potable water as possible (Living Architecture Monitor, 2022).

Additional benefits of this case study include three full-time employed farmers and six seasonal interns. It is open for volunteers in the community, "short travelled" organic flowers and vegetables, beehives that provide living conditions for pollinators, and locally produced honey. Rooftop farms have some advantages; the drainage and sun conditions are considered good. In climate zones like this, the start of the season is limited by how early it is possible to manage the soil. The experience of this rooftop garden is that due to the location and design, they can get a head start in the growing season (Living Architecture Monitor, 2022).

Project	IGA Duchemin Urban Rooftop Farm
Scale	*Micro* ○ ● ○ ○ ○ *Macro*
Urban Degree	*Natural* ○ ○ ● ○ ○ *Urban*
Initiator	IGA (owner), La Ligne Verte (designer)
Date	Completed 2017
Relevance	Rooftop farming (productive, semi-intensive green roof in an urban context) As mentioned in chapter 5, an effective semi-intensive green roof can produce crops while at the same time absorbing, retaining and filtrating water.

Fig 44. Structure of the SOPRANATURE system used in this project. (Living Architecture Monitor, 2022)

Fig 45. The design of the urban farm. (La Ligne Verte, 2022)

Fig 46. The urban farm creates jobs and strengthens the local community. (IGA, 2022)

Learning outcomes

- *Effective land use*
- *Improving local community*
- *Self-sufficient, providing local and short travel food*

Fig 47. The vegetables produced on the rooftop is sold at the store downstairs. (IGA, 2022)

5.4. RE-OPENING STREAM IN AN URBAN AREA – HOVINBEKKEN

The capital of Norway is located between the fjord, forests and lakes in Oslomarka, placed on higher terrain. They have experienced increased urban floods during the past decade, both in intensity and frequency. The policy for water management in Oslo is now to re-open rivers and streams that were previous placed in pipes during the 20th century (Røed, 2016). Hovinbekken is a result of this approach. It stretches over 1,5 km, regulates the water balance, and provides the area with natural elements and identity (Haikali & Thomson, 2019). It is now a delightful area both for residents and visitors.

The landscape architect's vision for the project was to create a holistic and elongated public space that would connect the surrounding areas. According to Haikali and Thomson (2019), the holistic planning of the project is one of the main factors for its success. The design is well balanced based on the natural appearance and artificial elements with concrete and corten steel elements.

Project	Hovinbekken
Scale	*Micro* ○ ○ ● ○ ○ *Macro*
Urban Degree	*Natural* ○ ○ ○ ● ○ *Urban*
Initiator	Oslo Municipality
Date	Completed Feburary 2019
Relevance	An innovative approach within urban water management, where historical streams and flood paths are reintroduced to the city as an element with many additional qualities. The solution connects the entire area together and creates a sense of place. It functions as a recreational area while it provides habitats for plants and animals.

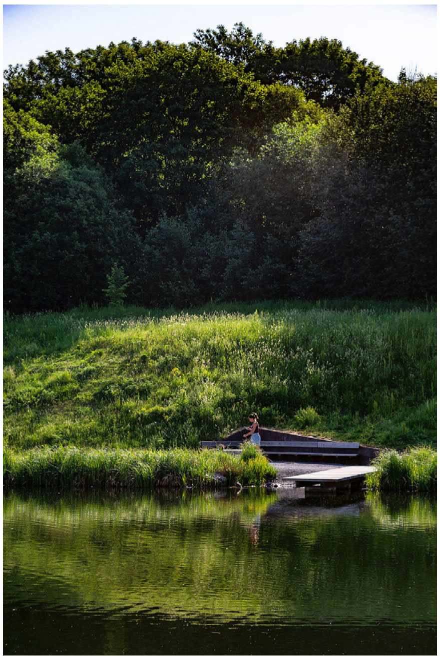


Fig 48. Recreational areas along the blue-green infrasturcture (Dale, 2019)

Fig 49. Contemporary design in residential area (Dale, 2019)

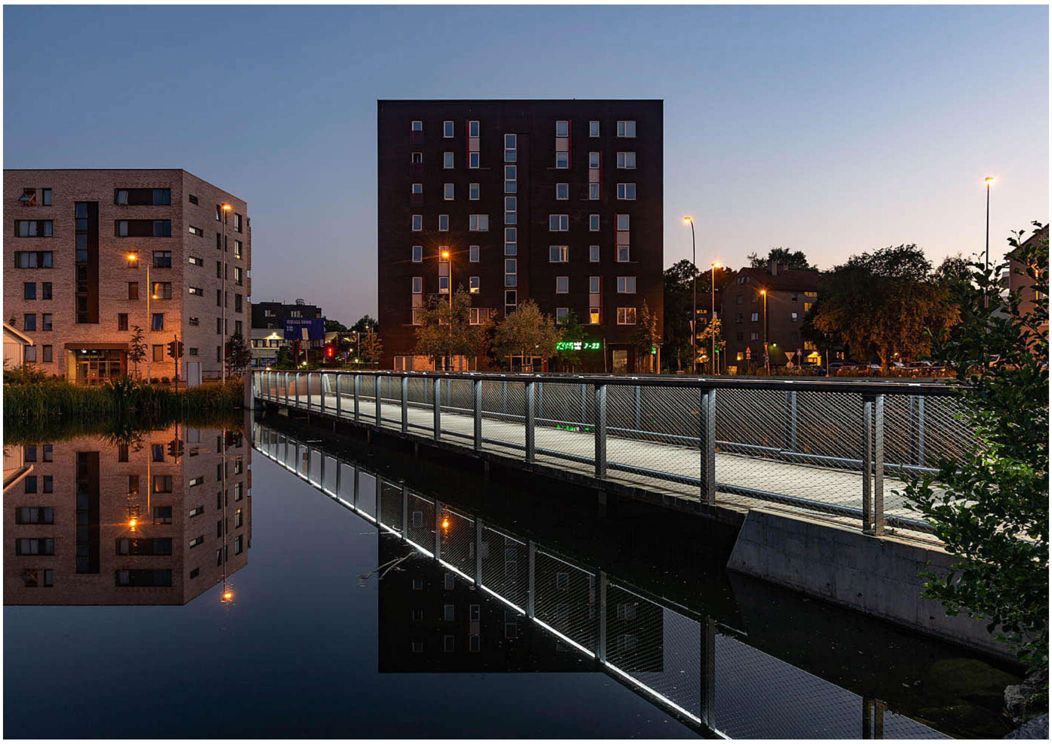


Fig 50. The blue-green elements provide addtional value to the community (Dale, 2019)

Fig 51. Hovin bekken has become an attractive area for both people and animals (Dale, 2019)

Learning outcomes

- *Long-term perspective*
- *Providing increased place quality*
- *A place of community and biological diversity*

5.1 PUBLIC SPACE - RUTEN PARKEN

Ruten Park is in the city centre of Sandnes, Norway. The park has facilities such as a play area, skatepark, seating areas, and several types of urban planting. The park was fully completed in February 2021 and has become a public site that provides a meeting ground for many different ages. According to the architects, “Ruten is a story about making junk space beautiful, accessible, safe, skateable, fun, green, quiet, collective and free” (Spacegroupe, 2022).

During the building process, biochar was implemented. The soil reused local waste products, and the stone was recycled from excavation masses from Velde (washed). The biochar is locally produced from garden waste. Urban planting in biochar has several positive effects, such as better drainage, better plant growth, and a reduced need for fertilisation (Sandnes Kommune, 2020).

The reinforcement layer consists of 90/150 rocks, a biochar mixture, and compost flushed into the pore structure. It creates good plant growth conditions and acts as a battery for water and nutrients released over time. Green structure is built up with environmental masses in two layers, compost, and biochar, 80% rock and 20% biochar and compost. Biochar can replace ordinary plant soil and lead to robust areas that are not compact, and it ensures good drainage. When using biochar, approximately 75 kg of CO_2 can be stored in a thickness of 80 cm (Sandnes Kommune, 2020).

After the park’s completion, Sandnes has gained an urban centre that is a key pivot point for the city’s development, creating identity and putting people first (Spacegroupe, 2022).

Project	Ruten Park
Scale	*Micro* ○ ● ○ ○ ○ *Macro*
Urban Degree	*Natural* ○ ○ ○ ○ ● *Urban*
Initiator	Sandnes Municipality
Date	Completed Feburary 2021
Relevance	Ruten utilizes biochar to create an urban area that includes rain gardens and urban trees. The use of green structure is implemented in the municipality surface water management, the aim is that rainwater in the plot area is collected on-site and led to rain gardens, as well as creating an attractive public square within the city core

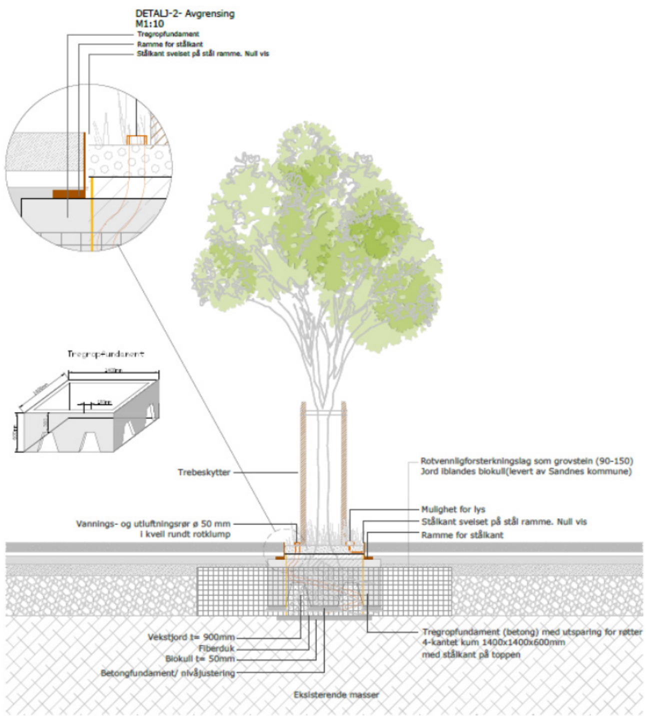


Fig 52. Technical solution of how Sandnes municipality has integrated urban trees and biochar in the public space. (Sandnes kommune, 2020)

Fig 53.Integrated water elements at Ruten Parken along with multifunctional skatepark that can retain water at cloud-bursts.

Fig 54. Rain garden at Ruten with biochar and compost.

Learning outcomes

- *Designed conscious of future challenges.*
- *Important to explore new or unknown solutions and interventions.*
- *The importance of site-quality and focus on public health.*

6

RESULTS AND DISCUSSION

CHAPTER SIX

RESULTS AND DISCUSSION

In this chapter, the main findings from other parts of the thesis are compiled and discussed to answer the overall aim of the thesis. The overall aim is to explore how to create urban design guidelines with NBS for climate adaptation in urban projects in a Norwegian context. The premises, adjustments and recommendations that are needed to create the proposed urban design guidelines are included in this chapter. The final product is presented in Chapter 7 Proposed Urban Design Guidelines.
To create contextualized urban design guidelines for pluvial flooding mitigation, basic knowledge of the topics NBS and urban hydrology is needed. This was presented in the theory chapter. The majority of the reviewed research were merely positive to the use of NBS as a flooding mitigation approach. However, after conducting interviews with local planners and looking at relevant case-studies, it became clear it is not simple to introduce NBS in praxis.

Findings from the case-studies showed that the end-result do not always correspond to the plans for the project, and a comprehensive plan is often needed in complex urban settings to achieve a successful result. A successful project can add great value to the area and bring many positive co-benefits.

The main issue experienced by the municipalities was a resource demanding set of unstructured information concerning NBS, often presented in text-heavy reports. They believed the information available was sufficient, but it would take them a great amount of time to get acquainted with, time which they did not have. Lack of time is not only a concern for the local planners. Another limitation discovered in the work with this thesis is the timeframe of NBS reaching its full effect and inherent potential. In the proposed design guidelines, the recommended NBS are therefore divided into short term and long term. The year of 2030 is mentioned by IPCC as an important milestone in reaching the goal of limiting global warming to 1.5 °C above pre-industrial levels by the end of this century (Roy et al., 2018). To achieve this, the necessary actions must be taken by 2030. In the proposed design guidelines, NBS that will have a great effect within 2030 is therefore considered as short-term actions, while NBS that take longer time to establish and perform sufficiently are considered long term. Long term actions are nevertheless relevant, as they often are more efficient when reaching their full capacity. The long term actions may also contribute in reversal of effects of climate change in the long run.

Representatives in the interviews mentioned that people they worked with in collaborative projects did not always see the value and potential of NBS. Using arguments about green roofs not being effective in rural areas. This shows the general lack of knowledge concerning the range and possibilities of NBS and the need of a structured knowledge-base according to the given spatial characteristics. Among the recurring suggestions regarding the format for an improved presentation of the knowledge, was a simple, visual and communicative layout which could easily be understood and used by anyone. As such, keeping the proposed design guidelines simple and visual has been one of the key principles in this thesis.

Varying amounts and intensity of precipitation are predicted outcomes of climate change (NOU 2015:16). The premise mentioned in the Three-Step Strategy to achieve a holistic flooding management is to plan for all the steps of this strategy. In the proposed urban design guidelines, it is therefore included NBS that serve all the steps within this strategy. All zones within the specified transect will then be prepared for change in precipitation.

6.1 THEORETICAL MODEL

For this thesis, the interpretation of the rural- to urban transect by Duany Plater-Zyberk & Company is used as a framework to integrate spatial characteristics found at Jæren along with appropriate NBS. Some adjustments were needed as Duany Plater-Zyberk & Company (2012) rural to urban transect is most suited for areas created based on one main master plan. The model therefore usually applies better to younger cities. The cities and towns on Jæren have developed gradually and organically over several centuries, which is reflected in the morphology and other urban patterns. In order to create a generic model, an adjusted transect, for the context of Jæren, a theoretical model is needed. One theoretical model is created for cities and another for towns. The theoretical models illustrate the composition of t-zones at Jæren. The models are presented in figure 55 and 56.

Cities at Jæren often consist of a historic centre with protected buildings and modern high-rise buildings. The built pattern clearly shows how the city has expanded and is compared to the growth rings of a tree trunk. The centres are surrounded by large detached wooden houses, which historically housed several families. Densification projects are located outside the wooden house environment. The policy from the regional authority is to densify along the main transit axes (Rogaland fylkeskommune, 2021). Special districts have often been located outside the city when the planning praxis was car-oriented planning and zoning, a strategy based on strict division and segregation of functions; housing, retail, and workplace. These buildings often have only one purpose, reflected in the poor architectural quality.

In the southern parts of Jæren, the towns are of smaller size but share some of the same features as the cities. They consist of an urban or town centre with a mixture of typologies. Outside of the centre, the typology of the built environment is mostly T3 and SD. Densification projects with T4 typology are generally spread in fields outside of T3 and SD. Finally, these towns are surrounded by a T2 landscape.

Although the rural – to urban transect does not describe the urban landscape perfectly, it provides a good framework that categorises NBSs according to different building typologies. Therefore, in the following chapter, Duany Plater-Zyberk & Company's interpretation of the rural to urban transect will be used as a base for the proposal. Even though the order of T3 and T4 could have been changed for this context, it still provides a good framework for the structure of the given recommendations for the proposed design guidelines.

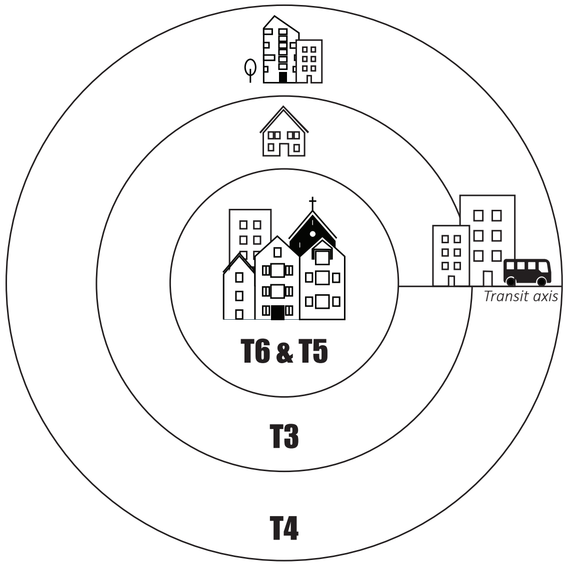


Fig. 55 Theoretical model of the transect within cities found on Jæren.

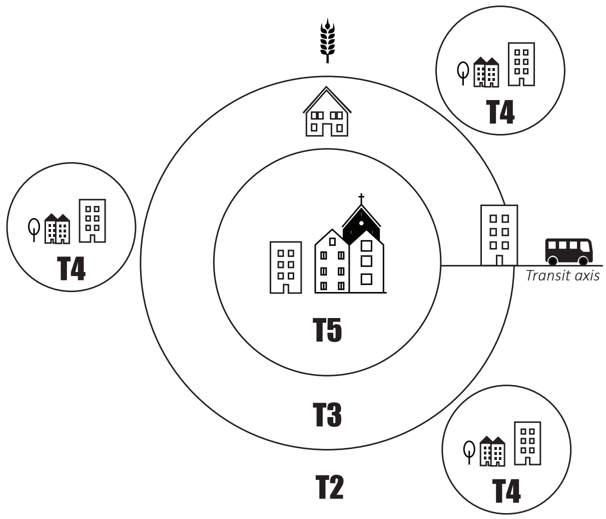


Fig 56. Theoretical model of the transect within towns found on Jæren.

6.2 GENERIC MODEL BASED ON SPATIAL CHARACTERISTICS AT JÆREN

The generic model is derived from the developed theoretical models. The generic model is an adjusted version of the rural- to urban transect for the given context of Jæren. However, it is general for natural and built environments found at Jæren, and not site-specific for a given area. Specific considerations must always be taken for the given site.

All the t-zones, from T1 to T6 & SD, are found at Jæren. Most of the land consists of a cultural landscape with agricultural areas and coastal moorland presented as T2. Natural areas, T1, are found in the western part of the district, with mountains, peatland, and forests (conifer and mixed forests). Some woods are of natural occurrence, while some have been planted as a part of industry and forestry programs.

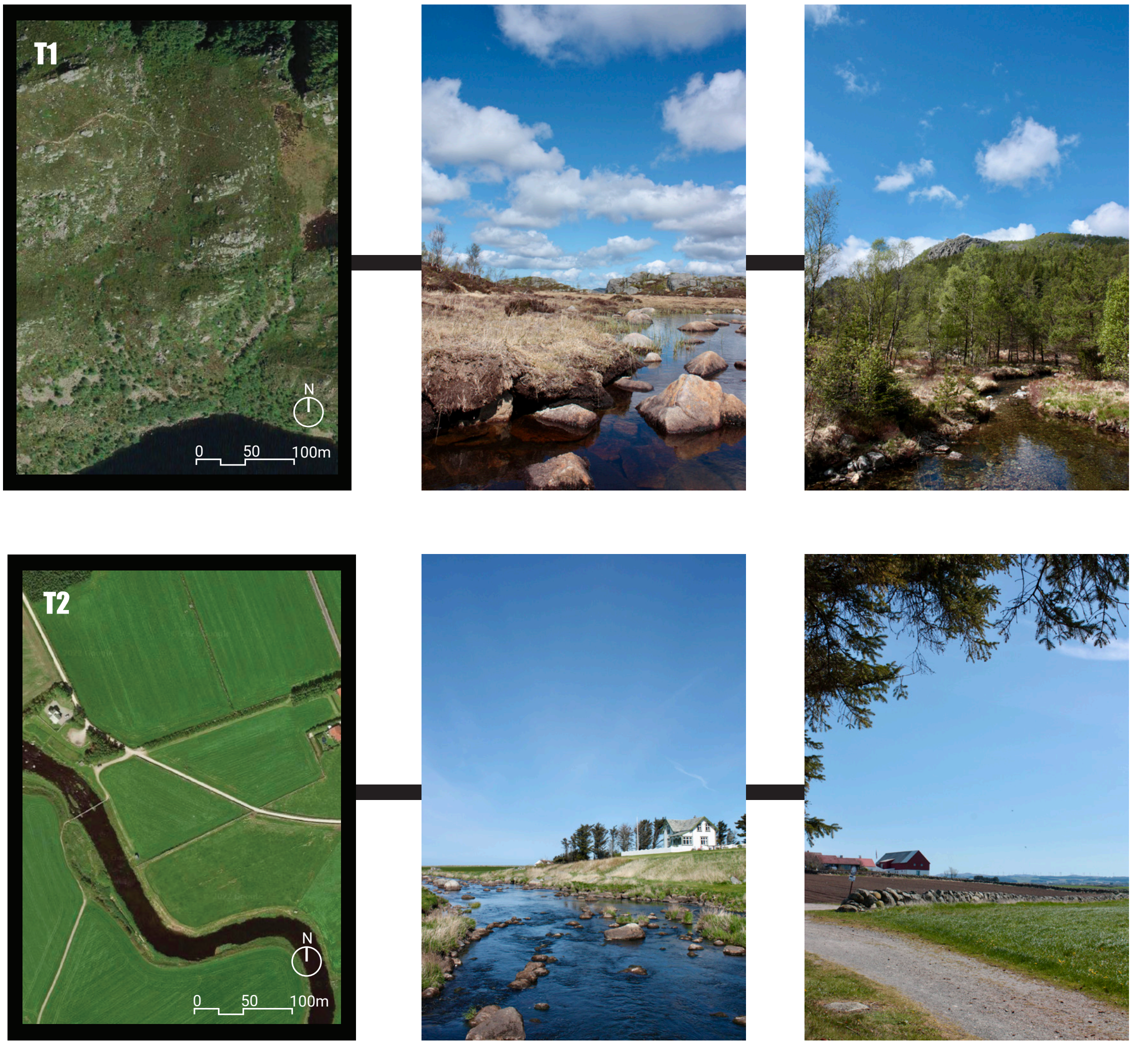


Fig 57. T1 (above) and T2 (below) at Jæren.

The main difference between T4 and T3 is the built density, both in terms of building footprint and height to land coverage ratio. Many of the measures may be applicable for both zones, but T4 requires a greater extent of measures due to the higher built density, which reduces the natural infiltration.

Fig 58. T3 (above) and T4 (below) at Jæren.

As mentioned above, the built environments in the district have been shaped based on planning ideas and policies. The district has some urban centres. Some of them still have urban morphology that dates back many centuries ago. These areas are considered T6, while urban centres with newer morphology and building typologies are included in T5. This is done because the measures presented in T6 and T5 are not entirely the same. T6 building typology is adapted to human scale, meaning smaller buildings with richer detailing on a small scale. T5, on the other hand, has a building typology consisting of larger building masses with large plain surfaces. An essential criterion of the proposed design guidelines is that the NBS should contribute to the quality of the place rather than undermine it. T6 measures must be carefully selected so it does not damage cultural and architectural details that are essential for the city's identity. The exact details are not as critical for the T5 due to the lesser detail.

Fig 59. T5 (above) and T6 (below) at Jæren.

Forus is the primary business park, shopping, and industry area within the district, being the main area for SD. The building typology is dominated by large building masses with passive facades, meaning a low degree of detail. The remaining land cover is mostly asphalt used for road infrastructure, industry, or designated parking areas. The perceived quality of this zone could be increased by implementing NBS. This zone also holds great potential for combined uses and functions, especially on the rooftops. SD is found outside the urban centres, but much is being converted to T4 and T5 due to new planning strategies.

Fig 60. SD at Jæren

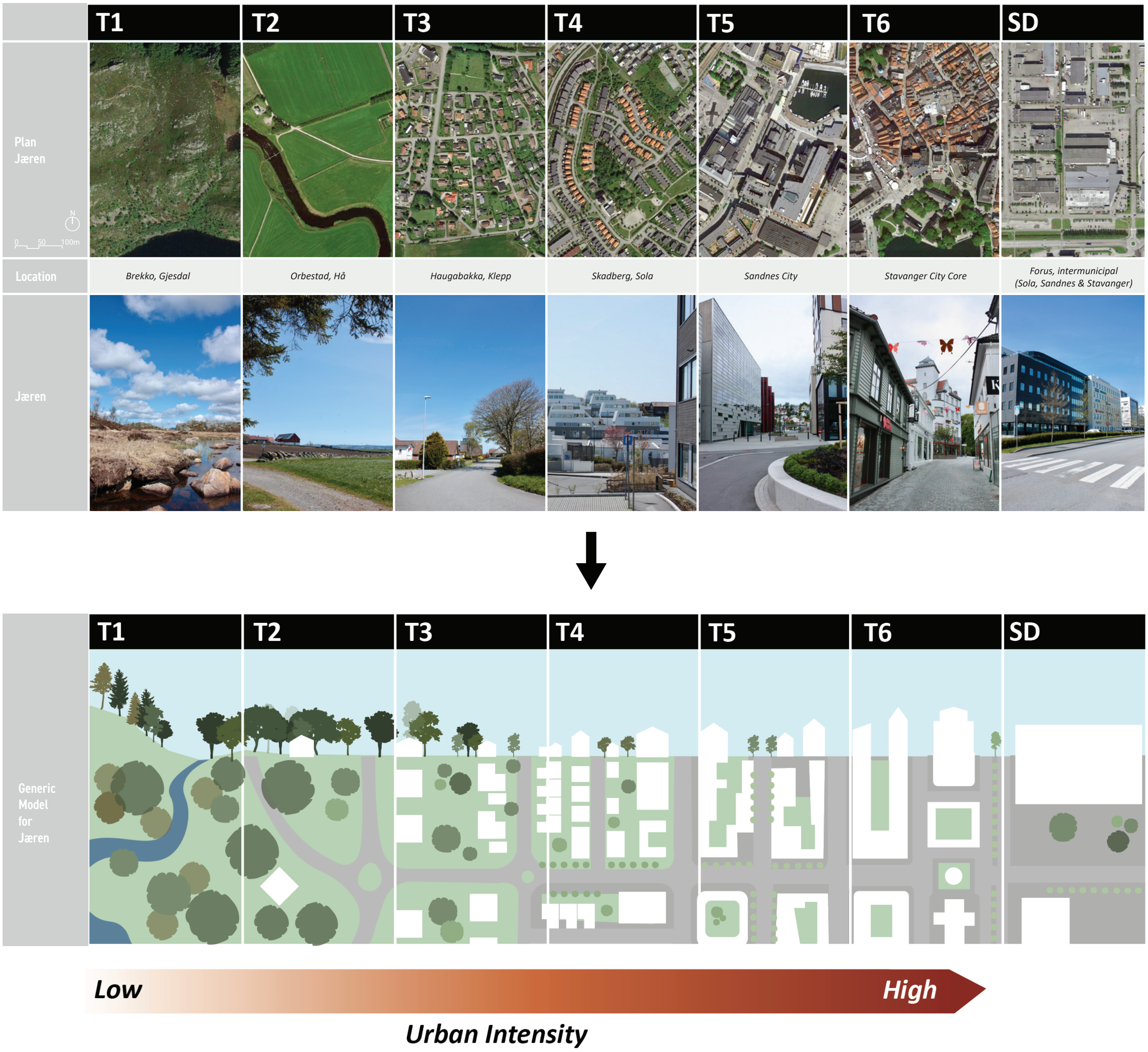


Fig 61. A generic model for the rural- to urban transect adapted to a Norwegian context, Jæren.

The natural and built patterns observed at Jæren through the work with this thesis, are generalised into a generic model, shown in figure 61. As can be observed in the figure, the proposed generic model, similar to the original rural- to urban transect, is divided into six t-sones accompanied with a SD zone. The model is also graphicly presented through a cross-section and a plan view, illustrating the spatial relationships between natural elements, buildings and road infrastructure.

6.3 CATEGORISATION OF NBS

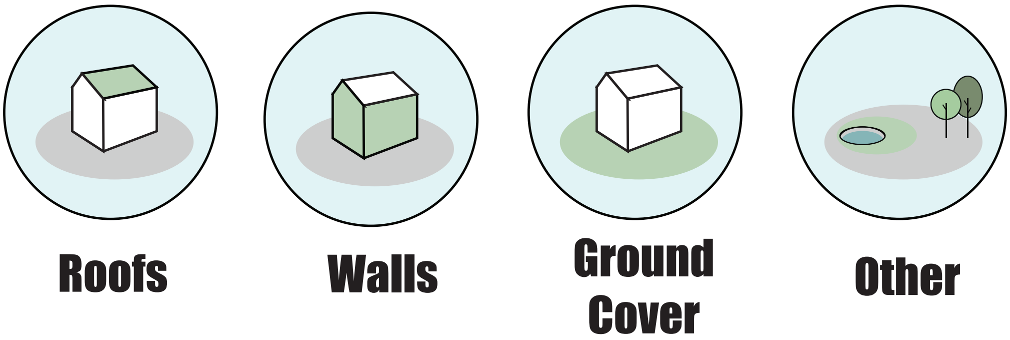


Fig 62. Categories of NBS

For this thesis, the NBS presented in the theory chapter are categorised in the following groups: roofs, walls, ground cover and other. This is done to easily align NBS with the appropriate t-zones.

- *Roofs* include all NBS that are located at the rooftops on houses and other buildings.
- *Walls* include NBS that are found on the building's façade.
- *Ground cover* include NBS that are based on the ground level.
- The category "*other*" include NBS that can be distinguished from the categorises above, due to their unconventional use as urban flooding mitigation. Examples include wetland restoration, road profile (hybrid solution) and private gardens. Many of these solutions rely on private or political initiative.

Roofs: The main benefit of roofs is the available surface area, which yields great potential for utilization. As mentioned in previous chapters roofs can be used for creating microhabitats, farming, production of renewable energy, recreational use among others. Due to the great area available, they can withhold great amounts of water if designed for this purpose. The main issue for NBS roofs includes roof angle and load bearing capacity.

Walls: The benefits of NBS walls include infiltration and retention of water, improving air quality, noise pollution and aesthetical value. Maintenance is the main concern with these solutions as they can be hard to reach. Upkeep of this type of NBS may require special knowledge and a regulatory maintenance schedule. Furthermore, green facades can have challenges connected to the ground conditions; the roots might affect the foundation of the building.

Ground cover: Benefits of ground based NBS is that they infiltrate and retain water well. They can also serve as purification of pollutants that are collected in the runoff. These NBS can contribute aesthetically in the cityscape. However, there is limited available space on the ground level in the city and the NBS may conflict with other functions.

Other: To protect vulnerable urban areas from distant water bodies, flooding issues should be tackled locally at the problems origin. Flooding issues can emerge in natural areas and should therefore be included in the evaluation of holistic water management. Some of the NBS found in this category can provide natural habitats for a range of species, some of which are vulnerable. Wetlands can also store a large amount of carbon, which is important to achieve the international climate goals. The constraints for this category are found at several levels, since it is a matter of initiative from private stakeholders, planners and politicians.

6.4 EVALUATION OF NBS IN RELATION TO T-ZONES

To create urban design guidelines with NBS for various landscape forms and urban patterns found at Jæren, it is necessary to evaluate the specific solution's appropriateness for the given spatial environment. Therefore, this thesis has categorized the NBS from the theory chapter and will evaluate them accordingly to the given t-zones. The main criterion for this evaluation is to improve the water balance within the given t-zone. While the recommendations for each t-zone is based on this evaluation along with criteria 2 and 3 in the table: add spatial qualities and strengthen the zone's identity, maintaining a holistic flooding management.

The evaluation of each NBS appropriateness according to the given t-zones is presented in figure 63. The lightest shade is when the NBS is not appropriate given the listed criteria, while the darkest shade is when the NBS is very suitable for the given t-zone. It is important to note that they are revised individually, and a combination of other less suitable could in theory be more effective. Site-specific knowledge is also needed to select the most beneficial combination, which may deviate from the given recommendations.

Criteria	Premisses	
1. Improve the water balance within the given zone.	*Feasibility*	The implementation of the selected NBS must be feasible, given spatial and structural constraints. Also including realistic expectations regarding operation and maintenance.
	Efficiency and utility	The NBS must be effective for flooding mitigation for the given zone.
2. Add spatial qualities and strengthen the zone's identity.	*Architectural design and scale*	Urban design is about weaving together elements in an urban fabric. The NBS should co-exist with the area's existing design elements, and not undermine them.
	The area's current function and uses	The NBS should not change the current uses of the site, unless it is objectively for the better.
	Sensitivity to natural heritage	The NBS should not challenge vulnerable natural environments. Local knowledge concerning ecosystems are needed.
3. Maintaining a holistic flooding management	*Three-Step Strategy*	All steps within the three-step strategy should be included.
	Time perspective	Avoid dependence on only long-term interventions.

Fig 63. Main criteria for the NBS recommended in the proposed urban design guidelines

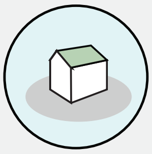
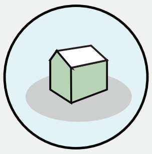
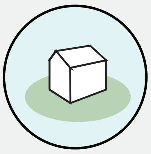
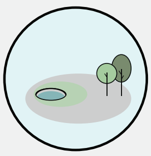
		T1	T2	T3	T4	T5	T6	SD
	Intensive roofs	Not appropriate	Not appropriate	Not appropriate	Somewhat suitable	Very suitable	Suitable	Very suitable
	Semi-intensive roofs	Not appropriate	Not appropriate	Somewhat suitable	Suitable	Very suitable	Suitable	Very suitable
	Extensive roofs	Not appropriate	Not appropriate	Suitable	Very suitable	Very suitable	Suitable	Very suitable
	Blue-green roofs	Not appropriate	Not appropriate	Not appropriate	Somewhat suitable	Very suitable	Suitable	Very suitable
	Living walls with planter box	Not appropriate	Not appropriate	Suitable	Suitable	Very suitable	Suitable	Very suitable
	Living wall with foam substrate or other	Not appropriate	Not appropriate	Somewhat suitable	Somewhat suitable	Very suitable	Suitable	Very suitable
	Green facade	Not appropriate	Not appropriate	Suitable	Suitable	Very suitable	Somewhat suitable	Very suitable
	Permeable pavement	Not appropriate	Not appropriate	Suitable	Suitable	Suitable	Very suitable	Very suitable
	Raingarden	Not appropriate	Not appropriate	Very suitable	Very suitable	Suitable	Suitable	Suitable
	Downspout disc. and rain-barrel	Not appropriate	Not appropriate	Very suitable	Very suitable	Suitable	Suitable	Somewhat suitable
	Bioswale	Somewhat suitable	Very suitable	Suitable	Suitable	Somewhat suitable	Not appropriate	Very suitable
	Urban street tree	Not appropriate	Not appropriate	Very suitable	Very suitable	Very suitable	Very suitable	Very suitable
	Private gardens	Not appropriate	Somewhat suitable	Very suitable	Very suitable	Somewhat suitable	Somewhat suitable	Not appropriate
	Dams	Somewhat suitable	Very suitable	Somewhat suitable	Somewhat suitable	Somewhat suitable	Not appropriate	Very suitable
	Infrastructure (road profile)	Not appropriate	Not appropriate	Very suitable	Very suitable	Very suitable	Very suitable	Very suitable
	Stream re-opening	Very suitable	Very suitable	Suitable	Very suitable	Very suitable	Somewhat suitable	Suitable
	Wetland restoration and protection	Very suitable	Very suitable	Suitable	Not appropriate	Not appropriate	Not appropriate	Not appropriate
	Biochar	Not appropriate	Very suitable	Very suitable	Very suitable	Very suitable	Very suitable	Very suitable

Fig 64. Evaluation of NBS accordingly to the t-zones.

VERY SUITABLE
SUITABLE
SOMEWHAT SUITABLE
NOT APPROPRIATE

7

PROPOSED URBAN DESIGN GUIDELINES

CHAPTER SEVEN

PROPOSED URBAN DESIGN GUIDELINES

Urban design guidelines are a series of design statements or recommendations based on design principles presented through images and illustrations (Peterborough, 2018, p.1). Design guidelines explain the desired outcome regarding design elements and qualities. In contrast to zoning requirements, design guidelines intend to achieve flexibility based on site-specific conditions (Peterborough, 2018, p.1). They can also be applied during various stages of the development process.

The proposed urban design guidelines presented in this thesis are based on recommendations given according to the design principle of landscape and urban form. The framework for this design principle is the rural- to urban transect. The recommendations are given based on the appropriateness of the specific solution concerning the different rural-urban forms for the given context. These recommendations are presented in illustrations showing how the various transect zones usually appear and how the recommendations can be implemented to achieve a holistic nature-based water management approach.

7.1 PROPOSED URBAN DESIGN GUIDELINES

The proposed design guidelines are presented in the following subchapter. This makes the final result of this thesis and is a synthesis of knowledge from the prior parts. The transect used is the generic model presented in Chapter 6 *Results and Discussion*. The t-zones are presented and visualised before and after the proposed recommendations are applied. Also presented are the proposed NBS co-benefits, which step they serve of the Three-Step Strategy, and if they are considered long- or short term actions in light of the time frame for achieving the SDGs by 2030.

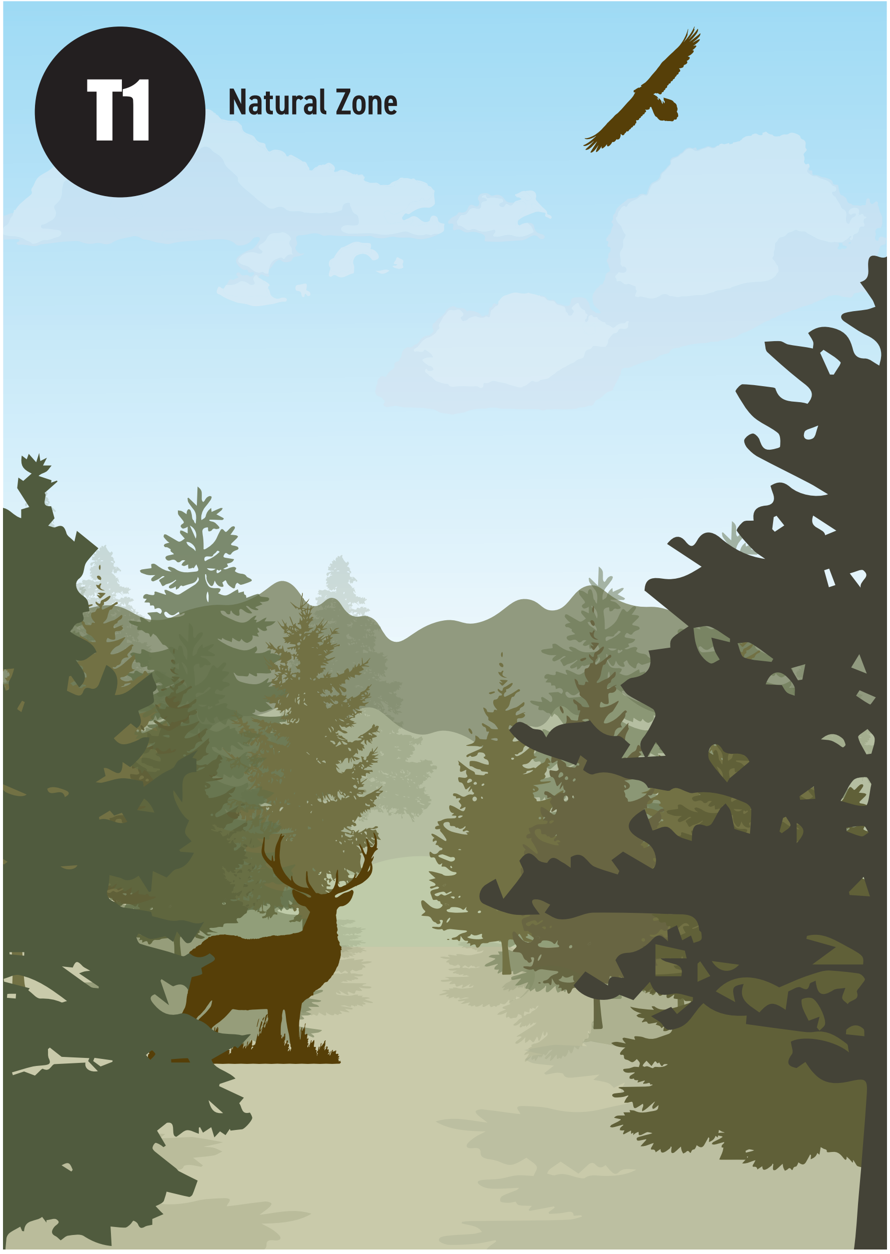


Fig 65. T1 Before.

Typical characteristics: Wilderness conditions. Natural areas or semi-natural. No buildings. Natural vegetation.

Characteristics for given context:
- Nature reserve
- Coastal landscape with sand dunes and cliffs
- Mountain terrain and fjords, with conifer and mixed forests, moorlands
- Some of the woodland and moorlands can be considered as semi-natural since it is a result of human managed forestry and grazing animals

Aim: To preserve existing natural areas and restore damaged areas into natural state, especially vulnerable habitats such as bog landscape. In this manner, the natural water balance could be restored for this zone and contribute to avoiding disrupted hydrologic patterns in other zones.

Co-benefits: Biodiversity, carbon storage, water quality

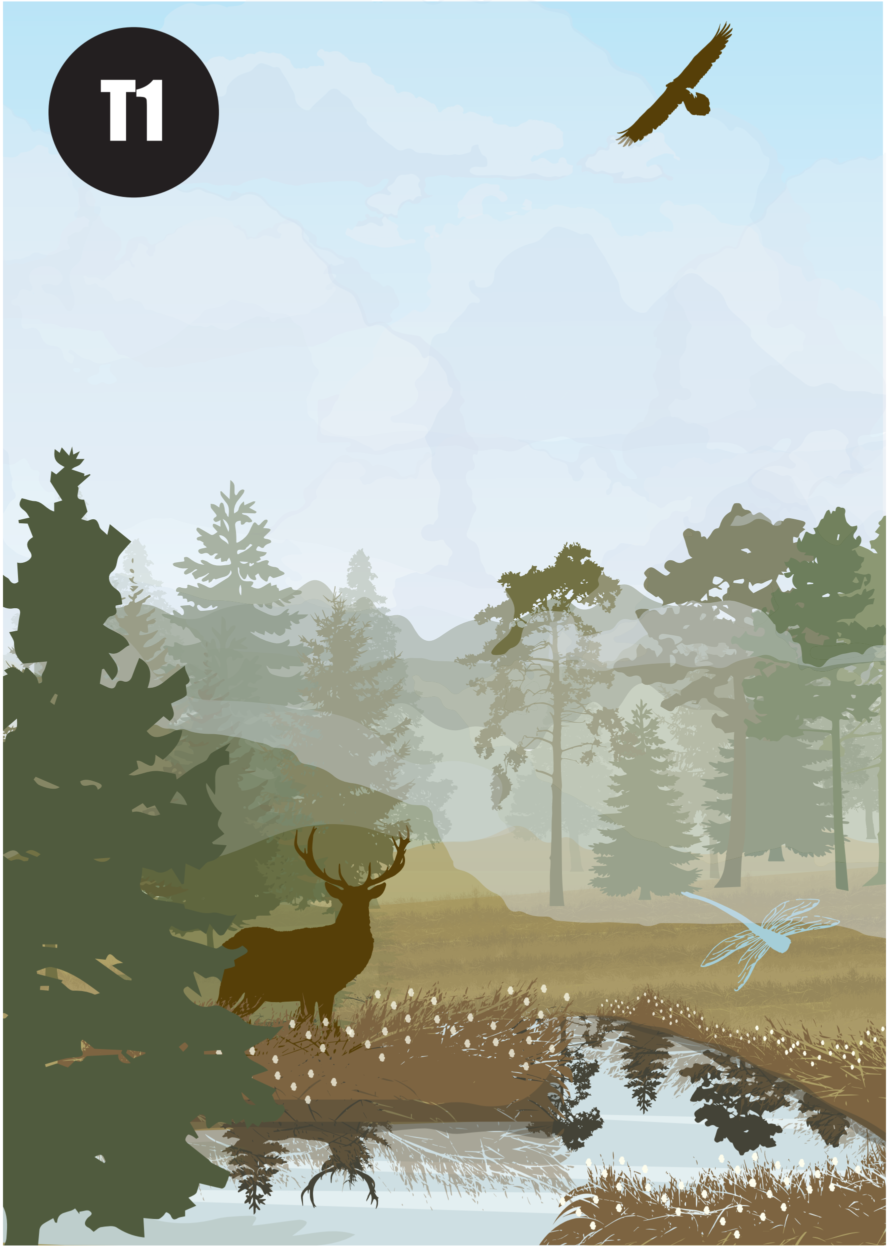


Fig 66. T1 After.

Recommendations for this zone are to preserve existing vulnerable habitats and restore damaged natural areas to their original state. The figure illustrates how a semi-natural area with monoculture can be restored into the natural state of bog landscape and improve the natural water balance along with greater variety of species.

Recommendation	Time frame		Three-step strategy		
	Short term	Long term	1	2	3
Protect and preserve	X		X	X	X
Restore		X		X	X

Fig 67. T2 Before.

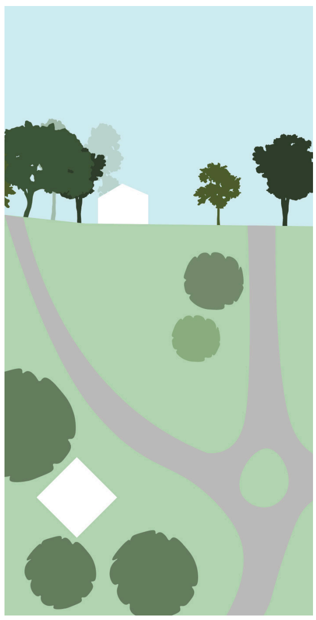
Typical characteristics: Cultural landscape is the product of natural and cultural history—cultivated or sparsely settled, open space (e.g., agricultural land, meadows).

Characteristics for given context:

- Cultural landscape, agricultural land with adjacent buildings
- Semi-natural: Meadows, moorland, lakes, and rivers. semi-natural areas facilitated for leisure activity and recreational use

Aim: Protection and maintenance of the cultural landscape. Sustain the natural water balance and establish buffer zones to secure the natural habitats from polluted runoff from agricultural processes.

Co-benefits: secure food production, cultural heritage, biodiversity



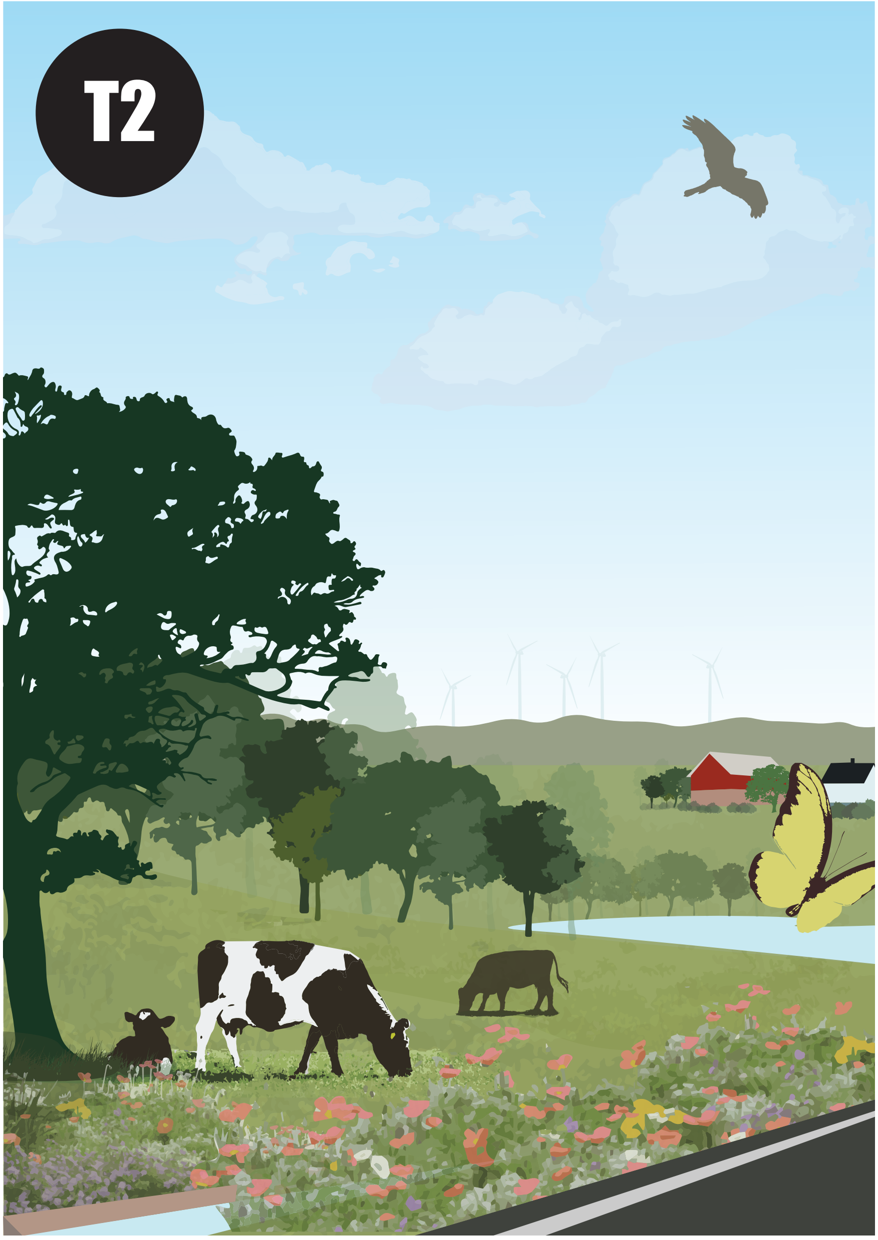
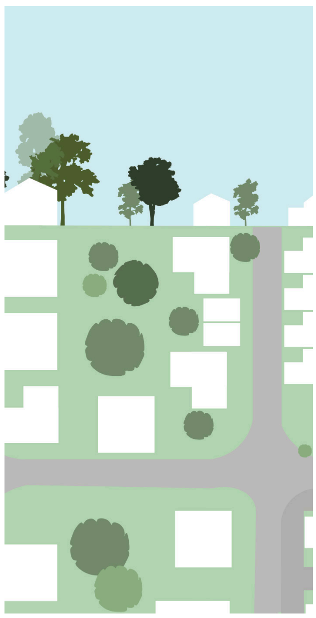


Fig 68. T2 After.

The recommendations suggest preserving the existing cultural landscape while integrating bioswales (buffer) along the road to prevent polluted runoff from penetrating agricultural soil. The vegetation used in the bioswales could be beneficial for pollinators. Dams could be installed as a part of the second step in the Three-step strategy or as a recipient. A hybrid design of the dams should be used to clean polluted runoff from the use of fertilisers before the water is released into natural rivers.

Recommendations	Time frame		Three-step strategy		
	Short term	Long term	1	2	3
Preserve	X		X	X	
Dams	X			X	
Bioswale	X		X	X	X

Fig 69. T3 Before.



Typical characteristics: Suburban area with relatively low built density. Rather large plots with detached single-family dwellings. Often sole use (residential). Natural vegetation and developed landscaping.

Characteristics for given context:
Suburban

- Single-detached houses, large plots (low built density), 1- 4 storeys
- Not only single-family homes, but some buildings are also horizontal split, making them semi-detached homes
- Primarily residential, homogeneous use.

Aim: Facilitate steps 1 and 2 of the Three-step strategy on the residents' plot. Excessive runoff is guided safely away through planned flood paths by using road profiling.

Co-benefits: recreational, aesthetic, cultural heritage

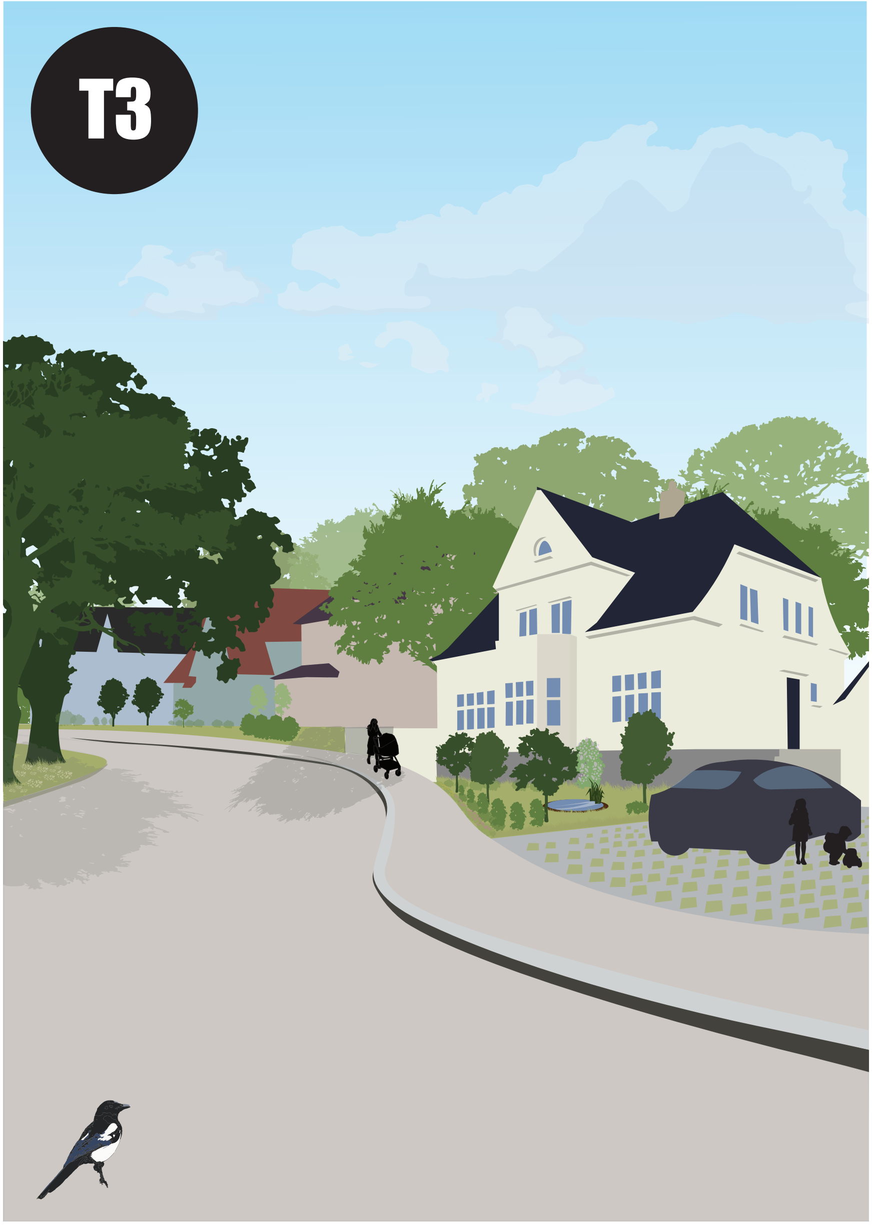


Fig 70. T3 After.

In T3, much of the area consists of private plots (gardens) and road infrastructure. Therefore, it is recommended to implement NBS strategies on these surfaces instead of installing measures on the buildings. For example, the downspout on the buildings could be disconnected, and the water can be used for landscaping in the private gardens. The driveway surface can be changed from asphalt to permeable surface coverings such as reinforced grass. One-sided fall road profiling is recommended in combination with a vegetated zone with street trees.

Recommendations	Time frame		Three-step strategy		
	Short term	Long term	1	2	3
Private gardens	x		x	x	
Urban street trees		x	x	x	
Infrastructure (v-profile)	x				x
Permable pavement	x		x	x	

Fig 71. T4 Before.

Typical characteristics: Mixed-use, primarily residential. Varying building typologies. Varying landscaping.

Characteristics for given context:

- Mixed housing types (semi-detached houses, rowhouses, townhouses, apartments)
- Primarily residential, some mixed-use with basic amenities. "10-minute city".
- Varied landscaping
- Community shared areas (semi-private) and public spaces

Aim: Increasing the blue-green factor through blue-green ground-based measures (rain gardens, street trees, re-opening streams) makes it possible to create a well-connected community while managing runoff locally and securing safe percolation patterns.

Co-benefits: Recreational, aesthetic value, place-identity

Fig 72. T4 After.

T4 is for the given context characterised by newer development as a part of the regional densification strategy. The context means many developers and construction steps where the focus is on the specific prospect and meeting the zoning requirements. Some of these actors lack knowledge of available solutions such as NBS. Thus, the overall area within the t-zone lacks a comprehensive "green plan" regarding flooding prevention.

The recommendations, therefore, propose several NBS approaches combined. Some buildings can be established with NBS roofs and walls, but the primary approach should be through ground-based measures implemented in public spaces. The figure illustrates how public space in a neighbourhood can go from mainly having impervious surfaces to using NBS ground-based measures that increase the infiltration.

Recommendations	Time frame		Three-step strategy		
	Short term	Long term	1	2	3
Ground covering measures	x		x	x	
Walls	x		x	x	
Roofs	x		x	x	
Infrastructure	x				x

Fig 73. T5 Before.

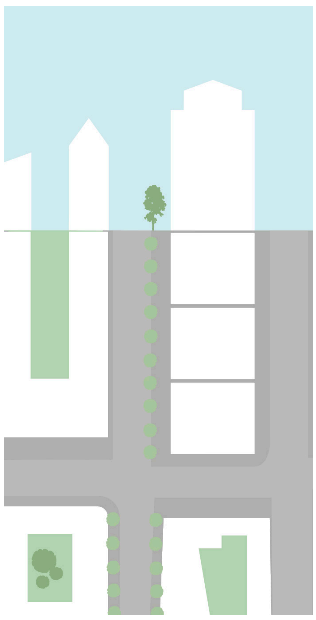
Typical characteristics: Mixed-use, multiple functions. High built density. Street tree planting.

Characteristics for given context:

- Mixed building typology with relatively high density. Coarse-meshed grid.
- Mixed uses and active first floors (use include mostly business, retail, services and some residential)
- Low infiltration due to hard surfaces (roads, roofs, pedestrian pathways, squares)

Aim: As for the other zones, the overall objective is to treat surface water locally. This is a complex area with many functions and stakeholders to consider. Thus, it is necessary to implement different measures to achieve the goal, utilising available surfaces such as roofs and walls and taking greater actions such as re-opening streams.

Co-benefits: Air quality, recreational, place-identity



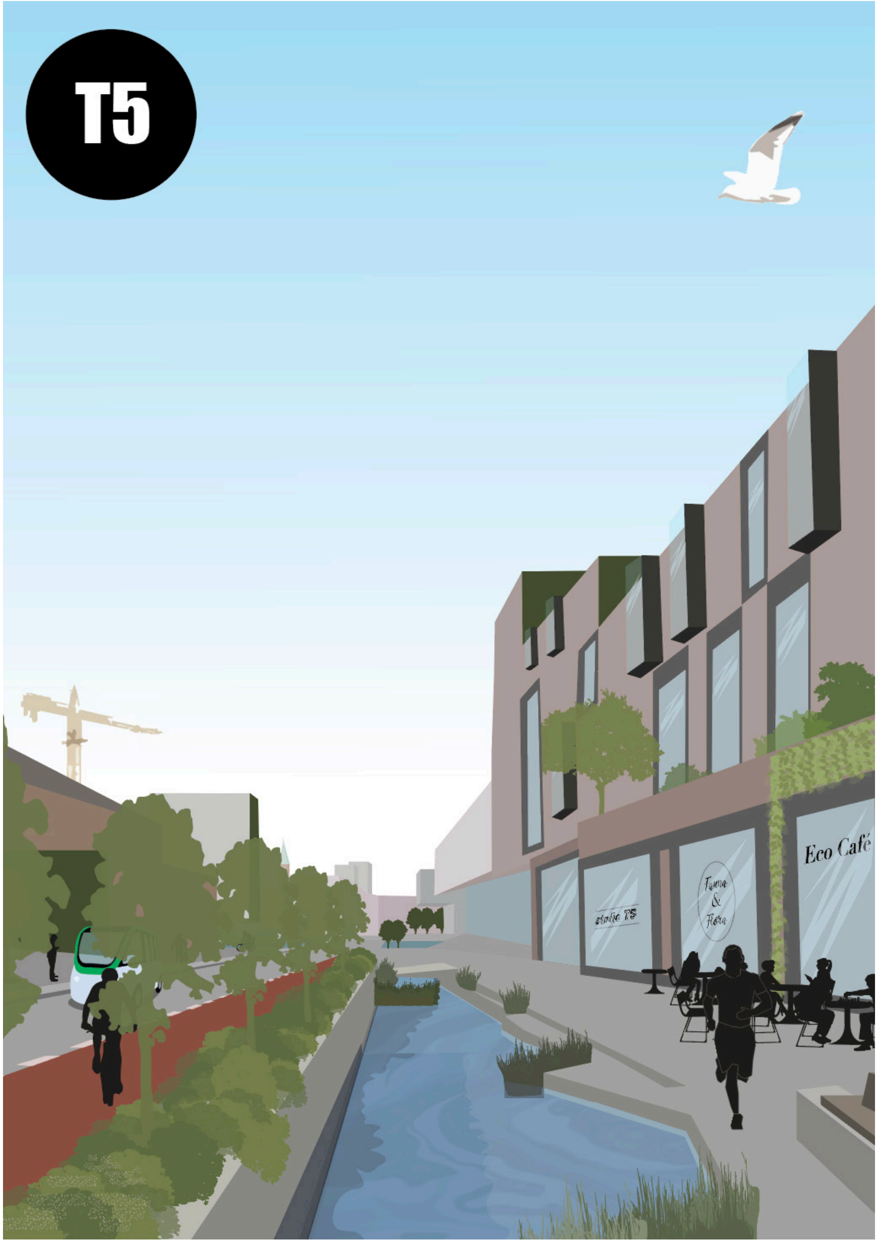


Fig 74. T5 After.

Despite the limited area available within this t-zone, it is still possible to achieve the desired outcome by utilising roofs, walls, and other underused areas and implementing greater measures such as river re-opening. For this t-zone, it could be more appropriate with technically adapted NBS, and hybrid interventions, due to the complex underground infrastructure. The recommended NBSs can contribute to re-naturing the city and providing a better quality of life for people and animals living in urban areas.

Recommendations	Time frame		Three-step strategy		
	Short term	Long term	1	2	3
Roofs	x		x	x	
Walls	x			x	
Stream re-opening	x		x	x	x
Infrastructure (v-profile)	x				x
Biochar	x		x	x	
Urban street trees		x	x	x	

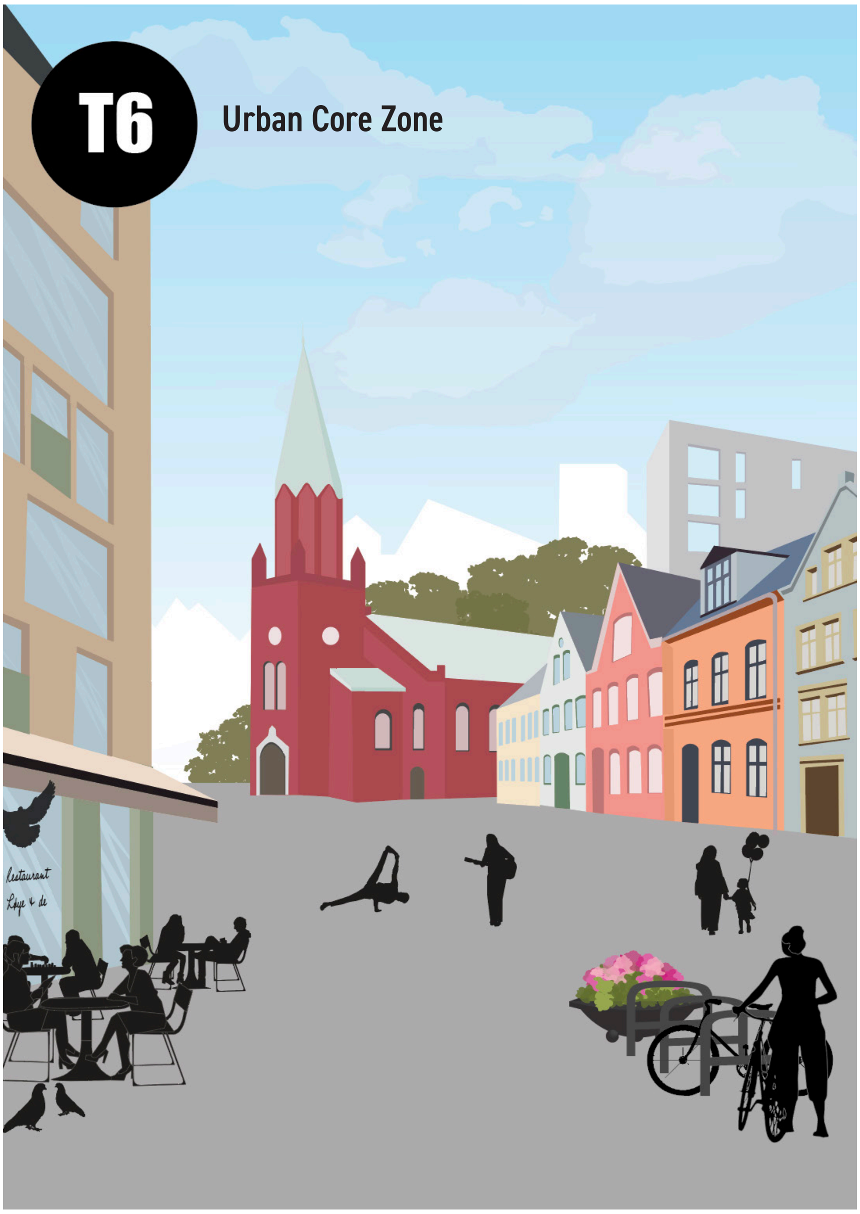
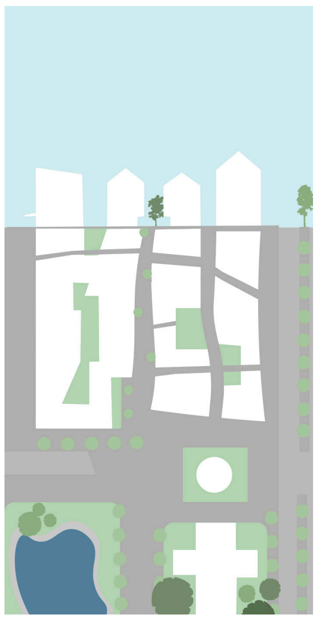


Fig 75. T6 Before.



Typical characteristics: High density. Wide variety of uses. Street tree planting.

Characteristics for given context:

- Building typology with historical and official buildings with a clear place-identity (Buildings adapted to human scale with active facades). Fine grid pattern.
- Mixed-use with active first floors
- Complex area (vulnerable identity to changes in cityscape)

Aim: By implementing several more minor NBS interventions, it is sought to achieve the overall goal of local management of water from precipitation while keeping the spatial characteristics and functions of the area and maintaining place identity.

Co-benefits: Air quality, aesthetical value, recreational

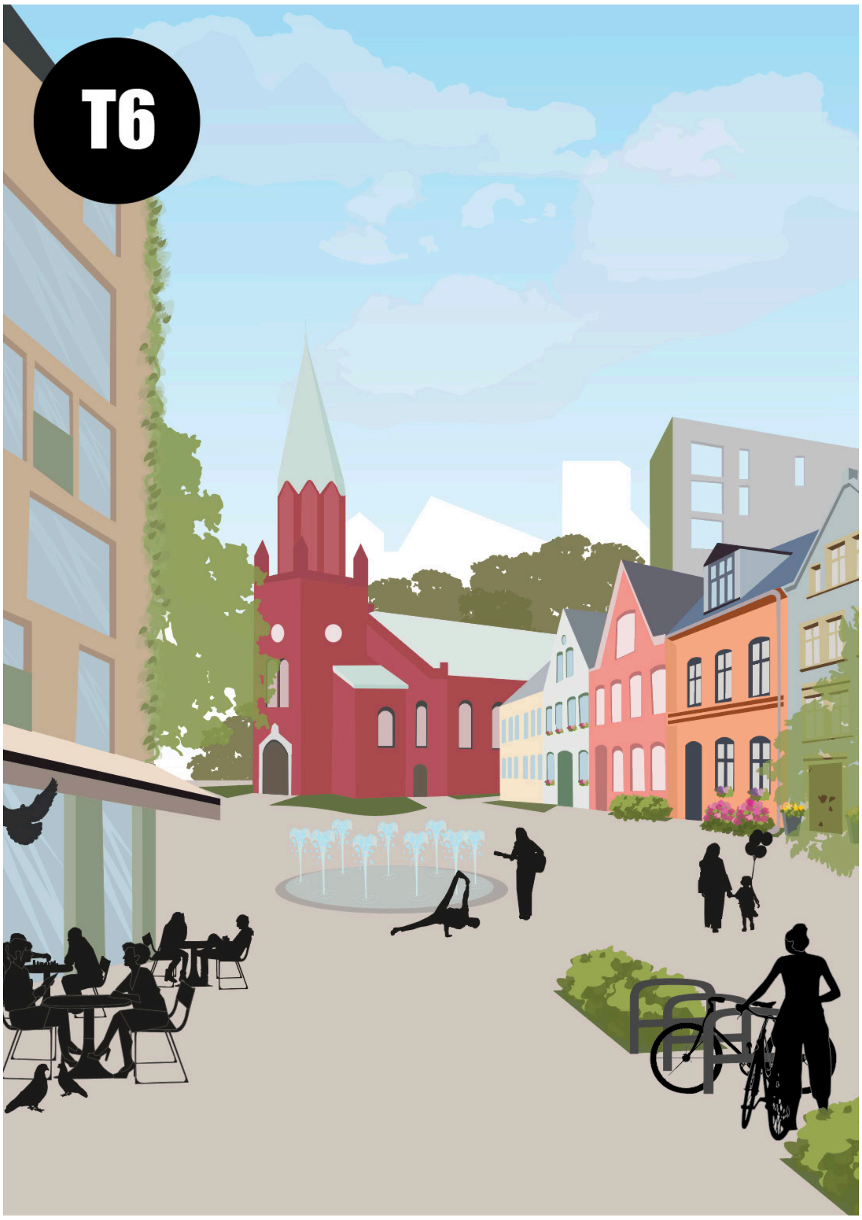
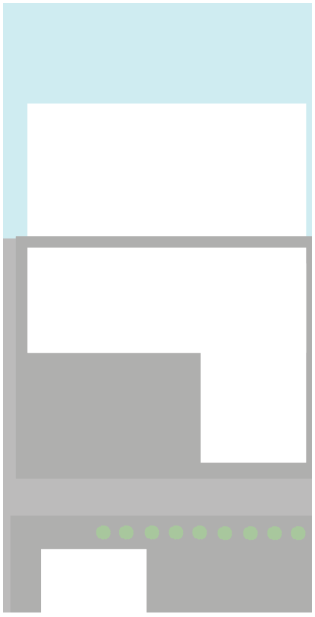


Fig 76. T6 After.

For this t-zone it is important not to undermine the existing architectural qualities that play a significant role in the place-identity of the city. Therefore, it is advised against extensive use of (blue) green roofs and walls. On the other hand, it is recommended to use permeable pavement and avoid hard surfaces such as asphalt and concrete. This measure will also support the cultural heritage. Other recommended measures are ground covering NBSs, including urban water elements, rain gardens and urban street trees. In addition, existing urban trees are suggested to be protected. NBS will make the city more vegetated and greener without significant compromise.

Recommendations	Time frame		Three-step strategy		
	Short term	Long term	1	2	3
Urban street trees		x	x	x	
Infrastructure (v-profile)	x				x
Permable pavement	x		x		
Biochar	x		x	x	
Preserve exsisting street trees	x		x	x	
Downspout disconnection and rain barrels	x		x	x	

Fig 77. SD Before.



Typical characteristics: large building masses with large plots. Few uses. Some street tree planting.

Characteristics for given context:

- Large buildings with passive facades are not customed to human scale
- Large plots with simple landscaping (grass-covered surfaces with a few trees) are mainly used for parking and industry.
- Modest cityscape with slight variation, resulting in an area that lacks a clear place identity.
- Coarse-meshed grid.
- Uses include business, retail, parking, industry and storage

Aim: Utilizing under-used areas for flood preventing NBSs with co-benefits to collectively increase the area's overall quality. An outcome of this approach could be increased attractiveness, more effective land use, recreational use and place identity.

Co-benefits: Identity, attractiveness, more effective land use

Fig 78. SD After.

The advantage of the SD zone is that many NBSs are appropriate and can be successfully implemented. Either by using a few measures on a larger scale or by combining many interventions. The figure illustrates some possibilities, including bioswales, green walls and productive semi-intensive roofs (urban farming). Taking the rooftop areas in use makes it possible to produce food and renewable energy and create recreational areas while addressing the flood challenge.

Recommendations	Time frame		Three-step strategy		
	Short term	Long term	1	2	3
Roofs	X			X	
Walls	X			X	
Bioswale	X		X	X	X
Permable pavement	X		X	X	
Biochar	X		X	X	

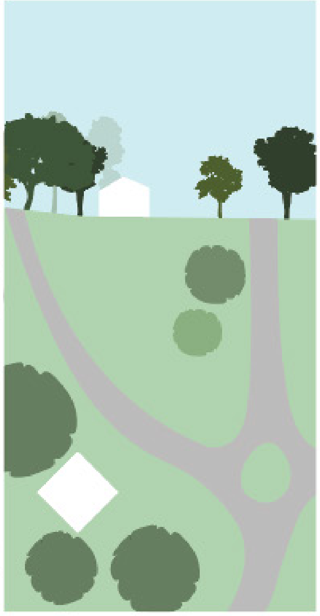
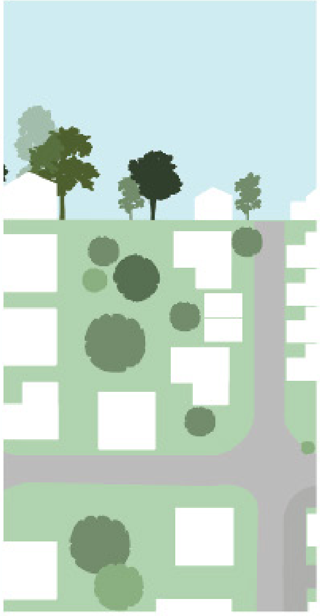
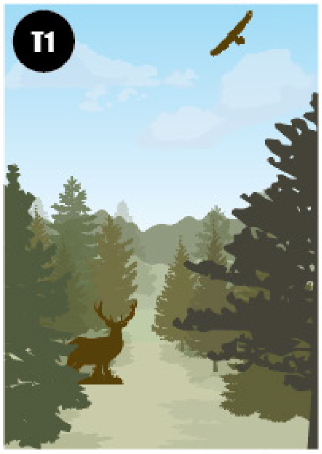
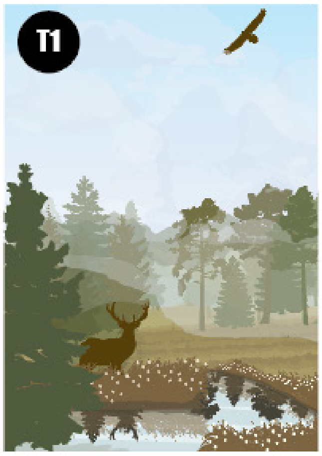
	T1 Natural Zone	T2 Rural Zone	T3 Sub-Urban Zone
Section Plan			
Current state			
NBS implemented			
Key solutions	• Protect • Preserve • Restore	• Preserve • Ponds • Bioswale	• Private gardens • V profile • Street trees

Fig 79 . Summary T1-T3

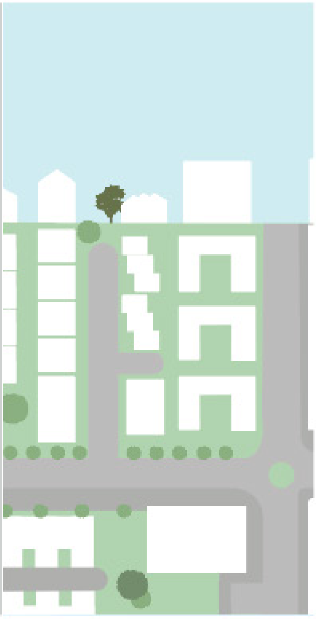
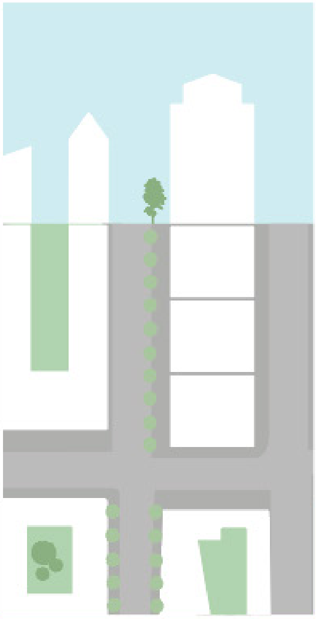
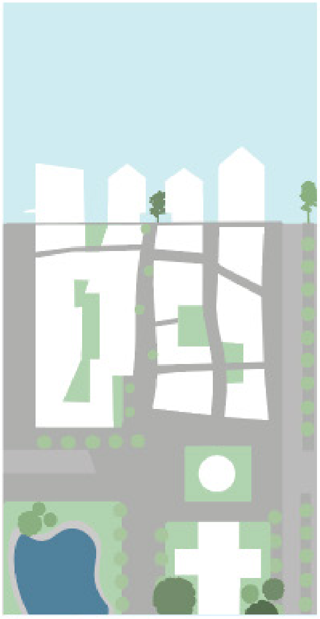
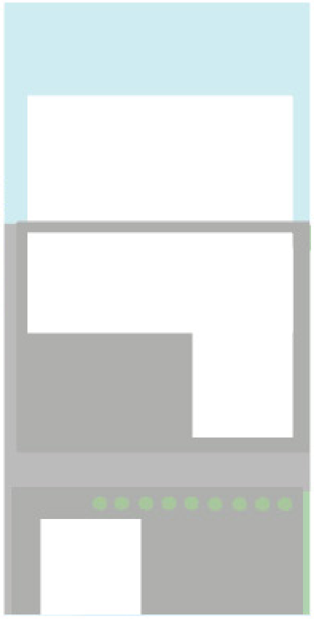
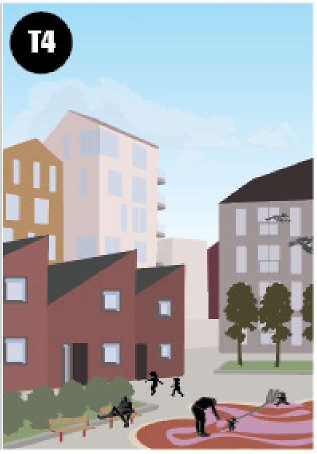
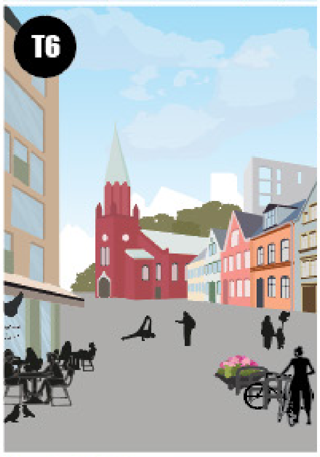
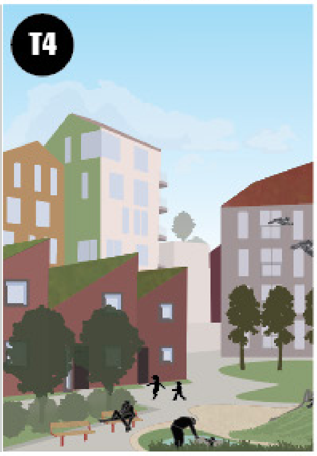
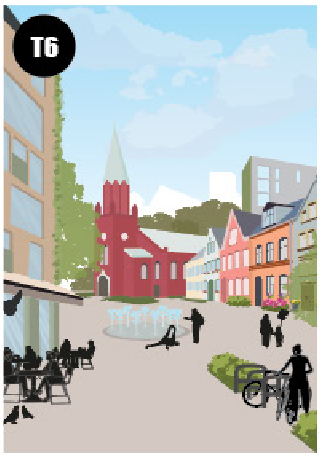
	T4 General Urban Zone	**T5** Urban Center Zone	**T6** Urban Core Zone	**SD** Special District
Section Plan				
Current state				
NBS implemented				
Key solutions	• Ground covering measures • Walls • Roofs	• Urban street trees • Walls • Roofs	• Ground covering measures • Permeable pavement • Urban street trees	• Roofs • Bioswales • Permeable surface

Fig 80 . Summary T4-SD

7.2 APPLICATION OF THE GENERIC MODEL

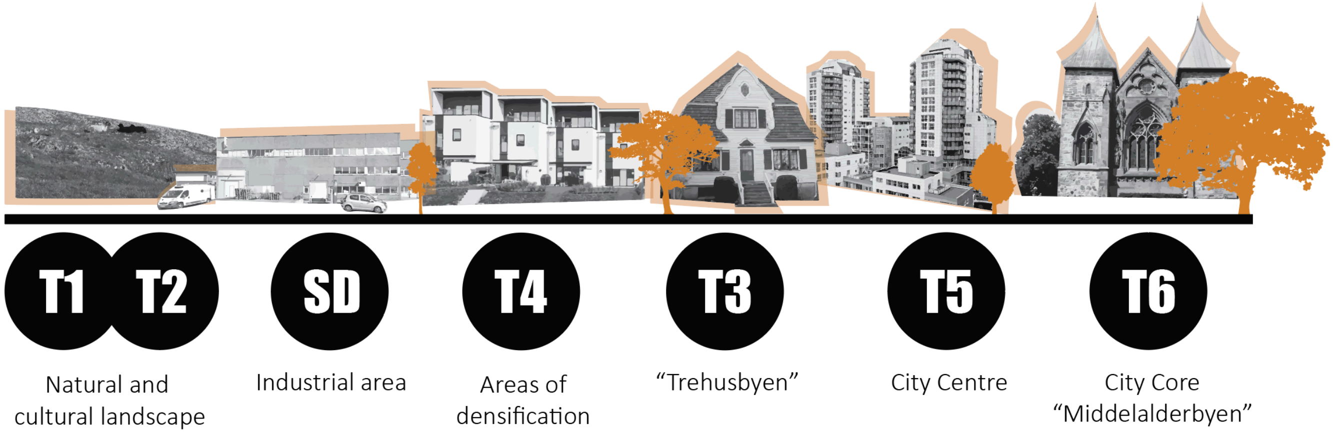


Fig 81 . Site-specific transect, Stavanger

To illustrate that the generic model, which is the rural- to urban transect adjusted for the context of Jæren, is applicable for a specific location, an example with Stavanger is demonstrated. In the following, the t-zones within the site-specific transect are described.

T6 is the oldest part of the city, with a morphology dating back to the Middle Ages. T1 and T2 are well-established areas within the transect, although some land is taken for densification projects (such as Madla-Revheim T4 in the given example). The area marked with T3 was originally the suburban area in the city back in the early 20th century. It is often called "Trehusbyen", a protected built environment of wooden houses. This area is referred to as T3 instead of T4. Based on the building typology, the vegetation aligns with the description for this t-zone. Historical aerial photos at norgeibilder.no show that T5 was previously the same typology as T3 and was densified in the late 20th century. The policy from the regional authority is to densify outside the boundary of T3 and along the main transit axes (Rogaland fylkeskommune, 2020). Special districts are located outside the city due to car-oriented planning. These buildings have only one purpose, and have poor architectural quality. In the given example of a transect in Stavanger, the military base HNoMS Harald Haarfagre is also included as a part of the SD in addition to the industry and commercial area at Revheim.

The appropriate NBS according to the different t-zones are as mentioned in the proposed urban design guidelines. This site-specific version of the adjusted transect in the generic model illustrates that the model does indeed apply to a given area in Jæren.

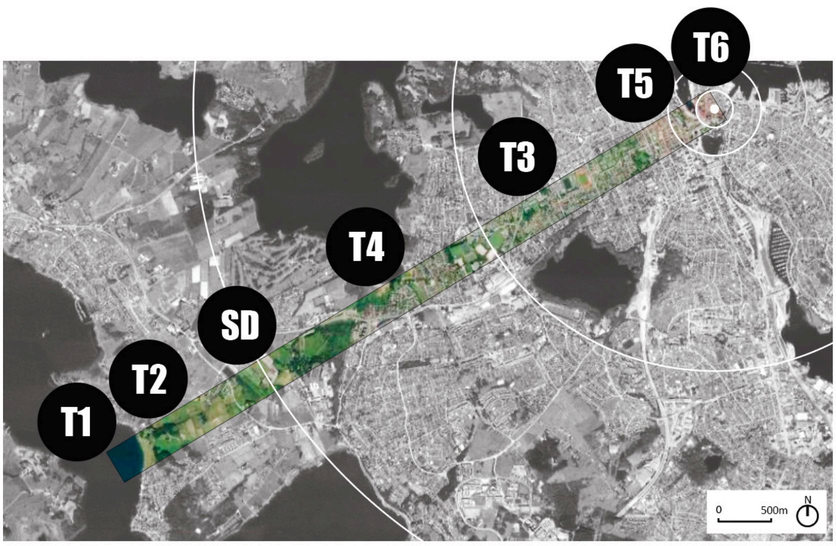


Fig 82 . Location for the site-specific transect, Stavanger

7.3 REFLECTION AND FURTHER WORK

Further work based on this thesis can include both the development of the tool and working on the practical thematic. In addition, further academic work can be done. The findings of the interviews can be further explored and done on a larger scale, including an extended assemblage of stakeholders, found in official government and private operators working within city and regional planning.

The design guidelines can also be explored in more detail, including more site-specific context, this can be elaborated on from an overall perspective, and in a more detailed context. The information regarding NBS can be further explored and systemised to be included in the proposed transect.

Based on the findings in the literature and the interview there is a clear knowledge gap related to the use and information regarding NBS. The interview respondents are open to implementing NBS more in their work. although there is a need for a tool to make this feasible, the informants requested a user-friendly, easily accessible tool that should include examples and relevant information. The aim is to give the users one place to access the knowledge. A solution for this would be to develop a webpage or app that both officials and private users both officials and private users can access.

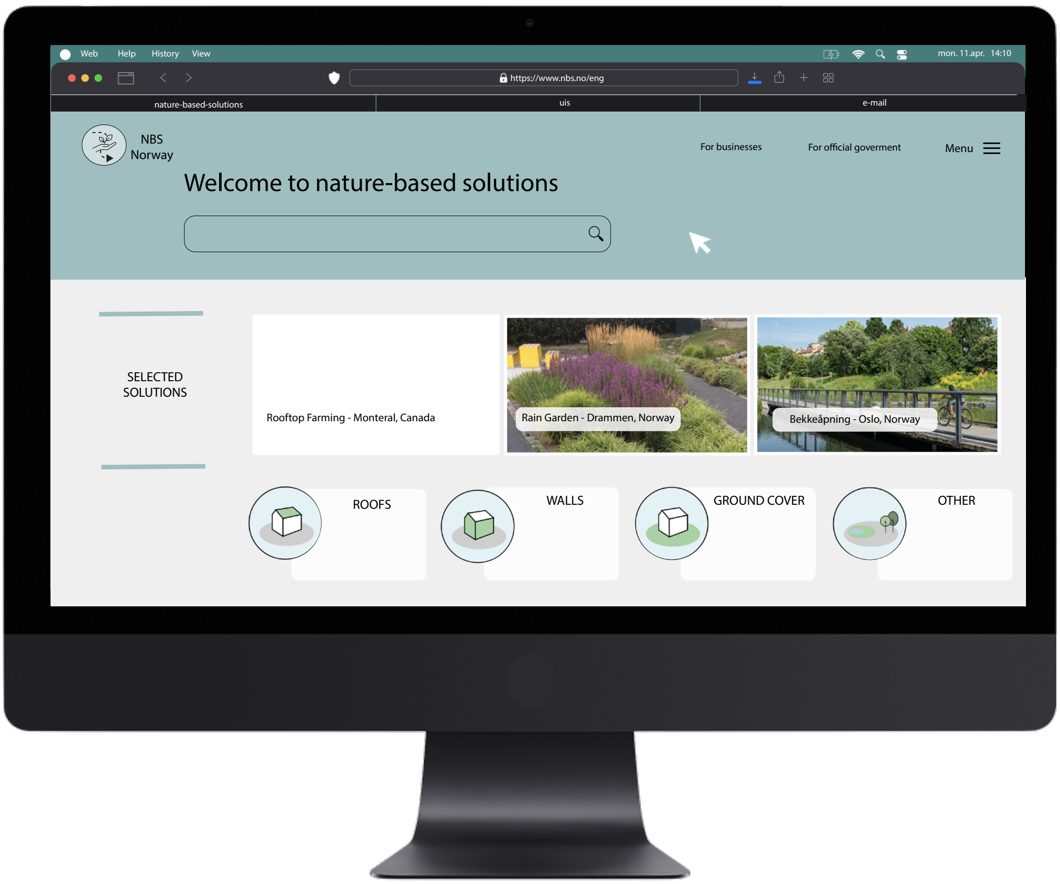


Fig 83. fig. A web page including examples of the measures in use and articles with relevant information.

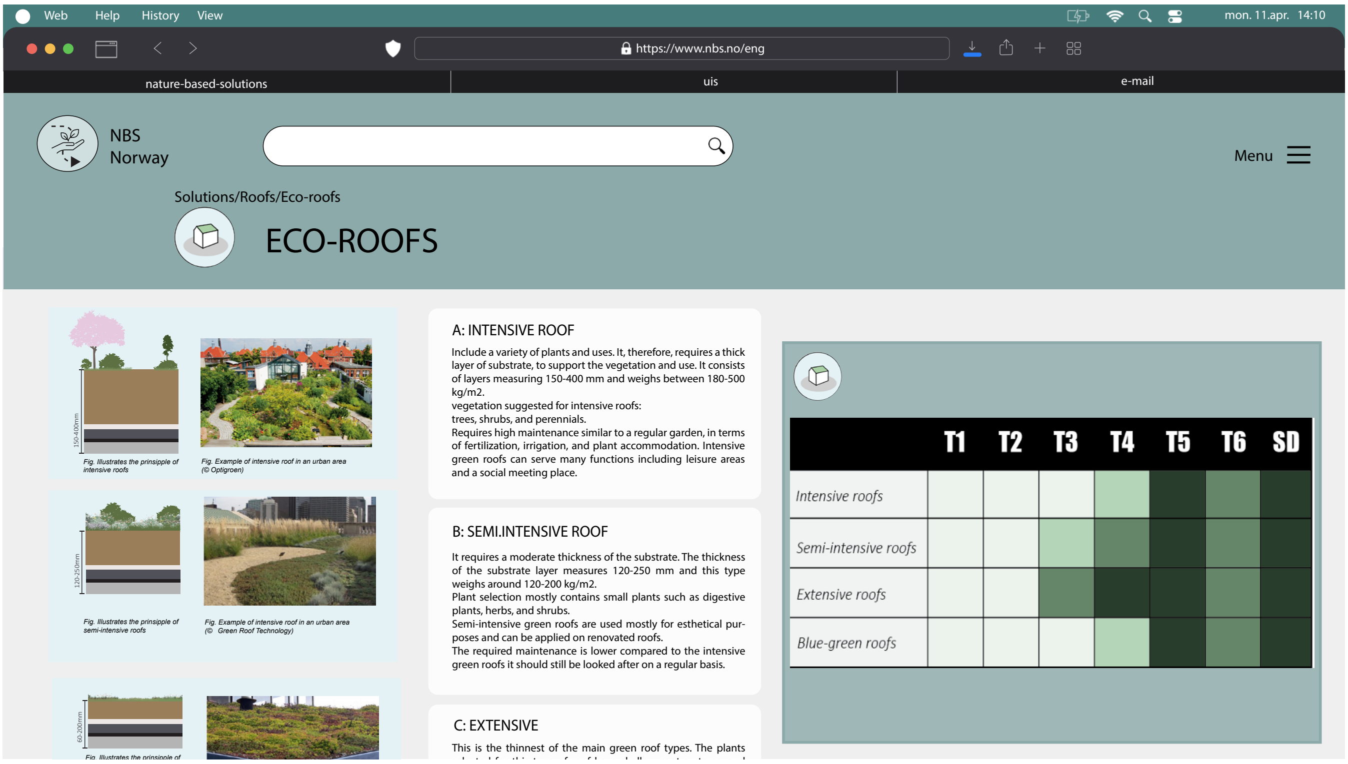


Fig 84. Suggested layout for intervention webpage that includes general information, illustrations and matrix of suitability. By using a web-application it is possible to collect all relevant information according to the thematic.

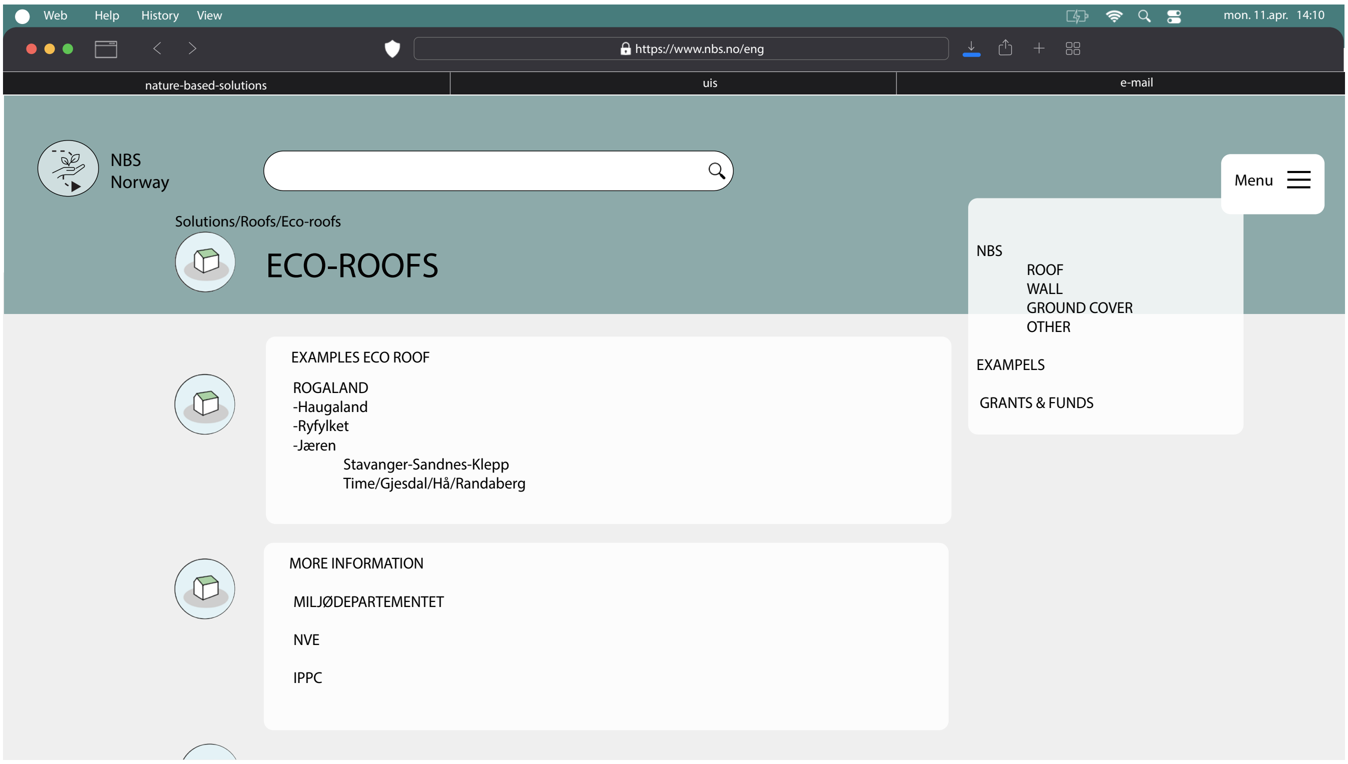


Fig 85. In the intervention there can be included links to resources such as funding, examples and further information regard-ing the interventions.

8

CONCLUSION

CHAPTER EIGHT

CONCLUSION

To create climate-resilient cities, selecting appropriate and effective solutions is crucial. Using interventions based on nature's own solutions makes it possible to create natural and urban environments that are more adaptable to the climatic changes ahead and decelerate the negative development. However, it became evident that not all available technologies and solutions are as propitious. Another barrier identified through interviews conducted with people working in the field, was that municipalities lack the resources to keep up with the frequently updated technology and communicate this both internally within the organisation and externally.

The intention of this thesis was to create urban design guidelines with NBS to facilitate flood mitigation in a Norwegian context. Throughout this thesis, various NBS and cases with NBS have been presented and to which type of environment they give the optimal effect, without significant compromises to the existing identity and use, in tackling the challenge of pluvial flooding. The findings were shown using urban design guidelines, where the specific NBS were systemised based on which transect zone they are considered to give the most successful results.

The proposed urban design guidelines are intended to be user-friendly for people working with urban planning and collaborative stakeholders to make communication and information sharing efficient. Therefore, the format was intentionally based on a visual representation and illustrations, allowing the message to be communicated clearly. We believe the design guidelines could increase the pace of climate-adaptive NBS implementation by simply highlighting the possibilities and placing the interventions within the context of urban- and landscape patterns.

GLOSSARY OF TERMS

English	Norwegian	Abbreviation	Definition	Reference
Biodiversity	Biologisk mangfold		*Plants and animals and their habitat, the living nature around us.*	Stortinget, 2021
Blue-green factor	Blå-grønn faktor	BGF	*Tool used to ensure the water manag-ement, vegetation, and biodiversity in development projects*	NS 3845, 2020
Blue-green infrastructure	Blå-grønn infrastruktur	BGI	*Follows the benefits created by nature. is based on innovative solutions created with engineering structures*	Pochodyla et al., 2021
Climate adaptation	Klima adaptasjon		*The process of adjustment to actual or expected climate and its effects.*	IPCC, 2014
Design Guidelines	Retningslinjer for utforming		*Urban design guidelines are a series of design statements and images that explain the desired design elements and qualities that shape development.*	Ødegaard, 2012
Diversion Pond	Fordrøyningsdam, rensedam		*A permanent water surface. Purifies water*	Pochodyla et al., 2021
Drainage basin, catchment	Nedbørsfelt		*An area that has a common outlet point for its drainage. The outlet point is naturally drained e.g. at the outlet of a fjord, lake or where two rivers meet.*	NVE, 2022
Ecosystem-based adaptation	Økosystem system basert tilpasning		*EbA focuses on protecting, restoring, and sustainably managing ecosystems to help humanity adapt to climate change. Ecological engineering is another term relating to technologies developed to solve urban challenges based on natural.*	Magnussen et al., 2017
Floodway/ Flood path	Flomvei		*A route that divers surface water to a recipient, can be a natural or planned path.*	NOU 2015:16 , 2015, s.7
Infiltration	Infiltrasjon		*Penetration of water into loose materials or cracket rock.*	NOU 2015:16 , 2015, s.7
Local runoff distribution	Lokal-Overvanns-Disponering	LOD	*Measures that infiltrate and/or dissipate surface water.*	NOU 2015:16 , 2015, s.7
Marshlands, peatlands, boglands	Myrlandskap		*Area with peat and high groundwater level with low water flow and hydrophilic vegetation that can make peat itself.*	Universitetet i Oslo, 2011
Moorland, heather hey	Kystlynghei		*Open hei character habitat type, it is developed through traditional management with swaying and grazing.*	Artsdatabanken, 2014

English	Norwegian	Abbreviation	Definition	Reference
Nature-based solutions	Natur baserte løsninger	NBS	*Solutions that use or restore exciting nature types or ecosystems Answers that are based on nature (including semi-natural solutions) Solutions often characterised as blue-green infrastructure involve "nature mimicking" to some degree. E.g., construction of runoff dams and bioswales or ditches.*	Magnussen et al., 2017)
Permable pavement	Permable dekker		*Permeable pavement is a porous urban surface composed of open-pore paves, concrete, or asphalt with an underlying stone reservoir. It catches surface runoff and stores it in a pool, then slowly allows it to infiltrate into the soil below or discharge via a drain*	Ødegaard, 2014,
Recipient	Resipient		*A common term for stream, river, lake, sea, bog or other water sources.*	Miljødirektoratet, 2021
Resilience	Motstandsdyktig		*Not only the ability to maintain essent-ial function, identity and structure, but also the capacity for transformation.*	IPPC, 2022
Retention	Fordrøying		*Measures that delay run-off through collection.*	NOU 2015:16 , 2015
River and stream Re-opening	Bekkeåpning		*Restoring and opening up rivers that have been placed in pipes can provide a better ecological condition and often leads to greater hydrological capacity.*	Miljødirektoratet, 2018
Runoff/ Surface water	Overvann		*Surface runoff due to precipitation or meltwater.*	NOU 2015:16 , 2015
Sustainability	Bærekraft		*A development that meets todays needs without destroying the opportunities for future generation to have their needs meet.*	FN-Sambandet, 2021
Three-step strategy	Tre-ledd strategi		*Combination of measures that infiltrate, delay and divert surface water to the recipient in a safe way.*	Miljødirektoratet, 2021
Urbanization	Urbanisering		*Population shift from rural to urban areas, the process through which cities grow.*	National Geographich, 2022
Vegetated greening systems	Plantebasert system	VGS	*living vertical gardens that are self-sufficient.*	Perez et al., 2019

English	Norwegian	Abbreviation	Definition	Reference
Water course	Vassdrag		*All stagnant or running surface water with year-round water flow, associated bottom and withs up to the highest normal flood water level, is considered a watercourse.*	NVE, 2022 VRL § 2, 1. ledd
Water manage-ment (flood-, surface water-, runoff management)	Overvannshåndtering		*Measures to utilize surface water as a resource, and to prevent damage and inconvenience as a result of surface water.*	Ødegaard, 2012
Wetland	Våtmark		*Land with groundwater table sufficie-ntly close to the ground surface, or with such an abundant supply of surface water that organisms which are adapted to live under water saturated conditions occurs.*	Lyngstad, A., Brandrud, T. E., Moen, A. og Øien, D. I. (2018). V åtmark. Norsk rødliste for naturtyper 2018. Artsdatabanken. Collected (06.06. 2022)

FIGURE LIST

Figures not included in figure list have been produced entirely by the authors.

Fig. 6. Zevenbergen, C., Cashman, A., Evelpidou, N., Pasche, E., Garvin, S., Ashley, R. 2011. *Urban flood management.* CRC Press, London. https://www.researchgate.net/profile/Chris-Zevenbergen-2/publication/279418972_Challenges_in_Urban_Flood_Management/links/5e4b052792851c7f7f43ccf2/Challenges-in-Urban-Flood-Management.pdf

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Fig. 9. Modified by the authors with information collected from the following sources:

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Fig. 19. Modified by the authors with information collected from the following sources: Ødegaard, Norheim, B., & Norsk Vann BA. (2014). *Vann- og avløpsteknikk* (2. utg., p. 664). Norsk Vann.

Fig. 20. Modified by the authors with information collected from the following sources: Pochodyła, E., Glinska-Lewczuk, K. & Jaszczak, A. (2021). *Blue-green infrastruc ture is a new trend and an effective tool for water management in urban ar eas.* Landscape Online 92, 1-20 https:// doi.org/10.3097/LO.202192

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Fig. 41. By the news room (2021) *Economic bene fit of peatland restoration revealed*. Re trieved from Economic benefit of peatland restoration revealed | Farming Life

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Fig. 44. Living Architecture Monitor (2022) *The Inside Details on The Award-Winning IGA Organic Rooftop Farm* https://livingarchitecturemonitor.com/articles/award-winning-iga-organic-rooftop-farm-sp22

Fig. 45. La linge verte. (2022) Collected 06.06.2022 La ligne verte- Pour verdir toute surface

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APPENDIX

Intervju guide

Takk for at dere har mulighet til å stille til intervju.

Formålet med intervjuet er å forstå hvordan ulike kommuner håndterer klimatilpasning, og få et innblikk i hva dere opplever som utfordringer og barrierer i arbeidet.

Anonymitet – Vi ønsker å ta opp intervjuet til bruk i etterarbeidet, opptaket vil bli slettet når arbeidet er ferdig, og vil bare være tilgjengelig og i bruk av undertegnete. Alle svar vil bli anonymisert og arbeidet vil bli delt i vår masteroppgave, den leveres inn 15.juni.

Innhold – Intervjuet har til hensikt å få en oversikt over hvordan kommunene på Jæren arbeider med klimatilpasning på lokalt nivå. Intervjuspørsmålene er ment som veiledende, og et utgangspunkt for samtalen.

Tid – Intervjuet er forventet å ta ca. 30 min.

Intervjuspørsmål

1. Hva opplever dere som hovedutfordringer knyttet til endring i klima?
2. Hva er utfordringene knyttet til planarbeidet i forhold til klima og klimatilpasning?
   2.1. Hvordan arbeider dere med klimatilpasning?
   2.2. Hva legger dere i begrepet klimatilpasning?

3. Hvordan tilegner og bruker kommunen ny kunnskap knyttet til temaet i planarbeidet?
4. Samarbeider kommunen deres med andre aktører? I så fall, på hvilket nivå og hvordan?
5. Har dere igangsatt tiltak I forhold til klimatilpasning?
   5.1. Hvilken type? Hvordan fungerer de?

6. Blir naturbaserte løsninger (NBL) brukt og fremmet i kommunens planarbeid? I så fall, hvordan blir disse løsningene integrert?
   6.1. Har dere noen konkrete prosjekt med fokus på NBL? I så fall, fungerer de som tiltenkt?
   6.2. Kjenner dere til noen NBL case-studier som er relevant for Sør-Rogaland?

7. Opplever dere at det er et behov for et planverktøy for å bedre arbeidet med klimatilpasning?
   7.1. Hva burde et slikt verktøy inneholde? Format?
   7.2. I hvilket steg I planprosessen ville et slikt verktøy være nyttig?

Har dere spørsmål er det bare å ta kontakt!