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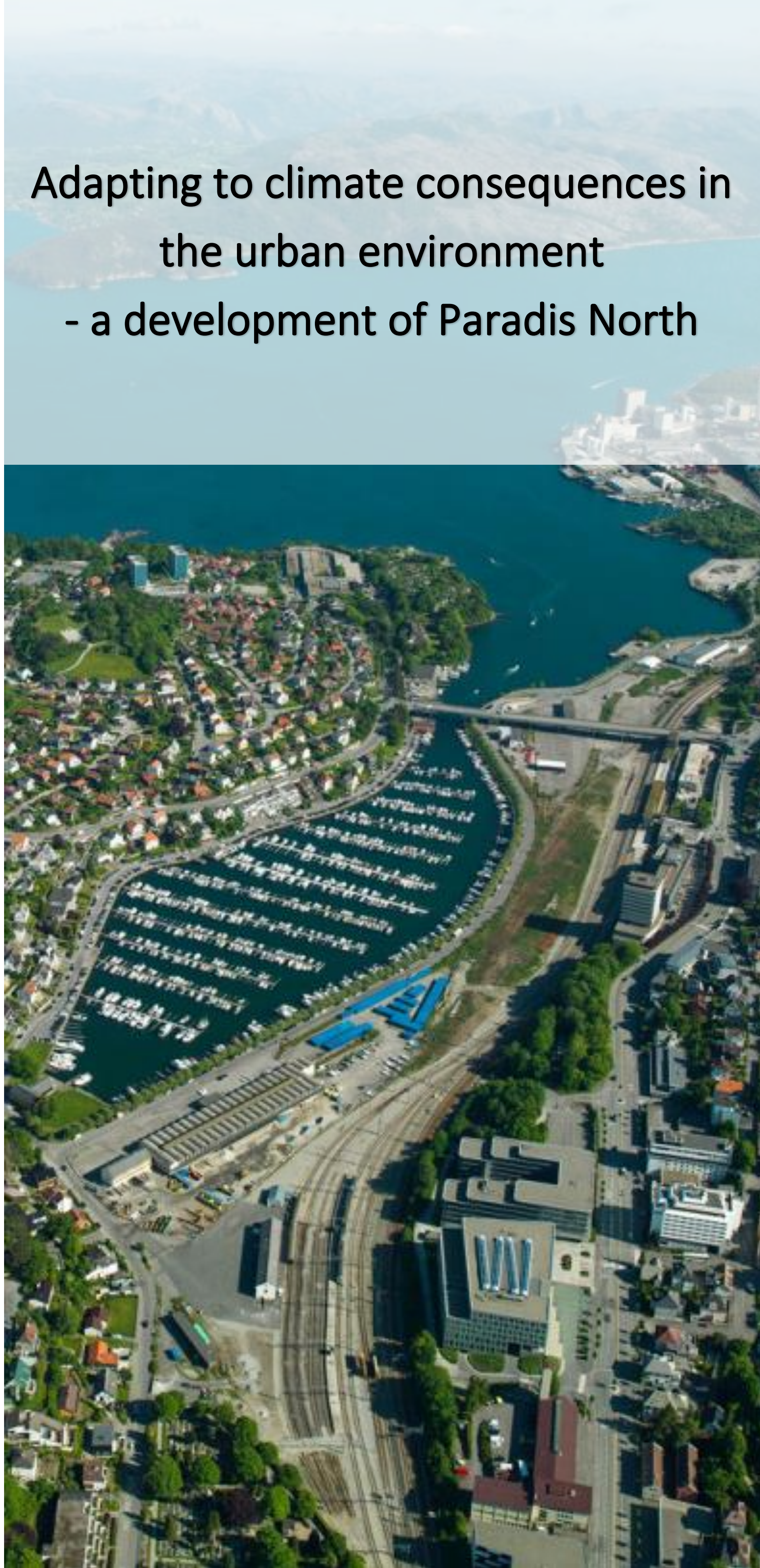
Adapting to climate consequences in the urban environment - a development of Paradis North



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Abstract

The impacts of climate change are now increasingly relevant in everyday life as projections assert that many of the future climate consequences are now no longer possible to avert. This has created a recent realization of the need to adapt to future climate changes as opposed to avoiding their pathway. As urban projects take several years to develop and are supposed to last decades, urban planners will need to proactively adapt their projects to climate consequences far into the future. Furthermore, urban areas are often vulnerable to climatic impacts as a result of their prevalent expanse of impervious surfaces and increased density of people. It is therefore imperative to integrate climate adaptation into urban development in an effective, cohesive and attractive manner so that intolerable risks are mitigated and liveability is increased.

This thesis will therefore explore how an urban area can be developed with an increased focus on building climate resilience. A masterplan with design principles and guidelines specifically suited to climate adaptation has been constructed for the undeveloped urban area of Paradis North, Stavanger in Norway.

Projections of climate consequences in the RCP8.5 scenario have been used as the baseline for adaptation measures, whereas strategies and methods of urban climate adaptation have been acquired through relevant literature. The development area's exposure to climate impacts has been studied through a spatial analysis to create an understanding of the required climate adaptations.

Consequences related to rising sea levels, increasing temperatures, and stormwater flooding have been addressed primarily through low-impact development and nature-based solutions. Factors relating to wind- and sun conditions have also been addressed. Nature-based solutions proved an invaluable asset in the development of the masterplan due to their versatility. Several adaptations, such as urban wetlands, parks, or trees, were applicable in distinct ways as adaptation measures to a multitude of climate consequences while also integrating attractiveness and liveability in the urban setting.

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List of abbreviations

AMSL	Above Mean Sea Level
FSI	Floor Space Index
GHG	Greenhouse Gases
GI	Green infrastructure
NBS	Nature-Based Solutions
UHI	Urban Heat Island
RCP	Representative Concentration Pathway
SUDS	Sustainable Urban Drainage Systems
TCR	Tree Cover Ratio

1. Introduction

By 2021, the global average temperature has already increased by 1,11°C since the pre-industrial period (WMO, 2022) and projections assert that it will continue to rise to approximately 2,4°C by 2100 (Climate Action Tracker, 2021) and reach the 1,5°C target by 2040 even in the most optimistic scenarios (IPCC, 2021a). Other studies suggest an even higher projected increase in global temperature of 3,2°C (World Economic Forum, 2019, p. 56). Unfortunately, a 2°C increase in the average global temperature is considered the threshold for when climate change impacts will become dangerous (NASA, 2020; IPCC, 2021a).

As there is essentially no doubt that the abrupt changes observed in the climate are of anthropogenic origin, the actions of the current generations will shape the future climate conditions. Government policies and human involvement will greatly impact the severity of climate change and society is at large responsible for the impacts derived from it. Regrettably, most countries are currently considered to be highly insufficient in sustainable and environmentally friendly practices, and the global climate is steadily moving towards the tipping point of which the climate impacts will be of great concern (NASA, 2020; IPCC, 2021a).

Many of the impacts are now no longer possible to avert, as even if global net negative emissions were to be achieved immediately, the lingering effect of previously released emissions would continue to contribute to climate change. While the average global emission-induced temperature would be gradually reversed with large net negative emissions, it would take several hundred to thousands of years before the effects of climate change like sea-level rise would follow (IPCC, 2021b). Consequently, it will be necessary to proactively adapt to changes in the climate regardless of how well emissions are reduced, now it is just a matter of how extreme these impacts will be.

Cities are at the forefront of this change – they are predominantly responsible for its main driving force (GHG emission) while also bearing the brunt of its consequences as more and more people are expected to live in them (C40 Cities, 2020). Floods caused by extreme weather, storm surges magnified by the rising sea levels, and heatwaves exacerbated by global warming are among the more likely and crucial climate consequences in cities (Frank, et al., 2019b; NASA, 2022). These risks are greatly increased by the prevalent expanse of hard, imperviable surfaces like concrete and asphalt replacing vegetation and other natural areas (C40 Cities, 2020). This way of urban development needs to be addressed through climate adaptation.

Historically, climate mitigation measures have received more attention than adaptation measures (Füssel, 2007). But, with the recent realization that many of the emission targets are out of reach, there is an increasingly recognized need for a proactive adaptation pathway to these changes (Meyer, Gebhardt, & Alves, 2015). Cities, and by extension urban planners, will need to both mitigate further damage to the environment and adapt to the already coming impacts. This can be accomplished by urban design that accommodates, resists, or avoids climatic impacts through adaptation measures that reduce climate vulnerability and build resilience. In tandem with building urban climate resilience, it is important that liveability and attractiveness in the urban setting are not ignored, but rather integrated into its features.

1.1. Project description and research question

To understand how urban planning can adapt to climate impacts, an undeveloped urban area relatively exposed to climate impacts will be analysed and developed with a focus around climate resilience. For this purpose, Paradis North, Stavanger has been selected, where a masterplan with guidelines and principles for climate adaptation will be constructed. As the concepts of urban attractiveness and liveability are indivisible to urban development, they will be included in the thesis as a secondary focus.

This thesis is described as a project regarding the development and implementation of an urban area focused on climate change. The primary objective of the thesis is the reduction of climatic risks in the development area of Paradis North, whereas the secondary objective of the thesis will be to incorporate liveability and urban attractiveness. This leads to the following research question:

''How can the urban development project of Paradis North, Stavanger adapt to current and future climate impacts in an effective, cohesive, and attractive manner?''

4 sub-questions are formulated to better answer the research question:

- What is climate adaptation, resilience, vulnerability, and risk?
- What are the current and expected challenges for urban areas related to the climate?
- What are the strategies for dealing with said challenges?
- How can attractiveness and liveability be incorporated into a climate adaptation project?

While economics is an important aspect of urban development, it will not be a focus of the thesis. Climate adaptation strategies deemed more cost-effective will still be prioritized, but the underlying economic aspects will not be considered as this will increase the scope of the thesis significantly.

1.2. Choosing the case area

As climate adaptation is the main focus of the master thesis, urban areas close to the sea were prioritized due to their relevance to ocean-related impacts. Coastal areas are generally more exposed to the effects of the current climate and climate change, largely because of storm surges, rising sea levels, and increased wind and precipitation. Currently, coastal floods are the costliest and most disruptive natural hazard worldwide (Kousky, Fleming, & Berger, 2021, p. 2). Coastal areas are also objectively more relevant as they are the world's most densely populated and economically active (Toimil, et al., 2020). The food, ecological, and transport benefits that coastal areas offer have set a precedence for populations to naturally migrate to and create cities near the shore. Roughly 10% of the world's population live in coastal areas less than 10m above sea level, and most of the big cities worldwide are considered vulnerable to sea-level rise. This trend of population growth in coastal cities is only expected to accelerate, making coastal cities an extremely relevant subject for climate adaptation (UN Atlas of the Oceans, 2016; the Ocean Conference, 2017).

Norway covers a wide variety of climate zones, with a marine climate in the west, warmer temperatures in the east, and arctic climates in the north. As such, the optimal strategy for climate adaptation will therefore differ depending on the local climate. As the main effects of climate change relevant to city planning are largely divided between sea-level rise, stormwater flooding, and increasing temperatures, an undeveloped urban area especially exposed to these impacts were chosen.

Mainly due to its favourable topography, most of Norway is relatively at low risk of widespread impact from sea level rise (dsb, 2017). Yet, several important areas are exposed to adversities from ocean-related flooding events as all the main cities are located close to the shore. The chosen starting point for a case area was Stavanger, where the thesis is written. Being close to the case area facilitates visits and grants 'in situ' experience frequently, which is a valuable asset to any project. Stavanger is also particularly exposed and sensitive to changes from rising sea levels due to having many low-lying, flat areas bordering the sea (NCCS, 2021; COWI, 2017).

Areas with already existing buildings that are not planned for redevelopment were not applicable as the case area. Since climate adaptation with regards to sea levels and storm surges is largely relevant, areas close to the shoreline were naturally prioritized. Case areas in Stavanger that were considered included Lervig Brygge, Paradis, Vågen, Mariero, and Bekhuskaien (see Figure 1.2). Ultimately, Paradis, more specifically Paradis North, were chosen as the area. Many of the other areas may prove more challenging in terms of intensity of storm surges, wind, and flooding, but choosing the area based on which one has the most extreme climate conditions were not the main focus of this thesis. Paradis North was chosen as the case area due to its unique topography, attractive location, and potential for interesting development while still being a relevant candidate for climate adaptation.

Figure 1.2. Overview of potential case areas

Figure 1.1. Paradis, Stavanger

2. Method

2.1. Literature review

To build the foundational knowledge required for answering the research question, a literature study was performed. Theoretical knowledge has been gathered and utilized to find the appropriate technologies, methods, and strategies necessary to create the proposal. The most important aspect of the literature review was to highlight the relevant climate impacts and their respective climate adaptation strategies for the selected case area.

To create a scientifically accurate and objective basis for the thesis, peer-revied literature and other documents from credible publishers have been gathered from the search engines Google Scholar, ScienceDirect, Scopus, and Oria. Here, relevant search strings like ''urban climate adaptation'', ''stormwater management'', and ''climate change urban areas'' have been used. Official documents from municipalities and governments were gathered for certain parts. Both national and international sources were used to create a broader spectrum of understanding, but information more applicable to the local realm was highly prioritized.

As the two subjects of urban planning and climate impacts are particularly broad, only the most relevant aspect of each subject has been included in the thesis. While this is necessary to maintain a realistic scope, many useful topics could therefore not be included due to the restrictions of the thesis.

2.2. Reference projects

Previous cases of climate adaptation projects were shortly studied to gain a better understanding of how such developments are executed. Their strategies and implementations were used as a basis for inspiration when building the proposal for this thesis.

2.3. Spatial analysis

A site analysis of Paradis was carried out to achieve a firm understanding of the spatial aspects of the area. The analysis was specifically aimed at involving climatic impacts such as flood risk or sun conditions as this is invaluable information when creating the climate adaptation strategies in the proposal. The most important aspect of the site analysis was to highlight specific areas concerning their strength and weakness to relevant climate impacts. This was done by gathering data from official documents as well as maps from the websites Kommunekart, Kartverket, and Temakart-Rogaland for information about the climate impacts, zoning plans and regulations. The drawing program Krita was used to edit the maps.

Stavanger municipality and Ghilardi + Hellsten Arkitekter (the architects responsible for the development of Paradis South) were also personally contacted by email regarding specific maps, the railroad development, and a digital model of Paradis South.

A 3D model of the area and its immediate surroundings was constructed to analyse sun conditions, gain visual insight helpful for developing the proposal, and used to create a visualization of the proposal. This model was constructed in the program Blender using SOSI-files gathered from the university and a DWG file of Paradis South provided by Ghilardi + Hellsten Arkitekter.

2.4. Proposal

After gathering sufficient data from the literature review, site analysis, case studies, and inspirational sources, the information was used to create a proposal for the development of Paradis North focused on climate adaptation. The principles and guidelines for the proposal were established prior to creating the masterplan. The master plan was first created in AutoCAD for more accurate measurements and was later transported into Blender to create a 3D-model of the proposal. Krita, a digital drawing program, were used to create the final touches of the masterplan as well as several of the illustrations.

Part 1: Theory

Defining adaptation, resilience vulnerability, and risk

Establishing relevant climate adaptations

Presenting relevant adaptations strategies

Researching reference projects

3. Adaptation, resilience, vulnerability, and risk

To create a better understanding of how climate adaptation can be applied in an urban environment, an extensive understanding of these four terms is essential. The concepts of *adaptation, resilience, vulnerability* and *risk* are at the core of anything related to surviving and thriving in a changing environment. The terms are interrelated, and to fully understand one, a firm grasp of the rest is needed.

3.1. Adaptation and adaptive capacity

Adaptation is a term used in many distinct fields and its definition will differ depending on the context. The word derives from the Latin word *adaptare,* which translates to ''to fit'' (Roeckelein, 2006, p. 8) and while there is no one clear definition of adaptation, it can generally be defined as:

''A process, action, or outcome in a system to better cope with, manage or adjust to a changing condition like stress, risk, or opportunity.'' (Smit & Wandel, 2006)

Adaptation essentially refers to adjusting to better suit the surroundings, where the adjustment is made to thrive in a changing environment. The IPCC defines six different types of adaptation: proactive, spontaneous, planned, private, public, and reactive. As they are defined by the IPCC, they are generally defined with climate adaptations in mind but still work as more common terms. Not all the categories are relevant for this thesis, so only the distinction between proactive and reactive adaptation will be described.

Proactive and *reactive* adaptation refers to when the adaptation takes place concerning the relevant change. Proactive adaptation takes place before the change occurs, while reactive adaptation takes place during or after. To be proactive, one must be able to predict future outcomes sufficiently enough for the adaptation to be effective. As such, it is much harder to effectively implement proactive adaptations, but much more effective and cheaper if done correctly. On the other hand, reactive adaptation is based on learning from current conditions and adjusting accordingly. It is therefore simpler to perform, but significantly more damaging and expensive since the change must occur first before reactive adaptation can be performed. Of these two, proactive adaptation is by far the better alternative if implemented successfully, as damaging effects can be avoided or significantly reduced prior to occurring. (IPCC, 2001, p. 982)

The extent to which a system can adapt refers to the system's *adaptive capacity* and can be defined as the *ability of a system to adjust to changes, often measured in resources* (OECD & IEA, 2006). Systems with lower adaptive capacity are at higher risk of sustaining severe damage from impacts. Adaptations can ultimately be thought of as manifestations of the system's adaptive capacity, which is closely related to the concepts of vulnerability and resilience (Smit & Wandel, 2006).

3.1.1. Climate change adaptation

In likeness to the general term, there are several definitions of climate change adaptation, where most are variations of a common theme (Smit & Wandel, 2006). Climate change adaptation is about the ability to adjust in accordance with the current and future changes, both positive and negative, that derive from the climate. The IPCC defines adaptation as:

''Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.'' (IPCC, 2001, p. 982)

Note that the definition for climate change adaptation similar to the general term, except the adjustment is specified toward climate impacts. The basis of climate change adaptation (CCA6Steps) is presented as a 6-step iterative process:

Figure 3.1. The process of climate adaptation (Tung, et al., 2019)

The first step, identifying problems and objectives, refers to data collection, analysis, and identification of key issues and objectives. This stage lays the foundation for the next steps and is an essential prerequisite to identifying the needs and priorities for successful adaptation. Without a sufficient understanding of the current and expected conditions, the planning and implementation stages are likely to fail (Tung, et al., 2019).

The second and third step, assessing and analysing current and future risks, analyses and uses models and available data to evaluate the climate risks of historical, current, and potential future events, where the future risks can be assessed by comparing baseline and predicted scenarios. Given that these steps highlight an issue, climate adaptation options will be assessed in the fourth step. This step should be implemented concerning local conditions, potential risks, adaptive capacity, and vulnerability of the area. In the fifth step, planning and implementing the adaptation pathway, the selected adaptations are put in motion concerning costs and benefits, marking the stage where the adaptation is being realized. The final stage involves analysing the performance of the implemented strategies and constructing criticism based on how well they completed the objective and if need be, they are modified (Klein, et al., 2001; Tung, et al., 2019).

3.1.2. Urban climate change adaptation

Cities act as the first responder to climate change. They are key contributors to emission sources and contain populations vulnerable to the risks and impacts of the changing climate. As such, cities face an increasingly important requirement of adapting. There is a lot at stake when considering urban climate change adaptation, both in terms of economic value and human lives, where a lack of sufficient climate adaptation can lead to extremely costly mistakes involving floods, storms, and heatwaves. In Europe, most economic losses have been caused by storms and floods, whereas deaths were mainly caused by heatwaves (most of which were during the 2003 summer heatwave). The average number of such events has significantly risen over the last couple of decades, and are projected to increase even further in the future (EEA, 2008, pp. 170, 171).

Adaptive capacity relating to climate impacts within the urban environment refers to a city's ability to adapt. It is the technical and financial ability, as well as the willingness, skill, and knowledge of the city's key actors and stakeholders at a local, regional, and national level to change under the adverse effects derived from climate impacts (C40 Cities, 2018).

Urban planners will act as a crucial component for creating opportunities and innovation relating to local and global solutions to climate risks and impacts in cities. Long term consideration will be a fundamental and imperative quality for climate change adaptation in cities. As the life expectancy of buildings and infrastructure usually span several decades and as new projects often take years to complete, adaptation measures in cities must be able to account for changes far into the future. Proactive adaptation measures will therefore be the most effective way of dealing with climate change risks and impacts (NOU, 2010, p. 182; Frantzeskaki, et al., 2019).

A city's ability to adapt to climate impact is greatly influenced by the characteristics of its landscape. For instance, a city with a high percentage of hard surfaces like asphalt will be more exposed to heatwaves and flooding. Cities that are expanding and experiencing both economic and population growth are faced with the issue of prioritization between using land to continue growth or to utilize the land for adaptive capacity. Naturally, prioritizing economic growth over adaptive capacity is cause for a detrimental impact on the exposure to climate consequences. Shrinking cities are provided with different challenges. In terms of adaptation, the emergence of empty land provides opportunities for securing adaptive capacity, mainly through employing green infrastructure (Carter, 2018).

3.2. Resilience

Resilience is generally defined as *the amount of change a system can undergo without changing state* (IPCC, 2001, p. 993). Resilience is about the ability to withstand adversity, and to recover from it. This connects to adaptive capacity as highly adaptable systems can be defined as resilient. It is important to note that for something to be defined as resilient, it has to be defined as resilient *against something* that is perceived as a negative impact, meaning it is a relative term (C2ES, 2019).

The term resilience can refer to two different qualities in a system, namely, the ability to *withstand* or *recover*. While resilience is usually defined as a combination of both, the distinction is important to understand as some systems can employ one quality more than the other. A system's ability to recover refers to its ability to easily bounce back to its original state after experiencing adversities. The system's ability to withstand refers to proactively adapting to external adversities, where the severity of the impact is largely reduced by facing it head-on (OECD & IEA, 2006). Both qualities rely on the ability to adapt, but the ability to withstand refers to proactive adaptation, whereas the ability to recover refers to reactive adaptation

3.2.1. Urban climate resilience

The term *resilience* is an increasingly common word regarding climate change, which is largely because the detrimental effects on the global climate have already passed a point of no return (C2ES, 2019). By extension of the general term, climate resilience is about being resilient to climate impacts, both current and expected. The exact characteristic of climate resilience is dependent on location, as different areas experience different impacts from the climate. Climate resilience can be defined as:

''The ability to prepare for, recover from, and adapt to the effects of the climate.'' (OECD & IEA, 2006)

Tompkins, Boyd, & Day (2005) states that resilience in cities is largely reduced by conditions such as poverty, rapid population growth, urban migration, lack of education, underemployment, extremely uneven patterns of land ownership, and unsafe buildings and infrastructure. Wealth and social stability have proven to be especially effective for creating resilience in cities but are more complicated than simply throwing money at the problem (C2ES, 2019). Prioritizing current events and ignoring future predictions are also means of reducing resilience. In contrast, greater access to resources and wealth increases the ability to cope with adverse changes and recover, while a highly educated and civilized population increases the ability to predict and withstand future impacts (Tompkins, Boyd, & Day, 2005).

3.3. Vulnerability

Vulnerability describes the degree of the potential damage a system can experience or the potential threat to the system. It is also thought of as a susceptibility to harm. As with resilience, vulnerability is a relative term, meaning a system must be defined as vulnerable to something. According to the IPCC, vulnerability is defined as:

The degree to which a system is susceptible to, or unable to cope with, adverse effects and is related to its exposure, sensitivity, and adaptive capacity (IPCC, 2001).

The vulnerability of any system is reflective of its exposure and sensitivity to adverse impacts and the ability to adapt or recover from the effects of those conditions. The Centre for Climate and Energy Solutions define sensitivity and exposure:

(Sensitivity) The degree to which a system, population, or resource is or might be affected by hazards.

*(Exposure) T*he presence of people, assets, and ecosystems in places where they could be adversely affected by hazards.

Essentially, sensitivity refers to the degree of potential harm caused by an impact, whereas exposure refers to the position in which such impacts can occur. Adaptability also plays into this, as a system must be capable of changing to keep the same degree of sensitivity and/or exposure. Vulnerability can ultimately be thought of as the product of the three components, sensitivity, exposure, and adaptability, meaning the three factors can vary in intensity without necessarily affecting the overall value. Should the product of sensitivity and exposure be sufficiently high, or greater than adaptability, the system can be thought of as vulnerable (Smit & Wandel, 2006; C2ES, 2019).

3.3.1. Urban climate vulnerability

The term urban climate vulnerability refers to the exposure, sensitivity, and adaptability of a city relating to present and future impacts derived from the climate. The potential damage from floods, heatwaves, droughts, hurricanes etc. are all examples of how an urban area can be vulnerable to climate impacts. By incorporating adaptation measures such as dikes, green infrastructure, climate funds for victims etc., it is possible to reduce vulnerability and increase resilience as it will become easier to adapt, withstand, and recover (C40 Cities, 2018).

Urban climate vulnerability can be thought of as having two main areas of focus, namely physical and social vulnerability. Physical vulnerability in the urban setting refers to how infrastructure such as roads and buildings are susceptible to damage from the climate, usually in the form of impacts like storms, fires, heavy rain etc. Naturally, a physical vulnerability to urban climate impacts can be reduced by implementing physical adaptations. Storm barriers reduce vulnerability to storm surges and rising ocean levels, green infrastructure reduces vulnerability to flooding, brighter surfaces reduce vulnerability to heatwaves, and so on. Physical vulnerability can be quantified and mapped by estimating the degree of potential damage for an area (sensitivity), estimating the likelihood of impact in that area (exposure), and estimating the area's ability to recover from impacts (adaptability) (C40 Cities, 2018).

Social vulnerability refers to the susceptibility of communities and individuals to hazards from the climate, mainly in form of qualities like order, politics, relationships, and economic status. Social vulnerability can also be affected on a time dimension, as the vulnerability can depend on seasonality, age, and life situation. There is also a spatial dimension to social vulnerability, as people with the same traits often live in similar areas (Wisner & Uitto, 2008). For instance, a part of a city with a high percentage of elderly can be particularly vulnerable to heatwaves, or a poor part of a city can be especially vulnerable to storms, as the affected may be unable to afford repairs or new homes (C40 Cities, 2018).

3.4. Risk

When considering adaptation, building resilience, and reducing vulnerability in a system, understanding the relevant risks and their context is paramount. Planning for resilience and proactive adaptation only works effectively when the risks of the system are sufficiently understood by the end-users and actors capable of implementing adaptations. Even if forecasts are accurate, they will be in vain if the risk is not well understood (Kohno, et al., 2019; C2ES, 2019).

Figure 3.2. Definition of risk (C2ES, 2019)

The term risk stems from the Italian word *riscare*, which translates to navigate among dangerous rocks (Rausand, 2011). Simply put, risk can be thought of as potential danger, or the *chance* that adversity can happen in the future. It can be defined as the product of vulnerability and threat, as Figure 3.2 depicts. Threat is the adverse impact on the system and the chance of it happening (Nelson, Adger, & Brown, 2007). The UNDP (2004) defines risk as:

''The combination of an event, its likelihood, and its consequences.''

The response to each risk should vary depending on how tolerable it is. In general, there are three different categories of risk: acceptable, tolerable, and intolerable. Acceptable, or negligible risk is at the level of insignificant and likely to produce extremely disproportionate costs to further reduce. Risks at the tolerable level must be reduced if it is practical to do so and should only be managed if it does not incur grossly disproportionate costs. Tolerable risks should generally follow the rule 'reduce to as low as reasonably practicable. Intolerable risks define the risks that should be reduced regardless of costs. In cases where intolerable risks are present, and where it is impossible to reduce said risks to a tolerable level, the action causing it must cease (Gardiner, 2005).

Managing risks in urban planning mainly revolves around risk mitigation or risk acceptance and can be done by one, or a combination of both methods (C2ES, 2019). The overall way of reducing risk can be thought of as increasing the adaptive capacity, and/or reducing sensitivity and exposure.

Risk mitigation refers to methods attempting to avoid or significantly lower risk by focusing on proactively adapting and building resilience to either avoid or withstand significant damage from the threat. Risk mitigation can be done by either avoiding the risk by moving assets away, or by strengthening the assets so they can resist the impacts. Risk mitigation can therefore be divided into the two sub-categories *risk avoidance* and *risk resistance* (Kousky, Fleming, & Berger, 2021). Either method can be thought of as lowering vulnerability and increasing resilience.

Risk acceptance, put simply, refers to accepting the risk. This implies that the risk is acknowledged and understood but nothing is done to reduce or prevent it. Risk acceptance is usually applied when there is no cost-effective way of managing the risk, or when the risk is deemed tolerable (Gardiner, 2005).

3.4.1. Urban climate risk

There is a correlation between climate change and climate risks. As the climate continues to change, the risks of climate impacts increase, where major risks will emerge from the failure to adapt (C40 Cities, 2018). For coastal cities, flooding caused by rising sea levels, storm surges, and heavy precipitation, as well as heatwaves caused by the increasing temperatures effect are among the more concerning risks of climate change (IPCC, 2021b).

The term ‘risk’ is used often in relation to the climate (OECD & IEA, 2006). Climate-related risk refers to the chance of climatic occurrences like storms and heatwaves, and the potential damage they can cause to given systems like urban areas. It can be defined as *the probability of a climate hazard multiplied by a given system’s vulnerability* (UNDP, 2004), which of course is a close resemblance to the general term. Concerning the urban environment, climate risks can be specified towards the systems of lives, health, ecosystems, economic, social, and cultural assets, services, and infrastructures (C40 Cities, 2018)

The concepts of implementing adaptation, planning for resilience, reducing vulnerability, and mitigating climate risk essentially refer to the same action, but from different perspectives.

Adaptation is the action of adjusting to survive and thrive in a changing environment.

> **Climate change adaptation** is therefore the action of adjusting to be better suited to the changing climate.
>
> **Adaptive capacity** is the extent of which a system is capable adjustment.
>
> The action of elevating a structure is a strategy of proactively adapting to flood impacts.

Resilience describes how well a system can withstand adverse impacts without sustaining permanent damage. It can be described as the either the ability to withstand, or to recover. Resilience is often the result of a successful adaptation measure.

> **Climate resilience** describes how well suited and prepared a system (like a city) is to climatic impacts.
>
> A well isolated house can be considered resilient towards cold temperatures.

Vulnerability describes the degree to which a system is susceptible to, or unable to recover from adverse impacts. It is the result of sensitivity, exposure, and adaptive capacity.

> **Climate vulnerability** describes how poorly suited and prepared a system (like a city) is to climatic impacts.
>
> Unless prepared, low-lying urban areas are often vulnerable to storm surges.

Risk is described as the combination of an event, its likelihood, and its consequences.

> **Climate risk** refers to the probability of a climate hazard multiplied by a given system's vulnerability to that hazard.

Exposure refers to a position where a potential hazard is likely to occur.

4. Climate consequences

To be able to adapt, the relevant risks, hazards, and consequences must first be identified. This chapter will describe the relevant climate impacts for Paradis and their projected impacts in 2100 where RCP8.5 will be used as the given climate scenario.

4.1. Identifying relevant climate impacts

The relevant climate impacts in this thesis can be categorized into two distinct groups: safety and comfort. Climate impacts relevant to safety involve intolerable risks for urban structures and populations whereas climate impacts relevant to comfort refer to effects on the perceived attractiveness of the urban area and the well-being of its residents.

The main challenges derived from climate change impacts experienced by cities globally are sea-level rise, coastal erosion and storm surges, urban flooding, increased drought leading to water scarcity, and heatwaves (Frank, et al., 2019b). For coastal cities in the northern hemisphere like Stavanger, flooding from weather and storm surges are the greatest points of concern, whereas droughts are likely to increase during summers (NCCS, 2021). High temperatures and heatwaves are usually not mentioned as crucial climate impacts in most documents but will be included in this thesis as it will focus on a higher emission scenario. Air quality will also be included as a climate-related impact deriving from the warming temperatures.

Regarding comfort, attractiveness, and liveability in urban areas, relevant climate impacts mainly include optimal sun, wind- and temperature conditions.

RCP stands for 'Representative Concentration Pathway' and is a description of possible future climate scenarios with relation to how emissions are curbed. Different RCP scenarios are depicted with increasing order relative to the amount of emission released in the future and are often categorized as RCP2.6 (low emission scenario), RCP4.5, RCP6.0, and RCP8.5 (high emission scenario) (National Geographic, 2021; IPCC, 2021a).

For urban planning, it is recommended to assume RCP8.5 as the given scenario even though it is considered highly unlikely. This is to maximize climate resilience and account for any uncertainties regarding climate change (dsb, 2017).

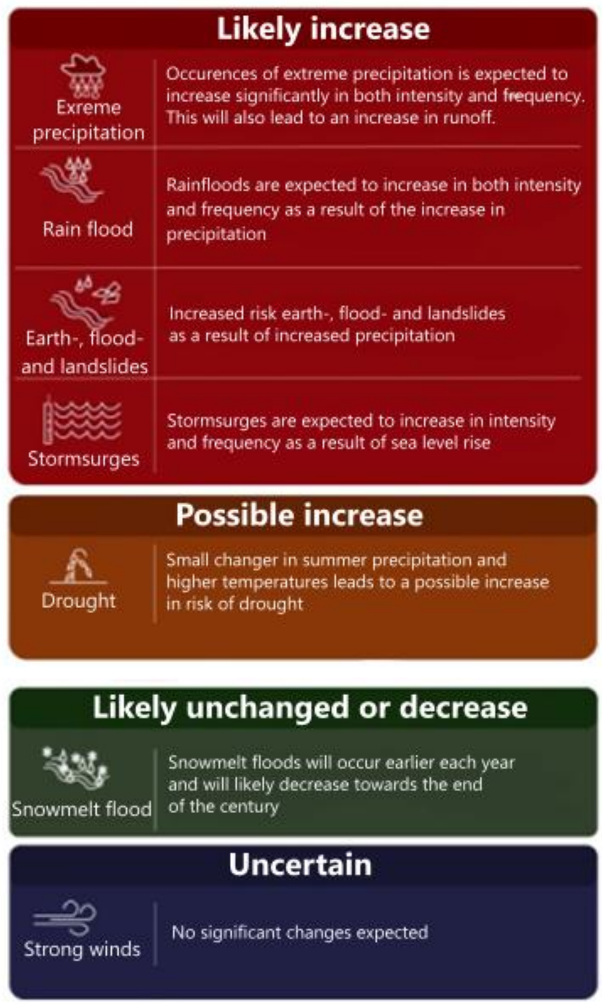


Figure 4.1. Relevant expected climate impacts in Rogaland by the end of the century (NCCS, 2021)

4.2. Expected climate changes by 2100

4.2.1. Rising sea levels and storm surges

As a result of the increase in the global temperature, the sea level rises through thermal expansion of the oceans and loss of ice in polar regions. According to the 2021 IPCC report, it is *virtually certain* that the average global sea level will rise continuously throughout the 21st century (IPCC, 2021a). However, the intensity of this increase is heavily reliant on which RCP scenario plays out. Figure 4.2 depicts the different increases in sea level rise with respect to which emission scenarios, ranging from about 0,2m AMSL in the low emission scenario to over 2m AMSL in the emission-intensive one.

While the sea level rise will not be distributed evenly across the globe due to Earth's uneven gravity field (NASA, 2020), sea level rises in Stavanger specifically is projected to rise significantly. One source from 2015 states that the sea level rise in the year 2100 under the high GHG emission scenario (RCP 8.5) is expected to rise by 50 cm with a likely range of 30 – 80 cm AMSL (Simpson, et al., 2015). Another more recent source states that the likely number for ocean level rise for Stavanger is 79cm AMSL (CICERO, 2019).

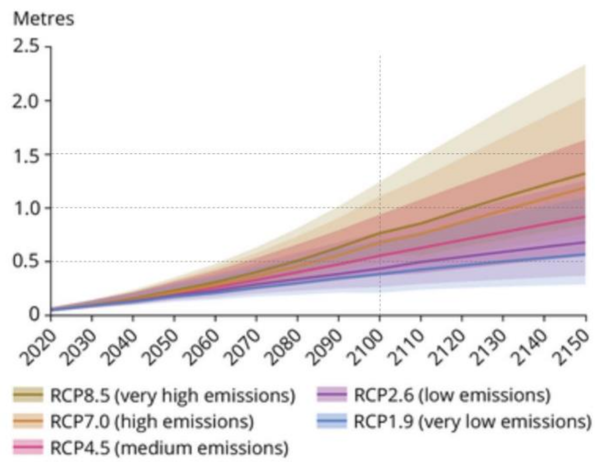


Figure 4.2. Expected sea level rise for each RCP scenario (EEA, 2021)

For coastal cities, storm surges pose as one of the major threats relating to climate change. A storm surge is a natural phenomenon resulting from strong winds pushing seawater towards land, causing the local sea level to rise abnormally higher than usual. Depending on the intensity of the storm surge, this local sea-level rise can be high enough for the seawater to reach parts of land much further in, often reaching buildings and important infrastructure in low-lying coastal areas. Storm surges are particularly devastating when combined with high tides, as the sea level is already above average. While strong winds are not expected to increase significantly in the future, the sea level increase derived from global warming will cause a much lower threshold for storm surges to occur, causing storm surges to increase in both frequency and intensity (dsb, 2017).

The intensity of storm surges is defined by how much they increase the standard local sea level and are categorized by their return period. The return period refers to the average amount of time it takes for a specific sea level to be exceeded at a particular location. Meaning the return period can vary depending on location. The return period of a storm surge is often categorized by three different levels: 20 years, 200 years, and 1000 years. This does however not mean that a 200-year storm surge will occur once every 200 years. It can instead be thought of as a 1/200 chance (or 0,5%) of occurring annually, regardless of the timing of the last occurrence (dsb, 2017). Figure 4.3 showcases these different categories and their potential impacts in Stavanger.

Flood Safety Category	Impact	Return Period (Annual probability)	Current increase over normal levels	With sea-level increase in 2100
1. Includes non-residential buildings, buildings with low societal importance such as storage facilities, garages, and boathouses.	Low	20 years (5%)	101 cm	171 cm
2. Includes most residential buildings. Economic damages may be high, but no impact on critical societal functions,	Moderate	200 years (0,5%)	115 cm	185 cm
3. Includes buildings that are vital for society, such as schools, hospitals, emergency services, etc.	High	1000 years (0,1%)	123 cm	193 cm

Figure 4.3 Safety categories for structures in exposed areas in Stavanger, based on RCP8.5 (dsb, 2016). Edited.

For Stavanger, the expected increase in average sea level of 79cm AMSL leads to a much lower threshold for storm surges to reach higher categories in the future. This means that a storm surge which currently occurs every 20 years on average may occur as much as several times per year by the end of the century, and 200-year storm surges by today's standard are likely to occur annually from 2070. Beyond 2080, 1000-year storm surges by today's standard are expected to occur annually (CICERO, 2019).

Storm surges in the future will also increase in intensity. A 200-year storm surge in 2100, meaning a storm surge with an annual chance of 0,5% of occurring in 2100, will reach a much higher level than a 200-year storm surge by today's standards. As seen in Figure 4.3, a storm surge with a 200-year return period is expected to increase the local sea level by as much as 185cm, based on the RCP8.5 scenario (dsb, 2016). 185cm is therefore the calculated *planned* level of ocean level increase that urban planners in Stavanger should adjust to when developing new urban areas next to shore (dsb, 2017).

4.2.2. Precipitation

Extreme precipitation is the main cause of flooding. Floods occur when the capacity of both natural (groundwater infiltration) and artificial (sewage, etc.) drainage systems have reached their full capacity, and an overflow of water will reach areas that are normally not submerged. This runoff often occurs during extreme or prolonged precipitation and carries a significant impact on the vulnerability to climate change. It is a potential hazard to many crucial aspects of the urban environment such as infrastructure, buildings, and livelihoods (NCCS, 2018). Figure 4.4 illustrates natural water cycle and the relationship between precipitation, runoff, and infiltration.

With the increasing intensity and frequency of extreme precipitation, the frequency of 200-year floods from precipitation in Rogaland as experienced today is expected to increase by approximately 20% (CICERO, 2019). As global warming will cause less snow and ice during winter, certain areas in Norway, mostly the Northern and eastern regions, are expected to experience less flooding in the future. This is because the high temperature causes less snowmelt build-up and higher evaporation losses, leading to less water runoff during shifts from cold to warmer temperatures. As such, rainfall-generated floods are expected to occur more often, whereas snowmelt-generated floods will likely be reduced (NCCS, 2017).

Stormwater runoff also carries pollution from roads and other impervious surfaces. It is important that this runoff does not reach bodies of water such as lakes, rivers, or oceans with ecosystems susceptible to contamination. Surface water transporting waste such as organics, nitrogen, phosphorus, and other contaminants can result in death of aquatic life, environmental hazards, and restrictions on recreational use (Saeed, et al., 2019). An important consideration is that the 'first flush' of rainfall, usually the first 5mm, carries the majority of pollution from stormwater runoff, making further rainfall following the first 5mm relatively cleaner. This is because the first part of a new rainfall will mobilise pollution deposited since the last rainfall occurrence (Russel, Pecorelli, & Glover, 2021). The expected increase in frequency of rainfall will therefore cause each rainfall to carry less pollution, as it will be spread out more evenly throughout each event.

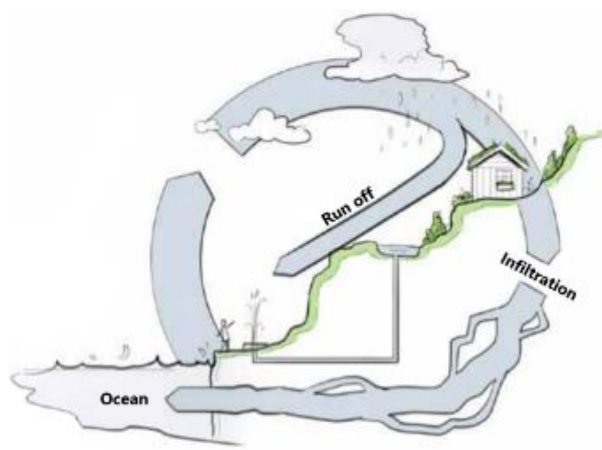


Figure 4.4. The natural water cycle (Stavanger Kommune, 2019 a)

The Norwegian climate is getting both warmer and wetter. The average annual precipitation in Norway has increased by approximately 18% since the period of 1971 to 2000 and is expected to increase even further by 2100. How much the average annual precipitation is going to increase relies on which RCP scenario will play out. The increase in precipitation under the RCP4.5 and RCP8.5 scenarios are projected as follows:

RCP4.5 leads to an increase between 3 to 14%, with 8% being most likely

RCP8.5 leads to an increase between 7 to 23%, with 18% being most likely

The increase is not expected to be distributed evenly over the whole country, as the western parts of Norway (including Stavanger) will see the largest changes. Figure 4.5 showcases the observed and expected precipitation under the two emission scenarios. In the figure, the y-axis showcases the deviation in precipitation compared to the reference period of 1971-2000 (NCCS, 2017).

As with the sea level rise, the increase in precipitation globally will also not occur evenly. For Stavanger, the annual average precipitation is expected to increase by 11%, with winters having the highest increase (18%) and summers expecting the lowest (5%). Furthermore, due to uncertainties, summers and autumns might experience drier weather. Percentage-wise, the increase in precipitation for Stavanger is likely to be somewhat lower than the national increase. This is because Stavanger is already rather wet compared to the rest of Norway, meaning that the relative increase won't be as high. Figure 4.7 shows the expected increase in precipitation in Rogaland (CICERO, 2019).

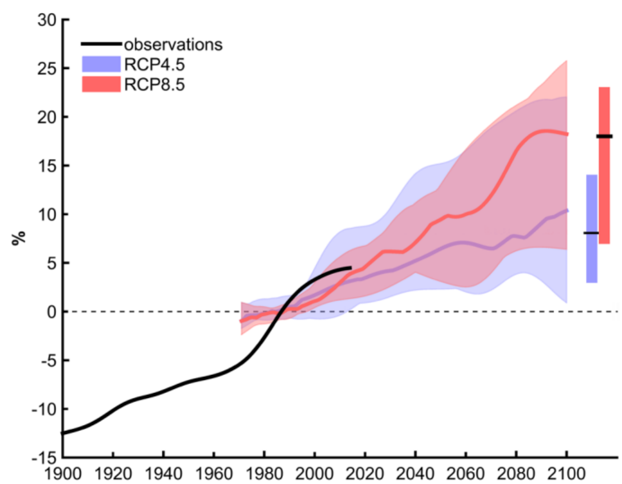


Figure 4.5. National increase in precipitation (NCCS, 2017)

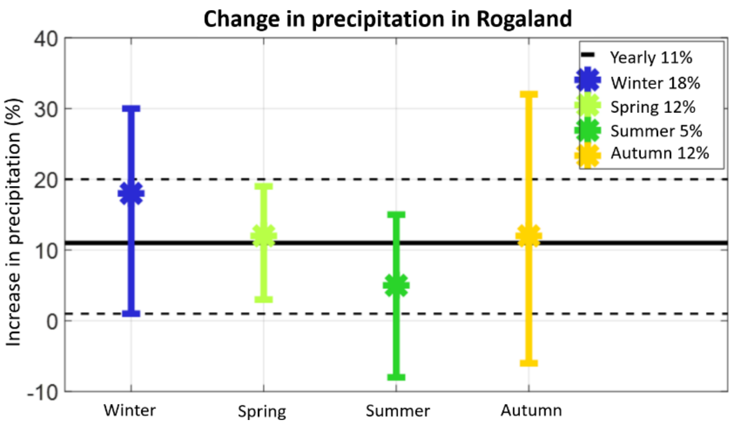


Figure 4.7. Projected increase in precipitation for each season between the periods of 1971-2000 and 2071-2100 for RCP8.5. The star marks the median, while the lower and upper limits are represented by the coloured lines. (CICERO, 2019)

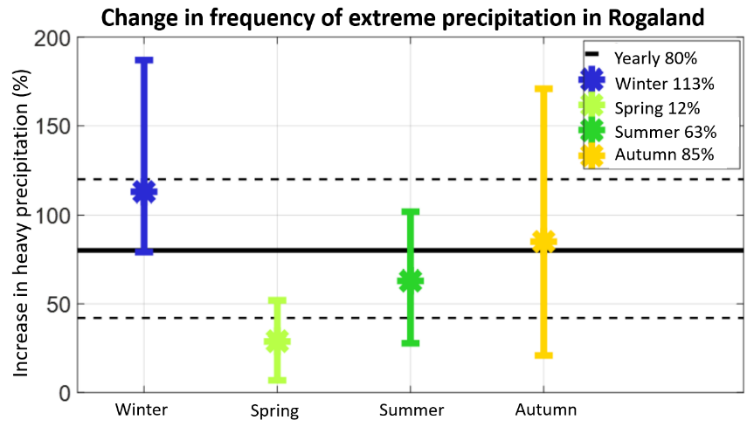


Figure 4.6. Change in frequency of extreme precipitation in Rogaland

While an overall increase in rain will lead to more rot and moisture damage in buildings and infrastructure, especially for wooden buildings, the more concerning effect of climate change is the high-intensity rainfall over shorter periods, defined as *extreme precipitation*, which is the main cause for flooding (CICERO, 2019). Days of extreme precipitation, defined as the 99,5th percentile for daily precipitation from 1971 to 2000, are projected to increase by 49% for the RCP4.5 scenario, and 89% for RCP8.5. The largest increase is expected for the winter period. It also cannot be ruled out that these days can more than double within the year 2100 (NCCS, 2017). For Stavanger, both intensity and frequency of extreme precipitation are projected to increase during all seasons. As Figure 4.6 shows, these occurrences are expected to increase by 80% on an annual average, with the winter season seeing the largest increase by far (113%). The intensity of heavy winter rainfall is also expected to increase by 17%, whereas the intensity of spring, summer, and autumn are projected to increase by 5, 13, and 15% respectively, resulting in an average of 15% increase (CICERO, 2019).

The expected increase in temperature along with the potential decrease in precipitation during summer seasons leads to a possible risk of drought during summers.

4.2.3. Rising temperatures and the urban heat island effect

The temperature rises derived from global warming will be distributed unevenly across the globe, with inland areas expecting the highest relative changes (NASA, 2022). For Norway, the average expected increase in temperature is between 4,5 and 5,5 °C for the higher emission scenarios (Røde Kors, 2019; NOU, 2018). Higher temperatures lead to elevated risks of heat-induced stroke, fatigue and cramps, increased emission of air pollutants and greenhouse gases, reduced water quality, detrimental effects on infrastructure, and increased energy consumption for cooling (Bhargava, Lakmini, & Bhargava, 2017)

For urban planning, it is not necessarily the average increase that requires the most attention, but the prolonged periods of extreme temperatures, also known as heatwaves. Heatwaves are simply defined as abnormally hot weather above historical averages for a specific area and usually last for two or more days (WHO, 2020). The intensity, duration, and frequency of heatwaves are expected to increase steadily throughout the world towards 2100, becoming an emerging risk for areas not normally exposed to them (IPCC, 2021b; Steffen, Hughes, & Perkins, 2014).

Figure 4.8 shows a simplified version of the NOAA heat risk index. This table shows the different ranges of increasing temperatures in relation to the effects they can cause on the body. The index is specified for shaded areas, if prolonged exposure to direct sunlight is involved, 9 °C is added to the existing temperature. Humidity also plays an important role in the effect as humidity regulates the evaporation from the body, where more humid conditions will lead to higher effective temperatures (effective temperature = mix of actual temperature and humidity). Due to climate change, humidity is also expected to increase throughout the 21st century (CICERO, 2019).

Temp (°C)	Classification	Effect on the body
27 - 28	Caution	Fatigue is possible with extended exposure and/or physical activity.
29 - 30	Extreme Caution	Heatstroke, heat cramps, or heat exhaustion possible with extended exposure and/or physical activity.
31 - 33	Danger	Heat cramps or heat exhaustion likely, and heat stroke possible with extended exposure and/or physical activity.
34 +	Extreme Danger	Heatstroke likely.

Figure 4.8. Heat index adopted from (NOAA, 2019). Specified to 80% humidity, which is the 1985-2015 average for Stavanger during the hottest months. A 1^{o}C rise in effective temperature is associated with a 2-3% increase in mortality rate (Marvuglia, Koppelaar, & Rugani, 2020)

For Rogaland specifically, the expected increase in average annual temperature is between 3,5 and 3,7°C (NCCS, 2021; CICERO, 2019). As Figure 4.9 shows, the temperature increase is somewhat even between the seasons, with summer having the largest uncertainty, ranging from an increase of 2,3 to 4,5°C (CICERO, 2019).

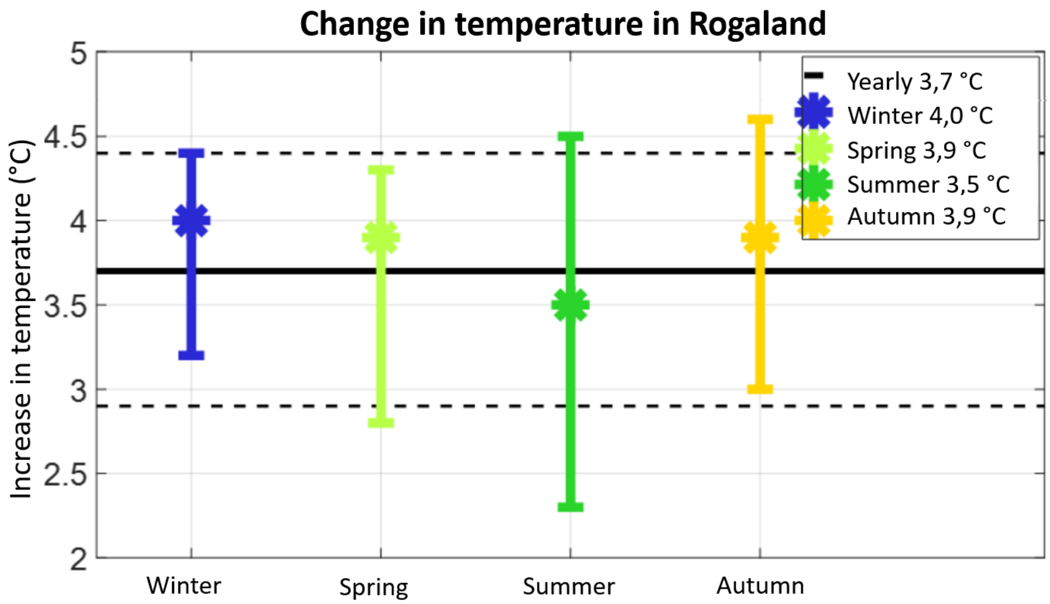


Figure 4.9. Temperature change in Rogaland for RCP8.5. Edited from (CICERO, 2019)

In the year 2021, the warmest temperature recorded in Stavanger was 27,5 ^{o}C (YR, 2022), which is already at the lower end of the heat risk index. With increasing temperatures derived from climate change, record temperatures like these are only expected to increase with time. Not only will temperatures above 27 ^{o}C occur more often, but higher records will emerge continuously. As the heat index states, temperatures above 27 ^{o}C (with 80% relative humidity) are when the temperature becomes concerning.

For RCP 4.5, the climate in Stavanger in 2100 can be compared to the current climate of Amsterdam. While for the more emission heavy scenario, RCP 8.5, the climate in Stavanger in 2100 can be compared to the current climate of Paris (Climate-Data.org, n.d.). Both cities faced enormous consequences during the 2003 heatwave in Europe, which killed close to 15.000 people in France and around 1500 in Amsterdam, an occurrence which can be seen as a warning related to heat risks from climate change (UNEP, 2004).

Figure 4.10. Stavanger, Amsterdam, and Paris (Google Maps, 2022)

The UHI effect, which is short for *urban heat island*, is a natural phenomenon causing heat accumulation in areas through urbanization and industrialization. The effect arises whenever large amounts of natural land are replaced with hard, dense, and heat absorbent surfaces like concrete and asphalt that are impermeable and dry by nature (EPA, 2021; Bhargava, Lakmini, & Bhargava, 2017). The urban heat island effect is characterized by the higher temperatures in urban environments compared to their local surroundings (see Figure 4.11), meaning it is a relative term and is caused by four main factors:

- A much greater prevalence of heat-absorbent surfaces like concrete and asphalt, which retain heat rather than reflect it.
- A reduction of vegetation, resulting in less evapotranspiration (evaporation and transpiration of water from plants).
- Heat caused by human activities (human metabolism, vehicle exhaust, buildings etc.)
- Tall, dense buildings that block wind and trap solar radiation, effectively isolating the city.

(Yang, Qian, Song, & Zheng, 2016; Mohajerani, Bakaric, & Jeffrey-Bailey, 2017).

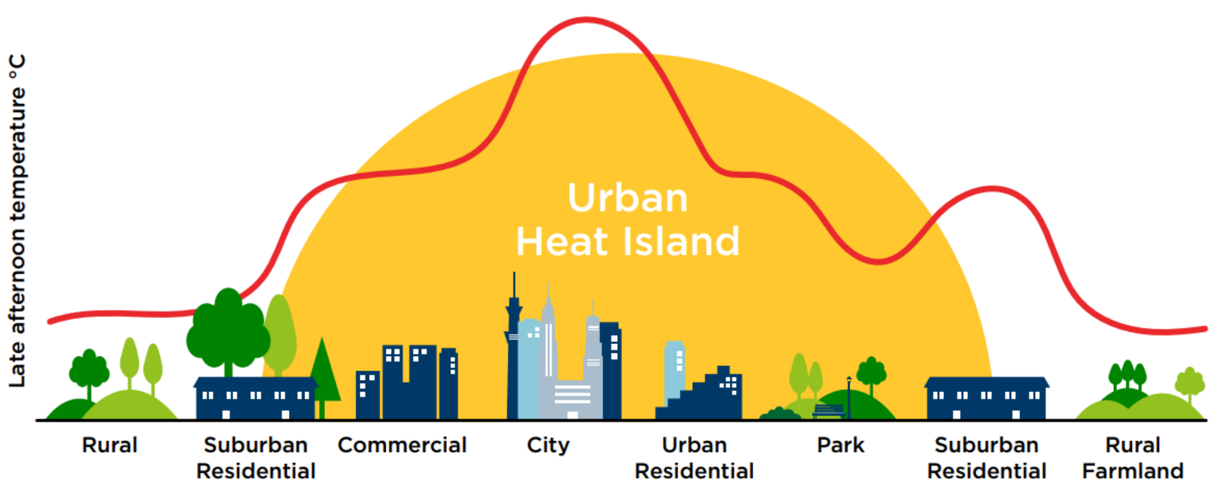
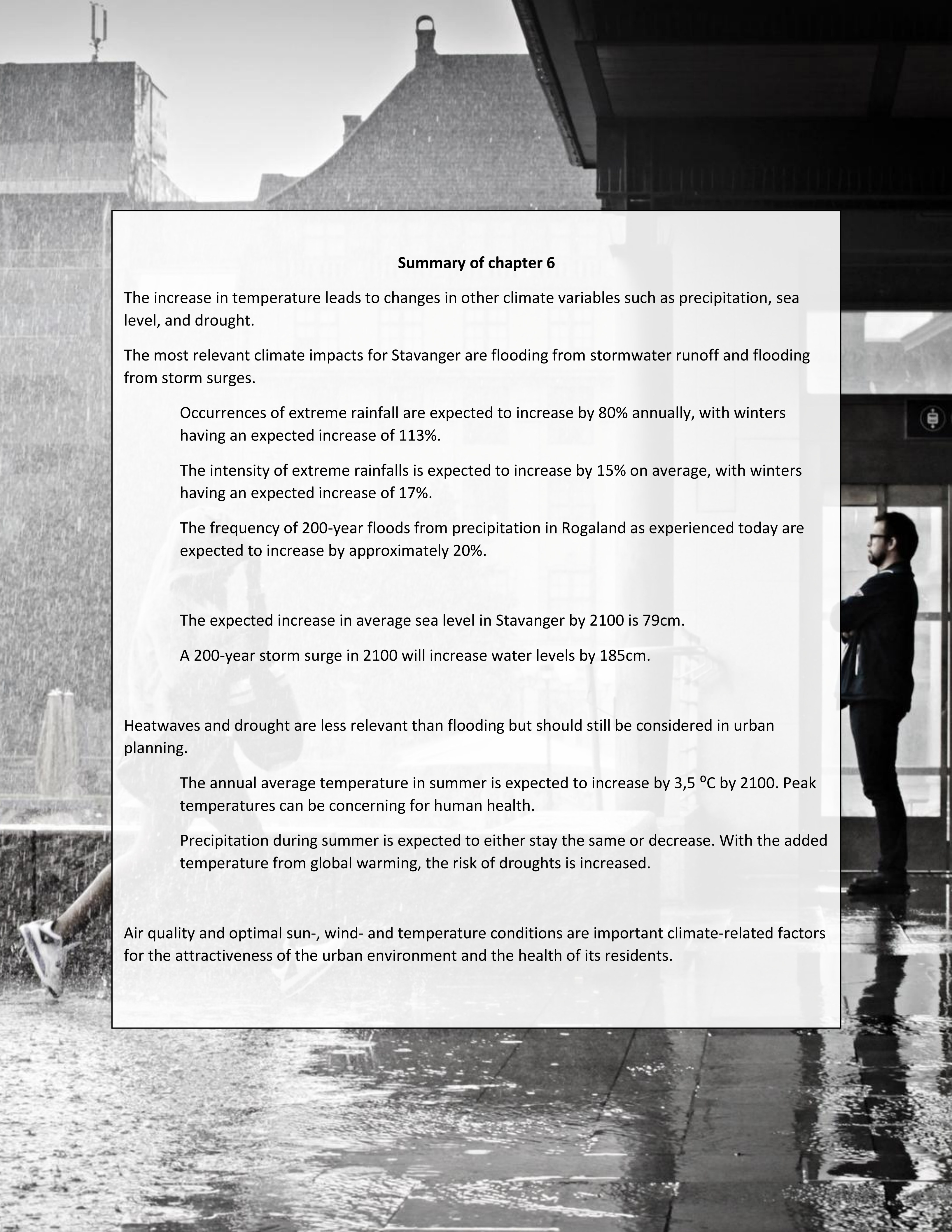


Figure 4.11. Illustration of the UHI effect (Fuladlu, Riza, & Ilkan, 2018).
The case area, Paradis, can be categorized as an urban residential area

The effect is more pronounced in the densest city centres, less so in residential areas, and is at its lowest in parks and rural areas. Recent studies suggest that the effect can cause air temperatures in larger cities to increase as much as up to 15°C compared to the surroundings (Mohajerani, Bakaric, & Jeffrey-Bailey, 2017), but is highly dependent on the way the city is structured. For Oslo, a considerably larger city than Stavanger, the UHI effect is estimated to increase the hottest month by 5,6 °C in 2050, even if the terms of the Paris Agreement are met (Venter, Krog, & Barton, 2019). While there is no data available for Stavanger, some relatively similar cities in terms of area, population and location to the shore have potential UHI effect values ranging between 2 and 7 (Malmö and Reykjavik) (WHO, 2004).



Summary of chapter 6

The increase in temperature leads to changes in other climate variables such as precipitation, sea level, and drought.

The most relevant climate impacts for Stavanger are flooding from stormwater runoff and flooding from storm surges.

> Occurrences of extreme rainfall are expected to increase by 80% annually, with winters having an expected increase of 113%.
>
> The intensity of extreme rainfalls is expected to increase by 15% on average, with winters having an expected increase of 17%.
>
> The frequency of 200-year floods from precipitation in Rogaland as experienced today are expected to increase by approximately 20%.
>
> The expected increase in average sea level in Stavanger by 2100 is 79cm.
>
> A 200-year storm surge in 2100 will increase water levels by 185cm.

Heatwaves and drought are less relevant than flooding but should still be considered in urban planning.

> The annual average temperature in summer is expected to increase by 3,5 ^{0}C by 2100. Peak temperatures can be concerning for human health.
>
> Precipitation during summer is expected to either stay the same or decrease. With the added temperature from global warming, the risk of droughts is increased.

Air quality and optimal sun-, wind- and temperature conditions are important climate-related factors for the attractiveness of the urban environment and the health of its residents.

5. Options for climate adaptation

This chapter will present several options, strategies, and technologies used as forms of climate adaptation in the urban environment.

5.1. The built environment

This chapter will describe how urban densification and the strengthening of cohesiveness in neighbourhoods can function as indirect measures of climate adaptation.

5.1.1. Densification

Urban densification is the process of densifying the urban environment by increasing the amount of built space in which people can live, work, or perform recreational activities in a given area. The focus of densification is to create a more compact and connected urban environment with a reduced need for transport, travel, and land use (Teller, 2021). It is a key method for urban planners to encourage conservation and efficiency in cities and is therefore regarded as a means to increase sustainability and alleviate the further decline in climate change (Frank, et al., 2019b).

Regarding climate adaptation, urban densification can both reduce and increase the resilience of infrastructure and human populations. If structures and people are located in vulnerable areas, then densification can create increasingly significant risks should it be incorporated without sufficient infrastructural and institutional frameworks. Conversely, should effective adaptations be implemented, or if the location is already resilient to the relevant climate impacts, densification can be a viable option to build large-scale resilience in a relatively cost-effective manner (Dodman, 2009). As densification carries the added benefit of a reduced need for transport, which is the largest cause of air pollution in many urban areas (Teller, 2021), it can also be a strategy for improving air quality when sufficient urban ventilation is achieved.

Furthermore, climate adaptation and densification measures need to be carefully coordinated to not compete for space as urban densification carries the added risks of increased heat-island effect, less permeable surfaces, and less area to mitigate CO_2. Densification done right will therefore often incorporate private and public spaces such as squares, patios, and parks to increase attractiveness and liveability. Densification is particularly appropriate in areas near jobs or services, in former industrial areas, and proximity to public transport (Tärk, et al., 2020).

5.1.2. Building community cohesion

Community cohesion describes how well a community and its members cooperate to achieve a shared well-being, focusing on a common vision, a sense of belonging, and strong relationships. A strong cohesive community works together to incorporate these values (LGA, 2002).

Promoting community cohesion is an often-ignored factor in strengthening climate resilience, especially so for low-income urban areas. Strong, cohesive communities are often characterized as more climate-resilient than socially disconnected communities as residents in connected communities often assist each other with supplies, relay local needs to authorities, and support each other when the need arises. Urban areas with strong, cohesive communities are also highly characterized by being able to recover fast and efficiently from adverse impacts, which previously mentioned is a form of resilience. Areas with urban sprawl and poor community cohesion often tend to perform worse by this measure, proving the benefit of encouraging social interaction and creating a connected community in urban environments (Tärk, et al., 2020; Baussan, 2015). The effect of community cohesion on climate resilience was made increasingly clear during the aftermath of the 1995 heatwave in Chicago, which to date is the deadliest heatwave ever to occur in the state, causing at least 465 heat-related deaths. Researchers discovered that some of the neighbourhoods with similar demographics fared extremely different in terms of heat-related deaths, where even some of the low-income communities were considerably better off than their higher-income counterparts. The researchers showed that strong community cohesion among the neighbourhoods proved to be a deciding factor in how resilient they were to the heatwave, where the most resilient communities often showed higher levels of interaction, communication, and a drive to decrease isolation amongst themselves (Baussan, 2015).

For urban planners, ensuring a strong cohesive community in a development project is not something that can be realistically guaranteed. Instead, urban planning can utilize the built environment to encourage it by implementing diverse options for socializing, commerce, recreation, and employment (Tärk, et al., 2020). Public- and semi-private spaces, parks, and squares contribute to increasing social interactions, thereby strengthening community cohesion. It is however important to design these features as true meeting spaces where people will actively go by including other activities such as recreation or transport. Streets can be designed as shared public spaces by improvements to bench seating, restricting car usage, and incorporating open first floors in adjacent buildings (Schreiber & Carius, 2016). Placing a park in between two crowded areas will also contribute to more social interactions, as research has shown that spontaneous interactions among people happen more often in the spaces and moments between different activities. This makes slightly crowded, widely used areas which also accommodate several activities considerably effective at creating social cohesion in a community. Street markets were shown to be especially in this regard (Bartholomew, 2020). Increased walkability, accessibility to public transport, and social activities were also shown to be positively related to a stronger cohesion in communities (Mouratidis & Poortinga, 2020).

When done right, mixed-used development and densification can be an additional strategy to build community resilience. According to Schreiber & Carius (2016), mixed-use areas should follow the principle of creating and ‘’urban village’’ that includes several different facilities and services which accommodate the needs of different social groups. In the wake of the COVID-19 pandemic and the following quarantines, the importance of quality and liveability in the neighbourhood environment has become increasingly clear. Balconies, gardens, local and private green spaces, recreational areas as well as closeness to both amenities and necessities have been crucial factors to improve the quality of life and to ameliorate stress. These types of features along with flexibility through mixed- and multi-functional use in the built space help build a strong community cohesion (Tärk, et al., 2020).

5.1.3. Urban attractiveness

Dempsey (2009) examined the arguably self-evident claim that high-quality and attractive built environments are positively related to social cohesion in urban neighbourhoods. The findings provided empirical evidence which indicated that there are significant associations between perceptions of high quality and social cohesion, it is however dependent on subjective perceptions of attractiveness.

As previously mentioned, cohesive communities are characterized with greater resilience to climate impacts, making urban attractiveness an indirect factor in vulnerability to climate hazards. As such, attractiveness will be included in the proposal as an indirect climate adaptation measure. However, seeing as how urban attractiveness and liveability are such a crucial and fundamental aspects of urban planning, they will be included as a secondary objective of this thesis regardless.

What makes an urban area attractive involves to a plethora of different factors like options for labour, closeness to amenities, economics, safety, identity, visual components and so on. Understanding what makes a city attractive and how to best implement it could easily be its very own research question for another thesis, which is why covering it thoroughly here in addition to climate adaptation is not feasible. Consequently, only key attributes of implementing urban attractiveness through design and layout will be included in the thesis.

This chapter will therefore briefly introduce the concept of attractiveness in urban design and its most influential methods of implementation. Much of this chapter is based on the video ''How to make an attractive city'' by The School of Life (2015).

Figure 5.1. Fargegata, Stavanger

Balance between order and variety

One key attribute of attractiveness is the balance between order and variety. Geometric order and variety are the most fundamental components of urban structures and while they are relatively simple to distinguish, the definitions of these concepts are difficult to describe. Geometrical order refers to symmetry, regularity, and repetition that is easy to predict and is often the result of planning. Variety is the opposite of this, it is represented by a complex structure that does not follow any understandable pattern (The School of Life, 2015).

In the urban setting, ''*geometric order evokes the feeling of harmony, seriousness, and monumentality. Elimination of geometric order causes the illegibility of compositions.* On the other hand, ''*variety revives the architectural space and gives it an individual dimension. Elimination of variety from the architectural composition causes spatial boredom.''* In essence, order creates harmony while variety creates identity, but too much variety and the environment will start to feel off-putting, exhausting, and unwelcome, whereas too much order will feel boring. The key is to create an organized complexity that incorporates just the right amount of both order and variety (Rubinowicz, 2000; The School of Life, 2015).

Figure 5.2. Too much variety (left) and too much order (right) (The School of Life, 2015)

Often, the best approach is to create an overlaying discernible pattern that follows the principle of order, but with traits of variety at a smaller scale. Java-Eiland in Amsterdam is a perfect example of how order and variety should coexist (see Figure 5.3). Here, there are building restrictions on height, form, and colour, creating a clear pattern, but within this grid, each housing unit is given complete freedom, creating a much-needed sense of identity (The School of Life, 2015).

Figure 5.3. Order and variety. Java-eiland

Visible functions, lively streets, and public spaces

An often-recurring attribute in modern urban areas is that technology and functions are hidden away. Places where people work are predominantly used for work and nothing else, which separates and alienates certain parts of the urban setting. Modern cities often hide life away, creating open, dull, and dead spaces where people rarely go unless they work there. Office buildings are brutally anonymous and industrial areas seem hostile and unwelcome (The School of Life, 2015).

Figure 5.4. ''Brutally anonymous'' buildings and dead streets (The School of Life, 2015)

''Today, people would be enraged if they were to find out about a pipeline being built over a nice river. Compare this to the ancient roman aqueducts which people now pay to see, and it is clear that it is not the pipeline itself that is the problem, but the ugliness of it.'' (The School of Life, 2015)

Urban planners should focus on both beauty and practicality, showing off every interesting component of the urban setting and how they work in an appealing manner. Open channels, as opposed to a combined sewage system for stormwater management, are a great example of how urban function can incorporate this concept (see Figure 5.5). Furthermore, it is important that people can feel safe and welcome in lively and attractive streets. A livelier and more attractive street is made by making sure pedestrians can see through the windows at ground level, have meaningful interactions, and have places to relax. As shown in Figure 5.6 Vågen is known for attractive and lively streets. Squares and other public places are a crucial requirement for achieving attractiveness (The School of Life, 2015).

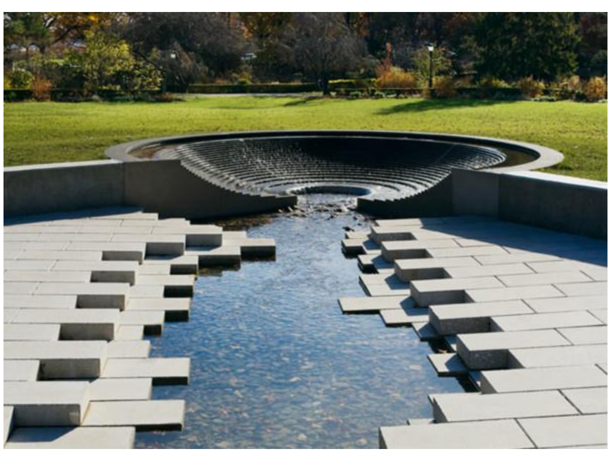


Figure 5.5. Creative solution to water management

Figure 5.6. Lively streets in Vågen

Sense of enclosure

''We're under the illusion that we want to live alone. More and more people tuck themselves in a private realm – and it's been a disaster. It's become dead, cold, boring, and very, very wasteful on the environment.'' (The School of Life, 2015)

There is a reason why so many urban planners want to work against urban sprawl. Along with its many other detrimental effects on both the environment and the population, it causes loss in open space and parks and creates segregation between residential, commercial, and recreational uses, all of which are crucial components of an attractive urban area. Working against this means putting buildings and urban functions closer together and creating a more compact city. Attractive urban areas often have a sense of enclosure and cosiness, they feel inviting and safe to be in. Usually in the form of public squares, small parks, or just places to sit. Public areas should feel like an extension of your home, they should be intimate and enclosed but still large enough to give sufficient privacy.

Figure 5.7. Sense of enclosure with vibrant colours. Fargegata, Stavanger

The ratio between street width and building height is an important factor to consider when regarding the compactness of an urban area. Streets that are too wide will no longer create a sense of enclosure, whereas streets that are not wide enough can start to feel claustrophobic. While there is no single best ratio, most streets considered attractive have a ratio between 1:1 and 1:4 (City Beautiful, 2020), although some studies claim that ratios of 3:1 are particularly appropriate for enclosed public spaces (Jaecheoul & Seungnam, 2019). As a general rule, squares and enclosed public spaces should not be more than 30 meters across, it should be possible to make out a face across the square (The School of Life, 2015). Trees and vegetation can also be used to create this sense of enclosure.

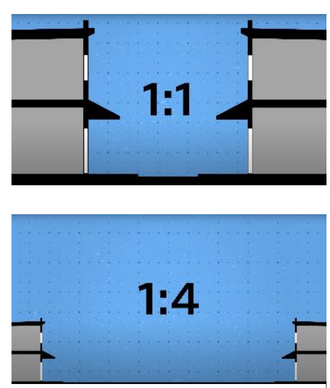


Figure 5.8. Preferred building-to-street ratios (City Beautiful, 2020)

Identity

Physical identity is part of what makes an area unique and interesting and if done right, identity can play a crucial role in the attractiveness of an urban area (The School of Life, 2015).

The identity of an area is influenced by the human perception of physical form, activity, and meaning. In the urban context, open space design, effective street design, and the conservation of heritage features are the primary attributes influencing identity. Identity is what shapes the image of an area and makes it intriguing. Strong communities or popular tourist destinations often derive from places with identity. Having an identity in a community empowers a sense of belonging and strengthens its connections (Misni & Aziz, 2016).

Figure 5.9. Old Stavanger

The best approach to creating identity is to utilize distinctive local forms and materials that reflect the history and character of the area, embrace the local culture, and make use of architectural styles that makes the location specific and unique. Colour palate, architectural styles, and interesting landmarks are powerful tools to achieve this. The ideal goal is to create an urban area that people would recognize immediately from a picture solely based on its visual components (The School of Life, 2015).

In Stavanger, the white tree houses with orange rooftops and the distinct, brightly coloured sea houses often recurring along the seafront are key sources of identity that draw upon the history of the city (see Figure 5.9 and Figure 5.10). These architectural styles have been imitated throughout new development in Stavanger to strengthen the identity of the city.

Figure 5.10. Colourful sea houses

Climate

The climate conditions of an urban area are inextricably linked to its perceived attractiveness by both residents and visitors. Here, the variables most relevant to urban attractiveness include air temperature and relative humidity, wind speed, rainfall, and sun access (Kapetanakis, et al., 2022). Air quality and noise levels are also variables to consider in some specific cases. According to Kapetanakis et al. (2022), the ideal climate conditions (mainly regarding tourism) are as follows:

A temperature of approximately 22,5 ^{0} C for a city in northern Europe.

Rainfall durations of less than 2 hours.

Light breezes with wind speeds ranging between 1 – 9 km/h.

Cloud coverage of less than 25% and well-lit areas.

As controlling the weather is not an option, the climate impacts have to be dealt with directly. Temperature and humidity conditions can be regulated by utilizing moderate amounts of vegetation and structure layout to allow for cooling breezes. Rainfall impacts can be ameliorated by providing shelter for public spaces. Wind conditions can be regulated by settlement layout and providing shelter from strong winds. Optimal sun conditions can be achieved by altering building orientation and height. Well-lit areas are also crucial for people to feel both comfortable and safe, and to reduce crime (Clarke, 2008). Air quality can also be regulated with the use of vegetation, whereas noise levels have to be reduced by sheltering important areas from sources of excessive noise.

Green areas

Facilitating vegetation and green areas in the urban structure is an effective way to promote attractiveness and quality of life in urban environments. Evidence has shown that spending time in nature has significant effects on the well-being of people and the attractiveness of areas. Even smaller vegetation like potted plants or singular trees have considerate benefits (Herzele & Wiedemann, 2003; Chowdhury, 2022)

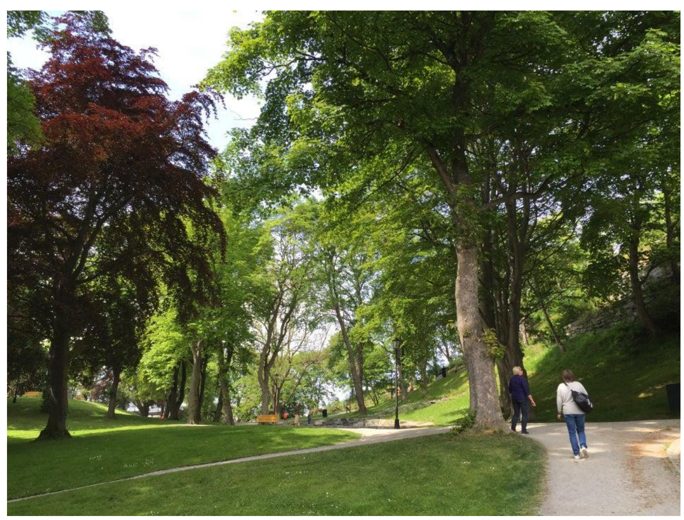


Figure 5.11. City park in Ålesund, Noway

5.2. Nature-Based Solutions

''Instead of focusing on the discovery of new technologies to combat the effects of climate change and global warming, it is also crucial to have new and insightful ideas regarding the green revolution in architecture and urban planning on a scale that goes from individual buildings to entire cities.''

(Gago, et al., 2013)

Nature-based solutions (NBS) refer to incorporating and replacing the hard and impermeable surfaces in cities with vegetation and permeable surfaces. It has recently been recognized as a sustainable solution to many urban issues by exploiting natural processes beneficially. This type of implementation is considered a low impact and cost-effective method of climate adaptation that simultaneously provides environmental, social, and economic benefits by reclaiming the natural landscape taken over by urbanization. However, the defining feature of NBS is not whether the implementation is in its 'natural' state, instead, they are utilized to achieve climate-related objectives (UNESCO, 2018).

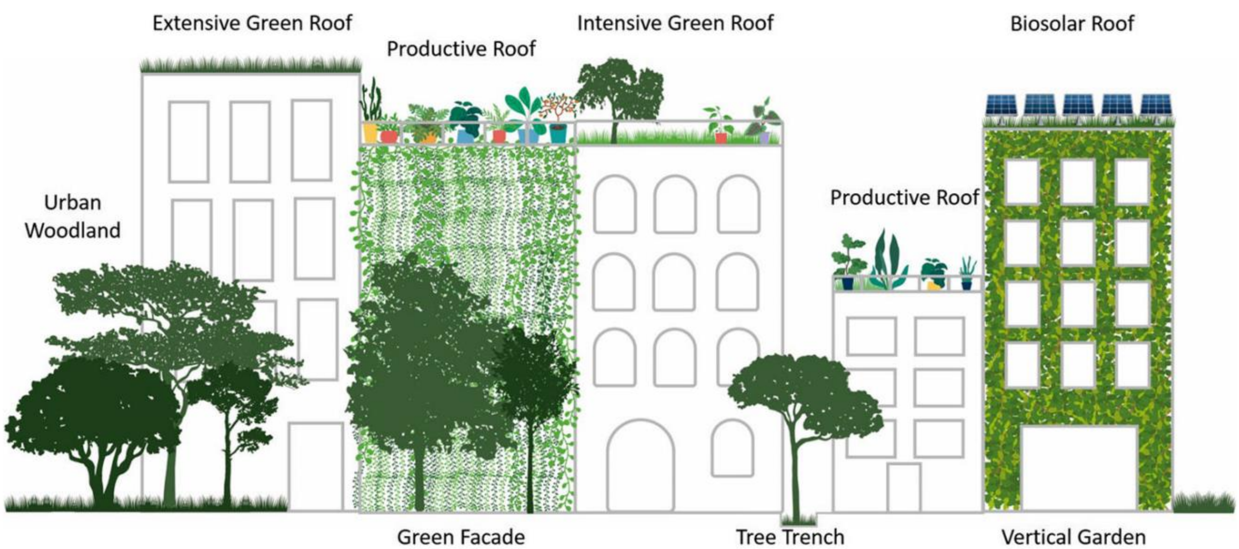


Figure 5.12. Integration of NBS into the built environment (Calheiros & Stefanakis, 2021)

The NBS concerning climate adaptation includes stormwater management, heat risk reduction, shading, air purification, increase in biodiversity, and wind- and noise reduction, but also includes other beneficial aspects such as attractiveness and options for recreation (Frantzeskaki, et al., 2019; Calheiros & Stefanakis, 2021). As Figure 5.12 shows, NBS includes a wide variety of options, such as green roofs, green facades, tree trenches, parks, and gardens, but also includes water-based options like wetlands, canals, and ponds.

5.2.1. Green roofs

Rooftops in an urban environment are one of the key contributors to many of the climatic impacts that cities face as they often consist of impermeable, dark-coloured surfaces with no other function than to isolate the building from the effects of the weather. They usually account for nearly half of all impermeable areas in a developed city, making them a crucial point of focus within urban climate adaptation. To revert many of the issues they initially cause, roofs can be transformed from part of the problem to part of the solution by incorporating vegetation into them. Switching from conventional roofs to green roofs has over the past decade been proposed as a sustainable practice to mitigate the impacts of urbanization as they present opportunities and benefits in several dimensions. (Shafique, Reeho, & Rafiq, 2018; Calheiros & Stefanakis, 2021).

Green roofs involve creating a soil-based medium as part of the roof of a building for vegetation to grow and can mainly be classified as either *extensive* or *intensive* (see Figure 5.13 and Figure 5.14) depending on the depth of the medium, type of vegetation used, allocated usage, and the maintenance required (Calheiros & Stefanakis, 2021).

Figure 5.13. Extensive green roof

Figure 5.14. Intensive green roof

Intensive green roofs are categorized as having a considerable depth to the layer of soil (deeper than 25 cm), allowing for more options in vegetation. This means that intensive roofs can be used as recreational spaces available to the public/residents as they can include vegetation similar to what can be planted at ground level. Intensive green roofs provide a more appealing natural environment, including many other benefits such as increasing biodiversity and stormwater management, and are often best utilized for medium- and smaller, relatively flat roofs but can at a greater cost be implemented in large ones as well (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014).

Extensive roofs are simpler and require much less maintenance and investment but do provide inferior results in terms of thermal resistance and other benefits as they are considerably shallower (less than 15 to 25 cm) than intensive roofs. Extensive roofs are characterized by substrate depth and the type of vegetation they contain, which is lightweight, self-sustaining, and hardy plants like succulents, shrubs, herbs, flowers and grass. They are therefore generally not accessible to people outside of maintenance and are often suited for larger or angled roofs as they typically do not need irrigation systems, are lighter, more affordable, and easier to implement (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014).

5.3. Coastal flooding

As coastal floods are particularly costly and disruptive, flood-related risk should be managed proactively. For ocean-related flooding, there are a few adaptation measures generally agreed upon. In essence, there are three main strategies for building flood-risk resilience: accommodation, resistance, and retreat (C40 Cities, 2020)

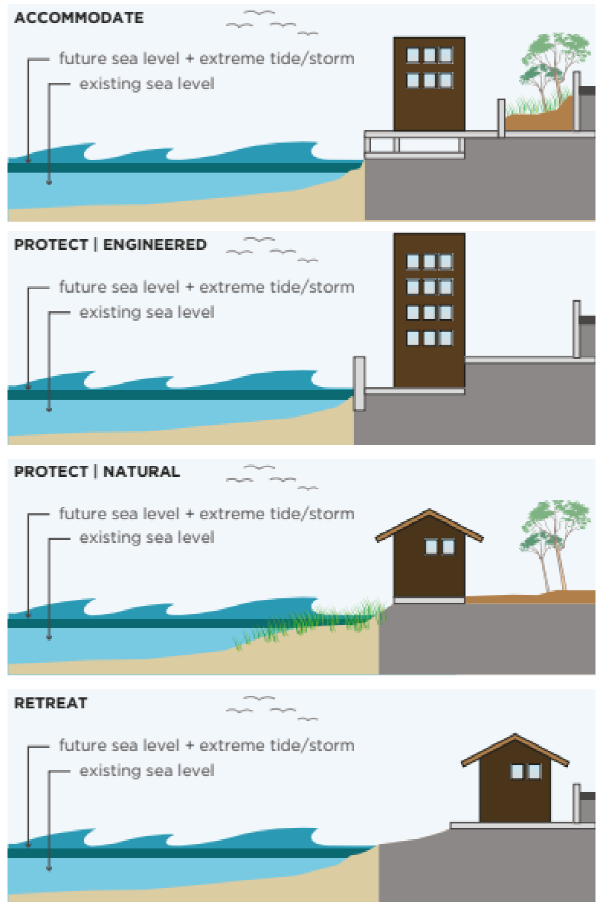


Figure 5.15. Flood adaptation measures (Davis-Reddy & Vincent, 2017)

Accommodation refers to accepting the hazard of flooding and adjusting to the impact accordingly without sustaining intolerable effects. Important infrastructure can be elevated or the lower floors at risk can be fitted with water-resistant materials. Accommodation also focuses on creating nearby areas which redirect and retain water, such as larger parks or channels. The latter method is more suited for stormwater management as opposed to coastal flooding (Kousky, Fleming, & Berger, 2021).

Retreat (also described as avoidance) refers to moving development outside of areas highly exposed to flooding. This method is naturally not applicable as a general solution for already existing infrastructure and is most effective when applied as a proactive measure during planning for new infrastructure. For undeveloped areas, the only cost of this method is the cost of the missed opportunity of more development. A strategical retreat is therefore usually the most cost-effective and simple solution for strengthening resilience to coastal flooding. However. sufficient knowledge of future areas at risk of flooding is required for this method to work near shore (Kousky, Fleming, & Berger, 2021).

Resistance refers to leaving the vulnerable development as it is, focusing instead on dealing with the impact directly. The main methods of flood-risk resistance are hard- or soft engineering. Hard engineering refers to keeping the water away from important areas by utilizing sea walls, storm-surge barriers, water pumps, overflow chambers etc. This option reduces through ''brute force'' and is often costly and carries adverse effects on its surroundings without providing any other benefits outside its intended purpose. Nature-based protection, also referred to as soft engineering mainly involves altering the coastline to absorb the impact from waves, thereby reducing the effect of storm surges by limiting the forward movement of water. However, this does not reduce the risk of flooding from extreme tidal heights. This method focuses more on shaping how floods will affect cities, rather than attempting to prevent them (Kousky, Fleming, & Berger, 2021).

5.3.1. Elevation

Elevating the ground floor of structures is a rather straightforward way of reducing the risk of flood-related damage. To artificially extend the threshold of inundation, structures may be elevated by raising the lowest occupiable floor above the safe threshold.

In areas not exposed to wave action, a structure may be raised to a safe height by elevating the lowest occupiable floor on solid foundation walls (see Figure 5.16). Depending on the circumstances, these walls can either be designed with wet floodproofing, allowing for water to enter but also leave without retaining significant damage, or designed with dry floodproofing, protecting the basement from being flooded at all. Wet floodproofing is preferred when increased water levels create too much pressure on the foundation walls, allowing the water to flow into the basement relieves this pressure (McGuinness, et al., 2019).

For areas exposed to wave action, the structure is raised on pylons specifically designed to endure site-specific flood loads (see Figure 5.17). Elevation on open foundations is normally applied for structures in coastal areas that are highly and frequently exposed to flooding (McGuinness, et al., 2019).

For both methods, it is important that the increased height in floor level does not interfere with the visual connectivity at ground level. Vegetation, lighting, art, etc. should be incorporated into the sidewalk-facing side of elevated foundations to create a more holistic and positive experience. Alternatively, ramps or inclined steps as shown in Figure 5.18 can be applied as a flood mitigation measure that blends seamlessly into the urban environment (McGuinness, et al., 2019).

Utilizing structural fill to raise the lowest occupiable floor above the safe threshold is a more permanent and secure solution for elevation. As shown in Figure 5.19, this method essentially raises the ground level, thus reducing the reach of flooding events in the elevated areas. Elevating by structural fill is especially applicable to larger areas and has the potential to incorporate landscape features such as vegetation or permeable surfaces that can further increase the flooding

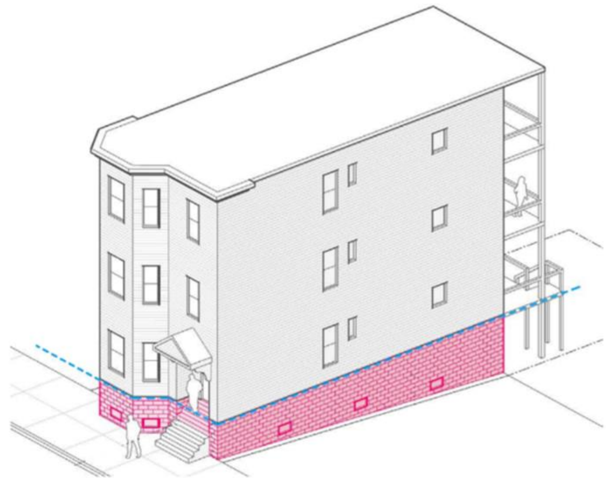


Figure 5.16. Elevation on solid foundation (McGuinness, et al., 2019)

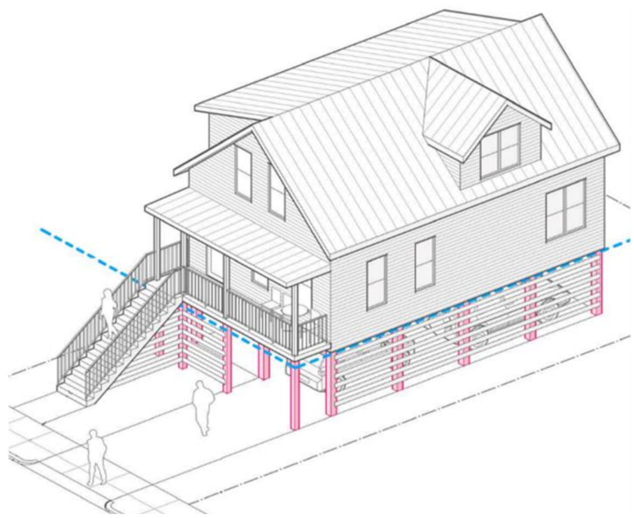


Figure 5.17. Elevation on open foundation (McGuinness, et al., 2019)

Figure 5.18. Using stairs as a flood mitigation measure (McGuinness, et al., 2019)

resilience of the area. This elevation should seamlessly slope into the surroundings without disrupting visual or physical connectivity. Elevation of an entire site, as opposed to individual buildings, is especially recommended for waterfront areas where parks and open spaces can be designed to function as elevated structural barriers to flooding from tidal waves and storm surges (see figure Figure 5.20). Preserving as much open space as possible in areas along the waterfront provides flexibility through future options for adaptations should climate impacts worsen (McGuinness, et al., 2019).

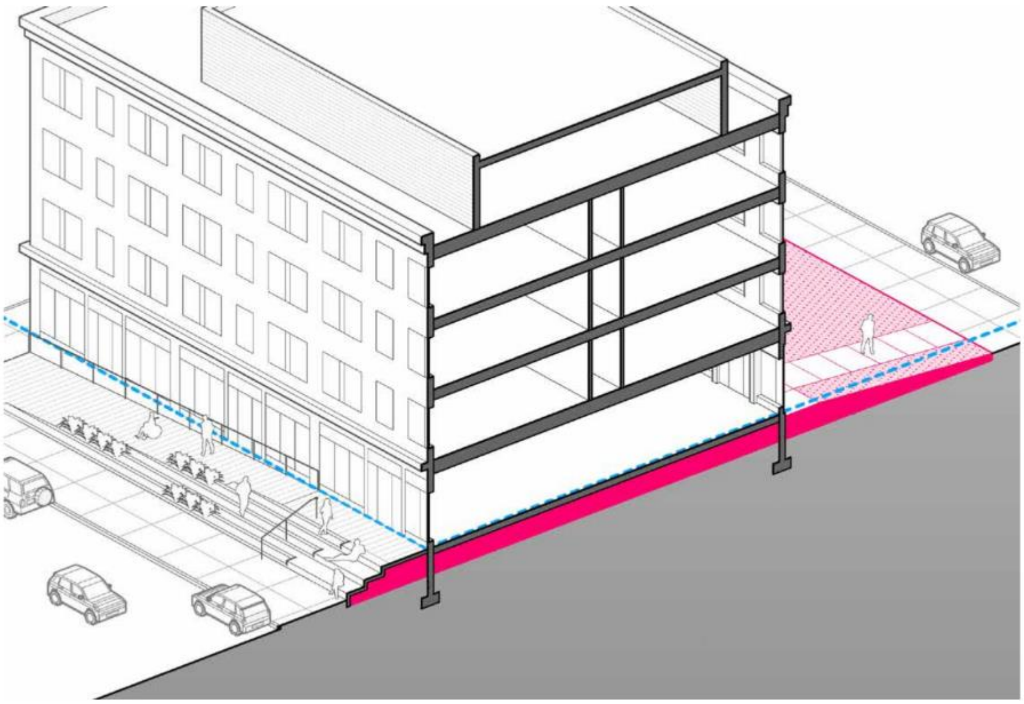


Figure 5.19. Elevation by structural fill (McGuinness, et al., 2019)

Figure 5.20. Waterfront park doubling as a flood resilience measure (McGuinness, et al., 2019)

5.3.2. Flood-damage resistant materials

Building materials, components or systems that are resistant to flooding and are capable of withstanding direct and prolonged exposure to floodwaters (including moving water) are used to build resilience towards flooding. These materials do not lose integrity during or after events of flooding and therefore facilitate a safer, faster, and more cost-effective post-storm recovery. Such materials are classified in terms of their resilience to flood damage, where highly resilient building materials include concrete, stone, masonry block, pressure-treated lumber, and ceramic and clay tiles. Unless treated, wood is generally deemed unacceptable as a flood-resistant building material (McGuinness, et al., 2019; FEMA, 2008).

Vegetation placed in areas exposed to flooding from ocean water should have special resistance towards salt-water inundation. Plant species with higher tolerance toward salt should be chosen in such areas, and landscape maintenance programs should flush plant-toxic salt out of soils (FEMA, 2008).

5.3.3. Floodgates

Categorized as a hard-engineered adaptation to storm surges, floodgates are fixed barriers designed to allow free passage of water during normal conditions and restrict water entering the gate during storm surges by closing the gate. As they are expensive, intrusive, and complicated structures, they are optimally placed in chokepoints where the instalment will be minimal, and where they will protect urban settlements largely vulnerable to sea flooding (Climate-ADAPT, 2020).

Despite their high costs of instalment and maintenance, existing floodgates have proven to be worthy investments especially effective against storm surges. For instance, the Thames Barrier has been closed and successfully protected against flooding over 100 times without problems since it was first installed in 1982. Regarding disadvantages for climate adaptation, technical failure (e.g., breach or gate not closing) is an important risk to consider as floodgates can create a false sense of security if not dimensioned or installed properly. They are therefore optimally used with other sea flood prevention measures such as elevation and beach nourishment (Climate-ADAPT, 2020).

There are several different types of floodgates, Figure 5.22 and Figure 5.21 shows an illustration of a radial floodgate (left) and a picture of a sluice gate (right).

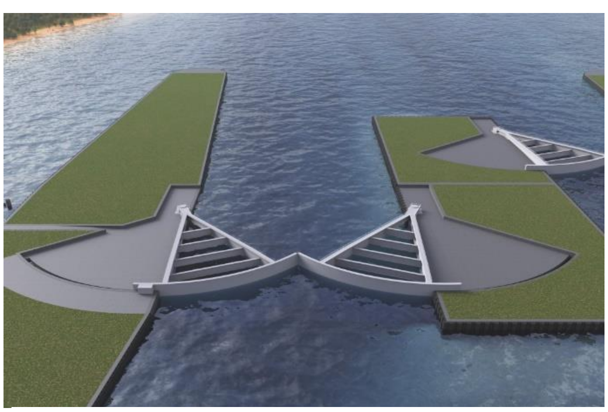


Figure 5.22. Illustration of a radial floodgate

Figure 5.21. Sluice gate. Tokyo, Japan

5.4. Stormwater flood risk and water pollution

In nature, most rainwater that reaches the ground will either infiltrate the soil, evaporate, or return to the air by evapotranspiration from plants. Urbanization has reverted this effect, suppressing these natural processes by replacing soil with asphalt and concrete, and converting rainfall into runoff (Qin, 2020). In urban environments with a high proportion of impervious surfaces, stormwater drainage mainly relies on the capacity of the sewage system (Huang, et al., 2019). If this capacity is overloaded and the excess stormwater cannot be discharged in time, flooding occurs. To keep the sewage system from overflowing, the excess water must be retained, slowed down, or directed away from key areas. Urban planning concerning managing flood risk is related to connectivity, circularity, and the balance between natural and urban elements (Oral, et al., 2020).

The prevalence of flooding caused by heavy precipitation can be anticipated with the help of advanced hydraulic models, or by utilizing simpler methods based on analysing the topography of the area. Both methods do however require a sufficient model of the terrain, as well as a high-quality database of the precipitation over the area. In urban environments, it is recommended to create a dynamic model consisting of both drainage systems and surfaces, so that an accurate model of expected rain flows and areas vulnerable to flooding can be drawn (COWI, 2017).

The loss of water circularity is often attributed to the impermeable surfaces in urban environments that reduce the capacity of soil infiltration and increase surface runoff. Furthermore, the loss of circularity by replacing the natural water cycle with the urban water cycle poses risks for soil, channelized urban drainage systems, receiving water bodies, and downstream urban areas. This causes uncontrolled leakage from sewage, which threatens groundwater and connected water bodies with contamination of pollutants. In this context, NBS aims to restore the natural water circularity, thus reducing flood risk and water pollution as vegetation and soil act as means for water purification, retention, and infiltration (Oral, et al., 2020).

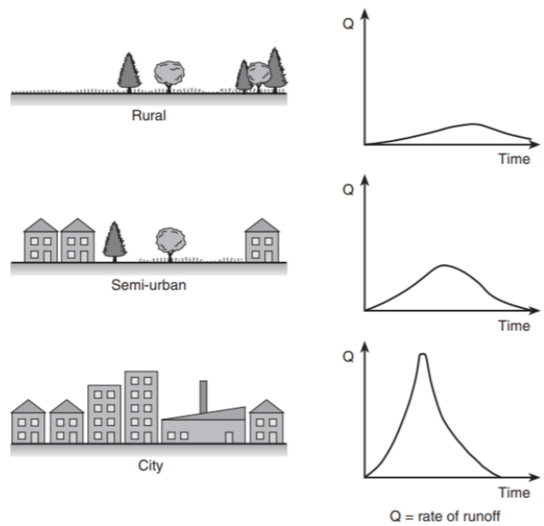


Figure 5.23. Effects of urbanization on surface runoff

As Figure 5.23 shows, the relationship between natural and urban elements directly correlates to the percentage of runoff, where according to the US EPA, there is a 45% increase in surface water runoff from an all-natural to an all-urban landscape (US EPA, 2003). Stormwater runoff, and thereby flood risk, can therefore be reduced by shifting this balance in favour of natural elements.

Bioswales, permeable pavements, rain barrels, urban wetlands, and green roofs are all examples of nature-based solutions that manage flooding by utilizing infiltration, storage, and evapotranspiration throughout the runoff period, while plant and soil systems reduce the effects of the more extreme flooding events (Huang, et al., 2019).

As mentioned, runoff should be managed through infiltration, retention, and safe transport. It should first be infiltrated into the ground where it lands to reduce the risk of flooding and alleviate the strain on other flood prevention measures. Then, the excess surface water should be retained in facilities that hold and delay the runoff which is later released when the risk of flooding has passed. Lastly, secure floodways should lead overflowing water away from vulnerable areas and toward capable recipients. Figure 5.24 depicts several stormwater flood prevention measures categorized by these three steps (Magnussen, et al., 2017).

Infiltration

Green roofs	Roofs covered with perennial vegetation
Green walls	Walls covered with perennial vegetation
Permeable pavements	Pavements that allow water to infiltrate into the ground
Bioswales	Artificially built channels with vegetation and permeable materials
Filter strips	Vegetated strips of sloped surfaces, often placed next to impermeable surfaces like roads
Infiltration pools	Open pools that combine water retention and infiltration
Rain gardens	Gardens specifically designed with increased capacity for infiltration and retention
Other green structures	Urban trees, parks, green corridors, and other green structures contribute to infiltration (trees are especially effective)

Retention

Urban ponds	Retention or detention ponds capable of storing large amounts of stormwater
Rain barrels	Barrels connected to gutters collecting water from roofs.
Bioswales	Bioswales can also be designed to retain excess stormwater
Constructed wetlands	Constructed areas with ecosystems similar to marshes

Safe transport

Channels	Natural or constructed pathways that transport excess stormwater

Figure 5.24. NBS for stormwater management (Huang, et al., 2019; Magnussen, et al., 2017)

5.4.1. Green roofs

Green roofs are recognized as an adaptation strategy for stormwater management as they absorb, retain, and evaporate considerable amounts of water during rainfall, leading to reduced surface water peak flows and reduced stress on the sewage system. They are generally considered a moderately effective stormwater management solution as they retain most of the water they receive during smaller rainfall events but will quickly become fully saturated during heavy rainfall. Naturally, intensive green roofs with a deeper substrate and more vegetation will have increased retention capacities compared to extensive green roofs (Magnussen, et al., 2017).

The retention capacity of a green roof sets an upper limit for how much water can be retained before the green roof will start acting like an impermeable surface, implying that extensive green roofs are most impactful in terms of water retention during short storms. This does however imply that the roof is at zero capacity before rainfall, which is rarely the case (Qin, 2020).

One study in Norway on extensive green roofs concluded that green roofs on average retained about 25% of the rainfall it received throughout the year (Magnussen, et al., 2017). Another study showed that the highest observed retention from green roofs in Norway is 12-16 mm for a single rainfall event, whereas many smaller rainfall events produced no. In Sandnes and Bergen, two cities with similar climates to Stavanger (Sandnes being adjacent to Stavanger), the average monthly retention rate of extensive green roofs with sedum was measured at around 50 mm/month, reducing the total runoff by a considerable amount (Miljødiretoratet, 2018)

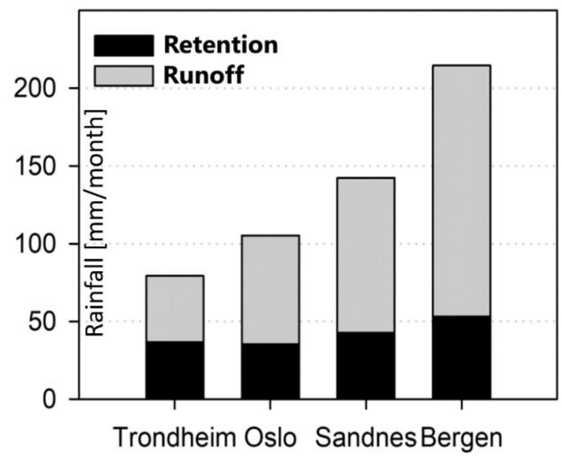


Figure 5.25. Retention and runoff from extensive green roof in Norwegian cities (Miljødiretoratet, 2018)

Green roofs produced by Leca in Norway are estimated to retain about 4 litres of water per square meter for each centimetre of soil depth. This means that an extensive roof with 10cm in soil substrate would be able to retain about 40 l/m^2, while an intensive roof with 1 meter of substrate would retain as much as 400 l/m^2 (Leca, 2022). While the estimate from Leca is substantially larger, calculating the actual retention capacity of green roofs is rather difficult as there are many variables such as type of soil and plant species that influences the retention capacity.

In terms of cost-effectiveness, green roofs - especially intensive green roofs, are generally not considered the best stormwater management strategy due to their high costs and maintenance (Magnussen, et al., 2017).

5.4.2. Permeable pavements

Permeable pavements are an alternative to sidewalks, smaller roads, parking areas, and other impervious surfaces. Due to their lower structural integrity compared to concrete or asphalt, they are mainly used as light-duty surfaces such as pavements but can be designed to cover a wider range of uses. Figure 5.27 depicts a cross-section of a permeable pavement with descriptions.

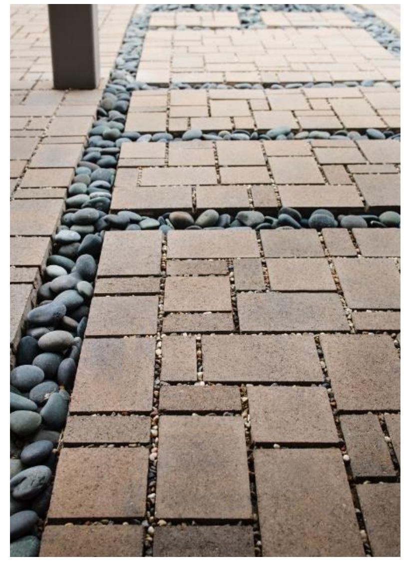


Figure 5.26. Permeable pavement

Their general function is to facilitate infiltration of surface runoff by collecting, treating, and filtering excess water, reducing the risk of flooding and enhancing the water quality of the area. Permeable surfaces reduce the runoff coefficient, and reduce peak time and flood peak, effectively mitigating the pressure of other stormwater management systems. The infiltration into groundwater they facilitate is considered one of the better stormwater management systems as it is sustainable and incorporates the natural water cycle as opposed to the urban one (Zhu, et al., 2019). A typical permeable pavement can hold about 15 l/m^2 of rainwater (Qin, 2020) and is best suited in areas with little to no pollution (Magnussen, et al., 2017).

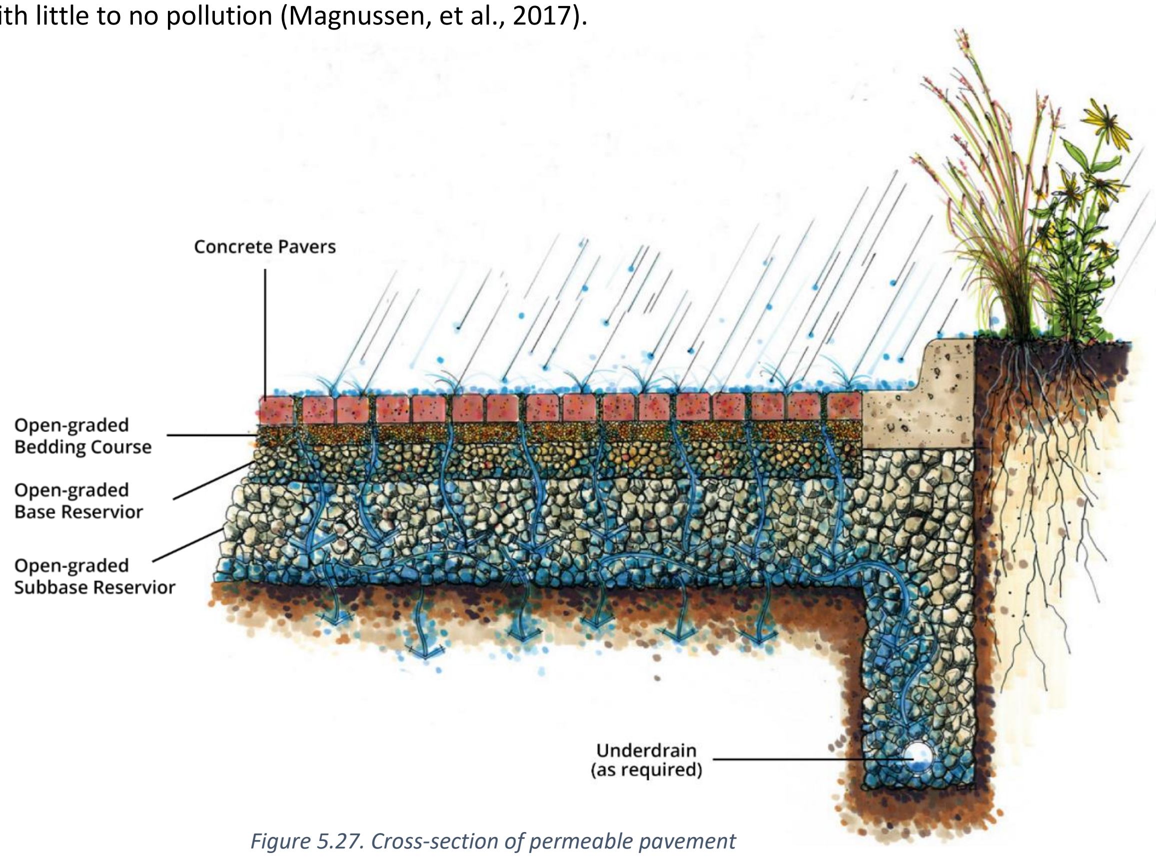


Figure 5.27. Cross-section of permeable pavement with descriptions

5.4.3. Rain gardens

Rain gardens are small, vegetated depressions fitted with local, perennial plants that accommodate collection, retention, and infiltration of stormwater by natural processes. Rain gardens are being increasingly adopted in both public and private urban areas as a measure to reduce stormwater flooding, attenuate peak flow, and filtrate rainwater (Qin, 2020).

Similarly to rain barrels, rain gardens are mainly placed near buildings and connected to downspouts to capture the runoff from the rooftops. They are also appropriately placed near other impervious surfaces such as roads or parking lots where they will collect runoff. The retention capacity of a rain garden is greatly influenced by its depth, soil amendment, and plant choices (varied native plants are optimal), its size should be between 5 to 10 per cent of its catchment area (Qin, 2020; NRCS, 2005).

Figure 5.28. Illustration of a rain garden

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Due to their high infiltration and retention capacities, rain gardens are considered highly effective as a stormwater management strategy, they do however have a relatively moderate cost of implementation and require some maintenance (Magnussen, et al., 2017). Like most infiltration based NBS, they are also considered less effective in preventing flooding from extreme rainfall as they can quickly become fully saturated (Autixier, et al., 2014).

Figure 5.29. Rain garden

Rain gardens also provide effective means of water purification by collecting and filtrating pollutants from surface runoff, are cheap to implement, accommodate biodiversity, and create natural attractiveness through lush plant life (Magnussen, et al., 2017).

5.4.4. Vegetated bioswales

Bioswales (shown in Figure 5.30) are vegetated inclined depressions in the ground designed as a green alternative to conventional storm sewers. They are often fitted with ornamental grasses, shrubs, and other native plants that can withstand prolonged exposure to flooding, larger stones are also be used to break flows and reduce water velocity. The main purpose of a bioswale is to collect stormwater runoff from nearby surfaces, which is then absorbed in the vegetation, infiltrated into the ground, retained in the bioswale itself, and later evaporated. Bioswales will also function as a transport medium for stormwater runoff should their infiltration capacity be exceeded. During such occurrences, the bioswale will channel the runoff away from vulnerable areas and into a natural recipient or tie into a storm sewer system as a last resort. An underdrain pipe can also be used in areas with insufficiently drained soils to remove excess water during peak flows (Caflish & Callahan, 2015).

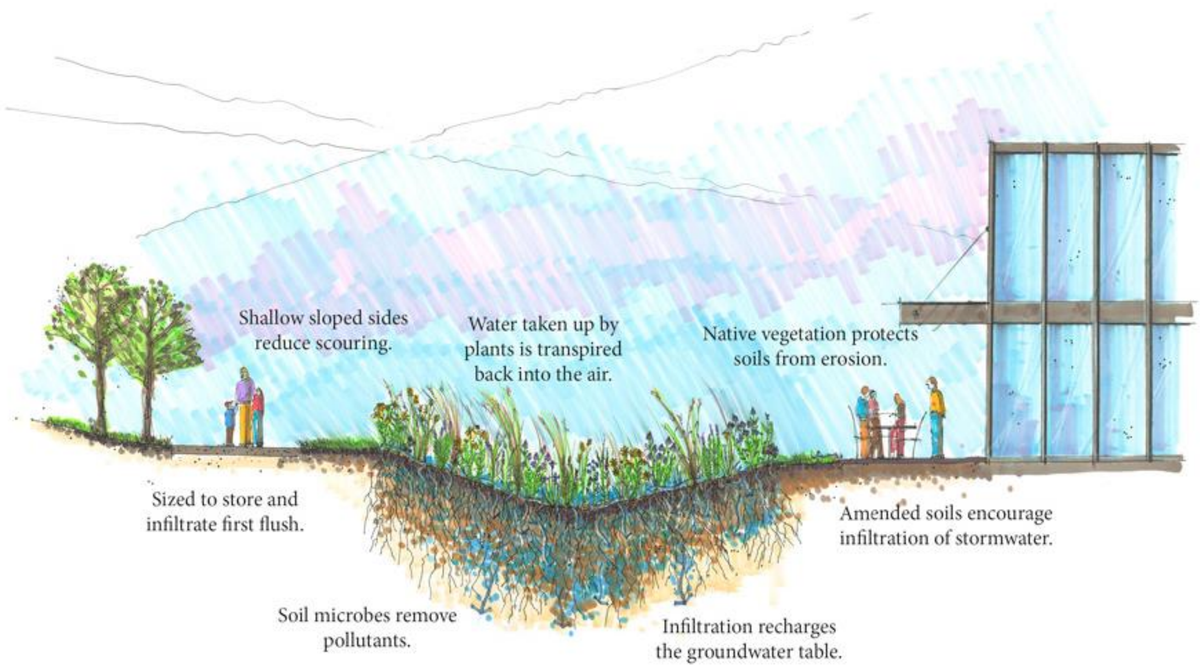


Figure 5.30. Illustration of a bioswale

The infiltration and retention capacities of a bioswale work exceedingly well in residential and industrial areas for moderate amounts of rainfall but are significantly less effective at preventing flooding for extreme rainfall occurrences, which is a similar trait for most green solutions to stormwater management. With its ability to function as a channel, bioswales can manage stormwater at all the three steps of infiltration, retention, and safe transport, making it an exemplary adaptation measure to build climate resilience to stormwater flooding. They are however impractical to implement in areas with either very flat or very steep topography and should not be used in areas with high water tables where the groundwater can reach the bottom of the bioswale or in highly polluted areas (Caflish & Callahan, 2015; EPA, 2013).

Bioswales are also considered to be highly cost-efficient due to their stormwater management capabilities compared to their cost of implementation and maintenance. While they function appropriately alone as a stormwater management measure, they are most effective when used in conjunction with a series of nature-based solutions such as permeable pavements and green roofs. Furthermore, bioswales are also very adaptable as they can be dimensioned according to the needs of the area, with possibilities ranging from small neighbourhood roadside trenches to much larger instalments (see Figure 5.32 and Figure 5.33). While the required size of a bioswale will vary situationally, a general approximation is that it should be at least one per cent of its catchment area (Magnussen, et al., 2017; Caflish & Callahan, 2015).

Figure 5.32. Vegetated bioswale in neighbourhood (Eduardo-Palomino, 2018)

Outside of stormwater management, bioswales also provide benefits for natural attractiveness, biodiversity, and water purification. One study of bioswales with trees and engineered soils in a parking lot found overall pollutant removal rates of 95% (Caflish & Callahan, 2015), and the Seattle Public Utilities reported that their houses increased in value due to the landscape that its bioswales generated (Eduardo-Palomino, 2018).

Figure 5.31. Larger bioswale (NRCS, 2005)

5.4.5. Native landscaping

Native landscaping (see Figure 5.33) involves reincorporating native vegetation such as grasses, flowers, shrubs, and trees in areas where urban and industrial development has taken over the landscape. It focuses on reclaiming and restoring the natural ecosystem by reintroducing plants that accommodate native life. The increased plant life and pervious soil also restore the natural water cycle, which functions as an infiltration and retention measure for stormwater management (NRCS, 2005).

The main benefit of native landscaping outside of stormwater management is that once it is established, it requires minimal maintenance due to the already well-adapted plant life. However, with the changing global climate, natural landscaping might need to adapt by changing its local vegetation to be more suited to higher temperatures and a wetter climate. Like rain gardens and bioswales, native landscaping promotes increased water quality through filtration and creates natural attractiveness, it also creates recreational spaces depending on its size (NRCS, 2005).

Figure 5.33. Native landscaping in a neighbourhood setting

5.4.6. Urban trees

If done right, incorporating trees into an urban environment is one of the more effective means of building resilience to stormwater flooding. Trees function as miniature reservoirs, controlling stormwater at the source and reducing the amount of runoff through the following methods:

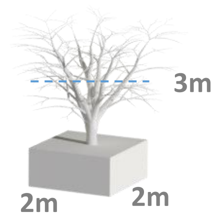
- Transpiration – a biological process where trees draw large volumes of water from the soil, which is later released as vapour from the canopies, effectively retaining stormwater.
- Interception – the tree canopy intercepts and absorbs rainfall which reduces the amount of stormwater falling on the ground, decreasing the peak flow and risk of flooding.
- Infiltration – The soil that trees require also creates infiltration. The larger roots from the tree also increase the infiltration capacity and rate of the soil, further facilitating runoff reduction.

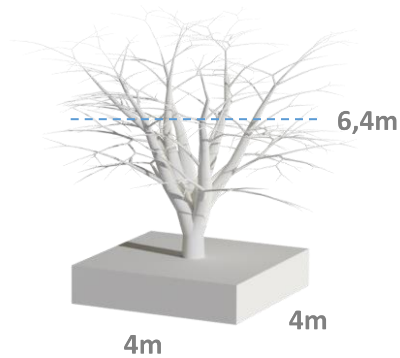
To optimize stormwater management, requirements of space, soil volume, drainage, and irrigation are crucial for urban trees. The soil volume needs to accommodate the size of the tree, and as bigger trees will divert and absorb more stormwater, the urban environment should include as many large trees as appropriate. Figure 5.35 depicts the required soil volume for tree differently sized trees (EPA, 2013).

Like most green infrastructure, urban trees are most effective for stormwater management when used in conjunction with other green measures. Placing several trees interconnected along a street will vastly increase their capacity to receive and manage runoff (EPA, 2013).

Trees as a stormwater management strategy are considered especially cost-efficient if installed and maintained properly, they can live for many decades and have relatively low instalment costs and maintenance. They are also vastly multifunctional as they provide benefits relevant to wind, sun, temperature regulations, biodiversity, water filtration, noise, air quality and attractiveness (EPA, 2013; Magnussen, et al., 2017).

Figure 5.34. Urban trees





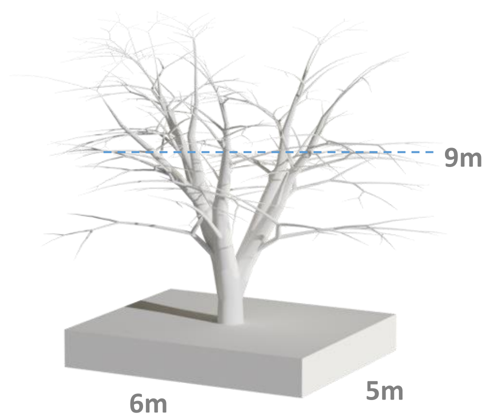


Figure 5.35. Space requirements for small, medium, and large urban trees. Soil depth is 0,9m.
Calculations adapted from EPA (2013)

5.4.7. Vegetated filter strips

A vegetated filter strip is a sloped permeable surface, often placed next to an impermeable surface like a road. As they are meant to absorb and retain large amounts of runoff from other surfaces, these filter strips should be designed with a higher capacity for retention than usual permeable surfaces, typically by increasing the soil depth and using the right type of vegetation. Because of the slope, the vegetated area is usually planted with dwarf turf grass, grassy meadows, or coarse bark/small pieces of wood to allow for a uniform flow of the runoff through the entire surface (Qin, 2020).

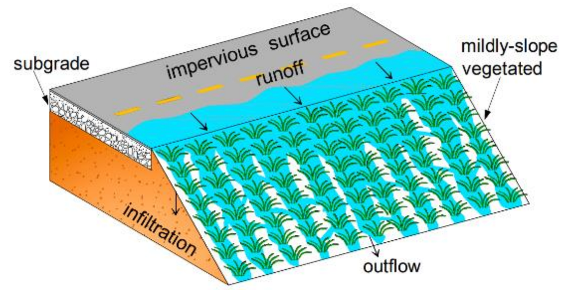


Figure 5.36. Vegetated filter strip (Qin, 2020)

5.4.8. Rain barrels

Rain barrels are an exceedingly simple and cheap technology to implement and only require some attention with regards to emptying in between rainfalls. They are small chambers connected to downspouts and placed near buildings to capture excess runoff from the rooftops where the collected water is stored for non-potable uses such as watering gardens or even flushing toilets. Similarly to other retention measures, rain barrels also have an upper limit to their water storage capacities and are effectively useless in further flood mitigation once they reach this limit (Qin, 2020).

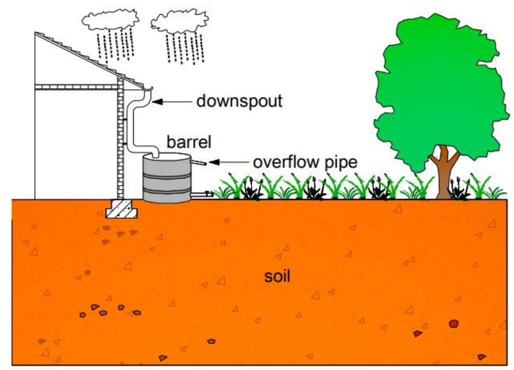


Figure 5.37. Rain barrel (Qin, 2020)

5.4.9. Stormwater ponds

So far, the nature-based solutions for stormwater management presented only work effectively for moderate rainfall events. In cases of prolonged or extreme rainfall, their retention capacities will likely not be enough to prevent flooding. To adapt to extreme rainfall events and to maximize climate resilience, urban areas particularly exposed to flooding should also include stormwater retention ponds as a multifunctional and powerful flood-risk adaptation measure (NWRM, 2013).

Figure 5.38. Stormwater pond

Stormwater ponds are depressions designed to catch and filter water with a greatly increased capacity in comparison to other green infrastructures and are constructed by excavating or utilizing natural depressions, or by creating embarkments. Their primary features are reduction of stormwater runoff, downstream erosion, and improvement of water quality in adjacent water bodies. The ponds can be designed to manage the runoff from more extreme storms by increasing their volume and storing surface water runoff which is released slowly after the risk of flooding has passed. They have a permanent water body often surrounded by vegetation which further increases the retention capacity of the pond as well providing protection from erosion (NWRM, 2013).

Additionally, well-maintained stormwater ponds fitted with lush vegetation can be attractive additions to the urban setting as well as local biodiversity. They also have a low/medium effect on reducing the urban heat island effect (Johnson, 2021).

While stormwater ponds are an effective climate adaptation measure, they have some significant recommendations and feasibility requirements before implementation. The most relevant parameters for urban planning are:

- The space required for a stormwater pond to allow for the required storage will typically be about 3 – 7% of the upstream catchment area, this will however vary depending on the scale of storage required. If the upstream catchment area is more permeable and has a relatively low runoff coefficient, the size requirement for the pond is reduced. The drainage area required to support a stormwater pond can be as little as 0,03 – 0,1 km^2.
- The ratio of the flow path length to pond width should be between 3:1 and 5:1 with inlets and outlets being placed opposite of each other.
- Ponds should be sited in low-altitude areas to allow for natural catchment by gravity, and outside the floodplain of any other watercourse to prevent additional flooding and contamination.
- Stormwater ponds are ideally combined with other upstream sustainable drainage components such as bioswales or urban trees to maximize stormwater quality and retention.

(NWRM, 2013)

5.4.10. Constructed wetlands

Wetlands are relatively shallow ponds with a high proportion of emergent vegetation relative to open water. They can be defined as marsh, peatland, or similar water bodies, whether permanent or temporary, with water that is static or flowing, fresh, brackish, or salt. Constructed wetlands are specifically designed features installed in the landscape that use natural processes to treat polluted surface water in an efficient and affordable manner (Russel, Pecorelli, & Glover, 2021). It is estimated that, compared to conventional, more high-tech water purification systems, urban wetlands reduce costs of managing stormwater runoff tenfold (atelier Groenblauw, 2020a). The main reason as to why they are so cost-effective is the natural processes they utilize to treat pollution, there are four key mechanisms for this (Russel, Pecorelli, & Glover, 2021):

- Nutrient uptake – Wetland plants absorb pollutants such as nitrogen and phosphorus to grow.
- UV irradiation – Exposure to sunlight removes pathogens and breaks down organic pollutants.
- Sedimentation – Wetland plants increase hydraulic resistance and reduce velocity; pollutants such as metals and non-soluble phosphorus settles at the bottom of the pond.
- Microbial action – Microbes created by the oxygen-rich environment break down pollutants such as hydrocarbons and transform nutrients. The oxygen-rich environment is created by wetland plant roots and is further assisted by the shallow water and large surface area of the pond.

In addition to improving water quality, constructed wetlands also provide benefits for flood risk reduction, biodiversity, and attractiveness (Russel, Pecorelli, & Glover, 2021):

- Flood-risk – Wetlands slow surface water flows and retain excess water, significantly reducing the risk of flooding downstream (a typical wetland should retain received water for 12-24 hours). They are by design similar in function to stormwater ponds.
- Biodiversity – Wetlands provide wildlife habitat for birds, insects, and amphibians.
- Attractiveness – If designed well, wetlands can create diverse and interesting landscapes for people, with possibilities of enhancing parks and open spaces and increasing public health and wellbeing.

Figure 5.39 depicts a section of a typical representation of a constructed wetland.

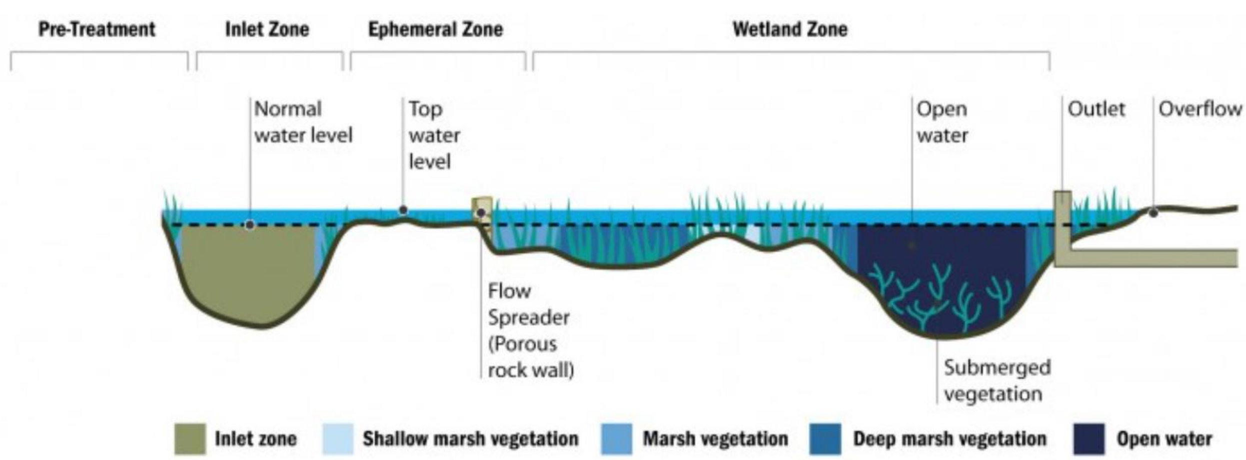


Figure 5.39. Section of a constructed wetland (atelier Groenblauw, 2020a)

Constructed wetlands are often more effective at stormwater management when created as a series of several interconnected smaller ponds as opposed to a single larger instalment. It is recommended that a constructed wetland system contains a minimum of 3 to 4 ponds of similar sizes, with a larger, deeper pond placed at the beginning of the system to handle the bulk of the pollution (seeFigure 5.40 Figure 5.41). This arrangement increased the effectiveness and potential for treatment and increased the overall resilience of the system. As the figures shows, constructed wetland ponds are typically elongated to allow for optimal water filtration. Generally, ovoid shapes with a length to width ratio of 4:1 is considered ideal for treatment purposes whereas long, narrow ponds should be avoided as they increase flow velocity, resulting in erosion and a reduced treatment effect. Bioswales can be used to connect ponds far apart as an alternative to narrow ponds (Russel, Pecorelli, & Glover, 2021).

Figure 5.40. First pond in a wetland system near Mosvatnet, Stavanger. Used to treat stormwater before it reaches the lake.

Figure 5.41. Second pond in same wetland system as previous figure. This pond is noticeably smaller and shallower.

Constructed wetlands require both space and water. To ensure effective operation, the catchment area draining into a wetland system should normally be at least 80 000 m^2. Furthermore, a general rule of thumb is that the surface area of a wetland system should be between 1-5% of the catchment area and should not be deeper than 3 meters. Following these statements, the surface area of any wetland system should not be less than $800m^2$. There is however no maximum requirement, as larger wetlands will be more effective at removing pollutants and retaining stormwater. Additionally, constructed wetlands needs to be placed strategically in low-lying areas prone to flooding or where water will pool naturally through drainage lines (Russel, Pecorelli, & Glover, 2021).

As wetlands include vegetation for filtration purposes, they should be designed to restrict water level fluctuations more than 30cm. Water levels beyond this point should be transported by an overflow outlet. This restriction will naturally affect the retention capacity of the wetland, so systems designed for higher water fluctuations will be more suited for flood risk reduction. Consequently, a wetland with lower water fluctuations and more vegetation will be more suited for water filtration (atelier Groenblauw, 2020a).

For a system of wetlands to replace conventional sewage, the wetlands must be fitted with appropriate vegetation and grates to manage all types of pollution from small particles to plastic bottles. The vegetation planted in the wetlands should be chosen with respect to water quality, biodiversity, and attractiveness. A diverse variety of native species is preferred, whereas non-native and invasive species should be avoided. Especially hardy species that thrive in polluted water should be selected for the larger ponds placed first in the system to manage most of the pollution, while the less hardy and more attractive plants can be used for the following ponds to enhance the urban landscape (Russel, Pecorelli, & Glover, 2021).

Figure 5.42. Common reed

Figure 5.44. Purple loosestrife (Russel, Pecorelli, & Glover, 2021).

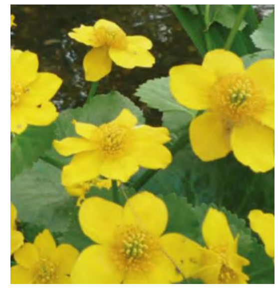


Figure 5.43. Marsh-Marigold (Russel, Pecorelli, & Glover, 2021).

Common reed is a very typical hardy plant that is especially suited for water filtration at increased depths but is generally not considered attractive. Purple loosestrife and Mars-Marigold are examples of more attractive plants which are less tolerant to polluted waters. However, the specific species of vegetation is highly dependent on location. One method of determining which species will thrive is to use a diverse selection of seeds and see which will survive, this will also increase the visual diversity of the pond (Russel, Pecorelli, & Glover, 2021).

For attractiveness, an important consideration is the gradual improvement of the water quality throughout the system. Ponds located further from the starting point will have considerable cleaner water and will therefore facilitate more diverse and attractive vegetation, enhancing the overall landscape. Wetlands can also facilitate recreational activities by including features such as boardwalks, seating areas, and steppingstones (see Figure 5.45, Figure 5.46, and Figure 5.47) (Russel, Pecorelli, & Glover, 2021).

Figure 5.47. Boardwalk over wetland (Russel, Pecorelli, & Glover, 2021)

Figure 5.46. Stones used as seating near wetland (Russel, Pecorelli, & Glover, 2021)

Figure 5.45. Steppingstones over wetland (Russel, Pecorelli, & Glover, 2021)

5.4.11. Above-ground drainage transport

Canals, channels, and gutters are examples of above-ground drainage systems that can manage and transport large amounts of stormwater depending on the dimensions of the system (atelier Groenblauw, 2020b). They can be categorized as either dry or wet, where dry drainage systems will as the name suggest, remain dry whenever it is not currently managing or transporting stormwater. Conversely, wet systems will always maintain a permanent water body capable of absorbing more water without overflowing during precipitation (FWR, 2013). Dry and wet channels are shown in Figure 5.48 and Figure 5.49 respectively.

Figure 5.48. Dry channel. Germany (atelier Groenblauw, 2020b)

Above-ground drainage systems are principally preferred to conventional and combined sewage systems when managing stormwater due to their several advantages. Above-ground systems are by design naturally more accessible and therefore much easier to prevent blockage and poor connections. They are also in most cases less costly to implement and maintain, as they are much simpler than their conventional counterparts (atelier Groenblauw, 2020b).

Figure 5.49. Wet channel. The Netherlands

When done right, above-ground drainage can be an attractive addition to the urban setting, capitalizing on the concept of ''visible functions'' as described in chapter 5.1.3. Channels can also be fitted with vegetation to accommodate many of the benefits green infrastructure incorporates, including an increased stormwater management capacity (atelier Groenblauw, 2020b).

5.4.12. Grey infrastructure

Grey infrastructure concerning urban flooding often refers to traditional stormwater management systems like gutters, storm sewers, and tunnels, and while they drain stormwater at a moderate pace, they are ineffective at coping with flooding caused by extreme precipitation. In contrast to NBS, grey infrastructure has the weakness of being solely focused on flood management, as well as providing low adaptability to future changes. They do however have some advantages, including a longer lifetime before major renovation, the ability to effectively transport water longer distances, and being better at handling rainfall events with medium and high return rates than infiltration-based measures. Grey infrastructure should therefore be used in combination with NBS to maximize the full capacity of urban stormwater management, utilizing both the reliability and acceptability of grey systems with the multifunctionality and adaptability of green systems (CIRIA, 2013; Alves, et al., 2018)

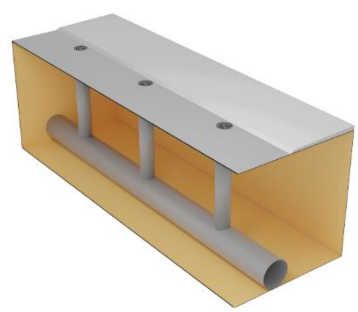


Figure 5.50. Illustration of a combined sewage system.

5.5. Heat-induced risk

Urban planning and building design can be means of reducing risks related to heat stress for residents in cities, increasing resilience against global warming and the urban heat island effect. The optimal way to counteract the urban heat island effect is to attempt to undo how it occurred in the first place. Ensuring that the city has a high proportion of green areas and vegetation, proper shading and building placement, as well as implementing lighter surfaces that reflect more heat are all methods to counteract it (C40 Cities, 2020; WHO, 2004).

Figure 5.51 condenses the relevant factors contributing to temperature manipulation for an urban area. There are essentially three distinct levels of exposure to heat stress, all relating to urban planning at a macro, meso, and micro level. The regional level refers to the impacts and factors at the macro level, which involves geographical placements and the function of the built environment, which is for the most part outside the scope of city planners if the area has already been decided. At the meso level, meaning factors relating to settlement, city planners have the most potential to influence the resilience towards heat stress. Here, the layout, open spaces, vegetation, density, etc. can be utilized to revert the effects of the urban heat island effect and reduce heat stress. At the micro-level, which concerns the buildings themselves, city planners and architects will need to collaborate to reduce the risk of heat stress. Here, orientation, lighter colours, and green roofs can be utilized (WHO, 2004).

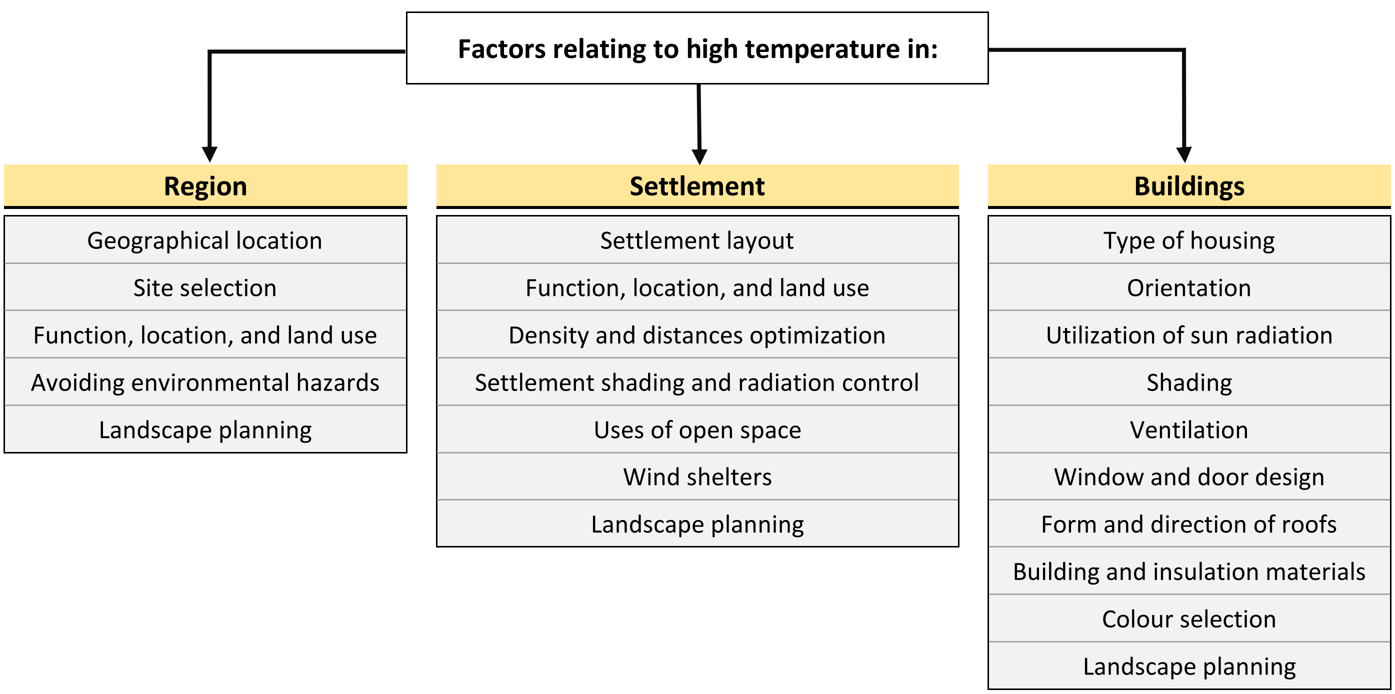


Figure 5.51. Factors relating to high temperature (WHO, 2004)

5.5.1. Settlement layout

According to Gago, et al. (2013) and MacLachlan et al. (2021), one method of mitigating the adverse impacts of increasing temperatures and the UHI effect is directly through urban planning, specifically regarding the placement and design of the buildings that enable optimal solar radiation, airflow, and reduced energy consumption. In dense urban areas, the combination of narrow streets and high buildings causes hot air to be trapped and reduces the airflow, which also creates a polluting and warming effect from the low wind speeds. To counteract this effect, several methods involving managing the layout are proposed. More methods are also presented in chapter 5.7.

The building site coverage and density of an urban area are one of the key factors contributing to the UHI effect, and by lowering the site coverage, the intensity of the UHI effect will be reduced proportionally. While it is not always practical to reduce the site coverage due to urban and political requirements, the most effective mean of doing so is to replace multiple low-rise buildings with fewer high-rise ones. This will in turn keep the FSI of the area while still lowering the total site coverage, allowing for increased airflow and optimal sun conditions.

Random assortments of tall buildings within an urban environment also reduce the effect of the UHI by increasing the aerodynamic roughness, the height of which wind velocity is equal to zero. Essentially, having an even vertical building layout creates an isolating effect from the wind, thus magnifying the UHI effect, while an uneven assortment of building heights breaks this effect, thus cooling the area. An overall increased building height also increases shading, which further reduces the temperature of the area through less exposure to sunlight.

Areal density and horizontal uniformity also affect the intensity of the UHI effect by isolating the area from airflows. By increasing the distance between buildings, cool and fresh air is allowed to flow, thus reducing temperature and air pollution. This also allows for more vegetation to be incorporated in between the buildings, further reducing the UHI effect through the added benefits of nature-based solutions. Furthermore, having a grid-like structure to the layout increases the need for pavements and hard surface areas, which magnifies the UHI effect and limits the options for vegetation. Therefore, another method of managing temperature is to optimize the horizontal placement of buildings by reducing uniformity.

Thus, the optimal layout of an urban area in relation to the UHI effect includes uneven building heights, uneven horizontal placement, and low site coverage. It is also recommended that to manage turbulence and wind at street level, the buildings should be on a perpendicular angle in relation to the predominant wind. These methods can also be utilized as an opportunity to increase the temperature in specific areas of interest, like an area close to the beach or a garden

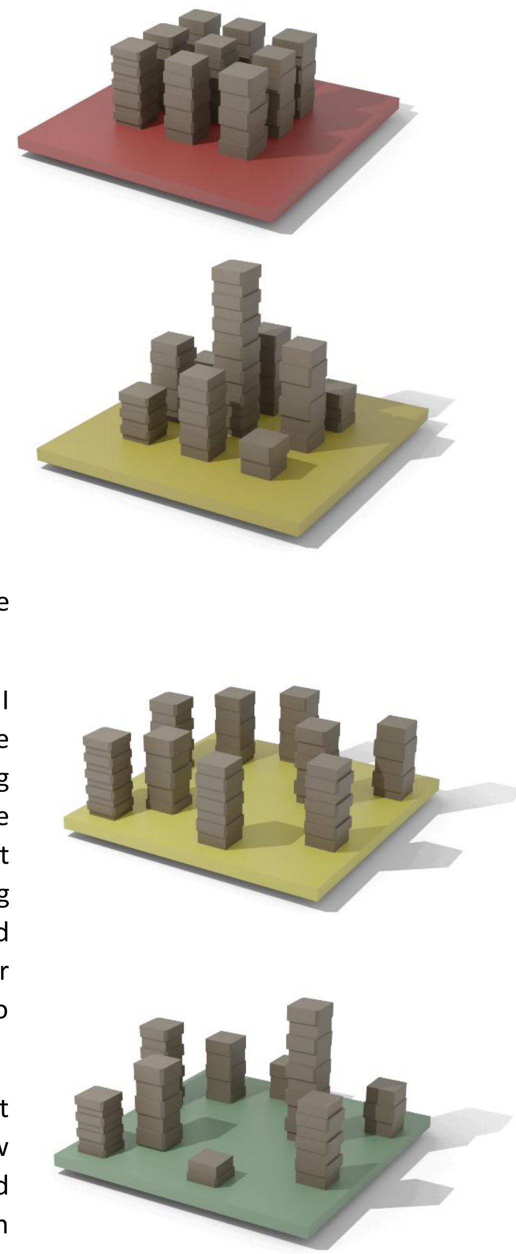


Figure 5.52. Optimal layout for reducing the UHI effect and facilitating comfortable wind conditions

5.5.2. Shade

As mentioned in chapter 4.2.3, direct sunlight causes the effective temperature to rise by up to 9 ^oC. Providing key areas with shade will therefore be a crucial strategy in reducing heat-related risks. Architecture in especially hot countries has regularly utilized shading structures such as arcades, pergolas, and other types of extended roofs to provide shade at ground level. Retractable awnings are especially suitable in temperate climates as they can be adjusted to both allow for and restrict sunlight and wind. Shade can also be created by vegetation as a multifunctional adaptation. Tall trees and vegetated canopies (see Figure 5.53) are especially effective at mitigating the UHI effect as they provide both shade and temperature regulation through evapotranspiration (Williams, 2021).

Figure 5.53. Vines over a street. Jerez, Spain. (Williams, 2021)

5.5.3. Water

Water has a natural cooling effect through evapotranspiration, making urban spaces next to larger ponds, waterways, and the shore more resilient to heat-related risks. A study done in Manchester showed that canals in the city reduced temperatures in nearby urban areas by up to 1,6 ^oC. The canals in the study also showed no cooling during cold seasons, meaning that utilizing water as heat reduction adaptation is especially suitable in temperate climates where further cooling is not desirable in winter (Canal & River Trust, 2021).

However, still water in canals and ponds has a limited effect on temperature regulation. Conversely, moving water generates spray and has a significantly increased cooling effect on its surroundings. Fountains and water cascades can be attractive means of achieving this. Their cooling effect can also be magnified if the source of water spray is located in a shaded area (Williams, 2021).

5.5.4. Reflective surfaces

The term 'albedo' is a measurement which refers to the reflectivity of a surface and in a climatic setting, it is often specified as reflectivity towards sunlight. Albedo is defined by the percentage of light a surface absorbs, ranging from a value of 0% to 100%, or often just 0 to 1, with light, reflective surfaces having a low albedo value close to zero, while dark, absorbent surfaces have a high value close to 1. Consequently, if exposed to sunlight, surfaces with high albedo values will remain significantly cooler than surfaces with low albedo as the absorbed sunlight will heat the darker material (Ramírez & Muñoz, 2012).

Implementing surfaces with low albedo and avoiding darker surfaces is a key strategy for lowering the intensity of the UHI effect and providing comfortable thermal conditions. However, not all surfaces are suitable for being painted white – pavements, roads, and walls cause the problem of reflecting heat at pedestrians while also creating a blinding effect. Implementing low albedo surfaces still creates a significant overall positive effect for an urban area in terms of heat reduction, so implementing reflective surfaces is best preserved for areas with lower pedestrian traffic, such as parking lots or back alleyways. Rooftops are especially suited for having a low albedo as they will not cause said problems (Williams, 2021).

Figure 5.54. Workers painting the pavement white to combat high temperatures.

5.5.5. Green infrastructure

Green roofs, trees, and other vegetation reduces the effect of the urban heat island effect and counteracts high temperatures by providing shade, deflecting radiation from the sun, and creating evaporative cooling (EPA, 2021).

Urban parks have shown to have significantly lower temperatures compared to their surroundings (Gago, et al., 2013)., for instance, the temperature of a park in Goteborg, Sweden was documented to be as much as 4 ^{o}C lower compared to the rest of the city (Eliasson, 1992). Urban parks will also contribute to reducing the UHI effect by cooling down their immediate surroundings and reducing energy usage by lowering the need for air-conditioning (Lin, et al., 2017). The intensity of the cooling effect from urban parks in relation to size, layout, and use of different types of vegetation is not well known, as the cooling effect and the size of parks were shown to have no linear pattern. It is however documented that parks and gardens as small as 755 m^2 can contribute noticeably to the cooling effect and that higher amounts of shrubbery and trees increase cooling while grass does not. For high-rise high-density urban environments, a tree cover ratio (TCR) of around 42% in green areas is required to maximize the cooling effect. Any lower than 42% and the effect is negligible (Lin, et al., 2017).

As for the average temperature over an urban area, Robitu et al. (2005) showed that trees and vegetation could reduce the temperature by 3-5 ^{o}C, depending on the extent of vegetation used and the layout of the city. Green permeable pavements have also been shown to significantly alleviate the UHI effect through evapotranspiration (Huang, et al., 2019).

Figure 5.55. Green roofs as a heat-reduction adaptation. New York, USA.

Another measure towards building resilience to heat is green roofs. One of the many benefits of green roofs is the reduction in heat risk for both the city on a collective basis and for the residents living under the roof as they provide a cooling effect through shading and evapotranspiration. Relative to conventional roofs, green roofs lower indoor temperatures by 1,5 ^{o}C to 3^{o}C, as they reflect about 20% - 30% solar radiation, absorb about 60% of heat through photosynthesis, and transmit only 20% to their growing medium. This reduces heat flow by about 70% - 90% in summer, and about 10% - 30% in winter, depending on the type of roof and the local climate (Marvuglia, Koppelaar, & Rugani, 2020; US Department of Energy, 2004).

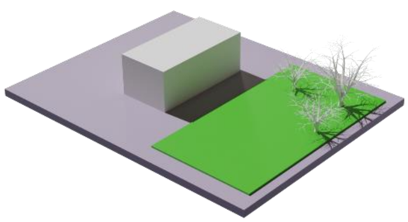
The extra layer of soil also contributes to the heat resistance of the building by providing insulation, further reducing related risks as well as increasing energy savings from air-conditioning. It is however important to note that the thermal insulation of green roofs will differ depending on the degree of saturation in the soil substrate, soil depth, and type of vegetation used. A saturated substrate creates a cooling effect on the building, which will have a positive effect on both comfort and electricity savings for the residents of the building during summer but will have a reduced effect on heating during winters (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014). Proper insulation is therefore important in temperate climates.

To optimize the heat resistance of green roofs, a diverse selection of vegetation involving a combination of succulents, sedum, tall forbs, and grasses is recommended (Lundholm, Maclvor, MacDougall, & Ranalli, 2010), but the exact species of plant will differ depending on the local climate. Taller trees are also an effective mean of reducing heat stress but are considerably more difficult to implement as they require deep intensive green roofs to grow.

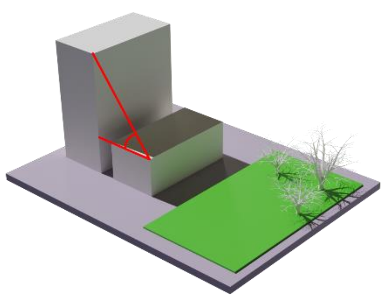
5.6. Sunlight access

Natural lighting is one of the more vital factors that ensure attractiveness in urban areas. It is recognized that at least 1 to 2,5 hours of sunlight are important to satisfy certain human psychological requirements (Pereira, Silva, & Turkienikz, 2001). Solar access to buildings and public spaces directly correlates with building orientation, height, and design, as well as the topography and latitude of the area. Naturally, solar access is preferred for public spaces and most buildings. Many plans and regulations have incorporated this, requiring a certain amount of sunlight for public areas. Adapting to sunlight in an urban project is much less of a climate change adaptation and more of a requirement for success. As such, sunlight should be a vital factor when determining the layout and building height of the area, but intolerable climate risks should still take precedence over it.

For an urban area, the optimal sun conditions are determined by the solar envelope. The solar envelope is a construct of space and time: ''*the physical boundaries of surrounding properties and the period of their assured access to sunshine*'' (Knowles, 2003). While it can be accurately calculated using descriptive geometry or computerized programs, a much simpler method is to use physical or digital models with a sun-simulator to visualize the effect of the sun's movement on an urban area. For instance, the optimal building typology can be determined by analysing the synergy between building height, slope of the roof and angle to subsequent floors, and solar access (Kristl & Krainer, 2018). Figure 5.56 depicts this relation.



The building height is raised to where the top floor will start to shade for areas of interest.



The height of subsequent buildings is raised to where it will also start generating shade in the area of interest. The angle between the top floors of the two buildings is called the obstruction angle and is decided by the latitude of the area (see figure Figure 5.56) (Pereira, Silva, & Turkienikz, 2001). The roof of the first building can also be sloped following this angle to add to the density of the area without compromising sun conditions.

Figure 5.56. Simulation of obstruction angle

For horizontal building patterns, the strategy to achieve optimal sun conditions is to arrange streets at right angles to each other, creating a chess pattern. Furthermore, orienting the main axis of the buildings to a northeast-southwest placement creates the overall best sun conditions throughout the year. Placing the axis on an east-west axis does allot the most amount of sunlight through the windows but has the disadvantage of leaving the northern side completely shaded half of the year. With the diagonal orientation, all sides of the building receive sunlight more evenly (Lepore, 2017).

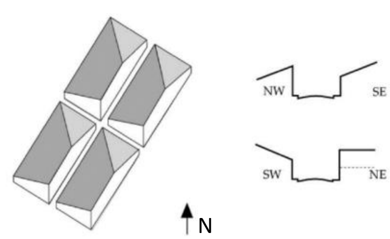


Figure 5.57. Optimal building orientation for solar access (Lepore, 2017)

For dense urban areas, optimal sun conditions can be achieved by utilizing a courtyard structure with building blocks following the obstruction angle. Figure 5.58 and Figure 5.59 depicts this concept where the sloped buildings uphold the solar envelope of the area, allowing for a high FSI without compromising sun conditions. Courtyards and other open public spaces are faced towards the sun, with buildings and other structures enveloped around them (Lepore, 2017).

Figure 5.59. Building shape following the solar envelope (Sarkar, 2009)

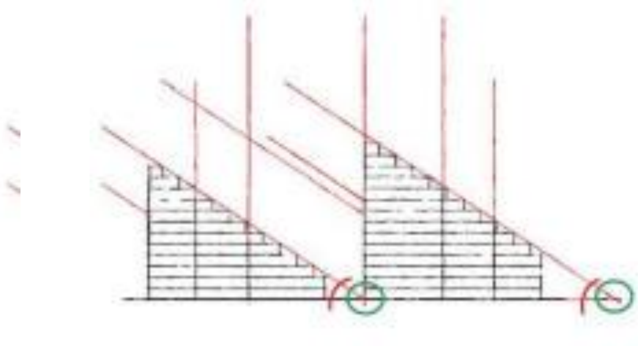


Figure 5.58. Depiction of the obstruction angle (Sarkar, 2009)

5.7. Wind

As with sunlight and temperature, wind dynamics in urban areas are also caused by human interference, affect the liveability of cities, and normally concern the comfort of residents and pedestrians in the area. High wind speeds (20 m/s and above) can also pose great risks for humans and structures (Qiu, 2016).

The goal of managing wind dynamics in the urban setting is to avoid unpleasant wind speeds at ground level caused by the surrounding structures. For instance, because of pressure difference, a building that is more than twice the height of the average proximal building is known to influence the comfort level of pedestrians and cyclists. Wind patterns such as these can be manipulated by the right design of buildings and the layout of them. Smaller additions such as trees, windbreaks, and balconies also contribute to changing wind patterns. Furthermore, wind dynamics in cities also connect to the ventilation of the city, as wind blocked by buildings, trees, or other obstacles causes air pollution and heat build-up (Qiu, 2016).

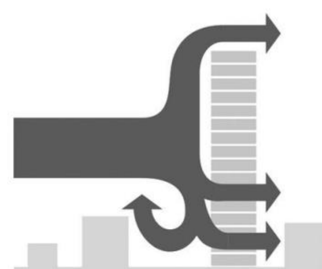


Figure 5.60. Wind pattern on tall buildings (Reiter, 2010)

The structure of the urban area can be used to adapt to wind patterns and avoid discomfort from high wind speeds. Long streets positioned parallel to the prevailing wind direction often cause the wind to be canalized along with it, creating high wind speeds especially if the street is getting narrower. As a rule of thumb, the length of a street should not exceed 10 – 20 times the height of the average proximal building (Wu & Kriksic, 2012).

The height of the buildings should be strategically determined to achieve optimal wind conditions. Tall buildings can be placed in context with prevailing wind directions to either restrict or encourage wind flow at street level in between the tall building and shorter buildings. As Figure 5.61a depicts, if a tall building is placed downwind of a smaller building, the wind is blocked, allowing flow at street level. Should the taller building be placed upwind of the smaller building, as depicted in Figure 5.61b, the wind will instead pass over the street. This phenomenon can be utilized depending on the local climate and prevailing wind directions, where a hot climate will benefit from allowing wind flow at street level, whereas a cold climate will benefit from restricting it (Wu & Kriksic, 2012).

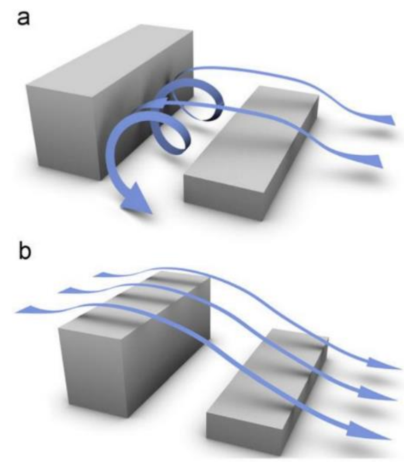


Figure 5.61. Different wind patterns on buildings (Wu & Kriksic, 2012)

One way of adapting to high wind speeds at ground level is to utilize canopies that deflects the wind, as shown in Figure 5.62. Canopies in the form of hard roofs are usually the most effective at restricting wind in key areas but often lead to transferring the high winds to other nearby areas. However, some areas may require that the wind is deflected without blocking out the sun, leaving canopies as a non-viable option. Alternatively, dense trees or elevated trellis structures can be utilized to create a compromise between sun- and wind conditions. Nature-based solutions like this also deflect less wind to nearby areas but will allow for higher winds directly below them (Cochran, 2004).

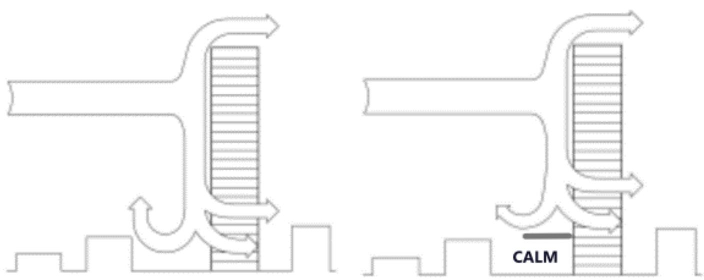


Figure 5.62. Effect of canopies on tall buildings (Cochran, 2004)

Placing entrances and areas where people gather at the centre of the building often leads to more inviting and calming winds (shown in Figure 5.63, left), whereas truncated corners at ground level often experience unpleasant winds (shown in Figure 5.63, right) (Cochran, 2004).

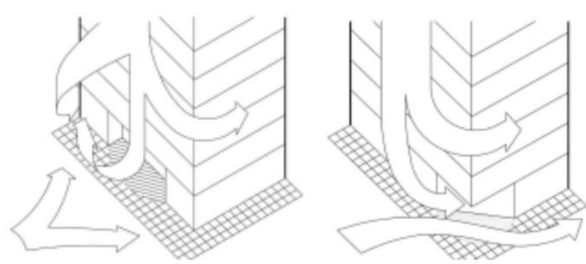


Figure 5.63. Good (left) and bad (right) options for entrances with relation to wind conditions (Cochran, 2004)

Building layout and morphology are other factors influencing wind conditions at the pedestrian level. In the courtyard structure, at least two openings are required to trigger adequate air circulation, where the openings need to be positioned in such a way that one will function as an inlet and the other as an outlet. Figure 5.64 depicts eight different ways to place these openings and the corresponding wind patterns. Here, the optimal placement to accommodate good ventilation, passive cooling, and interior comfort is to position the openings as shown in the lower right of the figure. Alternatively, if passive cooling is to be avoided, the two options in the lower left of the figure should be chosen (Casini, 2021).

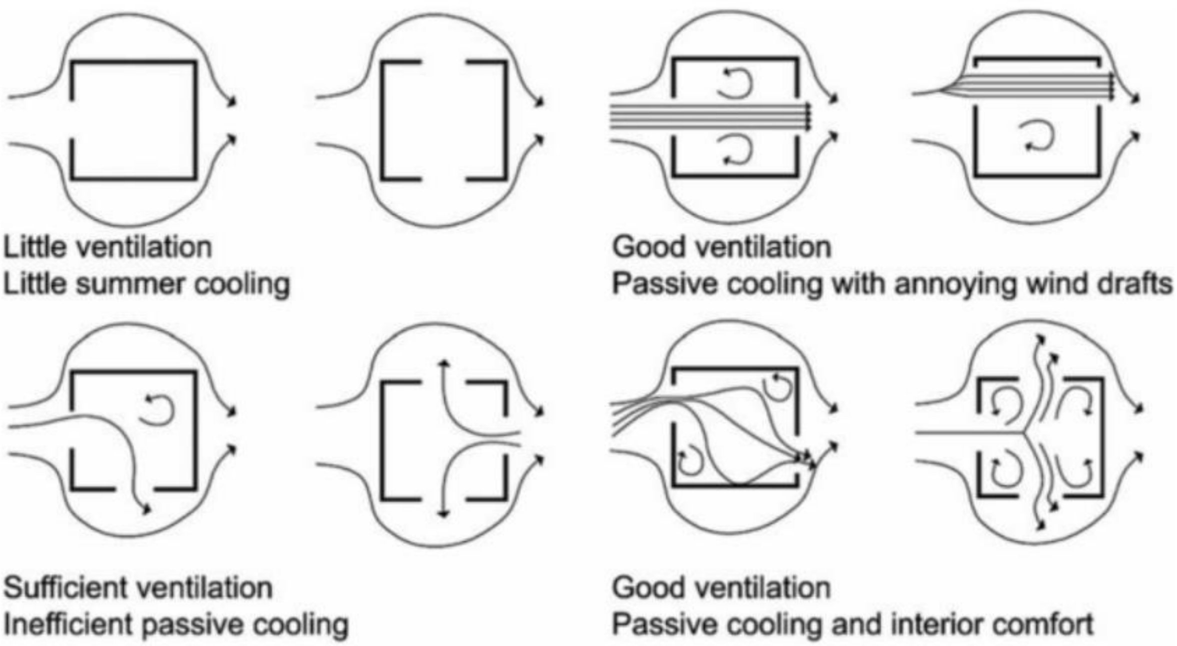


Figure 5.64. Effect of openings' position on wind dynamics in a courtyard structure (Casini, 2021)

5.8. Drought

Whereas droughts can be a devastating occurrence resulting in famine in many developing areas, countries like Norway are far more resilient due to their wet climate and economic status. As such, the risks of drought in Norway mainly cause economic restrictions on water usage and issues for local ecosystems (NVE, 2020).

The main adaptation strategy for urban planners to build resilience to drought in urban areas is to collect and store surface water runoff for later uses, also described as rainwater harvesting. Rainwater harvesting systems can be simple implementations such as rain barrels, ponds, and other types of water reservoirs used in private households. Infiltration measures such as permeable pavements with a storage chamber for urban trees and other vegetation can also be an effective method of rainwater harvesting (Sweco, 2020).

5.9. Air pollution

Within urban planning, air pollution can be alleviated through several of the already mentioned climate adaptations, namely by accommodating wind conditions, incorporating green infrastructure, and increasing walkability.

In general, areas experiencing low wind speeds will be subject to reduced air quality and pollutant build-up. By capitalizing on wind flows and urban ventilation, air pollutants can be filtered out through strategic planning of the layout and building height of an urban area (Henning Larsen, n.d.).

Green infrastructure is a significant contributor to increasing air quality by absorbing pollutants such as CO_2 and NO_2. Plant species with finer, more complex foliage are especially effective at air purification. However, the most influential green structure to increase air quality by absorbing dust particles is trees, with conifers being the most effective. The placement of trees should however not be blocking the wind in crucial areas and creating low wind speeds (Shafique, Reeho, & Rafiq, 2018; Henning Larsen, n.d.).

Increasing walkability reduces the usage of vehicles and thereby lowers traffic emissions. Accommodating electric vehicles by integrating charging stations and other benefits also reduces these emissions. It is however important that the walkability attained through urban densification is not responsible for lowering wind speeds and reducing air quality through poor ventilation (SWECO, 2018).

Summary of chapter 5

Urban areas with strong communities and flexible design are highly characterized by being able to recover fast from adverse impacts, which previously mentioned is a form of resilience. Community cohesion can be encouraged by improving the built environment for social interactions, liveability, and urban attractiveness.

Urban attractiveness is the product of several factors, some of which are:

- Order and variety – create streets that are neither boring nor chaotic
- Visible functions, lively streets, and recreational functions
- A sense of enclosure – streets should have a street to building height ratio between 1:1 and 1:4
- Identity and local features
- Climate, such as temperature, wind, and sunlight
- Green areas

Resilience to coastal flooding is mainly built directly by elevating terrain or structures and building barriers, or indirectly through avoiding development in exposed areas. Building barriers are usually far less cost-effective and carries added detriments to the environment.

Stormwater flooding should be managed by adopting the natural water cycle – infiltrate, retain, and safe transport. Green infrastructure such as green roofs, parks, trees, rain gardens, bioswales, and ponds are examples of measures that facilitate infiltration and retention. Urban wetlands and open channels also facilitate water purification and safe transport. NBS such as these should be used in collaboration with each other to optimize their effects.

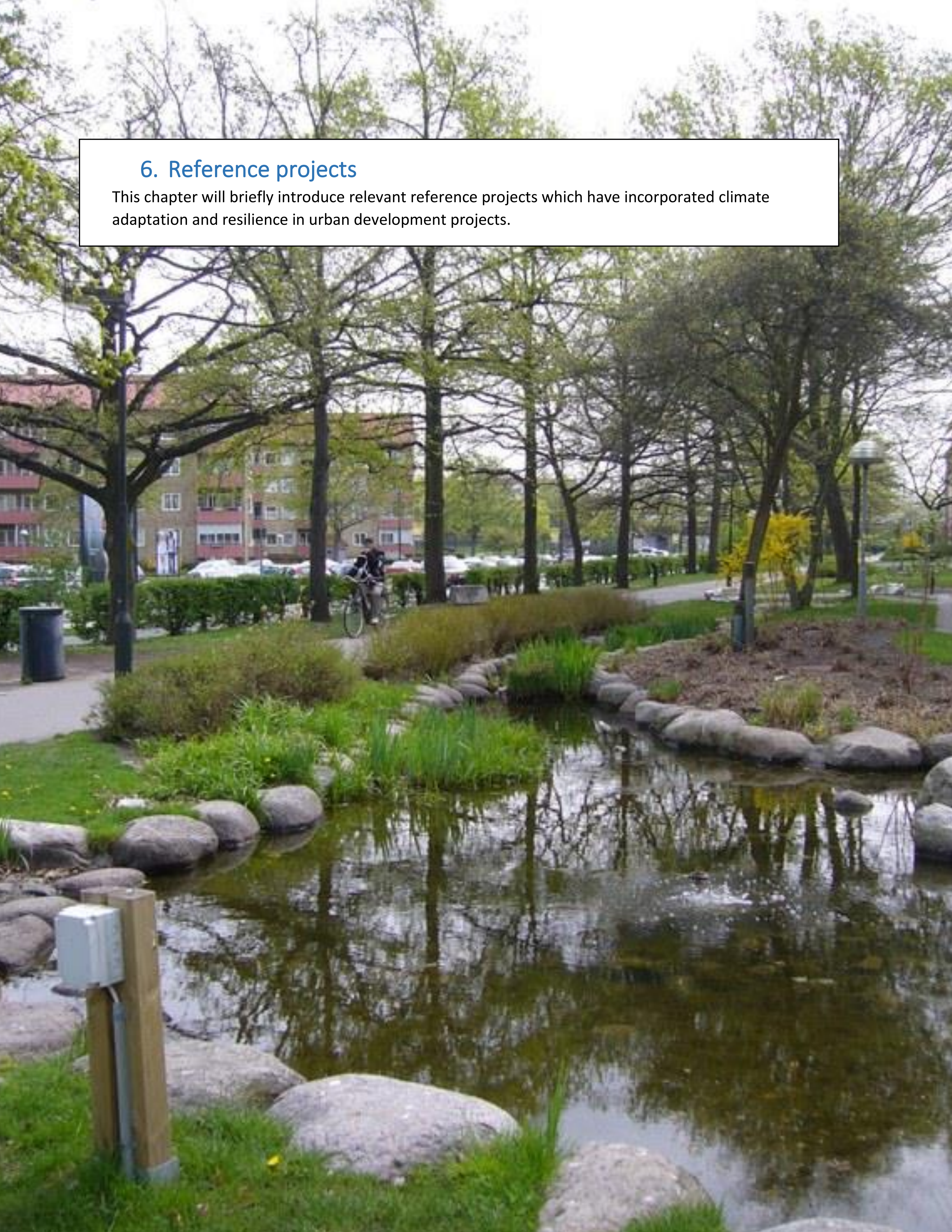
Resilience to heat-induced risks can be built by reverting the cause of the UHI effect. Impervious surfaces should be replaced with vegetation to facilitate evapotranspiration and reflection of radiation from the sun. Taller vegetation and other types of canopies are extremely effective in open areas exposed to sunlight. Wind drafts and sufficient ventilation will also reduce vulnerability to heat and can be achieved with the right building typology.

Sunlight access is also achieved through manipulating building typology, especially building height.

The consequences of drought and air pollution is largely solved by the secondary benefits from multifunctional adaptations such as rainwater harvesting, wind-manipulation, and green infrastructure.

6. Reference projects

This chapter will briefly introduce relevant reference projects which have incorporated climate adaptation and resilience in urban development projects.



6.1. Stormwater management in Malmö and Copenhagen

The municipality of Malmö, Sweden developed a strategic plan to make the city resilient to flooding from extreme rainfall by mainly using sustainable urban drainage systems (SUDS). The plan envelopes the entire city and aims to implement climate adaptations that minimise the risk of serious injuries, disruptions of vital services and death by 2025, and to make sure the city can handle a 100-year rainfall event with only limited material and personal damage by 2045. The plan highlights the importance of using multifunctional strategies with day-to-day functions, for example, a football field was redesigned as a flood catchment area during extreme rainfall (Frank, et al., 2019b)

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The main take-aways of the project are:

- Adopting a proactive approach to handle extreme rainfalls as opposed to a reactive approach is more cost-effective. Climate adaptations should be seen as an investment for the future rather than a financial burden in the present.
- Implementing climate adaptations is not only the responsibility of municipal administrations, but also calls for the action of homeowners, housing cooperatives, businesses, and citizens. Raising awareness is an important strategy to achieve action outside municipal administrations.
- Adapting to heavy rainfall can not be achieved through a ‘quick fix’ but requires an integrated and long-term perspective in all planning processes.

(Frank, et al., 2019b)

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Figure 6.1. Pond in a residential area in Malmö acting as a water catchment area (ClimateAdapt, 2021)

Augustenborg, a neighbourhood in Malmö (roughly twice the size of Paradis) was frequently flooded by an overflowing drainage system during the 1980s and 1990s and experienced economic decline partly because of it. With the projected increase in annual precipitation, the plan Ekostaden (Eco-city) Augustenborg project was developed in the late 1990s to create a more socially, economically, and environmentally sustainable neighbourhood (ClimateAdapt, 2021).

To solve the issue of recurring stormwater flooding and sewage overflow, it was proposed that the water runoff should be disconnected from the combined sewer and drained by employing SUDS and open water systems instead. These open systems were intended to handle 70% of the surface water runoff for impervious surfaces, which would eliminate the need for the combined sewer system by decreasing the total volume of water reaching pipes as well as reducing the peak flow (ClimateAdapt, 2021).

Several NBS have been included since the implementation of the plan. 6 Km of water canals and 10 retention ponds were created to retain and channel stormwater, green roofs have been implemented on all developments built after 1998 and retrofitted on more than 11 000 m^2 of existing rooftops. Green trenches, ditches, and wetlands have also been built to increase the retention capacity of the area. As a result of the implantation of the SUDS, issues with flooding have since ceased, and the image of the neighbourhood has been considerably improved. Figure 6.3 shows the map of blue-green solutions that were implemented in Augustenborg (ClimateAdapt, 2021).

Figure 6.2. Green roof in Augustenborg (Malmö stad, 2020)

Figure 6.3. Map of blue-green solutions in Augustenborg (Mottaghi, Sternudd, & Kärrholm, 2020)

While the stormwater management in Malmö is heavily focused on NBS, stormwater management in Copenhagen is mainly dominated by combined sewer systems releasing surface water mixed with sewage directly into the ocean. However, the heavily polluted water from the sewage system has stripped the harbour in the city of water-based recreational activities for decades. Copenhagen municipality developed a plan in which the aim was to reverse this effect and achieve a water quality suitable for swimming. Since implementing the plan, several retention basins were built in areas especially exposed to overflow, a strategy which reduced the required outlets from 93 to 38 and severely restricted the pollutants received in the ocean (Aspegren, et al., 2014).

Part of an earlier plan in Copenhagen involved using low-sensitivity public places (e.g., parks, sports fields) and open spaces for temporary storage for stormwater. However, a severe rainfall event in 2011 proved that the maximum capacity of these surfaces would only cover a portion of the flooding. As a result, Copenhagen municipality introduced additional measures focused on leading stormwater directly into the ocean via roads, canals, urban waterways, and underground tunnels. These large-scale blue-green measures proved to be one of the major available alternatives for sustainable stormwater management. Figure 6.4 shows an illustration of one of the proposed solutions that focuses on transforming the street into a storm-water runway in case of intensive rainfall (Aspegren, et al., 2014).

Figure 6.4. Illustration of open stormwater handling solution in Copenhagen (Aspegren, et al., 2014)

6.2. Building resilience to storm surges and stormwater flooding in Tromsø

The municipality of Tromsø, Norway faces climate change-related threats related to urban water management and has therefore incorporated climate adaptation measures into their new development projects. In corporation with Sweco, Tromsø municipality developed a concept plan of how to build resilience to flooding from stormwater and storm surges for both existing buildings and new development. The plan contains both general recommendations for the city as a whole and specific measures to be taken at a more detailed level (Sweco, 2021).

Figure 6.5 depicts the proposal for one of the areas developed with land reclamation. The first and likely most obvious measure to adapt to storm surges is that the land reclamation is elevated to a sufficient height, securing the important infrastructure from inundation. The difference in height between the previous development and the new development channels much of the surface water to the old shoreline, creating a strip along the area which will be frequently flooded low point. The plan accounts for the newly exposed area and places green structures along this line. Furthermore, canals are placed at the old shoreline to act as stormwater catchment areas that will channel excess water into the ocean. The canals can also be closed to restrict the increased sea levels from infiltrating further inland, and later be opened when the sea levels have returned. This allows the canals to act as measures for both stormwater management from inland flooding as well as engineered protection from storm surges. The canals are designed to be accessible to the public by descending steps, creating an integrated environment with the sea for social interactions, recreation and improving the attractiveness of the area (Sweco, 2021).

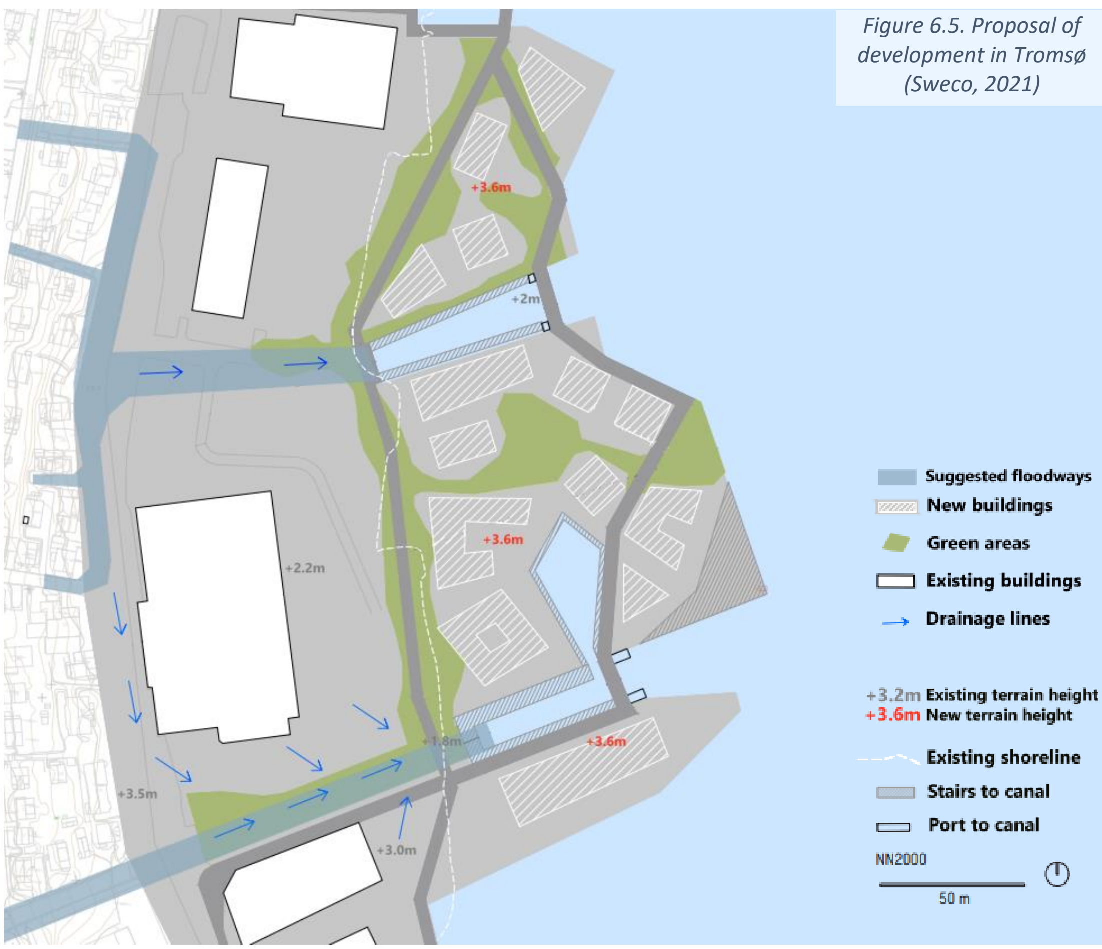


Figure 6.5. Proposal of development in Tromsø (Sweco, 2021)

Part 2: Analysis

Introducing the development area

Presenting relevant plans and regulations

Analysing the relevant climatic impacts

Establishing strengths, weaknesses, opportunities, and threats

7. Spatial analysis of Paradis North

To fully understand what type of climate adaptations is needed in Paradis, a detailed analysis of all relevant climatic factors must be undertaken, both current and expected. This includes the urban layout of the area, its local climate, its strengths, vulnerabilities, and areas of risk, while other aspects outside the scope of this thesis, like economics, culture, and history will be left out of the analysis. The overall objective is to lay the foundation for the proposal, which needs a firm understanding of the area to optimize the climate adaptation measures as well as attractiveness and liveability.

7.1. Introduction to Paradis North

The case area, Paradis North, is located in Stavanger, Rogaland, a county in southwestern Norway with relatively cool summers, mild winters, and a marine climate that receives considerably more precipitation than the rest of the country.

Paradis is seen as an attractive option with considerable potential for expanding the city centre further south. This potential derives from its position, view, closeness to the sea, and accessibility to public transport. Aside from the climate aspects, the main challenge of developing Paradis North as an urban area is its lack of spatial and visual cohesion with its surroundings, especially regarding the railway. The case area covers approximately 100 km^2 with a circumference of 2,3 km and is considerably elongated, being no wider than 70 meters at its thinnest and about 800 meters across the north to south (Kartverket, 2022 a).

Paradis North is situated approximately one kilometre south of the city centre in Stavanger and is located between the historical timber-built suburban areas of Storhaug and Våland. Bordering east is Hillevågsvatnet, a bay dominated by the boat harbour currently situated there. In the west, the area borders a railroad which separates Paradis from Våland. The area of Paradis continues further south (called Paradis South), where a developing office and residential area is currently forming.

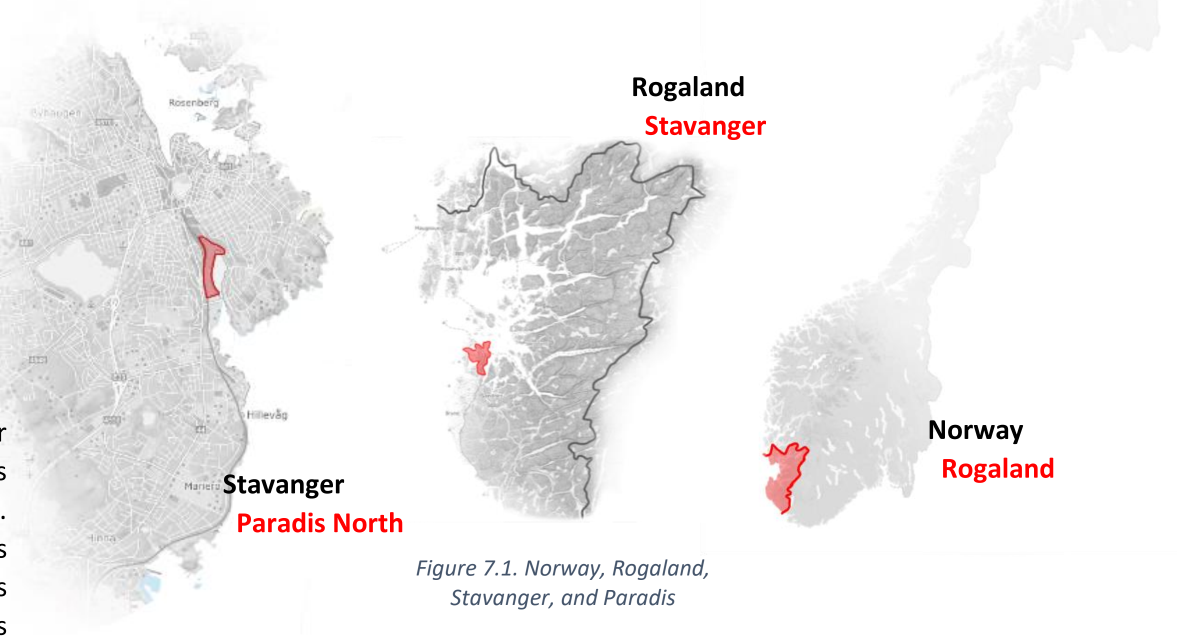


Figure 7.1. Norway, Rogaland, Stavanger, and Paradis

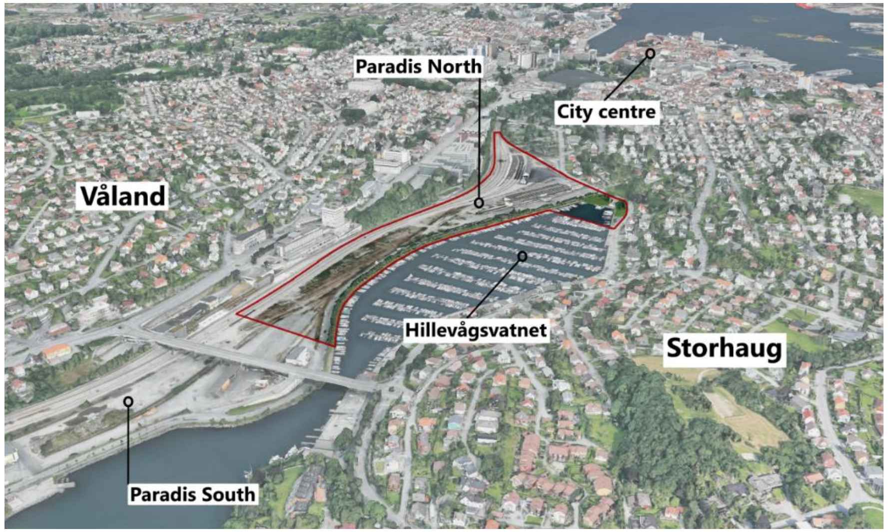


Figure 7.2. Site location, Stavanger

The case area is closely connected to the railroad, with a train station (Paradis Stasjon) being located just outside the southwestern border of the area. Paradis is visually divided into a northern and a southern part by Strømsbrua, a heavily trafficked bridge connecting Våland and Storhaug. Directly north of the area is Lagård Gravlund, a graveyard which serves as a green connection between Paradis North and the city centre. Northwest of the area is Lagård, an urban area with several important city- and residential functions such as business, housing, official services, and public transport. At the inner edge of Hillevågsvatnet and just inside the northeast border of Paradis North lies a smaller seaside park with a protected building, Terje Viken, which is used for rowing and other recreational activities. Figure 7.3 shows these points of interest.

Historically, the area of Paradis has been used as an industrial area which has led to a severe pollution of Hillevågsvatnet. Today this area is still considered unsafe for fishing and swimming due to its previous pollution, but also because of the boat activity from the harbour (Stavanger Kommune, 2021a). Currently, the area remains mostly unused as large parts of it are covered by mostly inactive railway tracks and storage facilities.

As seen in Figure 7.4, there are several different geographical boundaries of Paradis, each with their own definition. This thesis will define the case area of Paradis North after the new zoning plan for Paradis 2021 (yellow dotted line in the figure) (Temakart Rogaland, 2022), but will exclude parts of Støttparken and Lagård gravlund as these areas are already planned or developed. The exact boundaries of the development area of Paradis North are depicted in Figure 7.5 on the next page.

Figure 7.3. Points of interest around Paradis North

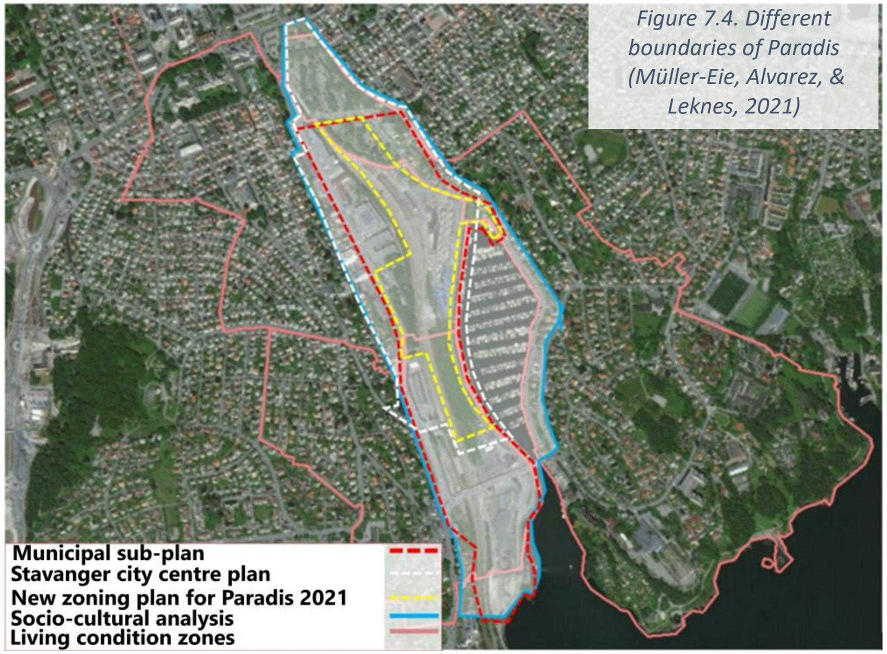


Figure 7.4. Different boundaries of Paradis (Müller-Eie, Alvarez, & Leknes, 2021)

7.2. Development and existing plans

The development of Paradis North is ultimately affected by several plans and documents that the urban planners will have to adhere to. These plans will differ depending on context, scale, and detail, and can essentially be divided into the four groups: national, regional, municipal, and zoning/regulation. This chapter will briefly introduce the most important and relevant details of these plans and how they affect the development area in this thesis.

The area of Paradis is divided into two separate parts. Currently, Paradis South has a zoning plan already developed, whereas Paradis North has not (seeFigure 7.6). As mentioned at the beginning of the thesis, a masterplan that emphasizes climate adaptation will be developed for Paradis North. The exact boundary of this plan is depicted in figure Figure 7.5

Currently, the redevelopment of the railroad tracks in the upper part of Paradis North is not included in any active plans. However, according to Bane Nor and Stavanger municipality, the extra set of tracks (see Figure 7.7) will at some point be removed to allow for further development of Paradis North. As this development does not have any plans yet, this thesis will assume that the extra sets of tracks are removed when designing the proposal for Paradis North, allowing for a larger case area.

Figure 7.5. Border of development area, Paradis North

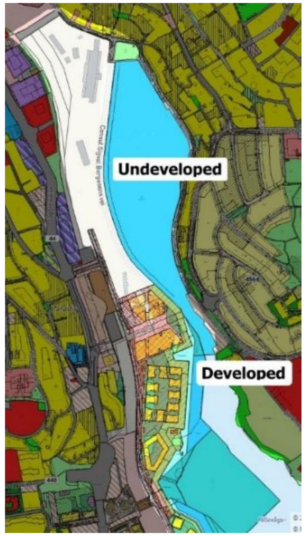


Figure 7.6. Zoning plan

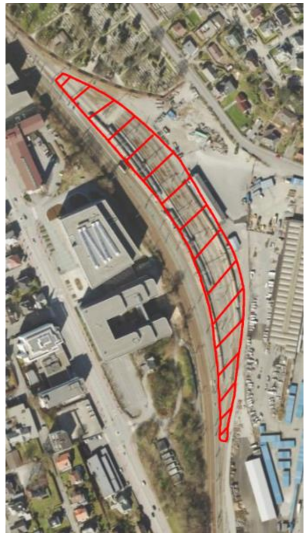


Figure 7.7. Railway

7.2.1. National plans

While there is no single comprehensive national plan for climate adaptation in urban planning, there are several regulations relating to it in The Planning and Building Act (Figure 7.9) and TEK17 (Figure 7.8)

The law states that an area can only be developed if it is sufficiently safe against adverse climate impacts and that for areas not sufficiently safe, the municipality shall either forbid development or implement changes that reduce the risk to a tolerable level (plan- og bygningsloven, § 28-1). The law also states that risk- and vulnerability analyses shall be carried out to assess and manage said risks (plan- og bygnigsloven, § 4-3). TEK17 further describes the building regulations for climate change adaptation, focusing mainly on climate impacts related to flooding, storm surges, and landslides. For storm surges and flooding, it states that buildings are divided into three safety classes depending on their vulnerability, with each type of building having an acceptable risk of either 20-year, 200-year, or 1000-year flooding occurrences.

According to TEK17, the area of Paradis should be secured against 20-year floods and storm surges, accepting flooding events in the 200-year range (TEK17, § 7-2). Guidelines for buildings at intolerable risks of storm surges mainly involve securing and proofing buildings for water damage, moving/avoiding development in areas at risk, the elevation of the areas, and implementing coastal armouring. For flooding caused by runoff, green infiltration measures and utilizing the natural water cycle are highly recommended as opposed to grey measures (TEK17, § 15-8; TEK17, § 7-2).

Figure 7.9. The Planning and Building Act

Figure 7.8. TEK17

7.2.2. Regional plans

The regional plan for Jæren og Søre Ryfylke (Figure 7.11) is a long-term plan for housing, area, and transport planning in 10 municipalities (including Stavanger) in Rogaland and is focused on the development of a sustainable and attractive region towards 2050. The plan consists of requirements and guidelines for urban- and regional planning, unlike its earlier versions.

The relevant aspects of the plan involving climate adaptation in urban planning heavily focus on avoiding building in areas at risk of climate impacts and incorporating green structures into urban areas as measures of risk mitigation. The plan specifically states that when establishing new residential areas, there should be no more than 300 meters of unobstructed walking distance from each building to a green area. Furthermore, urban areas are to be developed efficiently with high land use (they are densified) and facilitate for walking and cycling. Furthermore, a minimum of 50% of outdoor recreational areas are to be sunlit at 15:00 during spring equinox (20th of March) or have at least 4 hours of sunlight throughout that day. Municipal regulations state that 18:00 at midsummer (23rd of June) is also a requirement for this (Stavanger kommune, 2015; Rogaland Fylkeskommune, 2021).

Rogaland County has also developed its first regional plan specified toward climate adaptation focused. The plan is focused on creating climate resilience through proactively managing risks and creating opportunities derived from climate change. It states that the most relevant climate impacts for Rogaland are heavy precipitation (runoff), flooding, storm surges, landslides, and probable increase in drought. It is also especially emphasizing flood management as an important area of focus.

The guidelines emphasize proactive climate adaptations. Developing areas must be able to handle heavy precipitation and periods of long-lasting rainfall, with urban planners being responsible for identifying waterways and securing areas for water retention and infiltration. Water runoff is to be treated locally through the three principles: infiltrate – delay – secure safe floodways. Open and coherent nature-based solutions to flood risk mitigation should be prioritized (Rogaland Fylkeskommune, 2020).

Figure 7.11. Regional plan (Rogaland Fylkeskommune, 2021)

Figure 7.10. Regional plan for climate adaptation (Rogaland Fylkeskommune, 2020)

7.2.3. Municipal plans

As climate adaptation is involved in a broad spectrum of fields, there are several municipal plans relevant for climate adaptation in Stavanger. The general municipal plan (Figure 7.12) is more focused on attractiveness and connectivity but does mention climate adaptation, water runoff management, and blue-green solutions, emphasizing nature-based solutions as the preferred measure for climate risk reduction. The plan does not provide any specific requirements for urban planning in the area of Paradis but does describe Paradis station as an important stop for collective transport and refers to TEK17 § 15-8 for flood management (Stavanger Kommune, 2018 a).

In parallel to the general municipal plan, Stavanger municipality has also created a climate- and environmental plan (Figure 7.13). This plan emphasizes developing Stavanger as a green, environmentally friendly, and climate-resilient city but lackso any specific measures toward climate adaptation in urban planning (Stavanger kommune, 2018 b). Some of its goals include removing pollution in local ocean waters (fish caught anywhere should be safe to eat), clean air, increased plant life, and increased walkability.

The main plan for water management in Stavanger (Figure 7.14) focuses on surface water management and flood mitigation. The plan states that surface water must to a greater extent have the ability to be retained, leading directly to a recipient, or infiltrate through vegetation or the ground. Floodways are to be developed with minimal risk of adverse impacts during extreme precipitation. The plan focuses on handling the rainfall where it falls, emphasizing keeping or creating permeable surfaces as local solutions (Stavanger Kommune, 2019 a).

The green plan for Stavanger (Figure 7.15) is a plan under development aimed to be a strategic document for the green structure in Stavanger. The plan emphasizes the water management in the city, stating that green structures are to be an important factor in climate adaptation and surface water management (Stavanger Kommune, 2018 c).

Figure 7.12. Municipal plan (Stavanger Kommune, 2018 a)

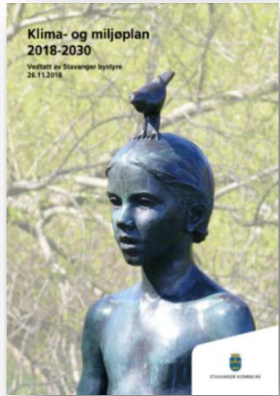


Figure 7.13. Climate- and environmental plan (Stavanger kommune, 2018 b)

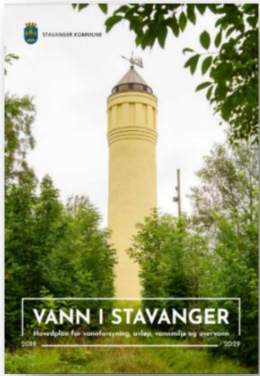


Figure 7.14. Main plan for water management (Stavanger Kommune, 2019 a)

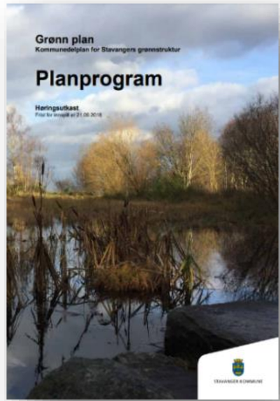


Figure 7.15. Green plan (Stavanger Kommune, 2018 c)

Figure 7.16. Stavanger municipal division plan (Stavanger kommune, 2019 b)

The municipal division plan for the Stavanger city centre (Figure 7.16) involves the development of Stavanger city and its goals, strategies, and planning concepts aimed at strengthening attraction for new residents and visitors alike. As such, the plan does not mention climate adaptation and is mainly focused on attractiveness and connectivity. However, there are many detailed descriptions of Paradis North included in this plan, in which Paradis North is enveloped in the ''City Centre South'' part of the plan, as shown in Figure 7.17.

The city centre plan states that the southern part of the area, ''Sentrum sør'', is to be developed as an extension of the main city centre, focusing on attractiveness and connectivity to the surrounding area. Sentrum sør mainly consists of Paradis North and Lagårdsveien, wherein Lagårdsveien is also under development and is to be developed as an attractive city street. Paradis is to be developed as an area with highly architectural and sustainable qualities, as well as being focused on attractive options for city life, unity between people, and connectivity through pedestrian and bicycle-friendly streets. The buildings of Paradis North are to be in a quarterly structure with between 5 to 7 floors.

(Stavanger kommune, 2019 b)

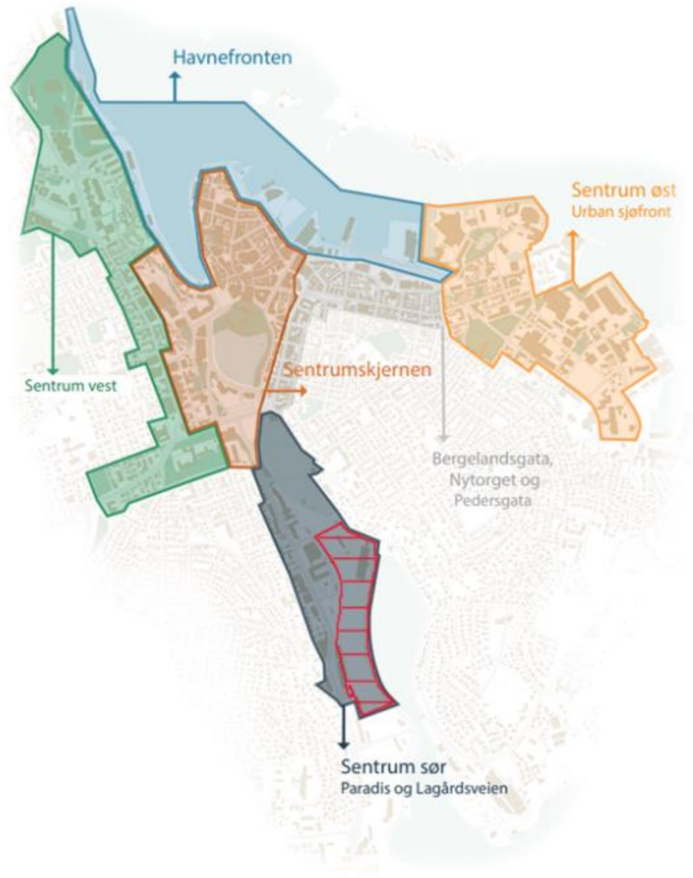


Figure 7.17. Boundaries for the Stavanger city centre municipal plan 2019-2030 Paradis North is marked with red lines.

Paradis North is specified to be developed with requirements of walking and cycling paths, green areas, and buildings with active first floors as shown in Figure 7.18, Figure 7.20, and Figure 7.21. These requirements are meant to make the area attractive and available for pedestrians. The green area along the shoreline is specified to be 18m wide, the main entrance for vehicles into the north area is via Kirkegårdsbrua, and the main entrance to Paradis South is still going to be south of the Strømsbrua bridge.

According to the plan, the terrain in Paradis North as marked in Figure 7.19 is to be elevated to account for flood-related risks in the area. A coherent terrain height of 2 meters above current sea level is to be achieved in the marked area, with an incline leading down surroundings. Existing structures outside the new flood protection under 2 meters above sea level are to be secured against temporary flooding.

(Stavanger kommune, 2019 b).

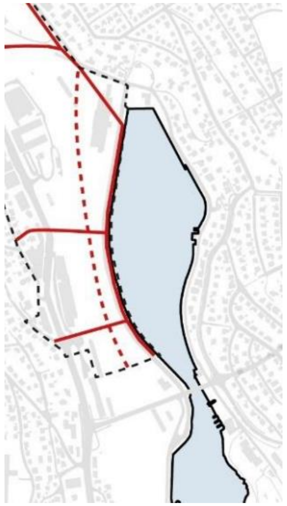


Figure 7.21. Walking and cycling paths

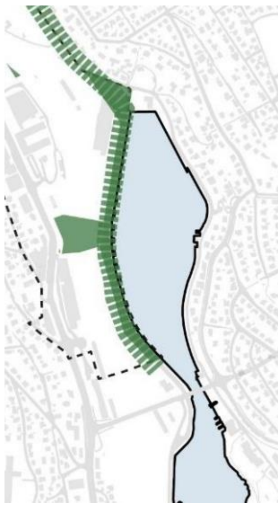


Figure 7.20. Green areas

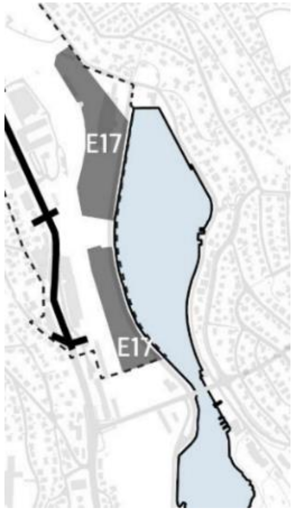


Figure 7.18. Buildings with active first floors

Figure 7.19. Terrain secured to 2m above sea level (Stavanger Kommune, 2017)

Plan 2760 area regulation for Paradis (Figure 7.22) is developed by Stavanger municipality and aimed at describing the vision, ambitions, and goals of developing the area of Paradis. The plan also contains current regulations of the area that will be accommodated in this thesis.

As this is a rather comprehensive document, the most relevant points are summarized below (some points are already mentioned in the previously described plans):

- Considering both flood management and attractiveness, the development and strengthening of a blue-green profile and how blue-green structures can contribute to the qualitative experience of the area are prioritized. Open canals leading water out to the sea are brought up as a possible example.
- Increased public availability to the sea is to be considered. Moving part of the moorings from the westside of Hillevågsvatnet is possible to accommodate this.
- Paradis is to be developed with restrictions on car use, instead focusing on pedestrians. The least amount of detours and as little conflict as possible with motorized vehicles is to be accommodated.
- The upper middle part of Paradis North is to be developed as a residential area with city life functions. The lower part of Paradis North is to be developed as a workplace area with city life functions (see Figure 7.23)

(Stavanger Kommune, 2021b)

Figure 7.22. Plan regulations Paradis (Stavanger Kommune, 2021b)

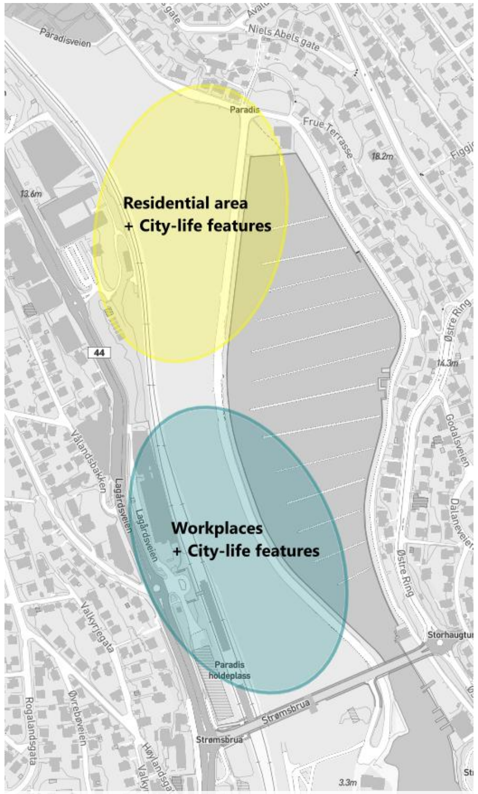


Figure 7.23. Recommended functions

7.2.4. Zoning plans in Paradis South

Paradis South is developed by Ghilardi + Hellsten Architecture, who won the architectural competition of the area in 2019. The area envelops approximately 76.000 m^2 and is closely connected to the railroad in the west and the sea to the east. Its design takes inspiration from the historical wooden houses in Stavanger and includes sharp angles in its building typology (see Figure 7.25 and Figure 7.26).

As a part of the development, the seafront was extended to grant more contact with the sea and emphasize a new attractive waterfront identity. Several challenges were present in the site involving infrastructural barriers, sound pollution, topography, access, and sun conditions

Additionally, a new harbour is planned for development just south of the area (see Figure 7.24), allowing some of the docks in Hillevågsvatnet to be relocated.

(Ghilardi + Hellsten Arkitekter, 2012)

Figure 7.26. Illustration of Paradis South

Figure 7.25. Zoning plan of Paradis South

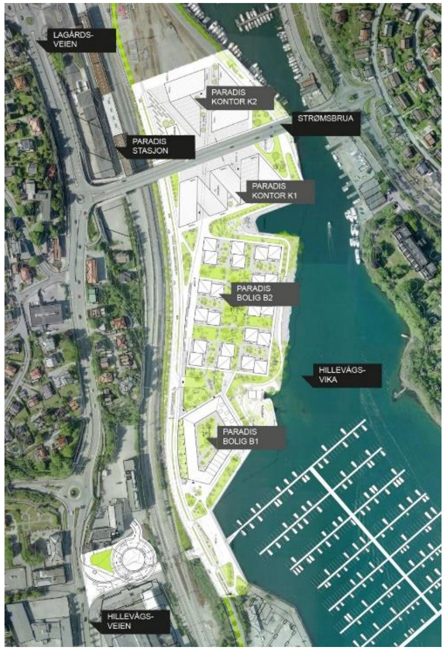


Figure 7.24. Masterplan concept of Paradis South by Ghilardi + Hellsten Architects (Ghilardi + Hellsten Arkitekter, 2012)

7.2.5. Connections

Figure 7.27 shows the planned connections to Paradis North. The main road for both vehicles and pedestrians is planned to be relocated from its current position along Hillevågsvatnet to the western edge of the area. It will have entrance points north in Lagårdsveien and south at Paradis Station. The connection through Strømsbrua is removed in the zoning plans.

The promenade along Hillevågsvatnet will be transformed into a walkway for pedestrians and cyclists to strengthen the area's connection to water. An additional walkway is planned at Støttparken to increase walkability in the area

(Kommunekart.com, 2022).

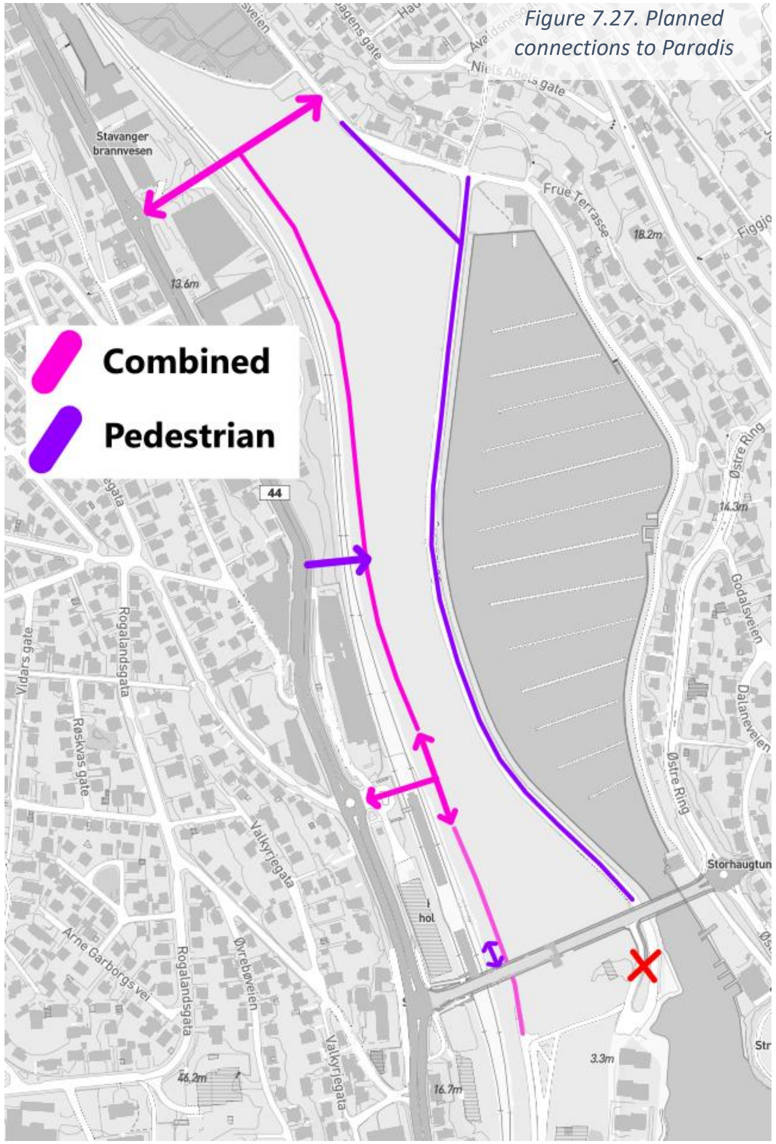


Figure 7.27. Planned connections to Paradis

7.3. Climate and environment

To create the optimal climate adaptation measures in the area of Paradis North, a firm understanding of the relevant environmental and climatic aspects is required. This subchapter will analyse these aspects that will later be connected to how the climate adaptation measures in the proposal should be developed.

7.3.1. Topography

Figure 7.27 depicts the height above sea level for the terrain around and inside the boundaries of Paradis North. As seen from the figure, the majority of the area ranges between 2 and 2,5 meters above sea level, increasing to 3 meters towards the western edges, Lagård and the Graveyard, and Paradis South. The inner area of Paradis North is especially flat and low lying with no significant changes in terrain height throughout the area. At the northeast part and the inner edge of Hillevågsvatnet, the terrain lowers to 1,5 and 1 meters above sea level. An especially steep hill between 6 and 15 meters lies adjacent to the railroad tracks west of the area, whereas a steep slope along the east side borders Hillevågsvatnet

Outside the boundaries of Paradis, the area of Lagård and Våland are significantly higher above sea level relative to Paradis, with the tallest peak in Våland measured at 83 meters above sea level and the connecting area to the west is around 30 to 40 meters above sea level.

The topography of an area and its surroundings are especially relevant when considering surface water runoff. Areas at risk of flooding are often low-lying and closely connected to sloped areas where excess water will originate.

(Kartverket, 2022 c).

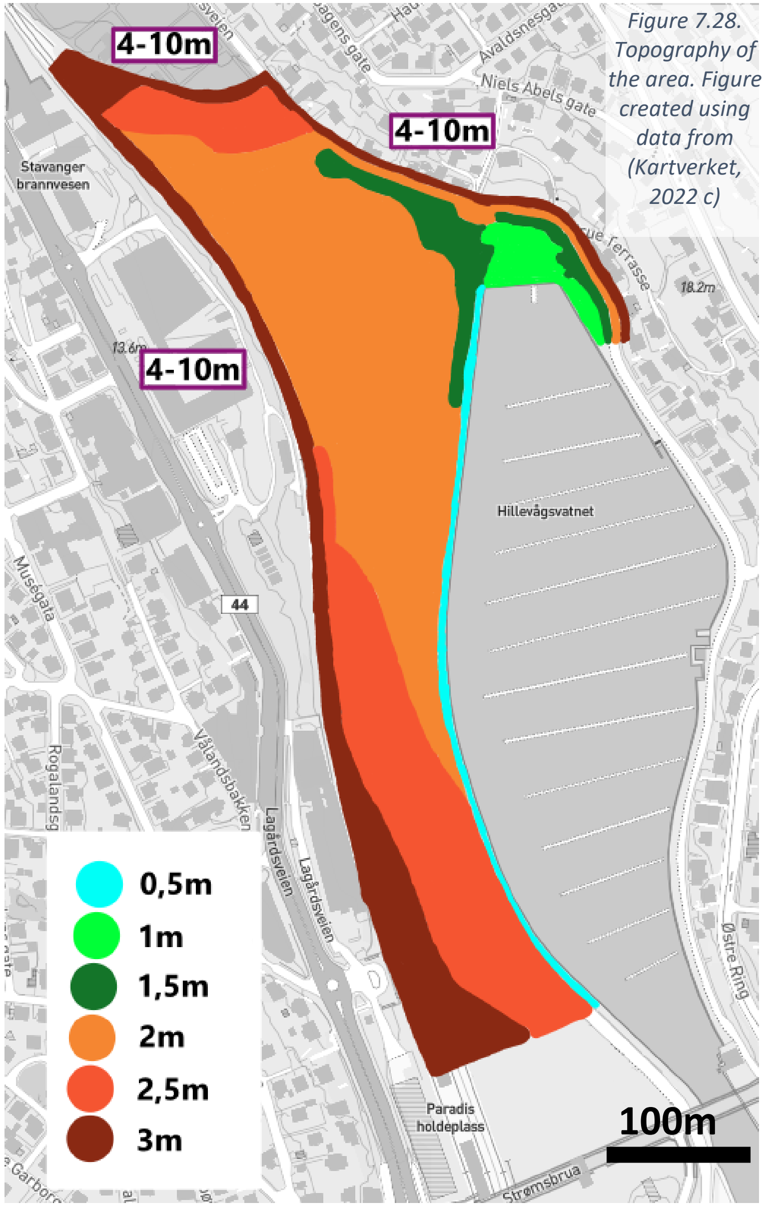


Figure 7.28. Topography of the area. Figure created using data from (Kartverket, 2022 c)

7.3.2. Green structures

The area of Paradis is still heavily influenced by the previous railroad activity and as a result, it is predominately grey and devoid of green structures. The only clear exception is the green promenade bordering Hillevågsvatnet. This green walkway consists of a stretch of grass and trees, creating a much-needed natural respite from the surrounding grey area.

The nearby urban areas do have a noticeably higher density of green structures compared to the more central parts of Stavanger, mainly consisting of patches of trees and private gardens. These green structures act as biological corridors in the area, benefitting both the surface water runoff and the biological diversity.

At the inner edge of Hillevågsvatnet, is a smaller park-like area consisting of a patch of grass and some trees. While this park is minimal, it acts as an important connection between Hillevågsvatnet and surrounding area. In the municipal plan, this park is extended towards the west, infiltrating further into the case area.

Støttparken, a small generally inaccessible green area is located directly west of Paradis, in the Lagård region. While it is still an important quality for the green factor of the area, its practical uses are severely limited by its availability for people. This area is planned for redevelopment in the municipal subdivision plan, where it is to be developed as more accessible to people. It will also be connected to the planned green area in the middle of Paradis North.

For larger green recreational areas, the immediate vicinity of Paradis is lacking. With only a cemetery in the north, the closest actual parks are Vålandskogen to the West, and the Varden area east of the Strømsbrua bridge. The Varden area is about a 15min walk from Strømsbrua, whereas Vålandskogen is easily twice that.

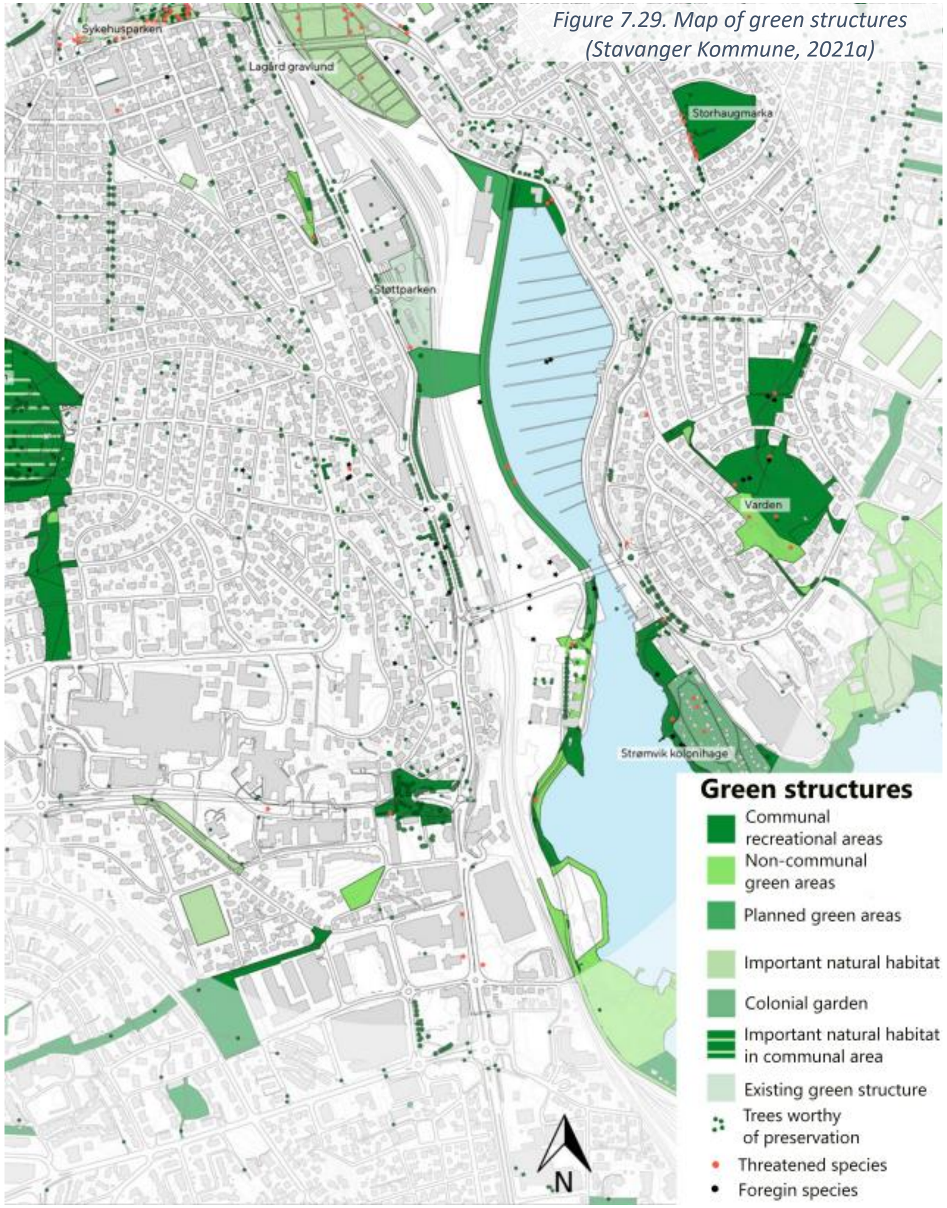


Figure 7.29. Map of green structures (Stavanger Kommune, 2021a)

7.3.3. Stormwater flooding

The case area is exposed to stormwater runoff from Våland and parts from Storhaug during occurrences of heavy rainfall. This combined with the relatively flat and low-lying nature of the area puts Paradis North at an especially high risk of flooding. The upper part of Paradis is North is also considered to be especially susceptible to flooding, as shown in Figure 7.31.

Figure 7.31. Rough susceptibility zones for flooding (Temakart Rogaland, 2022)

While the entire area of Paradis North is considered at risk, certain areas require special attention due to the topography and the drainage lines. Areas with multiple drainage lines converging will be at a higher risk of flooding due to the increased water flow. Figure 7.30 showcases a rough estimation of the theoretical drainage lines in and near the area of Paradis. These lines show where runoff will flow during the occurrence of heavy rainfall. The relatively lacking existence of green areas will contribute to an increase in water flow.

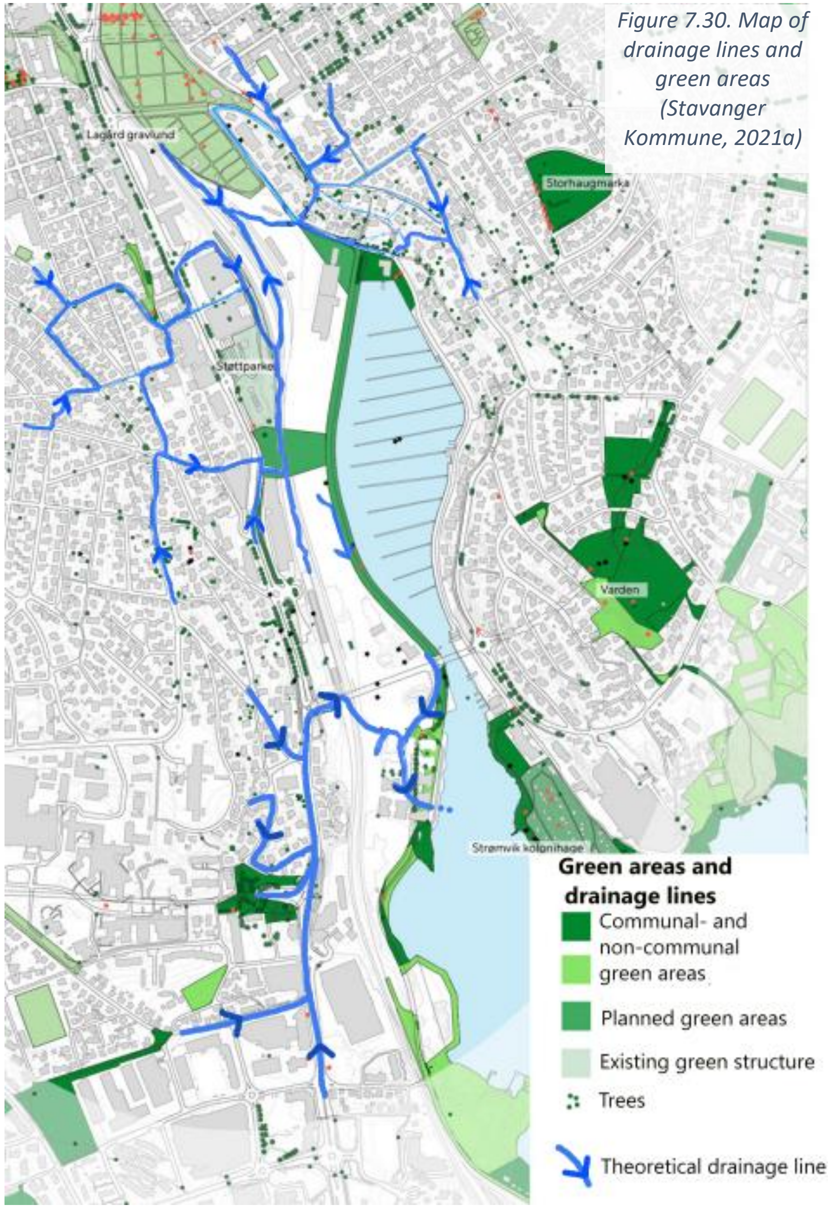


Figure 7.30. Map of drainage lines and green areas (Stavanger Kommune, 2021a)

Figure 7.32 focuses on the areas where several drainage lines converge at single points, creating an elevated risk of flooding. This is especially prevalent in the upper part of Paradis where drainage multiple lines converge from both Storhaug and Våland.

The middle part of Paradis North also acts as a chokepoint for several drainage lines and will be an important area of focus connecting Paradis to the surroundings. The planned green area at this point will contribute to the reduction in flood risk at this chokepoint

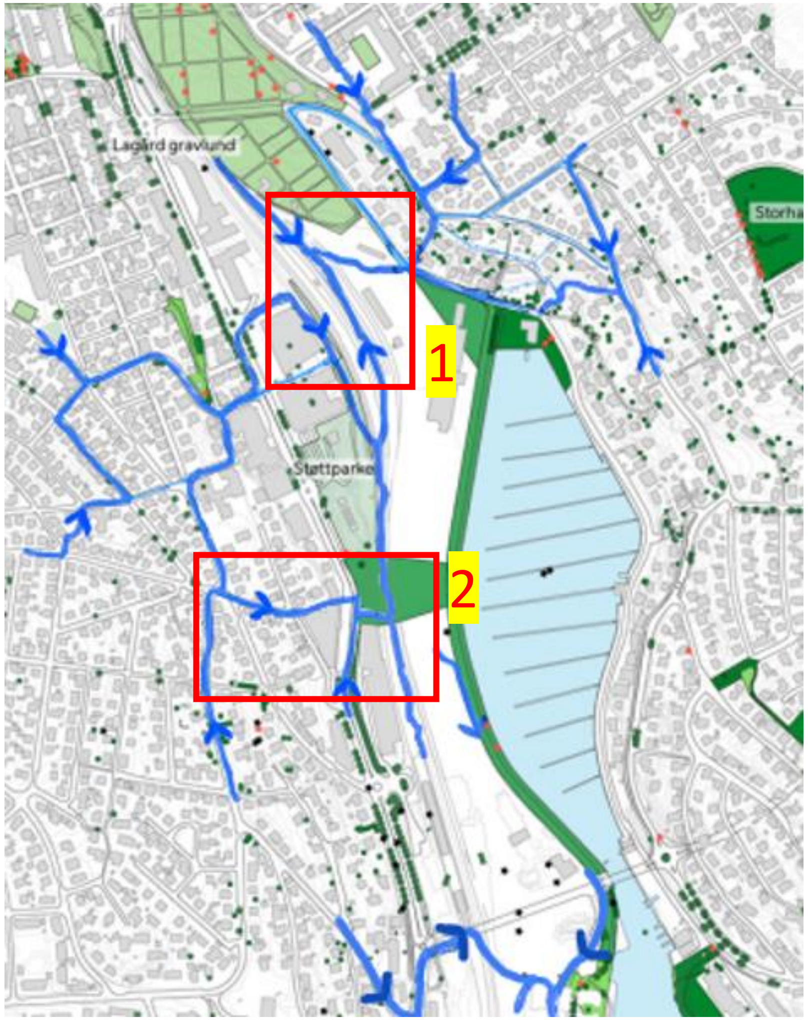


Figure 7.32. Drainage lines

7.3.4. Rising sea levels and storm surges

Due to its low-lying topography and location, Paradis North is exposed to rising sea levels. As depicted in Figure 7.33, Figure 7.34, and Figure 7.35, only the small park in the upper edge of Hillevågsvatnet is exposed to rising sea levels above the current mean.

However, a significant threshold is passed once the sea level rises two meters. Here, large parts of the north-eastern edge of the development area will be inundated, even reaching as far as the railway. A 2-meter increase in sea level in 2100 is not completely unrealistic as the effect of a 200-year storm surge in that year is expected to cause sea levels to rise by 185cm in Stavanger. However, this increase will likely have more effect in other areas such as Vågen.

At 3m, almost the entire area will be inundated, leaving only the highest point in Paradis South dry. A 3-meter increase should however be considered highly unlikely.

(Kartverket, 2022 b)

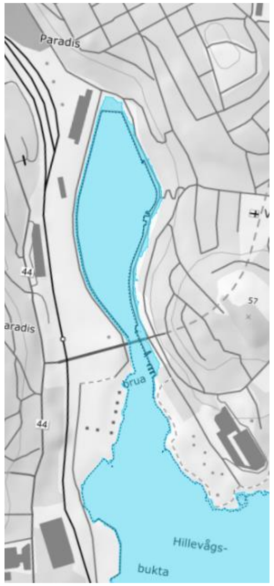


*Figure 7.33. Ocean level increase of **1m** (Kartverket, 2022 b)*

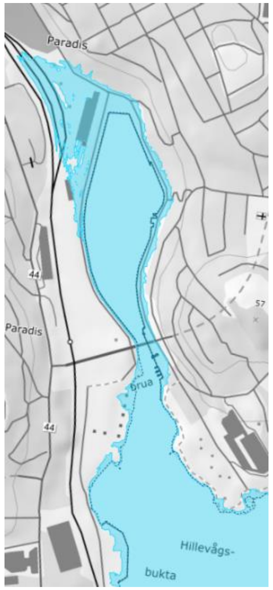


*Figure 7.34. Ocean level increase of **2m** (Kartverket, 2022 b)*

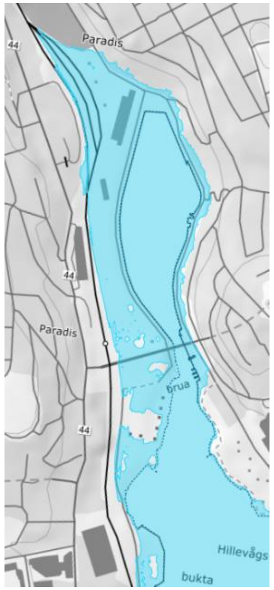


*Figure 7.35. Ocean level increase of **3m** (Kartverket, 2022 b)*

Currently, the area of Paradis is not at risk of inundation from storm surges as even a 1000-year flood will not reach further than the upper part of the coastline (see Figure 7.36).

As seen in Figure 7.37, Figure 7.38, and Figure 7.39, the difference in impact between a 20-year, 200-year, and 1000-year storm surge is relatively low. A storm surge in 2090 will primarily affect the park at the northern edge of Hillevågsvatnet, where the Terje Viken building will be completely flooded. The storm surges will also affect the lowest parts of Paradis North, which will primarily affect the planned park, part of the green promenade, and the main road.

Figure 7.36. Current 1000-year storm surge barely impacting the area (Kartverket, 2022 b)

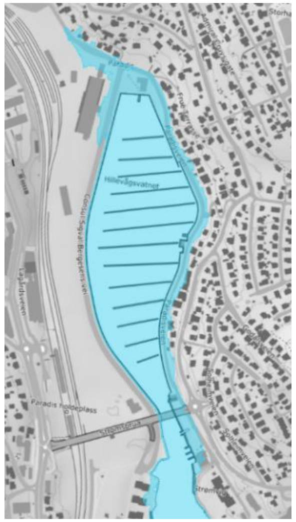


Figure 7.39. 20-year storm surge in 2090 (Kartverket, 2022 b)

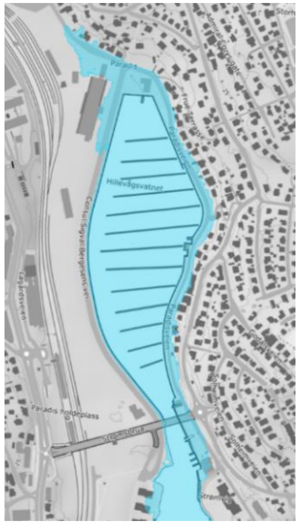


Figure 7.38. 200-year storm surge in 2090 (Kartverket, 2022 b)

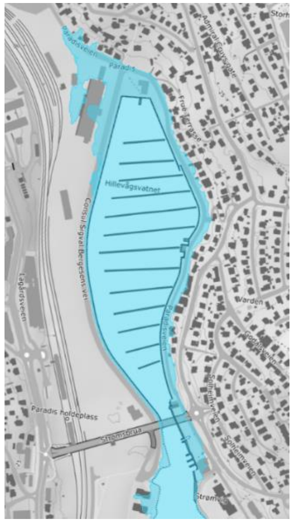


Figure 7.37. 1000-year storm surge in 2090 (Kartverket, 2022 b)

Figure 7.40 depicts the overlapping exposure zone for both stormwater flooding and flooding from storm surges. This area will therefore be particularly exposed to inundation.

(Kartverket, 2022 b)

Figure 7.40. Overlap of stormwater flooding and storm surge flooding

7.3.5. Wind conditions

The coast of Rogaland is largely affected by the low pressures entering the Norwegian sea, resulting in fairly strong winds. The average annual wind speeds in Rogaland usually range from 9,5m/s at the outer edges of the coast to 6,0m/s further inland. The area of Paradis receives relatively mild winds with an annual average of 6,5 to 7,0 m/s, which is rather usual for the inner parts of coastal areas in Norway (NVE, 2009).

Figure 7.41 shows the wind roses measured at Utsira lighthouse, which is located approximately 60km northwest of Paradis. The leftmost figure is for the winter season (October – March) while the one on the right is for the summer season (April – September). During the winter season, the most frequent wind direction is from the southeast. During the summer season, there is often a large daily variety of wind directions, mostly favouring northwest and south. For low-lying areas further inland, wind direction is often determined by local topographical conditions, following the direction of fjords and valleys (Mayer, et al., 2020).

Due to the topography and position of Paradis, the wind will mostly follow along in parallel to the length of the area, coming mostly from the southeast during winters or northwest during summers. Figure 7.42 shows the prevailing wind directions in Paradis

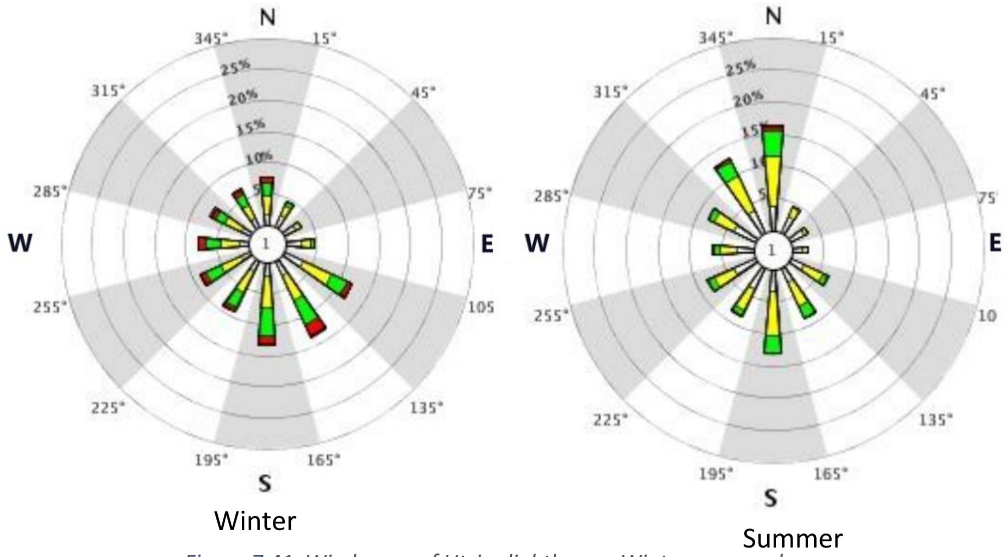


Figure 7.41. Wind roses of Utsira lighthouse. Winter season above, summer season below (Mayer, et al., 2020)

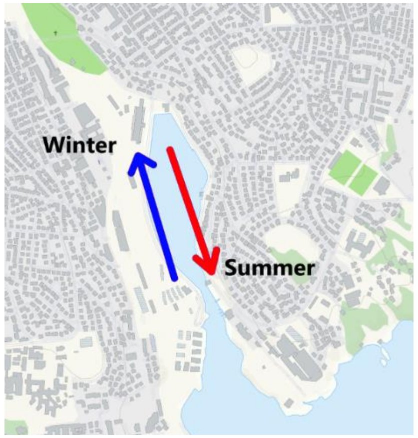


Figure 7.42. Prevailing wind in Paradis

7.3.6. Sun conditions

The area of Paradis is oriented in a north-south direction, meaning that the area will mostly face the sun at a perpendicular angle during early and late hours, and will face away from it during the middle of the day. As such, creating good sun conditions for the entire area will be significantly difficult without compromising building height. This will be especially true for the middle part of Paradis, where due to the thin nature of the area combined with the steep elevation in the Våland area to the west creates particularly bad sun conditions. Conversely, Paradis South and the upper part of Paradis North have excellent sun conditions.

Figure 7.43 shows the sun position throughout midsummer, where the sun rises at 05:00 and sets at 22:00. For spring equinox, the sun rises and sets at 06:00 and 19:00 respectively (Agafonkin, 2009).

Figure 7.45 and Figure 7.44 shows the simulated sun conditions throughout the area of Paradis North at midsummer and spring equinox.

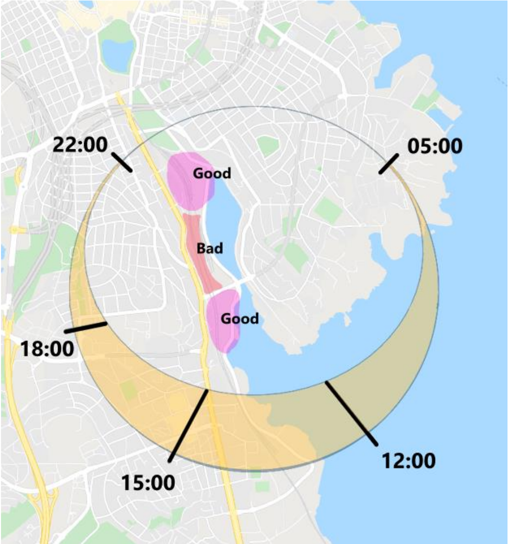


Figure 7.43. Sun conditions in Paradis at 23rd of June (Agafonkin, 2009)

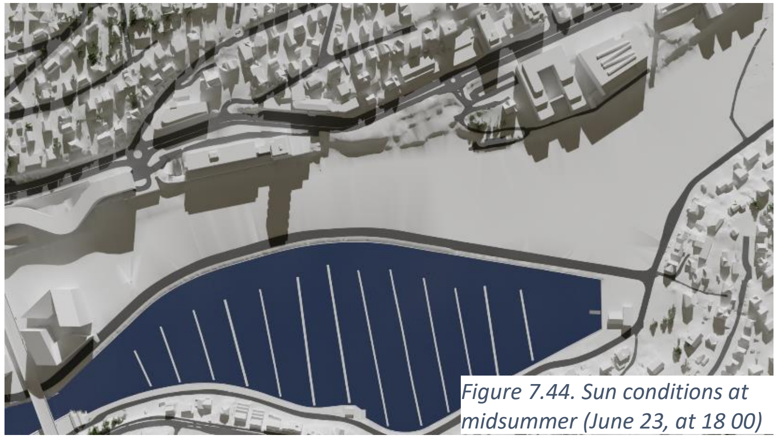


Figure 7.44. Sun conditions at midsummer (June 23, at 18 00)

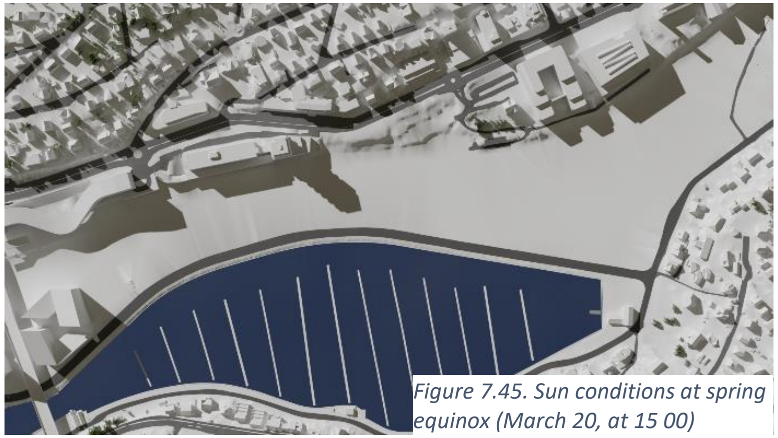


Figure 7.45. Sun conditions at spring equinox (March 20, at 15 00)

7.4. Pictures of the area

Figure 7.46. Northern end

Figure 7.50. Industrial park at northern end

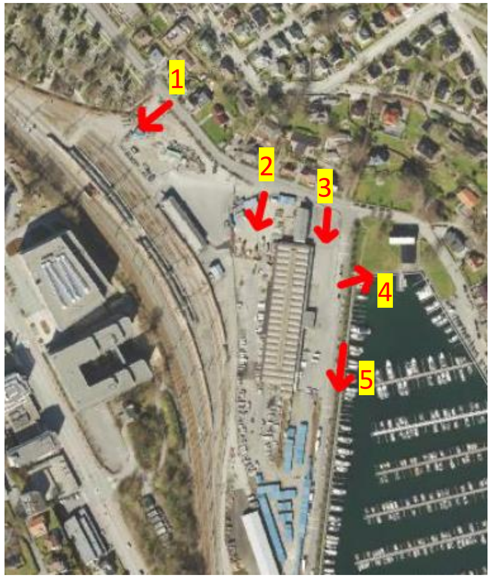


Figure 7.49. Current parking area and skate hall

Figure 7.48. Terje Viken building and small park

Figure 7.47. Current green promenade

Figure 7.55. Middle part of Paradis North

Figure 7.54. View from north to south

Figure 7.53. View from south to north

Figure 7.52. View from Paradis Station

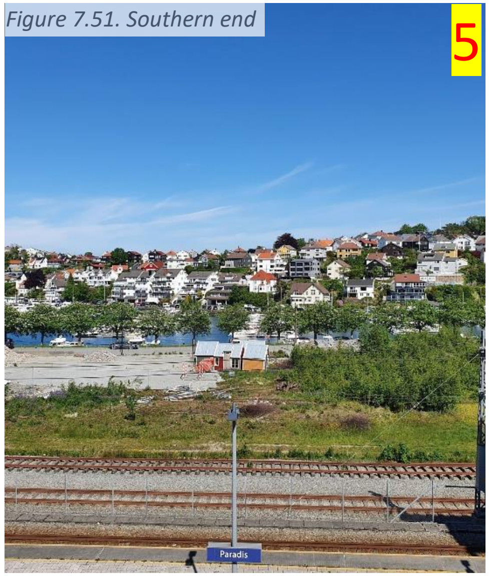


Figure 7.51. Southern end

7.5. SWOT-analysis

Strengths

Most of the area is currently not exposed to storm surges.

The lower part of Paradis North has reduced risk to flooding from stormwater runoff.

Relatively high winds and a wet climate reduce vulnerability to heatwaves and droughts.

The area is especially flat, making urban development significantly more accessible.

Closeness to the sea and nice views create attractiveness.

Good sun conditions in the northern area

The area has great access to public transport.

The lower half of Paradis North is at significant risk of climate impacts from stormwater flooding and storm surges in the future.

Weaknesses

The park in the northern end of Hillevågsvatnet is particularly exposed to storm surges.

Most of the area is impervious and lacking vegetation, increasing vulnerability to flooding as well as decreasing attractiveness.

Unfavourable topography exposes much of the northern area to flooding from surface water.

Relatively few entrance points due to the railroad tracks in the west and Hillevågsvatnet in the east. The railroad tracks separate the area in the west, creating a spatial and visual barrier.

Hillevågsvatnet is heavily polluted and mainly used by private docks, restricting marine life and public access.

The area is relatively exposed to wind, the middle part has rather bad sun conditions as much of the area is shaded by the buildings in the west.

The area itself is not considered attractive in its current state.

Opportunities

Constructed elevation of the area can create resilience to both storm surges and stormwater flooding.

New development can be placed outside of areas exposed to storm surges and stormwater flooding.

Hillevågsvatnet can be a central recipient for surface water runoff if managed correctly, making it a significant opportunity for surface water management.

Rainwater harvesting has a high potential of reducing vulnerability to droughts and heatwaves.

Paradis North is completely undeveloped, granting more opportunity for building climate resilience and urban development.

Cleaning up Hillevågsvatnet and moving some of the docks can make for an extremely attractive swimming/recreational area.

Paradis is an especially defined and secluded area, making it easier to create local community cohesion and identity.

Constructing bridges for pedestrians over the railway will greatly increase accessibility.

Threats

Storm surges have the potential to be extreme hazards in the future.

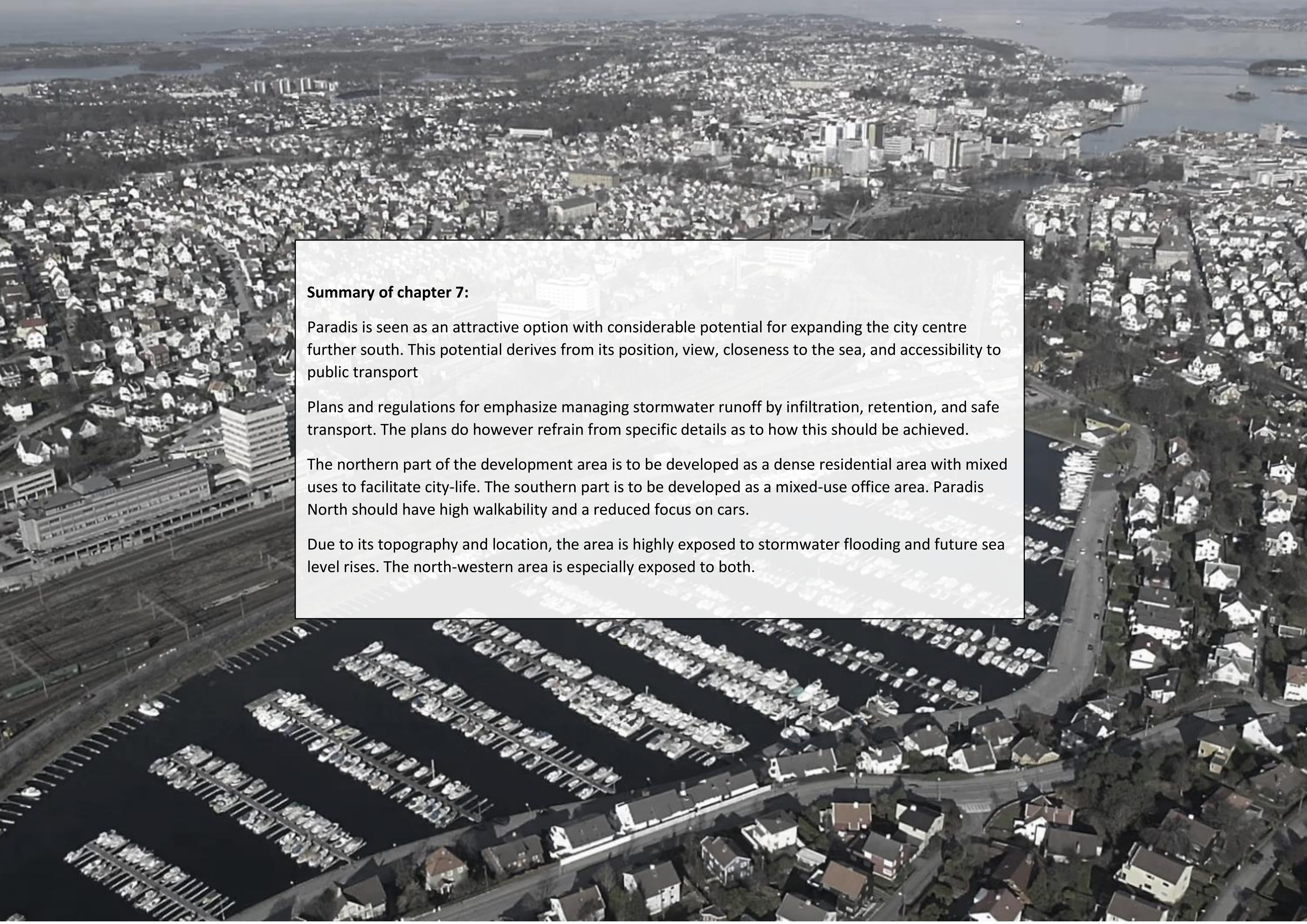
Stormwater runoff can create significant risks is not managed properly.

In the future, heatwaves can exceed dangerously high temperatures.

Pollution from nearby traffic can contaminate the area.

If public transport and accessibility is not managed properly, the area will likely not be an attractive and popular city destination.

Several climate adaptations rely on residential and public maintenance for optimal functionality.



Summary of chapter 7:

Paradis is seen as an attractive option with considerable potential for expanding the city centre further south. This potential derives from its position, view, closeness to the sea, and accessibility to public transport

Plans and regulations for emphasize managing stormwater runoff by infiltration, retention, and safe transport. The plans do however refrain from specific details as to how this should be achieved.

The northern part of the development area is to be developed as a dense residential area with mixed uses to facilitate city-life. The southern part is to be developed as a mixed-use office area. Paradis North should have high walkability and a reduced focus on cars.

Due to its topography and location, the area is highly exposed to stormwater flooding and future sea level rises. The north-western area is especially exposed to both.

Part 3: Proposal

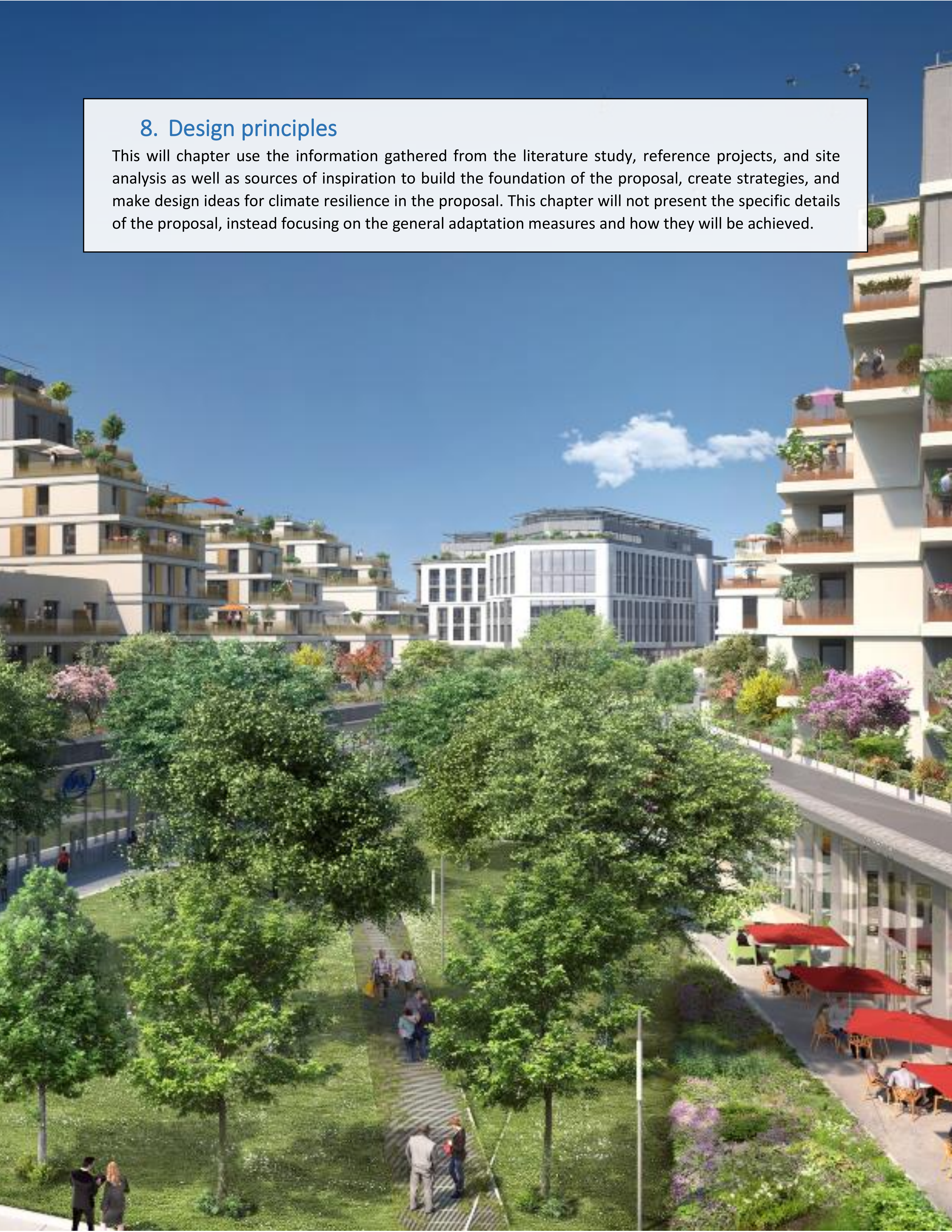
Establishing the principles and guidelines for each climate impact

Presenting the masterplan

Illustrating specific implementations

8. Design principles

This will chapter use the information gathered from the literature study, reference projects, and site analysis as well as sources of inspiration to build the foundation of the proposal, create strategies, and make design ideas for climate resilience in the proposal. This chapter will not present the specific details of the proposal, instead focusing on the general adaptation measures and how they will be achieved.



To ensure resilience and adaptation to climate consequences in the urban development project of Paradis North, the first five steps of the CCA6Steps as described in chapter 3.1.1 is utilized (see also Figure 3.1). So far, the first 4 steps have been described in chapters 4 and 5 and will briefly be summarized here.

The sixth step, monitoring and modifying the adaptation pathway, will naturally not be possible for this thesis.

Figure 3.1. The process of climate adaptation

1. **Identifying problems and objectives:**
   The problems and objectives related to climate consequences for the area have been identified as follows:
   - Ensure climate resilience towards stormwater flooding
   - Ensure climate resilience towards rising sea levels and storm surges
   - Ensure climate resilience toward heatwaves and drought
   - Ensure optimal sun- and wind conditions
   - Ensure good air quality.

   Additional objectives have also been identified:

   - If stormwater is to be directed to Hillevågsvatnet, polluted water must first be filtrated
   - Incorporate urban attractiveness
   - Encourage a strong community cohesion

2. **Assessing and analysing current risk:**
   Technically, as the area is yet to be developed, there are no current risks since there is no potential damage to be sustained from climate impacts. The only building currently at risk is the Terje Viken building at the inner edge of Hillevågsvatnet, which is highly exposed to flooding from storm surges. Nevertheless, storm surges currently barely affect most of the area whereas the north-west part of Paradis is exposed to stormwater flooding. Heatwaves, drought, and strong winds are not of great concern as they currently have a low impact. Sun conditions are generally good, but large parts of the area are shaded by

3. **Assessing and analysing future risk:**
   While there are no significant current risks, most of the climate impacts are expected to increase in both intensity and frequency. Under the higher emission scenarios, storm surges will reach much of the northern side of Paradis, posing a great risk for future development. Stormwater flooding will also pose greater risks in the future, as most of the area, especially the north-western part, is projected to experience frequent flooding which can cause structural damage to urban development. Regarding heatwaves and drought, summer temperatures during heatwaves will exceed the safe threshold at an increased rate, increasing the risk of heat-related problems like stress, stroke, and increased energy consumption for cooling. While less likely, droughts can also pose risks in the future for energy costs and ecosystems.

An important point to note is that the lower half of Paradis North is not at risk from flooding from either stormwater or storm surges, making it significantly less vulnerable than the upper half.

4. **Identifying and assessing adaptation options:**
   The proposed adaptation options have largely revolved around low-impact developments and nature-based solutions due to their multifunctionality and sustainability. For stormwater management, infiltration-based measures such as parks, trees, and bioswales has been proposed to manage lesser rainfall events and accommodate the natural water cycle, whereas retention- and transportation-based measures such as ponds and channels have been proposed to handle pluvial flooding. Green infrastructure also functions as adaptation options for air quality, wind manipulation, and heat regulation. For storm surges, elevation of land and foundations, as well as beach reclamation have been proposed as more sustainable options, whereas floodgates has also been proposed as an effective but expensive and intrusive measure. Layout and reduced built space have been proposed as measures for implementing optimal sun- and wind conditions and to facilitate ventilation and passive cooling.

The fifth step, planning and implementing the adaptation pathway, will be described in the two following chapters. Planning the pathway will be described in this chapter, whereas implementing the specific details will be presented in the next.

Overarching implementations and noteworthy points:

- The upper part of Paradis North will be developed as a residential area with mixed-use functions that facilitate city-life. The lower part of Paradis North will be developed primarily as an office area.

- Following the concept of risk mapping in chapter 3.3.1, the upper part of Paradis North can be defined as being at a higher risk to climate impacts. This is because the lower part of Paradis North is significantly less exposed to climate hazards while also being developed as an office area less sensitive to hazards as people don't live there. Therefore, the lower part of Paradis North (marked in Figure 8.1) will be less prioritized in the proposal

Figure 8.1. Exposure and vulnerability in Paradis North

- The main road for vehicles will be placed adjacent to the railway as opposed to its current position next to Hillevågsvatnet (see Figure 8.2). A green promenade will be developed over the current main road in its stead. This will mainly be intended as a strategy to strengthen the areas connection to water and to create a safe and attractive walkway with opportunities for recreation and commerce. It will also be partly intended as a climate adaptation as the current placement of the road is exposed more exposed to rising sea levels, which would restrict access of emergency vehicles during extreme storm surges.

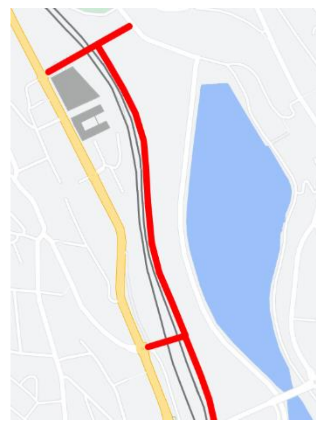


Figure 8.2. Placement of main road

- Parking will not be a major focus of the proposal but will still be implemented. Street parking will be implemented at the main road and a parking house will be included.

- The development area will be implemented with densification and multi-use functions, adopting the concept of the 10-minute city. As mentioned in chapter 5.1.1, densification is especially appropriate in areas near jobs or services, in former industrial areas, and in proximity to public transport. Paradis North satisfies all of these specifications.

- The proposal should feel like an extension of the planned development in Paradis South. This will be achieved by incorporating the identity that Paradis South has adopted, which includes sharp angles within their layout and a slight imitation of the typical historical wooden buildings in Stavanger (see Figure 8.3.)

Figure 8.3. Illustration of Paradis South

To reduce pollution in Hillevågsvatnet, increase public access, and strengthen the development area's connection to water, several of the private boat spaces will be relocated to the planned docks further south (as explained in chapter **Error! Reference source not found.**). This development is shown in Figure 8.4.

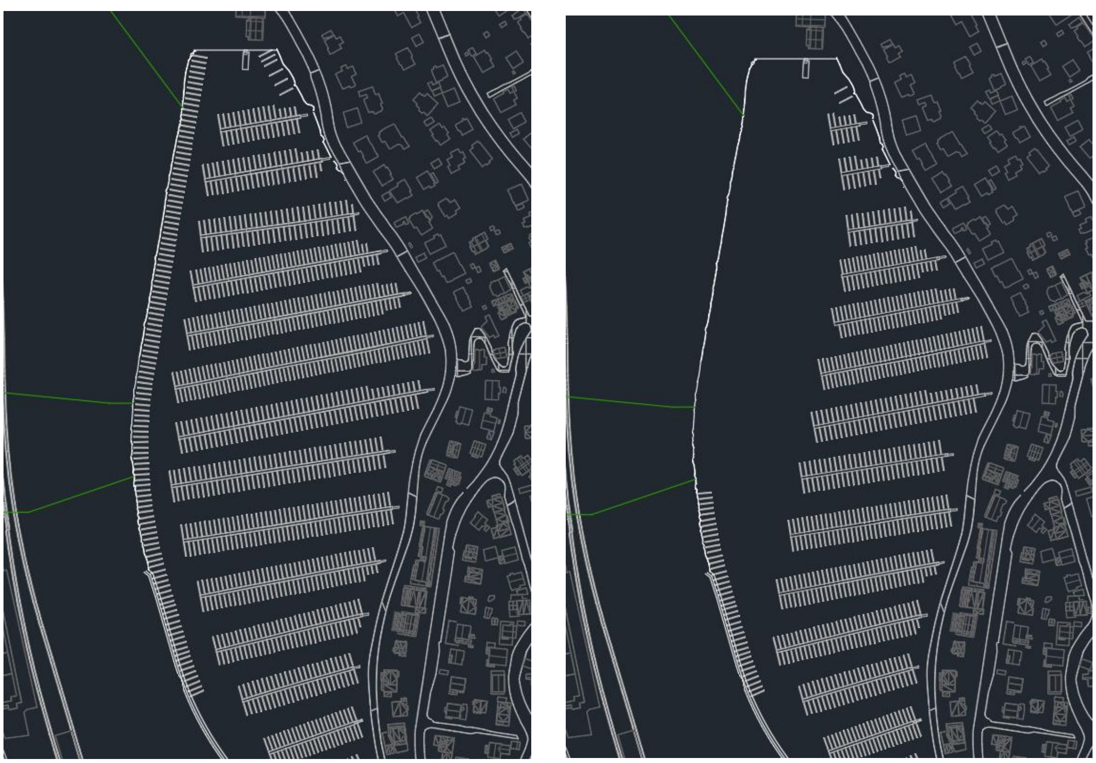


Figure 8.4. Proposed relocation of the private docks

8.1. Ensure resilience to stormwater flooding and pollution

As mentioned in the Stavanger municipal plans, part of their vision is to treat rainfall where it lands through infiltration, retention, and safe transport to nearby recipients as opposed to relying on expensive and wasteful sewage systems. The proposal of this thesis will also adopt this strategy as it focuses on a sustainable and low impact development with great potential for multifunctional benefits.

Infiltration methods such as parks, trees, permeable pavements, and green roofs will be heavily incorporated to maximize the infiltration capacity of the area. Residents should be encouraged to implement and maintain private climate adaptations such as rain barrels and rain gardens.

Hillevågsvatnet will naturally be used as the recipient for excess stormwater runoff. However, much of the water originating from Våland, Storhaug, and the adjacent railroad will contain pollutants. Following the goals of the municipality to have clean local oceans as well as adopting sustainable climate adaptations, polluted stormwater runoff will be treated through retention methods such as swales, ponds, and wetlands. By doing so, the climate measures implemented in Paradis will not contribute to further pollution of Hillevågsvatnet, but rather increase the chances that it will be an attractive swimming and fishing area sometime in the future.

For extreme rainfalls causing all other adaptation measures to reach full capacity, the excess stormwater should be led directly into Hillevågsvatnet as a last option to avoid critical damages and intolerable risks of flooding in the area. However, these events should not be damaging to the ecosystem and purity of Hillevågsvatnet, seeing as the most pollution occurs during the first 5mm of each rainfall. Direct transportation of runoff to Hillevågsvatnet can therefore be kept as a possible option of stormwater management without causing pollution, granted that the 'first flush' of each rainfall is retained and treated. Sufficiently clean runoff, such as the runoff from rooftops adjacent to the ocean can also be led directly into Hillevågsvatnet to alleviate the strain on other measures.

8.1.1. Infiltration – Green roofs, parks, and permeable surfaces

Green roofs will be utilized as a multifunctional climate adaptation measure to increase infiltration capacity throughout many of the rooftops in the proposal. Extensive green roofs will be prioritized due to their lower costs, requirements for installation, and maintenance.

Intensive green roofs will be used in the larger public and residential buildings where most appropriate. They will be placed in the upper part of Paradis North as shown in Figure 8.5 as this area is at an increased of flooding from surface water runoff and have better sun conditions. This part of Paradis is also closer to the city centre and will be developed as a mix between a residential and city-life area, so the intensive green roofs will be optimally placed there to increase urban attractiveness.

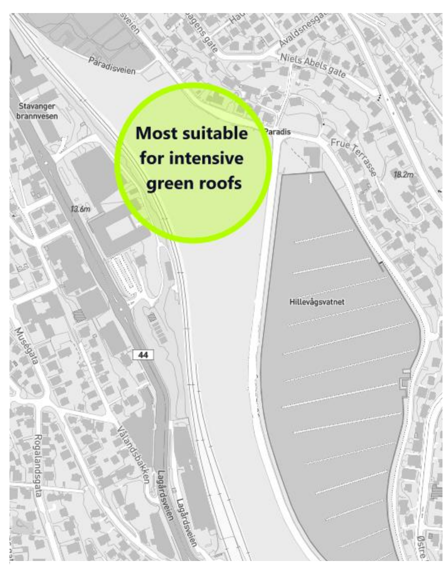


Figure 8.5. Optimal placement for intensive green roofs

Figure 8.7. Illustration of intensive green rooftops

Figure 8.6. Example of extensive green rooftops. Sørenga blokk 6 by Mad arkitekter

The development area will partly as a flooding-adaptation strategy include several urban parks connected by green corridors spread semi-evenly throughout the area. These parks will function as the principal strategy for infiltration of runoff. To optimize stormwater management capacity, the larger and denser parks will be situated in areas more prone to flooding. The parks will also be especially developed with recreation, attractiveness, and public availability in mind. Figure 8.8 depicts the approximate placement of these urban parks/green areas:

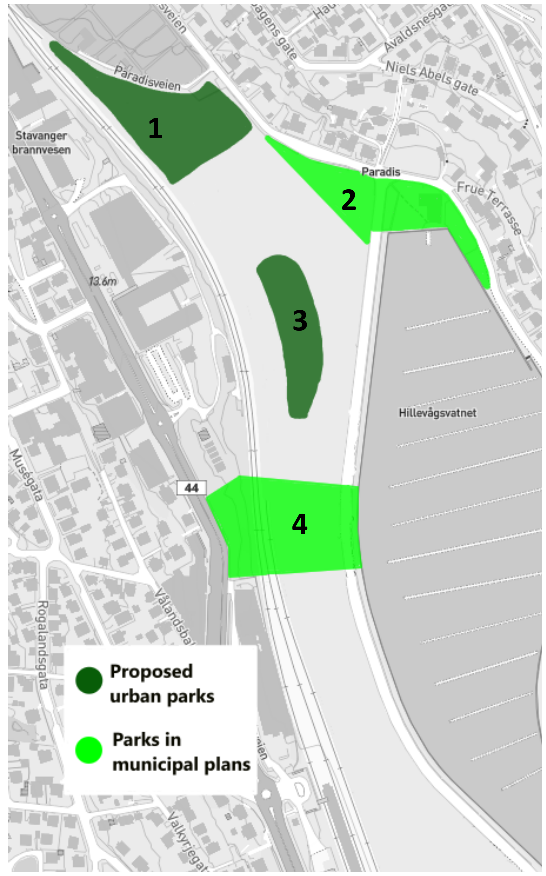


Figure 8.8. Proposed placement of parks/green areas

Park 1 will be developed as a landscaped urban forest functioning as the main recipient for most of the surface water runoff originating from Våland and Storhaug. This park will have a denser canopy of vegetation and trees.

Park 2 will be developed as a park with close connections to Hillevågsvatnet and vegetation especially resilient to sea water due to it being exposed to storm surges. The innermost areas of this park will have urban trees to receive, filtrate, and retain much of the polluted excess stormwater from the Våland area.

Park 3 will be developed as park centralized around most of the residential development to catch and infiltrate the majority of the runoff from the nearby impervious surfaces.

Park 4 is already part of the municipal plans and will therefore be included in this proposal regardless. This area is mainly meant as a public gathering point but the placement of it also coincides with building flood resilience due to the converging drainage lines in this particular area. It will be designed as a relatively open park with less dense vegetation to accommodate public availability.

As an additional measure to increase infiltration capacities of the area, permeable pavements and urban trees are to be included as much as practically possible, especially in or near areas more exposed to flooding. Rain gardens will also be used near buildings where appropriate with the added benefit of enhancing the natural landscape.

Figure 8.12. Inspiration for park 1

Park 1 will be developed with as a natural landscaped park

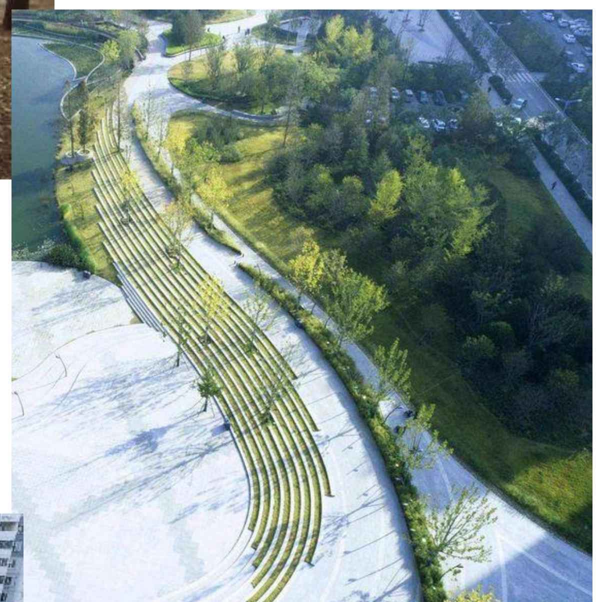


Figure 8.11. Inspiration for park 2

Park 2 will incorporate vegetated steps leading up to the green promenade.

Figure 8.10. Example park 3

Park 3 will emphasize water infiltration and retention but will also be an important focal point for recreational and social activities

Figure 8.9. Example of park 4

Park 4 will be primarily intended as a public space and will therefore include less dense vegetation

8.1.2. Retention, filtration, and transport - Urban ponds, wetlands, and channels

Due to their capacity for retaining and filtrating larger quantities of surface water runoff, a system of urban wetlands with strategically placed larger ponds will be adopted as the main strategy for flood-prevention and water filtration (see Figure 8.15). This system will mainly consist of a series of ponds and wetlands starting in the upper left end of Paradis North where exposure to stormwater flooding is at its highest. The ponds and wetlands will vary in intended function depending on location. Ponds further inland will be primarily focused on filtrating and retaining stormwater, whereas ponds situated closer to residential areas and public places will be more intended for attractiveness and recreational value while still maintaining retention and filtration capacities as a secondary objective. Ponds at the lower end of Paradis North are much closer to Hillevågsvatnet and will therefore be primarily focused on filtration. Figure 8.13 depicts the intended function for each location:

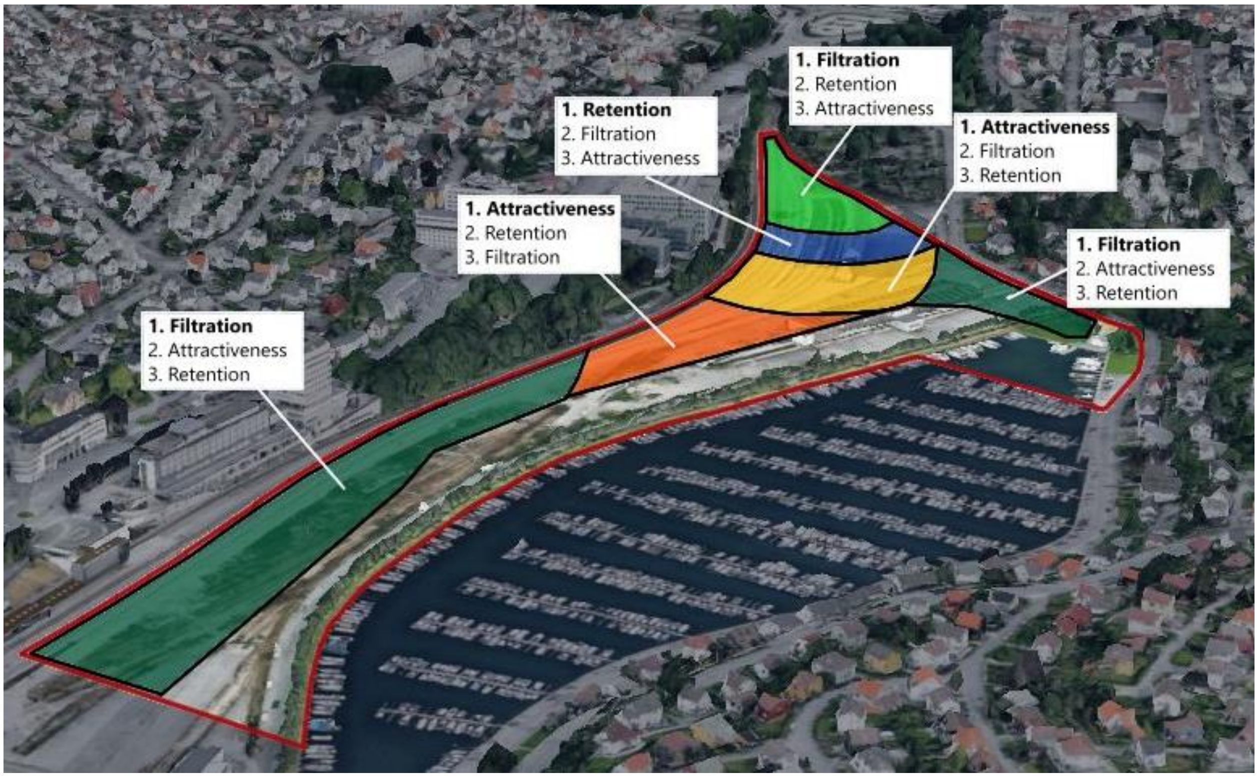


Figure 8.13. Intended function of urban wetland system depending on location

A continuous series of ponds will be connected from the northwest end leading to Hillevågsvatnet (see Figure 8.14). Smaller, ovoid-shaped ponds will also be used throughout the area as multifunctional flood prevention measures that provides attractive spaces, water retention, and water filtration. These smaller ponds will mostly only gather excess stormwater from their immediate surroundings and will therefore require less water filtration due to the decreased pollution. As such, they can lead overflowing water either directly into the later stages of the wetland system or into Hillevågsvatnet.

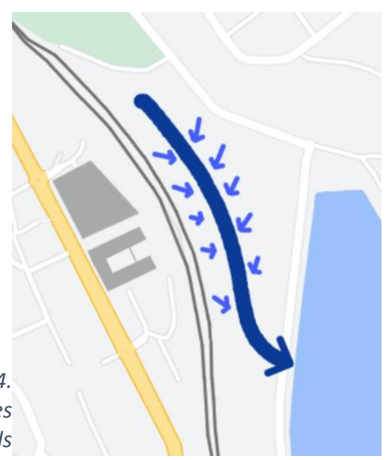


Figure 8.14. Continuous series of wetland ponds

The system of wetlands will as mentioned start in the upper left end of Paradis North (at park 1). Here, conditions are met for a larger urban pond due to the converging drainage lines and the topography of the area. This pond will be designed with the intended function of collecting, retaining, and filtrating the majority of the surface water runoff originating from the Våland and Storhaug areas. As its main function is to retain and filtrate larger quantities of runoff, it will be designed with an increased depth and witted with pollution-resistant vegetation that can handle higher water fluctuations.

Figure 8.15. Placement of large ponds

Another large pond will be placed in the middle of park situated in the centre of the residential area (park 3). In addition to increasing water retention and purification capacities, this pond will mostly function as strategy to naturally enhance the area, increase attractiveness, and create meeting spaces.

The wetlands and urban ponds will as mentioned facilitate direct flow to Hillevågsvatnet in the event of extreme rainfall where retention capacities are reached. It will also be connected with bioswales especially suited for a higher water velocity to further increase retention and filtration capacities, as well as to enhance natural attractiveness. Open channels without vegetation can also be utilized in more tight spaces where plants are less suitable. Grates will be placed at the end of pond to restrict flow of garbage and larger organic matter such as leaves and branches. They will however require maintenance in the form of cleaning and garbage removal.

As an additional strategy to increase the retention capacity of the area, rain barrels will be installed for most, if not all buildings due to their cost-effectiveness and simplicity. The water they store will also be used to build resilience to droughts by granting access to water for non-potable uses such as watering of gardens. Smaller bioswales, vegetated filter strips, or dry channels will also be placed next to impervious surfaces such as roads, parking lots, and buildings where they will retain and transport excess runoff into urban ponds, the wetland system, or into Hillevågsvatnet.

Figure 8.18. Illustration of wetland canal integrated into an urban neighbourhood

Figure 8.18 provides a considerably accurate illustration of the intended scale and look of parts of the wetland system.

Medium sized ponds will be connected by smaller canals.

Figure 8.16. Urban pond and channel in Augustenborg, Malmö

Figure 8.17. Example of urban pond closely connected to buildings

Urban ponds and wetlands will have close connections to the surrounding buildings

Figure 8.21. Example of larger pond at park 1

The larger pond at park 1 will be intended primarily for water filtration and retention

The larger pond at park 3 will be primarily intended as a retention and attractive recreational space

Figure 8.20. Design idea for larger pond at park 3

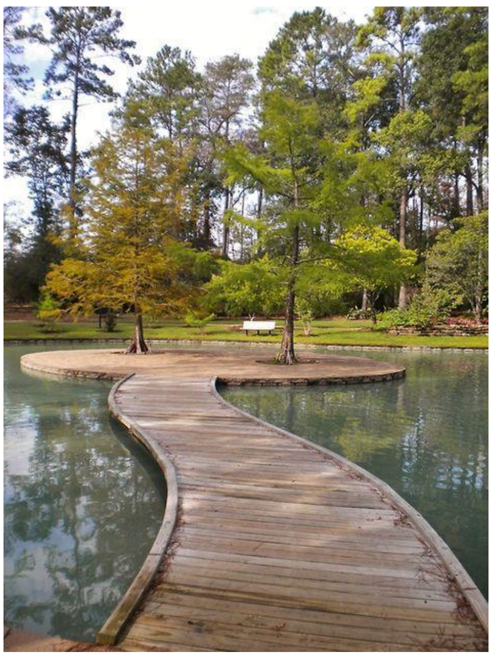


Figure 8.19. Design idea for larger pond at park 3

The pond at park 3 will have boardwalks leading to smaller landscaped islands with seating areas.

Wide boardwalks will have holes to showcase vegetation in wetland ponds

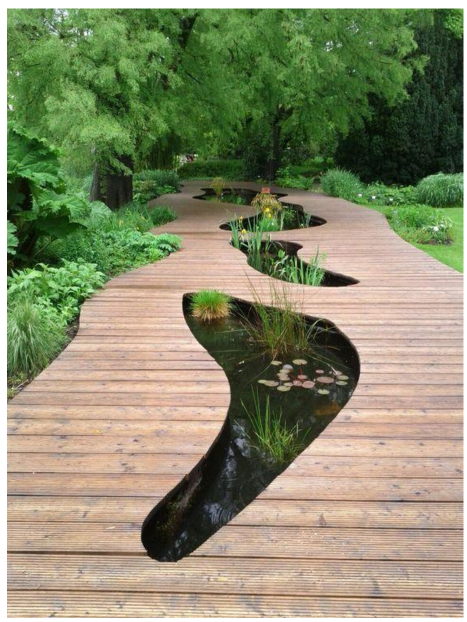


Figure 8.22. Inspiration for boardwalk over wetlands

A larger bioswale with thick vegetation will be placed between the railroad and the main road as depicted in Figure 8.23 and Figure 8.24. Thick, tall vegetation will act as a sound barrier alleviating the noise pollution from the train activity, as well as creating a natural buffer zone between the tracks and the area of Paradis. This strip of vegetation and permeable ground will act as a first line of defence against the surface water runoff that originates from the Våland area and will channel surface runoff from the Våland area into the larger ponds.

Additionally, a continuous green strip with trees will be placed along the road to further increase infiltration and retention capacities as well as creating a buffer zone between the main road and the pedestrian area. This strip will also facilitate street parking through a fortified permeable road to reduce the need for parking space inside the area.

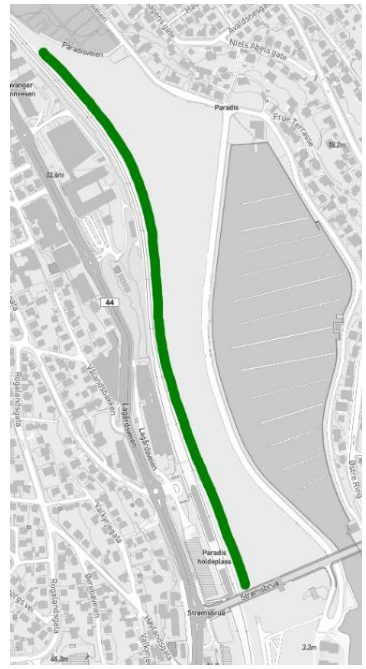


Figure 8.23. Placement of larger bioswale and green strip

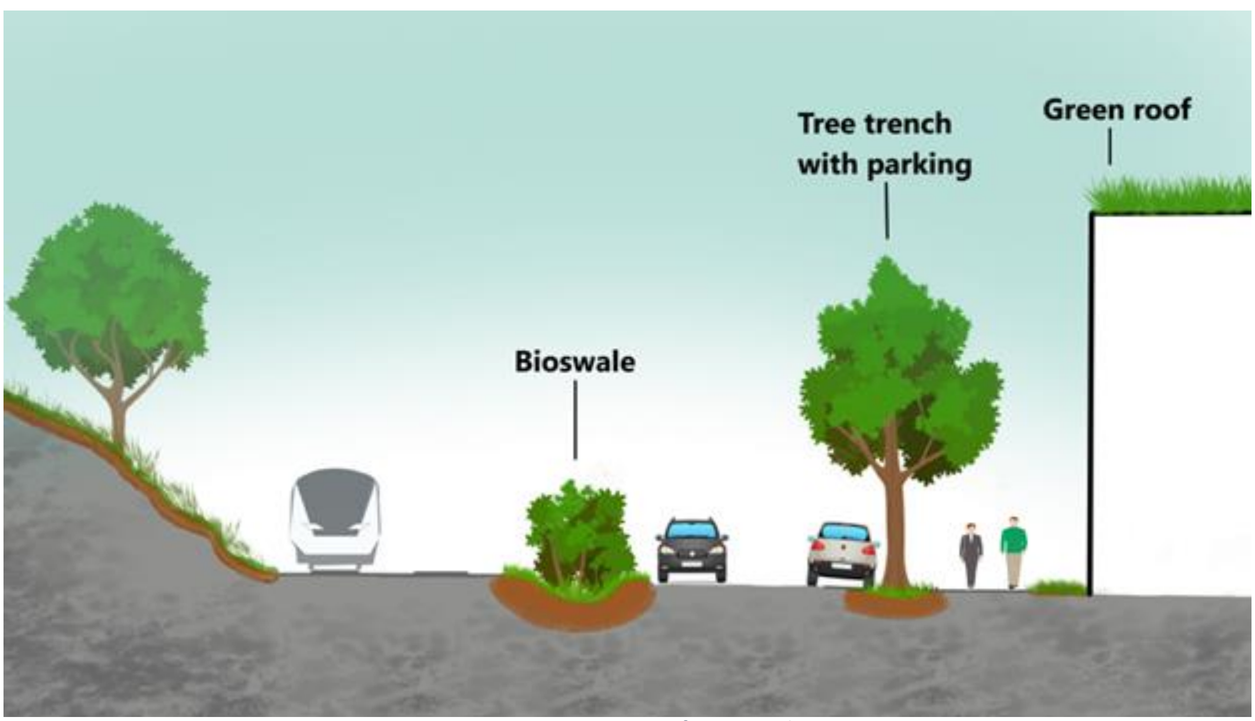


Figure 8.24. Section of main road

Figure 8.27. Example of larger bioswale

A larger bioswale capable of transporting stormwater will separate the main road of Paradis and the railway. Tall, dense vegetation will further increase retention capacities, filtration, and create a noise barrier to the railway.

A continuous tree trench will separate the main vehicle road from the pedestrian road.

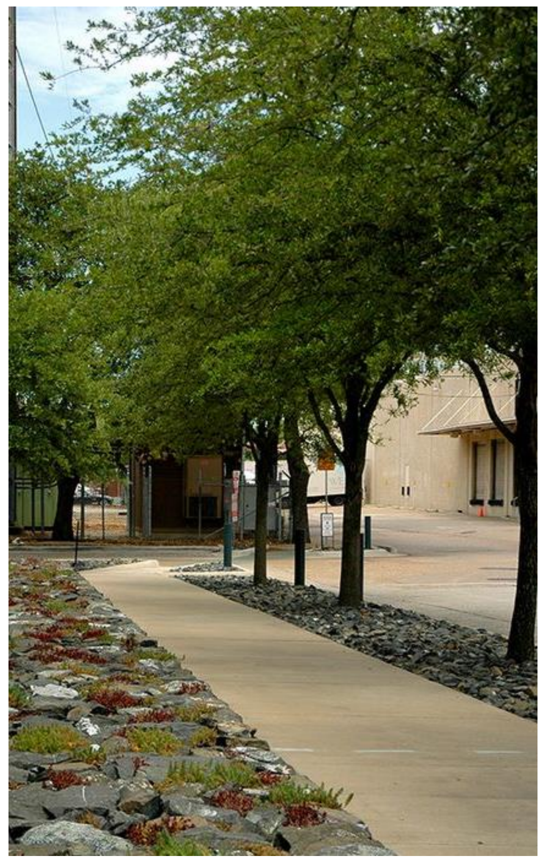


Figure 8.26. Example of continuous tree trench

A strip of permeable ground along the road will facilitate street parking and increase infiltration

Figure 8.25. Example of permeable pavement for parking

A green promenade will be implemented adjacent to Hillevågsvatnet as depicted in Figure 8.28 and Figure 8.29. Concerning stormwater management, this promenade will be intended to retain and filtrate polluted stormwater before it reaches Hillevågsvatnet. It will include a smaller bioswale at the inner edge of the pedestrian road, a green strip with urban trees at the outer edge, a vegetated filter strip leading down to the seaside boardwalk, and a permeable walkway. The vegetated filter strip will be fitted with vegetation that can withstand occasional flooding by saltwater. Smaller trees can also be placed along the smaller bioswale where appropriate. Rain gardens will also be placed next to the buildings facing the promenade to further increase the natural aesthetic of the promenade in addition to increasing filtration and retention capacities. An embarkment along the outer edge of the walkway will keep surface water from flowing directly to Hillevågsvatnet, where instead it will be infiltrated to the ground to allow filtration of pollutants. However, the embarkment will not cause flooding in crucial areas as it will allow for overflow directly into Hillevågsvatnet in the event of pluvial flooding.

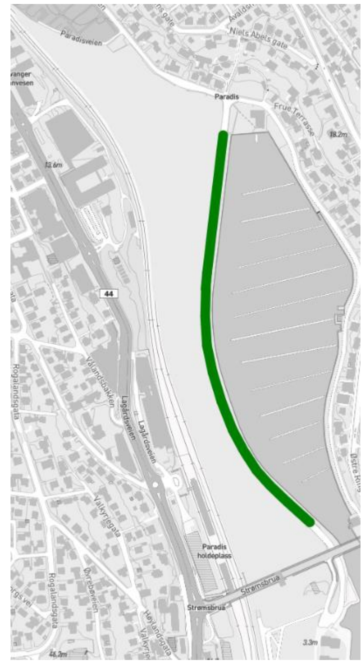


Figure 8.28. Green promenade

This promenade will however be predominately intended as an attractive function to enhance the natural aspect of the seaside area, keeping stormwater management as a secondary intention. The permeable walkway will prioritize accessibility and attractiveness and may have a reduced capacity fir infiltration as a result.

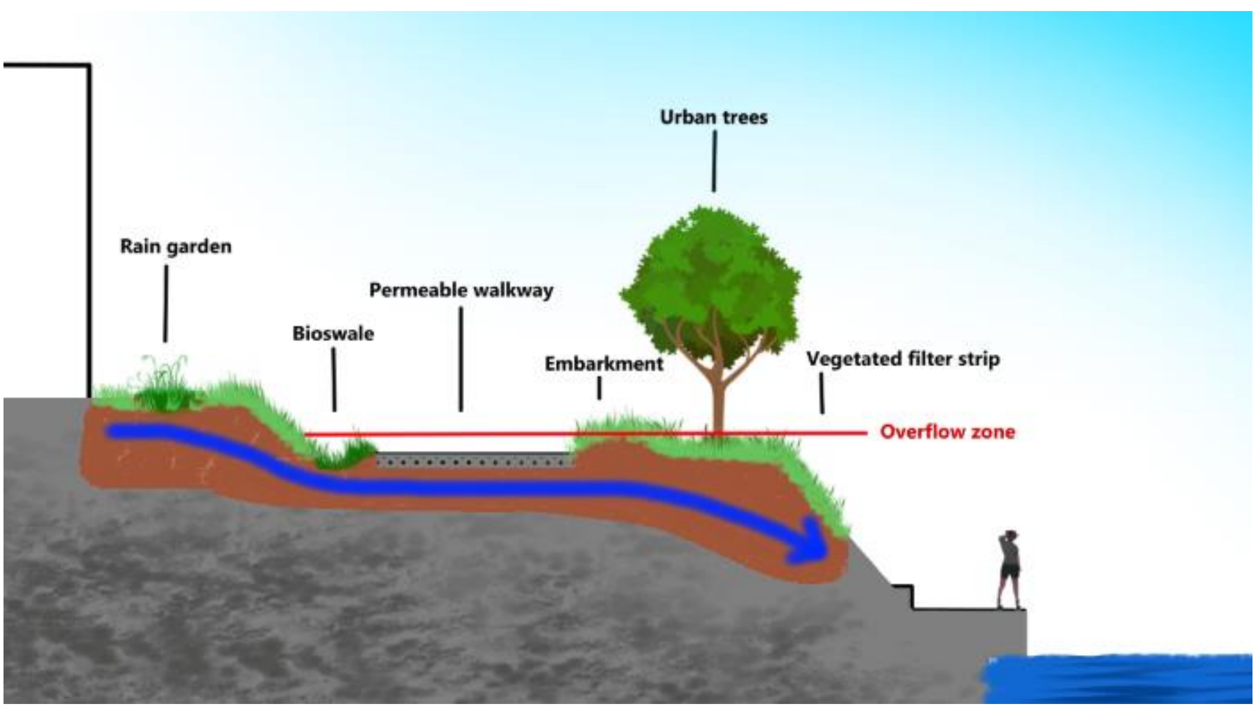


Figure 8.29. Section of green promenade

Figure 8.31. Example of smaller bioswale

Figure 8.32. Example of rain garden

Figure 8.30. Example of permeable walkway prioritizing pedestrian comfort

Figure 8.33. Example of green promenade

Figure 8.34. Example of green promenade

8.2. Ensure resilience to rising sea levels and storm surges

Considering the area of Paradis North will be completely redeveloped, terrain elevation presents an invaluable opportunity to build resilience to rising sea levels and storm surges at a relatively low cost. In addition to elevating in the terrain, other methods of strengthening resilience to rising sea levels such as elevation of buildings, flood-resistant materials, and retreat will also be implemented.

8.2.1. Land elevation

Following the municipal regulations, the area of Paradis is to be secured to 2m AMSL. To secure the development area to 2m above current sea levels, only the north-eastern area will need to be elevated (green part in Figure 7.28). However, the expected future sea level rise of 79cm exposes the entire area to flooding. To account for future changes and to strengthen resilience to rising sea levels, all areas considered vulnerable to ocean-related flooding will be elevated to 3m above current sea levels. This will equate to 2,21m above future sea levels, which is well over the threshold of even a 1000-year storm surge in the year 2100.

To allow runoff to naturally flow towards stormwater management facilities and Hillevågsvatnet, a slight increase will be created at the western edges of the development area. The white arrows in Figure 8.35 marks this slope.

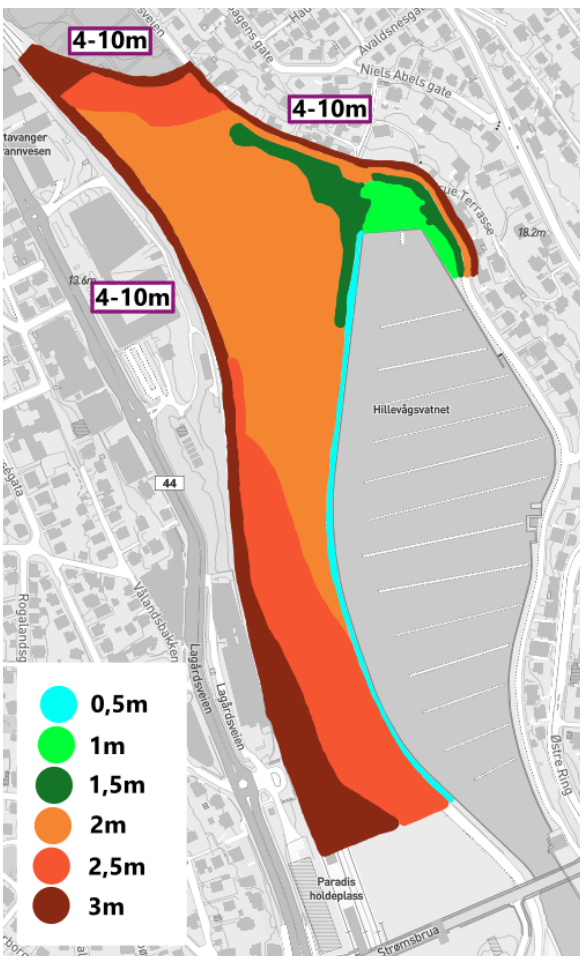


Figure 7.28

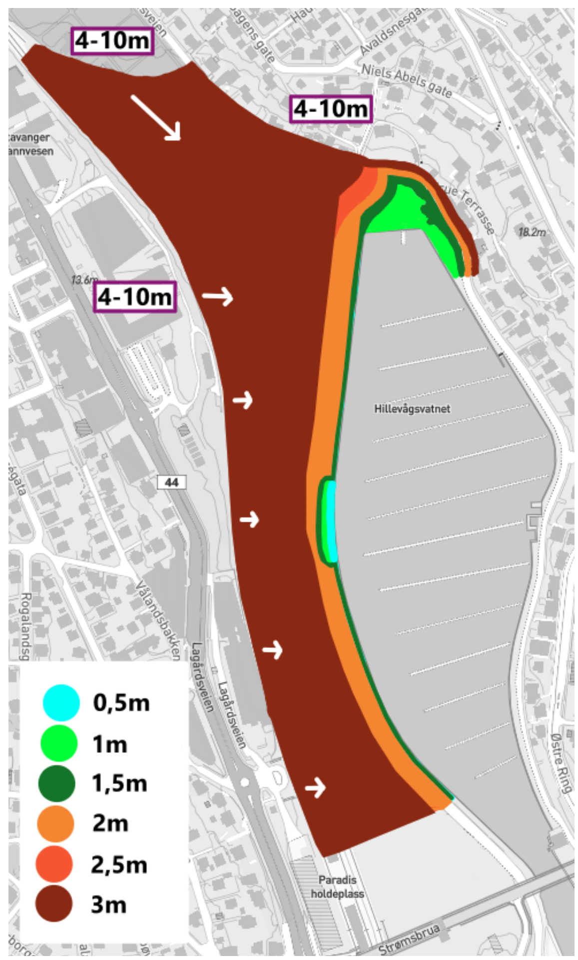


Figure 8.35. Proposed terrain elevation

A section of the promenade adjacent to Hillevågsvatnet is depicted in Figure 8.36. The values in the figure are set to meter above future sea level, using the expected sea level rise of +0,79m.

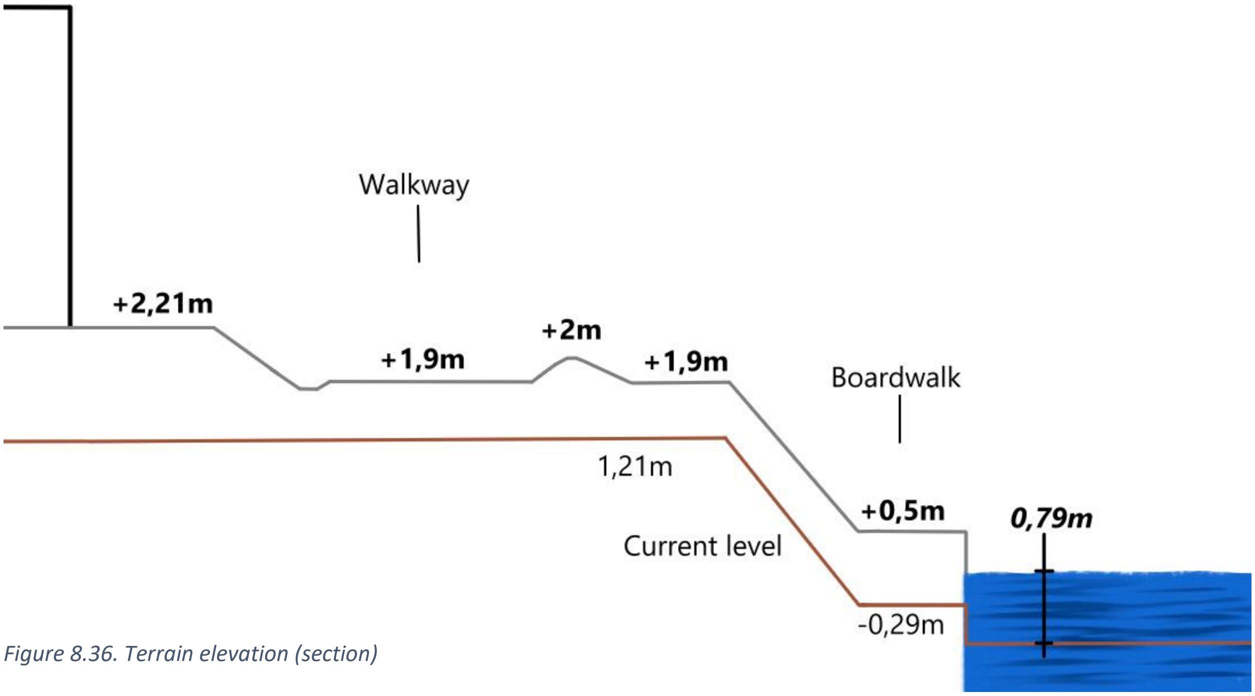


Figure 8.36. Terrain elevation (section)

Building level
Current height above AMSL: 2,0m
Height above AMSL with sea level rise: 1,21

Building level will be elevated to **2,21m AMSL** for future levels
Increase needed for elevation: **+1m**

Walkway
Current height above AMSL: 2,0m
Height above AMSL with sea level rise: 1,21

Walkway will be elevated to **1,9m AMSL** for future levels
Increase needed for elevation: **+0,69m**

Seaside boardwalk
Current height above AMSL: 0,5m
Height above AMSL with sea level rise: -0,29m

Seaside boardwalk will be elevated to **0,5 AMSL** for future levels
Increase needed for elevation: **+0,79m**

8.2.2. Elevation of buildings

To maximize resilience to ocean-related flooding, buildings will also have a raised foundation resistant to sea water. As the terrain elevation already puts the ground level at a relatively safe distance, the elevation of buildings will not be significantly high. Raising the first floor by 80cm will put it at a height of +3m AMSL for future conditions.

Figure 5.18. Using stairs as a flood mitigation measure

To create a connected and holistic environment, the buildings with open first floors along the green promenade will have inclined steps leading up to public areas as shown in Figure 5.18. Buildings without open first floor will also have a slightly raised foundation, both as an adaptation to rising sea levels as well as stormwater flooding.

Some of the lower buildings will also be raised on pylons as shown in Figure 5.17 to create a completely open first floor available to the public as well as to increase resilience to rising sea levels.

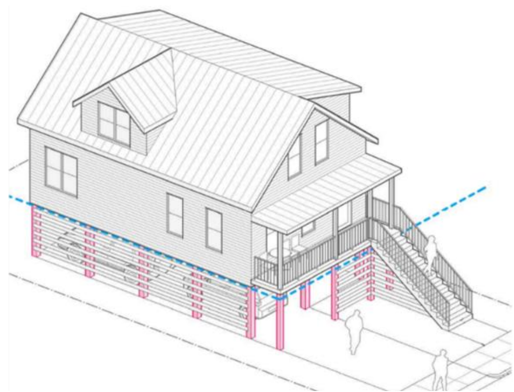


Figure 5.17. Elevation on open foundation

The Terje-Viken building at the northern end of Hillevågsvatnet (park 2) will be frequently flooded in the future and will therefore require special attention. As it is a protected building, it will not be redeveloped, nor will land elevation or embarkments be considered as they would need to be too high to sufficiently protect the building. Instead, the building could be adapted to future sea levels by, for example, raising it on pylons as shown in Figure 5.17.

8.2.3. Retreat

Due to the simplicity and cost-effectiveness of adopting the strategy of avoidance, the proposal will avoid placing structures in areas particularly exposed to storm surges as a form of strategical retreat. Structures adjacent to Hillevågsvatnet and the green promenade will be placed further away from shore, where attractive implementations such as rain gardens will function as a natural buffer.

The strategy of retreating is also indirectly applied as an adaptation to stormwater flooding by developing the north-western part as an urban landscaped park without important infrastructure.

8.2.4. Floodgate

As a potential option to further increase resilience to storm surges, a floodgate can be strategically placed in the chokepoint located beneath Strømsbrua as shown in Figure 8.37. The exact placement, dimension, and type of this floodgate will not be specified or discussed as this will require intensive research outside the scope of this thesis.

This development would realistically require a feasibility study as floodgates are expensive and intrusive. Whether or not it would be a suitable and worthwhile adaptation is highly reliant on the frequency and intensity of future storm surges and the potential damage that can be sustained in the area. It will therefore only be kept as a guideline in this thesis.

It is however arguably likely that the economical aspect of it will be a valuable investment due to the significant amount of vulnerable urban development in Hillevågsvatnet. A floodgate placed at the chosen chokepoint will be especially effective as it secures the entire inner area of Hillevågsvatnet and its harbour, which includes Paradis North in its entirety, the east side of Hillevågsvatnet, and the inner park, the last two of which is exposed to sea level rises of just 1 meter.

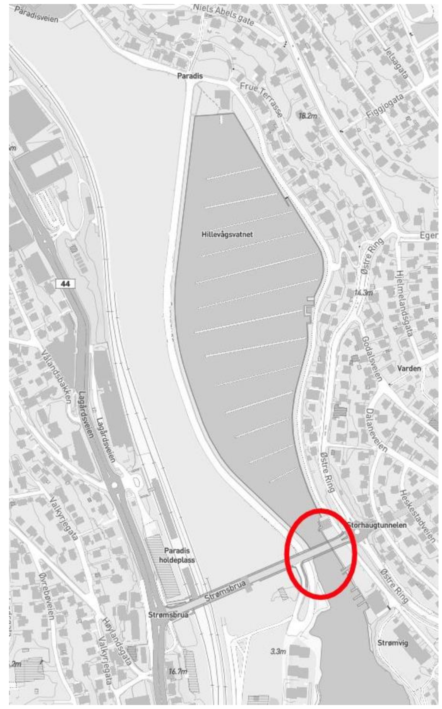


Figure 8.37. Placement of potential floodgate

Another benefit of this floodgate is that whenever flooding from stormwater runoff occurs in addition to a storm surge, Hillevågsvatnet can function as a recipient for stormwater without overflowing from increased sea levels. This makes the proposed floodgate a multifunctional climate adaptation that builds resilience to both stormwater flooding as well as storm surges.

Depending on the placement and type of floodgate, the proposed development can also function as a pedestrian bridge connecting the east and west side of Hillevågsvatnet. This would increase walkability considerably as the pedestrian entrances at Strømsbrua is located at the ends of the bridge, resulting in a lengthy walk between Paradis and Storhaug.

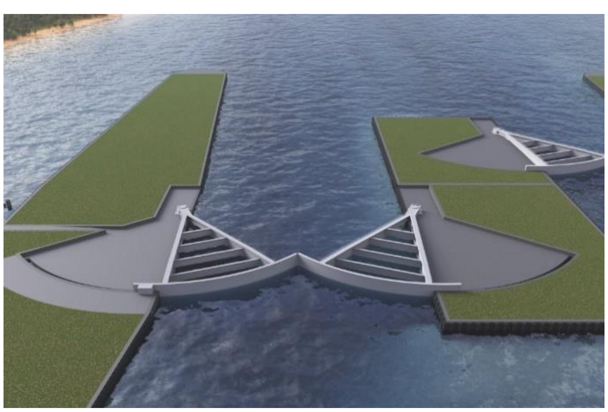


Figure 5.22. Illustration of a radial floodgate

Figure 5.21. Sluice gate. Tokyo, Japan

8.3. Ensure resilience to heatwaves and drought

Resilience to heatwaves will be ensured by careful channelling of wind drafts to cool the area, implementation of vegetation to facilitate shade and evapotranspiration, water features to cool down nearby areas. Selected roofs and other surfaces not fitted with vegetation will be coloured with light, reflective materials to reduce thermal heating from sunlight. Resilience to drought is built through facilitating rainwater harvesting, ensuring access to water during in the long-term. It is also strengthened through adopting the natural water cycle as opposed to transporting surface water away with conventional sewage system.

8.3.1. Building layout and passive cooling

Passive cooling will be facilitated through careful manipulation of the building topology, both vertically and horizontally. Winds in Paradis mainly originate from the south-east during winter and north-west during summer. As such, the optimal design of building heights to accommodate for vertical winds will be to place taller buildings south of low buildings. This lets tall buildings function as wind barriers during winter and lets them generate cool breezes during summer as depicted in Figure 5.61. The proposal will adopt this method by increasing building height for buildings south-east of public spaces and courtyards. Following the data presented in chapter 5.5.1, building heights will also adopt a non-uniform structure to allow for optimal wind flows in the area.

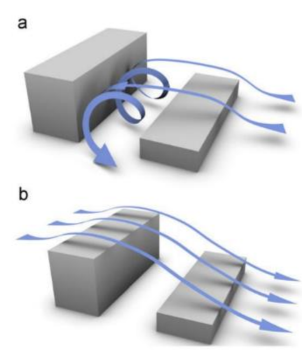


Figure 5.61. Different wind patterns on buildings

A non-uniform structure will also be adopted at the horizontal level to further increase passive cooling and restrict wind tunnels. A permeable typology, especially for buildings further north-west, will also be implemented to facilitate wind flow at pedestrian level. Buildings with courtyards will follow the structure as depicted in Figure 8.38.

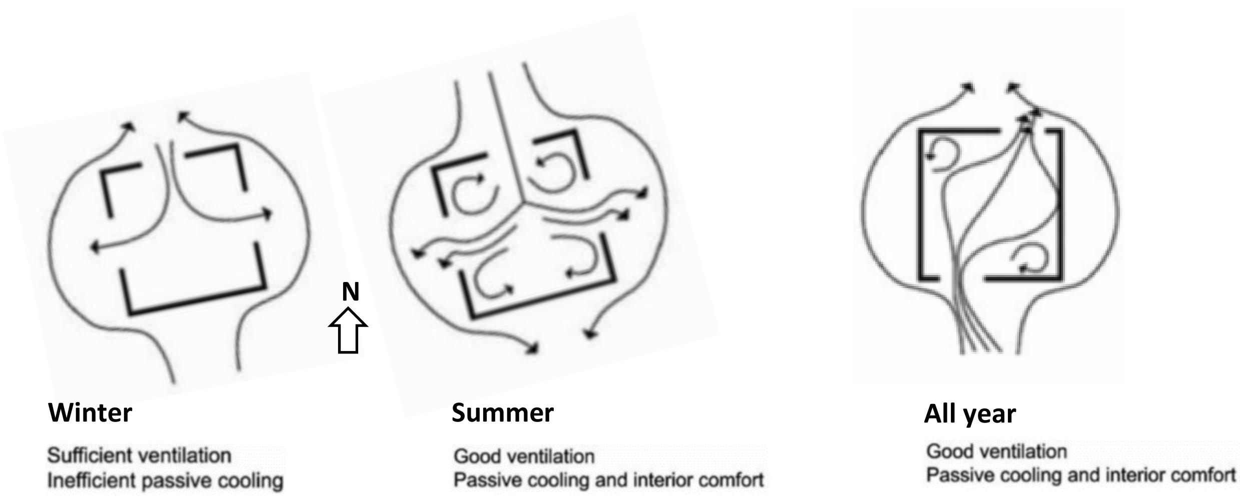


Figure 8.38. Wind dynamics for courtyards

8.3.2. Vegetation

As explained in Chapter 5.5.5, maintaining a tree cover ratio above 42% will considerably decrease the urban heat island effect in high-rise, dense urban environments. Considering Paradis North will not be a high-rise development, this requirement is arguably not as relevant. However, a high TCR will be upheld regardless to strengthen resilience to heatwaves through evapotranspiration and shade. Large trees will be especially implemented in the marked areas as shown in Figure 8.39, which shows the urban parks, the main road, and the green promenade. Urban trees and other vegetation will also be implemented in the semi-private courtyards and as green corridors connecting parks and public areas. The trees along the existing green promenade will be kept.

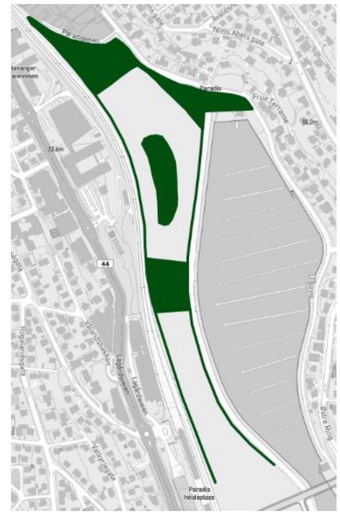


Figure 8.39. Areas with high density of urban trees

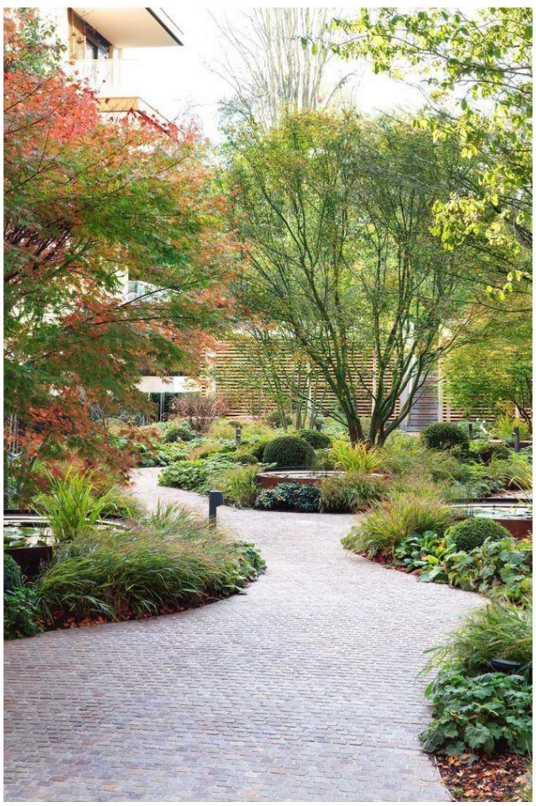


Figure 8.41. Example of urban trees and vegetation in semi-private courtyards

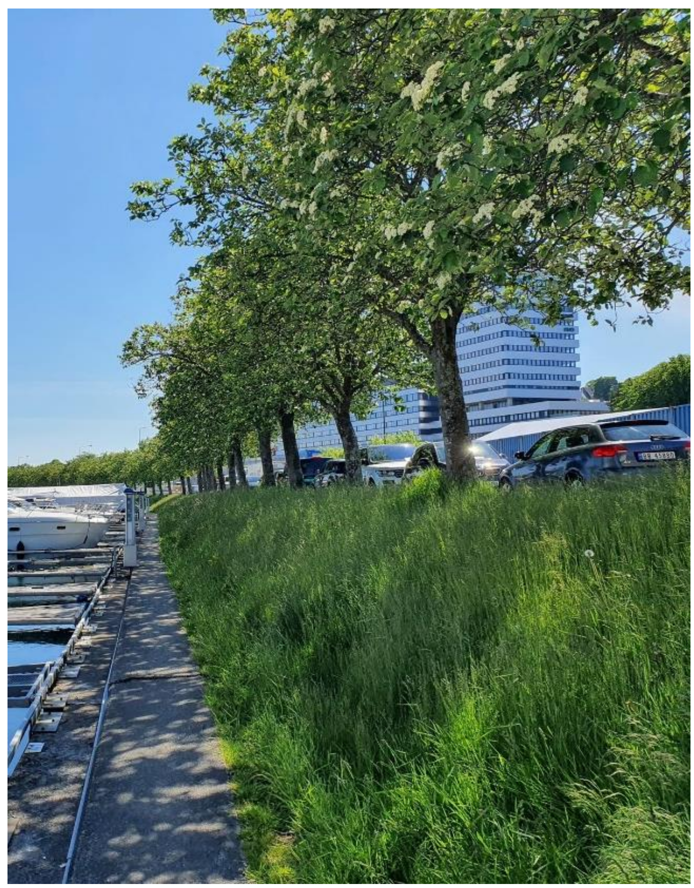


Figure 8.40. Green promenade next to Hillevågsvatnet in Paradis North.

8.3.3. Water features

As a product of their multifunctionality, the urban ponds and wetlands implemented primarily as a stormwater management adaptation will also reduce vulnerability to heatwaves and drought. They will as mentioned in chapter 5.5.3, have a cooling effect on nearby surroundings through evapotranspiration. Ponds and wetlands which are sufficiently clean will also be fitted with fountains to generate spray both as a measure to increase cooling and as an attractive addition to the urban landscape.

Another adaptation to heatwaves implemented in the proposal will be the addition of a harbour bath for residents and visitors to cool down. This facility will be placed at the inner edge of Hillevågsvatnet (approximately as shown in Figure 8.43) where several of the private boat docks will be relocated. Whether or not this bath will require filtration will depend on the state of pollution in Hillevågsvatnet when implemented.

Figure 8.42. Example of fountain in urban wetland/pond

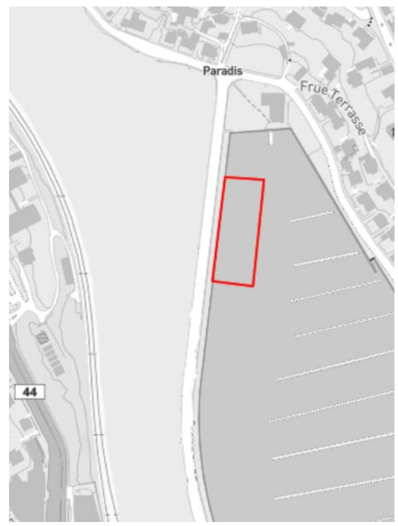


Figure 8.43. Placement of harbour bath

Figure 8.44. Example of harbour bath. Copenhagen

8.3.4. Rainwater harvesting

Drought is likely to not be a significant risk in the future due to the temperate climate in Stavanger, even with a possible decrease in precipitation during the summer months. However, to maximize overall climate resilience, rainwater harvesting will be incorporated through the implementation of rain barrels and urban ponds. As mentioned, rain barrels will be implemented throughout the area to reduce the risk of flooding. These barrels will also function as a strategy to reduce vulnerability to droughts as they store rainwater for non-potable uses when needed. Urban ponds and underground storage units can also function as a strategy for rainwater harvesting.

Permeable ground and underwater storage around trees and other important vegetation will be implemented to allow rainwater to infiltrate and be stored. This will act as a reservoir for trees during droughts.

8.4. Ensure optimal sun- and wind conditions

Following the municipal regulations described in chapter 0, a minimum of 50% of outdoor recreational areas will be sunlit at 15:00 at spring equinox and 18:00 at midsummer. Additionally, wind conditions at ground level should not create discomfort. To achieve this, the proposal will ensure comfortable wind- and sun conditions through careful arrangement of building height, orientation, and placement.

8.4.1. Solar envelope

As described in chapter 5.6, one of the regulations to ensure sufficient solar access near a building is the obstruction angle of the roof or height difference between floors. By simulating sun in the program Blender, the obstruction angle of Paradis North was found to be 50^o. As such, the angle of the slope of building roofs and subsequent floor heights will not exceed 50^o nearby public or private open spaces.

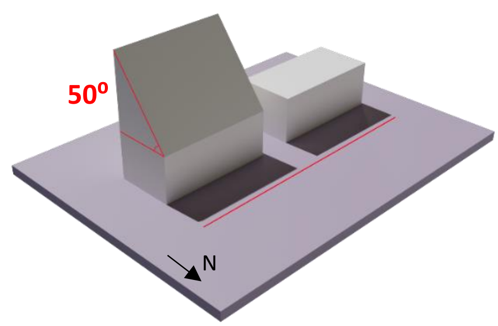


Figure 8.45. Obstruction angle and sun conditions in Paradis at 12:30, 20th of May

Building heights will also be adjusted according to the sun conditions in the area. Buildings near public or private open spaces located on the western side of the area will have a reduced building height to accommodate optimal sunlight access in evenings. Buildings close to the green promenade at Hillevågsvatnet will also be reduced.

Furthermore, much of the building typology will follow a quarterly structure at a 45^o angle relative to north as shown in Figure 5.57 when possible. This will accommodate optimal sun conditions throughout the entire year for the residents living in the buildings

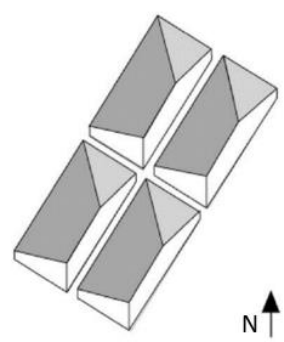


Figure 5.57. Optimal building orientation for solar access

8.4.2. Comfortable wind conditions

While the building typology will incorporate passive cooling to reduce vulnerability to heatwaves, it will also restrict wind tunnels and uncomfortably high wind speeds at the pedestrian level. This will as mentioned be achieved by adopting a non-uniform and permeable layout for winds to flow without generating wind tunnels and annoying drafts.

Urban trees will also be implemented to break and slow down wind drafts in particularly exposed areas such as long streets or directly below taller buildings.

8.5. Encourage community cohesion

As described in chapter 5.1.2, a strong, cohesive community is often characterized with resilience, often in the form of being able to recover faster and more efficiently from adversities. While a strong and cohesive community can't be ensured directly from a standpoint of urban planning, the proposal will encourage it by incorporating public and private meeting spaces, parks, and social arrangements. Mixed-use functions and a high density will be incorporated into the proposal partly as measure to strengthen community cohesion.

8.5.1. Meeting spaces

The building structure of the proposal will implement courtyards intended as open meeting spaces to build community cohesion and create social bonds. The building typology will be modified to create these partly enclosed areas both as semi-public courtyards and as public spaces in between the buildings (see Figure 8.46).

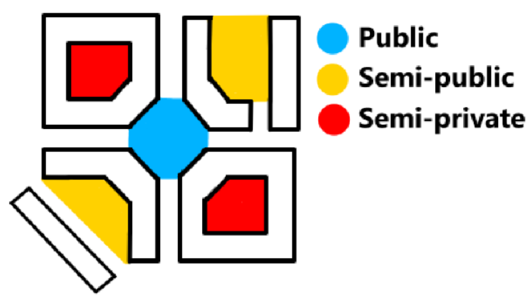


Figure 8.46. Public, semi-public, and semi-private areas

The semi-public courtyards will be intended as welcoming and walkable areas where interactions between residents of the area are made. Here, people travelling to and from their own building will have the opportunity to greet residents in these courtyards as they pass by.

The enclosed public spaces will be formed by the outer edges of residential buildings and will therefore be intended as a meeting point for residents of the entire area as well as visitors. These spaces will include recreational functions such as open restaurants and shops to transform the area into a busy meeting space where people can meet.

Private or semi-private courtyards create complications for both sun- and wind conditions and are more restrictive to transporting stormwater. Therefore, private spaces for each residential building will instead be mainly implemented at their own respective rooftops as terraces. Here, the rooftops will be designed as spaces where residents can enjoy the view, relax, sunbathe, or arrange larger social gatherings such as birthdays or parties. Gardening of herbs and other vegetation will also be facilitated as several of the rooftops will be designed as green roofs. The rooftops will be implemented with seating areas, green spaces, and other recreational features. Should it be economically feasible, the rooftops will also include thermal baths (see Figure 8.50) that accommodates several people.

Figure 8.47. Example of semi-public courtyard

Figure 8.49. Example of enclosed public space

Figure 8.48. Example of enclosed public space

Figure 8.50. Public bath on rooftop in Budapest, Hungary

Figure 8.52. Example of semi-private rooftop terrace

Figure 8.51. Example of public rooftop terrace

The parks in the proposal will also function as extended meeting spaces designed to feel welcoming and inclusive for both residents and tourists. To create true meeting spaces where people will frequently attend to, the parks in the proposal will be designed with specific purposes for recreation.

Park 1 will as mentioned primarily be intended as the main recipient for surface water management. However, due to its location, it will also be intended as an important connection for cyclists and pedestrians to and from the city centre. Walkability will be increased by connecting this park to the Lagård gravlund area and seating areas will be implemented along the urban wetland to provide a respite in a natural landscape.

Figure 8.53. Park 1

Park 2 will be developed with close connections to Hillevågsvatnet and as the main entrance to Paradis. During the summer months, it will temporarily be transformed into an open market with food stands and other activities along the western side of the park as shown in Figure 8.54. The previously mentioned harbour bath implemented as an adaptation to heatwaves will also be an important attribute of park 2 to build community cohesion as it offers an attractive recreational meeting area. Sunbathing will also be an intended recreational function of this park.

Figure 8.54. Placement of market and park 2

Park 3 will be intended as the main meeting point for residents in area due to its centralized location around residential buildings. It will be an important point of connectivity and walkability as residents will frequent this park travelling to and from the area. Boardwalks will be placed over the larger wetland pond to further increase walkability, whereas seating areas will be facilitated in smaller islands spread across the pond connected by said boardwalks. This will encourage interactions between residents as the boardwalks will be busy travel points where people will also frequently sit. Figure 8.59 depicts this concept at a larger scale.

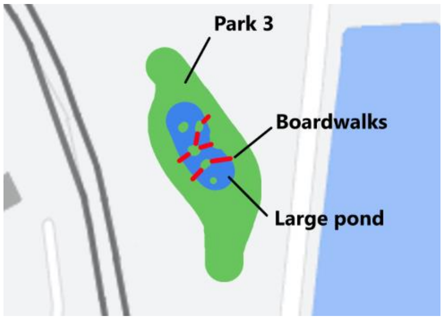


Figure 8.55. Park 3

Seeing as park 4 will be the main connection between Våland and Paradis North, it will be developed with increased focus on public availability and function. To increase walkability, the park will include a bridge connecting Paradis to the main road at Våland. A beach volleyball course will be included to increase recreational options, and steps leading down to Hillevågsvatnet will increase the parks connection to water. A special floating platform available to the public will be included at the edge of the park. Here, special arrangements such as concerts can be held.

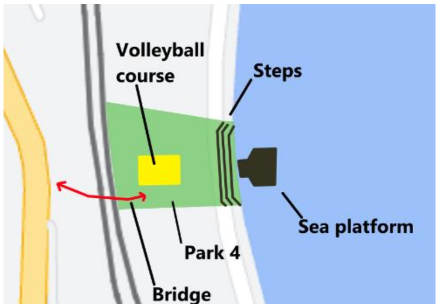


Figure 8.56. Park 4

The green promenade along Hillevågsvatnet will be designed as a shared public space with improved bench seating and attractive vegetation. Open first floors with restaurants and shops will be implemented at adjacent buildings to create a busy and lively street.

Figure 8.61. Example of temporary market at park 2

Figure 8.62. Example of wetlands next to pedestrian road at park 1

Figure 8.60. Example of beach volleyball course at park 4

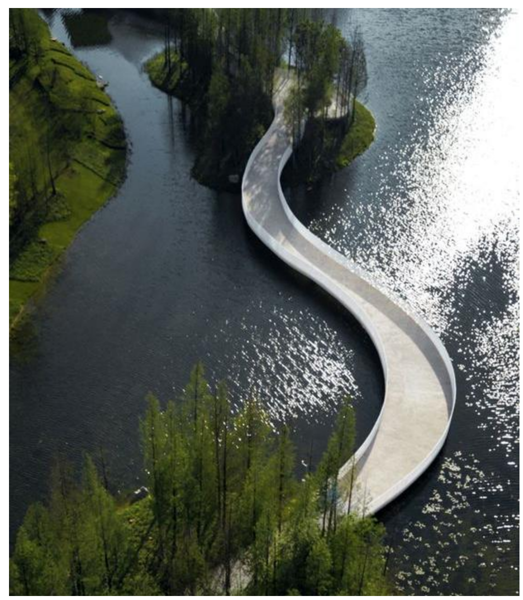


Figure 8.59. Inspiration for larger pond at park 3

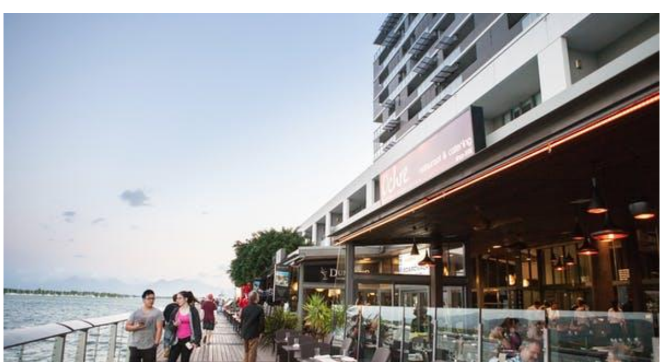


Figure 8.58. Example of open first floor at green promenade

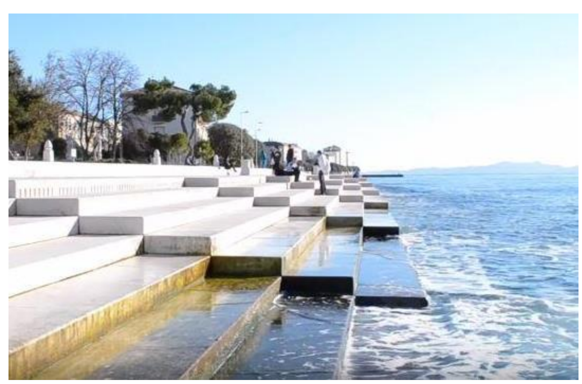


Figure 8.57. Example of steps leading down to Hillevågsvatnet in park 4

8.6. Implement attractiveness

Chapter 5.1.3 presented several concepts to develop urban areas with attractiveness:

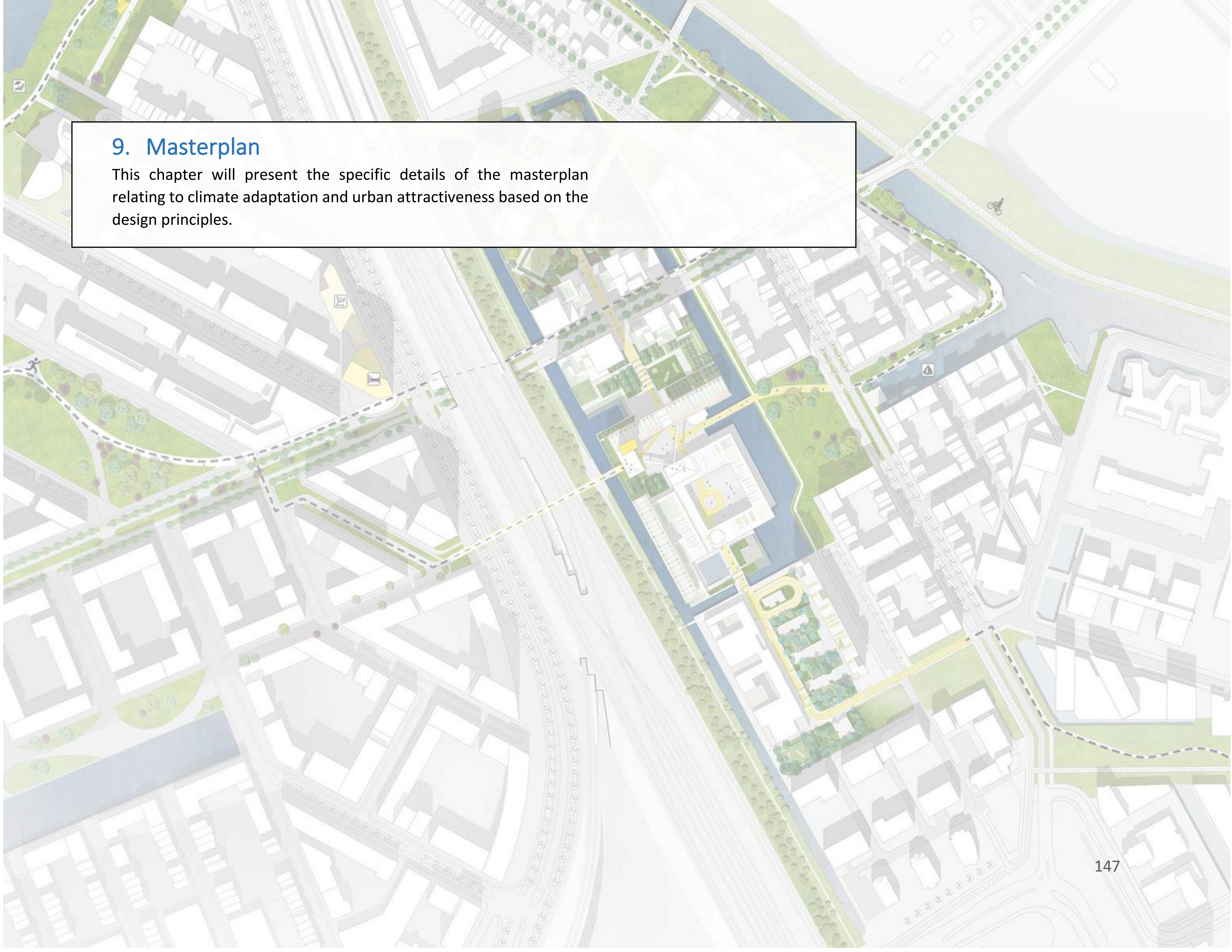
- Balance between order and variety
- Visible functions, lively streets, and public spaces
- Sense of enclosure
- Identity
- Climate
- Green areas

Several of the mentioned features in the proposal are also intended to enhance attractiveness as a product of their multifunctionality. Green roofs, urban wetlands, bioswales, parks, and the green promenade all contribute to the increasing the natural attractiveness of the area. Public spaces and semi-public courtyards, private rooftops, and recreational features will also have a positive effect on perceived attractiveness. The concept of 'visible functions' as explained in chapter 5.1.3 is also incorporated into stormwater management by open channels, bioswales, and the wetland system. To enhance a sense of enclosure and invitation, the ratio of street-to-building height will be kept between 2:1 to 1:4 for the most public spaces. The buildings will also be arranged in quarterly structures without exceeding 5 floors.

Identity and balance between order and variety will be incorporated into the building typology and the form of the individual structures. Buildings will form an overarching and recognizable structure to create a sense of order, whereas individual alleyways or minor extensions will create interesting variety. This concept will be especially applied in some of the residential areas, where Figure 8.63 will be used as an influential source of inspiration.

Figure 8.63, which is an illustration of Liaparken by Mad Arkitekter, depict how the concept of balance between order and variety can be implemented into an urban block to create a visually appealing area. Furthermore, it adopts a high density, which as mentioned can be a multifunctional strategy to increase attractiveness, social cohesion, and climate resilience. The typical Stavanger identity can also be incorporated into this type of structure by drawing inspiration from the shape of the historical wooden buildings.

Figure 8.63. Illustration of Liaparken



9. Masterplan

This chapter will present the specific details of the masterplan relating to climate adaptation and urban attractiveness based on the design principles.

9.1. Building form

The lower half of Paradis North is intended as a mixed-use office area designed with much larger buildings to accommodate their function and resemble the structures of the planned buildings of Paradis South. Their building shape and orientation is designed as a seamless extension of the area by keeping sharp angles in their built form, which is especially seen in the roofs.

The upper half of Paradis North is designed with a smaller grid to loosely resemble the residential areas of Storhaug and Vågen while still maintaining a block structure with open spaces in between them. This residential area builds upon the concept of balance between order and variety by keeping an overall recognizable structure while also creating variety at the smaller scale, where hints of symmetry can be seen throughout the area.

The building layout is specifically designed to accommodate space for climate adaptations such as the wetland system. The courtyards and open spaces formed in between buildings are intended to create options for ponds to infiltrate and retain water, whereas the numerous streets in between the buildings grant an ease of access for open channels and bioswales transporting runoff. The horizontal permeability also allows for sufficient ventilation to reduce heat-related risks. The open spaces are also intended as attractive public and private areas designed for recreational functions. Both horizontal and vertical variety is maintained in the building form to restrict high wind tunnels and create passive cooling during summer.

The building form maintains a high horizontal density to create a more closely connected neighbourhood where social interactions can happen frequently. An increased horizontal density also allows for an overall reduced building height without negatively impacting the FSI of the area.

Figure 9.1. Illustration of the proposal

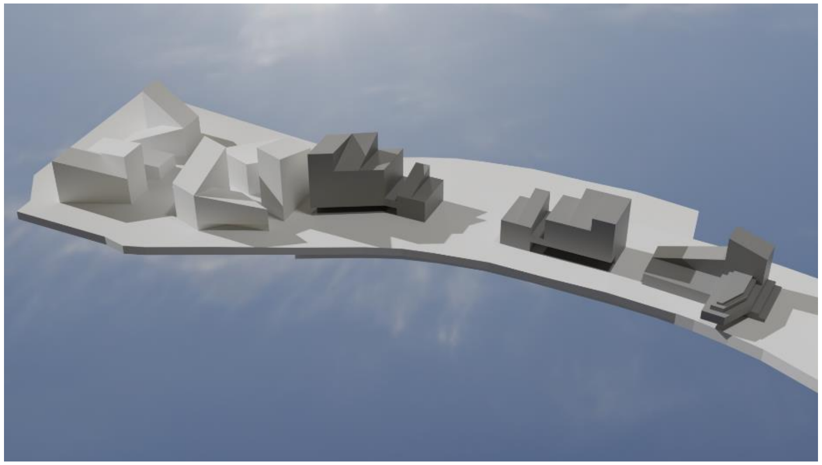


Figure 9.5. Lower part of Paradis North seen from east.

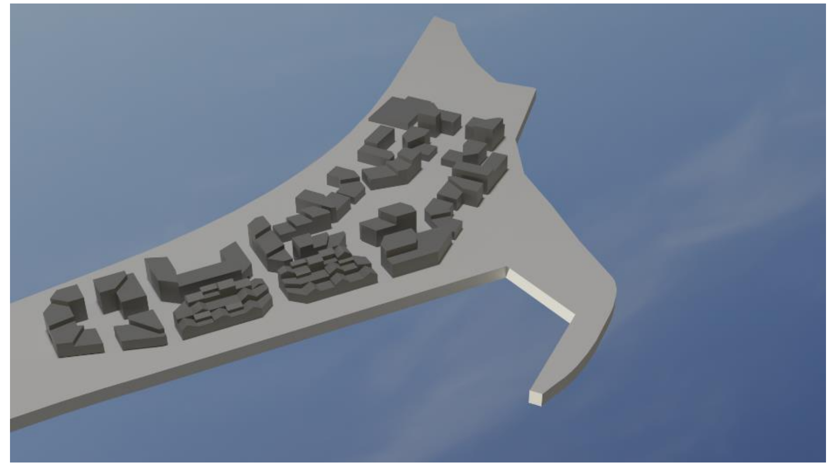


Figure 9.3. Upper half of Paradis North seen from east

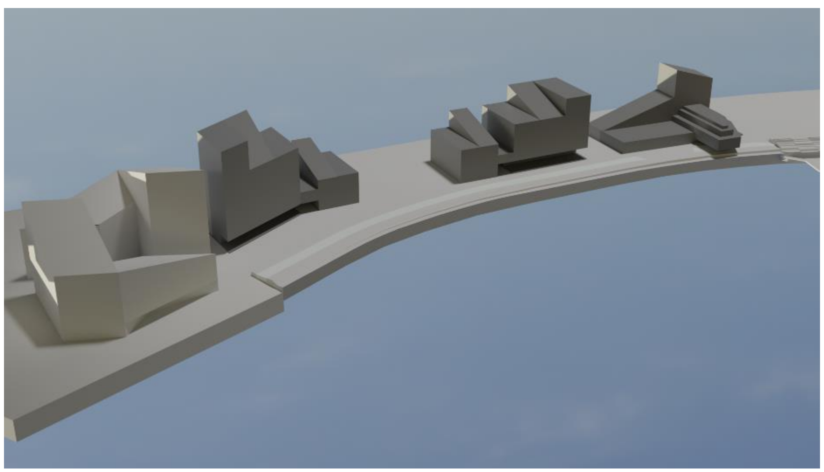


Figure 9.4. Lower part of Paradis North seen from south-east

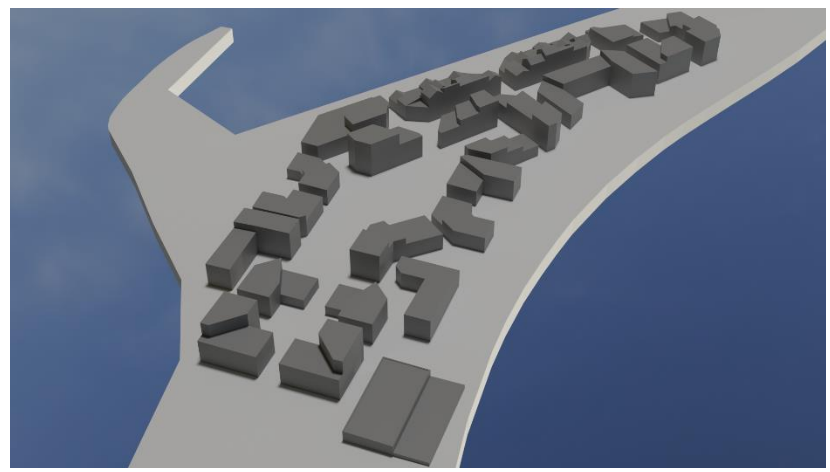


Figure 9.2. Upper half of Paradis North seen from north-west

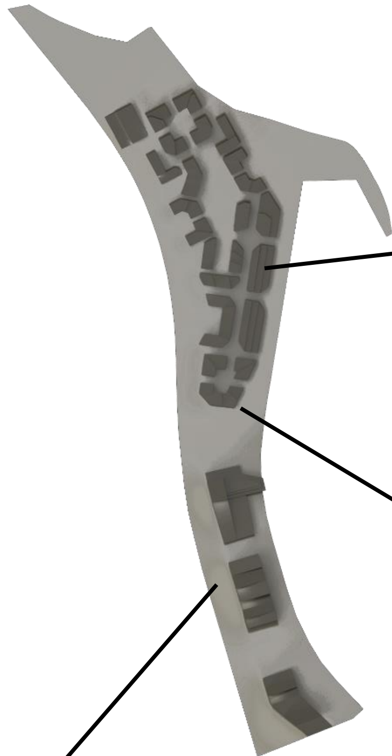


Figure 8.63. Illustration of Liaparken

Figure 8.6. Example of extensive green rooftops. Sørenga blokk 6 by Mad arkitekter

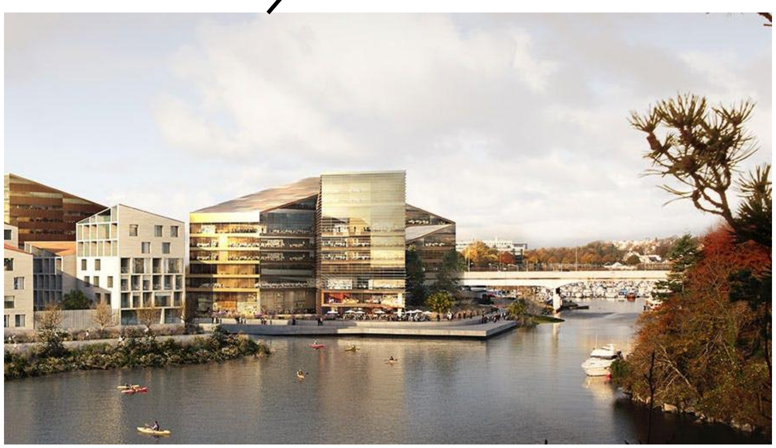


Figure 8.3. Illustration of Paradis South

9.1.1. Building height

Figure 9.6 depicts the building height of the residential area and the prevailing winds during summer. About 60% the buildings are between 3 to 4 floors and about 20% are between 5 and 6 floors. The remaining 20% are only 2 floors, which are lowered to account for sun- and wind conditions, as well as to create a more seamless environment next to Hillevågsvatnet. The upper left building is intended as a parking house and its height will therefore be adjusted according to the area's need for parking (the left part of it is under a bridge and will therefore be set between 1 to 2 floors). Its height will not impact sun- or wind conditions of the surrounding area.

Not counting areas intended for public parks, the FSI of the residential area is around 100%, which is considered relatively low for new urban development projects. However, maintaining a lower FSI is as mentioned often required to build climate resilience in exposed areas. Space is required for physical adaptations, whereas a lower building height and less horizontal density is requited for sufficient ventilation and passive cooling.

The reduced building height also greatly facilitates optimal sun- and wind conditions in the area. Figure 9.7 through Figure 9.12 depicts the sun conditions of the residential area at specific times throughout the summer months. As seen from the figures, keeping dense areas sunlit are considerably difficult, even when reducing the building height to as little as 2 floors in some areas. However, the building layout also focuses on providing a balance between direct sunlight and shade to account for heat-induced stress in the future.

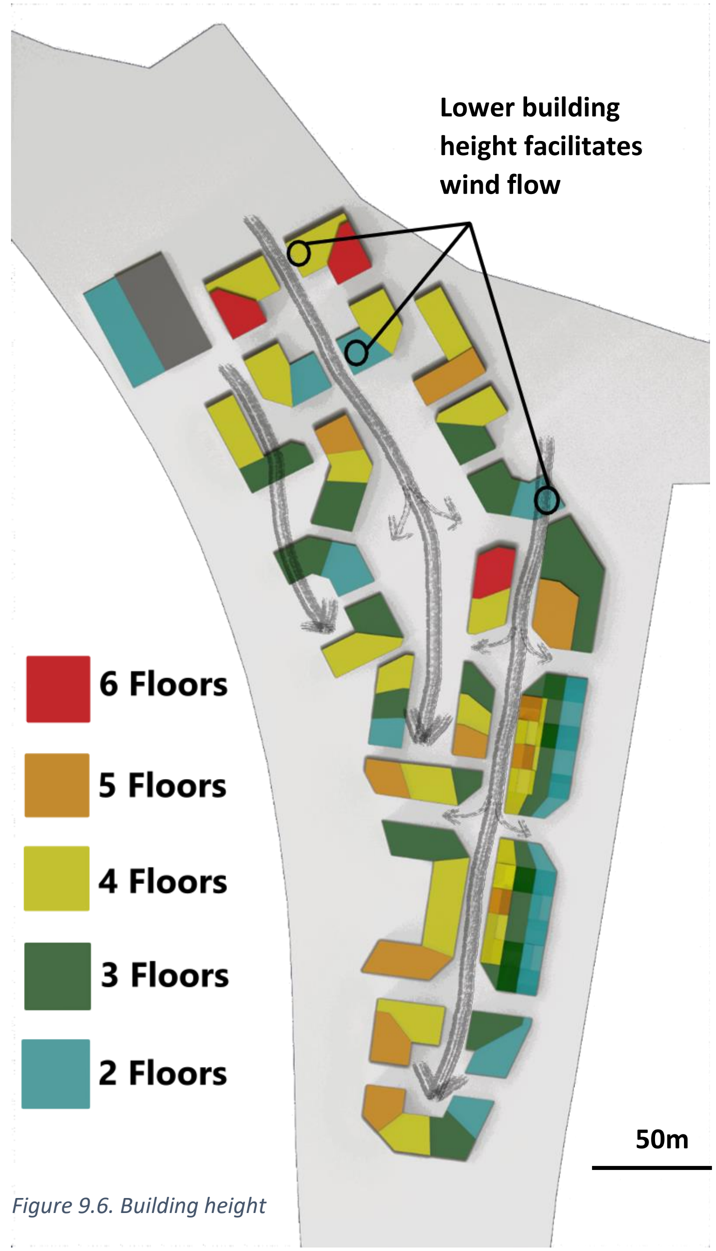


Figure 9.6. Building height

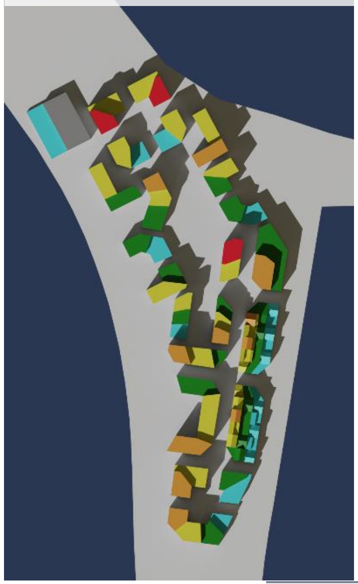


Figure 9.12. March 15:00

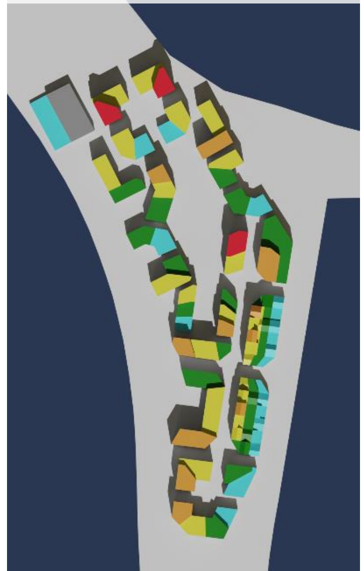


Figure 9.11. April 12:00

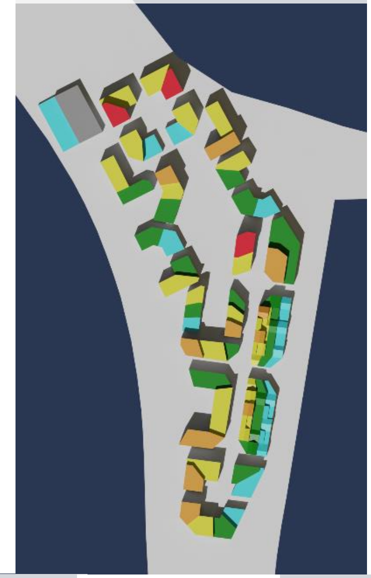


Figure 9.9. May 13:30

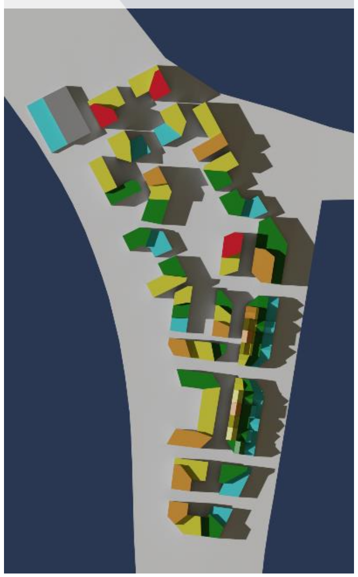


Figure 9.7. June 18:00

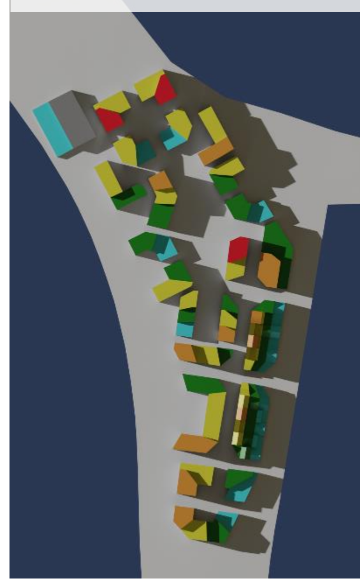


Figure 9.10. July 18:30

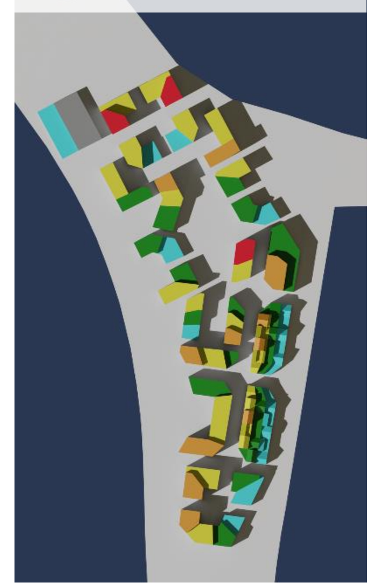


Figure 9.8. August 16:00

9.2. Functions

Figure 9.13 shows the intended functions of buildings and placements of active first floors. The upper part of Paradis North is predominately a residential area with mixed used functions located towards the waterfront, where a corner of the area is solely dedicated to recreational and commercial functions. This facilitates vibrant and lively streets with an attractive view for both residents and visitors along the green promenade. Active first floors are located along the waterfront to create an open public street with a welcoming and inclusive atmosphere. Active first floors are also located along the inner edge of the larger park with the wetland pond to create a close connection with the stormwater management functions of the area.

A larger hotel with office functions will create an attractive option for people visiting the area through business and act as a buffer between the residential area and the office area of Paradis. Mixed-use functions will still be implemented at the lower floors of the office buildings, where active first floors will maintain the important connection to Hillevågsvatnet and the waterfront.

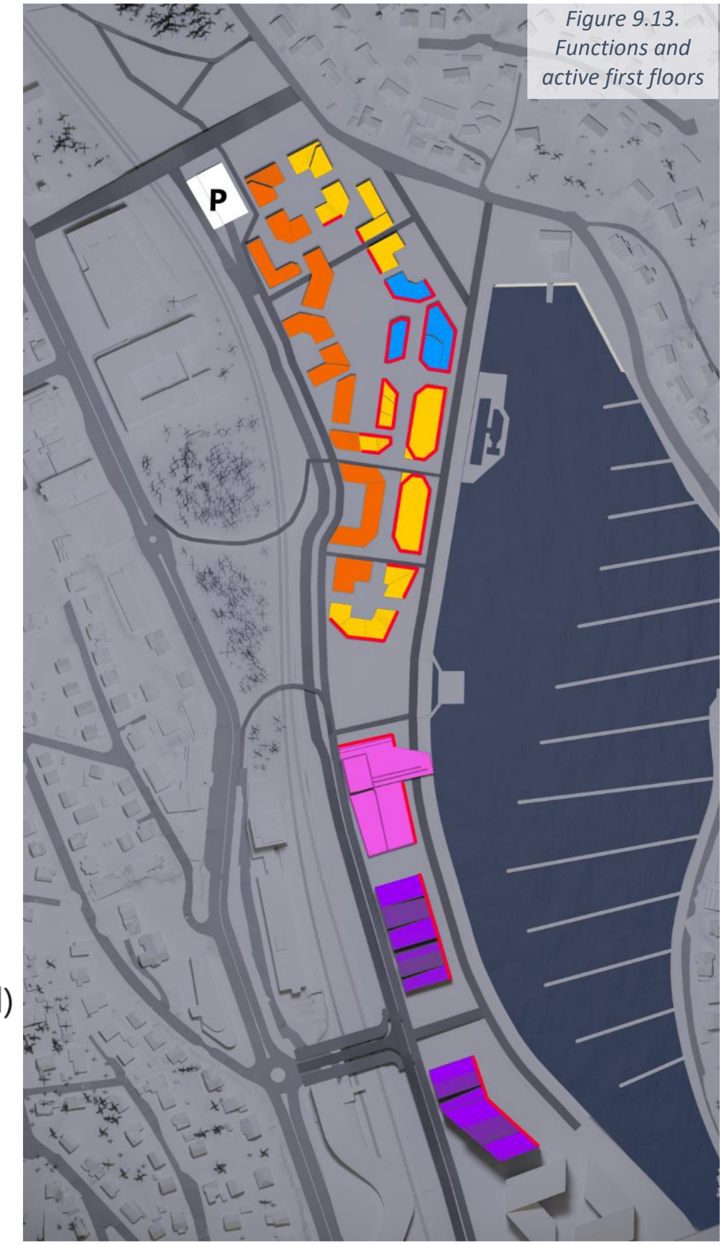


Figure 9.13. Functions and active first floors

As mentioned, the rooftops of Paradis North will be designed to accommodate recreational and social functions for their respective residents. The buildings marked red in Figure 9.14 will have private rooftops with these functions incorporated. The two rooftops marked in blue next to Hillevågsvatnet will have publicly available rooftops with the same range of functions.

Figure 8.51. Example of public rooftop terrace

Figure 8.52. Example of semi-private rooftop terrace

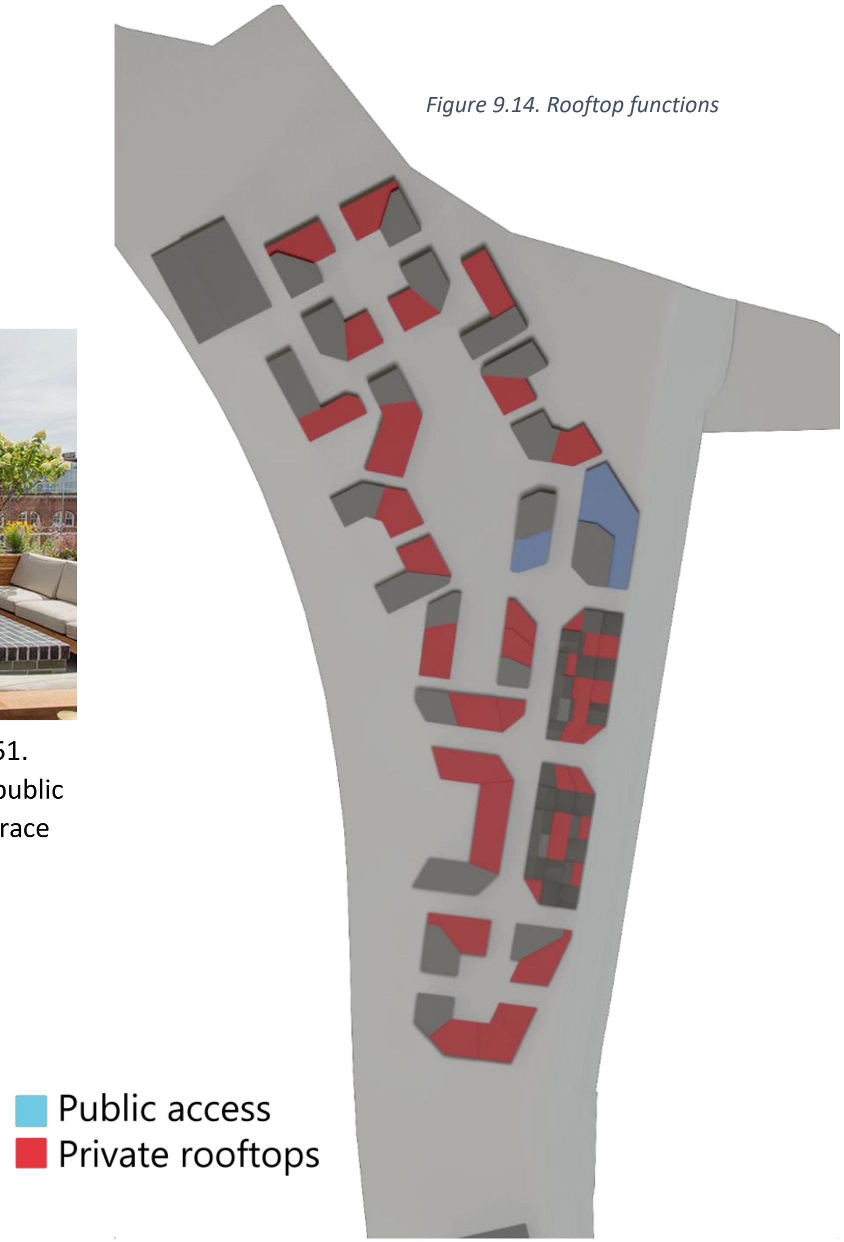


Figure 9.14. Rooftop functions

9.2.1. Open spaces

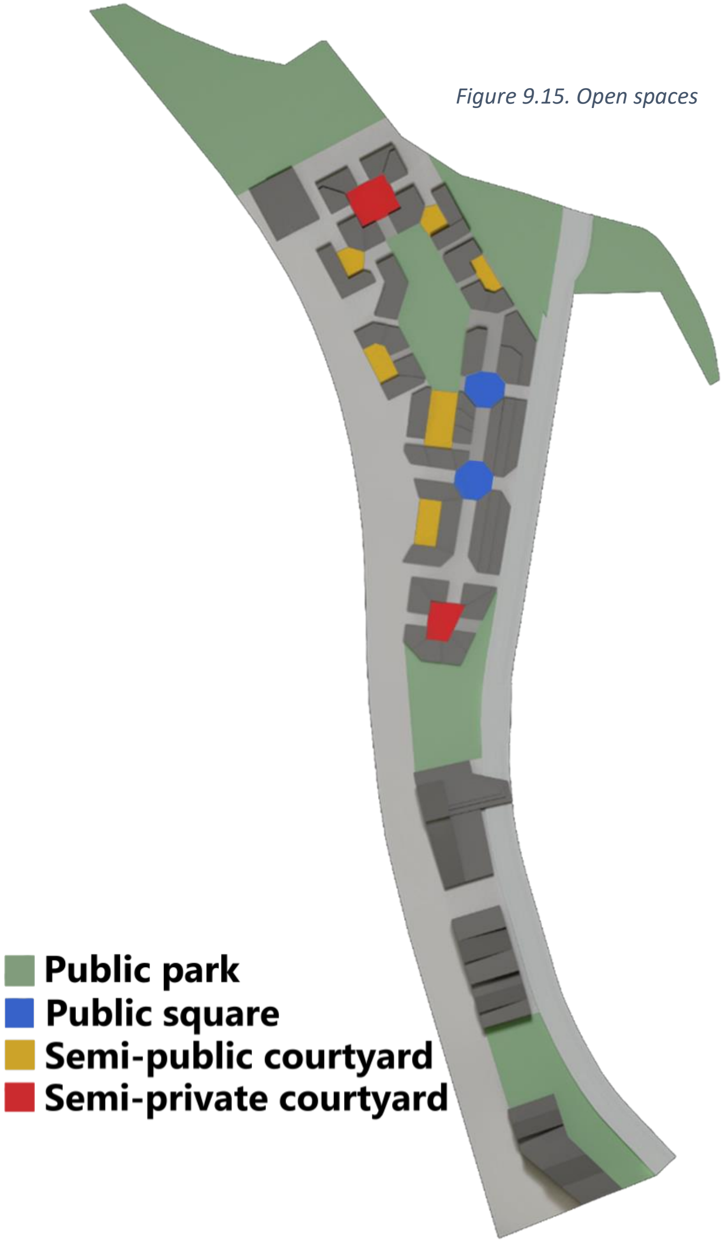
Figure 9.15 shows the open spaces of the proposal. Here, public parks cover large parts of the area to maximize infiltration and retention capacities, reduce the UHI effect, create passive cooling and sufficient ventilation, and facilitate meeting spaces and recreational functions.

The area has two enclosed public squares close to Hillevågsvatnet where the buildings with open first floors and mixed-use functions are located. These will act as important focal points for the city-life that Paradis North will bring to both residents as well as visitors.

Semi-public courtyards are spread throughout the area to increase the availability of recreational options as well as to facilitate space for physical climate adaptations. The semi-public courtyards are also placed strategically in locations where residents will travel frequently to and from the area. This increases the chances of spontaneous interaction between residents and will hopefully encourage social cohesion.

Figure 8.47. Example of semi-public courtyard

Figure 9.15. Open spaces



9.3. Connections

Figure 9.16 shows the connections for pedestrians, cyclists, and vehicles. The proposal will prioritize pedestrians and cyclists and will therefore restrict vehicle usage inside the area, where only emergency and delivery vehicles will have access. Walkability is increased by adding several connections around the area for pedestrians and cyclists, whereas cars will only have two entrance points.

In addition to the pathway connected to Lagård gravplass, and the entrance at Paradis Stasjon, two bridges connect Paradis North to the Våland area where there are options for public transport.

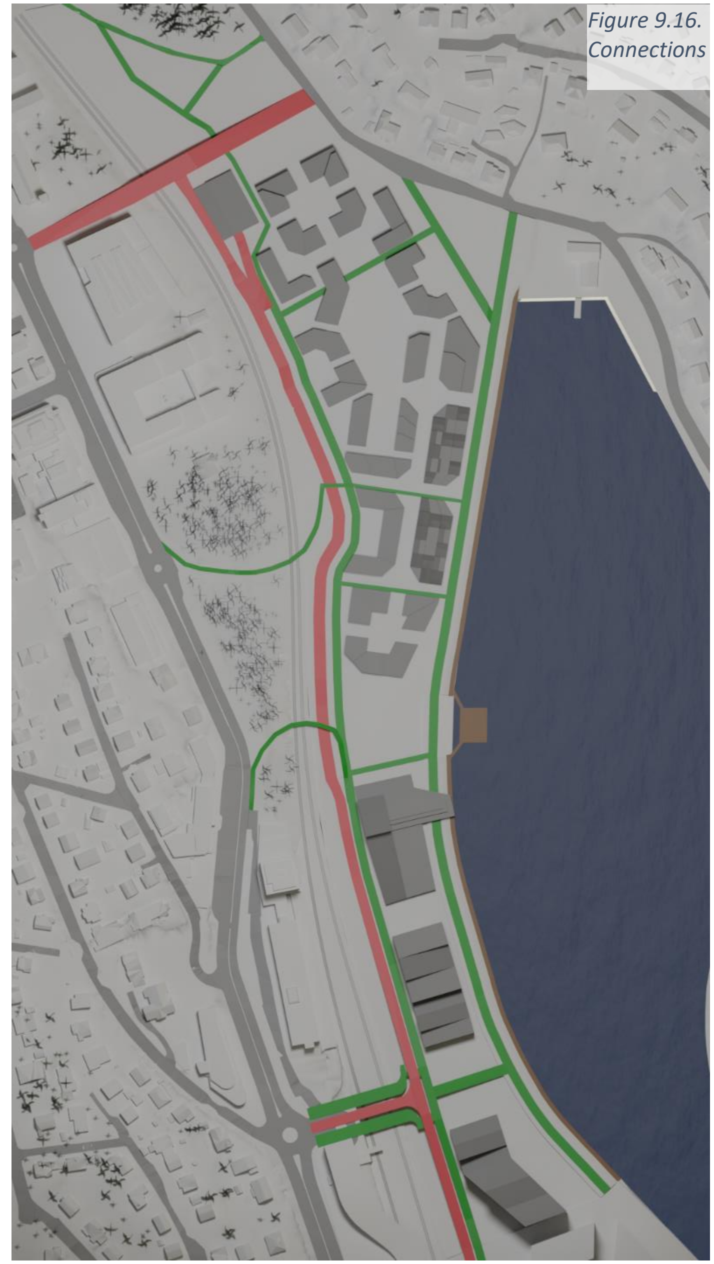


Figure 9.16. Connections

9.4. Stormwater management

Figure 9.17 illustrates the stormwater management adaptations in the upper part of the development area. Here the interconnected system of urban ponds, wetlands, and channels can be seen. Two larger ponds, one at the north end and one at the west end, will distribute excess runoff from Våland and Storhaug to the rest of the system through the larger bioswale/wet channel adjacent to the railway. Most runoff will be led through the larger pond at the centre of the residential area after it has been filtrated by prior wetlands. Here, it will create an attractive and lush aquatic environment before it eventually reaches Hillevågsvatnet. Local rainfall will also be treated by rain gardens and green roofs and will be led to the main system by open dry channels.

In the case of extreme rainfall where the system will be overloaded, overflow paths will increase the system's capacity for transporting excess runoff to reduce the risk of flooding

Figure 8.18. Illustration of wetland canal integrated into an urban

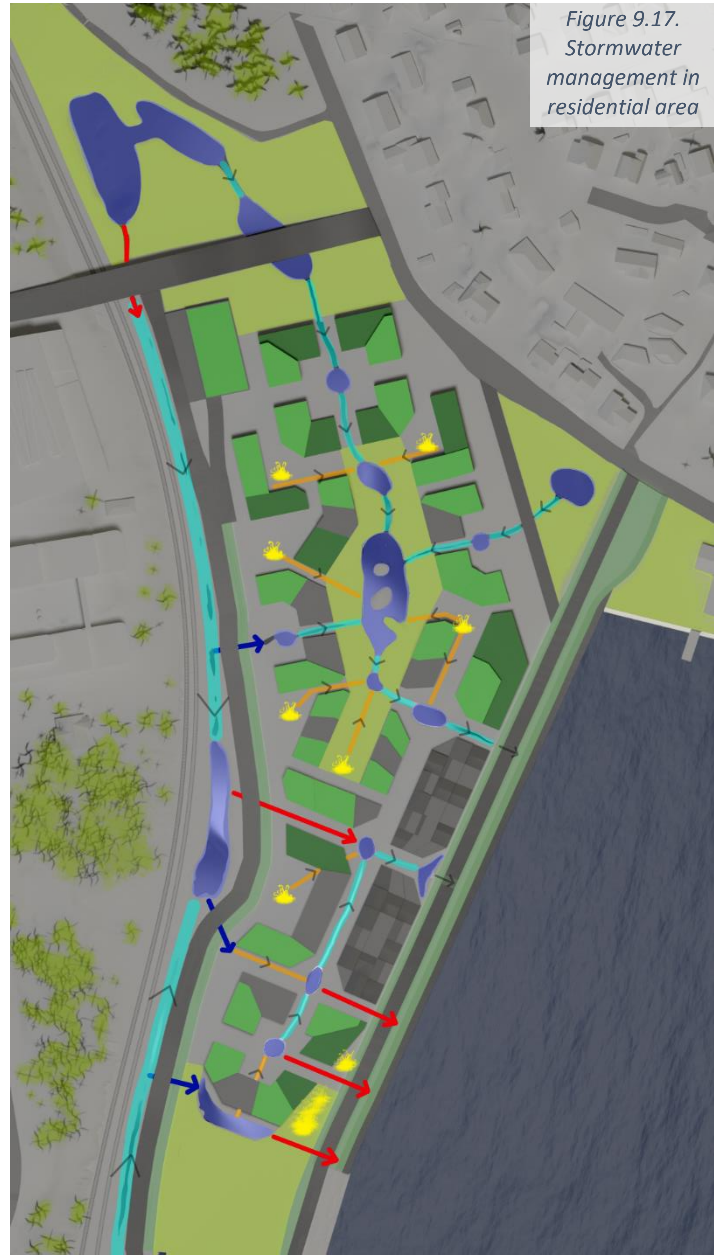


Figure 9.17. Stormwater management in residential area

- Intensive green roofs
- Extensive green roofs
- Park
- Green strip (incl. urban trees)
- Urban ponds + wetlands
- Raingardens
- Bioswales / wet channels
- Open dry channels
- Underground pipe
- Overflow path

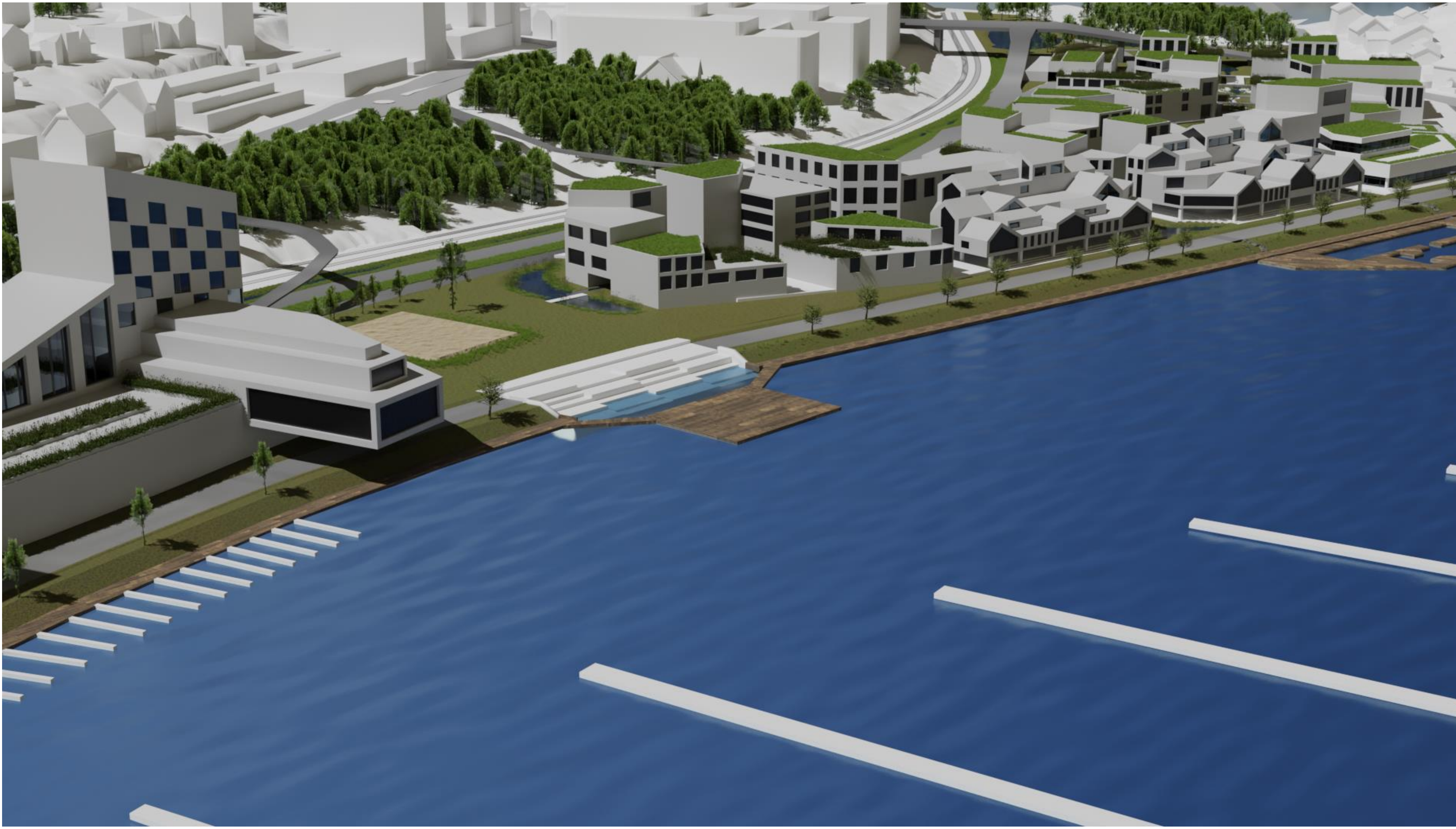
Figure 9.18 illustrates the stormwater management in the lower part of Paradis North. This area will be more intended for water filtration due to the short distance to Hillevågsvatnet. A larger pond connected to a series of smaller ponds will function as the main strategy for this intent. Rain gardens and green roofs will also increase the capacity for stormwater management but will mainly be intended for increasing the natural attractiveness of the area. A publicly available intensive green roof is placed on the hotel/office building to increase the recreational functions of the area.

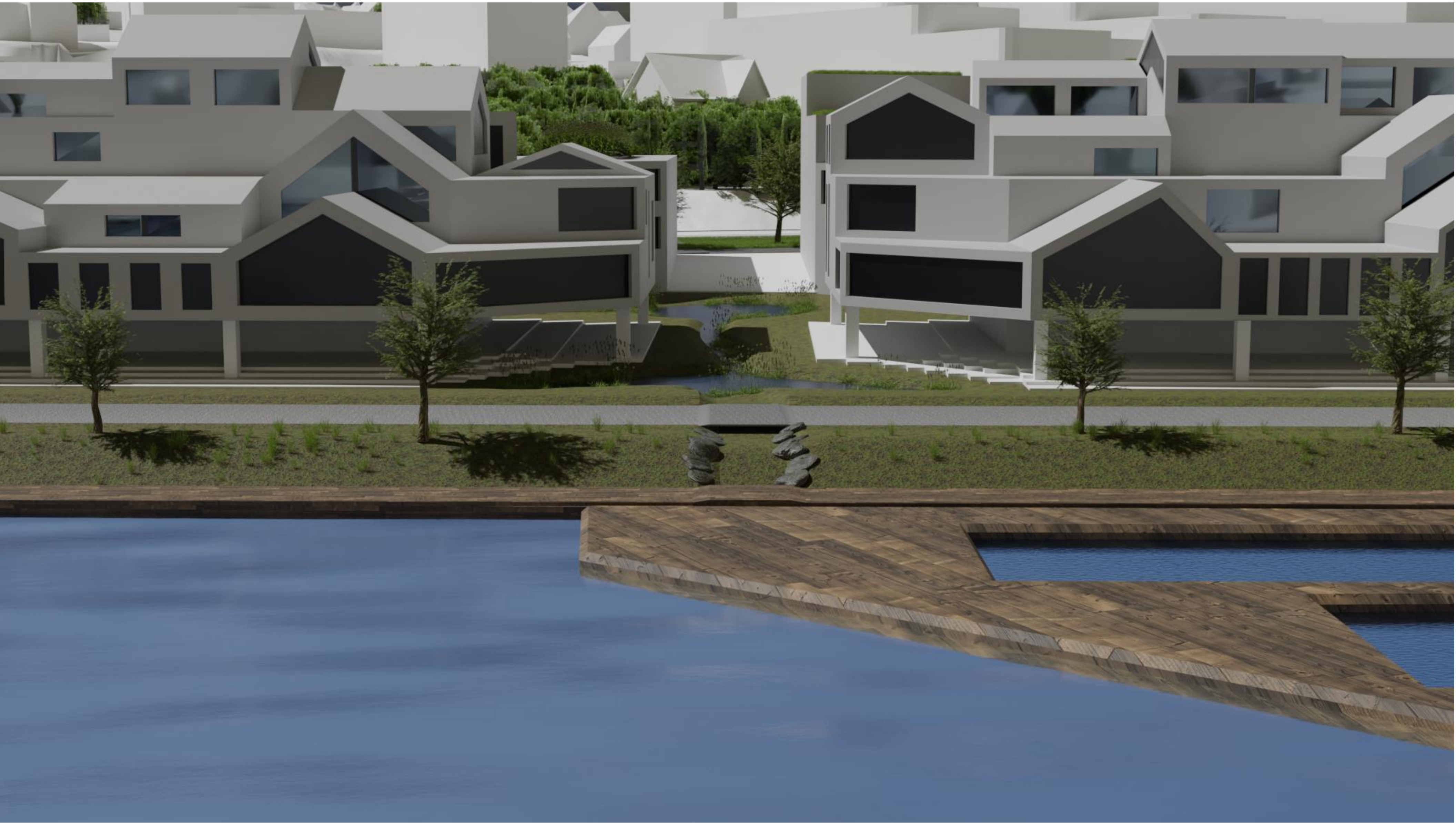
The wetland system as a whole covers approximately 16 000m^2. Assuming that the downstream catchment area is required to be 5% for both retention and filtration of the upstream area, the wetland system alone can manage runoff from a total area of 320 000m^2. This is not including urban parks, trees, rain gardens, and the green roofs, meaning the stormwater management capacity of Paradis North can handle runoff from both itself and a significant part of the surrounding areas.

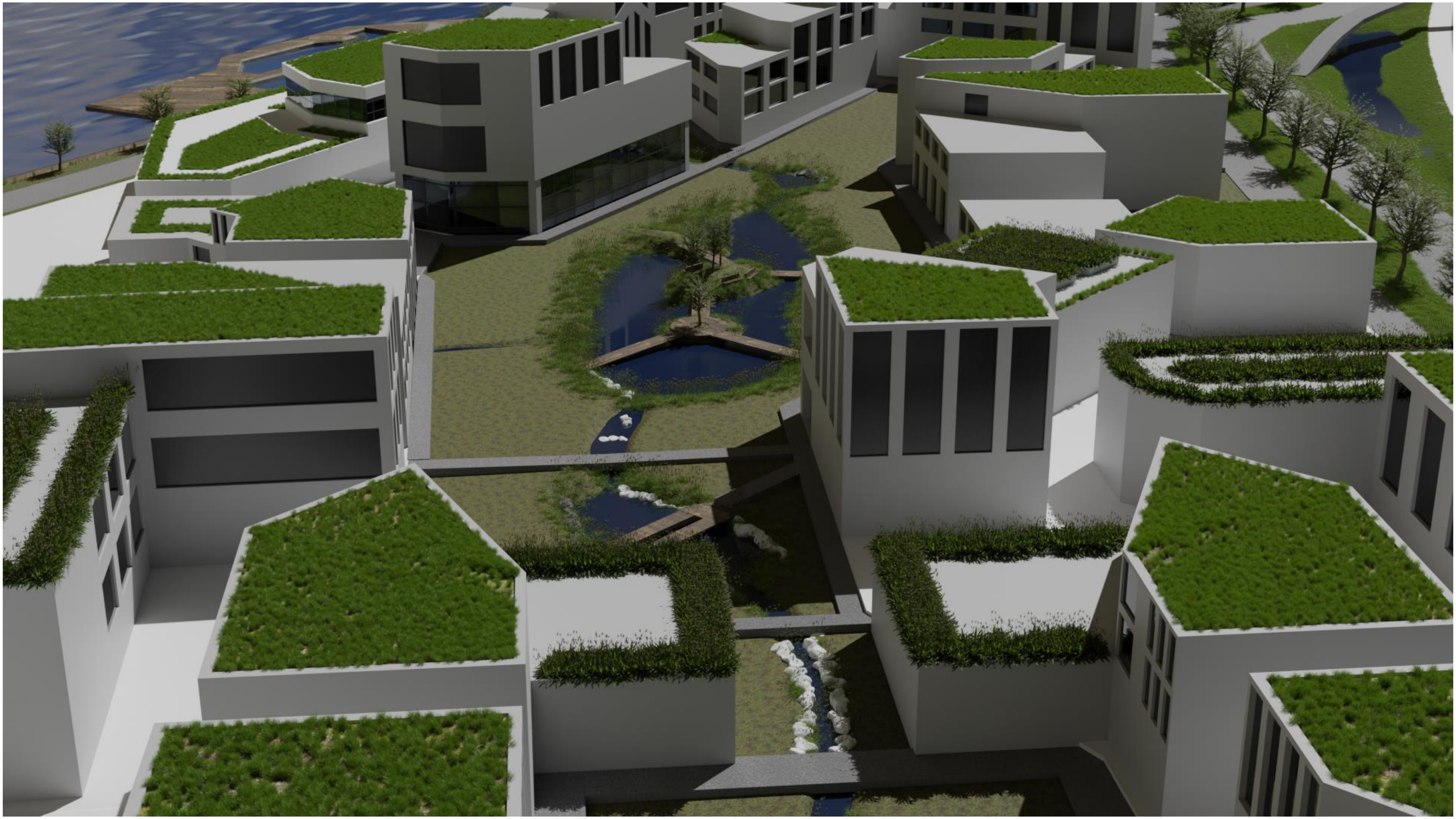
Figure 9.18. Stormwater management in the office area

9.5. Illustrations

This chapter will present illustrations from the 3D model of the area made in Blender. The illustrations will not necessarily be completely representative of the masterplan as several of the minor details will take too long to model.







Part 4: Ending

Conclusion

Discussion

References

10. Conclusion

Research question

"How can the urban development project of Paradis North, Stavanger adapt to current and future climate impacts in an effective, cohesive, and attractive manner?"

4 sub-questions are formulated to better answer the research question:

- What is climate adaptation, resilience, vulnerability, and risk?
- What are the current and expected challenges for Paradis North related to the climate?
- What are the strategies for adapting to said challenges?
- How can attractiveness and liveability be incorporated into a climate adaptation project?

What is climate adaptation, resilience, vulnerability, and risk?

- The thesis first presents the definitions of climate adaptation, resilience, vulnerability, and risk to establish a comprehensive understanding of the terminology used throughout. Climate adaptation were defined as the action of adjusting to climatic impacts, resilience and vulnerability were defined as the state of a system's susceptibility to adversities, and risk were defined as the combination of an event, its likelihood, and its consequences.

What are the current and expected challenges for urban areas related to the climate?

- The current and future challenges relating to climatic impacts in Paradis North were presented to establish the motive of the thesis and the requirements of the climate adaptations. Climate conditions in a high emissions scenario (RCP8.5) were used as the baseline to maximize climate resilience and to account for any uncertainties.

- The climate impacts subject to focus in the thesis were as follows:

    - Rising sea levels increasing the risk of storm surge flooding
    - Increased precipitation increasing the risk of stormwater flooding
    - Rising temperatures increasing the risk of heat-induced stress.

    For stormwater management, restricting pollution of Hillevågsvatnet (the adjacent bay) have been an important focus. Sun- and wind conditions as well as air quality have also been included as climatic impacts relating to urban attractiveness and liveability.

What are the strategies of adapting to said challenges?

- When researching the subject of climate adaptation, the prevailing literature focuses on nature-based solutions and low-impacts developments as cost-effective, sustainable, and multifunctional adaptations. This thesis has adopted these concepts as the main strategy to build climate resilience.

- The summary of the adaptations are as follows:

    - Incorporating green infrastructure such as urban trees, parks, green roofs, bioswales, rain gardens and other vegetation as cost-effective, multifunctional adaptations for practically every mentioned challenge in some aspect.

    - Bluegreen solutions such as urban ponds and wetlands are considerably effective as stormwater management adaptations to reduce the risk of flooding and pollution by runoff.

    - Encouraging community cohesion to build resilience, often in the form of increasing the adaptive capacity to recover from adversities.

    - Avoiding building in areas exposed to future impacts is a form of proactively reducing risks and is especially effective to mitigate both stormwater flooding and rising sea levels.

    - Elevation of both terrain and building foundations to combat rising sea levels.

    - Building typology can be utilized as a means to optimize sun- and wind conditions, and thereby air quality, in urban areas.

How can attractiveness and liveability be incorporated into a climate adaptation project?

- As a product of their multifunctionality, nature-based solutions are effective means of incorporating both climate resilience as well as enhancing the attractiveness of an urban area. Urban wetlands and open channels adopt the principle of 'visible functions' when managing stormwater, an attractive feature lacking in conventional sewage systems. It is also important to design climate adaptations to include social functions, such as seating areas around a well-maintained pond.

Resilience to stormwater flooding is built by integrating nature-based solutions that infiltrates, retains, and safely transports runoff. The main strategy for managing stormwater is the implementation of a system of wetlands connected by open channels which integrates well into the area. This system catches, infiltrates, and retains large amounts of stormwater originating in and around the development area. The wetland system retains and purifies polluted runoff through natural processes and eventually transports it to Hillevågsvatnet as a natural recipient. This eliminates, or at least severely alleviates the reliance on a conventional sewage system for managing runoff. Other adaptations such as green roofs, rain gardens, and urban trees are also implemented to increase the areas capacity for stormwater management.

Resilience to rising sea levels and storm surges is built by elevating the terrain to 3 meter above current levels, which by future standards is 2,21m AMSL. To maximize resilience and account for any uncertainties, the first floor of buildings adjacent to Hillevågsvatnet is also raised by extended foundations. Stairs and slopes are utilized to create a seamless environment for buildings with raised foundations.

Climate impacts relating to both high temperatures and comfortable wind conditions were reduced by adjusting the building typology to reach a balance between stale and high wind speeds. Buildings were strategically placed to allow for sufficient ventilation and passive cooling by designing the layout with horizontal permeability. Variety in both building orientation and height were also adopted to restrict high wind tunnels and achieve optimal ventilation. Building heights were also adapted to prevailing summer- and winter wind directions by increasing the height of buildings located south-east of areas of interest such as public spaces or courtyards. This restricts further cooling during winter by shielding said areas from the south-east oriented winter winds and increases wind flow for the north-east oriented summer winds.

A community cohesion between the hypothetical residents of Paradis North is strongly encouraged by including options for socialization, meeting spaces, and spontaneous interactions. The residential buildings adopt an apartment block structure with semi-public courtyards where residents and neighbours will often walk through to traverse the area. This encourages spontaneous interactions which can often be the first step to building social bonds. Private rooftops with recreational functions and attractive features for social gatherings are also available to the residents of each building to strengthen social cohesion.

The areas potential as an attractive extension of the city centre is utilized by focusing on a dense, mixed-use development with a close connection to Hillevågsvatnet. Buildings in select areas have open first floors with options for recreation and commerce to create busy, lively streets. Public parks and enclosed squares further integrate city-life functions and create a welcoming perception of the area. Natural features primarily intended to build resilience to stormwater flooding such as the green roofs and the wetland system is integrated into the area in a natural and cohesive manner to enhance the attractiveness of the area and to facilitate recreational functions.

To summarize, the proposal for the urban development project of Paradis, Stavanger is adapted to current and future climate impacts in an effective, cohesive, and attractive manner primarily by adopting multifunctional nature-based solutions that integrate well into the area. Reducing the FSI to accommodate space for both physical adaptations as well as sun conditions and passive cooling have also been an important strategy.

11. Discussion

This thesis includes several distinct climate risks affecting the urban development of Paradis North, where the solution is to implement nature-based solutions and to reduce the FSI. The implications of these adaptations are that the area will essentially exchange options for increased urban development for adaptive capacity to climate risks. It seems therefore inevitable that an urban climate adaptation project will be required to give up space intended for new development to optimally adapt to the climate. This compromise can be alleviated by combining urban development with nature-based solutions that enhance the natural attractiveness of the area and provide liveability. For new development, it seems crucial that space is developed as effectively as possible to increase both adaptive capacity as well as the economic gain from a new urban area. However, while it may seem undesirable for a municipality to reduce the built space to accommodate climate resilience, this may be a necessary requirement to avoid intolerable risks in the future. Instead of viewing climate adaptation as a pathway to a missed opportunity for expanded urban development, it should rather be viewed as an investment that can greatly pay off if managed correctly.

The proposal closely adheres to nature-based solutions as the main adaptation for most of the relevant climate consequences. This is also a prevailing strategy in most available literature, arguably due to their relatively low impact and high versatility. However, nature-based solutions are often lacking in capacity to handle extreme events of rainfall and can therefore be less optimal in certain locations, especially if there is no sufficient recipient nearby. On this account, Paradis is particularly suited to manage stormwater by nature-based solutions as it can utilize Hillevågsvatnet as a natural recipient and implement filtration and retention measures in the undeveloped areas. Paradis North can therefore be seen as a close to optimal example of where this can be applied. The same can likely not be said for a different urban development project without the same features. It is therefore important to recognize this distinction and not apply the methods of this proposal as a panacea for all urban development projects relating to climate adaptation.

While it would not be realistically possible due to scope and time constraints, it would be significantly interesting and relevant to delve deeper into each of the climate consequences and effectively quantify the impact of each adaptation to it. This is especially true for the adaptions to stormwater flooding. Here, a program could be used to simulate flow paths to accurately assess the adaptive capacity of the adaptations such as the green roofs or the wetland system. This would also allow for a different approach where a more optimal solution to flood-risk management could emerge from extensive trial and error. The lack of objective measurements outside of utilizing existing literature also creates a significant limitation of the thesis as there is no way of establishing the optimal adaptation pathway.

Simulations could also be carried out for wind conditions to adjust the building typology for optimal ventilation. Utilizing programs for simulating flood paths and wind conditions were originally planned to be a part of the analysis and proposal but were ultimately left out due to their intensive learning curve and use of time.

Social cohesion is used as an indirective approach to increasing climate resilience in the neighbourhood of Paradis North. This is an unusual and interesting topic as it is rarely discussed as a strategy of adapting to climate changes. However, the example of the Chicago along with other supporting literature suggest that strengthening community cohesion is an underrated and effective strategy to reduce climate vulnerability. It is although unfortunate that there is practically no way of demonstrating whether this will have a discernible effect in the face of climate adversities prior to them occurring. Unlike green roof and ponds, which can have their adaptive capacity to flood risk calculated and defined by measuring the amount of water they store, the effect of social cohesion cannot be quantified and predicted as easily. The only measurable approach would be to reactively compare Paradis North and its hypothetical cohesive community to another community with similar demographics after a climate impact.

The exact size requirement of the water filtration and retention capacity of the area was difficult to estimate accurately without extensive research. Without knowing exactly how much of the surrounding area should be included as a source of runoff, an estimation would have to suffice. As a result, it is possible that much of the ponds and wetlands in the proposal are too large due to overcompensation. Furthermore, a lack of sufficient data made adaptations to future heatwaves difficult to justify. Most predictions of local climate risks do not include high temperature among the relevant concerns, which is likely because a temperate climate like Stavanger is at a reduced risk of heatwaves. However, it is reasonable to assume that heatwaves are relevant should a higher emission scenario play out, as the thresholds for dangerously high temperatures are already passed during the hotter summer months.

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Figure 5.23. Image retrieved from:
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The illustrations of permeable pavement, rain garden, bioswale, and native landscaping in 5.4 are created by *Doug Adamson, RDG Planning & Design, provided by USDA-NRCS in Des Moines, Iowa.*

Figure 5.26. Image retrieved from:
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Figure 5.29. Image retrieved from:
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Figure 5.34. Image taken from:
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Figure 5.49. Image taken from:
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Snazzymaps:
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Figure 8.3. Image retrieved from:
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Figure 8.4. Proposed relocation of the private docks. AutoCAD-file retrieved from Ghilardi + Hellsten arkitekter. Edited by author.

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Figure 8.9. Example of park 4. Image retrieved from:
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Figure 8.16. Urban pond and channel in Augustenborg, Malmö. Image retrieved from:
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Figure 8.40. Example of urban trees and vegetation in semi-private courtyards. Image retrieved from:
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Figure 8.44. Example of harbour bath. Copenhagen. Image retrieved from:
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Figure 8.50. Public bath on rooftop in Budapest, Hungary. Image retrieved from:
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Figure 8.58. Example of open first floor at green promenade. Image retrieved from:
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Figure 8.63. Illustration of Liaparken. Image retrieved from:
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Other illustrations depicting design principles such as Figure 8.1 and Figure 8.2 are created by the author using edited maps.

Backgrounds:

Chapter 3:
https://g20.org/g20-edm-cswg-delegation-backs-global-commitment-to-address-environmental-issues-and-climate-change/

Chapter 4:
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Illustrations from chapter 9.5 are from the 3D model created by author and made in Blender