SHORELINE SHIELD

Hybrid Solutions for Sustainable Coastal Protection

Refshaleøen,Copenhagen

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SHORELINE SHIELD

Urban designFlood Resilience Refshaleøen, Copenhagen

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Acknowledgments:

First and foremost, I dedicate this work to my beloved mother and father, who, despite being far from me, have provided unwavering support and encouragement throughout this journey. Your love and sacrifices have been my greatest strength, and I miss you both deeply.

I would also like to express my deepest gratitude to my supervisor, Dr. Roberta Ingaramo, for her invaluable guidance and support from the very first seminar to the completion of this thesis. Your insight and encouragement have shaped this work, and for that, I am truly thankful.


SUSTAINABLE
DEVELOPMENT
GOALS
11
SUSTAINABLE CITIES
AND COMMUNITIES

Abstract:

The increasing threats posed by climate change and rising sea levels necessitate the development of flood-resilient urban strategies, particularly in coastal areas like **Refshaleon on Margretheholms Port.**
This thesis explores the integration of green infrastructure, low-impact development (LID), and nature-based solutions to mitigate flooding risks while enhancing ecosystem services. The research proposes a multi-layered approach, combining waterfront elevation, living shorelines, and floodable parks, which together create a sustainable, resilient waterfront. These strategies not only protect the urban landscape but also enhance recreational spaces and foster public access to natural resources. The proposed solutions are designed to provide long-term flood protection while creating environmental, social, and economic value for the community.

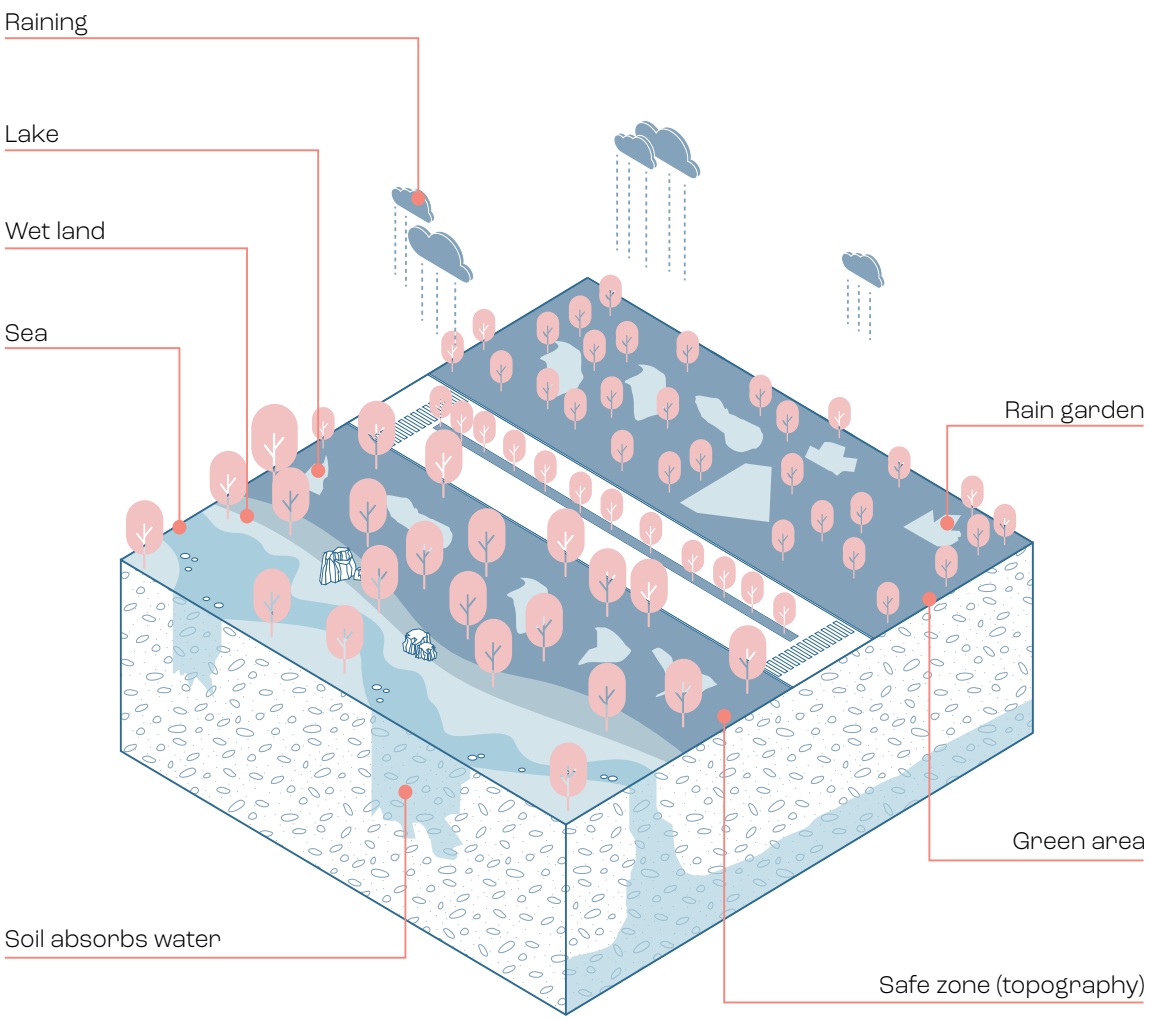

Figure 1: © Author

Introduction:

As climate change accelerates, urban areas, especially those located along coastlines, face unprecedented risks from flooding and rising sea levels. Refshaleon, situated in the vulnerable Margretheholms Port, exemplifies the urgent need for sustainable flood resilience solutions. The traditional approach of hard infrastructure, such as seawalls and bulkheads, is no longer sufficient to address the complex challenges posed by climate change. Instead, there is growing recognition of the value of integrating green infrastructure, low-impact development (LID), and nature-based solutions into urban planning.

This thesis investigates innovative flood protection strategies that leverage blue-green infrastructure to create a resilient waterfront. By focusing on floodable parks, raised harbor walks, and living shorelines, the study emphasizes a holistic approach that not only mitigates flooding risks but also enhances ecosystem services, improves public space, and fosters urban biodiversity. These solutions aim to strike a balance between protecting urban areas from climate impacts and maintaining access to the natural waterfront, offering both environmental and social benefits.

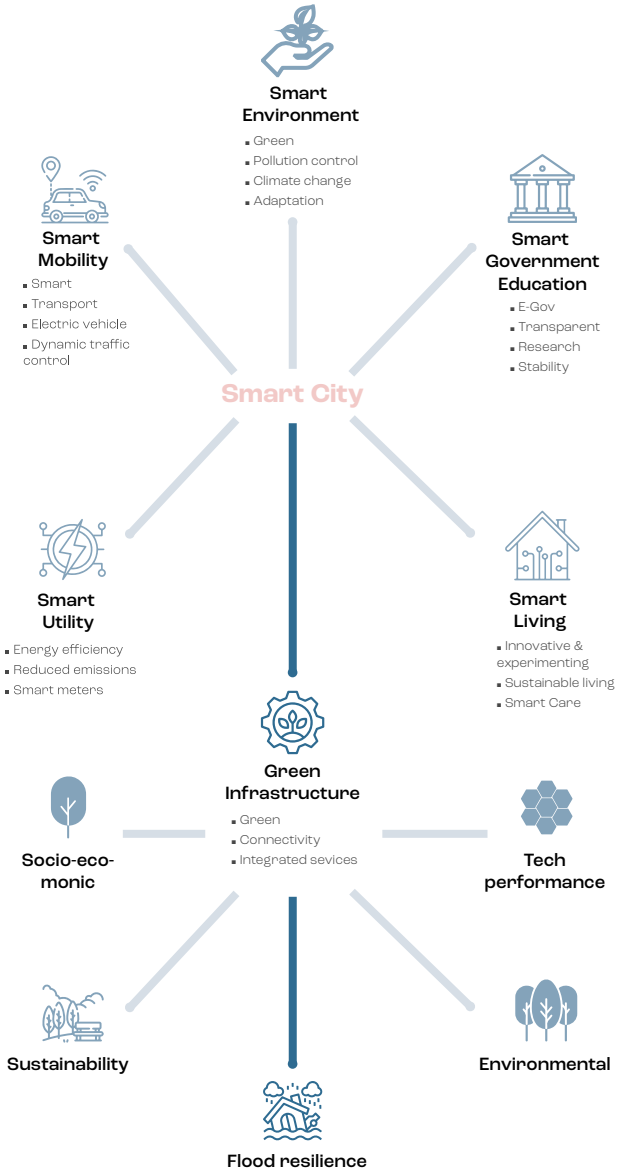

Figure 2: © Author

IPCC REPORT 2021:

The Sixth Assessment Report (AR6) of the United Nations Intergovernmental Panel on Climate Change (IPCC), along with the corresponding Summary for Policymakers (SPM) document was released in August 2021.
The IPCC is the leading world body for the assessment of climate change, and the re port complies more than 14 000 scientific papers to produce a 3 949 page report, approved by 195 governments. The report summarizes the assessments of 234 scien tists of 66 countries on scientific, technical, and socio-economic levels concerning cli mate change.
On a very synthesized way, the report states it is only possible to avoid warming of 1.5°C or 2°C if massive and immediate cuts in greenhouse gas emission are made.

Some key findings of the report are:

1.Sea level rise by 2100 is likely to be from 0.5 to 1 meter, but 2 to 5 meters is not ruled out, as ice sheet instability processes are still poorly understood by 2022.

2.The probable temperature rise by the end of the century is about 3°C. It is likely that 1.5°C will be reached before 2040.

The consequences of a global warming of just 1.5°C have been long documented and portrayed as irreversible and catastrophic.

Some quotes about the report by key people in the climate discussion are:
“The report is a code red for humanity“. António Guterres, UN Secretary General
“The report once again sounds the climate alarm. The EU is doing its part with the #EUClimateLaw and 2030 #EUGreenDeal“. Ursula von der Leyen, EU Commission President
“The next decade will be pivotal to the fu ture of the planet“. Boris Johnson, UK’s Prime Minister
“The report confirms what we already know from thousands of previous studies and re ports - that we are in an emergency“. Greta Thunberg, Swedish climate activist.

RESEARCH QUESTIONS:

1. How can coastal fortification strategies effectively balance natural ecosystems and engineered solutions to enhance waterfront resilience, as outlined in the “Resilient Shores” approach?

2. What are the key challenges and opportunities in integrating blue-green infrastructure for flood protection in urban waterfront developments?

3. How effective are low-impact development (LID) strategies in creating sustainable and resilient urban spaces while maintaining social, environmental, and economic benefits?

Thesis Objectives:

1.Evaluate Hybrid Coastal Protection Solutions: Assess the effectiveness of combining hard engineering and nature-based strategies in creating flood-resilient coastal protection, with a focus on the “Shoreline Shield” concept for Refshaleon.

2.Explore Blue-Green Infrastructure Impact: Investigate how green infrastructure and low-impact development (LID) techniques can enhance ecosystem services and flood mitigation while improving public space along coastal edges.

3.Address Implementation Challenges: Identify the technical, financial, and coordination challenges of integrating hybrid and nature-based solutions for sustainable coastal resilience.

4.Propose Adaptive Strategies for Long-Term Resilience: Develop adaptable, scalable coastal protection strategies that balance ecological sustainability, social benefits, and urban development in flood-prone waterfront areas.

Scale :

Urban Design

Evaluation Criteria for climate resilience strategies:

CATEGORY	CRITERIA
EFFECTIVENESS	Maximum level of protection (% annual chance or sea level rise scenario) Reduction in flood extent Avoided damage and loss Residents protected Critical assets protected
FEASIBILITY	Constructability Permitting Affordability: Cost of Construction + Cost of Maintenance Replicability
DESIGN LIFE + ADAPTABILITY	Design Life Performance Horizon Adaptability or Flexibility Phase-ability and Time to Implementation Maintenance Requirements
SOCIAL IMPACT	Recreational Cultural Aesthetic
EQUITY	New and Equitable Access to Waterfront Additional Benefits for Vulnerable Populations Community Partnerships Protection of Affordable Housing over the Long Term
VALUE CREATION	New Value Created on Sites or Adjacent Sites Capacity to Catalyze Future Funding and Investment
ENVIRONMENTAL IMPACT	Water and Air Quality Habitat Value Human Health Benefits Mitigation of Other Climate Hazards

Reference: COASTAL RESILIENCE SOLUTIONS FOR DOWNTOWN BOSTON AND NORTH END FINAL REPORT September 2020

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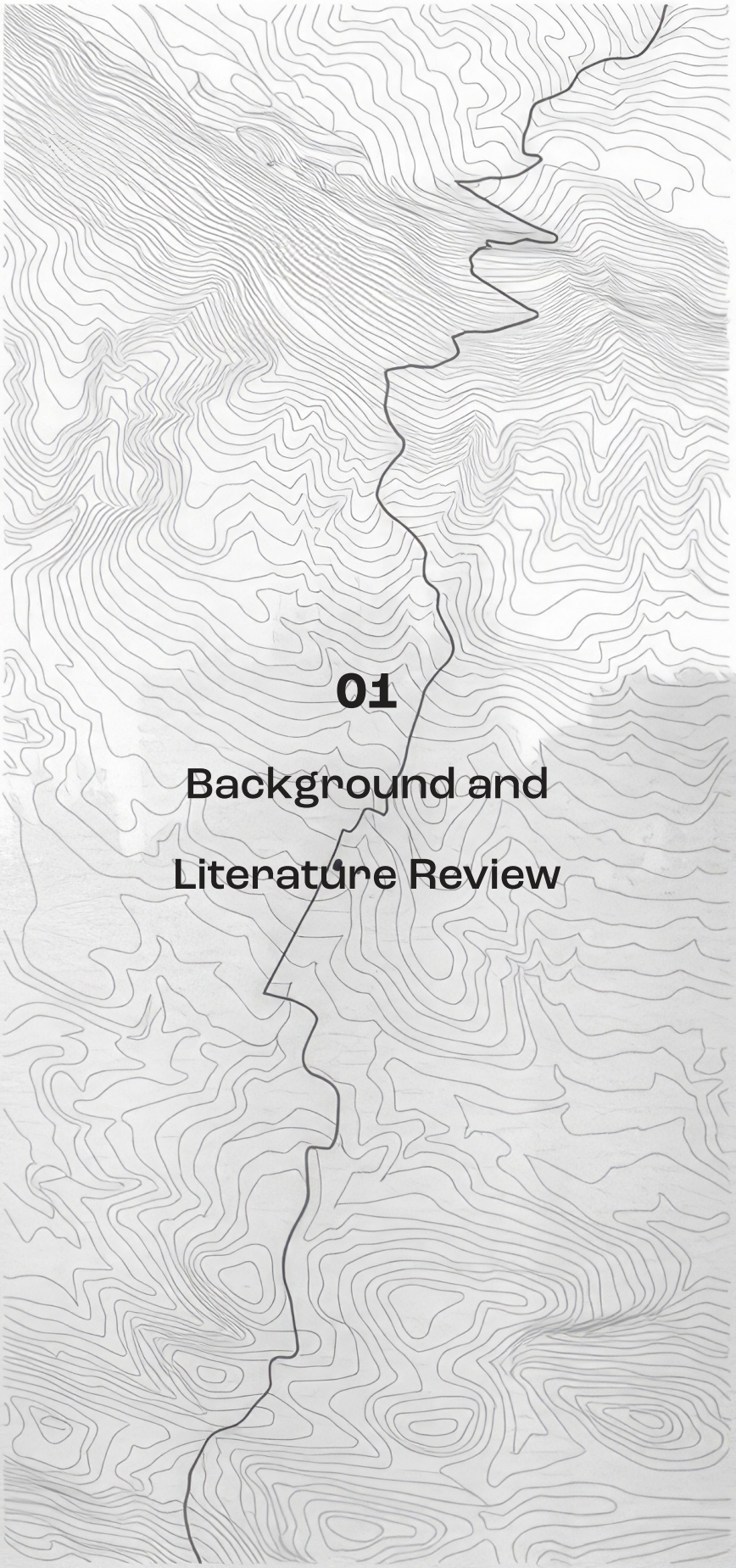


01

Background and Literature Review

Literature Of Green Infrastructure:

Green infrastructure emerged as a concept in the 1990s as planners began to consider the organised provision of ecosystem goods and services in the urban context. They noted that urban forests and rivers and streams provide ecosystem goods and services in a similar way to the way that transport and energy systems offer access and power.(Teaford, 1987; Walmsley, 1995)

This development drew from emerging research themes such as industrial ecology and the city as an ecosystem, but the maininspiration was the development of ecosystem goods and services.(Gill et al., 2007; Tzoulas et al.,2007)

The term green infrastructure is often used because of its similarity to conventional infrastructure, which is generally seen by federal and state governments as good for the economy and not a drain on resources. However, this is not necessarily the case for local government, who face a significant shortfall between revenue and limited revenue raising powers and demand on infrastructure renewal.(Victorian Auditor-General, 2014)

Three main approaches to green infrastructure have been identified in the literature review:

undertaken for a project (Symons et al., 2014):

1) Ecosystem goods and services. This approach emphasises the services that nature and natural cycles provide to society (Ehrlich and Mooney, 1983; Mooney and Ehrlich, 1997;Millennium Ecosystem Assessment, 2003; Costanza et al., 2014). These natural cycles occur over the entire planet (e.g., the carbon cycle), however, they can be restored and maintained within urban settings to provide benefits in that setting.

2)Green spaces network approach. This perspective highlights the importance of retaining and linking green spaces and nature corridors in cities to improve the functioning of ecosystems. This perspective mimics traditional infrastructure approaches in that it provides a network for the functioning of a city (Benedict and McMahon, 2002)

3) Green engineering approach. This viewpoint considers GI to be a subset of traditional engineering infrastructure whereby typical practices have green elements added to them which can provide ecosystem services such as cooling through the installation of green roofs and living walls (Margolis and Robinson, 2007)

Green Infrastructure for Urban Flood Resilience (Recent Literature)

Exposure to natural hazards is continually rising as a result of increased urbanization, population concentration, and the intensity of economic activity in cities [1]. Amongst them, urban flooding is a climatic disaster that can strike anywhere and is highly intertwined with climate, human activities, urban planning, and drainage systems [2]. The problem of urban stormwater, which is not absorbed by the urban drainage system and often carries high amounts of contaminants from the sewage, streets, and roofs, is arising due to climate change [3]. Compared with rural areas, the multiplicity of land uses, the density of construction, and the diversity of urban projects all contribute to more complexity in the flood risks in urban areas [4,5].

Additionally, disasters caused by urban flooding endanger the lives of city dwellers and can also cause substantial economic damage to the urban dynamic economy. This means that economic growth and the security of life and property depend critically on the resilience of cities and the capacity to rebuild after floods [6,7].

In this regard, in urban resilience research, the adaptive capacity of the urban systems is addressed by urban resilience, whereas urban flood resilience (UFR) signifies the adaptive capacity to cope with flooding produced by climate change [8]. Flood resilience may significantly mitigate the negative consequences of harsh weather [9].

Green infrastructure (GI) is a relatively new approach that has gained popularity as a means to lessen the destructive effects of floods and to strike a better balance between the needs of urbanization and those of nature [10,11,12]. In this regard, GI could be defined by its vegetated or sustainability-based techniques, such as porous pavements, green roofs, and bioretention cells, that may minimize the quantity of stormwater entering urban drainage systems [13]. In environmental engineering and within the context of stormwater management, GI is occasionally used as an alternative for gray infrastructure [14,15]. Although gray infrastructure (e.g., underground pipes, concrete structures) tends to be efficient in stormwater management, the advantage of GI is its multifunctionality, self-adaptiveness, and the co-benefits it produces in comparison to gray infrastructure's inflexibility and mono-functionality [16]. According to planners, engineers, and flood managers, GI helps reduce flood damage in a number of ways such as: (i) decreasing the amount of stormwater runoff [17]; (ii) decreasing the peak flow velocity [18,19,20]; and (iii) boosting the storage capacity and quality of water [10].

Keyword view and clusters in the reviewed literature from 2018 to 2022.

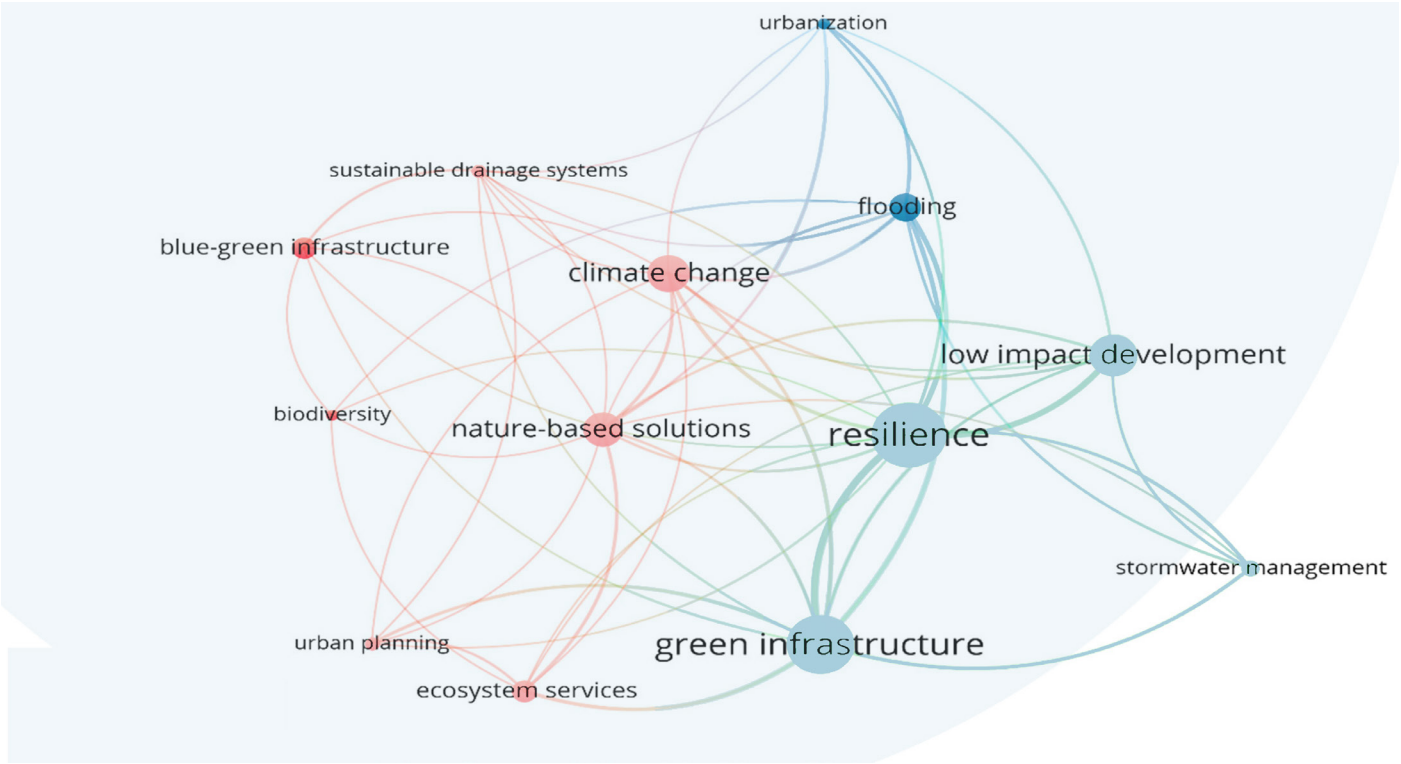


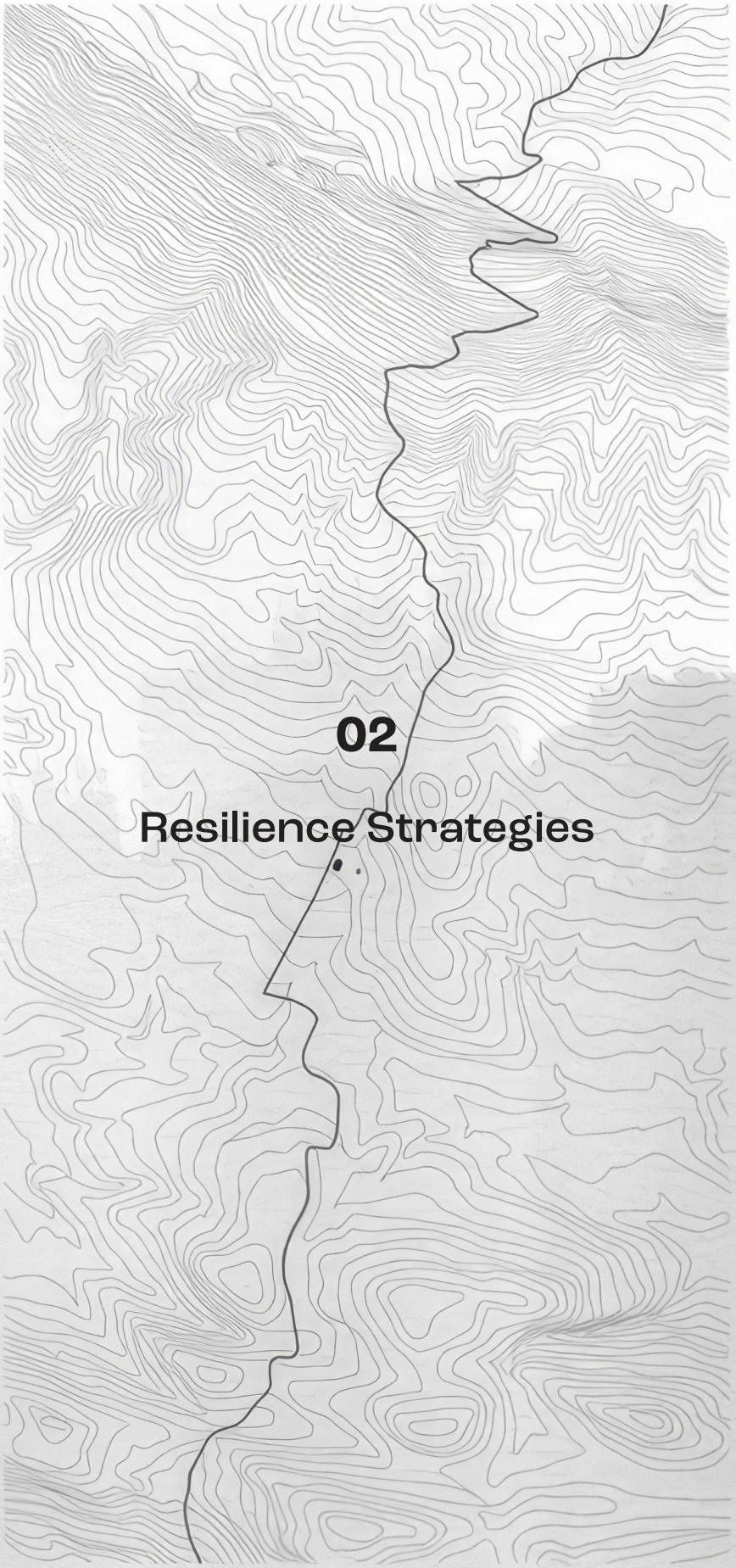
Figure 3:

Review Green Infrastructure for Urban Flood Resilience: A Review of Recent Literature on Bibliometrics, Methodologies, and Typologies Mina Khodadad, Ismael Aguilar-Barajas and Ahmed Z. Khan _School of Engineering and Sciences, Tecnológico de Monterrey, Monterrey 64849, Mexico 2 Building, Architecture & Town Planning (BATir) Department, Université libre de Brux-elles, 1050 Brussels, Belgium 3 School of Social Sciences and Government, Tecnológico de Monterrey, Monterrey 64849, Mexico * Correspondence: a00829591@itesm.mx or mina.khodadad@ulb.be

Subjects of Interest The most used keywords by authors were selected to show the subjects of interest in this field of research. our bibliometric analysis performed found that 13 keywords were used in at least five papers “Resilience”, “green infrastructure”, “low impact development”, “climate change”, and “nature-based solutions” were the most used keywords by the authors to represent the subjects of interest of their papers. These keywords had the highest number of links with other keywords among the 13 most used, except “low impact development” for which the total link strength was lower than “stormwater management” and equal to “flooding”.

Keyword:

Resilience
Green Infrastructure
Low-Impact Development
Climate Change
Nature-Based Solutions
Flooding
Ecosystem Services
Blue-Green Infrastructure
Stormwater Management
Sustainable Drainage Systems
Urban Planning
Urbanization
Biodiversity



02

Resilience Strategies

About Floods

Water is one of the most valuable natural resources of any country due to the social and economic benefits that brings to the population. Nevertheless, Along with the advantages there are also some "drawbacks" such as floods and droughts. Floods are natural phenomena which cannot be prevented. Temporary or continuous flooding has been common throughout the world for milleniums and they will be here for milleniums to come as well.
While droughts are placed first, as far as human deaths are concerned (about 74,000 deaths reported), floods are the most frequent hazard and cause greater economic losses. Moreover, few countries manges to avoid them, not even those located in desert areas. In Africa, for example, the drought is the most frequent disaster, but the floods and catastrophes related to strong winds occupy the second place (from 1991 to 1995, the floods caused almost half of the total of the economic damages caused by disasters of all kinds).

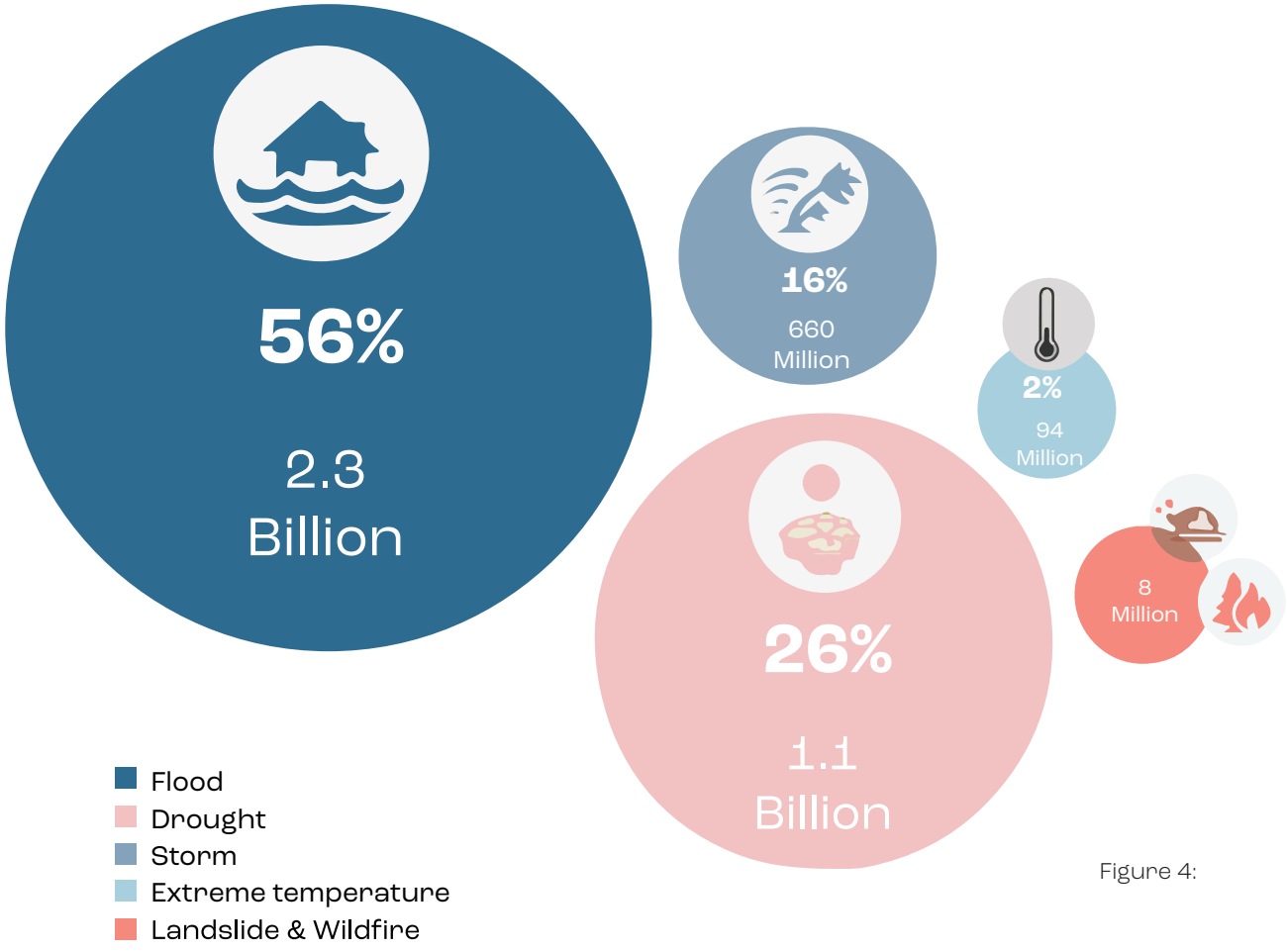


Figure 4:

https://public.wmo.int/en

Climate Change Role

According to the European Environment Agency (EEA), a further major potential impact of climate change, in combination with land-use changes and water management practices, is the intensification of the hydrological cycle due to changes in temperature, precipitation, glaciers and snow cover. Large changes in seasonality are also projected, with lower flows in summer and higher flows in winter. Flood events are projected to occur more frequently in many river basins, particularly in winter and spring, although estimates of changes in flood frequency and magnitude remain uncertain.

Climate change drives populations at risk in the developed and developing world alike – there is no clear distinguishing pattern. In Ireland, for example, 2 000 peple face flood risks. By 2030, 48 500 more people could face river flood risk, and 87 % of that would be driven by climate change. From the developing world, 715 000 people in Pakistan are at risk today. By 2030, river floods could affect 2 million more people, with climate change driving 70% of that increase.

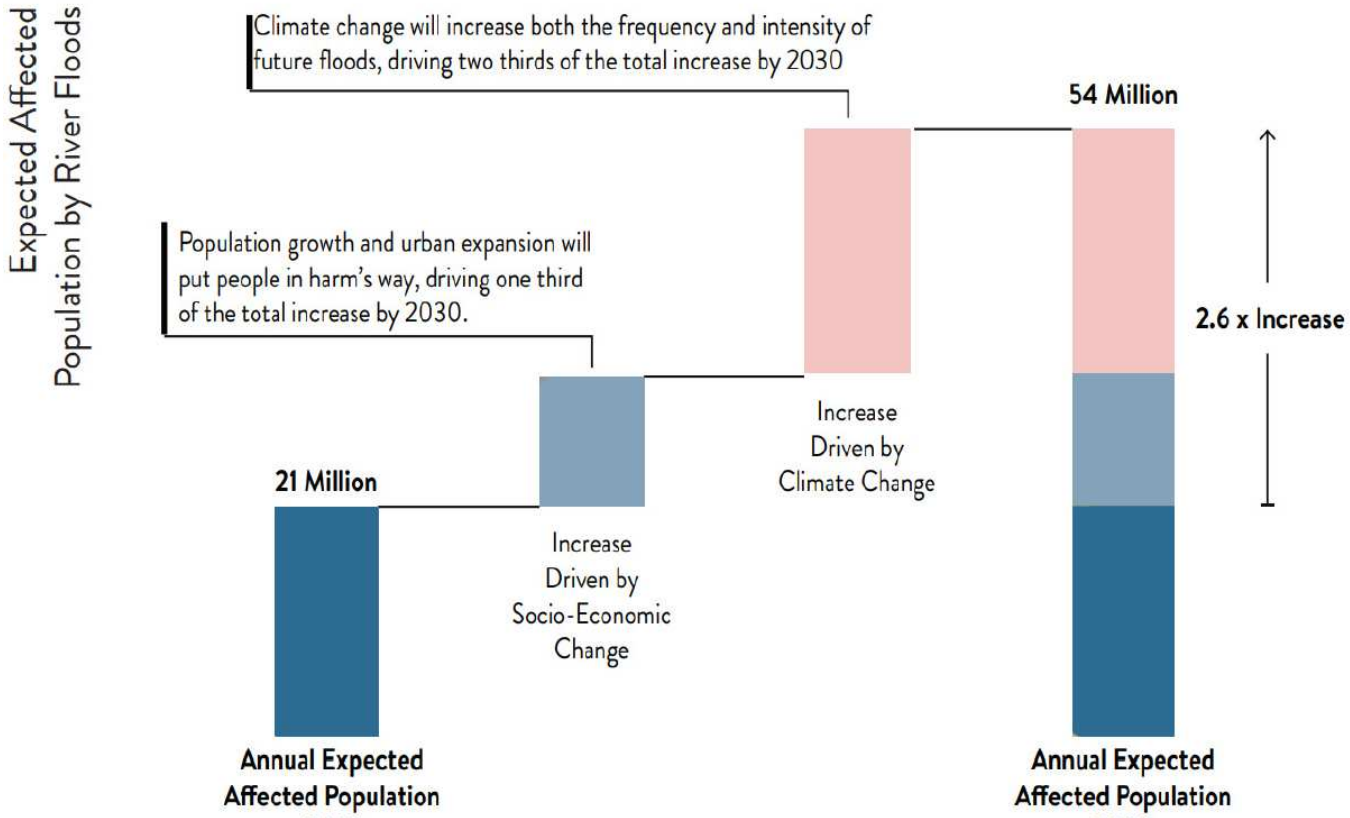


Figure 5:

https://blogs.worldbank.org
Jun RentschlerMelda SalhabBramka Arga Jafino|June 28, 2022

Types of Flooding:

Rain Floods

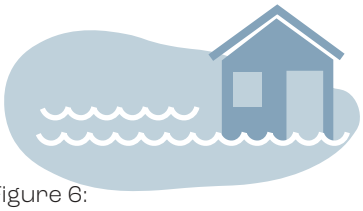
They happen when the terrain is saturated and unable to absorb more water, it causes the accumulation of excess rain for hours or days.

River Floods

They are generated when the overflowing water from rivers remains in the ground surface.

Coastal Floods

Occur when mean sea level rises due to the hurricane storm tide and waves, covering large tracks of land

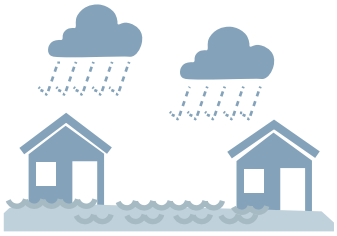


Lake Floods

Due to the increase of the average in a body of water (wetlands, lakes, lagoons, among others)

Figure 6:

Classification according to the time they occur



Slow Floods

They occur in large areas of low slope; they usually occur within days, giving a chance to evacuate.

Flash Floods

Those that occur within minutes due to heavy rainfalls over a small surface with steep slopes related to mudslides; for this reason, the are considered the most dangerous floods.

Figure 7:

National Oceanic and Atmospheric Administration (.gov)
https://www.nssl.noaa.gov › svrwx101 › floods › types

Pluvial Floods (surface water floods):

A pluvial, or surface water flood, occurs when heavy rainfall creates a flood independent of an overflowing water body. A common misconception about flood is that you must be located near a body of water to be at risk. Yet pluvial flooding can happen in any location — urban or rural — even in areas with no water bodies in the vicinity. There are two common causes of pluvial flooding:

1. Intense rain saturates an urban drainage system. The system becomes overwhelmed and water flows out into streets and nearby structures.

2. Run-off or flowing water from rain falling on elevated terrain, e.g. hillsides, that are unable to absorb the water. Hillsides with recent forest fires are notorious sources of pluvial floods, as are areas where the natural ground has been paved..

Pluvial floods occur gradually, which provides people time to go indoors or leave the area. The level of water is low to the ground (rarely more than one meter) and causes no immediate threat to lives. However depending on the flooded area it may cause significant economic damage

Risks associated with pluvial flooding

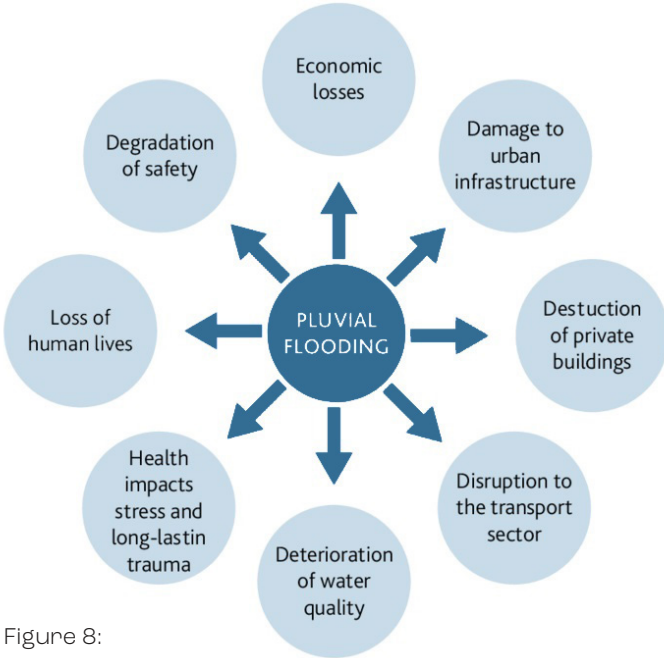


Figure 8:

Chris Kilsby, Vassilis Glenis , Richard J. Dawson and Selma B. Guerreiro: Pluvial Flooding in European Cities—A Continental Approach to Urban Flood Modelling -Newcastle University School of Civil Engineering and Geosciences, NE1 7RU Newcastle upon Tyne, UK-Willis Research Network, 51 Lime St., EC3M 7DQ London, UK, Water 2017, 9(4), 296; https://doi.org/10.3390/w9040296

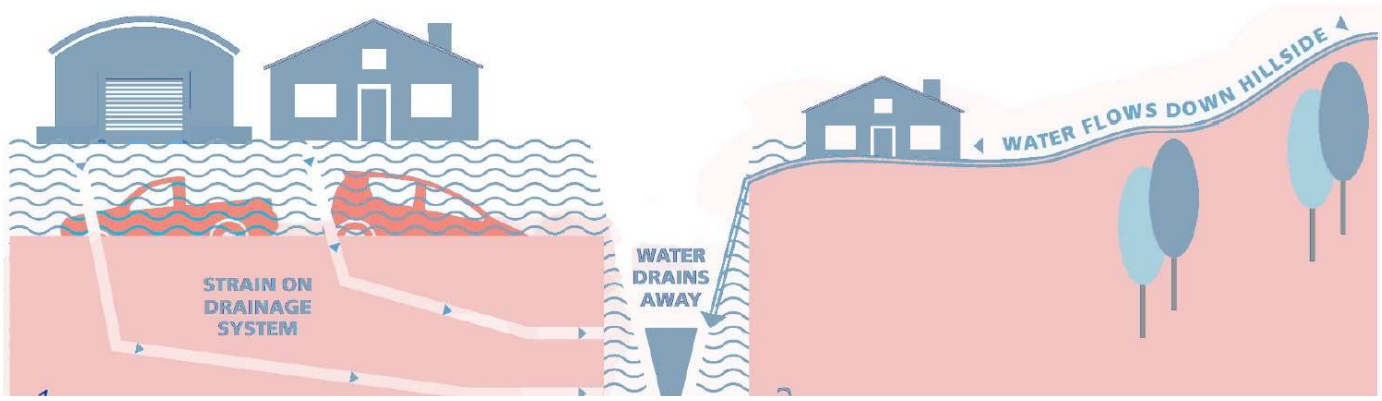


Figure 9:

National Oceanic and Atmospheric Administration (.gov)
https://www.nssl.noaa.gov › svrwx101 › floods › types

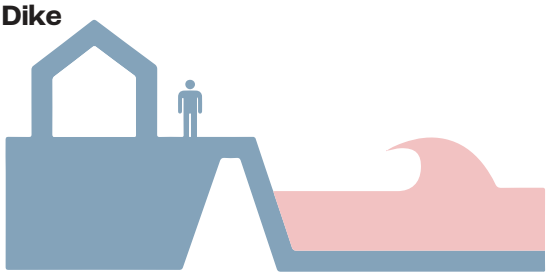
TYPES OF PROTECTION

There are **three well know strategies** of flood management.

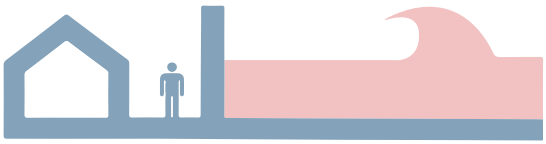
1.- Protection, which includes hard and soft solutions. These strategies aim to keep the water out by defending the shoreline with a permanent feature or claiming land to reduce wave energy. These solutions are the most commonly used to reduce the impact of sea-level rise. (24)

Hard solutions are permanent grey structures that protect from the high tide by holding the line of defence. Examples: dikes, seawall, breakwaters, rock walls, sluices and elevated buildings. (14)

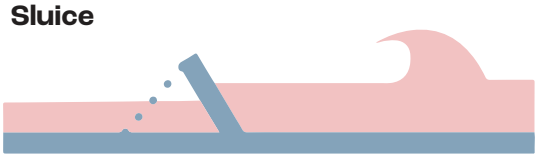
Dike



Seawall



Sluice



Elevated buildings

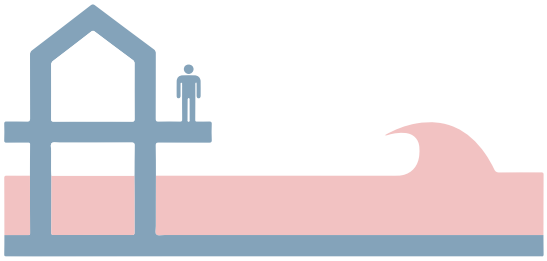
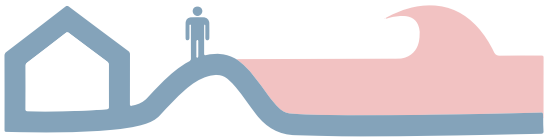


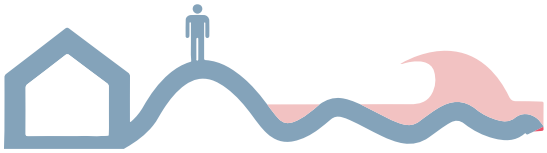
Figure 10:

Soft solutions are strategies to hold the line of defence using natural and green elements. Examples: dunes, sand nourishment, wetland and revegetation. (24)

Dunes

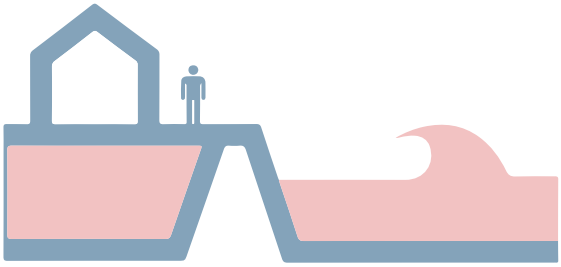


Wetland

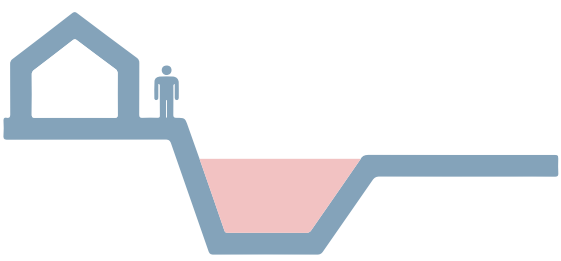


2.- Store, in contrast with the previous approach, the aim of this strategy is retaining water to reduce the pressure in the sewage system. The most common example of this solution is water tanks. However, new ideas such as adapting urban spaces into water collectors in extreme conditions are gaining popularity. (24) Copenhagen city recommends that new buildings and infrastructure are safe for 100 years storm event with an elevation of 2,63m above the current sea level. (25)

Parking water collector

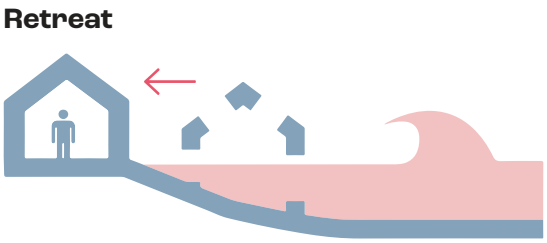


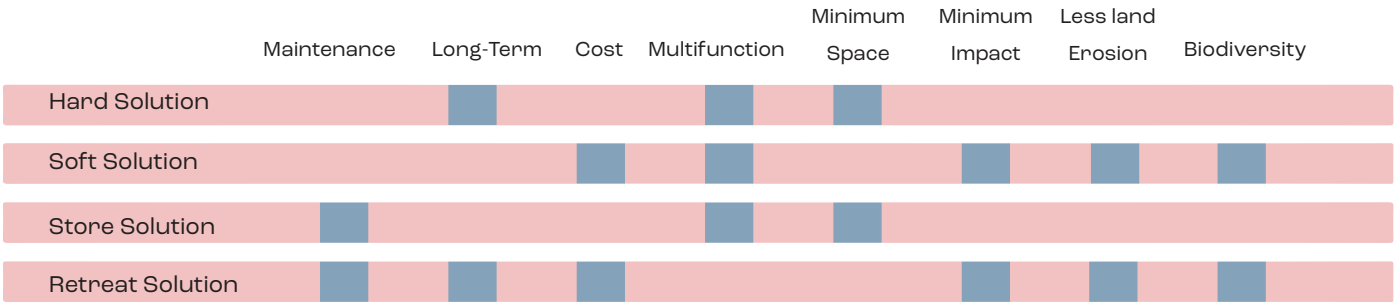
Urban space water collector



(24).Storm Floods Plan. Copenhagen : Kobenhavn Kommune, 2017.
(25). COWI. Byernes udfordringer med havvandsstigning og stormflod. Kongens Lyngby : Realdania, 2017

3.- Retreat, this strategy aims to move the infrastructure away from the risk zone. This approach is usually the first solution. It can be a planned retreat or unplanned after a natural disaster. The retreat strategy is the most long-term solution and avoids the cost of protection.





Climate Challenges

Heat

Drought

Flooding

Rainfall

Urban heat island

Impremeable Surfaces

Overflown Drainage

Land subsidence

Unfertile land

Biodiversity loss

Figure 11:

Potential Issues

Strategies

Climate-Adapted Buiksloterham

A risk-based approach, 4 scenarios

1. Identify vulnerable locations

The locations are spatial, multilayered & related to the 4 climate scenarios

2. Ideate multi-functinal Systems

The 4 scenarios interact & create join systems & a de-sign toolbox

3. Monitor & Active systems

The systems are deployed through the site, they enter operation & motion

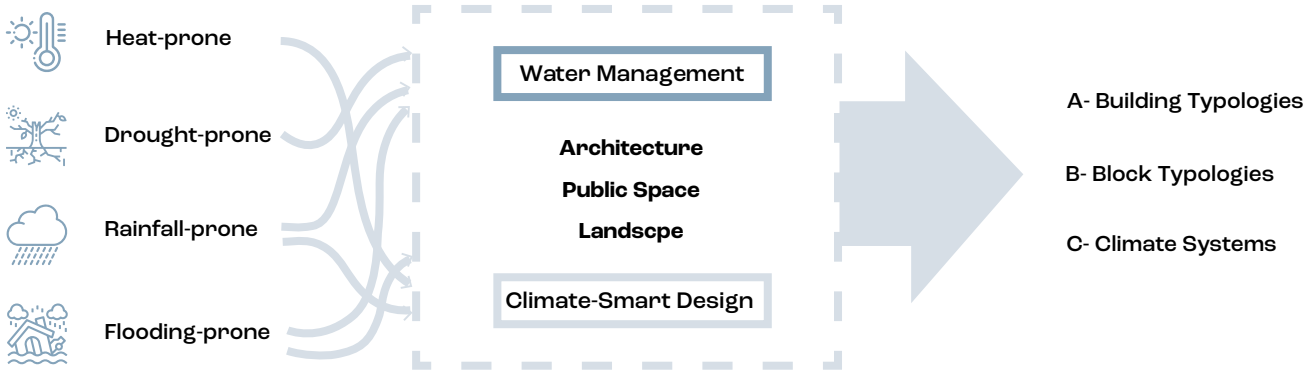
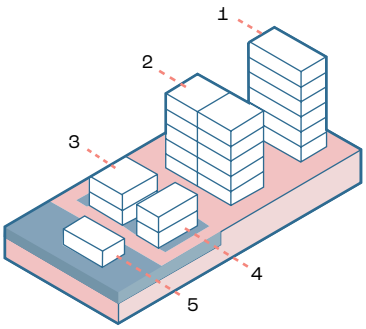


Figure 12:

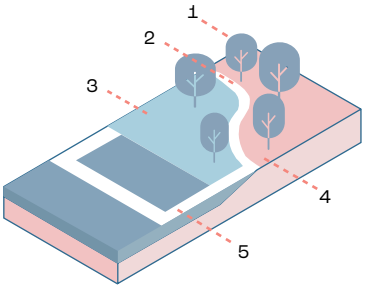
Design Toolbox

Architecture



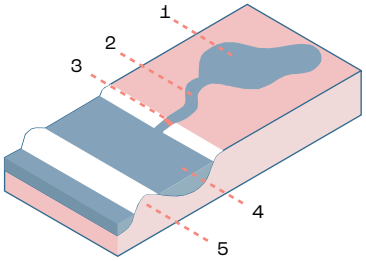
1. Fixed ground floor
2. Hermetic ground floor
3. Semi-floating house
4. Pier-connected house
5. Contemporary boathouse

Public Space



1. The green corridor
2. The pavement
3. The floodable surface
4. The permeable surface
5. The pier

Landscape



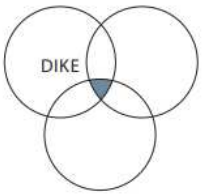
1. The pond
2. The canal
3. The sluice
4. The wetland
5. The dyke

Figure 13:

Flood Resilience toolbox:

The concept of integrated flood control adapted to the site provides a toolbox to experiment with

on site and develop flood resilient urban design.



Dike

The first step is to activate the dike with various functions and use it as a qualitative green space. This will attract many people and bring the dike closer to the city.The next step is to connect the dike with the city by pushing buildings and urban functions towards the dike.
The final step is to integrate the dike with the city through urban expansion of the dike. This can be done through buildings or platforms to overcome the height difference.

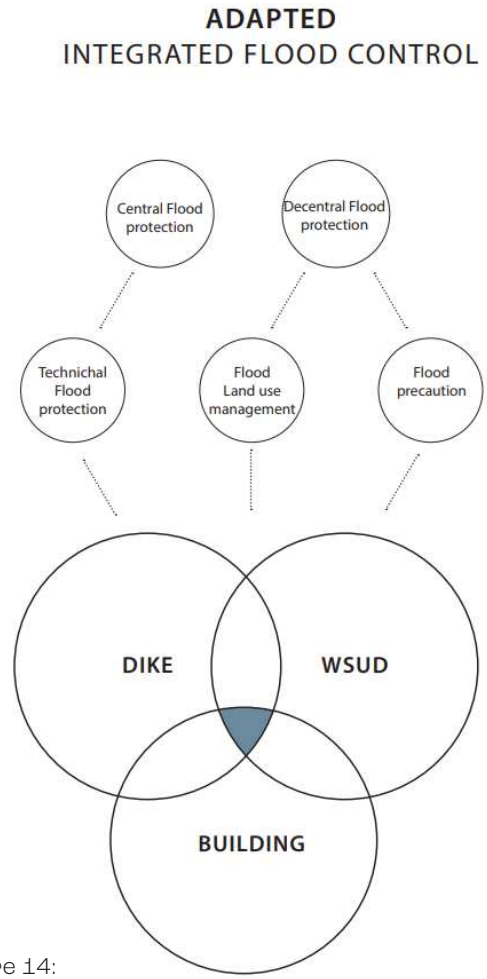


Figure 14:
Master thesis in Sustainable Urban Design 2017
Hanna- Celine Rauschkolb

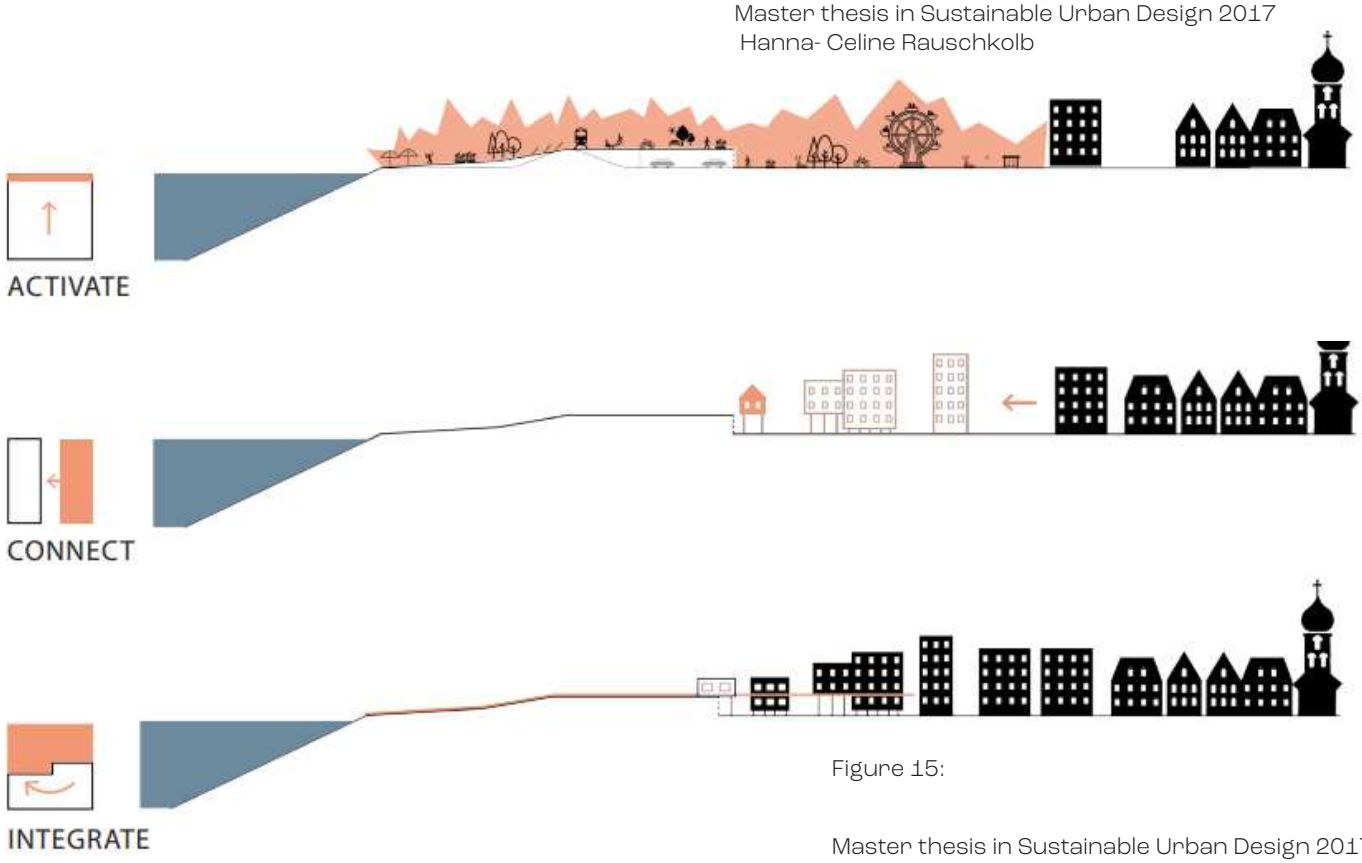
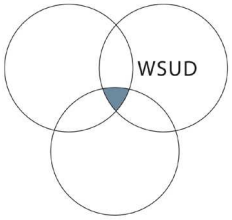


Figure 15:

Master thesis in Sustainable Urban Design 2017
Hanna- Celine Rauschkolb



WSUD

WSUD (Water sensitive urban design) tools such as retention basins, bio swales and wetlands are used to retain, channel, collect or discharge the water and to reduce run off.

Because of the high groundwater level of the site, infiltration that is usually used in storm water management is not the first priority. More important is to provide permeable surfaces to let the water come and go.

The WSUD tools are site-specific and help to make the development more flood resilient.

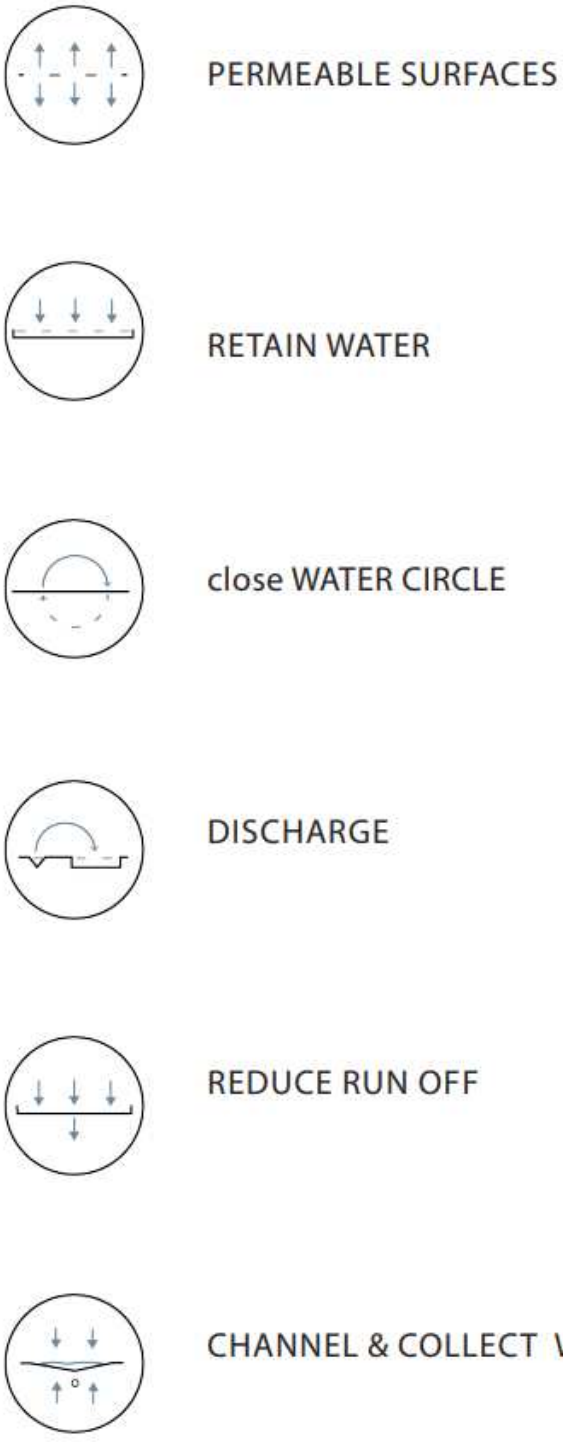
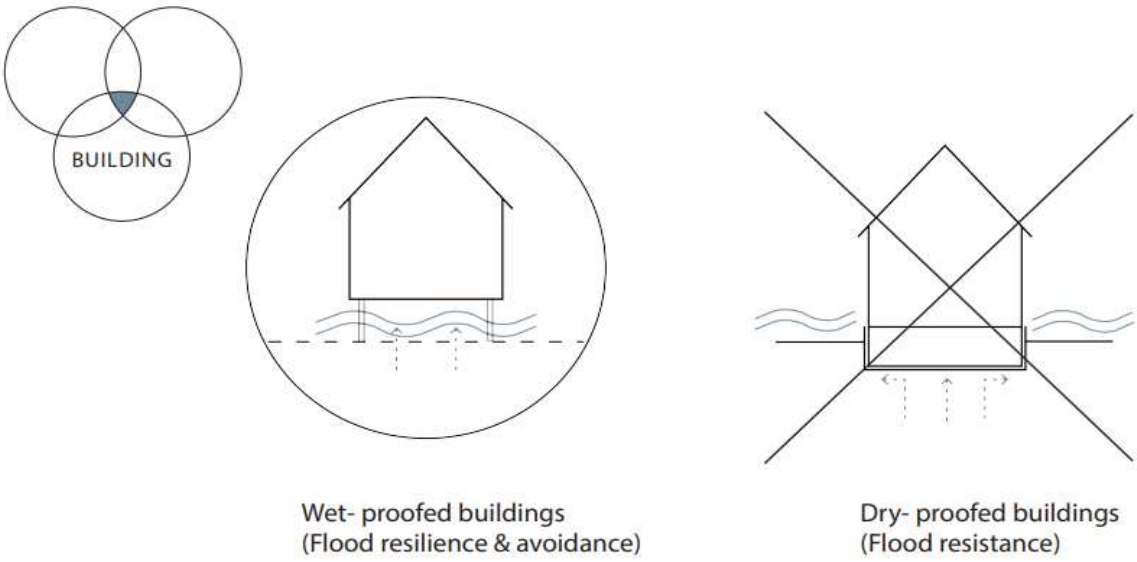


Figure 16:



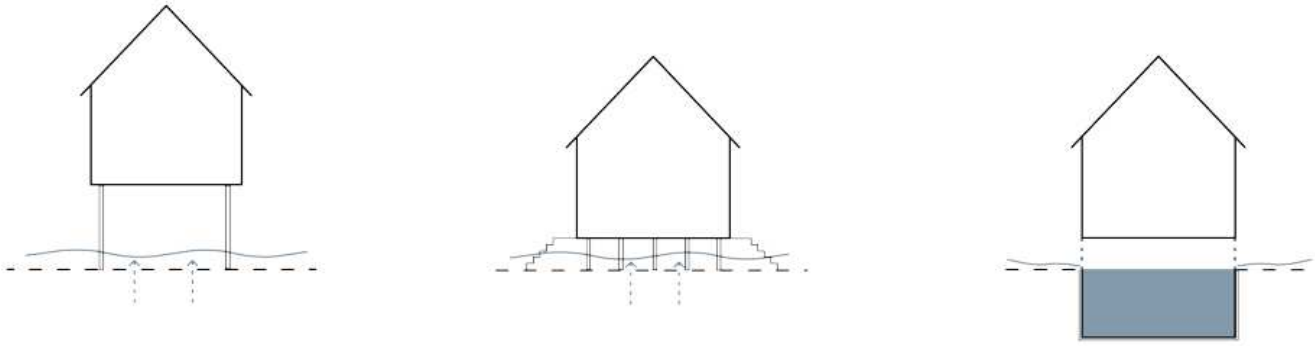


Figure 17:

Building

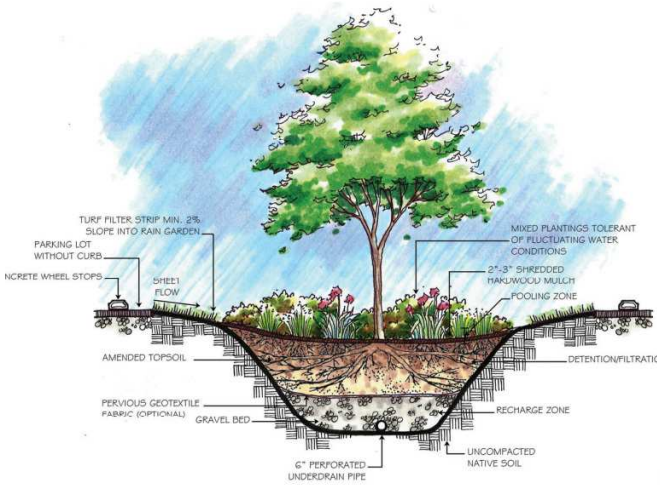
For a flood-proofed building design that adapts to the site conditions 3 types of buildings have been created after researching different flood proofed building types (see chapter 2.4.2).
The common practise in Germany is to develop buildings that resist floods through a more robust foundation. This building type has been neglected because they do not solve the problem but relocate it.
The first two chosen buildings allow the water to come and go, through permeable surfaces underneath them and do not increase the hydrostatic pressure and hence risk floods at another place or structural damage. They follow the principle of flood avoidance.
they do not solve the problem but relocate it.

APPROACHES TO SPONGE CITY

1. Bioretention

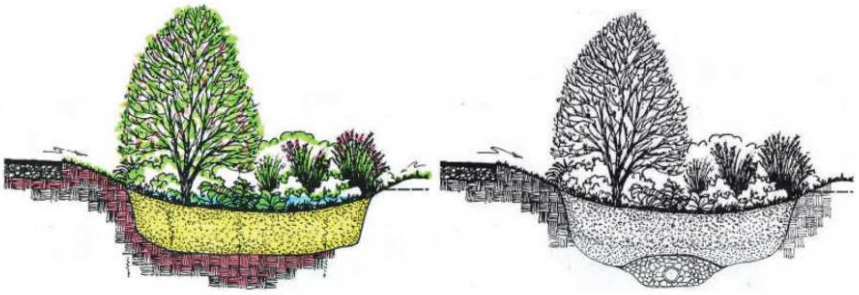
Basic Description The basic idea for the sponge city concept is the applications of “bioretention” (also named “biofiltration”[1]
Bioretention is a land-based practice using the chemical, biological and physical properties of vegetation, microorganism and soil to deal with the water issues including its quality and quantity in a targeted area. Practically, bioretention applies a model which provides places for the collection, infiltration, filtration, detention, storage and drainage of runoff with the cooperation of plants, soils and microorganisms.[2]

In general, there are three types of bioretention systems: “full infiltration system” with no underdrain (Figure 2-3), “partial infiltration system” with underdrain and “no infiltration system”underdrain and impermeable liner. The bioretention system types depend on the native soil permeability (infiltration rate) and other physical constraints. The basic component in a bioretention system is the filter bed that consists of sands, fines, aggregates and organic materials. Other components include selected plants, a mulch ground cover or pavements, etc. The particles which would clog the filter bed should be removed before the runoff reaches the bioretention system by pre-treatments such as vegetated filter strip, setting forebay, or stone diaphragm.[3]



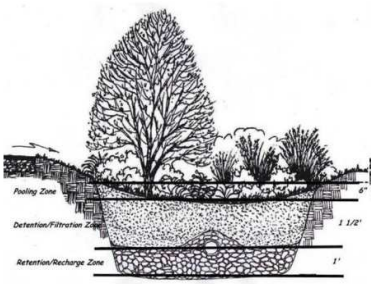
Typical Bioretention Cell [4]

Figure 18:

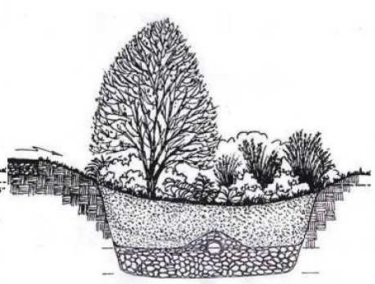


Full Infiltration System[5]

Partial Infiltration System[6]



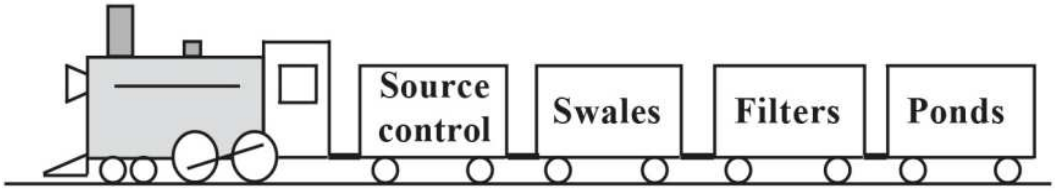
No Infiltration System[7]



Denitrification System[8]

1. Venhaus, 2012 (pg. 150)
2. Coffman & Winogradoff, 2002
3. TRCA & CVCA, 2010 (pg. 4-64)
4. Wallover, 2015
5. ESD et al., 2007 (pg. 25)

ESD et al., 2007 (pg. 26)
ESD et al., 2007 (pg. 28)
ESD et al., 2007 (pg. 27)



2. Stormwater Treatment Train

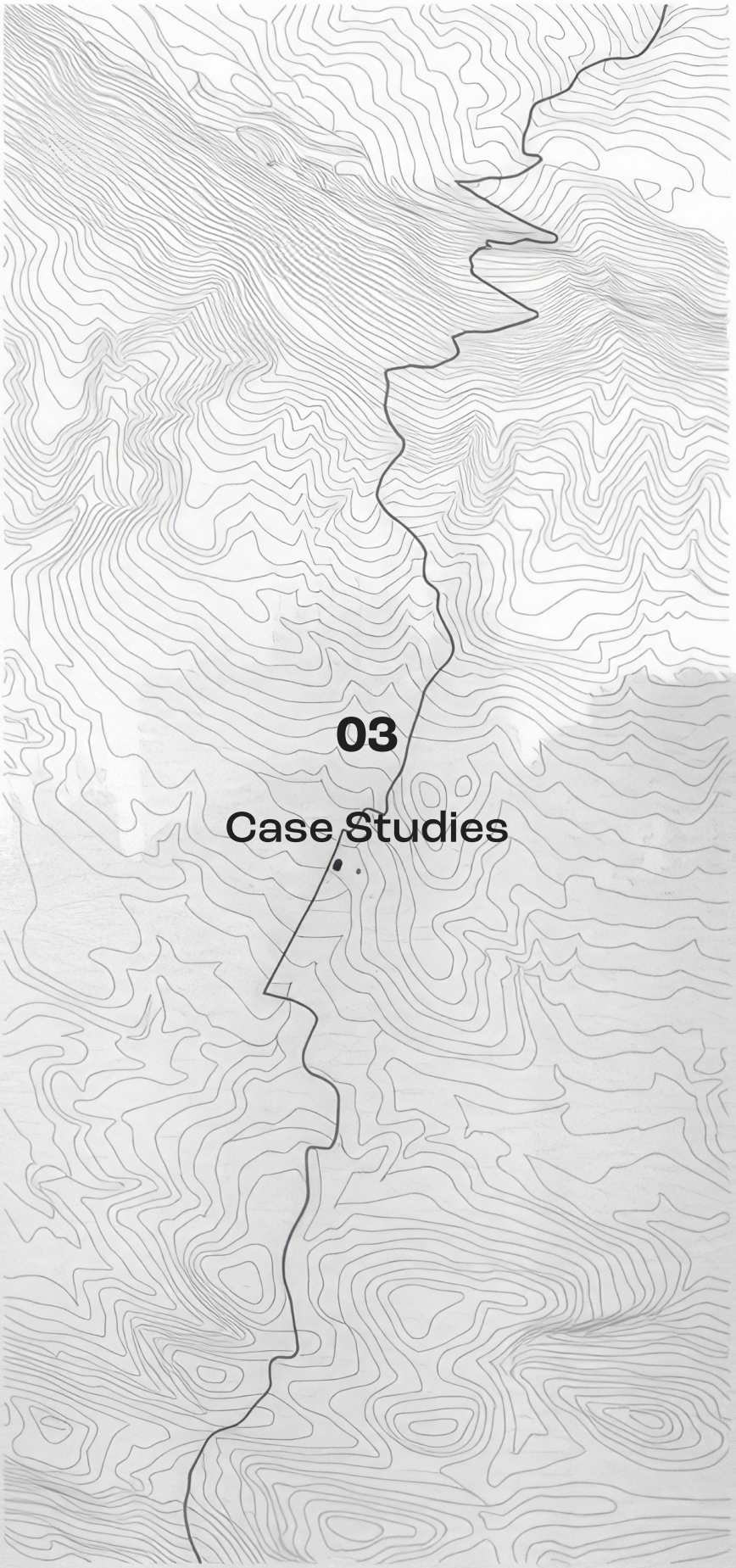
The essential objectives of a bioretention system can be summarized in two steps: to reduce impervious surface areas in order to reduce stormwater runoff, and to utilise plants, soil and microorganisms to move, store and filter stormwater runoff before it leaves the site.
The key to practically is to create an integrated approach that connect a series of different stormwater management facilities such as eco-roof, impermeable pavement, stormwater planter, filter strip, bioswale, retention pond, and rain garden with each other to form a continuous stormwater management chain, thereby taking all aspects of the runoff movements from a targeted area into consideration.[1]

This integrated approach is known as the "stormwater treatmenttrain", also named "stormwater chain".[2]
Stormwater treatment train is essentially a series of various designed facilities cooperating to deal with stormwater in a targeted site, for the purpose of maximum rainwater treatment effectiveness. It is especially needed when pre-treatments to remove specific contaminants are required before a rainwater management practice, otherwise whose water treatment performance will be impacted.

Facilities in Stormwater Treatment Train

Green Roof
Permeable Pavement
Planter
Filter Strip
Swale
Rain Garden
Pond

Dunnett & Clayden, 2007 (pg. 45)
Venhaus, 2012 (pg. 149); Dunnett & Clayden, 2007 (pg. 45)



03

Case Studies

02| CASE STUDIES

FLOOD RESILIENCE 2.0

Sustainable Urban Design
Adaptation For Flood
Resilience In Hamburg, Germany
Master Thesis Booklet
Author
Shenol Shahin Ahmed
Supervisors
Katerina Vondrova
Andreas Olsson
Examiner
Lars-Henrik Ståhl
Presentation Jury
Louise Lövenstierne
Daniel Wasden
Presented in March, 2018
Sustainable Urban Design
School of Architecture
Lund University

Figure 19:

Figure 20:

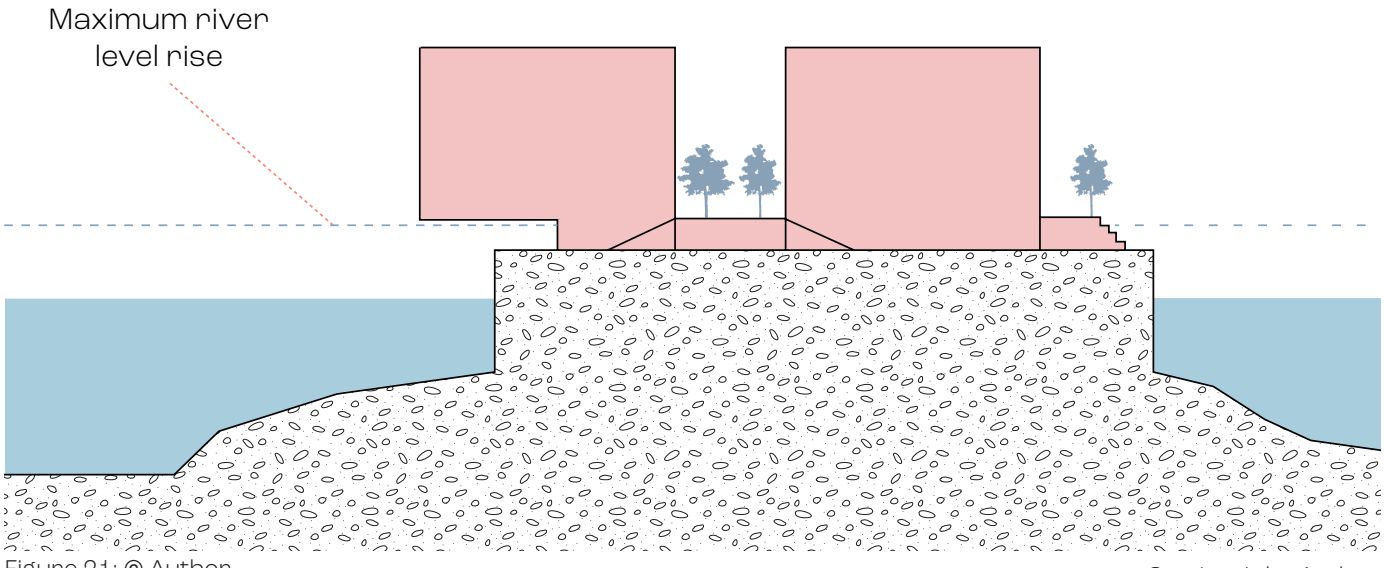


Figure 21: © Author

Section 1, by Author

Hamburg and Floods

The Hamburg city was flooded in 1962, after that significant flood protection measures have been used to save the city from floods. After the natural disaster and floods affecting the Hamburg's major coastline region the city has developed dikes, horizontal slopes, erections and reinforcing them to make them stand against the floods. In the mid-90s, Hamburg's flood protection program was started to raise the height of retaining up to one meter around the coastline regions. Much of the Hamburg's area is redeveloped and the buildings near coastline are surrounded by dikes to protect them against the flood. It has become quite common for the city to suffer flooding as a consequence of severe rainfall. Back in the summer of 2002, more than 20 trillion litres of rain fell over Germany, leading to what is known in the German media as the 'flood of the century'.Dikes and seawalls encompassing Hamburg are being elevated against floods. If we consider Hamburg history, it has faced flooding like the North Sea.

Flood protection wall

Hamburg has very high flood protection level but the areas located near the Elbe has a very risk of being flooded during a storm surge.

Approximately half of the Hamburg's area is declared as flood prone. The areas near the coastline
would be flooded if there was no flood control measures. While Harbor is tideexposed, the urban areas are under the protection of the dykes, sluices and flood barriers. Due to the climate change and average sea level rise the maximum water level rise of around 20 cm is expected in Hamburg by 2030. This increase in unpredictable by the end of the century therefore Hamburg has adopted flood protections for maximum sea level rise. Because of the various water bodies in Hamburg, there is also a risk of inland floods. The areas which are described as the high chances of flood events and huge anticipated harms from flooding are attributed to Alster, Osterbek and Wandse. Some areas like Berner Au, Ammersbek are situated in the district Wnadsbek. While some portion of the Alster is situated in Hamburg-Nord as well as the stream Tarpenbek. The las one is situated at the boundary to Eimsbuttel. Here, the creek Kollau is another stream affected by flood risks. In the southern part of Hamburg, Bergedorf faces the risk of flooding due to the rivers Mittlere Bille, Obere Bille, Dove Elbe, Gose Elbe and the creek Brookewetterung. In Harburg, there are the Este and the Falkengraben.

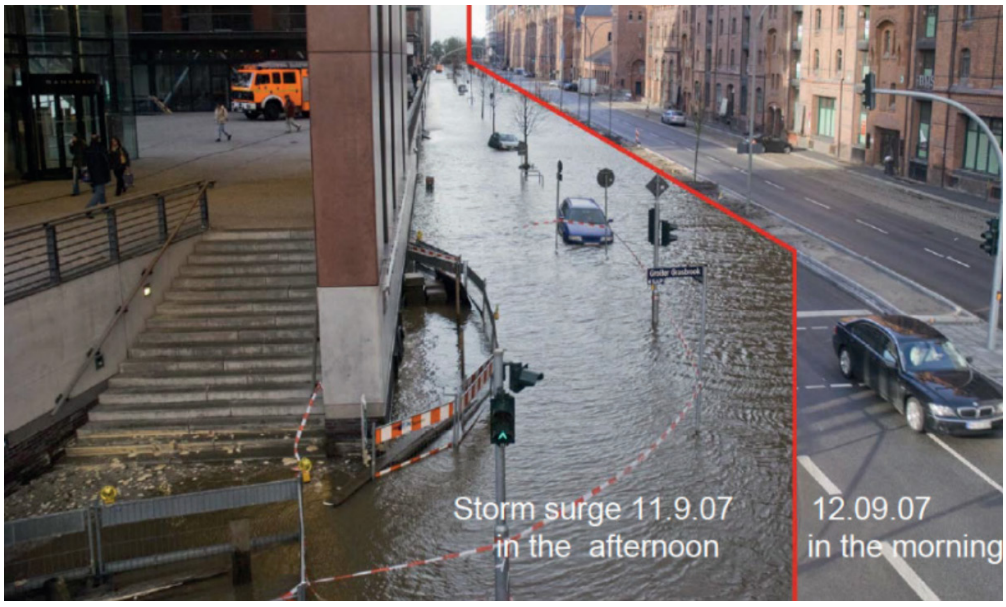


Figure 22:

MULTI-FUNCTIONAL FLOOD DEFENSES IN NETHERLANDS

Multi-functional flood defences are structures planned to safeguard land against the floods, these defences are also being utilized for different purposes, like transport, lodging, shipping, nature, and agriculture. Different examples of multi-functional flood defences includes a dike with a road on top, house with retaining walls against water and parking garages in ridges. In order to have an option to work as a flood defence these structures must be important for a whole flood protection framework, like dike rings in the Netherlands. This implies that the maintenance, review, control, inception and the formalisation of satisfactory safety levels must be organised.

In the case of Arnhem, Netherlands is a city merely 13 meters above sea level, has experienced extreme weather over the last few years. The city is recognising the new threats posed by flooding and planners have been taking action to adapt the urban environment areas and 'live with floods'. The coastlines areas are designed as the flood defence structures. Water authorities are playing a significant part for flood defences. The Dutch Ministry of Infrastructure and Environment plays a leading role in this regard. Land use planning authorities and non-governmental stakeholders, for example, inhabitants are now associated with the execution of room for the river measures.

Deventer, The Netherlands

Figure 23:

Figure 24:

Doesburg, The Netherlands

Figure 25:

The flood wall can be elevated

Figure 26:

resilience: Rainfall flooding in the city of Arnhem. Cities, 105, p.102843.
Mimura, N., 2013. Sea-level rise caused by climate change and its implications for society. Academy, Series B, 89(7), pp.281-301

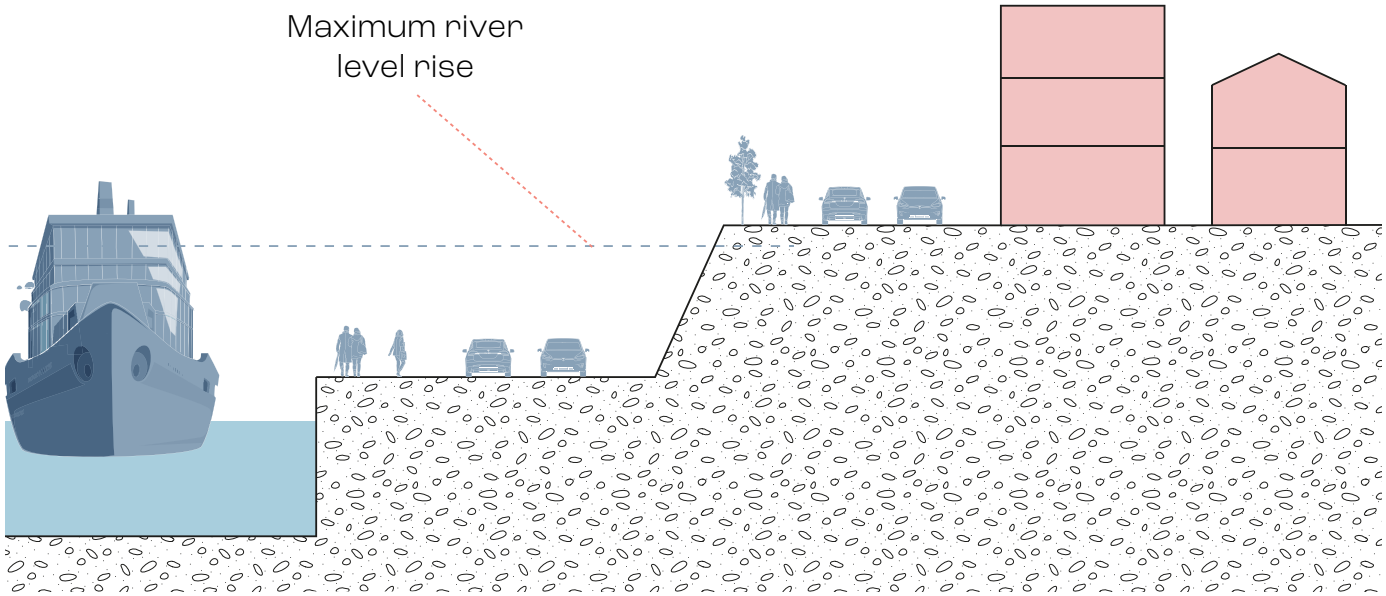


Figure 27: © Author

Section 3, by Author

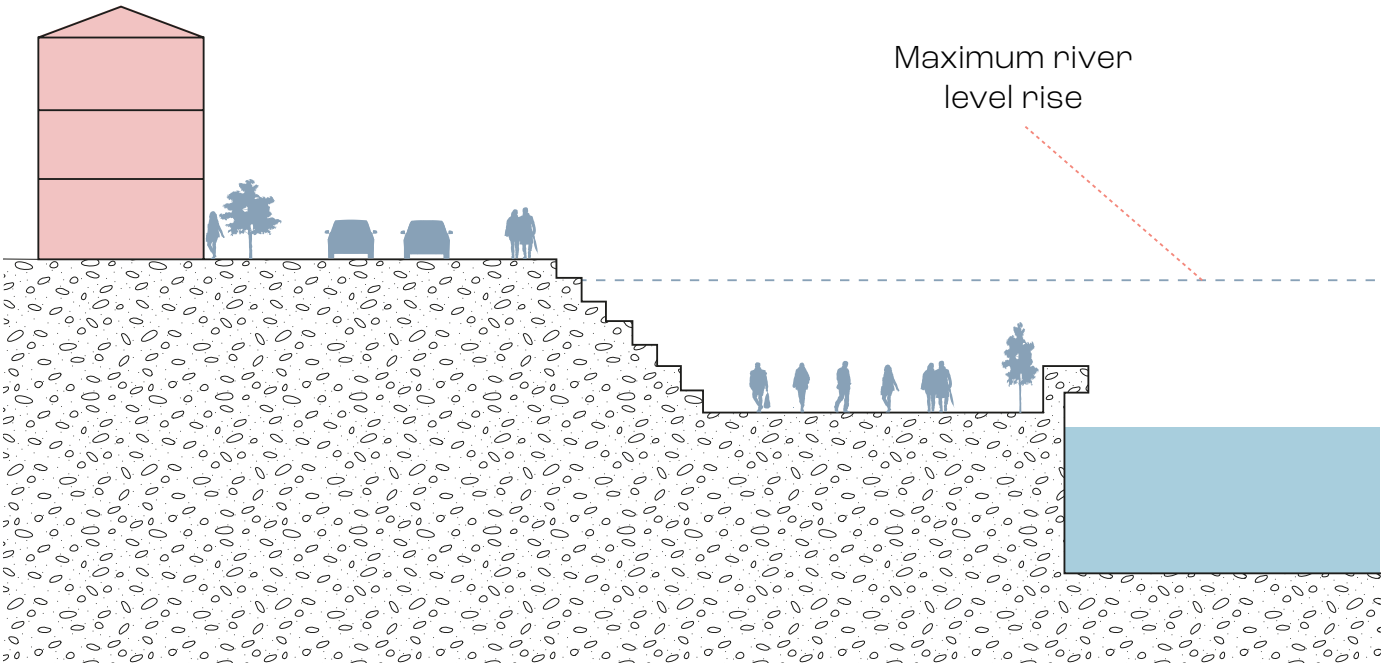


Figure 28: © Author

Section 3, by Author

wetter, hotter weather

Adaptation to climate challenges
in Amsterdam, Netherlands

ASBM01: Degree Project in Sustainable Urban Design

Sustainable Urban Design Programme
School of Architecture, LTH
Lund University, Sweden
May 2022
Author: Joel Carlos López Criollo
Primary Supervisor: Erik Johansson (Associate Professor, Senior Lecturer HDM, LTH)
External Supervisor: Rune Wriedt (Architect MAA, Tredje Natur, Copenhagen, Denmark)
Examiner: Lars-Henrik Ståhl (PhD, Professor, Programme Director Sustainable Urban Design)
Final Presentation Jury:
Jenny B. Osuldsen - (Snøhetta, University of Life Sciences Ås, Norway)
Peter Siöström - (Ax:son Johnson Institute for Sustainable Urban Design, LTH)

FLOATING HOUSES

SCHOONSCHIP, NOORD

Schoonschip is a residential community consisting of 30 floating houseboats, where people with diverse incomes live together with shared values.This project started as the initiative of a group of citizens to build up a floating community with high sustainability standards.Some of the final sustainability targets met by Schoonschip include: 100% renewable heat and hot water supply, renewable electricity, wastewater and organic waste treatment, water self-sufficiency, , 60 to 80% nutrient recovery, 50 - 70% reduction in electricity demand over conventional households, 60 - 80% vegetable & fruit production using locally recovered nutrients (Metabolic, 2013). The main feature of Schoonschip is its application of a floating community in the north of Amsterdam, as well as showing that the technologies and construction techniques are ready for use to imagine other ways to dwell in relationship with water.

Figure 29:

Source: (Space and Matter, 2012), (Metabolic, 2013)

Figure 30:

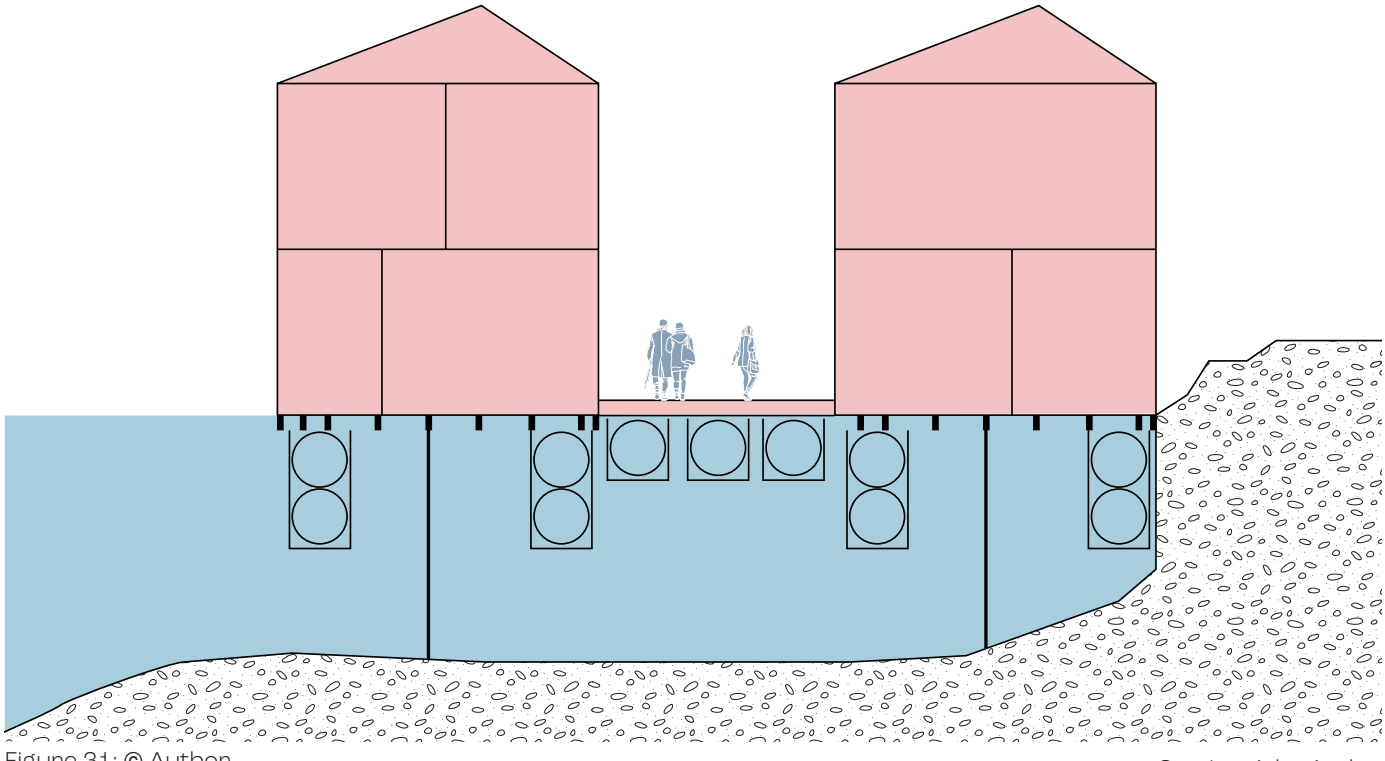


Figure 31: © Author

Section 4, by Author

Copenhagen Cloudburst Management Plan

Goal(s):
Enhancing sustainable urbanization
Developing climate change adaptation
NBS Actions:
Nature-based solutions and the insurance value of ecosystems
Keywords:
Green infrastructureGreen space managementHeritage (cultural and natural)Human well-beingNorthernResilienceSocietal choiceTemperateUrbanUrban Regeneration
Client:
City of Copenhagen, City of Fredriksberg, HOFOR
Design team:
Ramboll and Ramboll Studio Dreiseitl

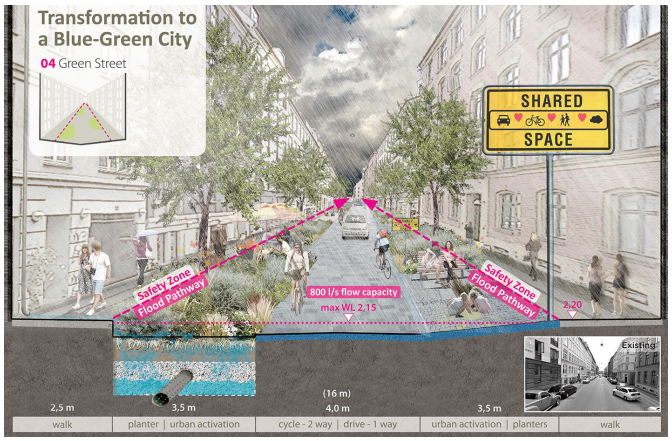


Figure 32:

Providing green areas with water permeability to provide safe zone for water flow ["Cloudburst Management Plan, Copenhagan," n.d.]

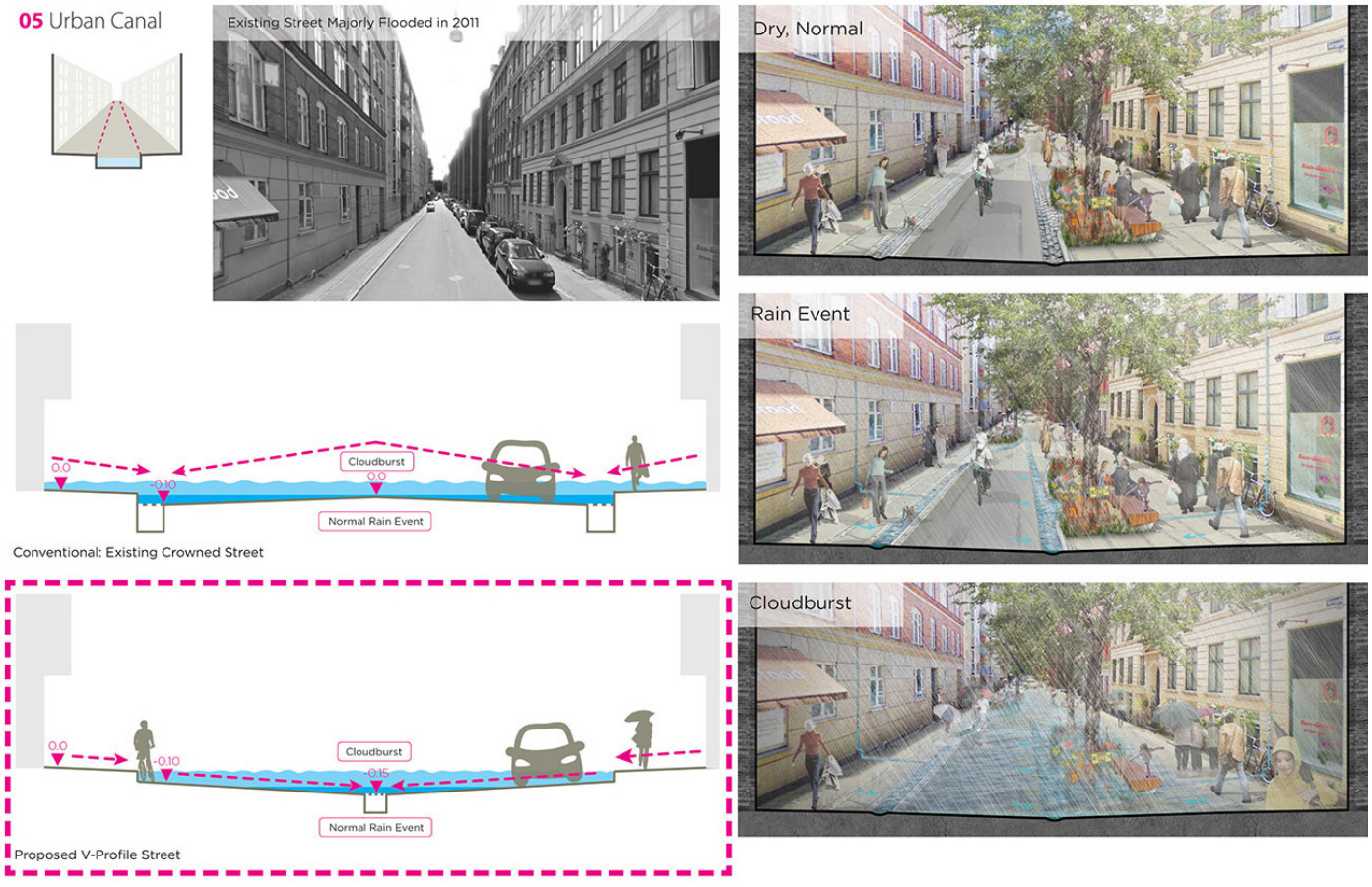


Figure 33:

Street planning to help during time of floods ["Cloudburst Management Plan, Copenhagan," n.d.]

DESIGN APPROACH

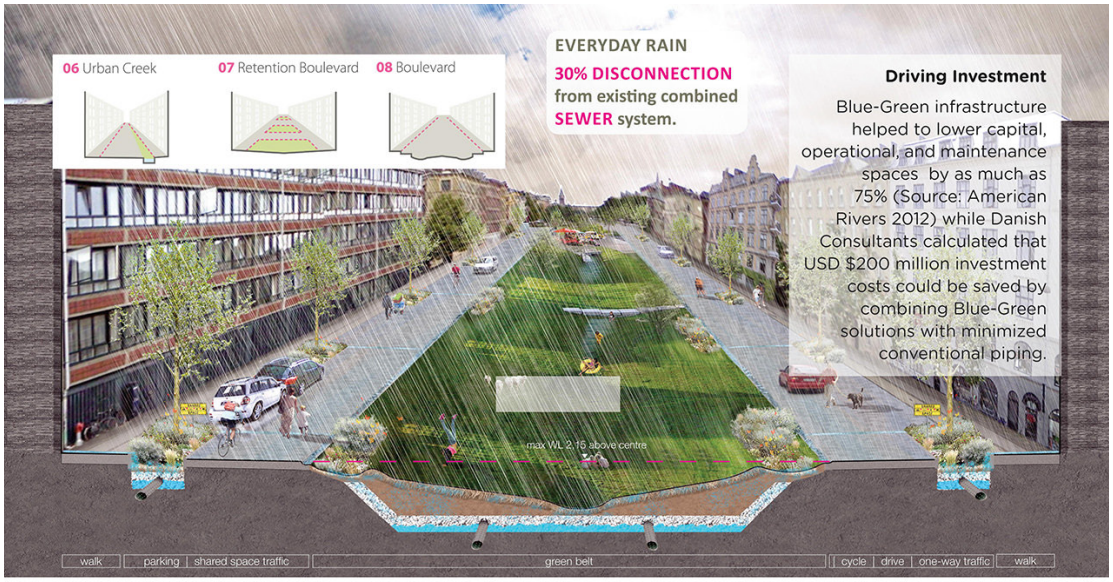
1. Green streets
Are suggested to connect all Cloudburst roads upstream. The stormwater planters or permeable paving should be used in conjunction with small scale channels to create the green streets. The Cloudburst roadways should receive stormwater that has been collected, held back, and then sent there.

2. Retention streets
That are a little bit upstream of weak points are known as retention streets. To treat rainwater before it reaches the more vulnerable sites downstream, a retention volume should be set up in these streets.

3. Cloudburst roads
Cloudburst water is channeled and directed using cloudburst roadways. Contrary to conventional engineering practice, these streets might be designed with a distinctive V-shaped profile and higher curbs to ensure that water will flow in the center of the road, away from houses. It is possible to create swales and channels along roadsides to direct water into green spaces or urban rivers. To generate tool synergies, Cloudburst roadways can also be connected to Cloudburst pipework underground.

4. Cloudburst pipes
Like Cloudburst roads, Cloudburst pipes manage rainwater. To assure connection to other surface solutions, these are positioned just below street level. If there is no space that can be used for aboveground solutions, this solution is adopted.

5. Central retention
Areas in the parks and squares where stormwater might be delayed are suggested so that Cloudburst roads can be built in lesser sizes. For instance, open recessionsin parklands or sunken seating areas might serve as the focal points. Typically, central retention components will be positioned beside nearby Cloudburst roads



Rain Event Handled within Multi-Functional Tools including Urban Creek, Retention Boulevard, and Boulevard

Figure 34:

Section showing flood water management (“Cloudburst Management Plan, Copenhagan,” n.d.)

Sponge City

Reduced flooding

Increase water storage by increasing permeability

Less load on the drainage and sewerage systems

Improvement in quality of environment and city ambiance by providing blue and green infrastructure

Good quality life for biodiversity

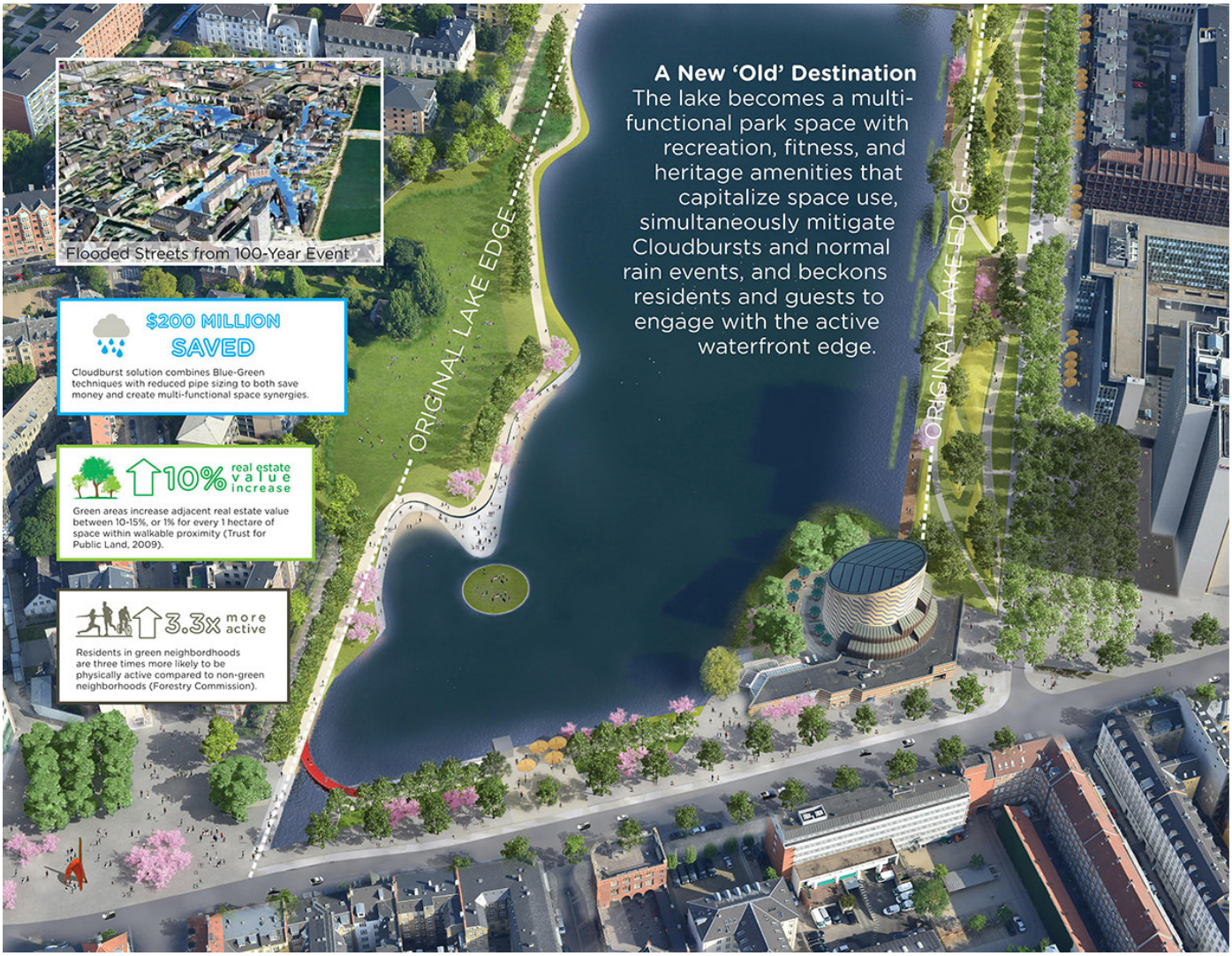


Figure 35:

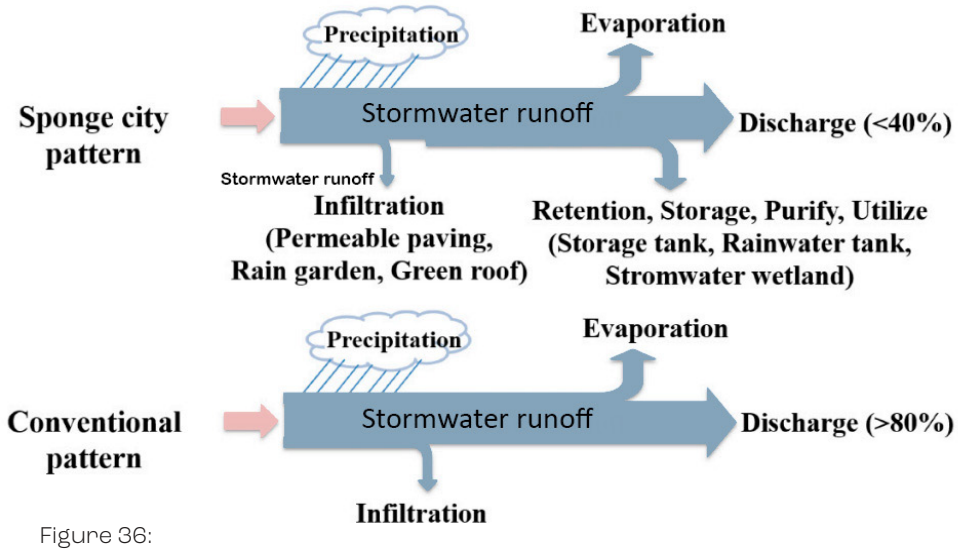


Figure 36:
A comparison between conventional flood management and the sponge city

Sponge Cities: Pluvial Flood Management

A sponge city refers to an approach of sustainably managing water, and is based on the "six-word" principle; infiltrate, detain, store, cleanse, use, and drain illustrates the underlying principles of sponge city and compares it with conventional flood management.

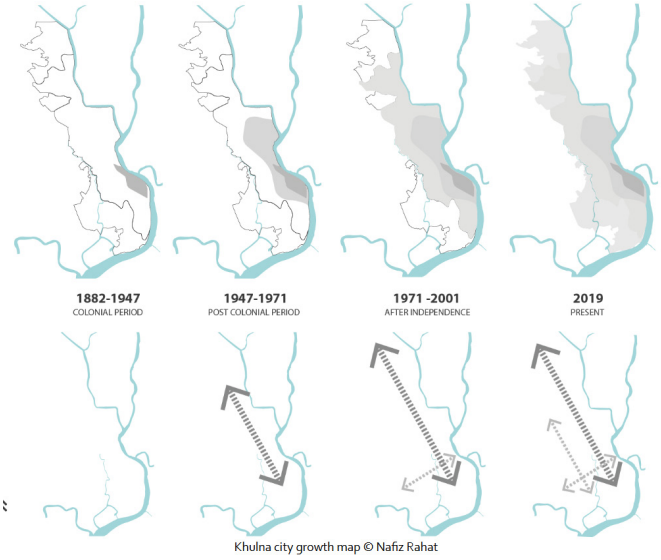


Figure 37:

Sponge City: A Water-Resilient Vision for Urban Khulna, Bangladesh

Name: Nafiz Rahat
Studio: Master Thesis
Studio Master:Prof. Cornelia Bott , Prof. Dr. Roman Lenz
Year:2021
University:HfWU, Germany

Khulna, a low-lying city in the Ganges-Brahmaputra delta, is located on the south-western coast of the Bay of Bengal. Water, being the source of life and hazards, has a large impact on this region. Over the last several decades, the region is experiencing notable changes in local human and natural habitats. Experts often explain this as an effect of climate change. Rising sea level coupled with an increasing amount of rainfall is causing frequent waterlogging and flooding in urban and rural areas of Khulna. Moreover, the soft surface to absorb the rainwater is disappearing fast due to continuing urbanization and river encroachment. The objective of this project is to explore sustainable design strategies for managing urban stormwater that would potentially perform as a catalyst for regenerating the landscape of the city.

1. Wheater, H.; Evans, E. Land use, water management and future flood risk. Land Use Policy 2009, 26, S251–S264. 2. Qiu, B.X. The connotation, approach and perspective of Sponge city and LID. Water Wastewater Eng. 2015, 41, 1–7. (In Chinese)3. Semadeni-Davies, A.; Hernebring, C.; Svensson, G.; Gustafsson, L.-G. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. J. Hydrol. 2008, 350, 114–125.

Figure 38: Mayur river present scenario © Nafiz Rahat

Figure 39: Mayur River: Proposed scenario © Nafiz Rahat

Figure 40: Moyur River Gollamari bridge area present scenario © Nafiz Rahat

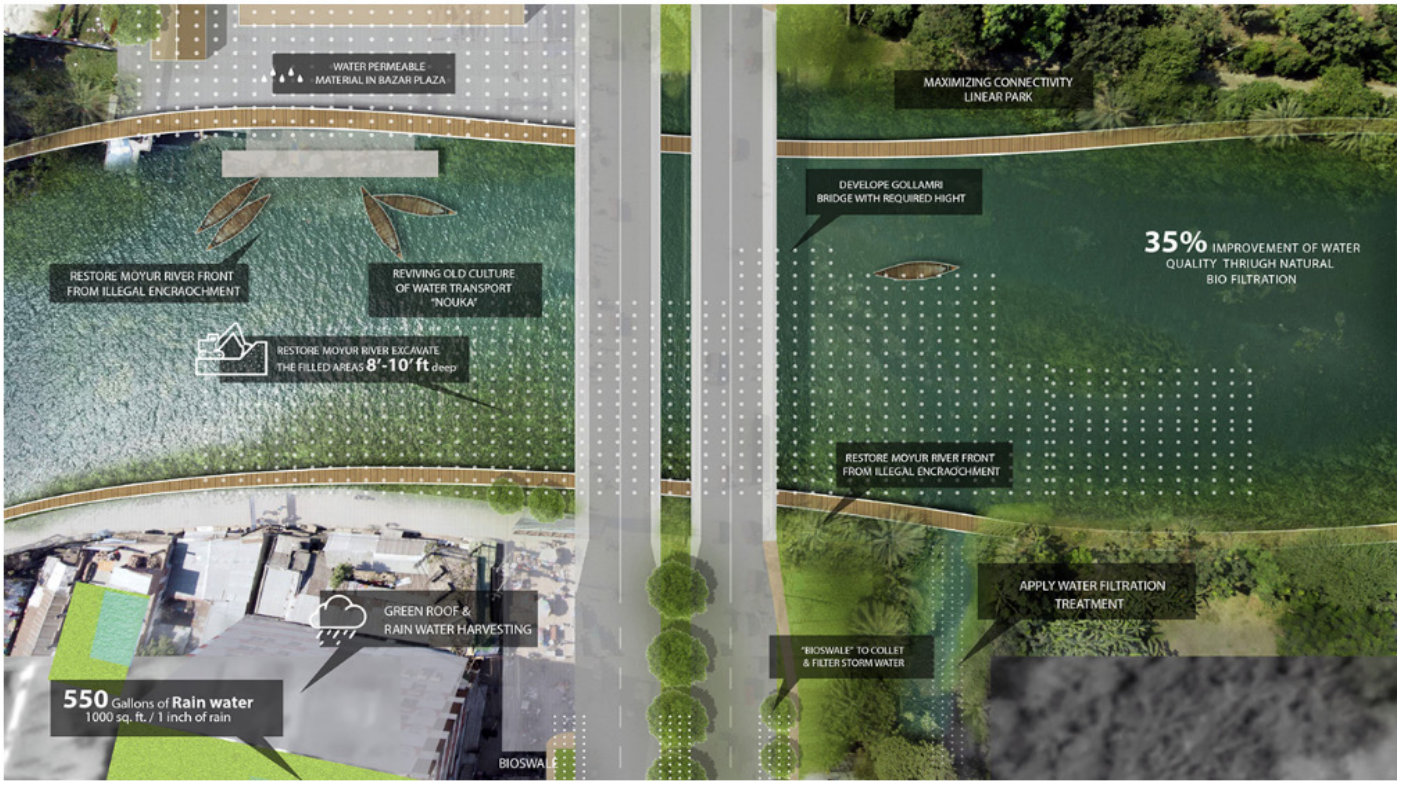


Figure 41: Moyur River Gollamari bridge area proposed scenario © Nafiz Rahat

04

Regional Context

Copenhagen Municipality

URBAN CONTEXTS :

Urban development areas

Refshaleøen, a former industrial area in Copenhagen, has transformed since the 1990s into a vibrant space with ample opportunities for urban development. It's designated in the Municipal Plan 2019 as a prospective area for future development, with plans set for after 2031. Despite future urbanization, it will still provide favorable conditions for creative industries, temporary initiatives, festivals, and events, while ensuring coherence with the surrounding town during the development of the East Harbour and new infrastructure

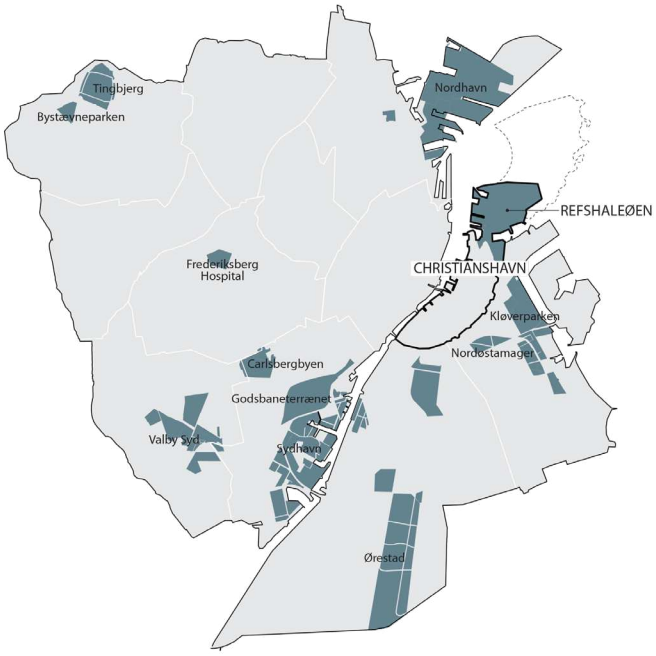


Figure 42:

Future urban development areas cf. KP19

A green, healthy and sustainable city

expand Copenhagen's green cycle route network, particularly in the northern harbor area, aiming to enhance accessibility to Refshaleøen and the city's northern parts. By prioritizing healthy and sustainable transport options like cycling, this initiative seeks to improve urban mobility and support the area's development.

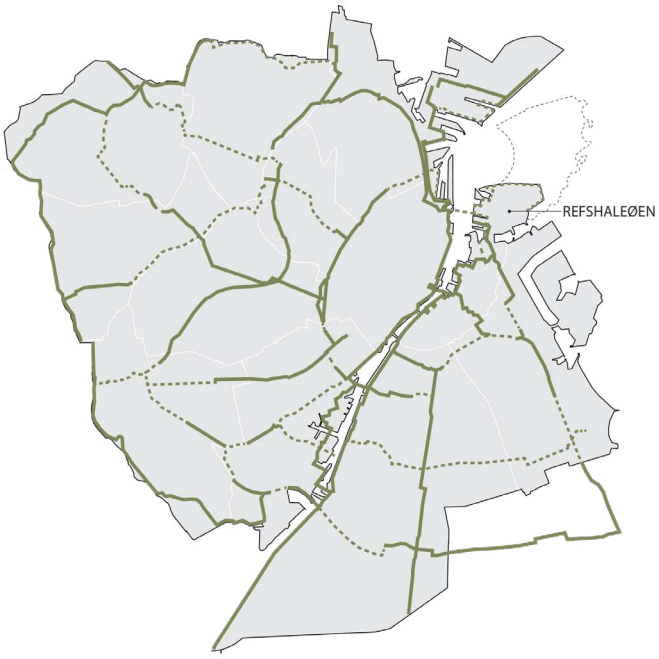


Figure 43:

Existing green cycle paths cf. KP19

Planned green cycle paths cf. KP19

Metro :

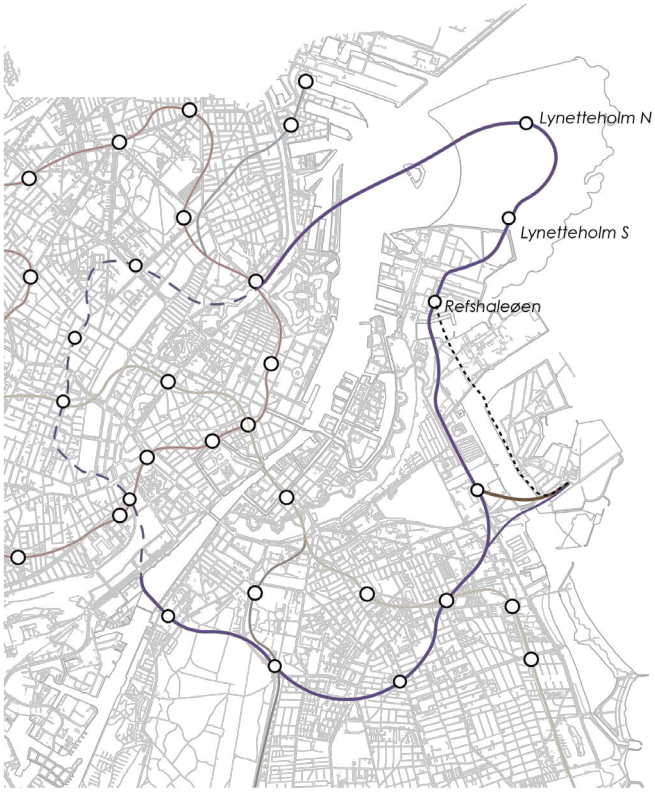


Figure 44:

- M5
- Perspective
- Technical track for control and maintenance center
- Possible branch to Malmö

Existing metro

M1 M3
M2 M4

POSSIBLE NEW ROAD LINKS :

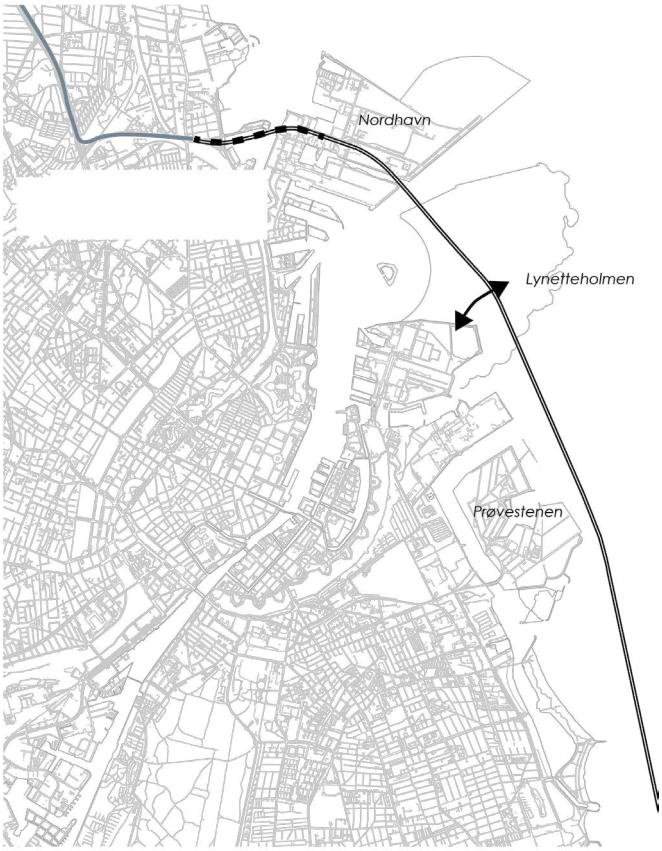


Figure 45:

- Eastern Ring Road
- Helsingør Motorvejen
- Nordhavns tunnel

Reference:MUNICIPAL PLAN KP19

Soft Road Users :

Refshaleøen's size, location and future connections make it easily accessible to vulnerable road users and an obvious way of promoting the possibility of more sustainable modes of transport.

pedestrian

you can, at an average speed, walk from the center of the island to the edge in about 10 minutes. The periphery around Refshaleøen is 5 km and will take about 24 minutes to walk.

cycling

As a cyclist, you can cycle from Refshaleøen within 10-15 minutes to Amagerbro, Kongens Nytorv, Rådhuspladsen and to Nordhavn, provided that a new bicycle connection is established across the harbor.

Metro

The metro makes an even larger catchment area accessible to vulnerable road users. With the metro M5 you will with only 6 stops get to Copenhagen H and with only 1 stop to Prags Boulevard Ø right by Kløvermarken's sports facility

Figure 46: Reference: MUNICIPAL PLAN KP19

“Why”Denmark? “Why”Copenhagen? :

Copenhagen has experienced significant urban and cultural growth since the millennium, driven by investment in institutions and infrastructure. It serves as Denmark’s cultural, economic, and governmental center, also ranking as a major financial hub in Northern Europe. Despite dropping to third place in global wealth rankings in 2012, Copenhagen remains a prominent city. The completion of the Øresund Bridge has enhanced integration with Malmö, forming the Øresund Region. The city boasts a unique cityscape with various bridges connecting districts, parks, and waterfronts. Tourist attractions like Tivoli Gardens and iconic landmarks draw visitors. Copenhagen is committed to achieving carbon neutrality by 2025 through initiatives in clean technology, already making significant CO2 emissions reductions

Øresund”Bridge

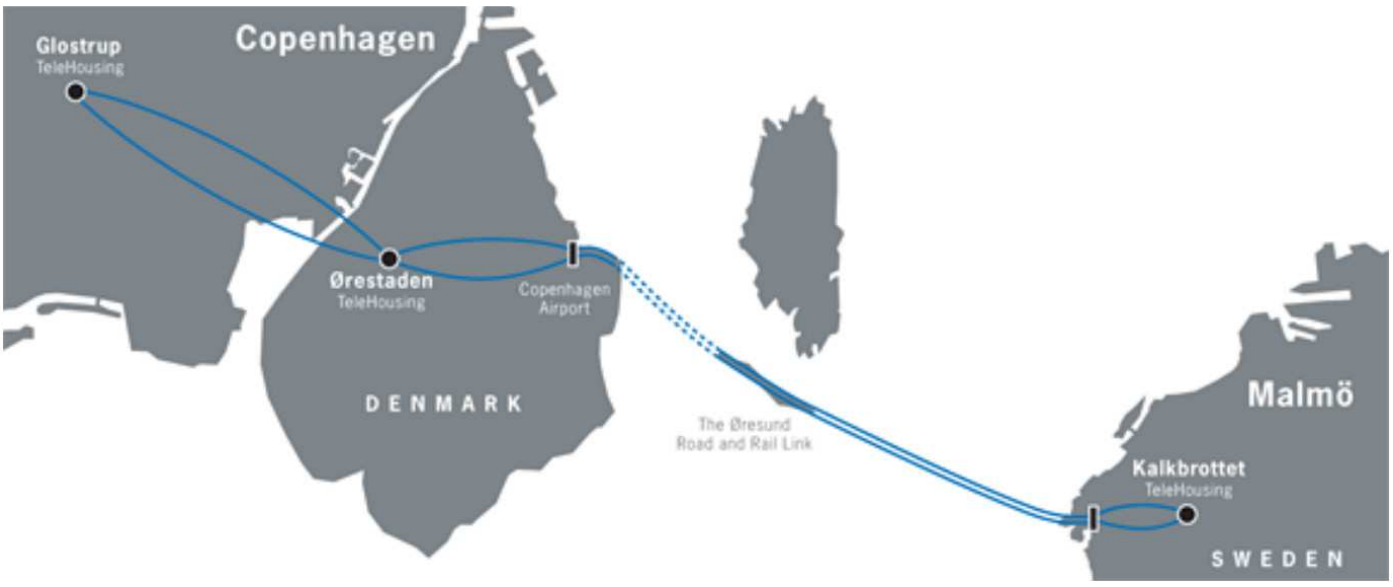


Figure 47:

1 . http://data.oresundsbron.com/image/illustrationer/dark_fibre_link_map.png

FACTS ABOUT COPENHAGEN :

· population in 2023: 654,000

· Every year 10 000 people move to Copenhagen

· average age in CPH is 35.8 y

· lack of housing in the center as well as in the suburbs of Copenhagen

· development of mixed-city needed

CLIMATE CHANGE

Main points about the Danish climate in 2100*:

· sea level in Denmark will rise about 0.1 - 0.5 m by 2050 and 0.2 - 1.4 m by 2100 as assumed.

· Copenhagen itself has 92 km of coastline.

· The annual average temperature increases by around 3.4 °C throughout Denmark.

· Precipitation in winter increases by almost 25%. Much of this precipitation will fall as rain.

· Summers will see around the same precipitation volume as today, but weather will be defined by two main categories: dry season and extreme rainfall events

· A storm surge will likely to occur every year or every other year in 2100.

URBAN (WILD) NATURE

· Copenhagen is one of the European Green City!

· City planning takes green areas into consideration ever since The Finger Plan from 1949.

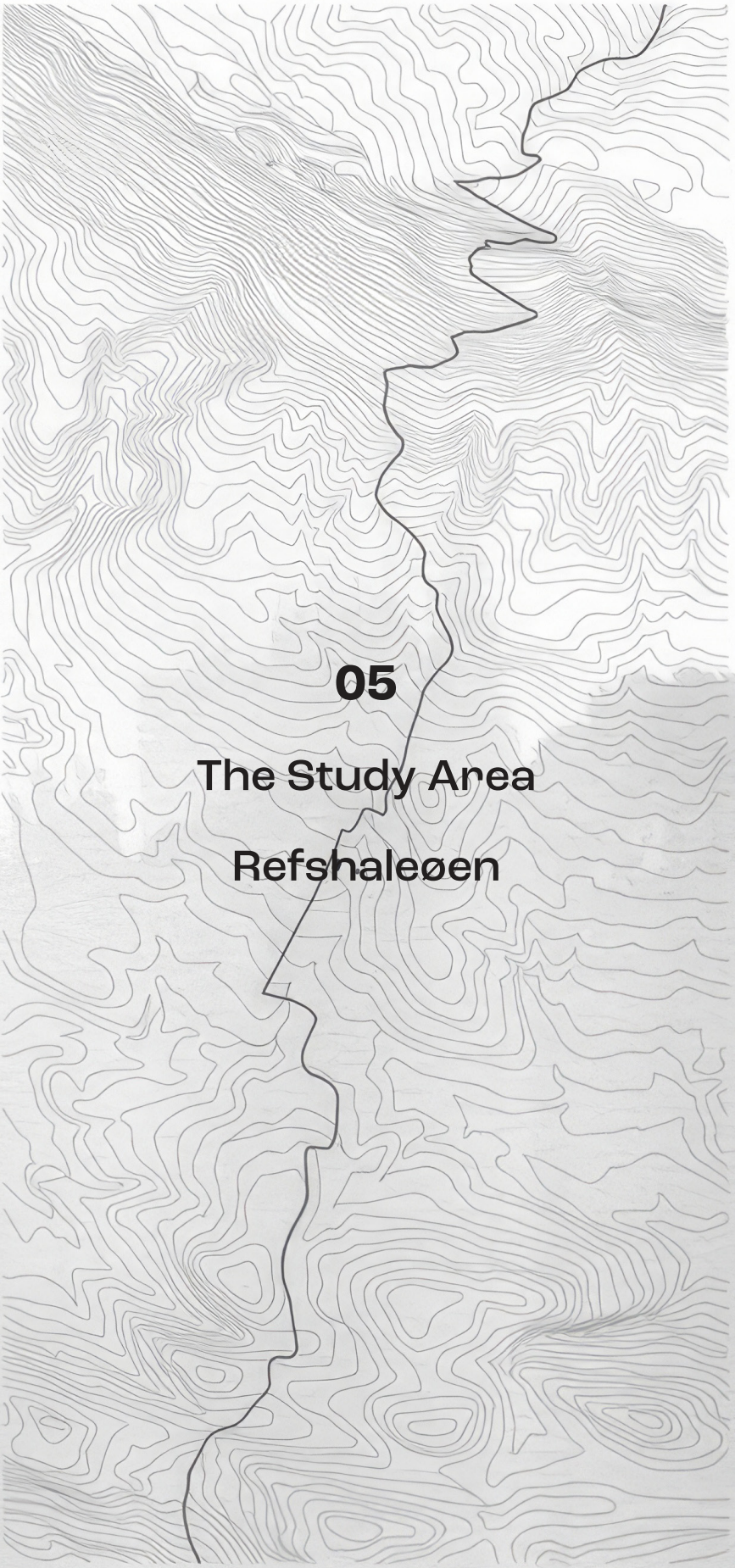
· Minimum 80% of Copenhageners live within a distance of 300 metres to a green area

· On average, each Copenhagener has 42.4 m2 of green area at their disposal.

·2260 hectares of green areas with public access were registered in Copenhagen.

· The city's green areas represent about 25% of the city's overall area.

available at: https://copenhageneconomics.com/publication/ demography-housing-needs-and-price-development-in-copenhagen/



05

The Study Area

Refshaleøen

Refshaleøen makes Copenhagen bigger :

Refshaleøen was created as a shipyard and is today known as Copenhagen's creative and cultural district with an attractive city life, informal atmosphere, blue and green qualities and a vibrant.

cultural history. Here, the city has gained an experimental edge, which creates a strong foundation for the future further development of the island.

1.We will be able to recognize Refshaleøen in the new district! The creative environment and cultural activities are a focal point for Refshaleøen today and in the future.
We preserve and transform all existing buildings, unless special circumstances speak against it.

2. We will go ambitiously towards the green transition! We have the ambition to at least build within the voluntary sustainability class and eventually be able to create new city within the planetary boundaries. We are creating a forward-looking district with collective and local facilities that support CO2 reduction, and an infrastructure where cycling and public transport are attractive and natural first choice

3.We will develop with space for urban nature, movement and strong communities! We create a district where the green and blue qualities are prominent in the plan, where there is a focus on biodiversity, and where we establish varied, high-quality urban spaces with access for all. We provide space for sports and movement, support social diversity and work in a community-oriented manner with a focus on physical and mental health.

4.We want to create an arch-Copenhagen district! We create a dense and mixed district with crooked street courses, a diverse urban and commercial life, architectural quality and site-specific urban neighborhoods with uniqueness, character and hierarchy of urban space. We develop housing and business premises in various sizes, types and forms of ownership, so that more business, population and income groups can establish themselves on Refshaleøen

Figure 48:

Figure 49: Google earth

Site location – Copenhagen

Refshaleøen arose at the same time as Copenhagen's bridge district at the same distance from the city centre.

CLIMATE PROOFING AND COASTAL LANDSCAPE :

Plant by LynetteholmLynetteholm
Is Copenhagen's new peninsula and storm surge protection project between Refshaleøen and up to Kronløbet in Copenhagen Harbor (Nordhavn).Lynetteholm is part of a comprehensive storm surge protection plan for the central part of the capital and must contribute to stemming future flooding of Copenhagen's coastal urban areas.Lynetteholm is to be filled up with surplus soil from construction projects in Copenhagen and the surrounding area. . In this way, Lynetteholm becomes the guarantor that the Municipality of Copenhagen can use the municipality's surplus land for the next several years, and that the transport time and thus the CO2 emissions from the city's soil transport are reduced.developing Lynetteholm with a green coastal landscape with stone and sandy beaches.

The coastal landscape and its rock dams are designed to be able to contain future sea-water rises, and will at the same time create potential for new habitats for plants and animals both above and below the water.

On 4 June 2021, the Folketing passed the law on construction of Lynetteholm. The work to build Lynetteholm's perimeter (stone dams) started in January 2022 and is expected to be completed in 2026. The whole of Lynetteholm is expected to be filled in approx. 30 years.LYNETTEHOLM AS CLIMATE PROOFING
In tandem with Nordhavn, the creation of Lynetteholm will form part of the overall climate proofing of Copenhagen against storm surges from the north. Storm surges often occur in connection with storms. Strong, onshore winds drive masses of water from the open sea towards the coastal area.Other projects related to LynetteholmIt is the vision that in the long term Lynetteholm will be developed into a new district in Copenhagen with a metro line and Eastern Ring Road and create space for both housing and workplaces.At present, it is only politically agreed to build the Lynetteholm peninsula itself. The plans for Lynetteholm's urban development and infrastructure have not yet been politically adopted, and these projects must first be environmentally assessed before they can be dealt with politically.

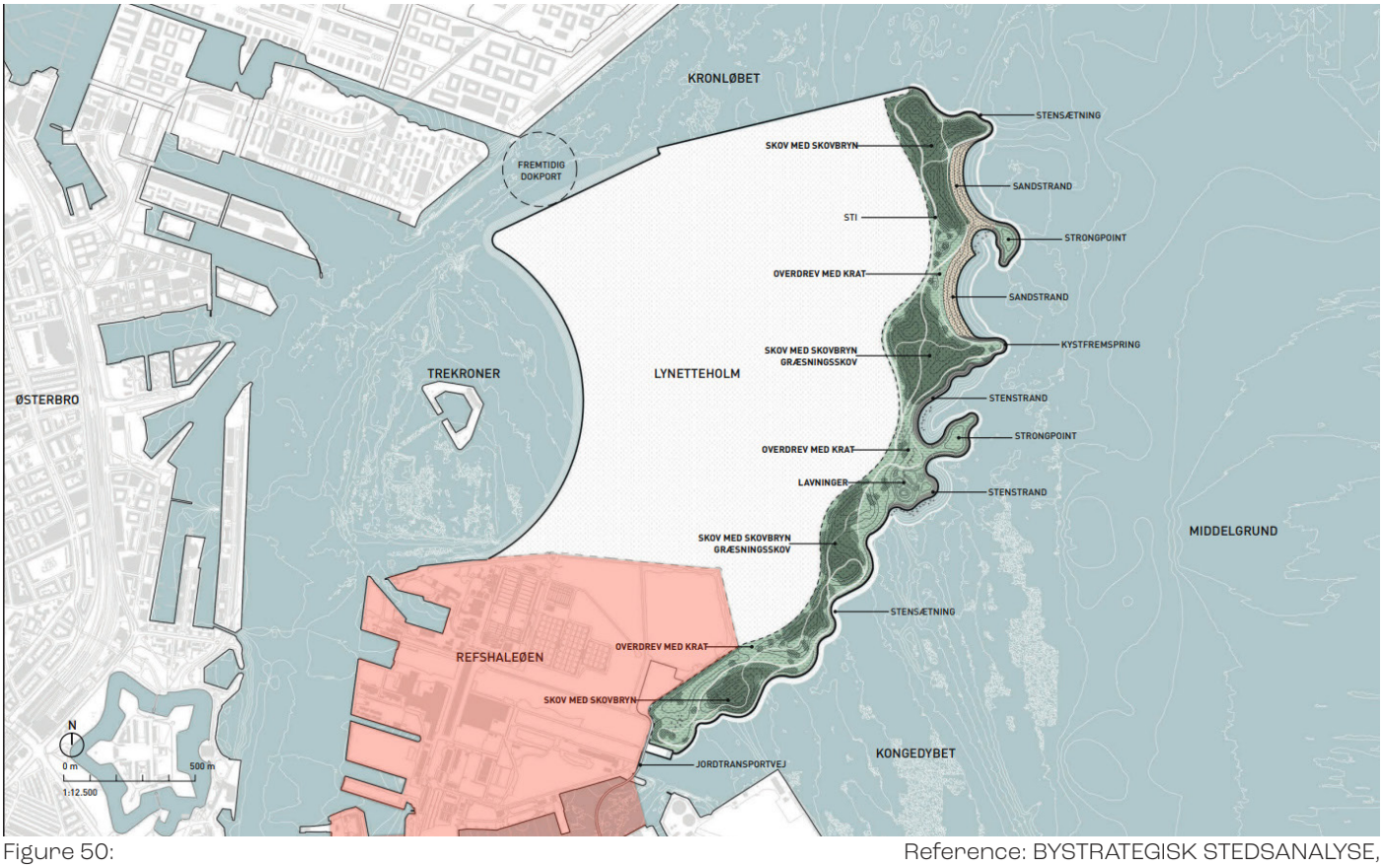


Figure 50: Reference: BYSTRATEGISK STEDSANALYSE,

From 1872, Refshaleøen has grown and changed in step with the B&W shipyard's expansions.

Over a current imprint with the temporary, creative, gastronomic, craft and cultural activities that Copenhageners know Refshaleøen for.

For a future mixed urban area with Lynetteholm in direct extension and good infrastructural supply.

Figure 51:

Site location – Copenhagen

Refshaleøen arose at the same time as Copenhagen's bridge district at the same distance from the city centre.

CLIMATE AND STORM UNSURANCE :

Lynetteholm enrolls in the city's large storm surge protection plan, where the eastern and northern edge of the peninsula together with a future dock gate, and later a possible lock, will protect Copenhagen against future climate change. The risk of storm surge in the Port of Copenhagen is currently estimated to be greatest from the south. It is assumed that storm surge protection is established in the south with some form of dock gate or high water lock

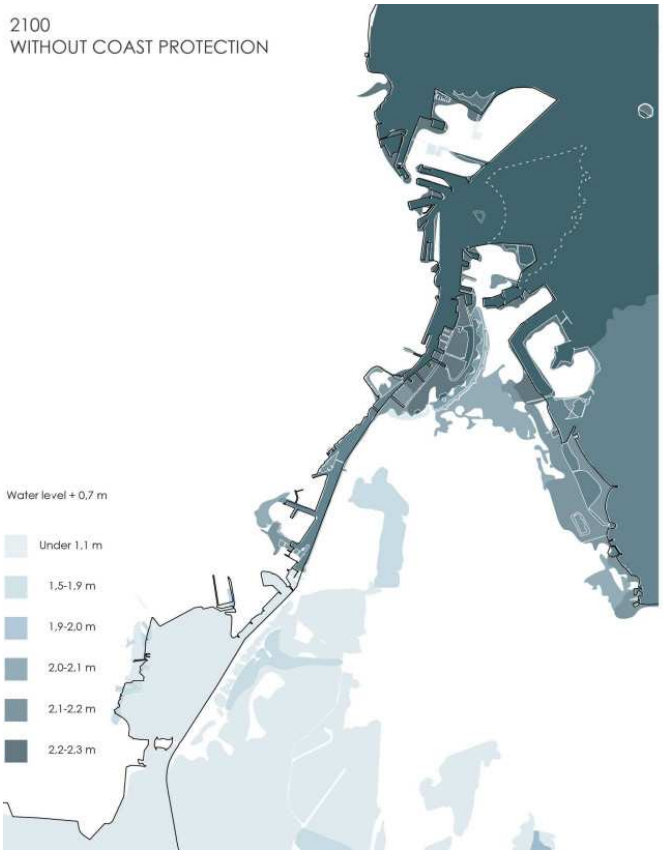


Figure 52: Source: IPCC's forecast - COWI has simulated staticwater level rise

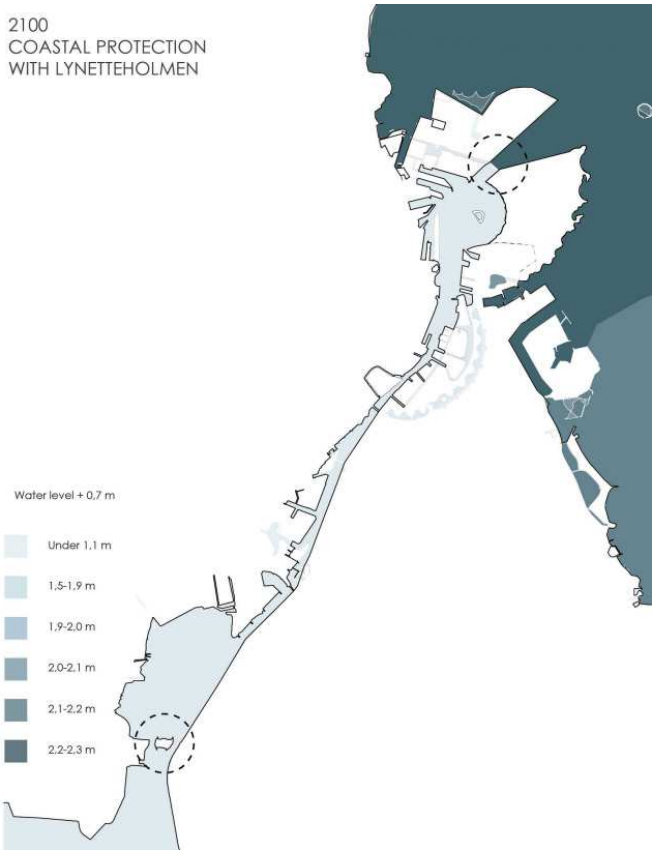


Figure 53: Source: IPCC's forecast - COWI has simulated staticwater level rise

Consequences of not adapting to the climate and floodproofing CopenhagenIn the year 2100, a sea level rise of +0.7 m combined with a storm surge event like Bodil of +1.7 m couldflood Copenhagen - especially the central part of the cityas well as large parts of Amager. The illustration above shows onetotal storm surge water level of +2.4 m as well as the massiveflooding it will cause.(Source: IPCC's forecast - COWI has simulated staticwater level rise)

Lynetteholm contributes to climate adaptation and storm surge protectionCopenhagen
As illustrated on the left, it will have massive consequences for the city, the infrastructure, the cultural heritage and the building mass in Copenhagen, if Copenhagen is not secured against storm surges. For example, this could mean the closure and repair of the metro for up to two years, just as it is estimated that the financial costs will amount to DKK 8 - 12 billion. kroner over the next 100 years. (Source: Copenhagen Municipality's storm surge plan, 2017)

Six identified characters, which are described below, will form a good starting point for programming in the development process for a new district on Refshaleøen.

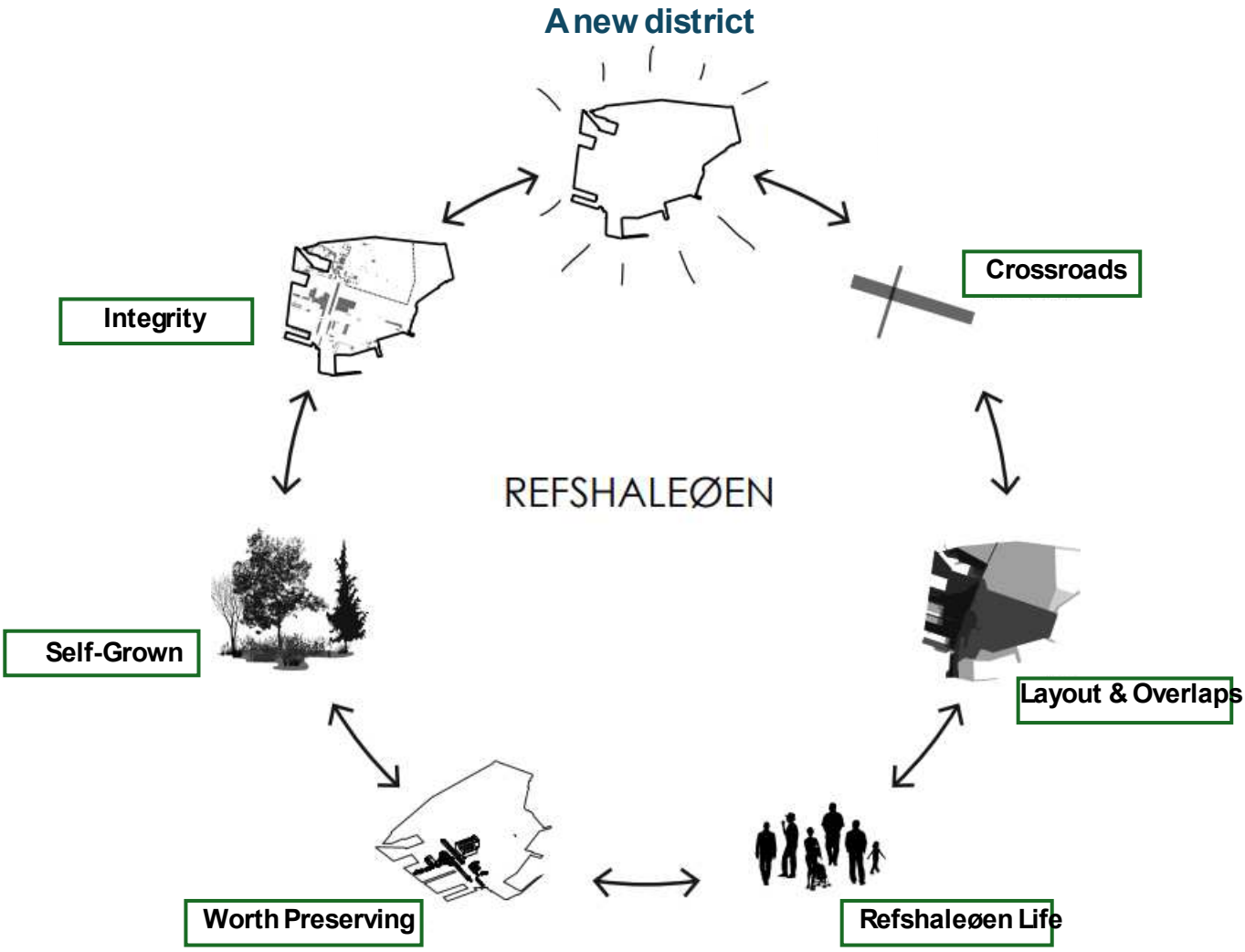


Figure 54:
Bystrategisk stedsanalyse af Refshaleøen Udarbejdet af Arkitema & COWI for Refshaleøens Ejendomsselskab og By & Havn

HISTORICAL TRACES :

Refshaleøen has been designated as a valuable cultural environment in Copenhagen, as it is one of 25 national industrial monuments, which illustrates Danish industrial history in the period 1840-1970.*

B&W on Refshaleøen reflects an important part of the story of Copenhagen as a port and industrial city, where B&W was among them large, leading shipyards in Denmark for 150 years. There are many historical traces from B&W's shipyard days, which are all included to carry the story on and who have the potential to contribute to local identities in a future city. The yard plan from 1978 on the opposite page shows a snapshot of the industrial environment with indications of roads, tracks and names. On them following pages, these layers are isolated to focus on their individual potential in further development of Refshaleøen.

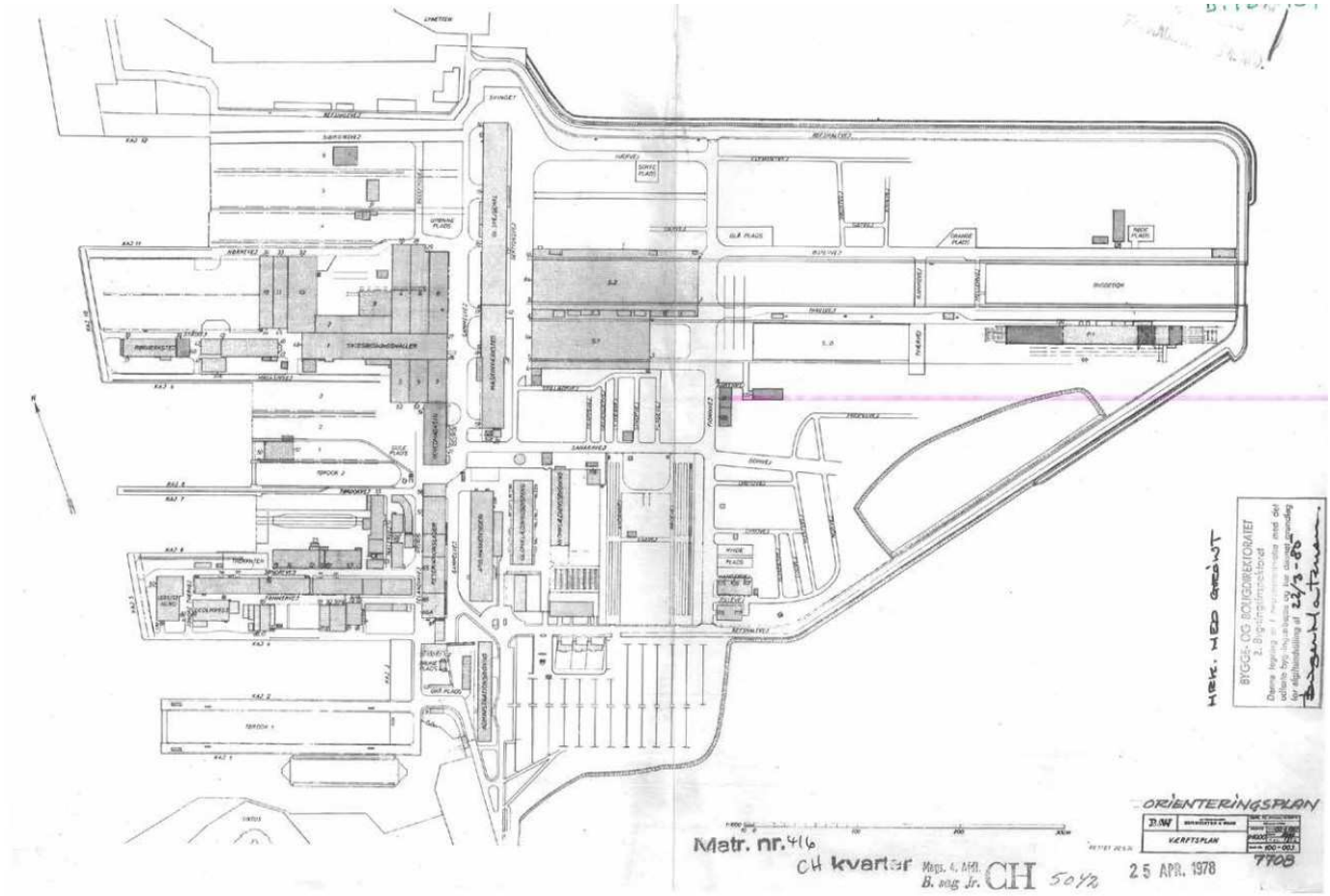


Figure 55:

YARD PLAN 1978; The plan is not fair in relation to the situation today

Figure 56:

Refshaleøen seen from west to east with Section Halls 1 and 2 at the top right of the picture and the old welding hall in front. Photo: Danmarksetfraluften.dk

CHRONOLOGY :

RAFSHALEØEN, COPENHAGEN

1624 established a block house - guard entrance to Copnehagen 1870s ports waterway made deeper 1871 Burmeister & Wain estab lished a shipyard 1996 ownership by pension fund 2011 Copenhagen yacht service opened 2013 Biofos - wastewater energy & resources 2018 Rafen claimed as bihhest street food market in Europe

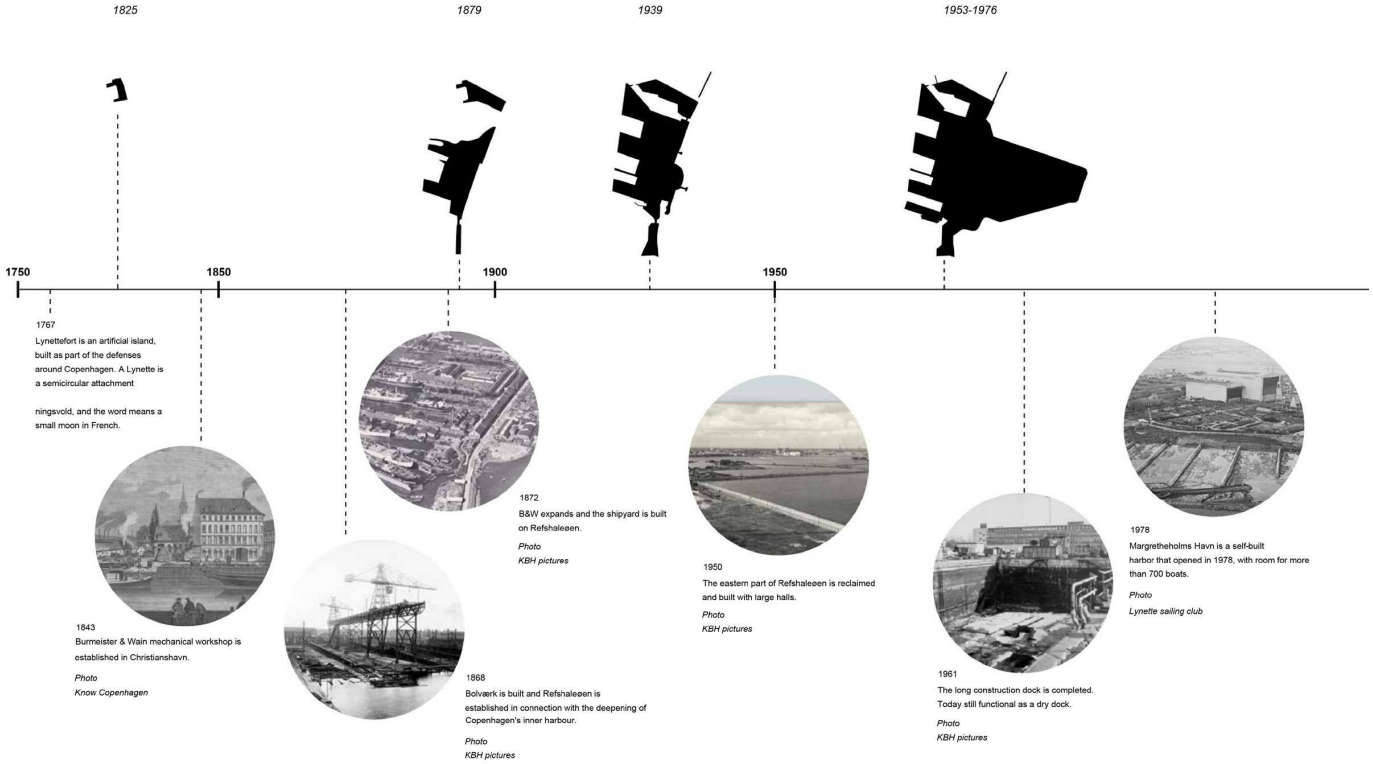


Figure 57:

Reference: BYSTRATEGISK STEDSANALYSE, P.23

Since the 1990s, Refshaleøen has developed from being a closed industrial area to being an open area in Copenhagen with lots of opportunities and urban development is now at the door. In connection with the development of Østhavnen and the planning of new infrastructure, Refshaleøen must be conceived as coherent with the surrounding ciy. Refshaleøen is retained in the Municipal Plan 2019 as a per pective area in the succession plan for the city's development. This means that urban development can only take place after 2031, and that the area will continue to have good location options for creative businesses, temporary measures, festivals and events.

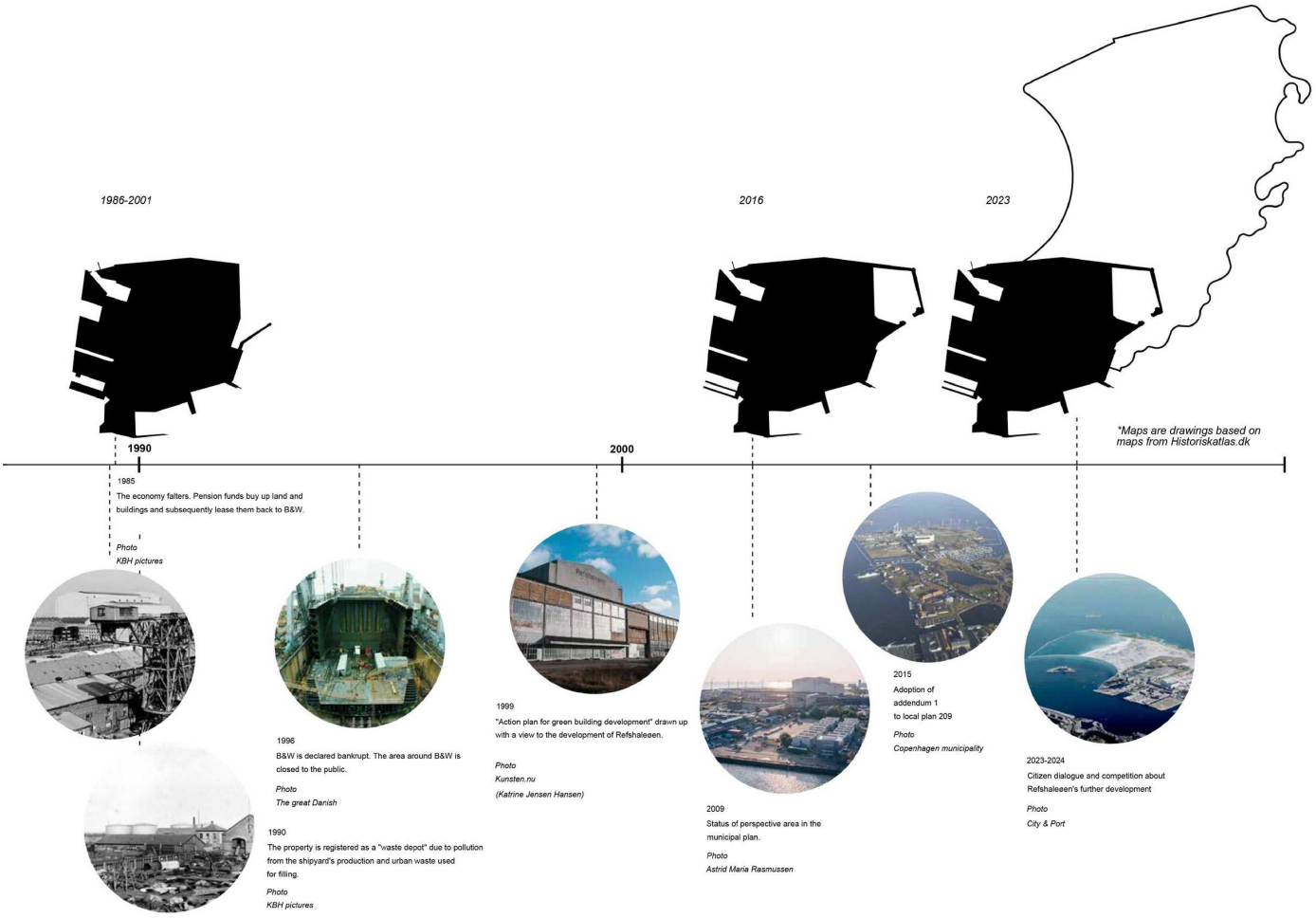


Figure 58:

Reference: BYSTRATEGISK STEDSANALYSE, P.23

PAST OF REFSHALEØEN :

Pictures from the B&W shipyard on Refshaleøen in the period 1872 to 1996.

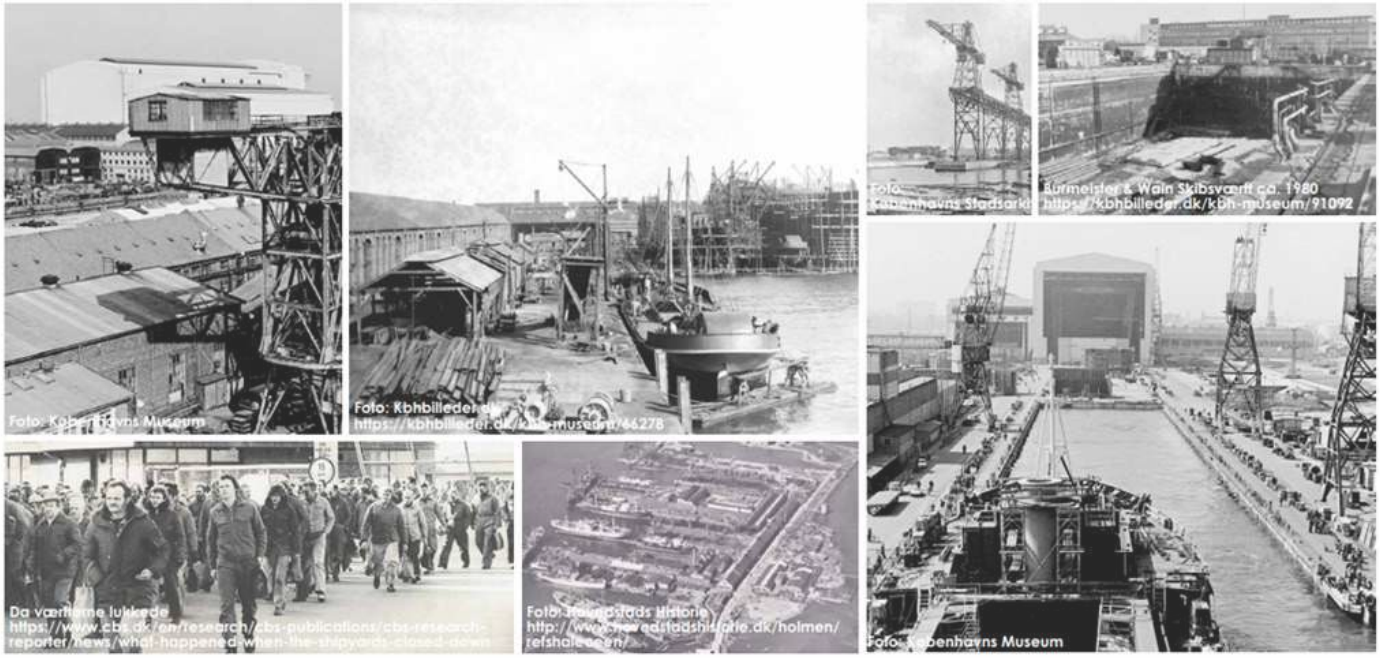


Figure 59:

TODAY OF REFSHALEØEN :

Today, Refshaleøen is particularly known for the temporary creative, gastronomic, craft and cultural activities.

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Figure 60:

Figure 61:

Mobility :

Today The road structure on Refshaleøen is primarily surfaces without division between different road users.
Refshalevej is a road with a pavement, where there is a bus connection with a bus stop at the start of Refshaleøen .

Main Access Points:

Refshalevej: This is the primary road leading into and out of Refshaleøen, connecting the area to the rest of Copenhagen. Refshalevej is a continuation of Prinsessegade, which is an important road in the Christianshavn district.

Langelinevej: Another important route that provides access to parts of the area, though it is less central than Refshalevej.
These roads are the main arteries for vehicular traffic, supporting the area's accessibility for both residents and businesses.

Secondary Roads:

The internal road network within Refshaleøen primarily consists of smaller, secondary roads that connect different parts of the area. These roads serve the local traffic and provide access to various sites, including former industrial areas now used for cultural, recreational, and commercial purposes.
The secondary roads often lead to large open spaces, former industrial sites, and new developments, which may include residential areas, commercial spaces, and cultural venues.

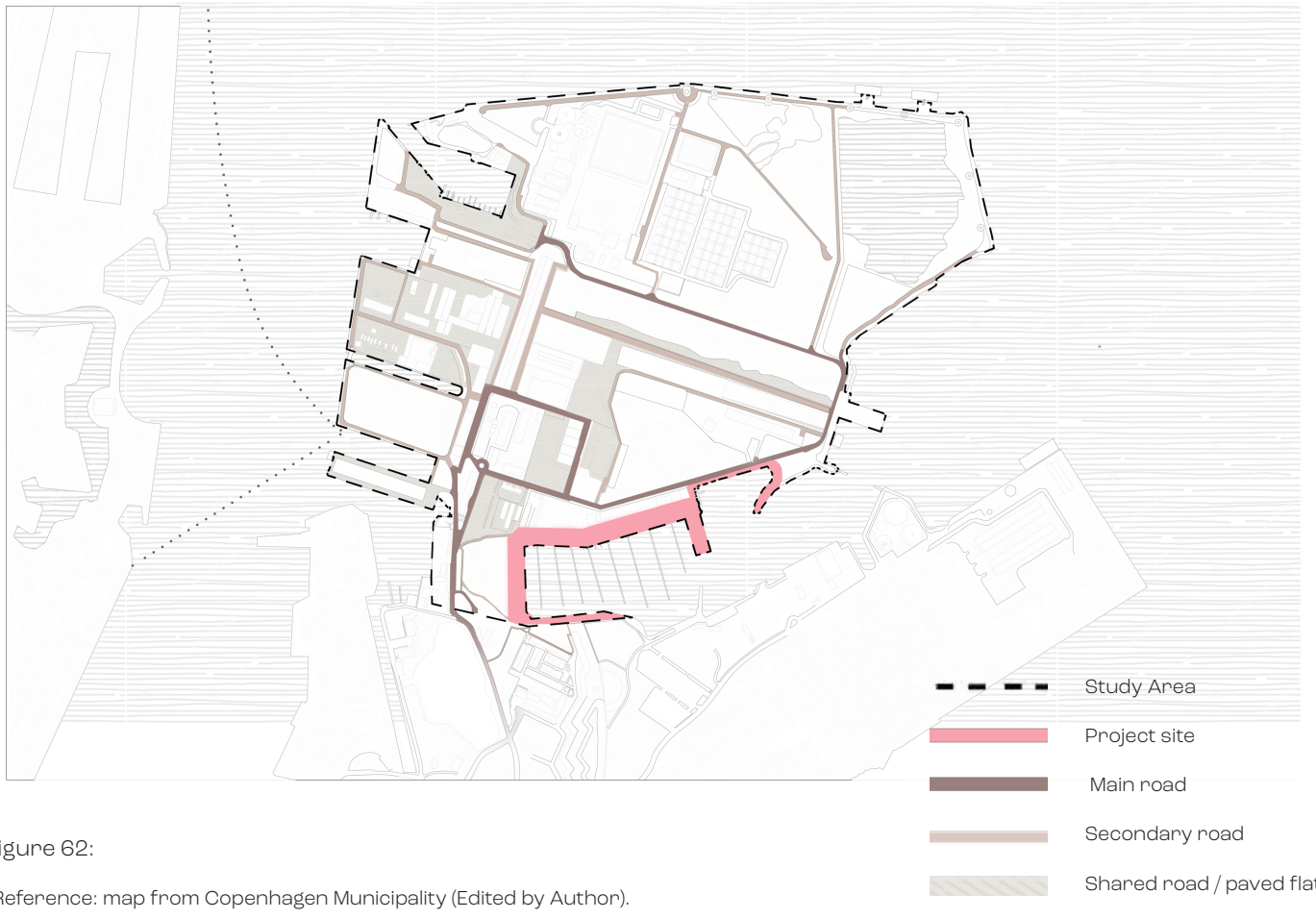


Figure 62:

Reference: map from Copenhagen Municipality (Edited by Author).

Function :

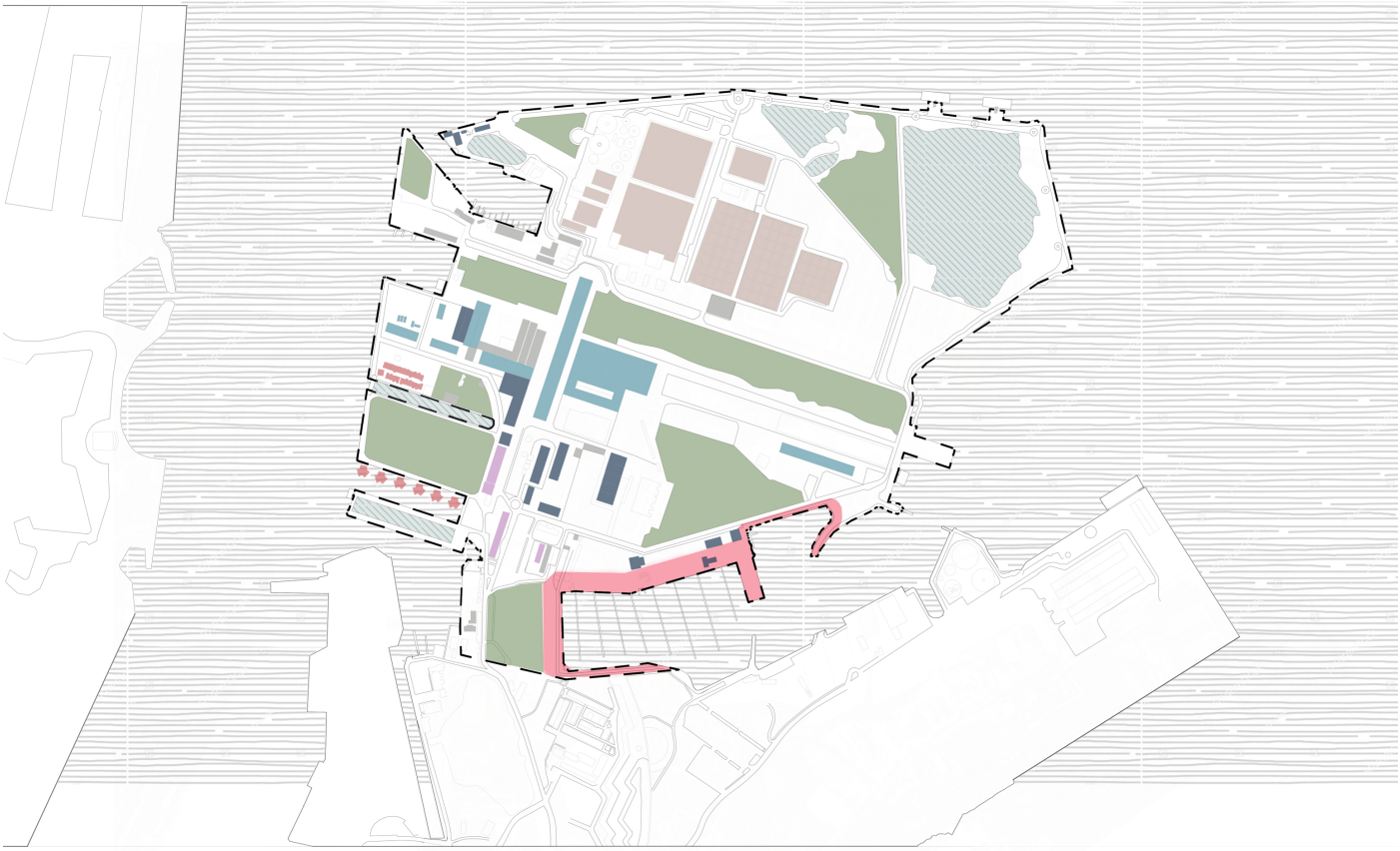


Figure 63:

INDUSTRY & WAREHOUSE
SERVICES
OFFICES
NATURE
Project site
Warehouse
Industry
Leisure & Culture
Nature

Reference: https://copenhageneconomics.com/publication/ demography-housing-needs-and-price-development-in-copenhagen/

Transportatin :

EXISTING AND POSSIBLE NEW CONNECTIONS

Public Transportation: While Refshaleøen is not yet served by the metro, there are bus services that connect the area to other parts of Copenhagen. Future developments may see enhanced public transport options, including potential extensions of the metro network or improved bus services.

In the KP19 plan, a bicycle connection from Langelinje to Refshaleøen is planned. The exact location has not yet been determined. There are several options for additional road connections to Refshaleøen from the south and an access road from Østre Ringvej from the north. Metro M5 will provide entirely new possibilities for connections to and from Refshaleøen, along with the Eastern Ring Road. The metro and the Eastern Ring Road are presented graphically on the following pages.

Refshaleøen is connected by a harbour bus across the inner harbour course, which provides 'short-cuts' A temporary road has been built at Margretheholm Harbour for heavy vehicles for soil depot in connection with the construction of Lynetteholm

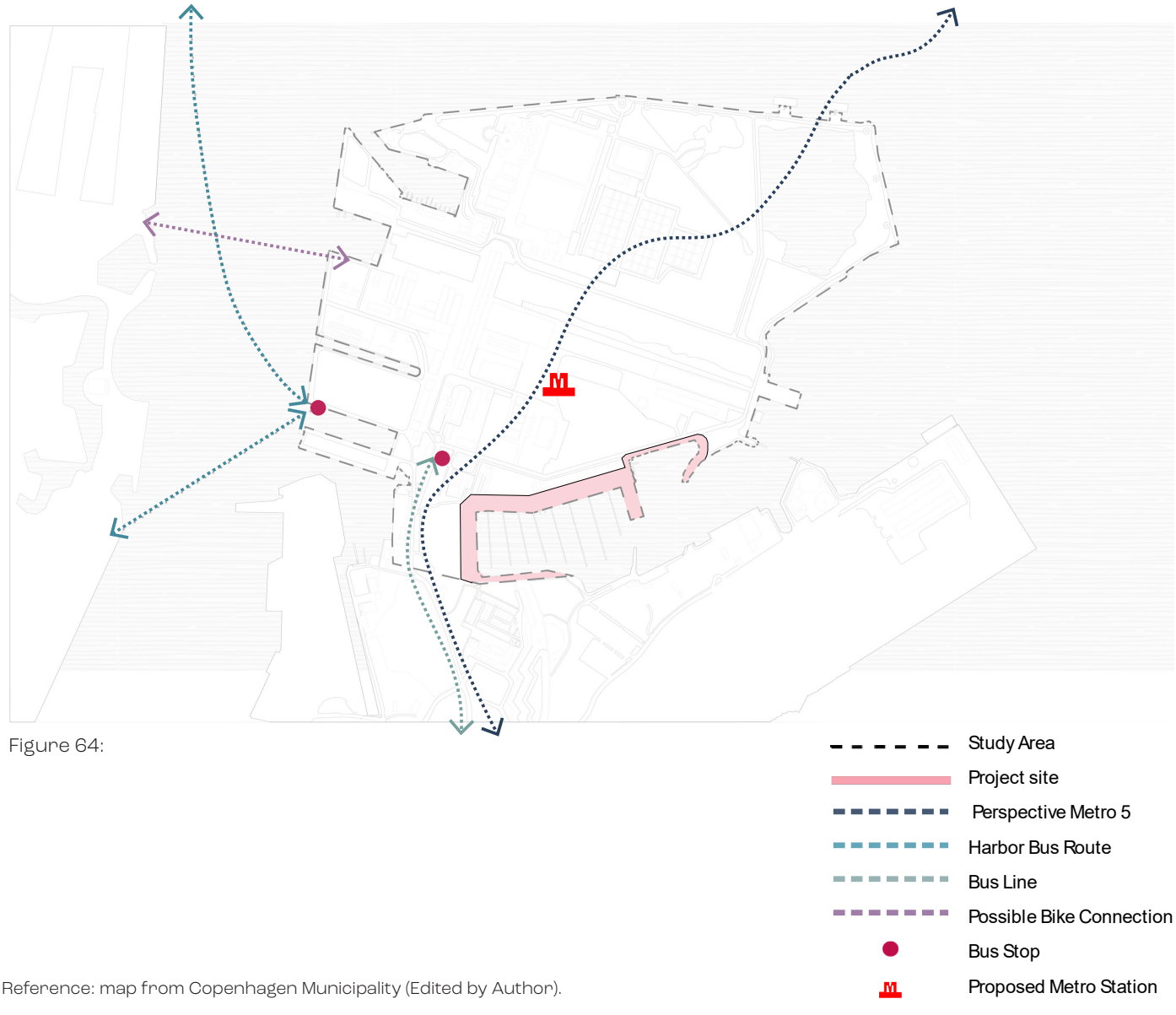


Figure 64:

Reference: map from Copenhagen Municipality (Edited by Author).

CHARACTER / IDENTITIES :

The project area can generally be divided into 9 sub-areas based on different character and identity:

B&W Site:
Large open space, high vegetated embankment, and large buildings. The area has a high degree of history and cultural heritage. The site is partially active during events. The large scale is dominant.
Natural Area:
Local self-grown nature, representing a sample of Refshaleøen's natural value. The area is an active landscape. The smaller scale is dominant.
Margretheholm Harbor:
Local environment with an active harbor. The scale is small.
The 'Unprogrammed' Area:
Open space facing the harbor and residential areas along the edge. The area represents both small and large scale.
Inner Axis:
Elongated urban space running north/south. A long view along the buildings—representing small, medium, and large scales.-The 'Active' Area: Large space with many temporary functions. The edge is active. Both small and large scale are represented.
Industrial Area:Open space facing the harbor with views of Trekroner and Nordhavn.A combination of cultural heritage and maximization of harbor activities.Both small and large scales are represented.
Lynettefort: Protected area with cultural heritage and self-grown nature.The scale is small.
Lynettedepot: Local self-grown nature. The water basin will be filled in the next few years.The scale is large.

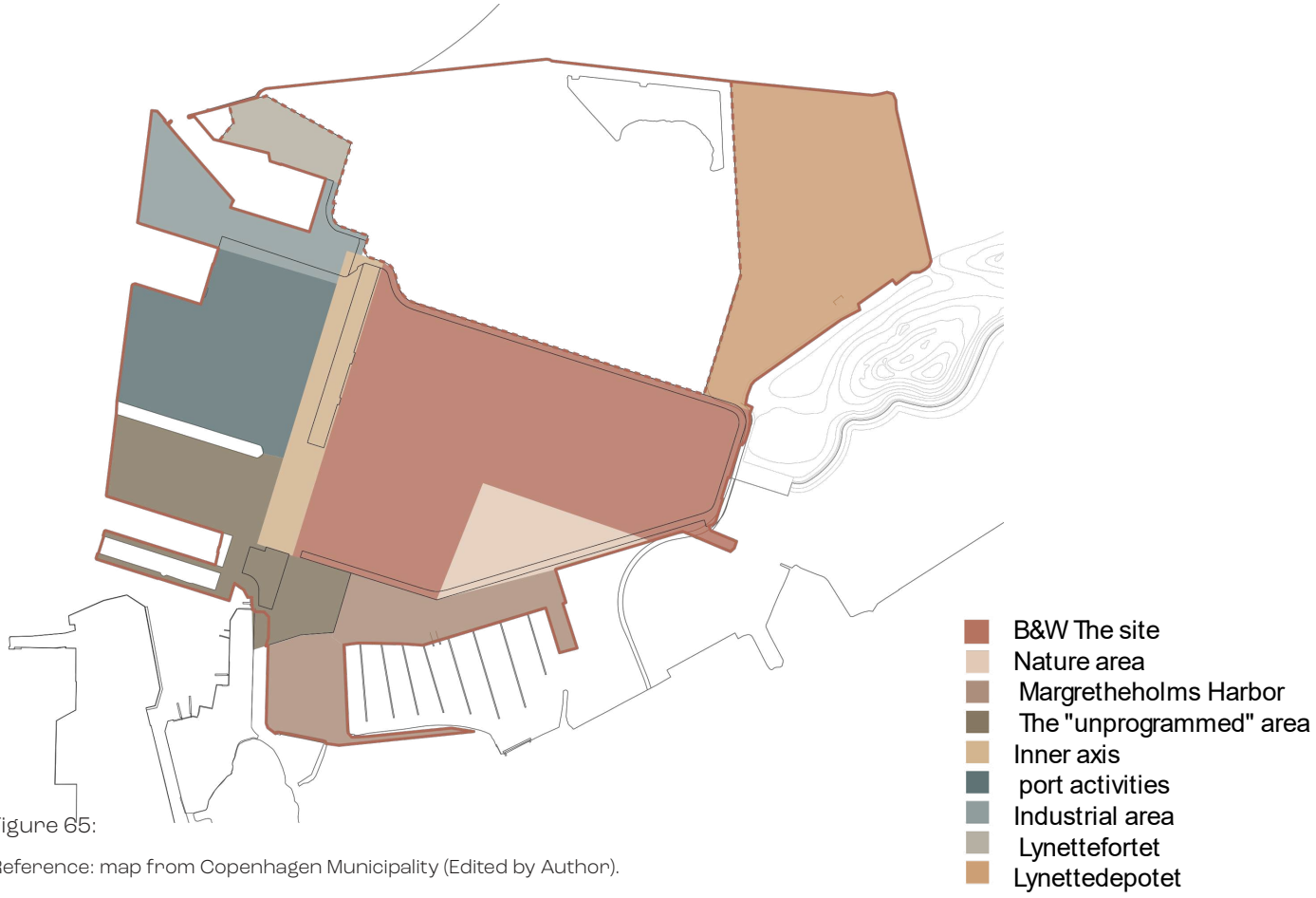


Figure 65:

Reference: map from Copenhagen Municipality (Edited by Author).

Site Sections :

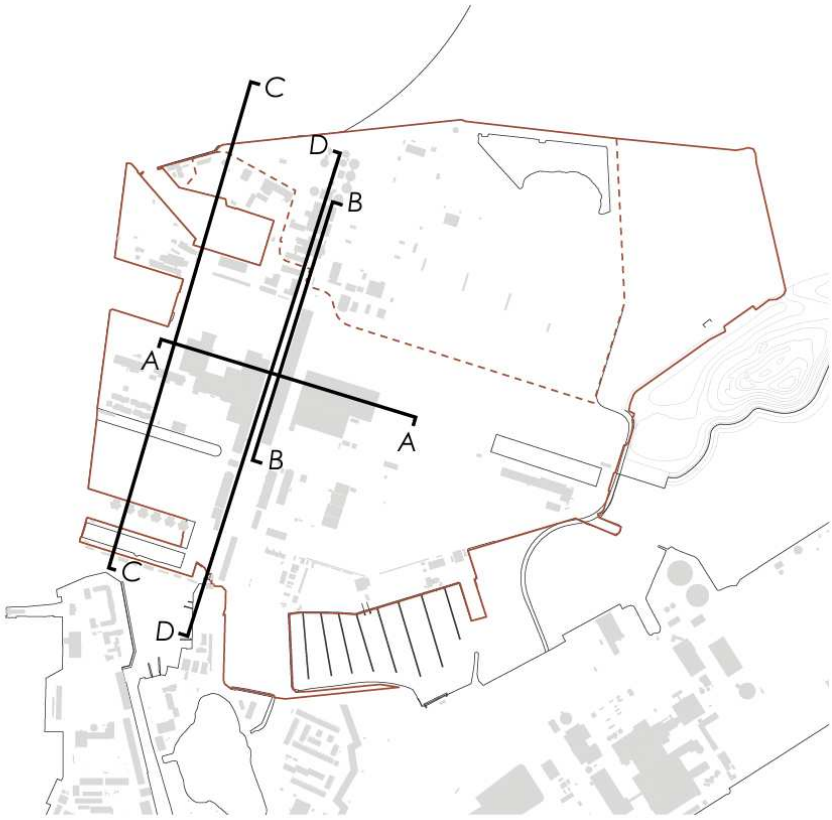


Figure 66:

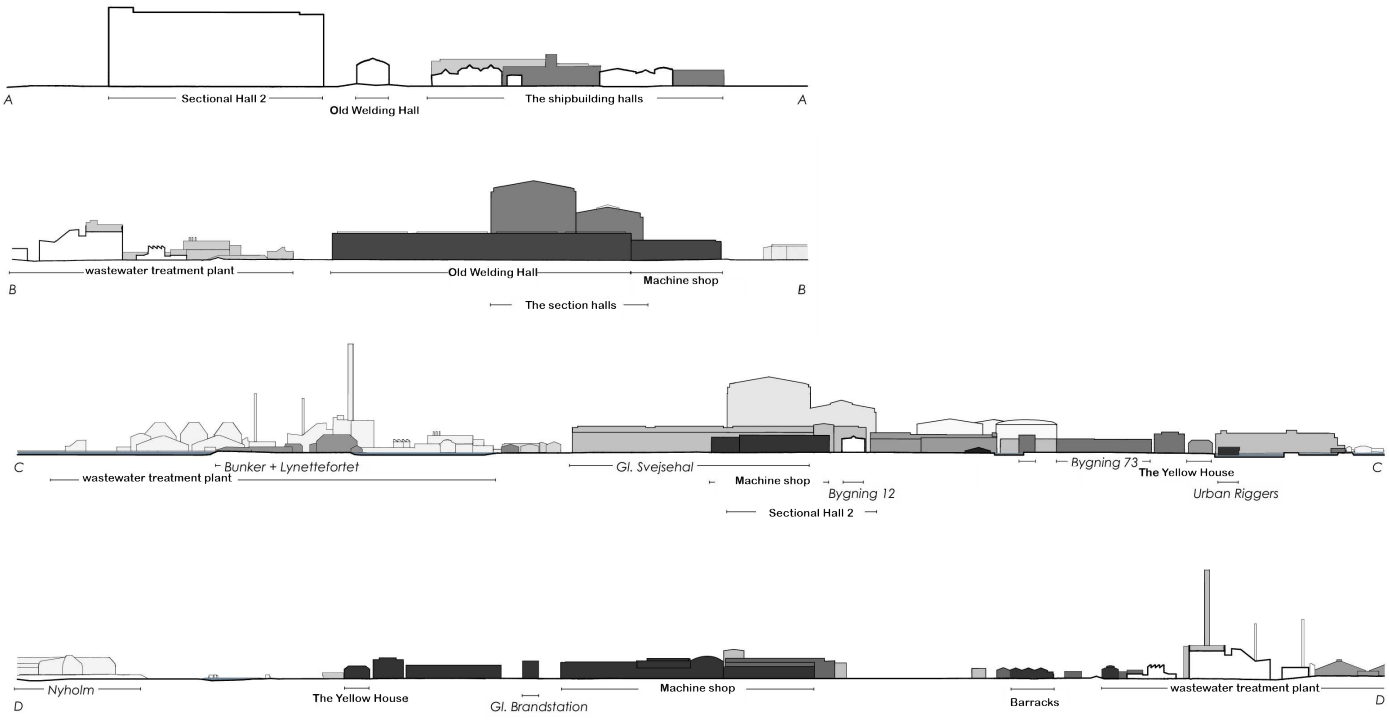


Figure 67:

Reference: map and sections from Copenhagen Municipality (Edited by Author).

sub-areas :

The settlement structure can be divided into 5 subareas, each with its own character.

In the island two plots in the northwest of Refshaleøen, as well as the plot in the south with Margretheholm's Harbor, a completely different building structure is experienced compared to central Refshaleøn

The area in the southwest with houseboats and the area with Lynettedepotet and wind turbines in the northeast also appear as subareas with a local distinctiveness.

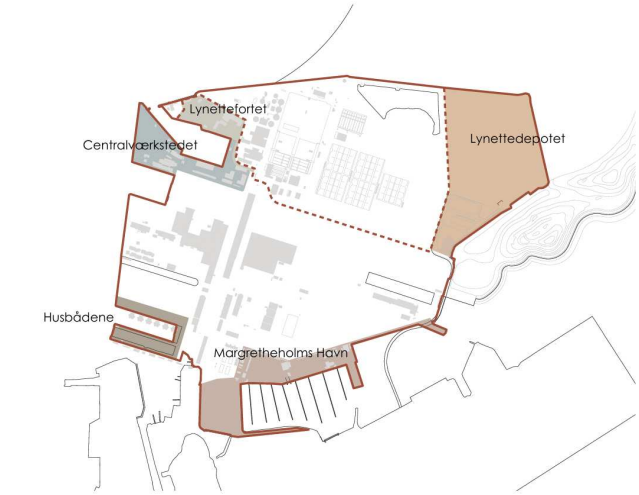


Figure 68:

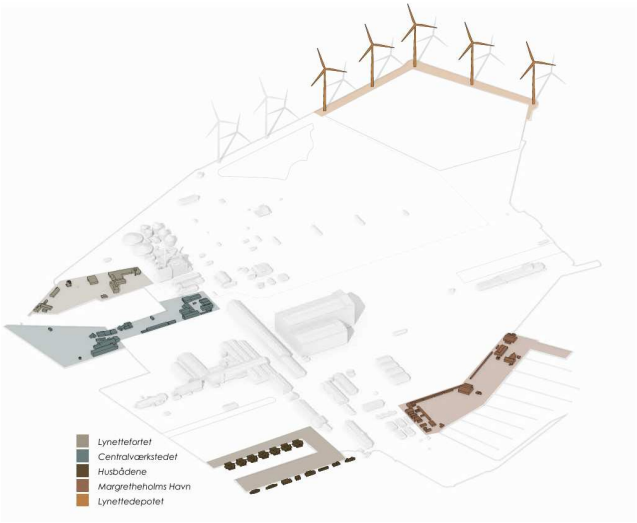


Figure 69:

Figure 70: STRUCTURE

Figure 71: DIRECTION / ORIENTATION

DIAGRAM EXTRACT FROM THE YARD PLAN FROM 1978 :

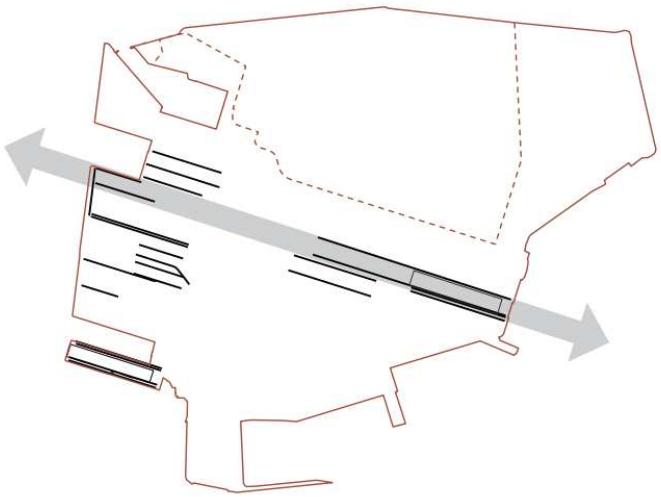


Figure 72:

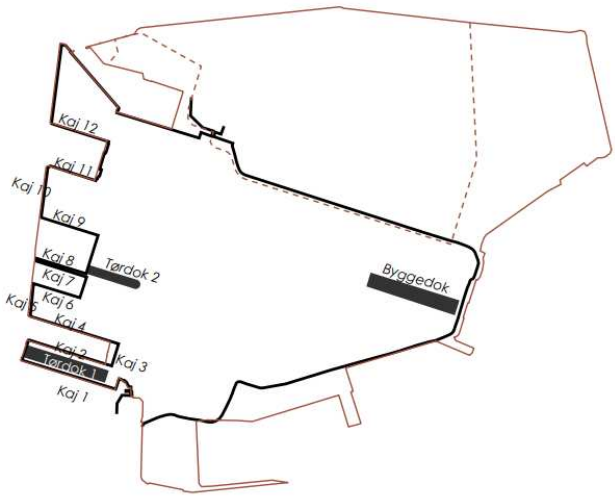


Figure 73:

CRANE TRACK

The map shows an extract of crane tracks in the pavement, which is shown on the yard plan. The primary direction on the rails is east-west, with the most dominant being found in the so-called 'steel line'. There is great dissemination potential of the cultural environment in the preservation and staging of shines in the coating.

BULK WORKS AND QUAY FACILITIES

Bulwarks and wharves, including the dry and floating docks, are also important in conveying B&W's importance in Danish industrial history. Today, the dry docks are wet and draw the water into the island.
The construction dock from 1961 can no longer function as a dry dock, but can be used for recreational purposes.

SCALE, SPACE AND BUILDING

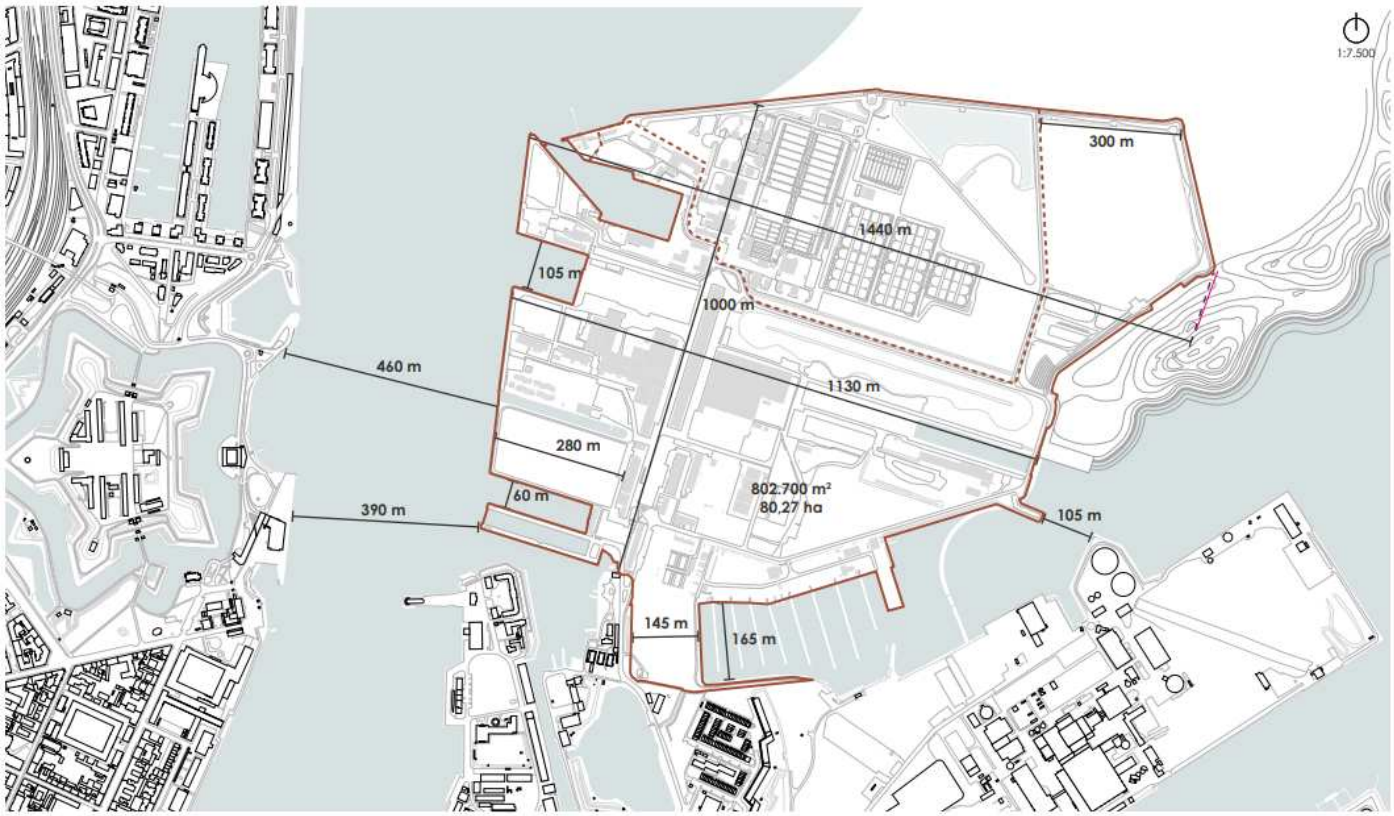


Figure 74:

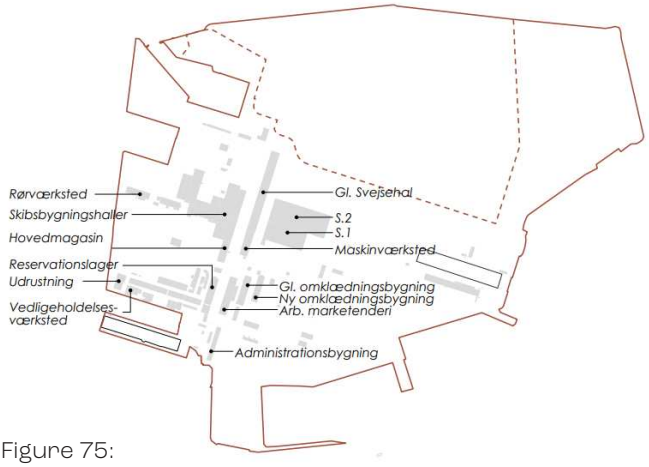


Figure 75:

Figure 76:

CONSTRUCTION

The buildings in the yard plan are numerous and all with functions that supported the yard complex.

BUILDING AGGREGATED OVER TIME

Not all buildings from the shipyard period have been preserved today. New ones have also been added and some of the buildings are temporary. The map is an illustration of where there have been or are buildings today, recorded on historical maps from historiskatlas.dk

URBAN NATURE :

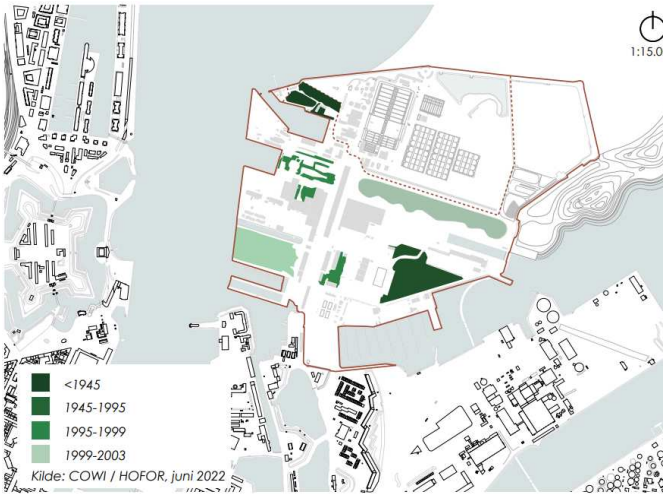


Figure 77:

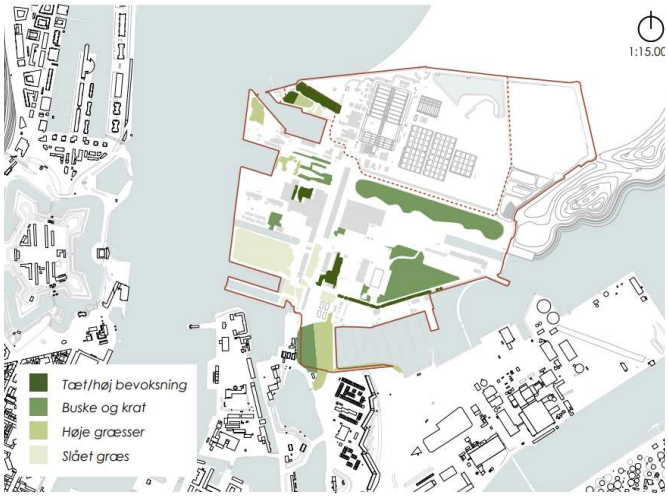


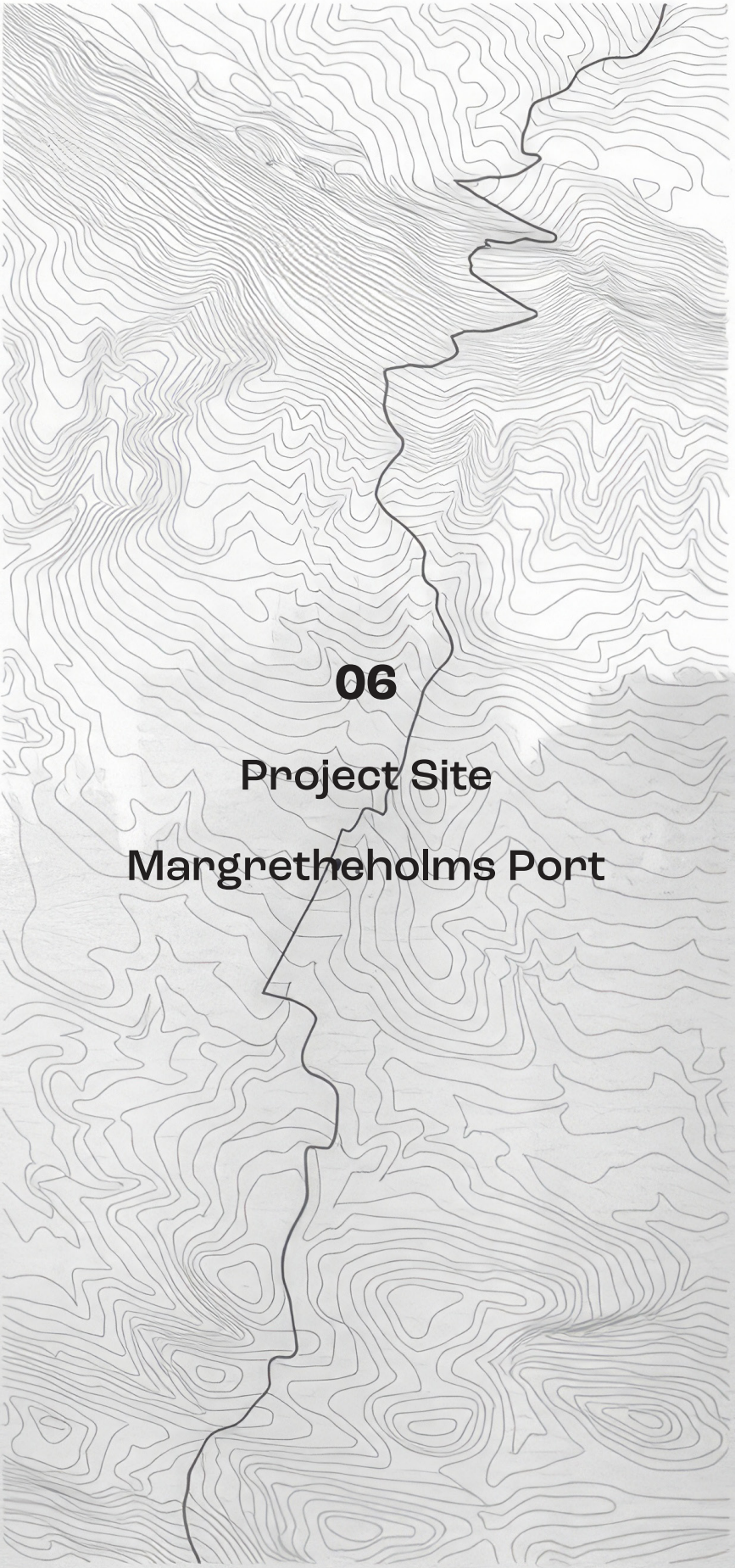
Figure 78:

The nature on Refshaleøen has developed over time, with the oldest vegetation seen at Lynette-fort and the youngest natural areas are found on the earth embankment and the meadow by the former dry docks

The character of the nature on Refshaleøen generally has a wild and self-grown expression and consists of natural areas of varying height and density. The urban environment on the island is rough and largely fortified. In unfortified as well as fortified areas, nature has found its way with its unplanned and uncontrolled character

Figure 79:

Nature bears the stamp of being wild and self-grown. The species diversity is represented by trees, shrubs and grasslands, which are reflected in open, semi-open and closed vegetation. These are both native and introduced species, which are typically found on grasslands, dry meadows, salt meadows and nutrates.



06

Project Site

Margretheholms Port

Overview:

Selected Harbor edge area is under the name of **Margretheholms Havn** is situated on the north-eastern side of Refshaleøen, near the entrance of Copenhagen harbor. The area is bordered by the waters of the Øresund Strait to the east and faces the city center across the harbor to the west.
It's connected to the rest of Copenhagen via bridges and roads, making it relatively accessible by bike, car, or public transport.
Margretheholms Havn, was originally developed in the late 19th century as part of Copenhagen's shipbuilding industry, mainly the Burmeister & Wain shipyard, which was one of the largest in Denmark.

Landmarks and Points of Interest:

Margretheholms Havn - Marina with Boat Storage, Piers, and Clubhouses

Marina: The marina at Margretheholms Havn is a key feature, offering mooring options and services for small boats and yachts.
In the marina, one can feel the vibrant atmosphere around the boats, the clubhouse, and the restaurant, particularly during the sailing season when activity peaks. The buildings and structures are closely aligned with the marina's functions, supporting the lively sailing environment. The direct connection to the Øresund through the marina is a key asset.

Maritime Activities: The harbor area continues to be used for yachting and boating, with several docks and marina facilities available.

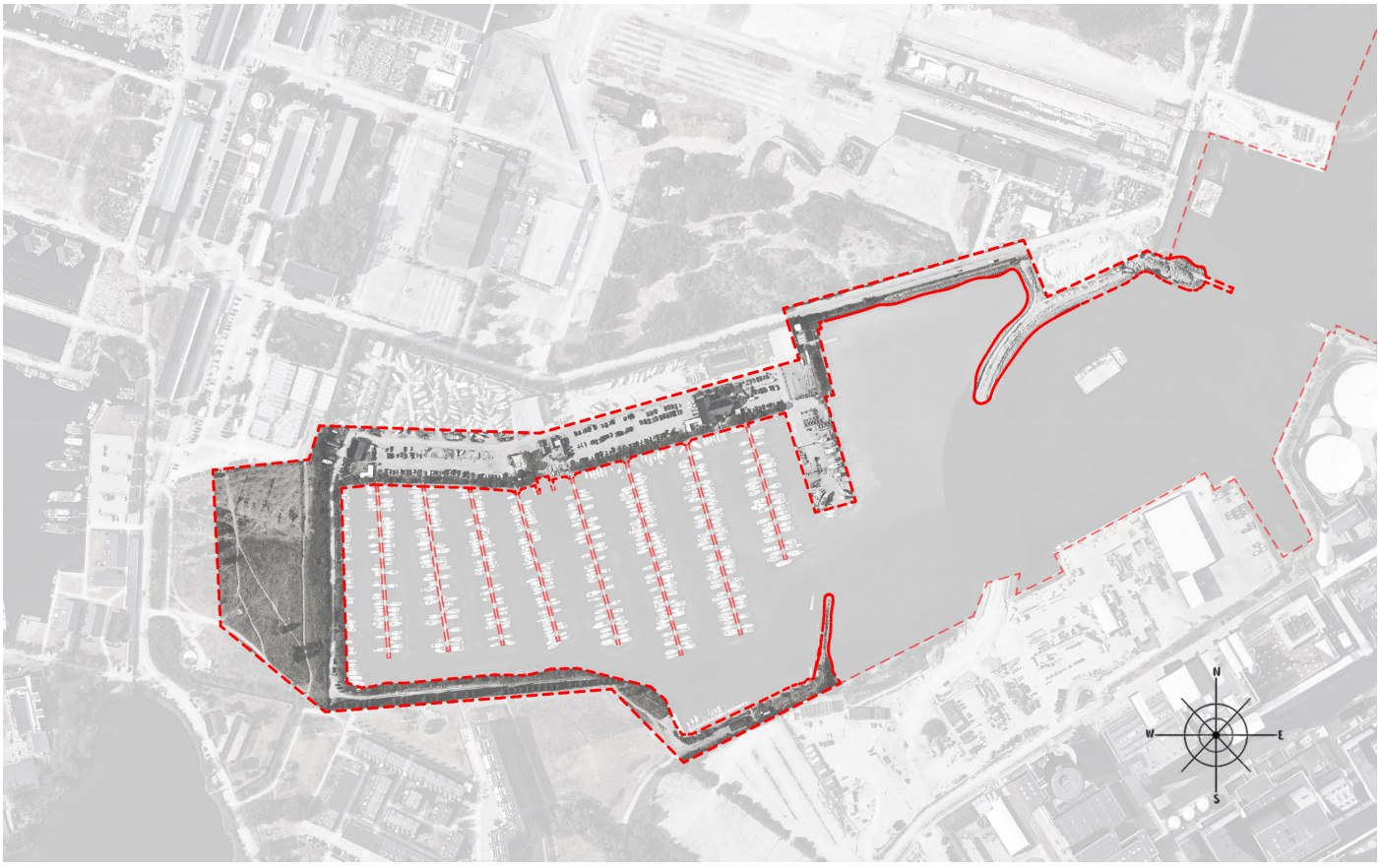


Figure 80:

Site Area.
Source: Google maps.

Figure 81:

Aerial photo Margretheholms Havn
Source:Google Earth

MOBILITY ARRIVAL:

When you go to **Margretheholms port** today, you arrive via Refshalevej, the only road providing land access to the area. Along Refshalevej, you can still see the remains of the Christiania Fortress, Quintus Lynette, which was established in the mid-18th century as part of the expansion of Christianshavns Vold (marked as point 1 on the map and in the image). The fortification stands near the road, almost like a gateway.

At marker 2, Refshalevej passes by former warehouse buildings, which have now been converted into residential homes. These homes are situated at the northern end of Krudtløbsvej, a private road accessible from Refshalevej.


Det gule hus
La Banchina
Krudtløbsvej (privat vej)
Refshalevej
Quinti Lynette
3
2
1
Kilde: Google Maps


3
Belægningsskifte


2


1

Figure 82:

Figure 83:

Plan, Site Area.

Source: Master plan Udarbejdet af Arkitema & COWI for Refshaleøens Ejendomsselskab og By & Havn

Some parts of Margretheholms Havn, including the wharves and nearby areas, are already experiencing flooding during high tides and severe storms. These present-day flood risks are a clear indicator of the growing challenges posed by climate change. As sea levels continue to rise and storms intensify, the frequency and severity of flooding in Margretheholms Havn will increase, following predictable pathways similar to those identified in detailed flood risk assessments.

Understanding these risks is crucial for developing effective strategies to protect the district and ensure it remains a safe and vibrant part of Copenhagen's waterfront.

All selected area includes some zones :

The long, straight stretch of road offers a striking and characterful space, with a clear sightline leading towards the dome of the Marble Church. This road, featuring a row of poplars along Refshalevej, is a significant landscape feature. The poplar row serves as a recognizable landmark in the area.

The 'Grassy Area' – This open green space, free from buildings, features landscaped pathways and footpaths. The grassland adjoins the northernmost section of Christianshavn's ramparts. It is primarily used as a thoroughfare on a daily basis.

The 'Arrival Space'—the square in front of the gable with its gatehouse, paved surfaces, manicured lawns, and two hawthorn trees—creates a distinctive urban setting. This carefully designed arrival area serves as a notable landmark in the vicinity.

Additionally, an area has been selected along the northeastern edge of the port.All parts area icloudes 43,580 sqm

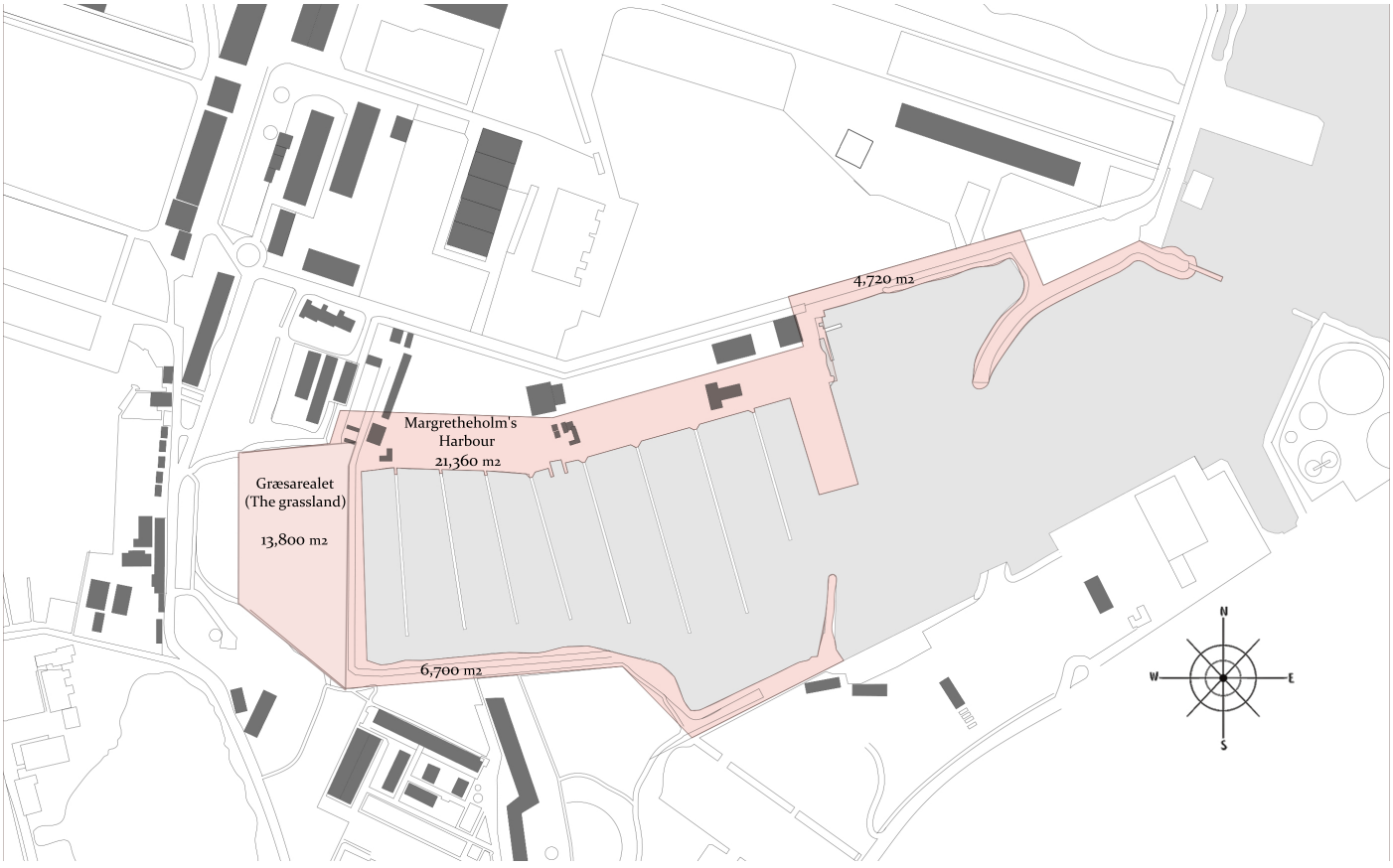


Figure 84: Plan, Site Area.
Source: Master plan Udarbejdet af Arkitema & COWI for Refshaleøens Ejendomsselskab og By & Havn

Figure 85:

Margretheholms Havn is accessible by bike, car, or bus. It's around 15 minutes from central Copenhagen by bike.
The area is undergoing gradual development with more housing projects, improved infrastructure, and efforts to blend the industrial heritage with modern urban living.

Margretheholms Havn represents a blend of Copenhagen's industrial past and its modern urban trends, with waterfront living, cultural attractions, and creative spaces emerging as key features of the area.

Figure 86:

Margreteholm's Harbour, with yachts as far as the eye can see, is a quiet area that invites you to stay and stroll on the wooden promenades

COASTAL FLOODING RISKS :

WASSESSING VULNERABILITIES

Assessing Vulnerabilities at Margretheholms Havn

Margretheholms Havn, located within Copenhagen's Refshaleøen district, shares a history and development trajectory similar to other waterfront areas worldwide. Originally an industrial hub, Refshaleøen's transformation reflects the city's evolving relationship with its coastal areas. Much like Boston's historic waterfront, which expanded through land reclamation and shifted from industrial use to mixed residential and commercial development, Refshaleøen has undergone a significant transformation over recent decades.
Today, Margretheholms Havn stands as an integral part of the district, blending maritime heritage with urban living. The area's revitalization has made it a vibrant and attractive spot for both locals and visitors. However, the very proximity to the water that defines its character also poses growing challenges.

Rising Sea Levels and Coastal Risks

As climate change drives sea level rise and intensifies coastal storms, Margretheholms Havn faces increasing risks from flooding. Similar to Copenhagen low-lying downtown waterfront, Margretheholms Havn's location puts it at greater risk as water levels rise. Projections for Copenhagen indicate that sea levels could rise by up to 1 meter by the end of this century, threatening not only the harbor but also the broader Refshaleøen district.
High-resolution flood models and historical data provide crucial insights into how potential flood pathways might impact Margretheholms Havn. Identifying these pathways allows urban planners and policymakers to develop both immediate and long-term strategies to protect the area from flooding and storm surges.

Strategic Responses and Resilience Planning

Learning from global examples like Boston's "Climate Ready" initiatives, Copenhagen has begun to incorporate similar resilience strategies into its urban planning. In Boston, large-scale public and private investments, including district-wide coastal protection and flood-resilient building guidelines, have played a vital role in safeguarding its waterfront. Refshaleøen's development is similarly guided by robust climate adaptation measures, aimed at preserving both the residential and industrial character of areas like Margretheholms Havn while reducing vulnerability to future climate impacts.
For Margretheholms Havn and the surrounding district, planning frameworks emphasize the need for integrated solutions. These include elevated building platforms, flood barriers, and green infrastructure that can absorb and mitigate excess water. Without such measures, the dense population and critical infrastructure in Refshaleøen will

Moving Forward with Adaptive Strategies

As Copenhagen continues to develop its coastal zones, addressing vulnerabilities like those at Margretheholms Havn is essential. Long-term scenarios, driven by global factors such as greenhouse gas emissions and local land subsidence, highlight the need for preemptive action. By integrating climate resilience into urban planning—through regulations, design standards, and ongoing community engagement—Refshaleøen and Margretheholms Havn can continue to thrive despite the changing environment.

Terrain Elevations :

Refshaleøen is located at an elevation of +2 meters.
Quaysides are at an elevation of 1.5 meters.
The encounter with Lynetteholm's coastal landscape is at 2.5 meters.

Figure 87:

Reference:
EXTRACT FROM MUNICIPAL PLAN KP19

NEED FOR SAFEGUARD +4 on the Margretheholm's Harbour:

To ensure future flood protection, it is essential to secure the eastern edge of Refshaleøen (selected area) to an elevation of +4 meters(from+ 1.5). This measure is necessary under the condition that storm surge barriers are installed both to the north of the inner harbor at Lynetteholm and to the south at Kalvebod Brygge. Without this additional safeguard, the area remains at risk of flooding due to rising sea levels and extreme weather events. The coordinated approach will enhance overall resilience and ensure long-term protection for the region.

Figure 88:

Reference:
EXTRACT FROM MUNICIPAL PLAN KP19

Sea Level Rise :

Sea Level Rise A map of sea level has been produced by Täby Muni ciplaity. These calculations have projected future water levels in average and extreme scenarios, based on a global average sea-level rise. The 100-year water levels have been mapped for differ ent scenarios of 1.20m (for the year 2010), 1.75m (for the year 2100) as well as a 2.70m scenario, which is the lowest recommended level of foundation (2.70 m) for Stockholm County, with respect to the County Ad ministrative Board

Figure 89:

1,5-1,9 m

1,9-2,0 m

2,0-2,1 m

2,1-2,2 m

07

Design Proposal

The four basic strategies for integrating flood protection outlined in this report are:

Spines:

Open Spaces:

Harborwalk Enhancements:

Offshore Elements

These four strategies form the foundation for generating flood protection options for a district-wide system. The options range from an inland approach, achieved entirely on City-owned land through the elevation of roadways and parklands, to a waterfront approach involving a combination of raised harborwalks, offshore elements, and elevated parklands on both publicly and privately owned land. These approaches are likely to be combined throughout the project area. A toolkit has been developed to guide design variations:

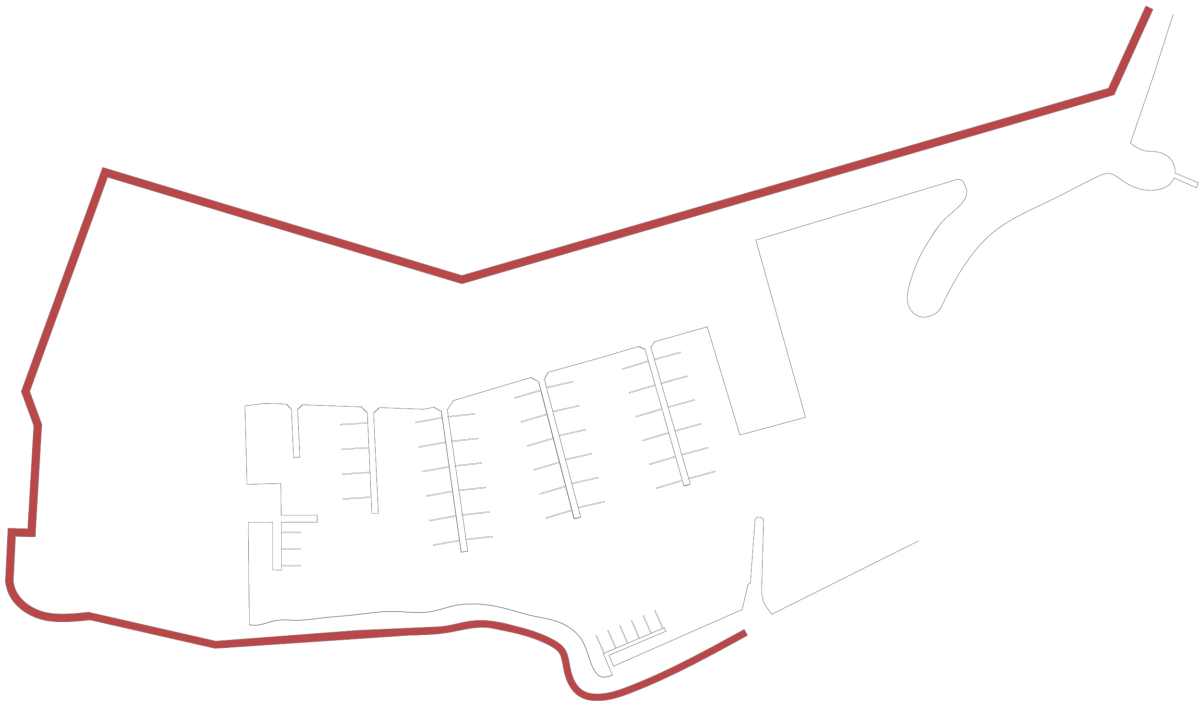


Figure 90:

Spines: Linear elements in the landscape, such as roadways and bike paths, which can be elevated to prevent the influx of floodwaters.

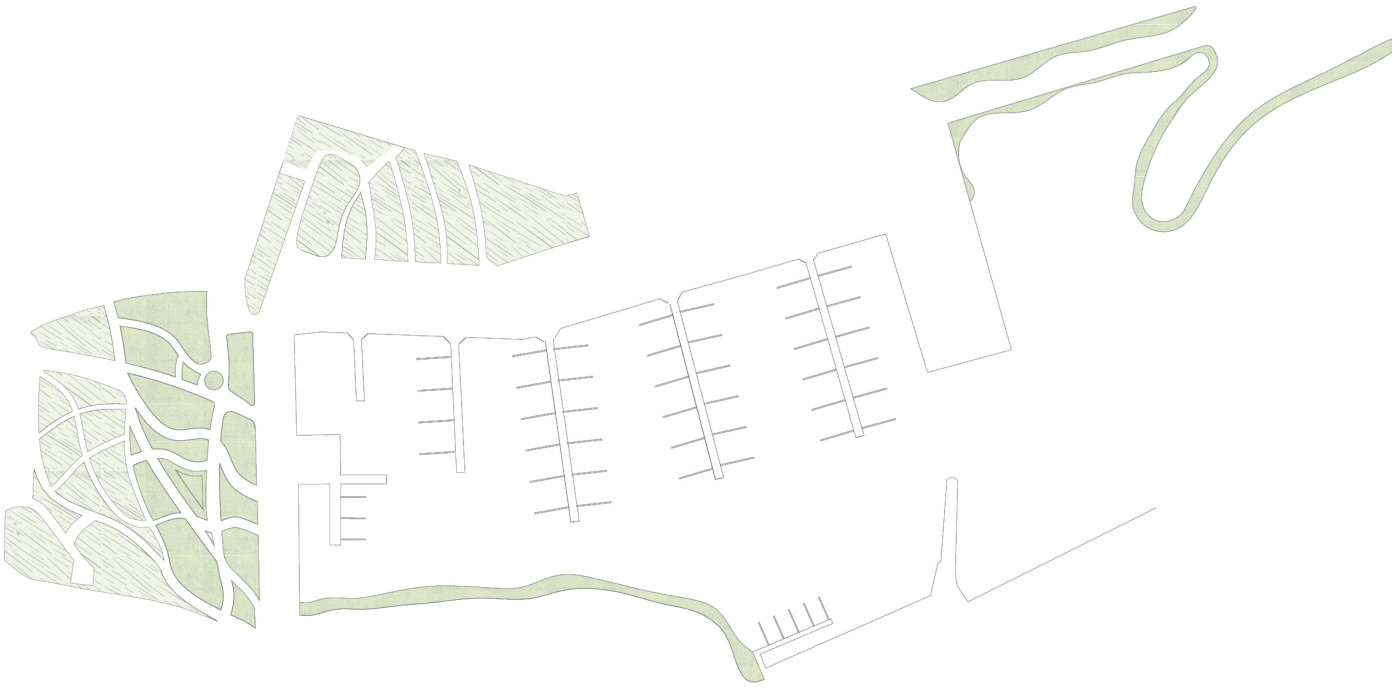


Figure 91:

Open Spaces: Existing and newly developed public areas along the waterfront that can be elevated to mitigate flood risks.

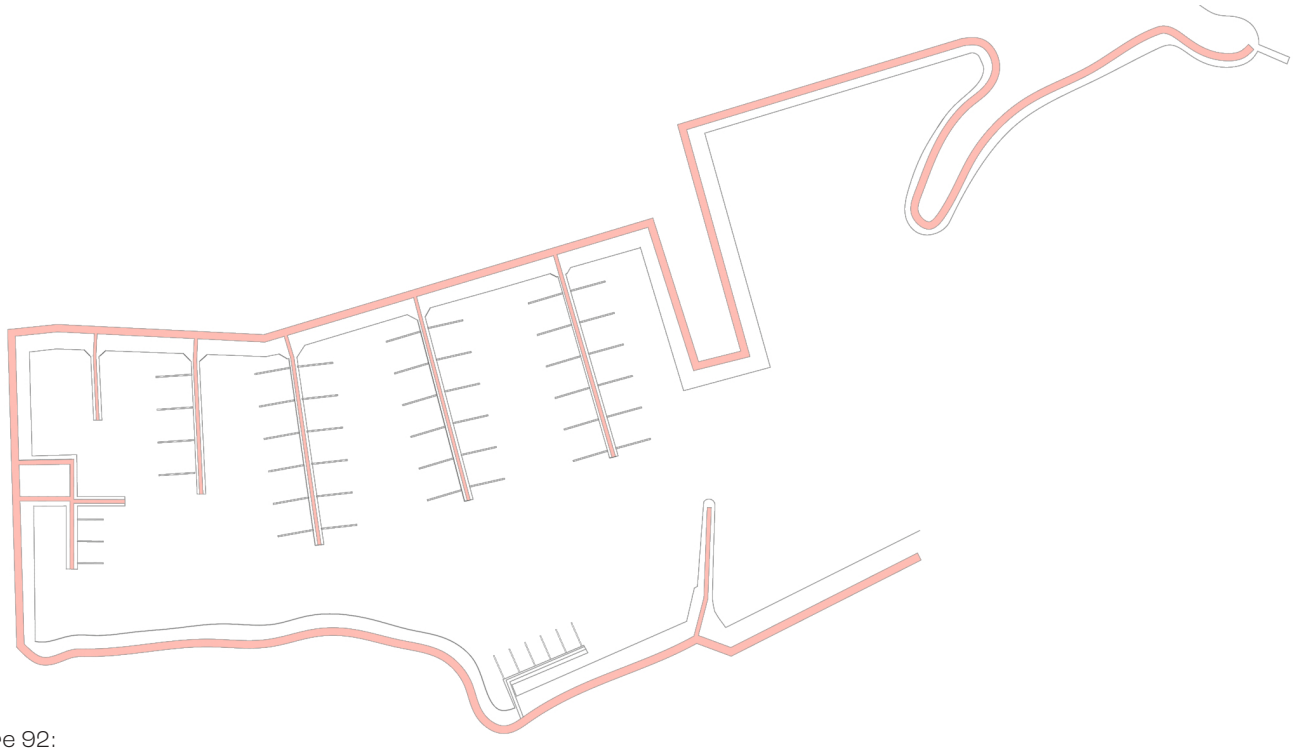


Figure 92:

Harborwalk Enhancements: The public Harborwalk along the water's edge can be raised and integrated with current bulkhead lines, or expanded where possible to allow for wider public walkways and improved access to the water.

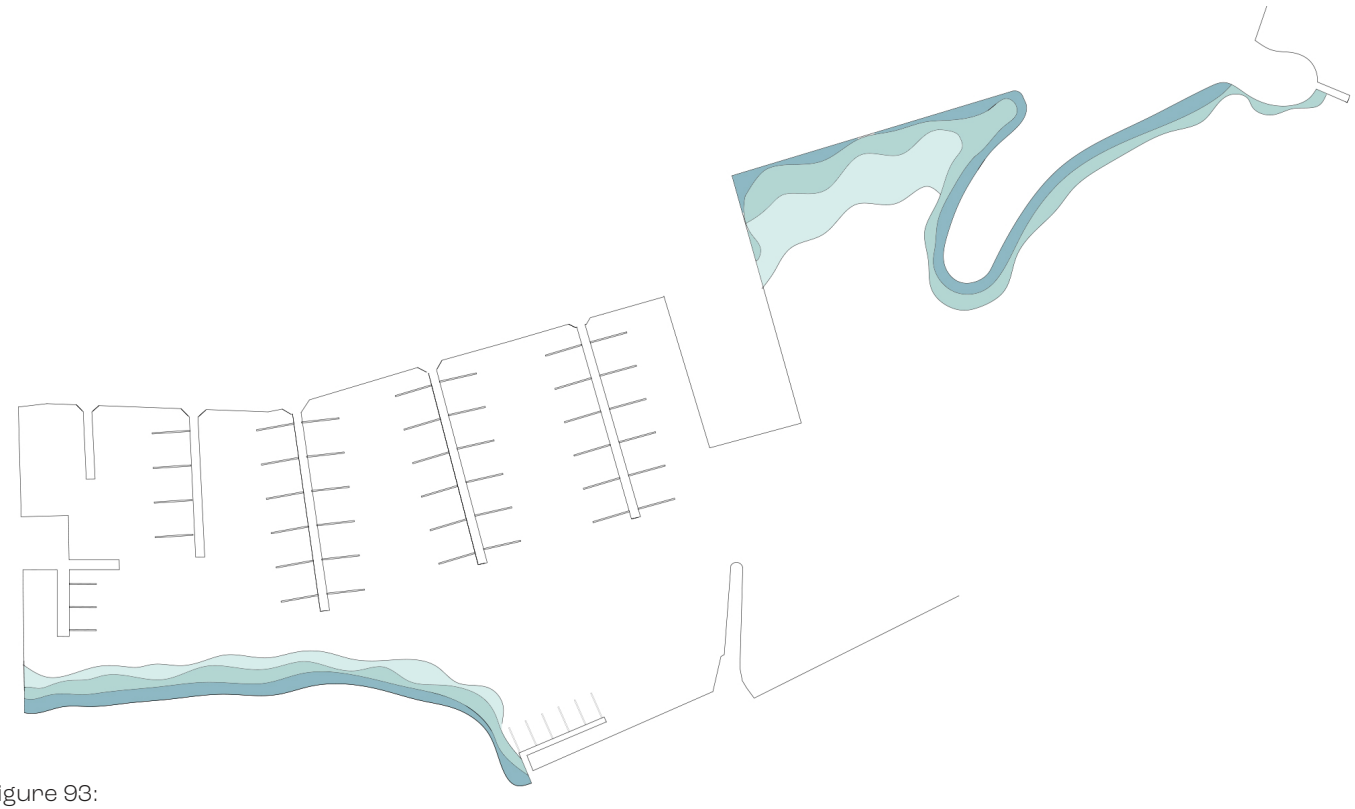


Figure 93:

Offshore Elements: Land reclamation or the introduction of breakwaters and ecological systems at the water's edge that reduce wave action while providing environmental benefits

Strategies at the Water's Edge:

Preferred waterfront strategies involve utilizing waterfront lands as part of flood protection efforts. These strategies require raising the waterfront edges to establish a physical barrier against rising sea levels. Parks, the Harborwalk, bulkhead edges, and even offshore infill could all contribute to creating a continuous elevated waterfront.

Existing elevations along the waterfront are generally lower and more uneven than the roadway, necessitating elevation increases ranging from two to 4 or 5 metre across the district to reach the target Design Flood Elevation. The primary advantage of a waterfront solution is its ability to protect a large number of properties and people on a district-wide scale. Additionally, this approach could positively impact the public realm by enhancing open space networks and improving waterfront access. Depending on the final design and specific site conditions, the waterfront alignment can more easily adapt to higher future elevations and offer ecological benefits.

Traditional solutions at existing bulkheads face significant constraints and limited flexibility, while in-water solutions may offer more opportunities for urban and environmental benefits.

A comprehensive, resilient waterfront solution may integrate both waterfront and offshore measures. If certain wharf or pier properties are unable or unwilling to participate in the implementation of the waterfront strategy, a roadway or "spine" strategy could be used as an alternative. This alternative would still require extensive coordination to maintain access to the waterfront and ensure a continuous flood protection system throughout the district.

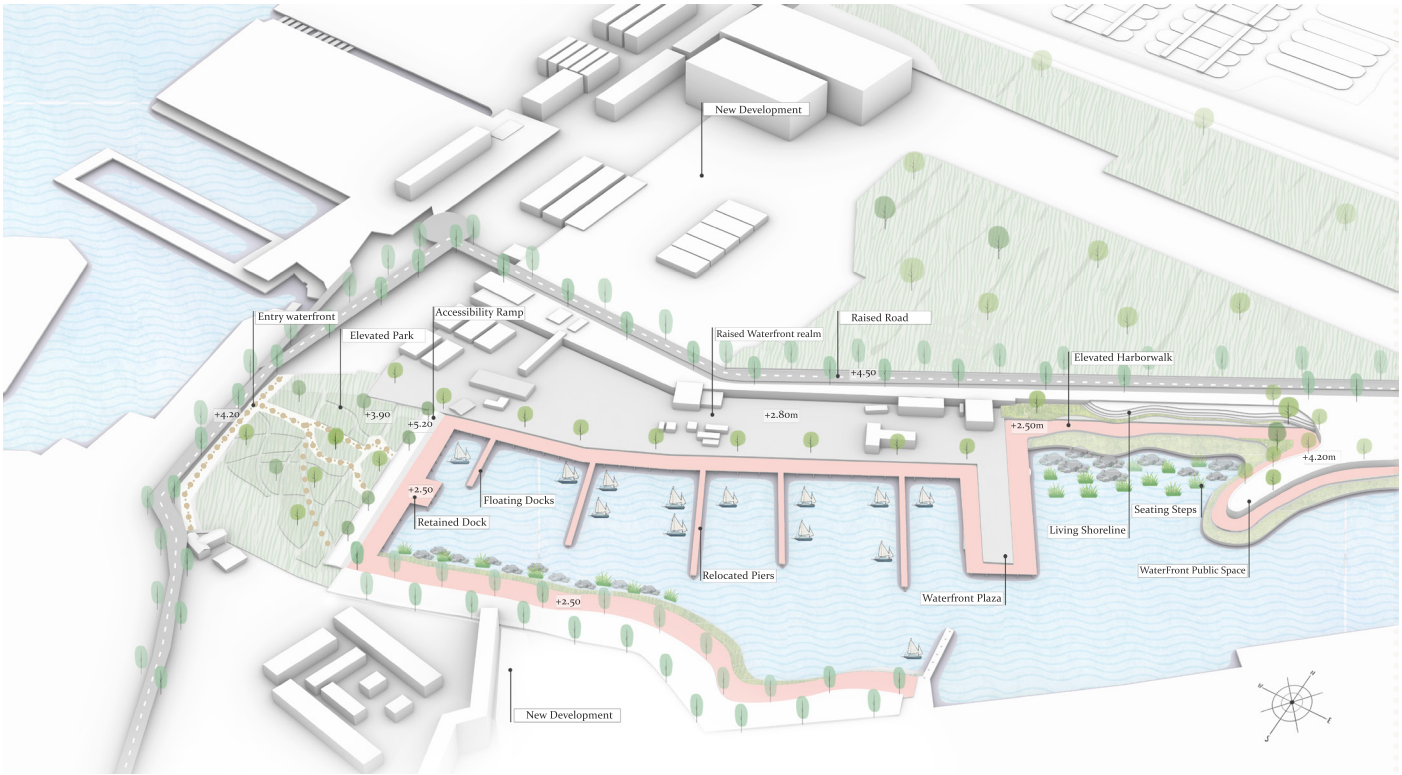


Figure 94:

Strategies on Public Land:

This strategy involves raising the roadway to create a barrier against coastal flooding, including adjustments to intersections to maintain access on and off the newly elevated road. Since this roadway is set back from the waterfront and situated on higher ground in most areas, the required elevation increases range from 2 to 3 meters above current levels.

The resiliency strategy embraces layered flood control and integrated green infrastructure measures that mitigate the effects of climate change and create social, environmental, and economic benefits for the community. These measures include waterfront open spaces with strategically elevated areas at key points of entry for coastal flooding, such as the Greenway in selected harbor areas. Additional measures include enhanced Harborwalks, improved connections to the waterfront, natural wetland buffers and 'living shorelines,' stepped hardscapes, temporary flood barriers, and increased planting of shade trees to combat higher temperatures. Together, these measures will provide flood protection, waterfront access, recreation, and mobility, while dramatically increasing waterfront open space and public access to one of Refshaleøen's greatest natural resources.

The top priority is to maintain a resilient edge while establishing critical connections and open space infrastructure. The expanded Central Park creates new recreational and ecological opportunities while building resiliency infrastructure on Boston's waterfront. The vision combines existing and proposed green infrastructure to create a protected district of greenways and waterfronts. A layered strategy of open space, existing developments, and temporary barriers creates an active waterfront to protect Boston from flooding.
The floodable park includes dry ponds of various sizes, which can be used as open spaces for recreational purposes during dry seasons. Rain gardens situated in the park and between the mounds at the lowest points help catch, retain, and transfer water to the sea or watersheds.The height differences and varied topography aid in water catchment and conveyance, while also creating an eye-catching landscape that offers views of the waterfront area for those walking or cycling in the park. The park facilitates seating and recreational areas for residents and enables easy access to different parts of the area.

RESILIENCE TOOLKIT:

EXISTING EDGES

RAISED HARBORWALK

The Harborwalk at the water's edge creates an opportunity for raising grades and integrating coastal flood protection into the public open space in many locations. Design approaches in these conditions may incorporate a raised seawall adapted to physical conditions or social functions. These include:

Simple Raised

Social and Stepped up

Over Water

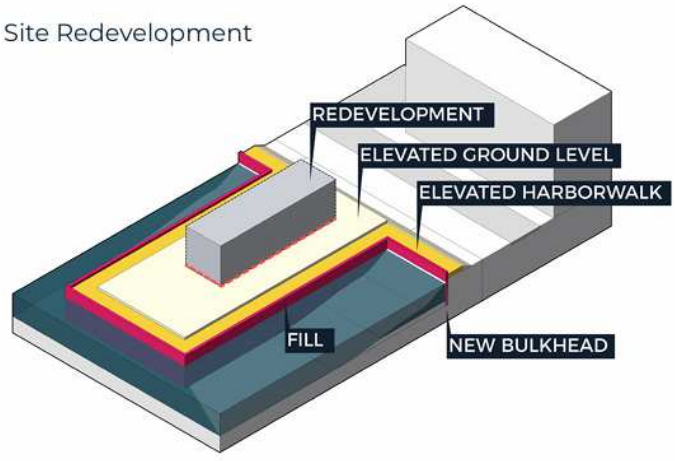
Water Access/Marine Transportation

Programmed

Elevated Parks and Open Space

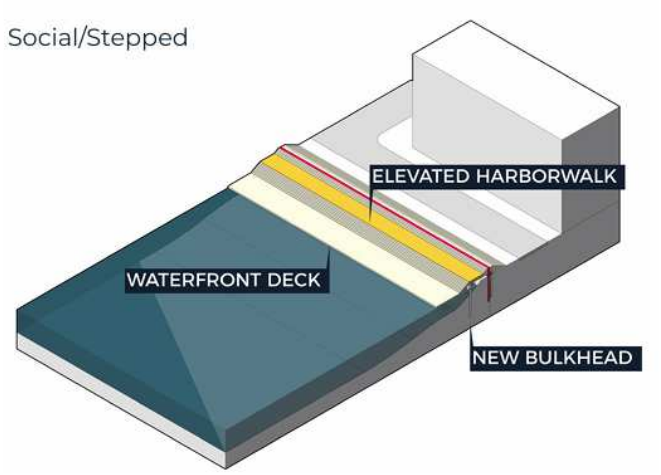
Simple Raised

A seawall constructed to the DFE(Design Flood Elevation) along the line of the bulkhead is feasible at the waterfront in multiple locations. In locations where access to marina or docking facilities is needed, the wall design will need to include accessible design standards compliant pedestrian and vehicular access and may require additional space landward of the seawall



Social/Stepped

To provide access and visual connection to the water, the flood protection system can be embedded in a hard or soft slope. The design of the slope must incorporate access from the city side. The engineering of the flood barriers on the waterside can vary according to site needs. This Harborwalk can provide easier access to marine and water dependent uses. The assumption is that it will be constructed at the water's edge and be inclusive of or enhance the Harborwalk.



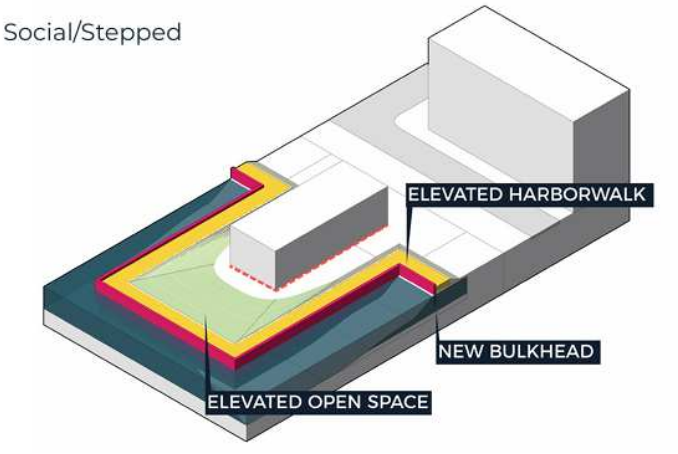
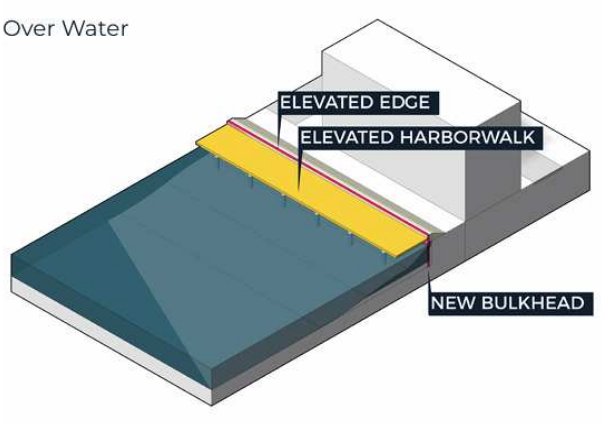


Figure 95:

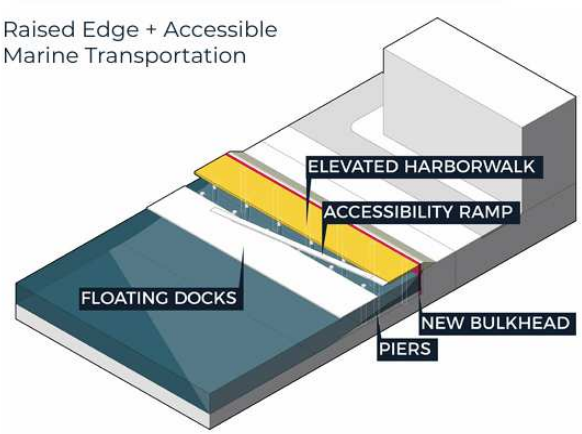
Over Water

In locations where space does not allow for the required width of the Harborwalk, the design of the flood barrier can include an overhanging pier Harborwalk Such a system can provide social activities and allow for water dependent uses with access points to the water. Providing public access on a lightweight structure could ease the load on the underground structure



Water Access and Marine Transportation

Docking and access infrastructures currently connect to specific locations throughout the waterfront. The f lood barrier can incorporate location for connections and access. In these cases, the space required for protection will need to accommodate horizontal space for queueing, ADA access, flexible connections for various boats scales, and allow for tidal changes.



Programmed

Locations for water access can be designed into or behind the continuous line of protection. Water dependant programs may include: kayak launch, fishing piers, water play such as simple fountains, beaches, and pools.

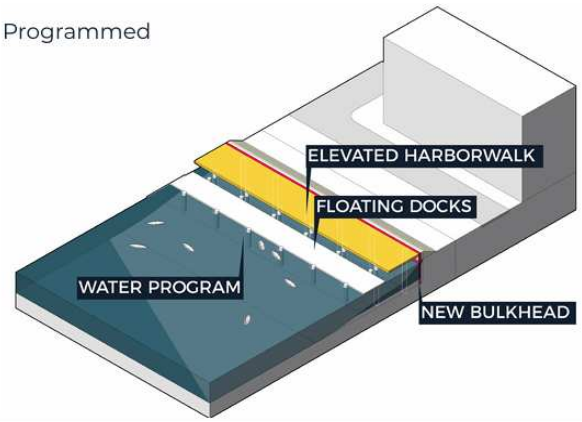
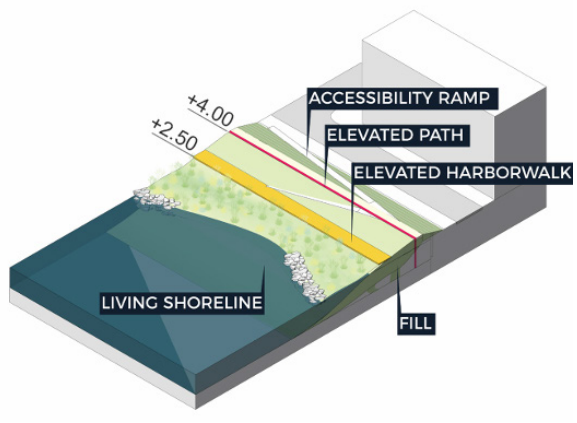


Figure 96:

nature-based approaches :

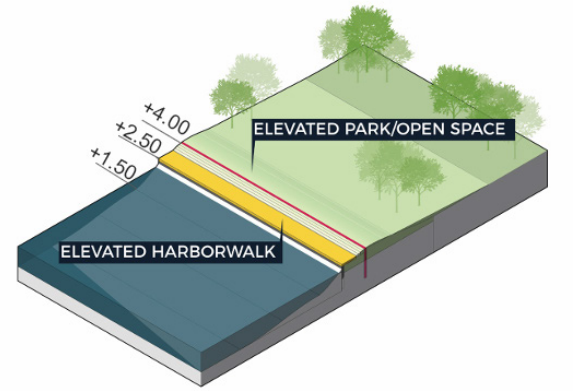
LIVING SHORELINE

These living edges provide opportunities for habitat and education can provide wave attenuation where wave action poses greater risk. Locations for implementation will depend upon appropriate bathymetry and hydrologic conditions.



ELEVATED PARKS AND OPEN SPACES

In specific locations along the existing waterfront park spaces or underutilized open spaces can be improved and redesigned to function as a flood barrier. These could be designed as either soft, such as landscape with vegetation and passive recreation spaces, or hard, such as plazas, and stepped hardscapes.



Breakwaters

These living edges will provide opportunities for habitat, education, historic acknowledgment of the original shoreline/mudflats, and wave attenuation where wave action poses greater risk. Locations for implementation will depend upon appropriate bathymetry and hydrologic conditions. These approaches are included in the higher cost rather living shoreline.

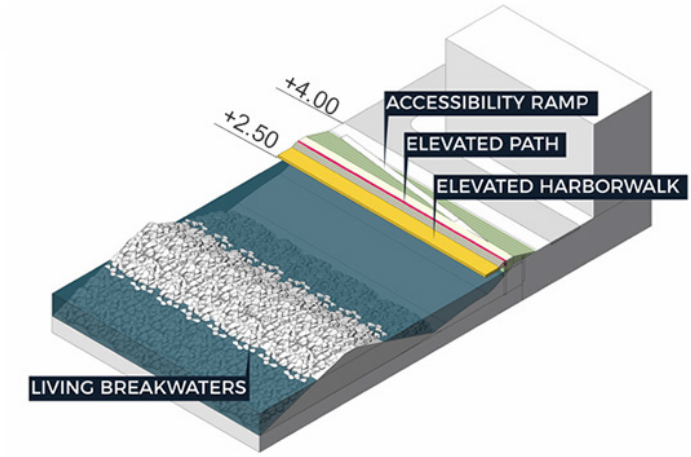


Figure 97:

Urban Strategies :

Connection and Accessibility

The current situation at the site features the main road of Refshaleøen, which provides access for cars and bikes, as well as a single bus stop. In our proposed plan, we aim to enhance accessibility from the main road and the entrance of the Refshaleøen zone to the selected waterfront area. This new route will pass through a proposed floodable park, which will serve as a grassland buffer before reaching the waterfront and ferry terminal.
In the northern part of the site, where the main road extends, we have defined additional entrances for cars and pedestrians, providing access to Margretheholm Harbor. Additionally, we have incorporated parking facilities into the proposed plan to accommodate visitors. From the central area of Refshaleøen, which is primarily recreational, we have designed a direct access route from the main road that leads to the newly designed harbor.
Furthermore, in order to increase accessibilities of both pedestrians and bicycles through connecting to the already exisiting paths in the neighborhoods,we are enhancing the edge lines for cycling, extending the Harborwalk, and providing scenic viewpoints of the sea. These improvements will not only boost connectivity and accessibility but also create a more enjoyable experience for visitors, blending recreational spaces with functional transportation routes.

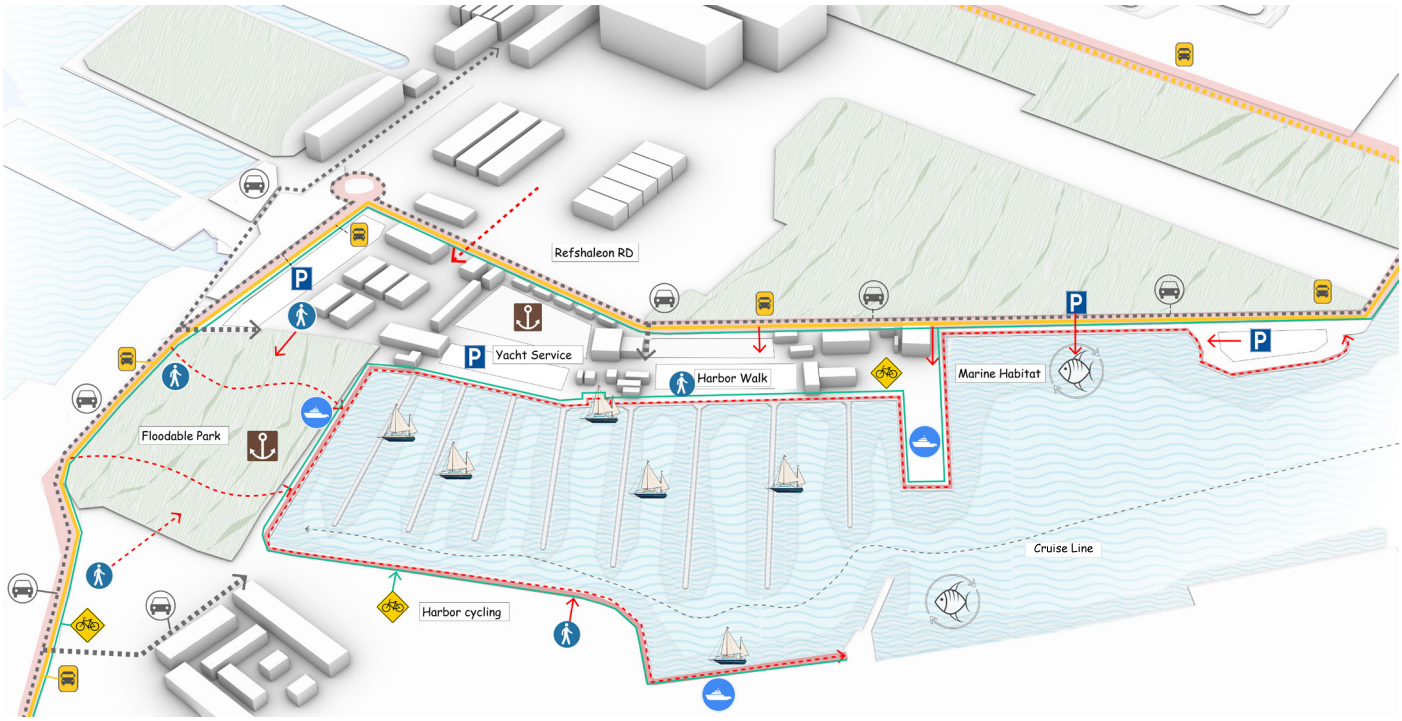


Figure 98:

Regeneration and Activation :

The revitalization and activation of Margretheholms Havn in Refshaleøen requires creating a welcoming entrance to the waterfront to draw in visitors and investors. This can be accomplished by developing a vibrant, mixed-use neighborhood that includes, cultural area where located in the center of reshaleon , as well as serviced like restaurants, bars and yacht club for diverse groups, including students, seniors, and families. While enhancing the area, it is crucial to preserve its ecological integrity. The design will prioritize not only maintaining but also enhancing the site's environmental values. By integrating nature-based solutions and coastal resilience tools, the project aims to transform the existing rigid infrastructure into a more harmonious, ecologically friendly environment, fostering a renewed connection between people and nature.

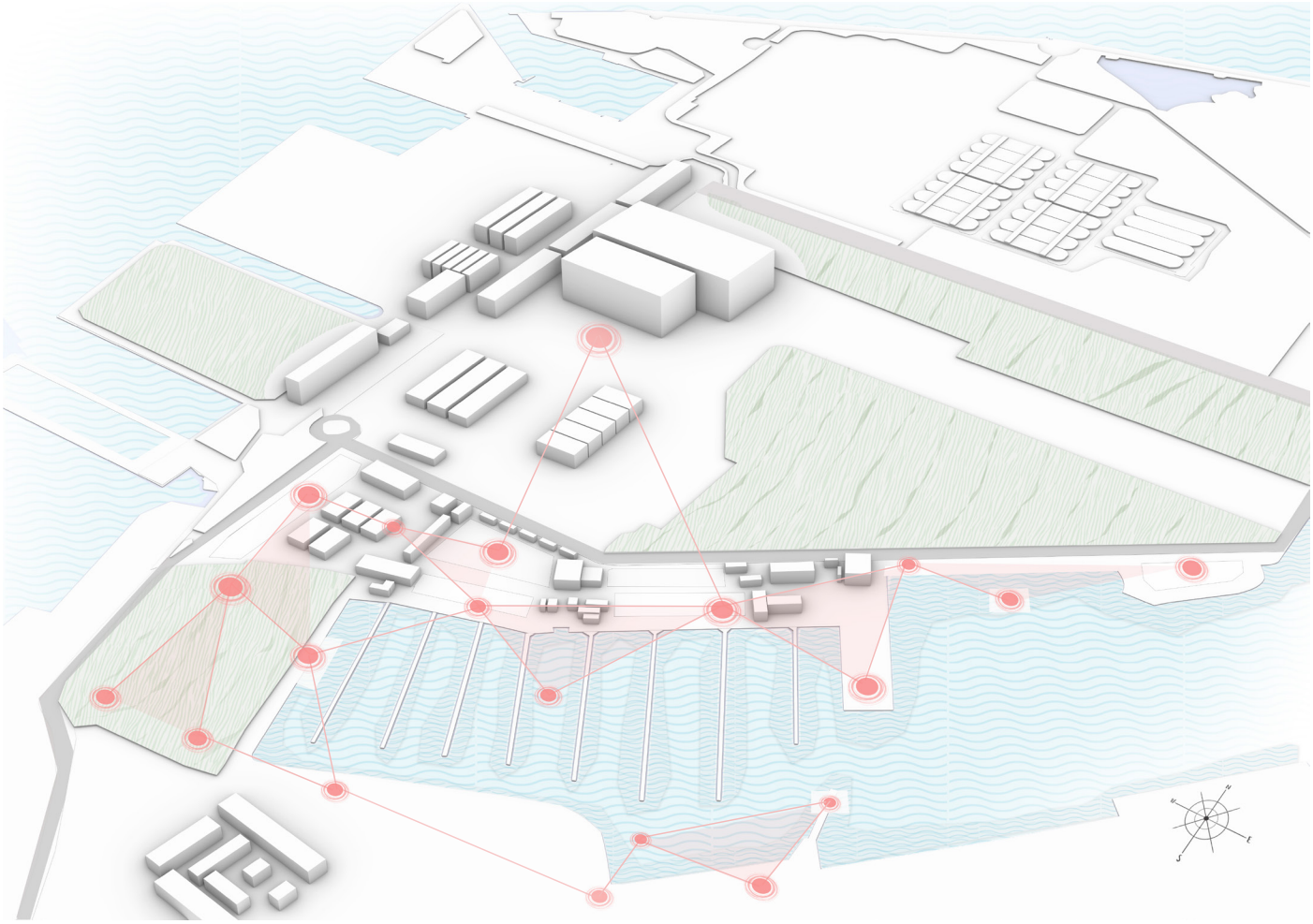
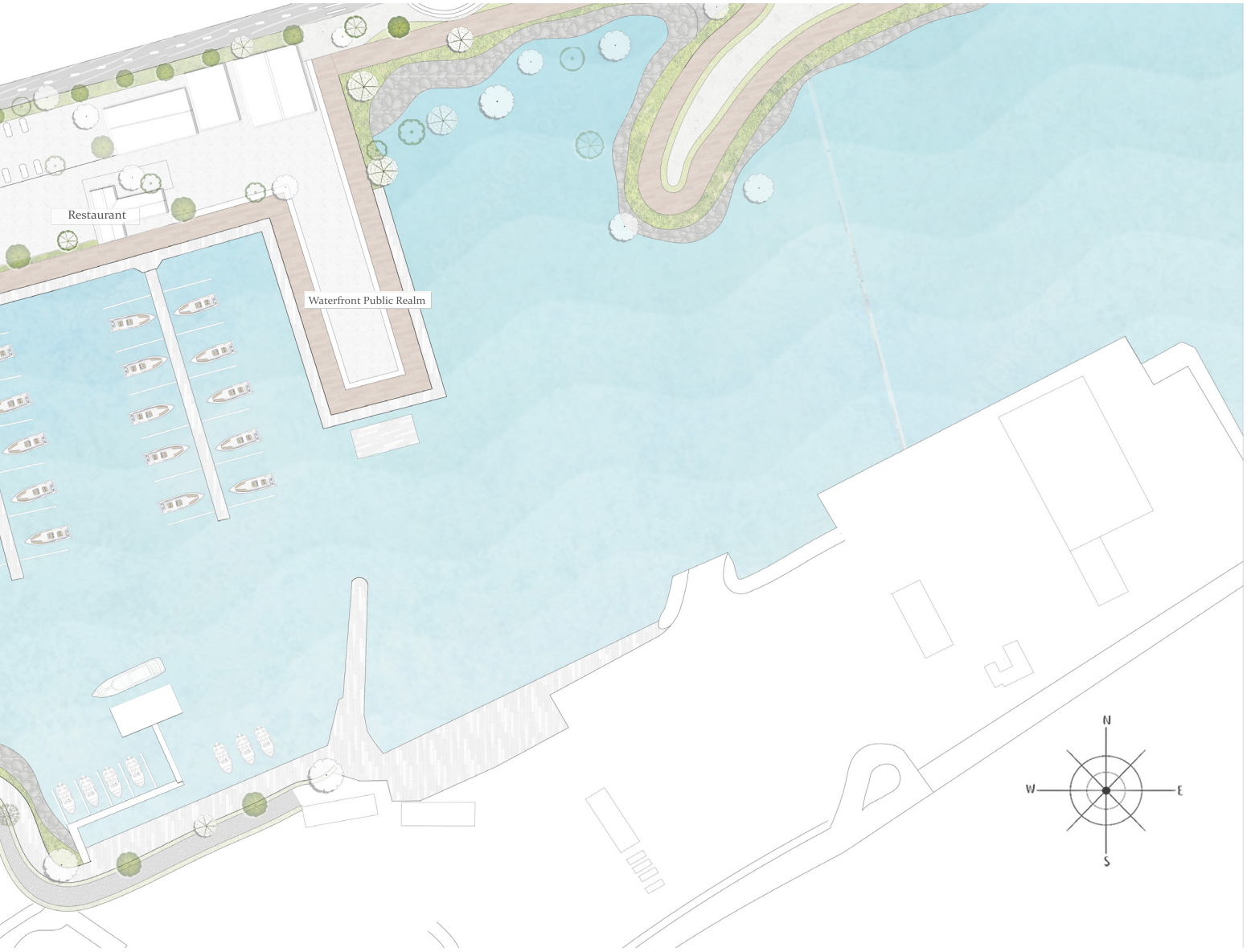


Figure 99:

6.3 Design Layout :

PROPOSED MASTER PLAN :

Figure 100:


Restaurant
Waterfront Public Realm
N
W
E
S

PROPOSED WATERFRONT PERSPECTIVES :

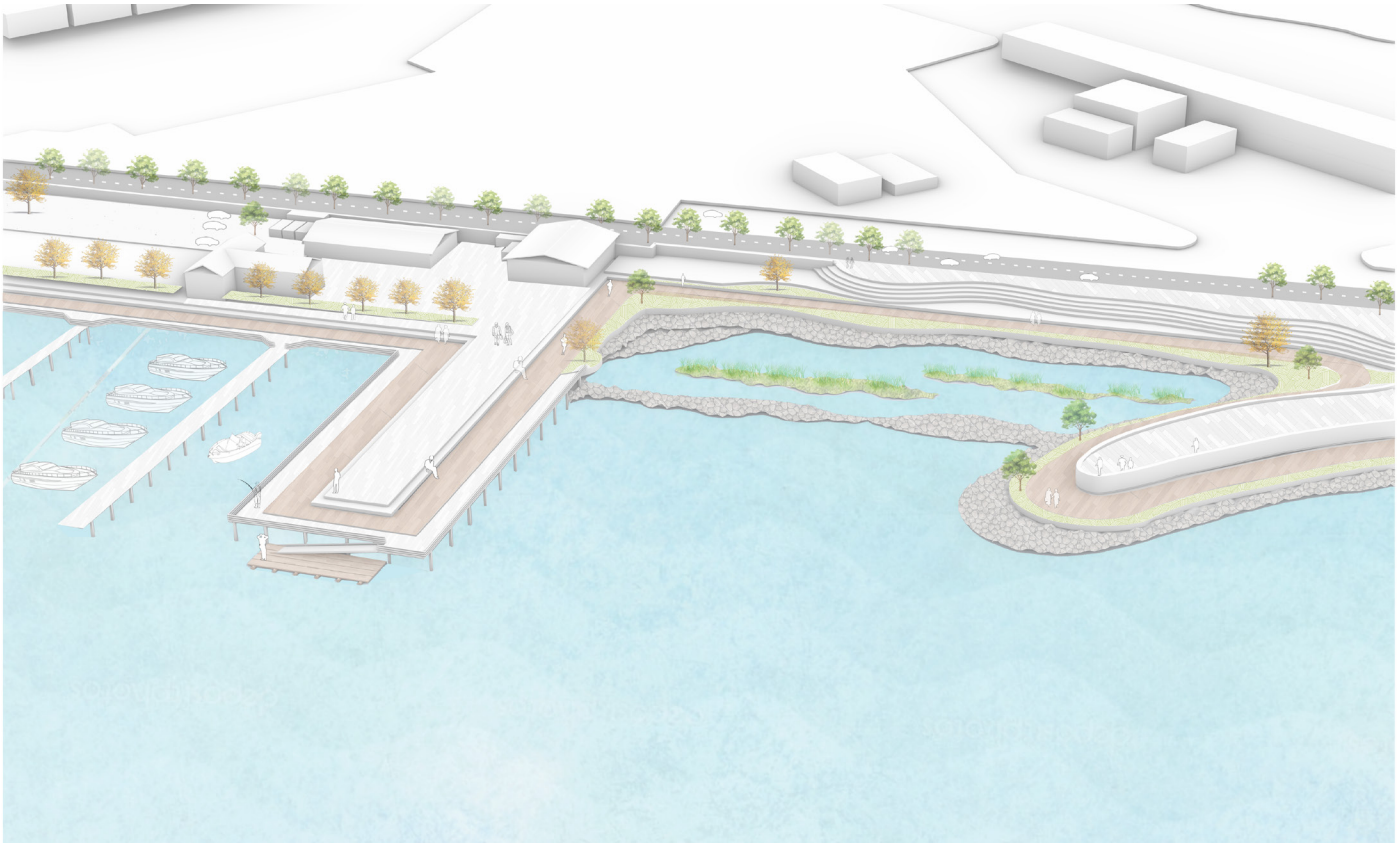


Figure 101:

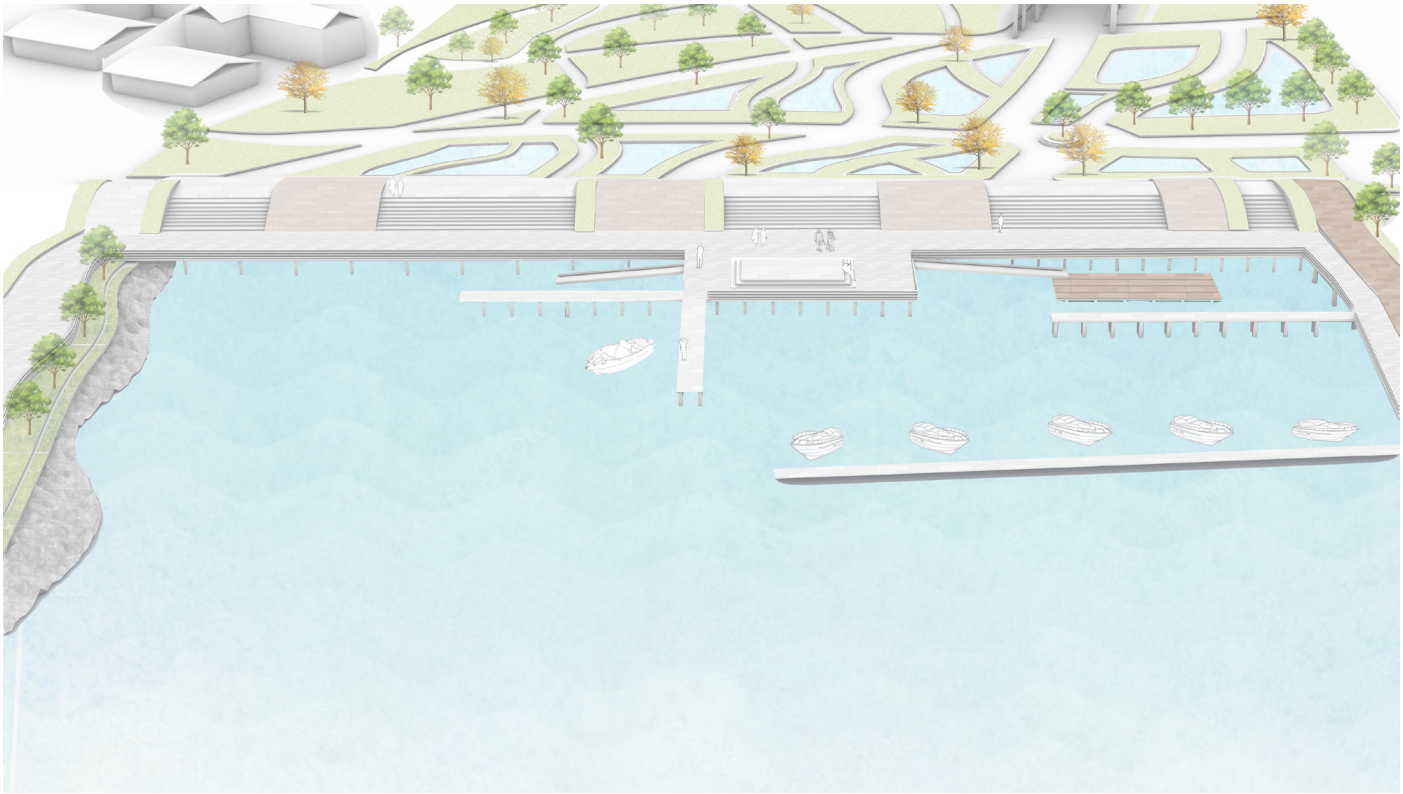
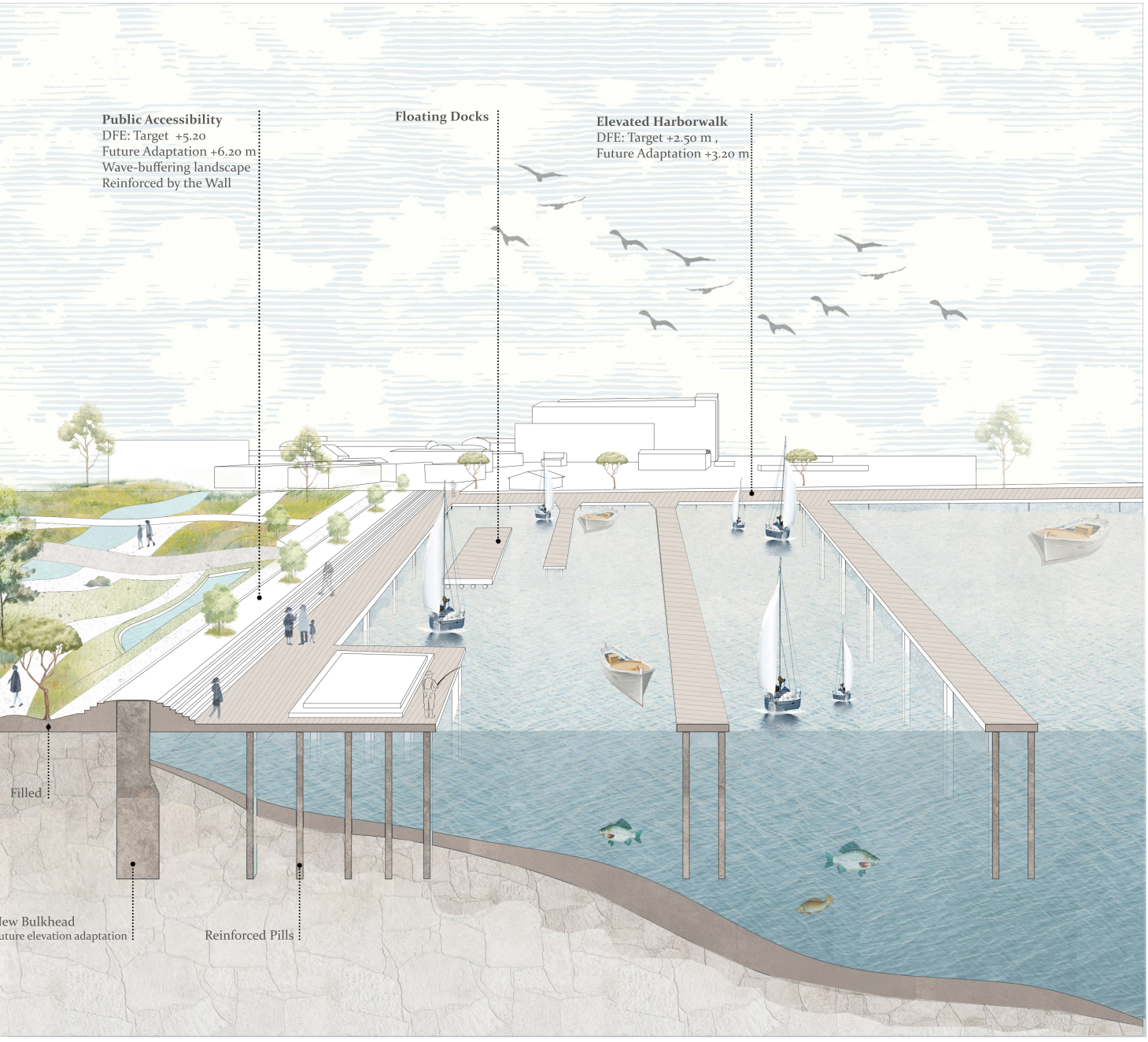
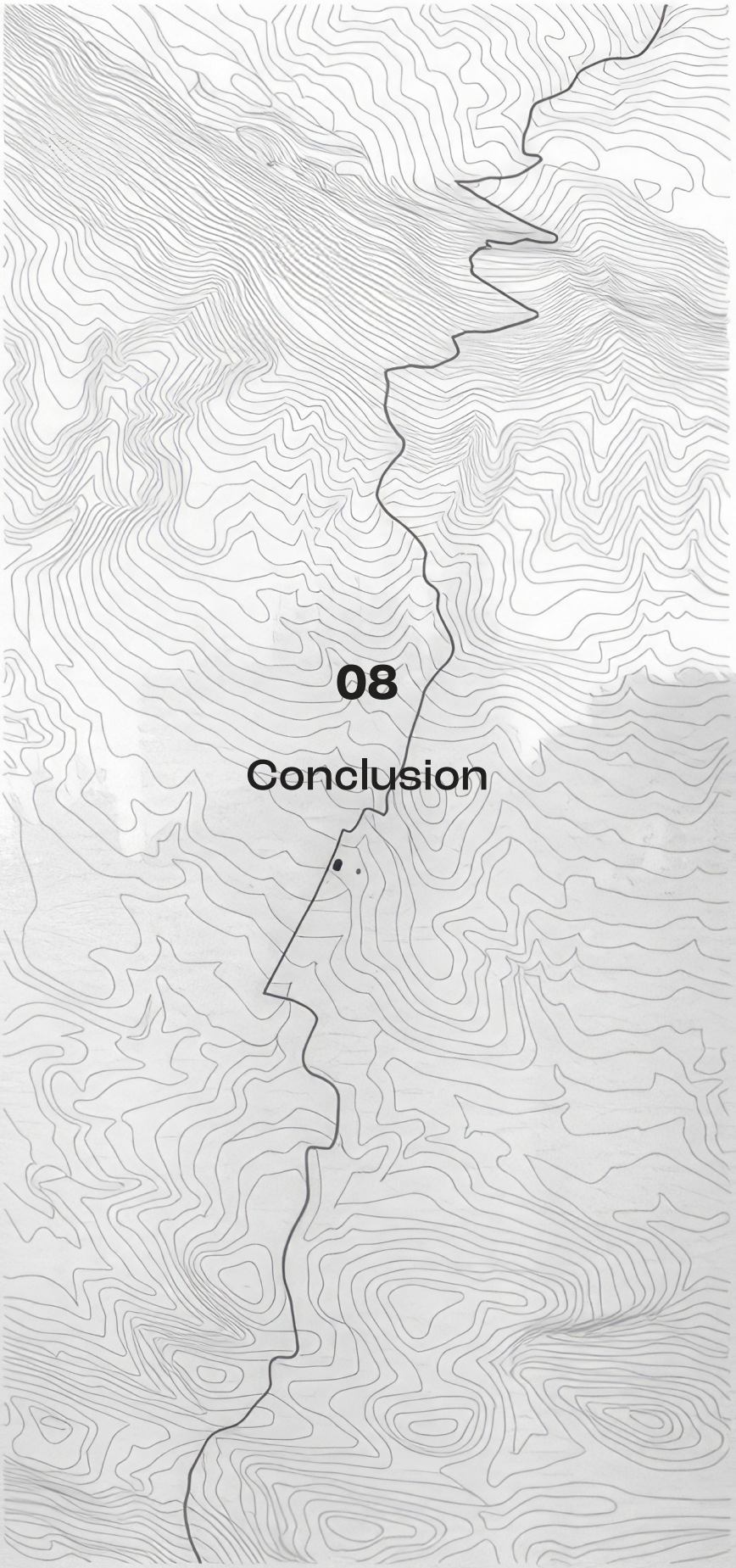


Figure 102:

PROPOSED WATERFRONT Section A_A :

Figure 103:


Public Accessibility
DFE: Target +5.20
Future Adaptation +6.20 m
Wave-buffering landscape
Reinforced by the Wall
Floating Docks
Elevated Harborwalk
DFE: Target +2.50 m ,
Future Adaptation +3.20 m
Filled
lew Bulkhead
uture elevation adaptation
Reinforced Pills



08

Conclusion

Conclusions :

As coastal city LIKE Copenhagen around the world grapple with the escalating threats of climate change, the need for innovative and resilient infrastructure has never been more pressing. Among the many challenges posed by rising sea levels, flooding stands as a significant concern, threatening both the built environment and the natural ecosystems that line our shores. In response, urban planners, engineers, and environmentalists are increasingly turning to integrated approaches that combine natural and built solutions to protect coastal communities. The proposed strategies for waterfront flood protection in one of flood prone zone Refshaloen of Copenhagen , as outlined, represent a forward-thinking approach to safeguarding coastal areas and piers while enhancing public spaces and preserving ecological integrity.

Raising the Waterfront: A Physical and Symbolic Barrier

One of the central components of this comprehensive flood protection strategy is the elevation of the waterfront itself. By raising the edges of parks, Harborwalks, bulkheads, and potentially even through offshore infill, a continuous and elevated waterfront can serve as a robust barrier against the encroaching sea. This approach, while ambitious, offers significant advantages. First and foremost, it provides protection on a district-wide scale, shielding a vast number of properties and residents from potential floodwaters. Moreover, this strategy has the potential to transform the public realm, creating an interconnected network of open spaces that not only serve as flood barriers but also as vibrant recreational areas.
However, the implementation of such a strategy is not without its challenges. The existing waterfront elevations are uneven and generally lower than the surrounding roadways, necessitating substantial elevation increases—ranging from two to nine feet in some areas—to meet the target Design Flood Elevation (DFE). The technical complexities of constructing such a system, particularly in areas with existing bulkheads or in locations where new structures would need to extend into the water, further complicate the process. The high costs and the need for coordination among numerous property owners add additional layers of difficulty. Despite these hurdles, the potential benefits—both in terms of flood protection and public amenity—make this an attractive option for many coastal cities.

Adaptive and Resilient Design

One of the key strengths of the waterfront elevation strategy is its adaptability. Unlike traditional flood barriers, which can be rigid and difficult to modify, the proposed elevated waterfront can more easily accommodate future increases in sea levels. As climate models predict continued rise in sea levels over the coming decades, the ability to adapt to these changes is crucial. This flexibility is particularly important in urban environments, where space is often at a premium and the need to balance development with environmental protection is paramount.
In addition to its adaptability, the waterfront strategy also offers significant ecological benefits. By integrating nature-based solutions such as living shorelines, breakwaters, and habitat restoration into the design, the elevated waterfront can enhance local biodiversity and provide important ecosystem services. Living shorelines, for example, not only act as natural flood barriers but also create habitats for marine life and offer opportunities for environmental education. These green infrastructure elements can soften the interface between the built environment and the natural world, creating a more resilient and sustainable coastline.

Challenges and Alternatives: The Role of Public Lands

Despite the promise of the waterfront elevation strategy, its implementation may not be feasible in all areas. In cases where certain wharf or pier properties are unable or unwilling to participate, or where the technical challenges of waterfront construction are insurmountable, alternative strategies must be considered. One such alternative is the elevation of roadways situated on higher ground further inland. This approach, often referred to as the "spine" strategy, involves raising key roadways to create a continuous barrier against coastal flooding. While this method may not provide the same level of district-wide protection as the waterfront strategy, it offers a viable alternative in areas where waterfront elevation is not practical.

Raising roadways involves its own set of challenges. The elevation increases required—ranging from two to three meters in some areas—are substantial, and maintaining access to and from the newly elevated roads will require careful planning and design. Intersections and access points must be reconfigured to accommodate the changes in elevation, and the overall impact on traffic flow and connectivity must be carefully managed. However, the spine strategy offers a more straightforward and potentially less costly solution, particularly in areas where existing infrastructure is already elevated or where land is available for expansion.

Enhancing Public Spaces: The Role of Parks and Open Spaces

Another critical component of the proposed flood protection strategy is the use of parks and open spaces as flood barriers. By raising and redesigning these areas, they can serve dual purposes—providing recreational opportunities and acting as protective barriers against floodwaters. Elevated parks and open spaces can be designed to blend seamlessly with the surrounding urban fabric, offering both aesthetic and functional benefits.

In some cases, these elevated spaces could be designed as "soft" landscapes, featuring vegetation and passive recreation areas that absorb and mitigate floodwaters. In other cases, "hard" designs, such as plazas and stepped hardscapes, could be used to create more formal flood barriers. The flexibility of these spaces allows them to be tailored to the specific needs and conditions of each site, providing a customized approach to flood protection.

Moreover, the use of parks and open spaces as flood barriers offers significant opportunities for public engagement and education. By incorporating elements such as living shorelines, educational signage, and interpretive displays, these spaces can help raise awareness about climate change and the importance of coastal resilience. This not only enhances the value of the public realm but also fosters a sense of community ownership and stewardship over these critical areas.

Conclusion: A Comprehensive and Resilient Approach

The proposed strategies for waterfront flood protection represent a comprehensive and resilient approach to addressing the challenges posed by rising sea levels. By combining natural and built solutions, and by integrating flood protection into the very fabric of the urban environment, these strategies offer a way to protect coastal communities while enhancing public spaces and preserving ecological integrity. While the challenges are significant—ranging from technical complexities to high costs and the need for extensive coordination—the potential benefits are equally substantial.

In the face of a changing climate, the need for adaptive and resilient infrastructure is clear. The proposed strategies for waterfront flood protection provide a roadmap for how coastal cities can rise to this challenge, creating a safer, more sustainable, and more vibrant future for all.

BIBLIOGRAPHY
References

Ingaramo, R., & Negrello, M. (n.d.). Surviving the city: Nature as an architecture design strategy for a more resilient urban ecosystem. In Green infrastructure. Springer International Publishing.

Ingaramo, R., & Negrello, M. (n.d.). Strategies for adapting the dense Italian cities to the climate change: The case study of the San Salvario historical neighborhood. Springer International Publishing. https://doi.org/10.6093/1970-9870/10212

Ingaramo, R., & Negrello, M. (2022). Progettare l'adattamento. Nature-based solution e biofilia per il progetto adattativo. In IX Forum ProArch: Transizioni. L'avvenire della didattica e della ricerca per il progetto di architettura, Cagliari, 17-19 November 2022 (pp. 786-791). ProArch. Available at: https://11583/2978650 (Accessed: 19 May 2023).

Negrello, M. (n.d.). Designing with nature: Climate-resilient cities: A lesson from Copenhagen. Polytechnic University of Turin.

Ingaramo, R., Negrello, M., Khachatourian Saradehi, L., & Khachatourian Saradehi, A. (Year). Transcalar project of nature-based solutions for the 2030 Agenda: Innovations and interconnections. Polytechnic of Turin, Italy

https://www.theguardian.com/global-development/picture/2013/may/20/climate-disasters-displace-millions-worldwide.

Sayers, P., Gersonius, B., den Heijer, F., Klerk, W.J., Fröhle, P., Jordan, P.,Ciocan, U.R., Rijke, J., Vonk, B. and Ashley, R., 2021. Towards adaptive assetmanagement in flood risk management: A policy framework. Water Security, 12,p.100085
resilience: Rainfall flooding in the city of Arnhem. Cities, 105, p.102843.

Mimura, N., 2013. Sea-level rise caused by climate change and its implications for society. Academy, Series B, 89(7), pp.281-301

Warming, Global. Cambridge dictionary. 2021. https://dictionary.cambridge.org/dictionary/english/global-warming?q=Global+warming+.

Ma, Qiancheng. Greenhouse Gases: Refining the Role of Carbon Dioxide. [Online] March 1998. https://www.giss.nasa.gov/research/briefs/ma_01/.

Prospects, World Population. United Nations, Department of Economic and Social Affairs. June 17, 2019. https://www.un.org/development/desa/publications/world-population-prospects-2019-highlights.html.

Projections, Population. Statistics Denmark. 2021. https://www.dst.dk/en/Statistik/emner/befolkningog-valg/befolkning-og-befolkningsfremskrivning.

Allen, M.R., O.P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M. Wairiu, and K. Zickfeld. Framing and Context. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the. s.l. : IPCC, 2018.

Pitman and Ely, 2014)
ASSESSING THE ECONOMIC VALUE OF GREEN INFRASTRUCTURE: Green paper / ROGER JONES, JOHN SYMONS, CELESTE YOUNGCELESTE/ VICTORIA INSTITUTE OF STRATEGIC ECONOMIC STUDIES
Irwin, E.G., 2010: NEW DIRECTIONS FOR URBAN ECONOMIC MODELS OF LAND USE CHANGE: INCORPORATING SPATIAL DYNAMICS AND HETEROGENEITY*. Journal of Regional Science, 50, 65-91Jones, M.J., 2010: Accounting for the environment: Towards a theoretical perspective for environmental accounting and reporting. Accounting Forum, 34, 123-138.Jones, R.N., C.K. Young, J. Handmer, A. Keating, G.D. Mekala and P. Sheehan, 2013: Valuing Adaptation under Rapid Change. National Climate Change Adaptation Research Facility, Gold Coast, Australia, 182 pp.

Nordman, E.E.; Isely, E.; Isely, P.; Denning, R. Benefit-cost analysis of stormwater green infrastructure practices for Grand Rapids,Michigan, USA. J. Clean. Prod. 2018, 200, 501–510. [CrossRef]
18. Kim, H.W.; Park, Y. Urban green infrastructure and local flooding: The impact of landscape patterns on peak runoff in four TexasMSAs. Appl. Geogr. 2016, 77, 72–81. [CrossRef]

Gao, M.; Wang, Z.; Yang, H. Review of Urban Flood Resilience: Insights from Scientometric and Systematic Analysis. Int. J.Environ. Res. Public Health 2022, 19, 8837. [CrossRef]

Adeyeye, K.; Emmitt, S. Multi-scale, integrated strategies for urban flood resilience. Int. J. Disaster Resil. Built Environ. 2017, 8,494–520. [CrossRef]

Finger, M. Bluegreen: A management perspective on urban blue and green infrastructures. IGLUS Q. 2022, 8, 15–18.4. Oliver, J.; Larsen, O.; Rasmussen, M.; Lanuza, E.; Chakravarthy, A. Understanding Flood Risks for Better Planning and Resilience:Novel Stochastic Models and Methods for South-East Asia. J. Disaster Res. 2015, 10, 308–318. [CrossRef]

Li, C.; Cheng, X.; Li, N.; Du, X.; Yu, Q.; Kan, G. A Framework for Flood Risk Analysis and Benefit Assessment of Flood ControlMeasures in Urban Areas. Int. J. Environ. Res. Public Health 2016, 13, 787. [CrossRef]6. Bulti, D.T.; Girma, B.; Megento, T.L. Community flood resilience assessment frameworks: A review. SN Appl. Sci. 2019, 1, 1663.[CrossRef]

Chen, K.-F.; Leandro, J. A Conceptual Time-Varying Flood Resilience Index for Urban Areas: Munich City. Water 2019, 11, 830.[CrossRef]

Lamond, J.E.; Rose, C.B.; Booth, C.A. Evidence for improved urban flood resilience by sustainable drainage retrofit. Proc. Inst. Civ.Eng.—Urban Des. Plan. 2015, 168, 101–111. [CrossRef]

Fu, G.; Meng, F.; Rivas Casado, M.; Kalawsky, R.S. Towards Integrated Flood Risk and Resilience Management. Water 2020, 12,1789. [CrossRef]

Coleman, S.; Hurley, S.; Rizzo, D.; Koliba, C.; Zia, A. From the household to watershed: A cross-scale analysis of residentialintention to adopt green stormwater infrastructure. Landsc. Urban Plan. 2018, 180, 195–206. [CrossRef]

McDonald, L.; Allen, W.; Benedict, M.; O'connor, K. Green infrastructure plan evaluation frameworks. J. Conserv. Plan. 2005, 1,12–43.12. Cheng, C.; Yang, Y.C.E.; Ryan, R.; Yu, Q.; Brabec, E. Assessing climate change-induced flooding mitigation for adaptation inBoston's Charles River watershed, USA. Landsc. Urban Plan. 2017, 167, 25–36. [CrossRef]

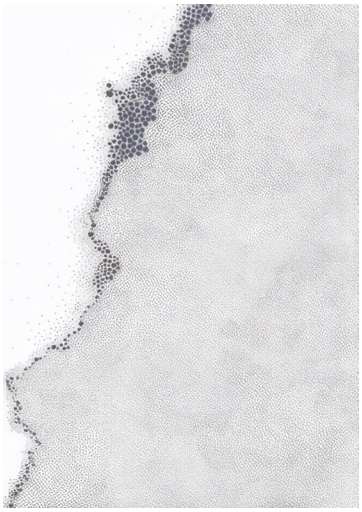
Tavakol-Davani, H.; Burian, S.J.; Devkota, J.; Apul, D. Performance and Cost-Based Comparison of Green and Gray Infrastructureto Control Combined Sewer Overflows. J. Sustain. Water Built Environ. 2016, 2, 04015009. [CrossRef]

Huang, G.; Cadenasso, M.L. People, landscape, and urban heat island: Dynamics among neighborhood social conditions, landcover and surface temperatures. Landsc. Ecol. 2016, 31, 2507–2515. [CrossRef]

Sohn, W.; Kim, J.-H.; Li, M.-H.; Brown, R.D.; Jaber, F.H. How does increasing impervious surfaces affect urban flooding inresponse to climate variability? Ecol. Indic. 2020, 118, 106774. [CrossRef]

Voskamp, I.M.; Van de Ven, F.H.M. Planning support system for climate adaptation: Composing effective sets of blue-greenmeasures to reduce urban vulnerability to extreme weather events. Build. Environ. 2015, 83, 159–167. [CrossRef]

18. Kim, H.W.; Park, Y. Urban green infrastructure and local flooding: The impact of landscape patterns on peak runoff in four TexasMSAs. Appl. Geogr. 2016, 77, 72–81. [CrossRef]



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