A HABITABLE SEA BARRIER/ EN BEBOELIG HAVSBARRIÄR

An approach to protect coastal cities from rising sea levels/
Ett sätt att skydda kuststäder från stigande havsnivåer

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A

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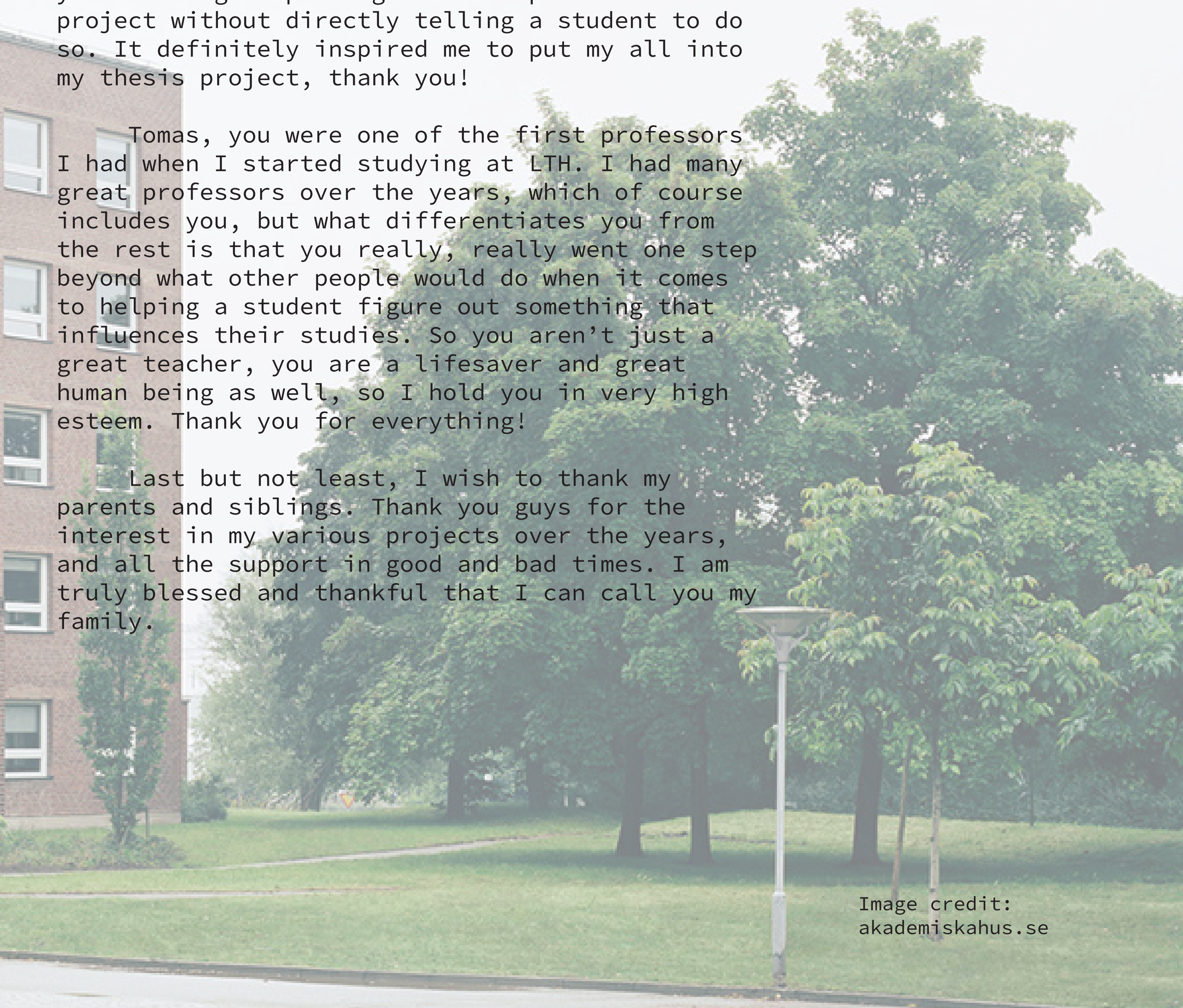

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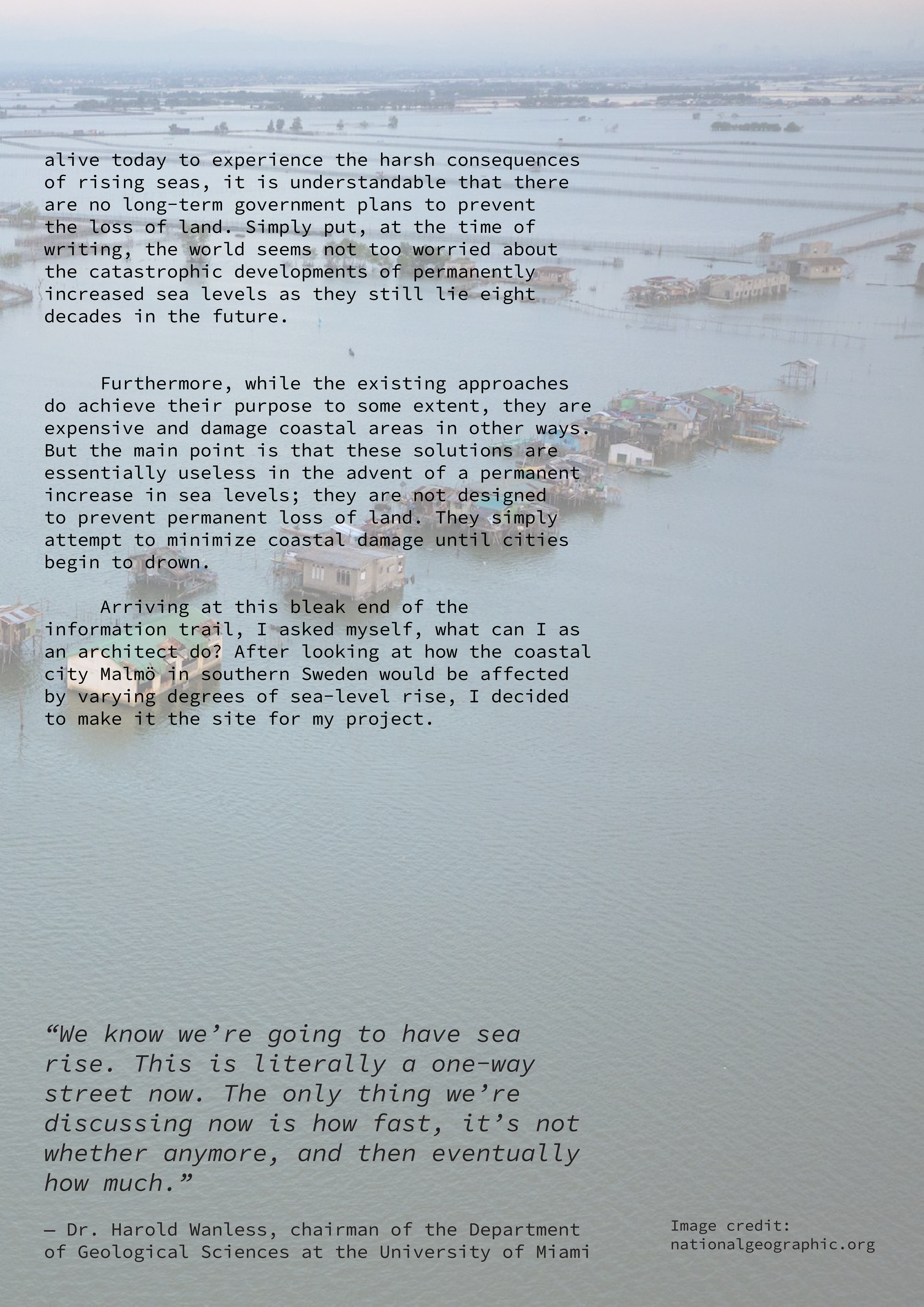
1. RISING SEA LEVELS

A topic that has long interested me as an architect is how cities will adapt to the consequences of climate change, in particular rising sea levels. Historically, prolonged environmental turbulence in the form of food- and water shortages through floods and droughts eventually even brought the greatest cities and civilizations to their knees. Considering this historical pattern, it is concerning how today, food- and water shortages, storms and hurricanes, as well as floods and droughts are becoming increasingly frequent and severe due to the already noticeable yet still relatively mild changes in the climate today. Yet the question remains, how would these extreme weather conditions, which already exert a strain on modern society, combine with permanently increased sea levels, an additional problem that no civilization has had to face in history? Researching the topic led me to conclude that increasing extreme weather phenomena in combination with rising sea levels may result in an unprecedented crisis for modern society on a global scale.

Today, 50% of the world’s population resides in cities, of which the largest ones are located on coasts. According to current trends and predictions, global sea levels are expected to rise by up to four meters in only 80 years. This implies that by the year 2100, most of these great coastal metropolises may not be suitable for human habitation anymore and would have to be abandoned.

After reading these unsettling predictions, you might expect to find global government plans for developing a solution to save cities and coastlines from being swallowed by the sea in the future. Yet, preventive approaches against rising sea levels today are more or less the same as thirty years ago. They are slightly renewed and adapted for the increasingly turbulent weather, but all of these approaches are made to serve a short-term purpose, which can be summarized as temporary flood relief, flood prevention or preventing beach erosion. The approaches are simply intended to handle contemporary climate turbulence. It seems that, due to the fact that it is highly unlikely for most of the people



alive today to experience the harsh consequences of rising seas, it is understandable that there are no long-term government plans to prevent the loss of land. Simply put, at the time of writing, the world seems not too worried about the catastrophic developments of permanently increased sea levels as they still lie eight decades in the future.

Furthermore, while the existing approaches do achieve their purpose to some extent, they are expensive and damage coastal areas in other ways. But the main point is that these solutions are essentially useless in the advent of a permanent increase in sea levels; they are not designed to prevent permanent loss of land. They simply attempt to minimize coastal damage until cities begin to drown.

Arriving at this bleak end of the information trail, I asked myself, what can I as an architect do? After looking at how the coastal city Malmö in southern Sweden would be affected by varying degrees of sea-level rise, I decided to make it the site for my project.

“We know we’re going to have sea rise. This is literally a one-way street now. The only thing we’re discussing now is how fast, it’s not whether anymore, and then eventually how much.”

– Dr. Harold Wanless, chairman of the Department of Geological Sciences at the University of Miami

Image credit: nationalgeographic.org

1.1 Purpose

The theoretical and technical part of this examination project is to propose a process for constructing a hypothetical structure, that through this meticulous process can be built before the year 2100, and the whole process is a promising option in terms of economy, ecology and structural integrity, resulting in a barrier that serves as a long-term solution for protecting cities and coasts from permanently increased sea levels up to 12 meters around the world.

A core idea regarding the process and the resulting structure is that the barrier is not only a large wall in the sea, the process and resulting structure also provide a foundation for sustainable urban and ecological development. This is the architectural part of the project. The architectural part is entirely visionary. Instead of passively protecting against increased sea levels, the structure tries to utilize them for urban development and harvesting energy through green technologies.

Considering contemporary advancements in science and technology, as well as future ones, the construction of the hypothetical structure is based on emerging technological possibilities, primarily automation and artificial intelligence. This is in order for the structure to embrace the contemporary spirit, ensuring efficient construction and planning to take place, as well as that the barrier can be built upon continuously as technology advances and sea levels rise.

The project’s relevance and necessity are underlined by providing an overview of existing strategies and their weaknesses along with the geological and economic consequences of increased sea levels which is explained by showing how existing cities are affected by the loss of land. These economic loss statistics are put in comparison to an estimated cost of the

To summarize, the questions I considered while composing this project are as follows:

- **What are the geological and economic consequences of sea-level rise on cities and land?**

- **What exactly are the existing approaches to handle increased sea levels and why are they not viable long-term solutions?**

- **Can something be built to permanently protect coastal cities from drowning?**
- **How would such a structure be built by the year 2100?**

- **How can the structure be expanded upon when sea levels rise further?**

- **How much would such a structure cost? What resources are needed?**

- **Could such a structure be more than just a barrier in the sea?**

- **Could such a barrier be sustainable and habitable, perhaps acting as an extension of the city that it protects?**

Image credit:
Nickolay Lamm/
Courtesy Climate Central

1.2 Disposition

This essay is divided into four sections:

1. The first section focuses on preliminary studies which explore the geological and economic consequences of rising sea levels globally. This also encircles existing approaches to prevent temporary flooding and erosion. This section is concluded with the weaknesses that these strategies have and how there are no solutions for cities to handle permanently increased sea levels, along with what my new approach to preventing rising sea levels is. This section also includes the geological features of Öresund, which is the sea that Malmö, the site, is built next to. The geological features provided are sea depth, seabed composition, sediment movement and wave patterns. The geological features are provided in order to argue for the feasibility of my hypothetical structure to be constructed there. The section is concluded with a conclusion about the preliminary studies.

2. The second section focuses on the site, the city of Malmö, Sweden. The goal of this section is to provide an overview of recent issues Malmö has faced with extreme weather conditions and how these are expected to worsen in the future.

3. The third section describes the scale and engineering aspects of the new process for the hypothetical sea barrier. The section explains what approaches were taken and dismissed in order to settle for the final approach. The aim of discussing early design ideas and approaches along with their weaknesses is intended to provide arguments as to why I concluded that the chosen approach is the most suitable strategy.

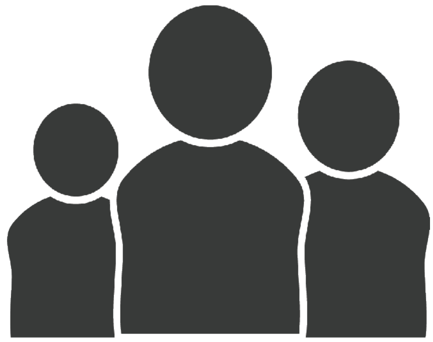
As I am pioneering ideas for long-term solutions for rising sea levels, I consider my approach a new strategy, which I have categorized as Utilize, and the process for building the structure has been coined Continual algorithmic aggregation (CAA). What the CAA process encompasses is explained starting with the foundational aspect of the process, which is a cube, and how this cube is designed to be aggregatable in order to be stacked upon each other to create a structure. The section is then continued by explaining how the cubes are designed to be compatible with an automated system that fills the cube structure with construction waste, resulting in a protective barrier that lays the foundation for urban development and harvesting energy through green technologies. Taking the timeframe of rising sea levels into account, the process is sequential, which is communicated through six different phases to reach 12 meters of protection, along with the resources and time required to complete each phase. The required resources and estimated costs for steel are included in this section to compare it to a nearby infrastructure project, the Öresundsbridge, to argue why the habitable sea barrier is a reasonable long-term investment as an infrastructure project.

4. The fourth section focuses on the architectural opportunities that the sea barrier may offer. Since the structure is based on an algorithmic aggregate, in my case a cube, the structure offers a foundation for sustainable urban development. Since the sea barrier also creates an inland sea outside of Malmö, the conditions of this inland sea could be highly regulated and controlled by humans, making maritime habituation possible. The structure itself also offers a range of green energy technologies that could easily be implemented, these being solar-, hydro, and wave power generators. The first part of the section highlights the logistics of the wall, that is how the seawall connects to the existing city of Malmö and its harbour as well as traffic. Of course, there must be an incentive for people to venture to the sea wall, so next, a variety of approaches are presented to show how the barrier may be divided into segments that serve a primary purpose, such as primarily private, primarily public, primarily commercial and primarily natural. The architectural aspect of this project is solely visionary, as there are endless ways that architects, engineers and city planners of the future would utilize and develop habitation on the wall.

2. PRELIMINARY STUDIES

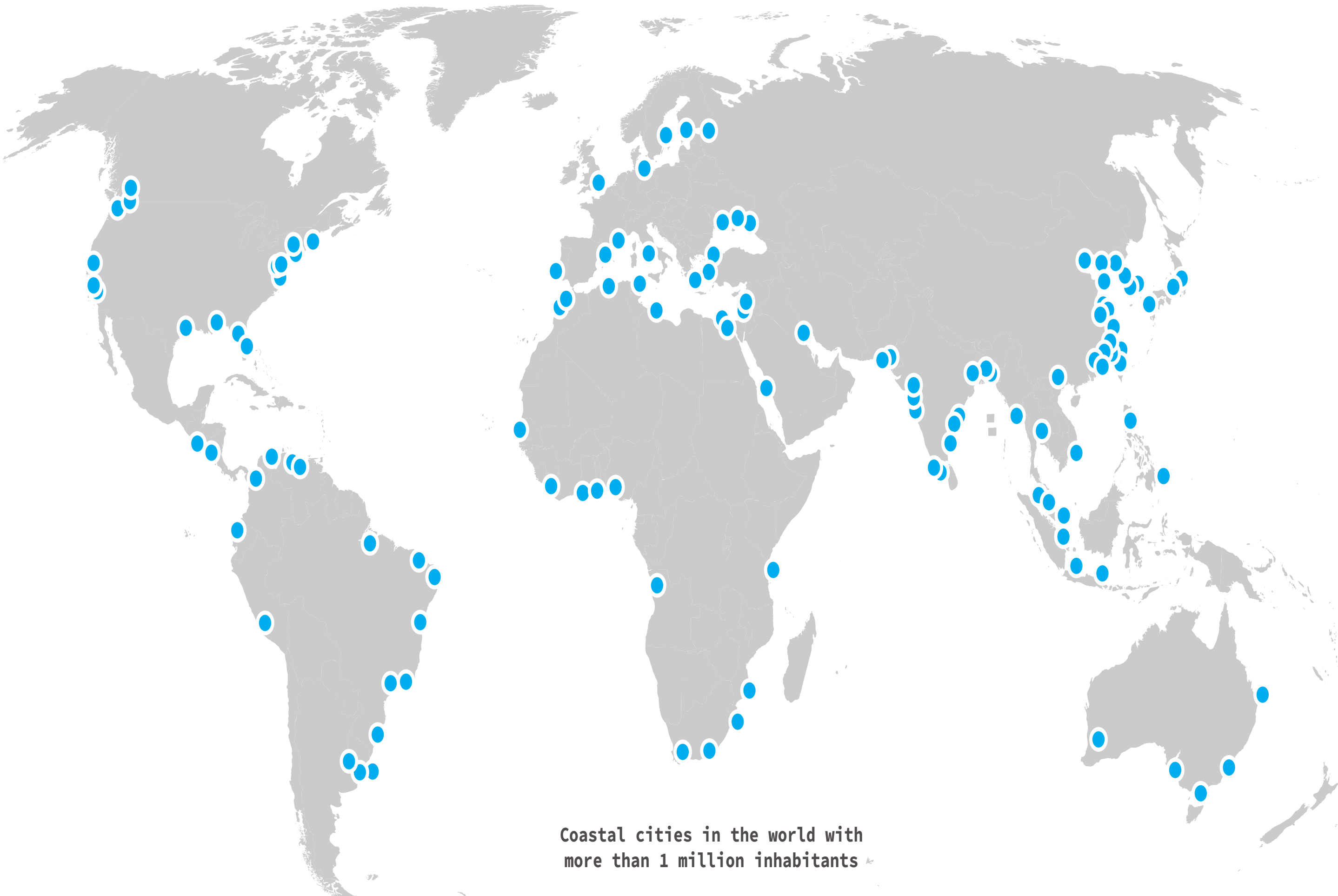
2.1 EFFECTS OF HIGHER SEAS

Today, more than 50% of the worlds population resides in cities, of which some of the largest ones are located on coasts. In total, a third of the world population lives in the coastal zone, which is 4% of the available surface land on the planet (UNEP, 2006). Considering these statistics, permanently increased sea levels would come with an unprecedented scale of people being displaced. Old data estimated that by the year 2100, 65 million people be displaced, yet this number keeps growing as studies with with more and more sophisticated data models are progressively conducted. The estimate of 65 million displaced people was updated to 250 million, and today it is estimated that as many as 630 million people may be displaced by rising seas in the year 2100 (Vaughan, A. 2019).



630 000 000

People displaced by rising sea levels in the year 2100



Coastal cities in the world with more than 1 million inhabitants

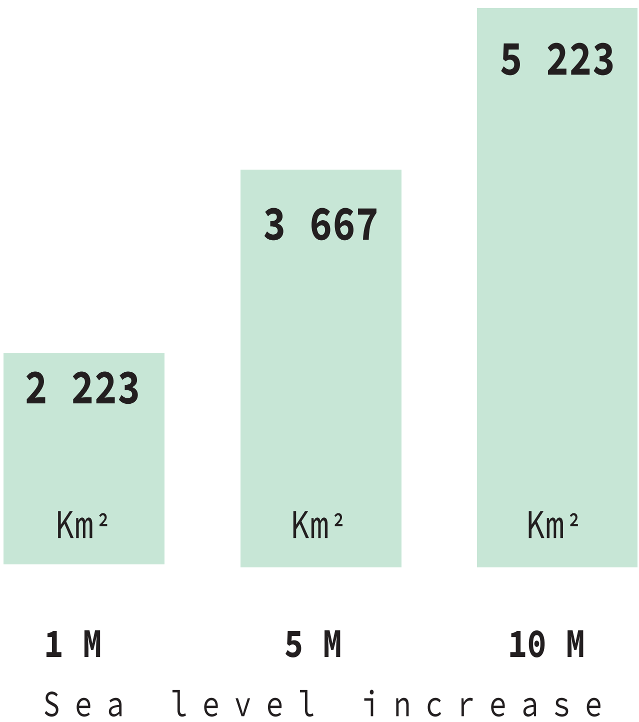
(Harrison & Pearce, 2001)

Rising sea levels would certainly not only result in millions of people losing their homes but there would also be a considerable global loss of land and GDP. In *Dire Predictions: Understanding Climate Change, 2nd Edition*, by Michael E. Mann and Lee R. Kump, a 5-meter increase in sea levels is estimated to cause 3 667 000 million square kilometres of land to be lost, and the global GDP would lose around 1.8 trillion USD.

Considering the massive quantity of displaced people that would have to be relocated with less land available, along with the financial blow that governments would take from losing land, infrastructure, development and providing a temporary living for the displaced people, it is reasonable to assume that these factors could lead to catastrophic social unrest on a global scale.

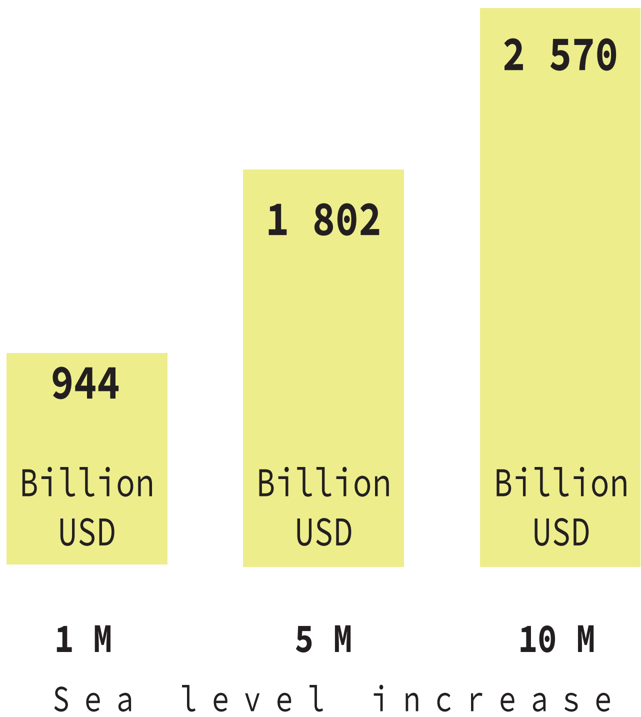
GLOBAL LAND LOSSES

(In 1000 km²)



GLOBAL GDP LOSSES

(in US $ billions)



(Mann & Kump, 2015)

The website flood.firetree.net is an interactive map based on coastal data, where users can select between 0-60 meters of increased sea levels to project how coastal areas would look in the specified circumstances.

To some extent, the interactive map is an interesting tool to see how the world map may look a few decades or even centuries into the future, yet considering that these projections may end up becoming reality, they are concerning.

To the right, I have provided images of how the coasts of Europe, North America and south-east Asia would look with a 4-meter rise in sea levels. As these images are quite zoomed out, they almost look no different from current world map projections. Hence, I outlined what areas in these parts of the world would be the most influenced by the 4-meter increase in sea levels.

To give a clearer picture of how exactly coastal cities would be affected by a 4-meter increase in sea levels, I also provided a projection how my thesis project site, Malmö, below.

Still, I implore you to zoom in on some of the other outlined locations on the world map on flood.firetree.net.

MALMÖ

Most visible changes:

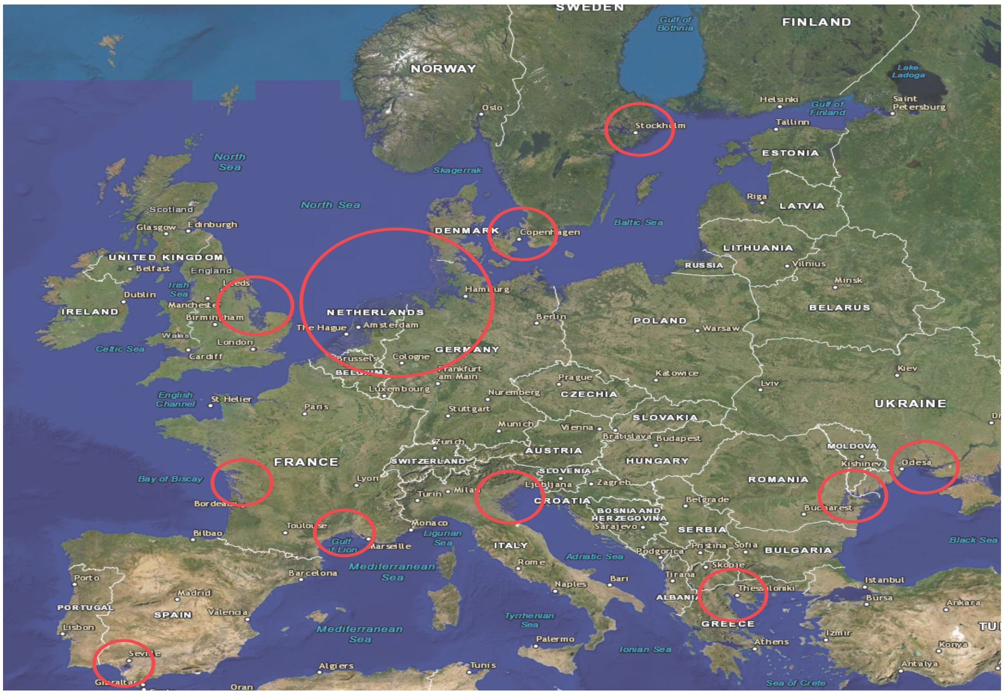
- The harborr is completely submerged

- The rail station is completely submerged

- Västra Hamnen, a huge and recent investment in urban development of the city, is almost completely submerged

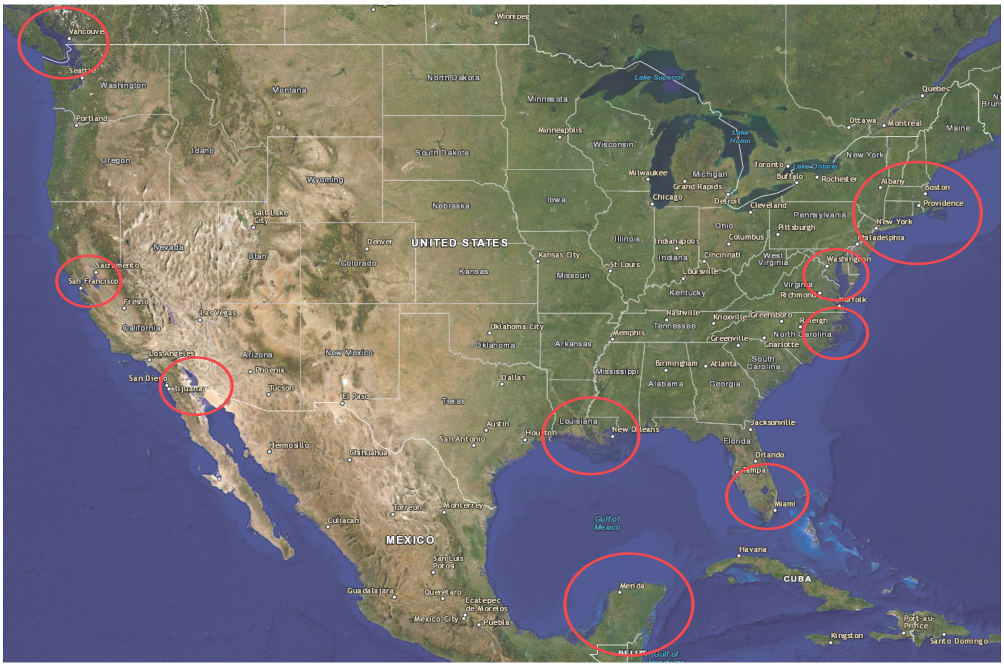
EUROPE

Most visible changes:
- Netherlands
- Denmark
- Northeast Italy



NORTH AMERICA

Most visible changes:
- Louisiana
- Florida



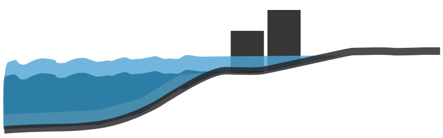
ASIA

Most visible changes:
- Southern Vietnam
- Southern Cambodia
- Southern Bangladesh
- Southern Myanmar
- Northeast China

2.2 EXISTING PREVENTIVE STRATEGIES

The Intergovernmental Panel on Climate Change (IPCC) was founded in 1988, and two years later the agency published a handful of approaches for coastal zone management. The proposed strategies were r**etreat, accommodate** and **protect**. The different approaches were defined along with their potential economic, environmental, social and legal implications (Gilbert & Vellinga, 1990) Since the 1990s, these strategies have remained largely unchanged, though accommodate was renamed to adapt. Also, two more approaches were added, do nothing and attack. The do-nothing strategy emerged because some land is not worth the financial investment for protecting it, and the attack approach emerged as a means to react to rising sea levels actively instead of passively (Miller, N. 2020).

DO NOTHING



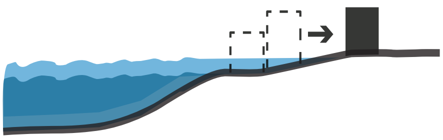
Just like the name of this strategy suggests, existing structures are simply abandoned to be taken by the sea. This approach is the international top plan of action in response to flooding and rising sea levels.

↓

New Orleans after hurricane Katrina

Image credit: pbs.org

RETREAT



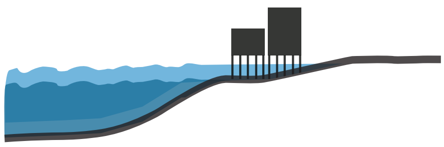
The retreat strategy focuses on relocating the built environment inland. This strategy is similar to the do nothing strategy since land is still lost, and temporary because buildings may have to be relocated again in the future.

↓

Relocation of Cape Hatteras Lighthouse

Image credit: pinterest.com

ADAPT



The adaptation strategy emphasizes adapting existing and new structures to flooding, minimizing the damages caused by flooding. Yet again, this is temporary, and with permanently increased sea levels, land is permanently lost.

↓

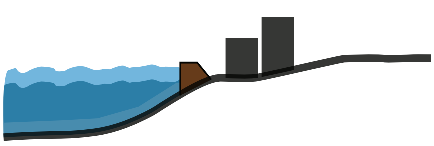
Coastal house on stilts

Image credit: housing.com

The pros and cons of each strategy will be outline in the next section of this essay, yet it can already be mentioned that these five strategies only serve a short-term purpose, which can be summarized as temporary flood relief, flood prevention or preventing beach erosion.

Hence, while some of these strategies are effective at fulfilling their task, they damage coastal areas in other ways and are simply not intended to handle permanently increased sea levels in the long term. There exists no strategy for permanently protecting coasts against rising sea levels.

PROTECT



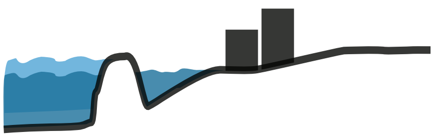
The protection strategy tries to limit flooding and beach erosion with barriers. These structures can be made out of rocks or vegetation. They are costly and do not take permanently increased sea levels into account.

↓

Breakwater structure

Image credit: deepbv.nl

ATTACK



The attack strategy focuses on protecting coastal regions from flooding by building artificial structures in the sea. While it is the most expensive option, it offers a more long-term protection and also wins land.

↓

Protective artificial island in the Maldives

Image credit: coastalmatters.com

2.3 UNDERSTANDING COASTAL BEHAVIOUR

To understand the features of coasts and beach erosion, it is important to understand the meaning of certain concepts. Hence, the next two parts of the essay will clarify some terminology that is necessary for understanding various concepts associated with coasts and beach erosion.

2.3.1 SHORELINE TERMINOLOGY

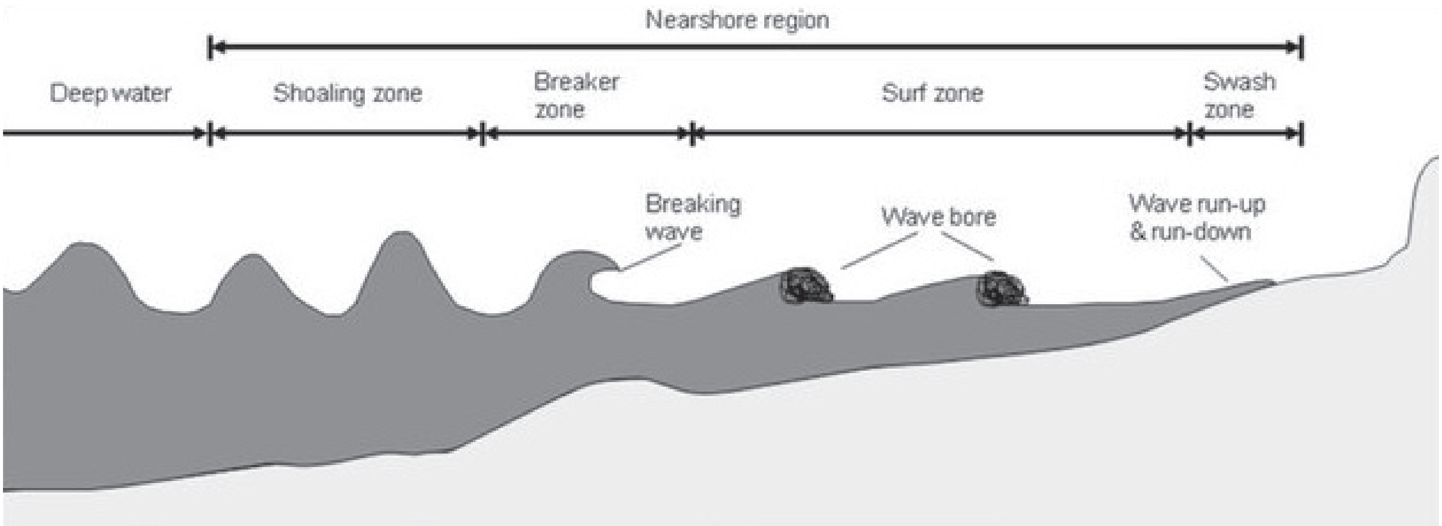
Nearshore region - the area of the shore where coastal waves begin to take shape.

Shoaling zone - The area where water depth becomes about half the length of the wave, which causes the wave to become steeper. This means an increase in wave amplitude while decreasing the wavelength.

Breaker zone - The area where waves begin to break.

Surf zone - The area where waves break on the surface.

Swash zone - The area where waves roll on and off the beach or shore.



(van Rooijen, Arnold. 2011)

Rip current - an extremely strong current that can occur in the Nearshore region. These currents are created when two outward currents overlap to move water from the beach back into the sea. They can pull swimmers extremely far out into the sea, which can lead to fatalities.

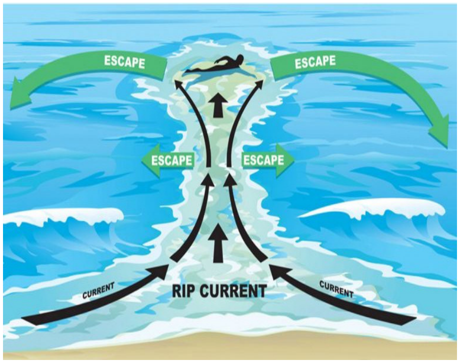
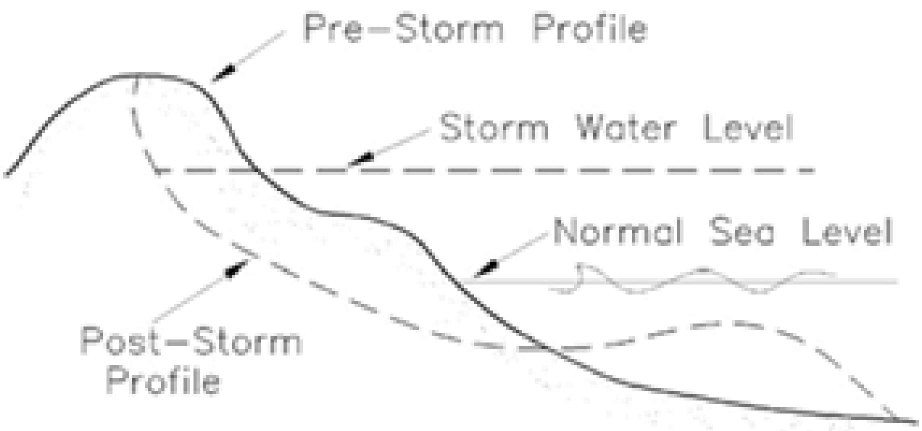


Image credit: National Oceanic and Atmospheric Administration

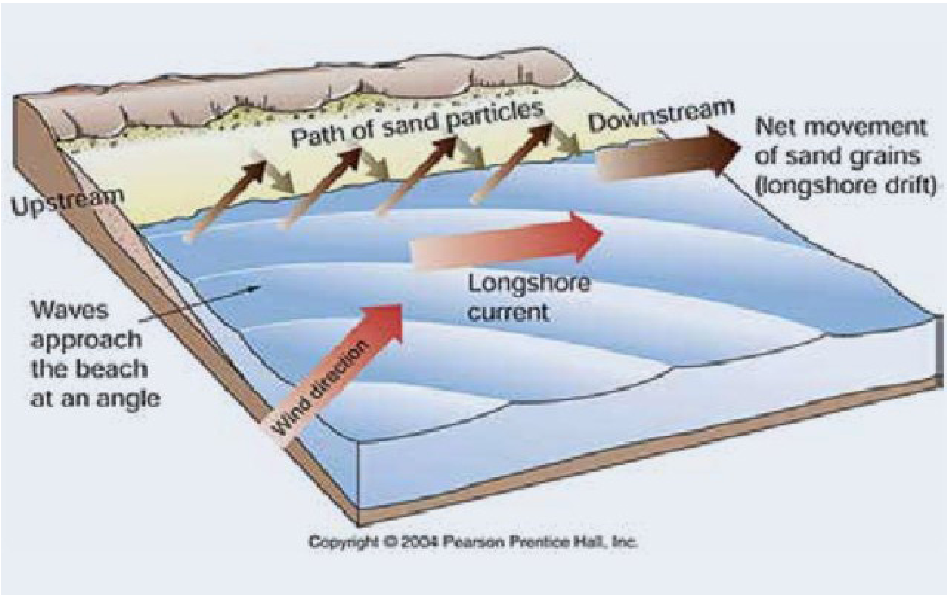
2.3.2 EROSION TERMINOLOGY

Cross-shore erosion - Erosion that occurs in the Nearshore region of the coast. The erosion is caused when waves pull sediment back into the sea after retreating from the Breaker-, Surf and swash zone. This type of erosion has the most significant effect during extreme weather events, such as storms.



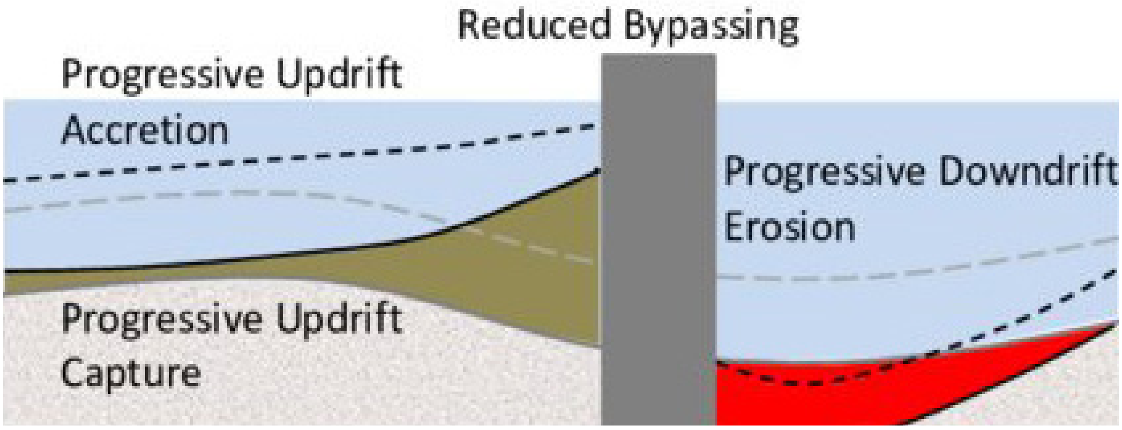
Cross-shore erosion diagram, Reguero & Fernando & César. (2017).

Longshore drift erosion - Erosion that occurs when the energy of waves is displaced in one direction, either by natural or artificial barriers or when the waves approach the beach at an angle. This causes sediment to move in that particular direction, which over time can cause loss of sediment in one area while causing accretion of sediment in another area.



Longshore drift erosion diagram, Reguero & Fernando & César. (2017).

Down-drift erosion - Erosion that occurs as a result of a structure interrupting natural currents of water. This primarily happens behind the structure. If the structure is large enough, accretion of sediment will occur in front of the structure, which can influence the structure's structural integrity.



Down-drift erosion diagram, Eliot & Stul & Travers, 2015

Toe scour erosion - Essentially the opposite of down-drift erosion: A structure interferes with the flow of currents, but instead of sediment being eroded behind it, sediment is eroded at the front, slowly digging underneath. This can damage the structural integrity of the structure, especially if it is not solid.

With this terminology in mind, we can begin to look at existing approaches to prevent flooding and beach erosion along with their advantages and disadvantages.

2.4 DO NOTHING STRATEGY

New Orleans after hurricane Katrina in 2005.
Image credit: PBS.org

Pros

1. Cheap as no investment for large scale infrastructure is made

Cons

1. The built environment is damaged

2. People lose their homes

3. Unsustainable as continued damages over time means continued costs over time

4. Land will inevitably be permanently lost to the sea

While the image above is the result of a temporary flooding event due to a hurricane, governments do consider simply sacrificing land and homes as it is a cheaper option than building protective means. For example, an article published by The Guardian in 2014 reads “Properties worth over £1bn will be lost to coastal erosion in England and Wales over the next century, with no compensation for homeowners, as it becomes too costly to protect them.” (Carrington, 2014). The do-nothing strategy can be considered the top choice of action, as “around the world, adaptation efforts are gravely insufficient” (Hogue, 2020).

2.5 RETREAT STRATEGY

Cape Hatteras Lighthouse being moved 1 km inland in 1999.
Image credit: DREW C. WILSON

Pros

1. Saves the built environment from being lost to the sea

2. No effect on beach current

3. Provide a habitat for wildlife

Cons

1. Temporary, as additional sea-level increase will require moving further inland

2. Expensive

3. Puts further strain on the environment, as these buildings are moved to farmland or preserved natural areas

4. Ineffective against permanently increased sea levels

The retreat strategy aims to relocate the built environment inland, putting them out of the risk zone of flooding and permanently increased sea levels. This strategy has not been implemented on a large scale, it is most often used to preserve buildings with cultural heritage. The effort itself is not a sustainable option, as moving buildings, especially larger ones, is a colossal effort, both practically and financially. It also means that natural environments or farmland has to be sacrificed for the moved buildings. The strategy can not be considered a long-term solution as buildings may have to be moved further inland as the sea rises further.

2.6 ADAPT STRATEGY

BUILDINGS ON STILTS

A coastal house on stilts.
Image credit: treehugger.com

FLOATING HOUSING

A floating house by SysHaus Architects
Image credit: archdaily.com

Pros

1. Limits the damage that flooding and rising sea levels can do to the built environment

Cons

1. Adapting existing structures is expensive

2. Land is still lost to the sea

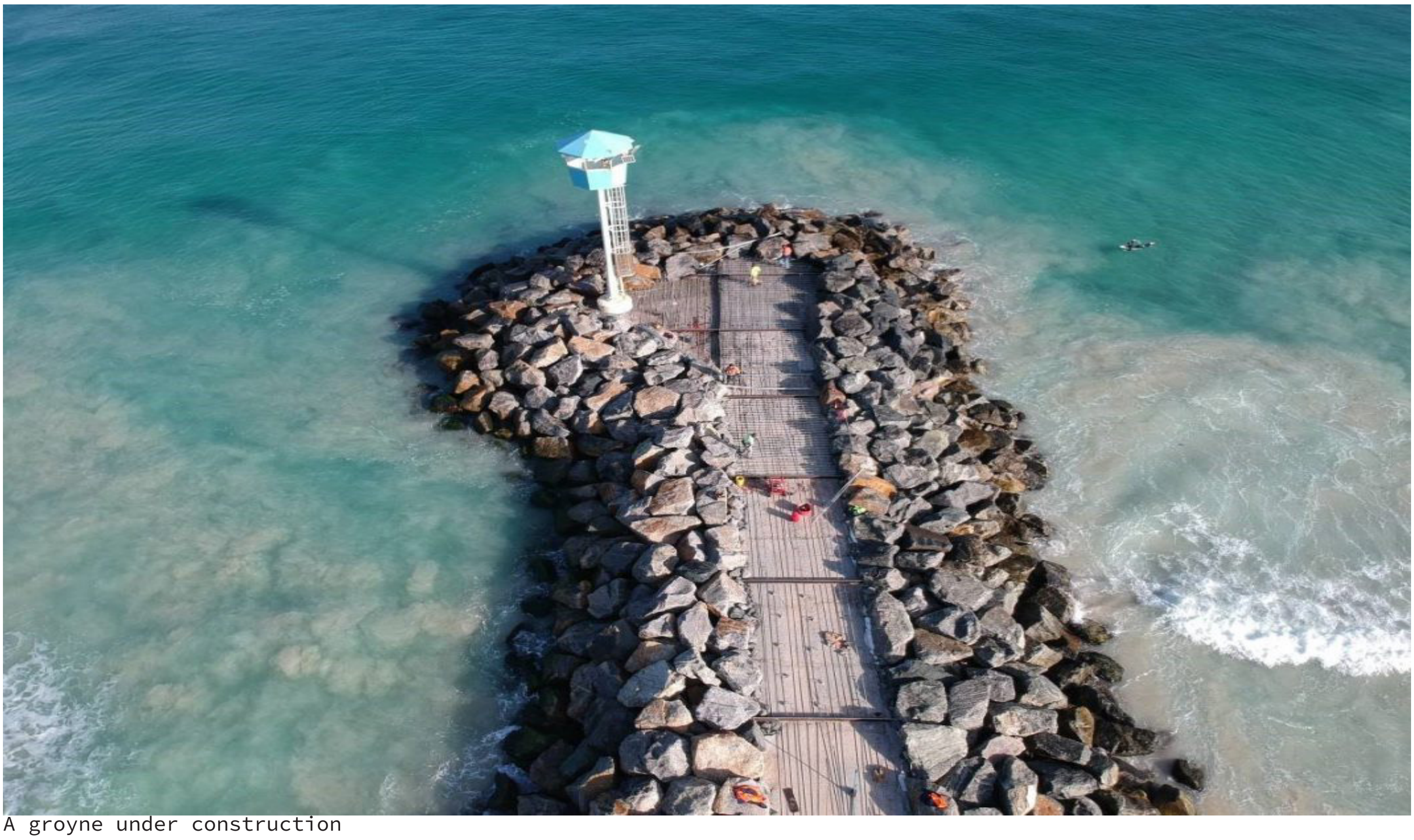
3. Ineffective against permanently increased sea levels

4. Ineffective against permanently increased sea levels

The adaption strategy does in fact take the long-term aspect of rising sea levels into consideration, yet the fact remains that it does not prevent land from being permanently lost to the sea, which categorizes this strategy as short-term. Buildings on stilts may only become accessible by boat after a while. In contrast, floating housing is flexible as they can be moved around, and they are not at risk of being flooded as they float above the waters they reside on.

2.7 PROTECT STRATEGY (HARD PROTECTION)

GROYNES



A groyne under construction
Image credit: advanteering.com.au/floreat-citybeach-groyne/

Pros

1. Effective in building beaches

2. Acts as a resourceful feature

3. Can be constructed fast and easily with a range of materials

Cons

1. Can increase erosion through **downdrift**

2. High maintenance costs, requires a continuous supply of sediment and becomes unsafe if not maintained.

3. Difficult to control **cross-shore** sediment movement

4. Generate **rip currents**, which can be deadly for swimmers

5. Not considered aesthetic

6. Ineffective against permanently increased sea levels

Groynes are man-made structures with the aim of reversing beach erosion. This is achieved by taking out the energy of waves before they hit the beach, in other words, groynes break the waves prematurely. This can lead to an accretion of sand, which naturally preserves the beach (Williams, Rangel-Buitrago, Pranzini, Anfuso, 2018). Groynes can also be built out of wood.

OFFSHORE STRUCTURES

Offshore structures that reduce the power of waves.
Image credit: Fröhle & Kohlhase, 2022

Pros

1. Promote beach build-up

2. Maintains beaches as they reduce interaction between waves and other defences closer to the beach

Cons

1. Massive and expensive

2. Create navigation hazards and safety issues

3. Increases **downdrift erosion**

4. Can usually only be constructed in shallow waters

5. Reduces the quality of the water

6. Not considered aesthetic

7. Ineffective against permanently increased sea levels

Similar to groynes, offshore structures aim to reverse beach erosion by breaking waves before they hit the beach and preserving sand. An additional benefit is that offshore structures protect other defensive structures closer to the beach.

SEA WALLS

Sea wall in Gudong, Yellow river delta, China. Built in 1985 and named the ‘Coastal Great wall.”
Image credit: Williams, Rangel-Buitrago, Pranzini, Anfuso, 2018

Pros

1. Prevent beach erosion

2. Can withstand extreme weather conditions

3. Can serve as a promenade

4. Has many different designs

5. Safe for the public

Cons

1. Low energy absorption and high wave reflection rate, which may contribute to beach destabilisation in the form of **long-drift erosion**

2. Usually requires an additional energy absorption apron, such as revetments rock armour

3. Expensive

4. Limits access to the sea

5. Not considered aesthetic

6. Ineffective against permanently increased sea levels

Vertical to semi-vertical stone or concrete structures that can be of various heights. Effectively deals with erosion and extreme weather conditions while also being safe for public use.

REVETMENTS ROCK ARMOR

Revetments rock armor structure protecting a beach from erosion.
(Čehovin & Zagar 2019)

Pros

1. Effective at regulating water flow and dispersing wave energy in vulnerable areas

2. Usually cheaper than a solid structure

3. Low maintenance

4. Can reduce **toe scour erosion** if combined with seawalls

Cons

1. Low energy absorption and high wave reflection rate, which may cause **long-drift erosion**

2. Expensive

3. Usually needs to be complemented with other defensive strategies

4. Acts more like an energy-absorbing apron than true protection

5. Limits access to the sea

6. Ineffective against permanently increased sea levels

An approach that consists of stacked rocks which usually are placed at the end of thin beaches or beaches with a high risk of flooding. The goal is to protect coastal infrastructures such as roads and train tracks.

2.8 PROTECT STRATEGY (SOFT PROTECTION)

NOURISHMENT

A boat nourishing a beach with sand.
Image credit: dredgingtoday.com/2019/10/21/beach-nourishment-begins-at-hayling-island/

Pros

1. Preserves sand beaches
2. No effect on beach current

Cons

1. Expensive
2. Temporary
3. No effect on erosive beach currents
4. Ineffective against permanently increased sea levels

Nourishment is a simple yet highly effective and neutral soft protection strategy. By filling up beaches that have suffered extensive erosion with new sand, the beaches are essentially rebuilt and restored. Yet the obvious problem is that this is a highly short-term strategy; one storm can undo the entire intervention.

SAND DUNES

Beach grass strengthens beaches resistance to erosion due to the roots of the plants.
Image credit: en.wikipedia.org/wiki/Sand_dune_stabilization

Pros

1. Dissipates wave energy

2. Aesthetic and rich features for wildlife

Cons

1. Extremely susceptible to erosion

2. Ineffective against permanently increased sea levels

Sand dunes occur naturally by accretion of sediment through wind and they can also be man-made fairly easily. To slow down erosion, simple plants like grass or bushes can be planted in the soil. This approach also promotes biodiversity at beaches, alleviating some of the strain that the environment is experiencing.

VEGETATION

Mangrove trees.
Image credit: NuttKomo/Fotolia

Pros

1. Preserves sand beaches
2. No effect on beach current
3. Provide a habitat for wildlife

Cons

1. Ineffective against permanently increased sea levels
2. Not applicable on all beaches
3. No effect on erosive beach currents

It is worth mentioning that plants are very good for beach preservation, in particular Mangrove trees, which can be found in tropical areas. The roots of these trees expand out of the soil all the way above the water level, which naturally reduces the energy of waves and limits sediment movement, while also providing a habitat for fish, crustaceans and birds. The only issue is that it is currently geographically limited to tropical areas and is therefore not suitable for northern climates.

2.9 ATTACK STRATEGY

The new artifical island Hulhumalé in the Maldives.
Image credit: Hassan Mohamed (Miller, 2020).

Pros

1. Land is won

2. Existing buildings and natural coastal areas are protected from erosion and flooding

Cons

1. Extremely expensive

2. Likely unable to handle permanently increased sea levels unless they are continuously built upon, which also is expensive and resource-intensive.

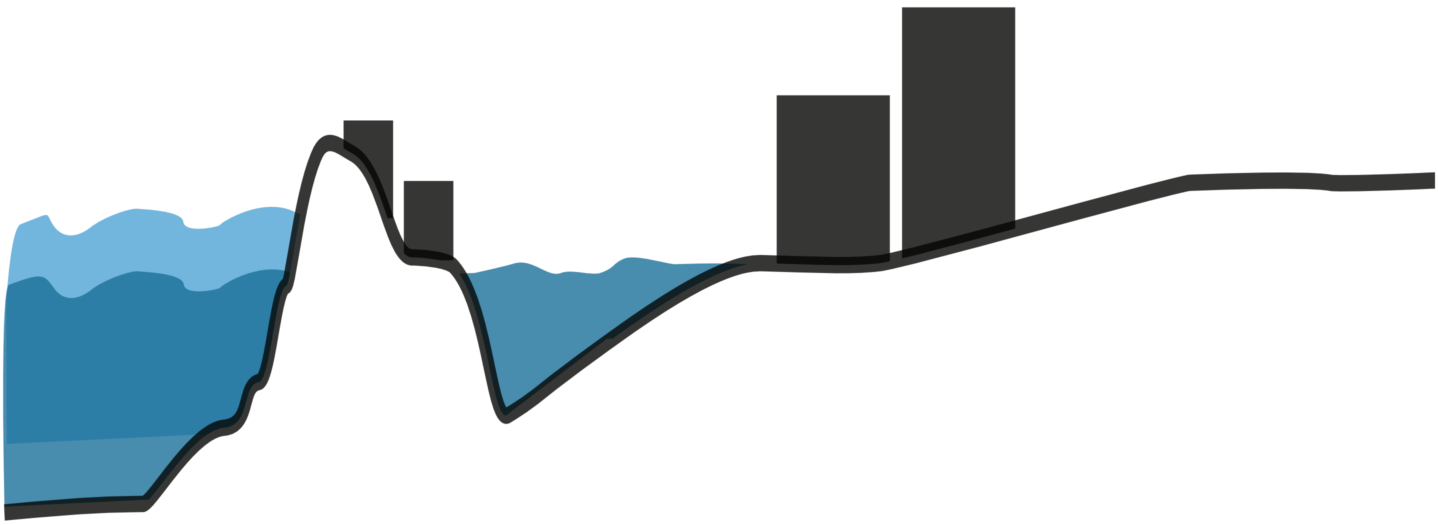
Instead of reacting passively to the threat of sea-level rise, the attack strategies brings the battle out to sea. Artificial islands can through their composition be engineered to withstand wave energy better than natural coasts, which makes these artificial islands act as a protective layer for natural coasts. Land is also won, which is the opposite outcome of all the other strategies. Yet, traditional methods of building artificial islands are too expensive to be implemented as a permanent, long-term solution on a global scale.

2.10 IMPLICATIONS WITH EXISTING STRATEGIES

As you might have noticed, the list of cons is longer than the list of pros for almost every generic strategy. Hence, the conclusion regarding existing approaches to protect and preserve coasts and beaches is that even though these approaches have a variety of effective benefits and to some extent successfully serve their purpose, they are far from perfect because they are expensive and can potentially damage coasts in other ways. Most importantly though, the con that all the generic approaches have in common is that they are ineffective or handling permanently increased sea levels, so they can all be categorized as short-term solutions with the sole purpose of protecting against temporary floods and beach erosion. If these protections are installed around coastal cities at a great financial cost, they will do little to nothing to protect coastal regions once sea levels increase permanently.

Considering this conclusion, it seems pointless to discuss which strategy is the best to implement for the long term, but this does not mean that these strategies should be completely dismissed or disregarded. As my approach definitely would affect the behaviour of coasts, in particular natural ocean currents and sediment movement, some of the generic strategies may be necessary to be incorporated to some extent along with my project to ensure that the natural behaviour of coasts is not influenced too greatly. The generic approaches in combination with my proposal may help undermine down-drift erosion, longshore drift erosion, cross-shore erosion and toe scour erosion caused by my massive sea wall proposal.

2.11 MY APPROACH: UTILIZE



Pros

1. Millions of square meters of land are won

2. Existing buildings and natural coastal areas are protected from erosion and flooding

3. The barrier is designed to lay a foundation for urban development, making it a long-term investment

4. The barrier utilizes rising seas to harvest green energy

5. Within the price range of other major infrastructure projects

6. Designed to be sequentially added upon when seas rise further

Cons

1. Expensive

2. Resources intensive

3. Experimental

2. Would largely affect natural coastal behaviour of the Öresund sea

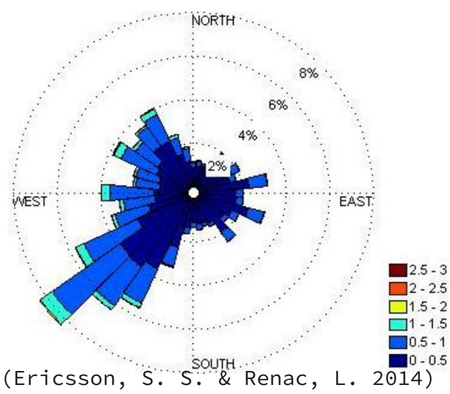
“When the wind of change blows, some people build shelter, others build windmills”

- Chinese proverb

Considering that the generic approaches are more or less passive in the advent of permanently increased sea levels, my proposal is a new, extensive long-term solution that utilizes rising sea levels for sustainable urban development and harvesting energy through green technologies.

2.12 ÖRESUND

Malmö Wave rose

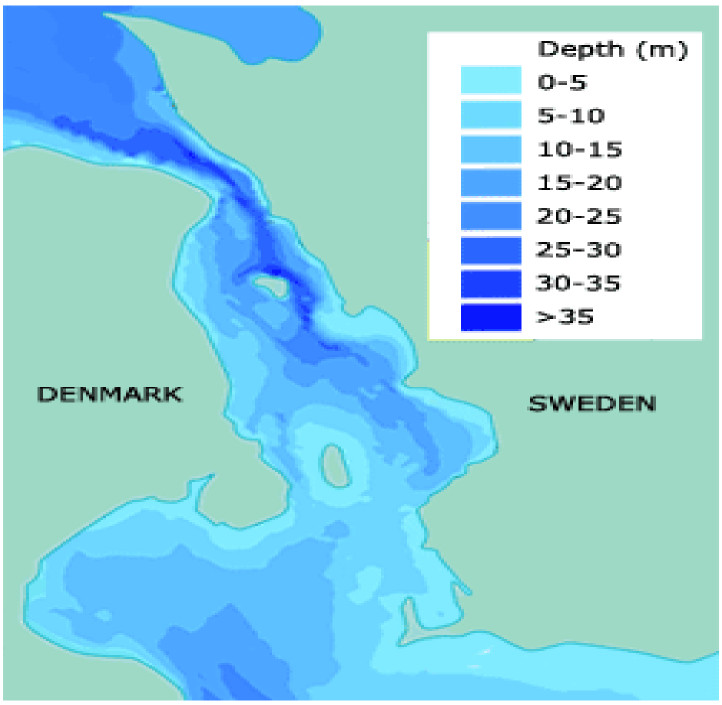


(Ericsson, S. S. & Renac, L. 2014)

To get a better understanding of the Öresund Sea, the sea where Malmö is located behaves and what is composed of, the research phase revealed a wide range of information regarding sediment transport patterns, seafloor composition as well as wave and water flow patterns.

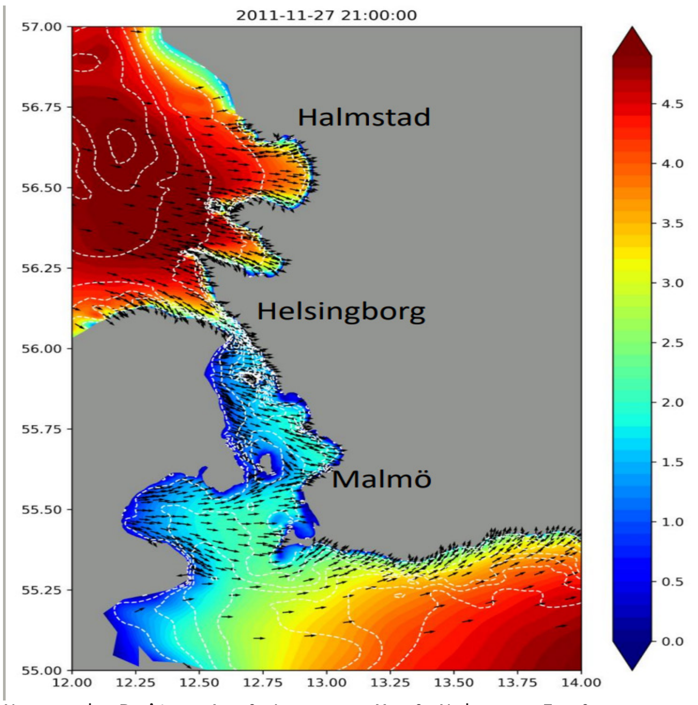
The Öresund as a body of water first emerged as a direct consequence of the last ice age in Europe ending, which is marked by the beginning of the Holocene epoch. Before that, Denmark and Sweden were connected by a landbridge known as Doggerland (Gaffney, V. & Fitch, S. & Smith, 2009). As the sea level rose from glaciers melting, and the landmasses rose from the weight of the glaciers being removed, the Öresund emerged as a thin straight that connects the North Sea with the Baltic Sea. Due to the Öresunds' slim entrance to the north, the sea is extremely calm in terms of waves, and relatively shallow. The seafloor at the site location mostly consists of mud, sand, moraine and pre-quaternary sediments. While this does not sound like a promising foundation for a megastructure, the nearby Öresund Bridge proves it can be. Sand that is dug out for the foundations can be used for the structure itself, much like the Öresunds bridge project did to make the artificial island Pepparholm, where the tunnel part of the bridge commences.

Öresund depth map



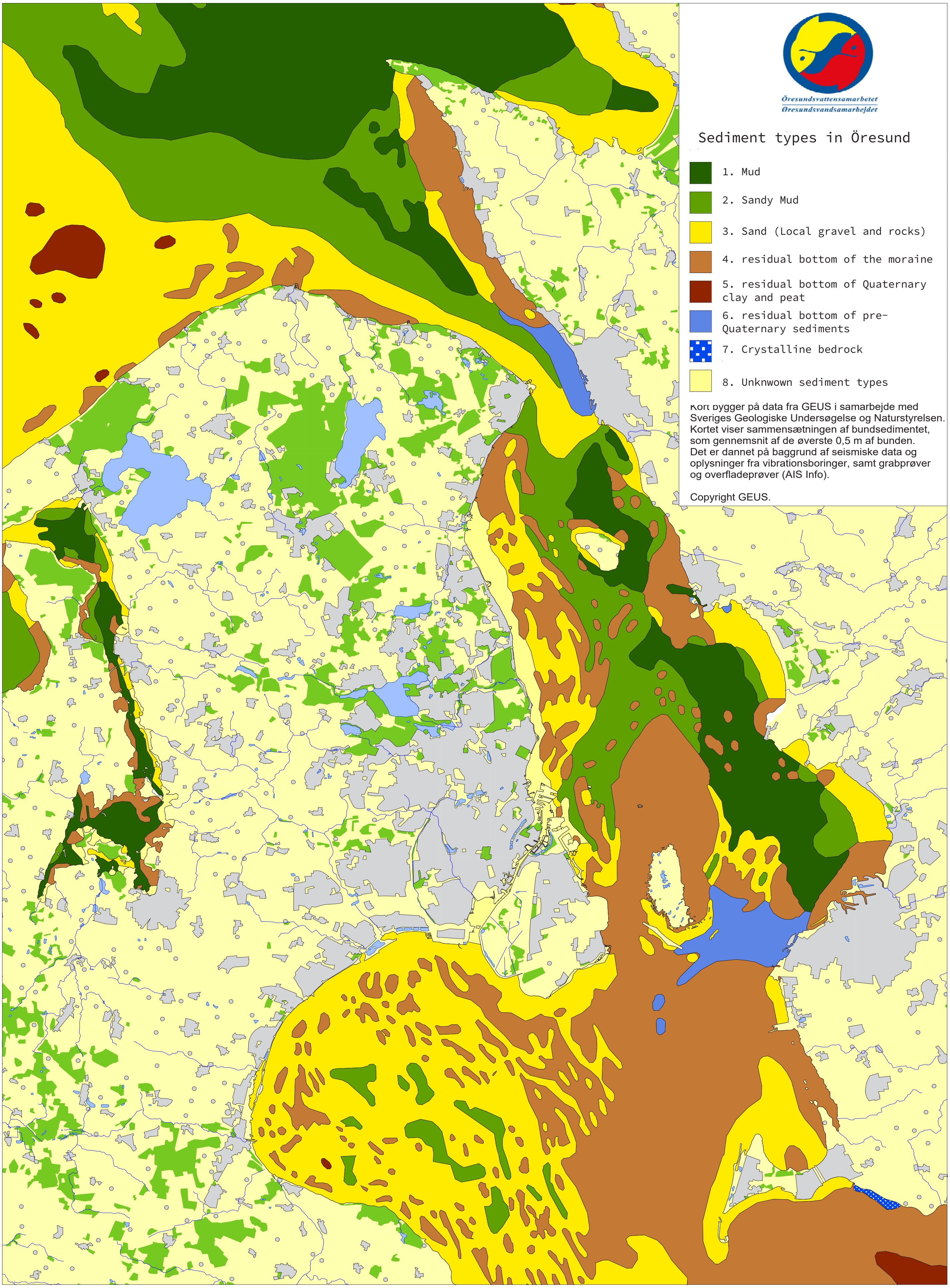
Copenhagen Municipality

Wave direction and height in Öresund



Nunes de Brito, A. & Larson, M. & Nyberg, J. & Goodfellow, B. & Ising, J. & Almström, B. 2015

Sea floor sediment composition



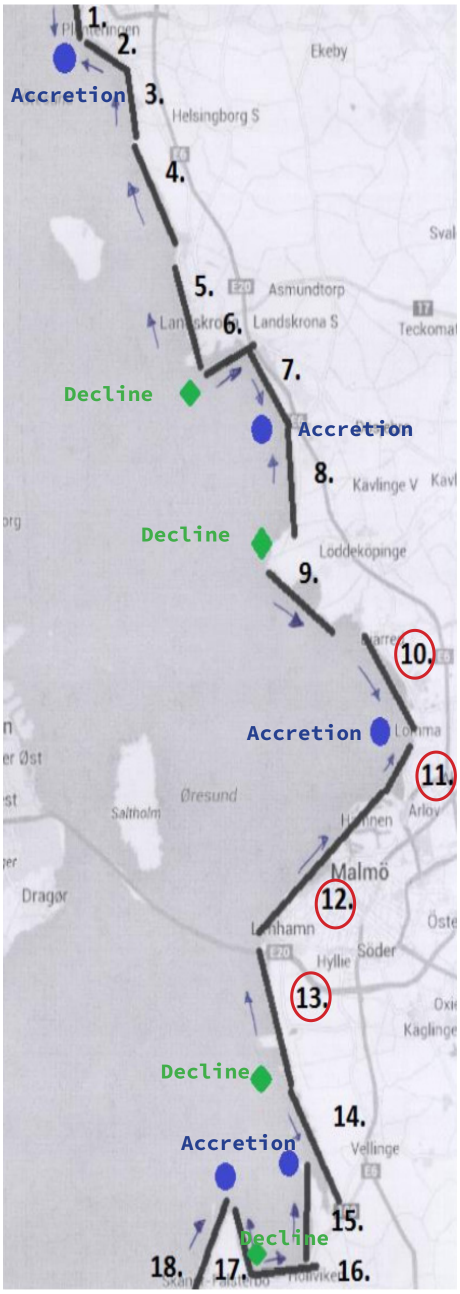
Copenhagen Municipality

SEDIMENT MOVEMENT

According to the 2014 study Hindcast of the wave climate in Öresund by Sara Schömer Ericsson and Laury Renac from Lunds University, the eastern coast of Skåne has varying degrees of transport volumes and directions, resulting in some points where sediment accretes and other points where sediment decreases. This means that in some areas, for example, Lomma, which resides north of Malmö, beaches may grow over time, while other areas, for example outside of Landskrona, will lose beaches due to long-drift erosion.

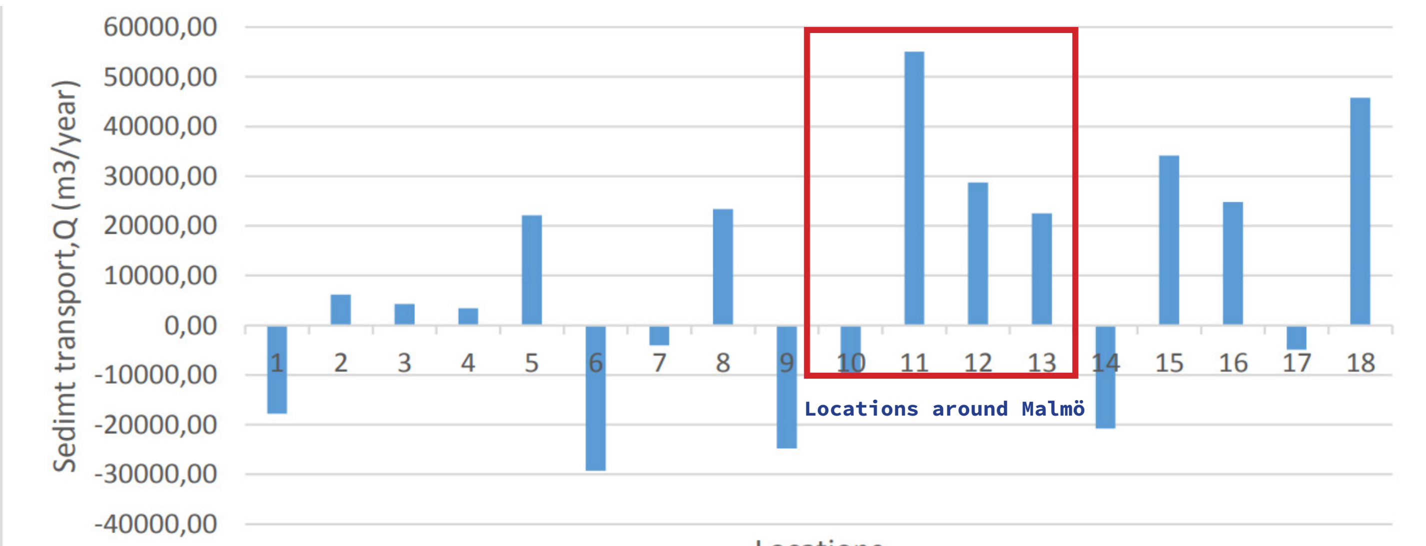
Early in the project, this information, and Malmö’s convenient location, gave me hopes about “hacking” this natural process in order to gradually accrete a barrier outside of Malmö, as around 50 000 cubic meters of sediment passed by the city annually.

Sediment movement



(Ericsson, S. S. & Renac, L. 2014)

Potential Sediment Transport



(Ericsson, S. S. & Renac, L. 2014)

2.13 PRELIMINARY STUDY CONCLUSION

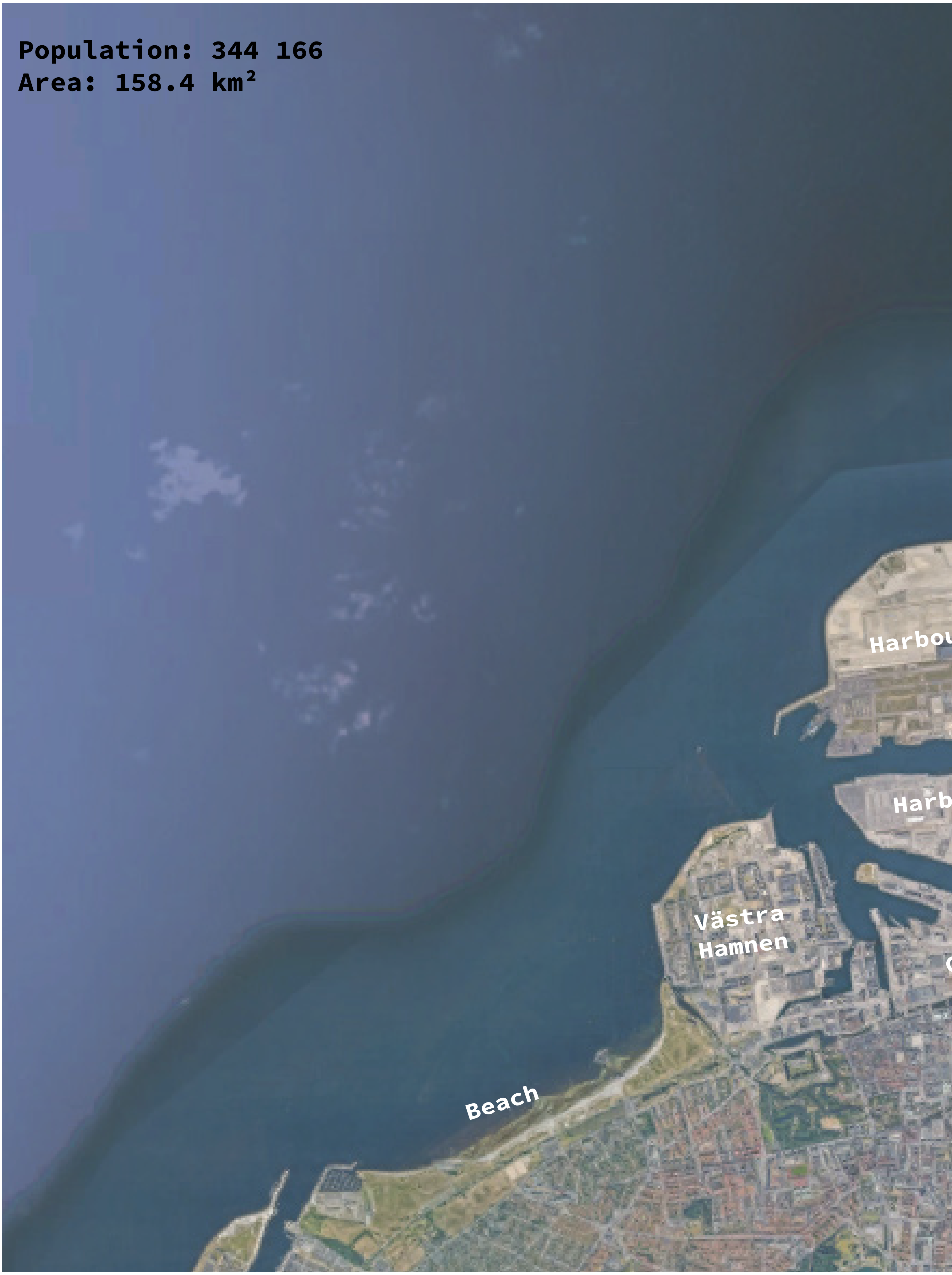
Considering the calm, shallow nature of the Öresund Sea along with its composition, it is a promising site to construct a sea barrier. The low wave heights would make the work effort of placing a foundation for a megastructure easier, and the seas' shallow depth would mean fewer materials would be required for making the structure reach above water.

The sediment composition of the Öresund enables dug out materials to be re-used for filling up a potential megastructure with local materials.

A sea barrier would definitely come with many of the problems that existing preventive strategies create, in particular changing the natural flow of water and sediment, which may affect other coastal areas in unexpected ways. How exactly this would unfold is difficult to tell as the sea barrier proposal is an architectural project, not an oceanography project. My prediction is that the flow of sediment and water would be completely altered if this mega structure would be placed off the coast of Malmö.

It would be logical that if a project like this habitable sea barrier were to be implemented in the future, governments would compose a large committee consisting of a wide range of professionals, for example, engineers, oceanographers, environmental experts etc. in order to accurately predict how a sea barrier would affect the natural behaviour of the coast. These professionals would likely find a way to minimize the potential implications that a sea barrier would bring.

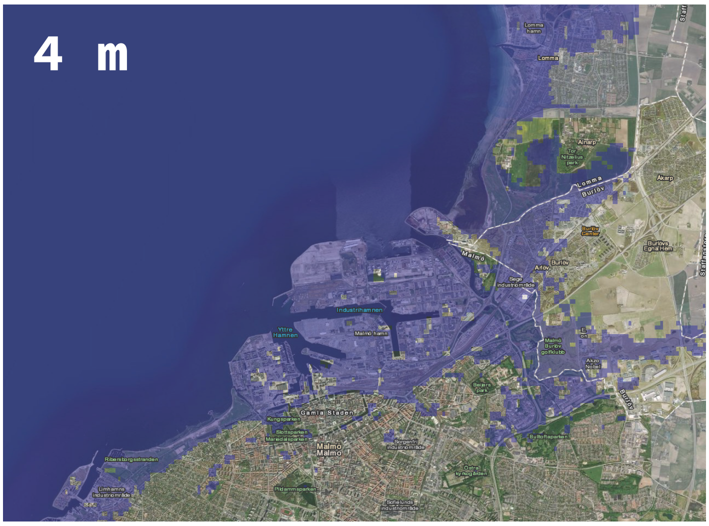
3. THE MODEL SITE: MALMÖ



ur
our
Central station

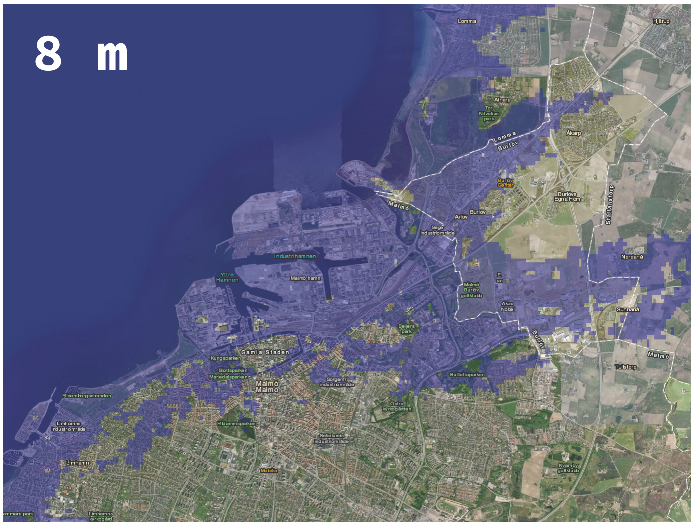
3.1 MALMÖ VS THE SEA

Current coastline
Image credit: flood.firetree.net

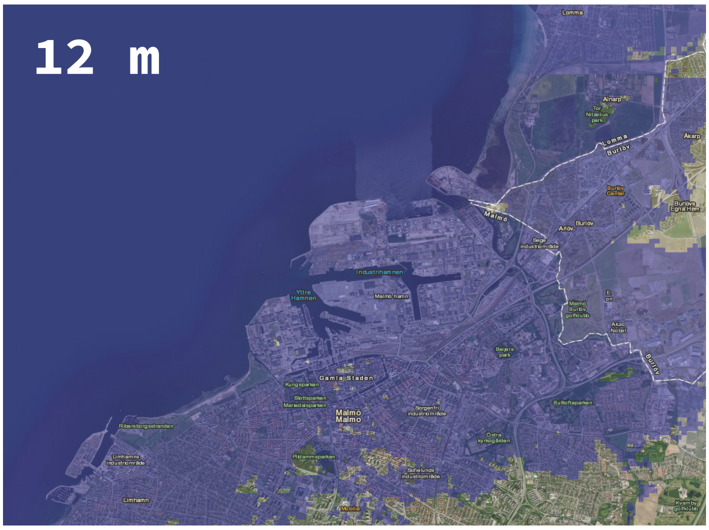


Permanent 4m increase in sea level
Image credit: flood.firetree.net

Being the harbour city that Malmö has been since it was founded in the late 13th century, it today faces the risk of being drowned once sea levels permanently increase, much like any other coastal city in the world. As the images above illustrate, a permanent 4-meter increase in sea levels would



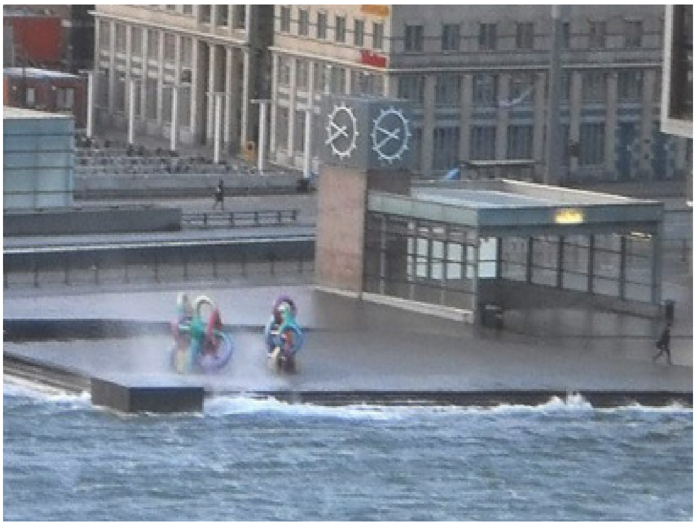
Permanent 8m increase in sea level
Image credit: flood.firetree.net



Permanent 12m increase in sea level
Image credit: flood.firetree.net

cover most of central Malmö, which can be considered Malmö's most essential part in terms of logistics, as the train tracks and harbour reside there, among other expensive city development. At 8 meters, the sea has engulfed half of the city. At 12 meters, Malmö has more or less been swallowed by the sea.

3.2 STORM SVEN



Entrance to the subway, Malmö
Image credit: sverigesradio.se

Canal in front the central station, Malmö
Image credit: svd.se

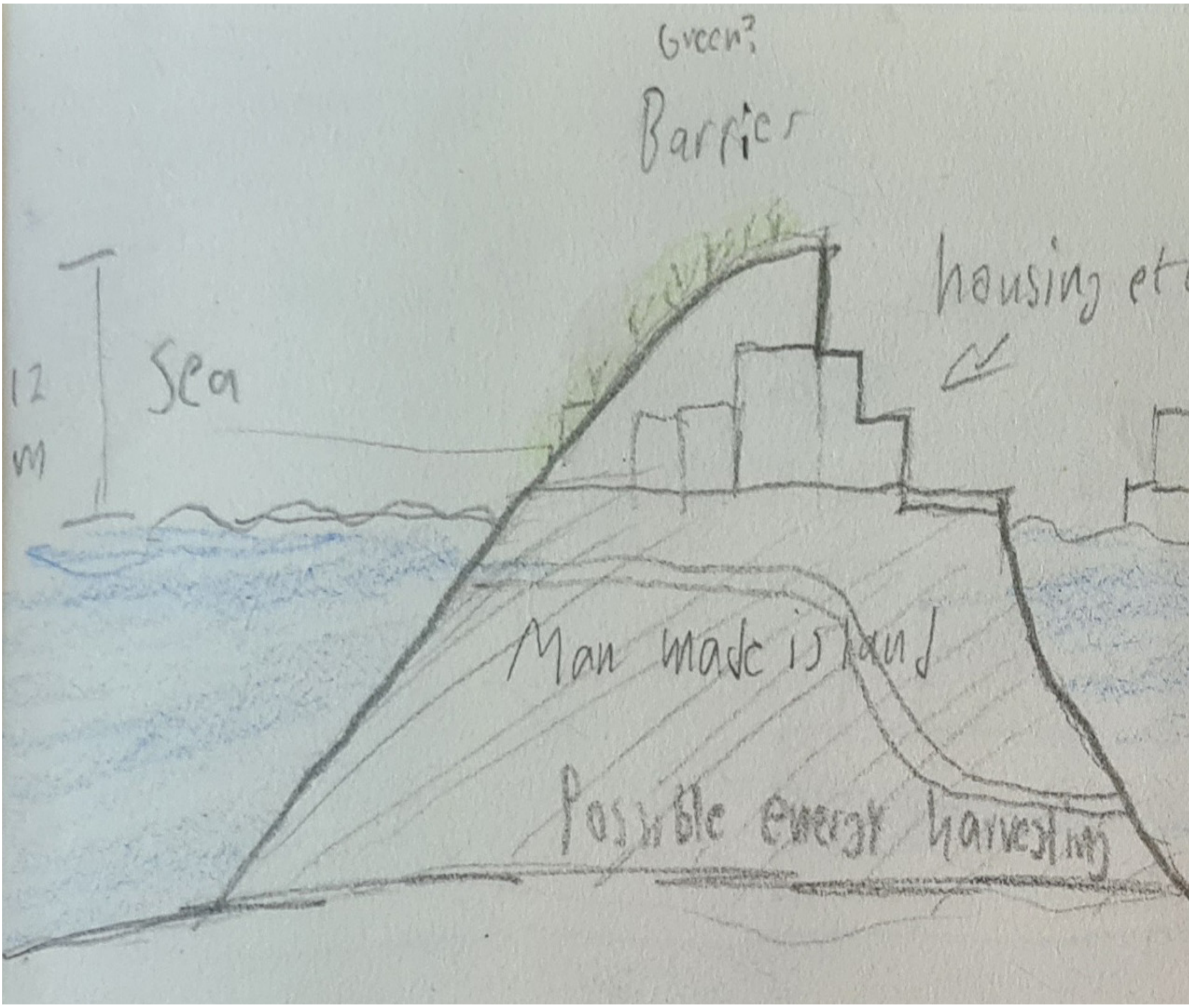
In December 2013, storm Sven increased the local sea level in Malmö by almost 2 meters. This temporary increase was just a few centimetres short of flooding Malmö's underground railroad station and tracks. Pedestrian areas next to the canals varied from slightly flooded to completely inaccessible. The estimated

A flooded restaurant, Malmö
Image credit: etc.se

The university bridge, Malmö
Image credit: sverigesradio.se

damage cost from storm Sven in Malmö was estimated to be around 6 000 000 SEK, which is roughly 629 208 USD. While this amount sounds manageable, the damage costs of future storms will add up over the years, especially considering that such storms will become increasingly frequent and severe as the climate changes.

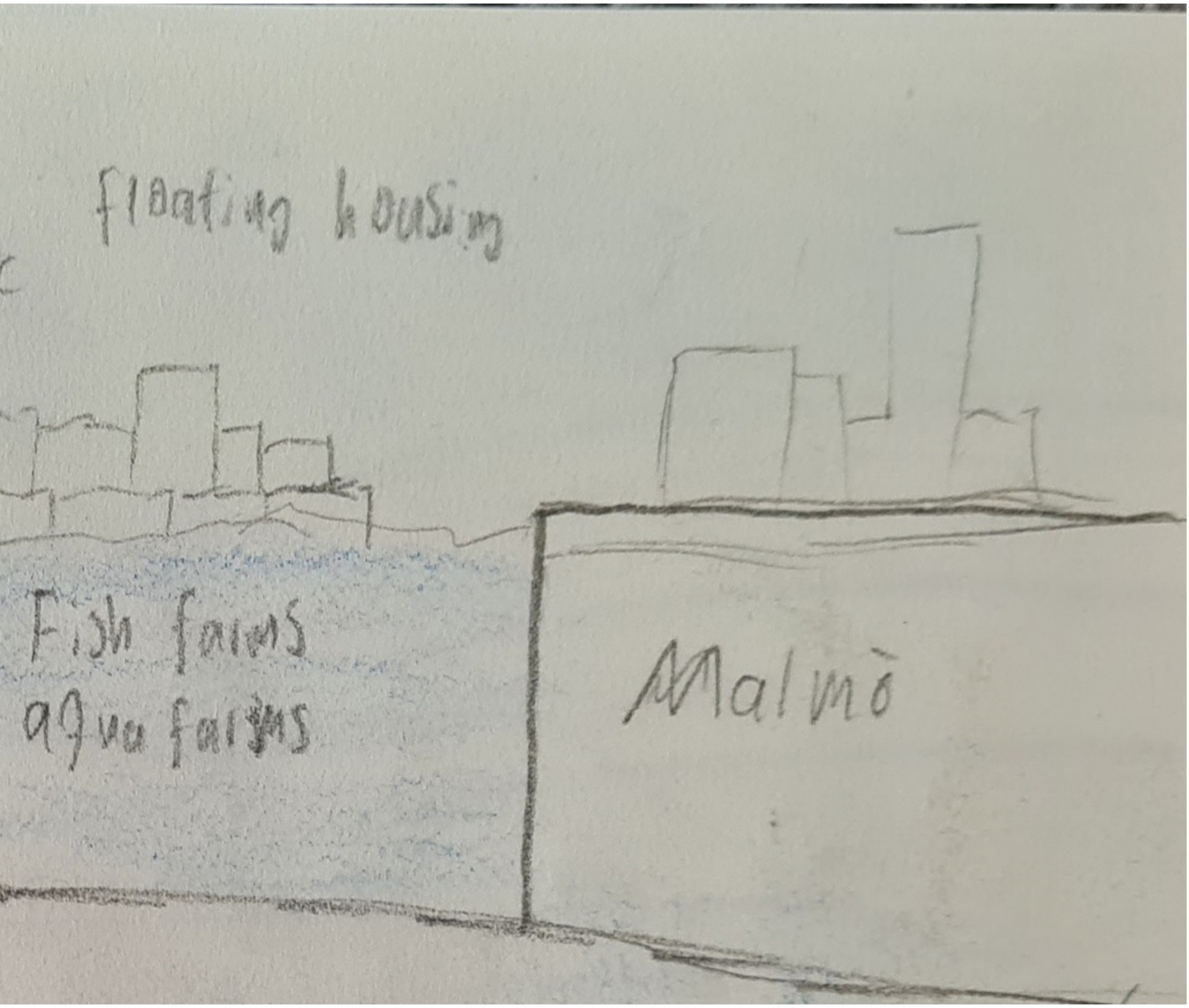
4. SEA BARRIER CONCEPT IDEA



This early sketch became the basis for designing the sea barrier, the core concepts being:

- Protect Malmö from up to a 12-meter sea level rise
- Make housing possible on the wall
- Floating housing in the new inland sea
- Fish/aquatic farms in the new inland sea
- Pipes for energy harvesting in the future under the structure
- Green habitats for animals, both terrestrial and maritime

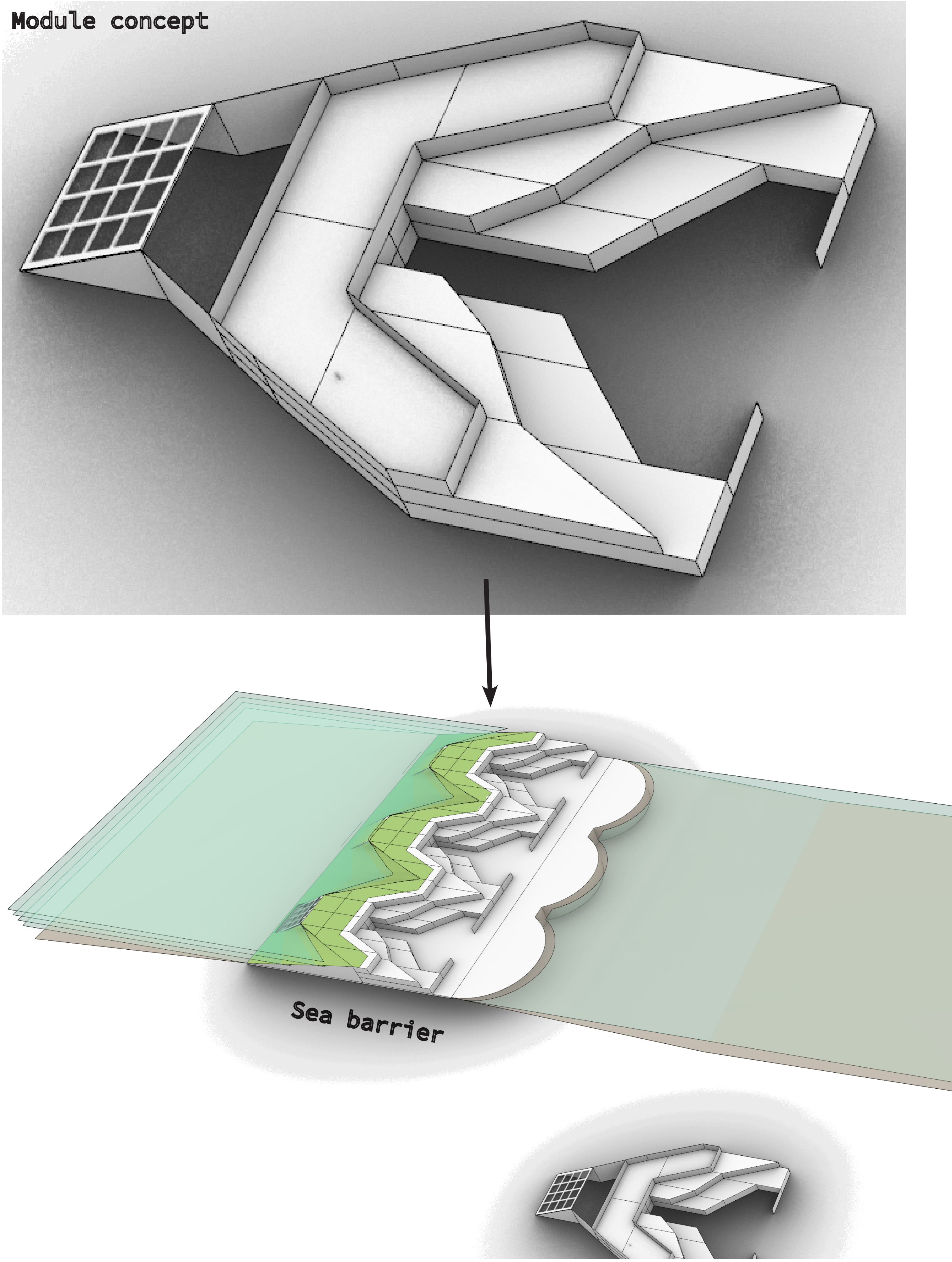
While this sketch seemed like a great start, I had no idea how such a structure would come into being or how it would end up looking. Testing things out, the two first approaches only led me to find a multitude of issues that could not be ignored, which led me to discard those concepts. The two first approaches



will shortly be discussed in the next section of the essay, as these two failed attempts were a necessary step on the path to realising what is possible and what factors have to be taken into account to realize a functional structure

The most important realization was the time frame in which the barrier will have to be built. We are talking about decades of continuous construction, primarily based on necessity as sea levels rise. Hence, the first two approaches led me to take a design approach that was based on the structure being able to be increased and developed continuously over time. I coined the process **Continuous Algorithmic Aggregation (CAA).**

4.1 MODULAR APPROACH



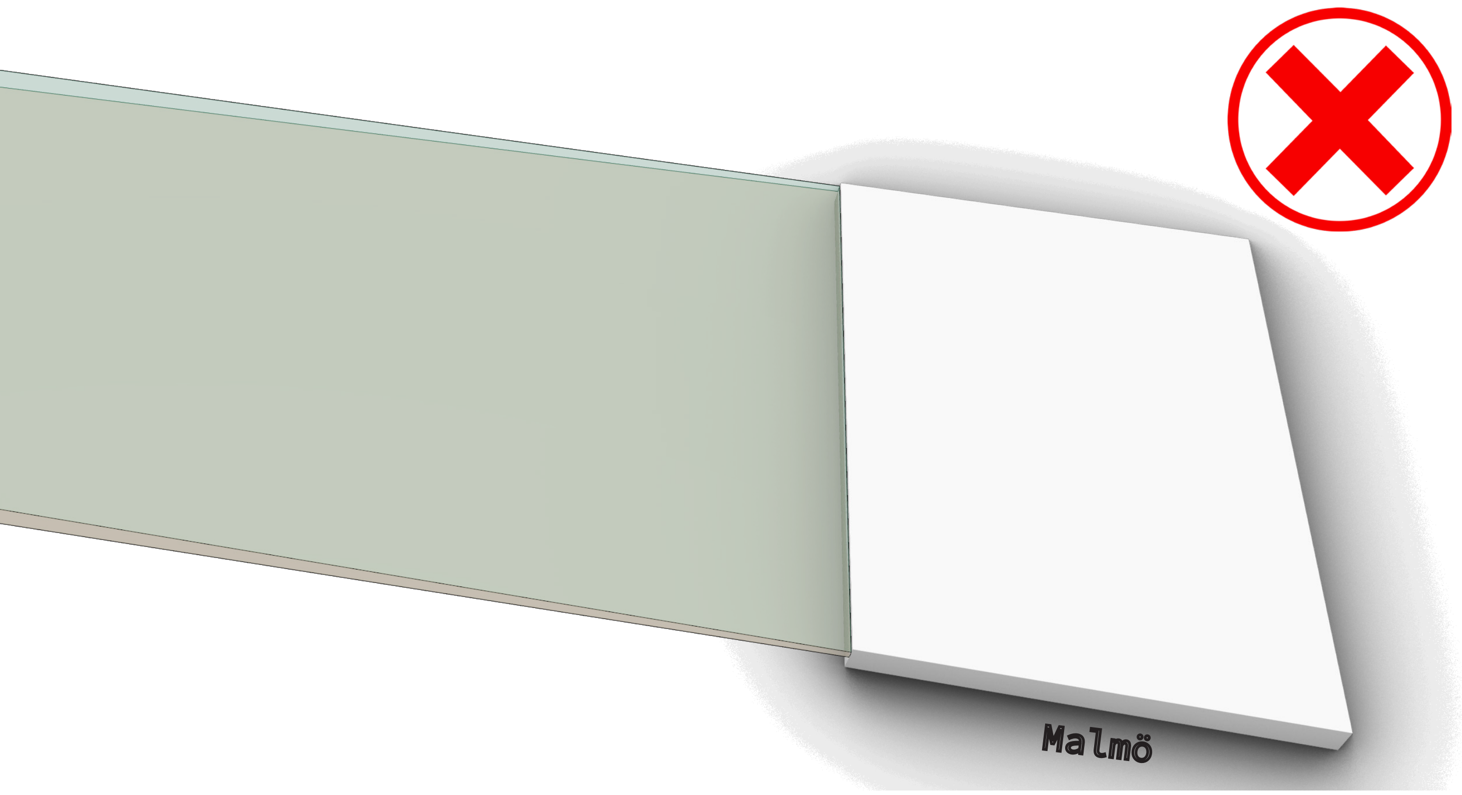
As modular approaches tend to lead to a standardized system that can easily be repeated, it seemed like a reasonable approach to start with. The idea was to create a multistory module that could immediately handle 12 meters of sea-level rise, with the dwellings themselves acting as the protective aspect of the barrier. On the outside, I envisioned a green landscape for animals, which would result in a long-stretched natural park that people also could access. Yet David, my supervisor, and I, quickly found some issues with this approach:

- Lack of sunlight in innermost dwellings
- Enormous as there was motorized traffic (barrier was 120m wide)
- Statically questionable
- A modular approach equals a lack of variation, making it unaesthetic
- An unimaginably expensive one-time investment
- Not flexible and does not take time into consideration; sea levels rise slowly, and the structure may be completed decades or centuries before the sea has risen 12 m. By that time, better solutions likely exist

Conclusion:

I designed a city and park along a barrier, not a barrier that functions as a city, and it may be outdated before it is even completed.

Idea discarded



4.2 “HACK” NATURAL PROCESSES APPROACH

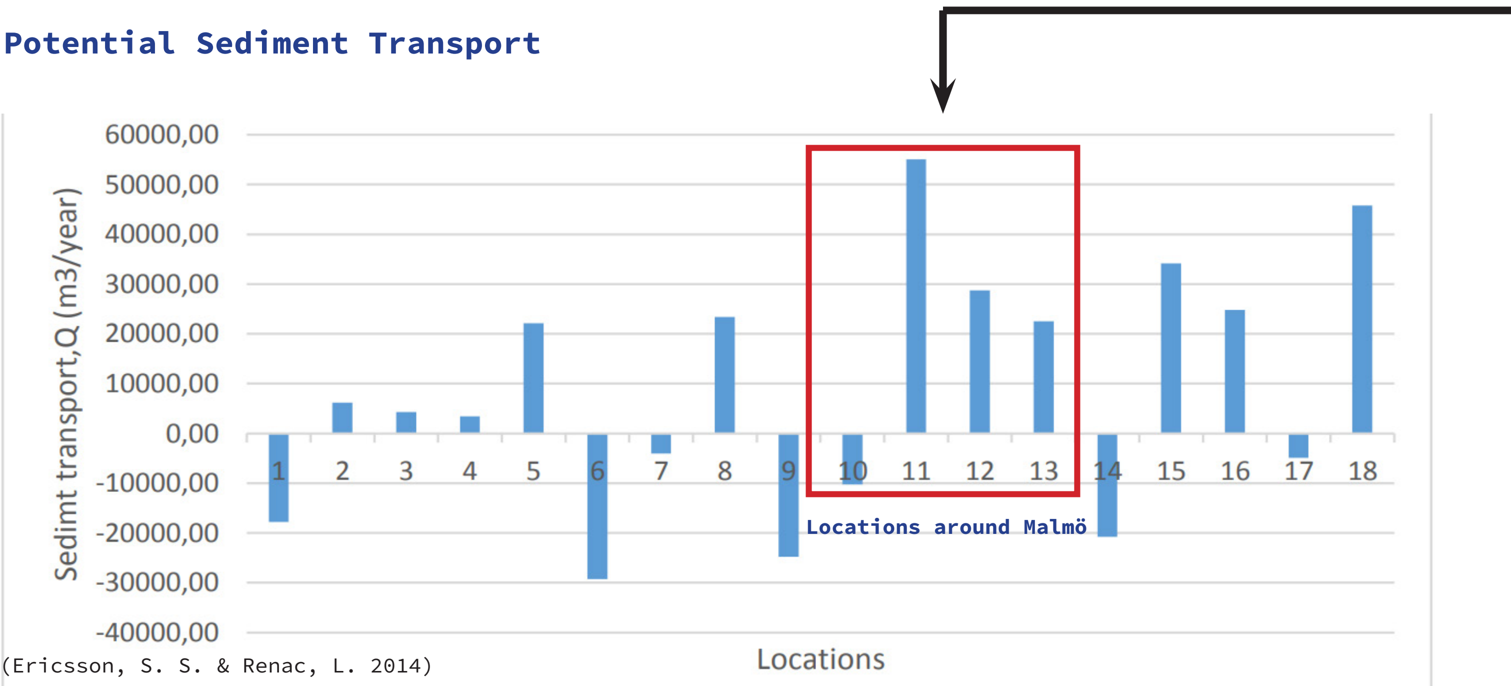
As the importance of taking the time aspect into consideration became obvious after the modular approach, I recalled that Malmö is located in a highly favourable location for sediment accreting naturally. This fact held the potential for building a structure that alters the flow of sediment in a way that could create a foundation for a barrier through natural means After doing some more research, calculations and reflections, I concluded that this approach likely is not possible because:

- The structure that would be built to alter the currents would in itself affect currents once material accretes, which would affect sediment transport
- Designing such a structure to function properly would require a legion of programmers and engineers to simulate the process
- The barrier is located at an average depth of 10 meters. Even in ideal conditions where sediment movement is not affected, it would take 90 years to allocate 5 meters of sediment at the site. It would make no difference
- Sediment successfully accreted at the desired location would easily erode due to more and more extreme weather phenomena
-

Conclusion:

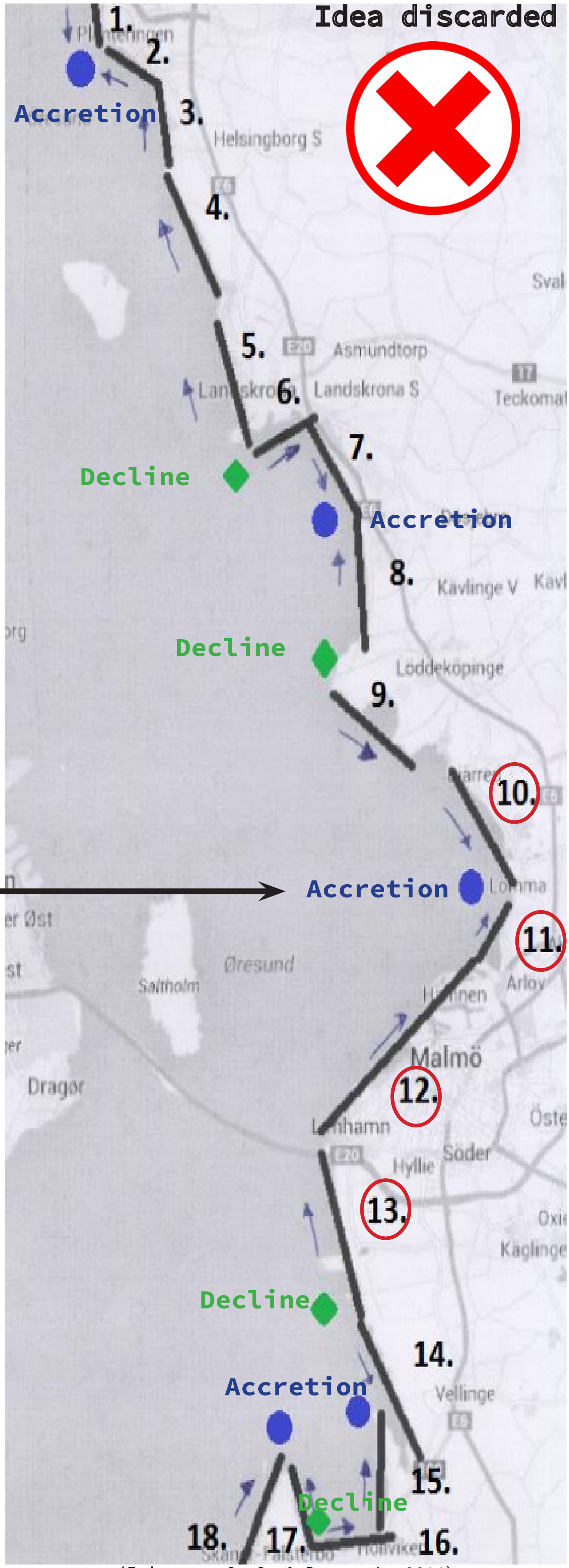
Improbable to succeed and too slow to meet the minimum required height by the year 2100.

Potential Sediment Transport



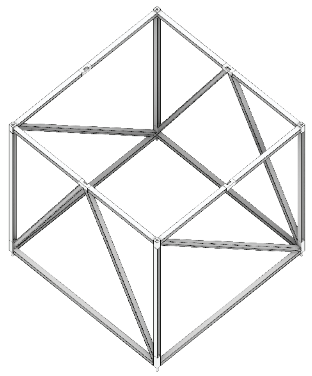
(Ericsson, S. S. & Renac, L. 2014)

Around 95 000 cubic meters of sediment flows toward Lomma annually



(Ericsson, S. S. & Renac, L. 2014)

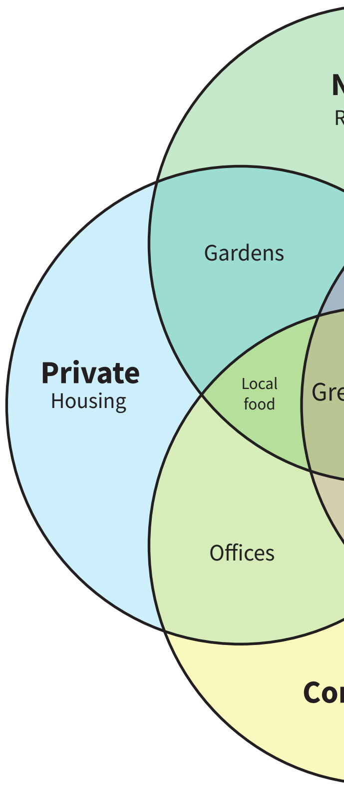
4.3 CONTINUOUS ALGORITHMIC AGGREGATION (CAA)



Aggregatable shape
- Mass produce-able
- Hollow
- Stackable
- Structurally sound

Image credit:
findskipbins.com

Construction waste
- Sustainable
- Geological material
- Does not end up in landfills

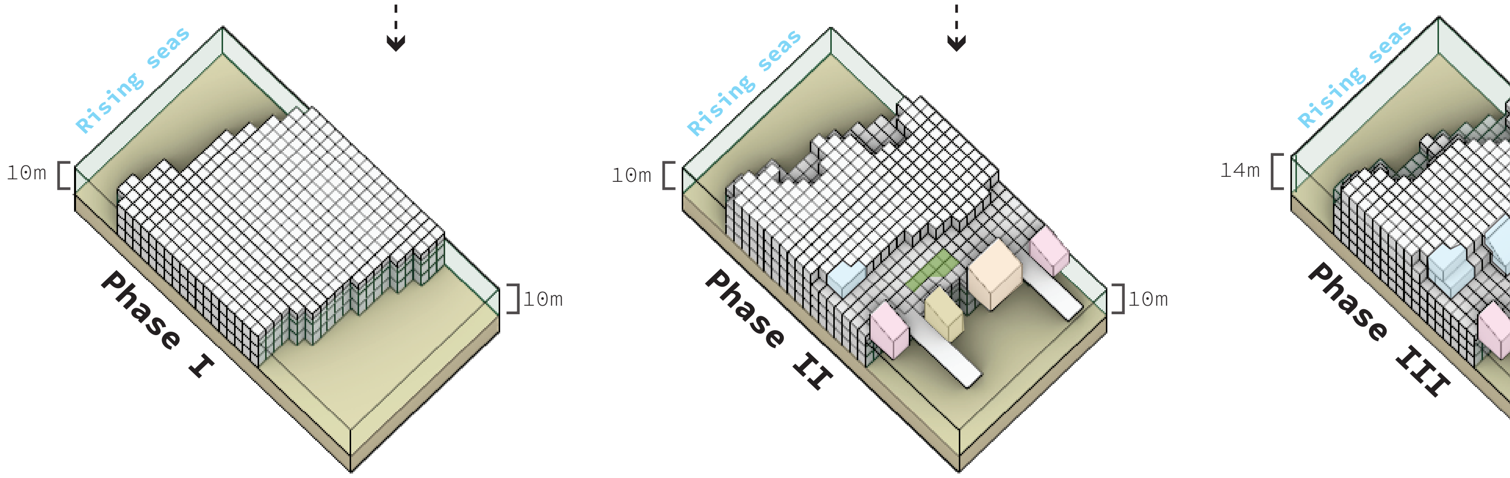


Laying a foundation

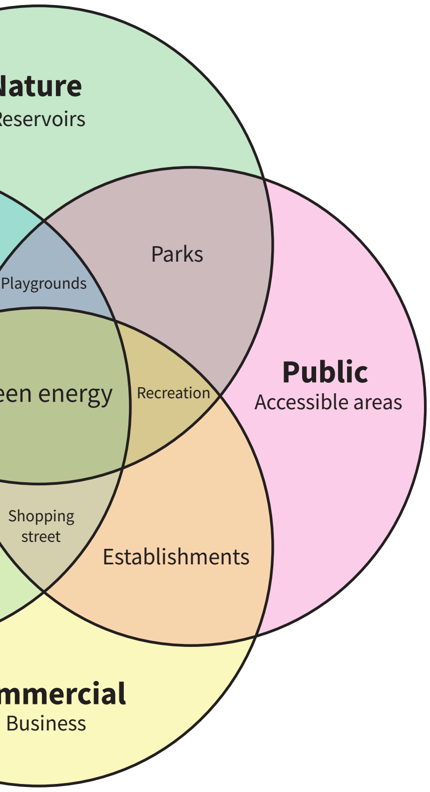
The concept relies on building a structure using an aggregatable shape and then filling up the structure with construction waste and other sediment to separate Malmö from the sea, creating a foundation that future engineers and architects can build upon.

Mixed development

As the height of the barrier will be incre
more protection for Malmö. Additionall
vast opportunities for sustainable devel
terms of housing but also in terms of ha



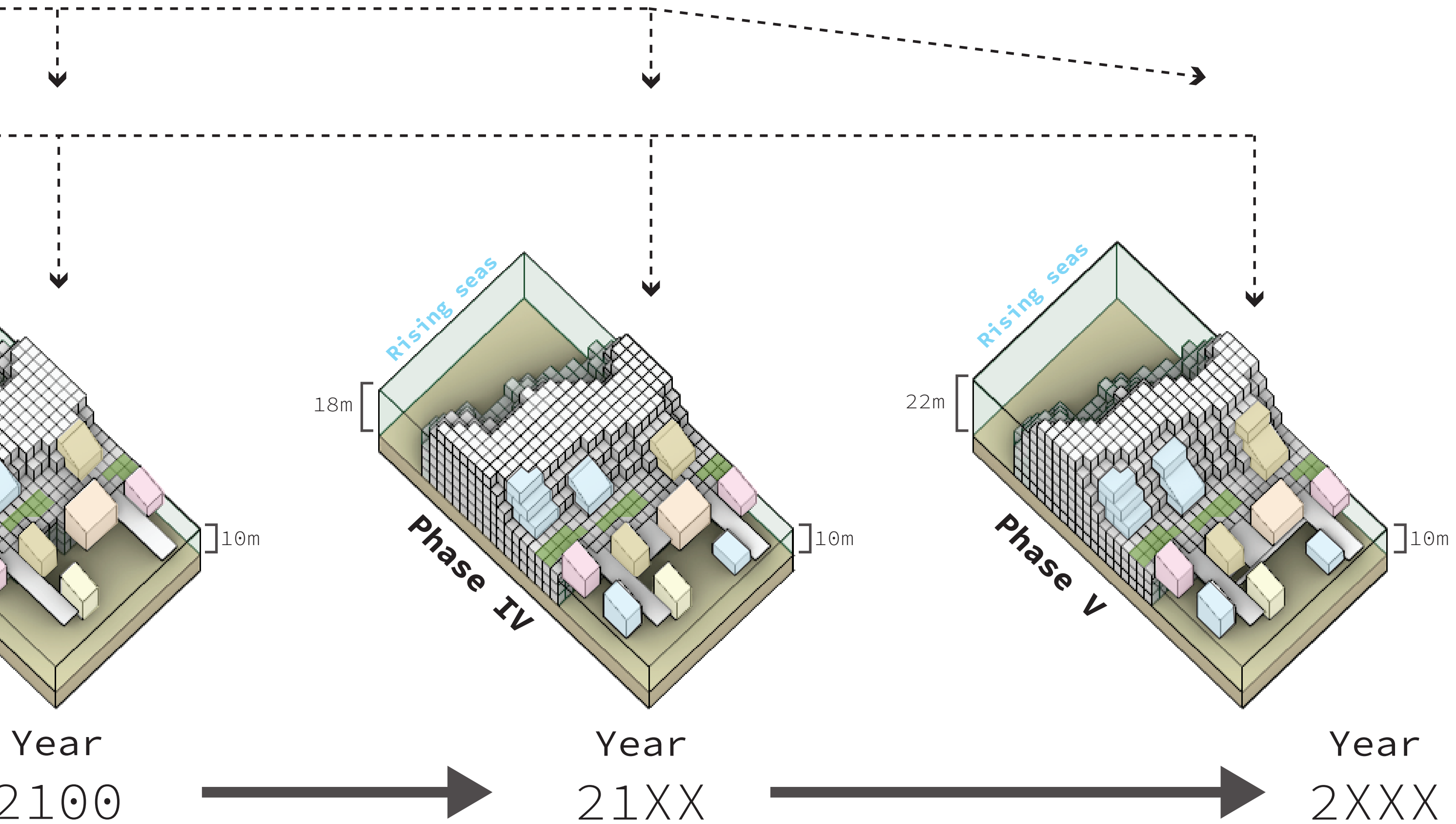
Year
20XX



ased in phases, each completed phase offers
y, as land is won from this process, there are
opment in the built environment, both in
arvesting energy from the sun and the sea.

An extension of Malmö

The population of the barrier should grow parallel to the height of the barrier. This can be done with traditional construction as well as floating buildings. Eventually, the barrier could become a natural extension of Malmö as a city.



4.4 WHY A CUBE?

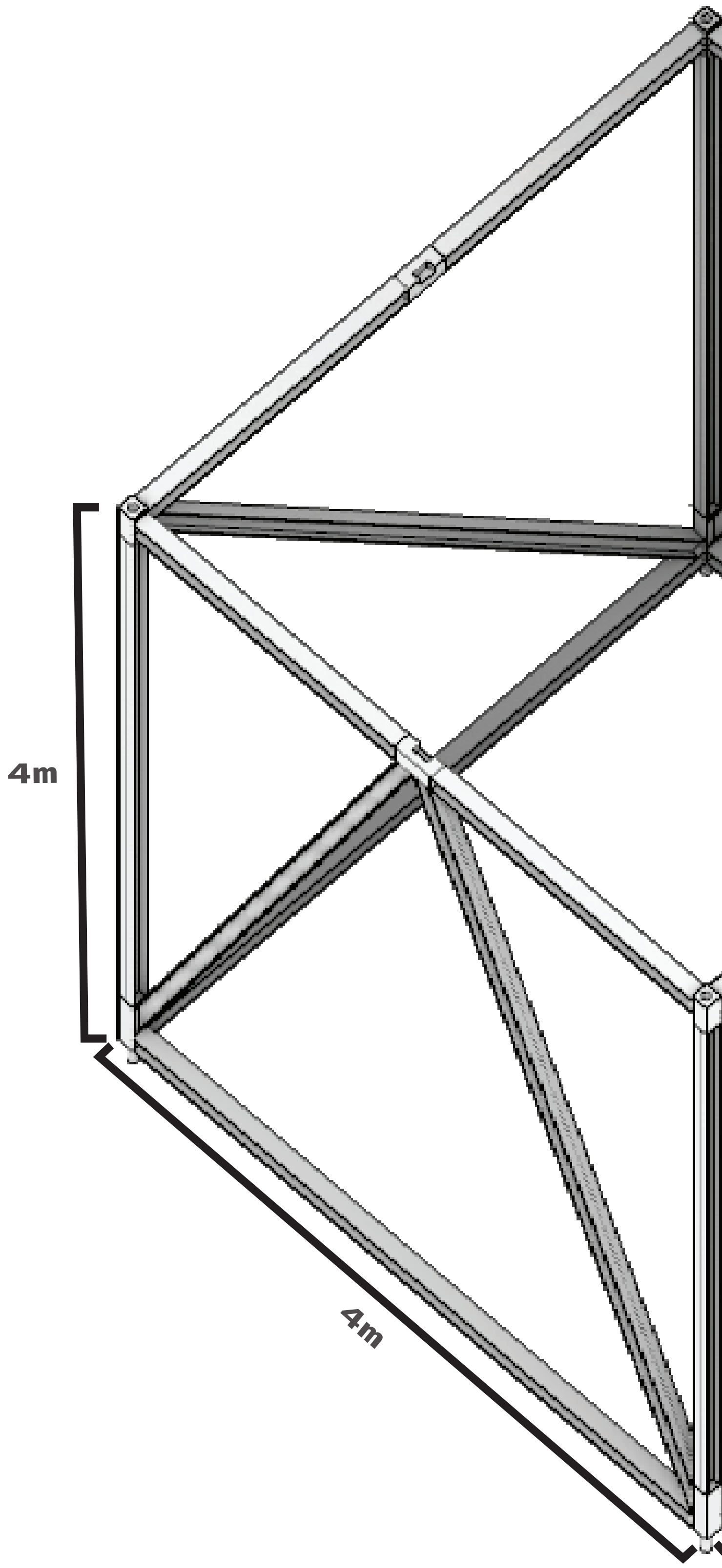
While deciding on the foundational geometry for the barrier, a cube shape became the decisive winner. Production is resource efficient and simple, transport is straightforward, assembly is minimal and the resulting geometry can easily be stacked and structured. Since most buildings built in Sweden today tend to follow a strictly rectangular shape, such buildings can be arranged and adjusted in accordance with the perpendicular nature of the cubes. Hence, no other shape beat the simple production, transport, assembly, structure and constructional flexibility of a cube.

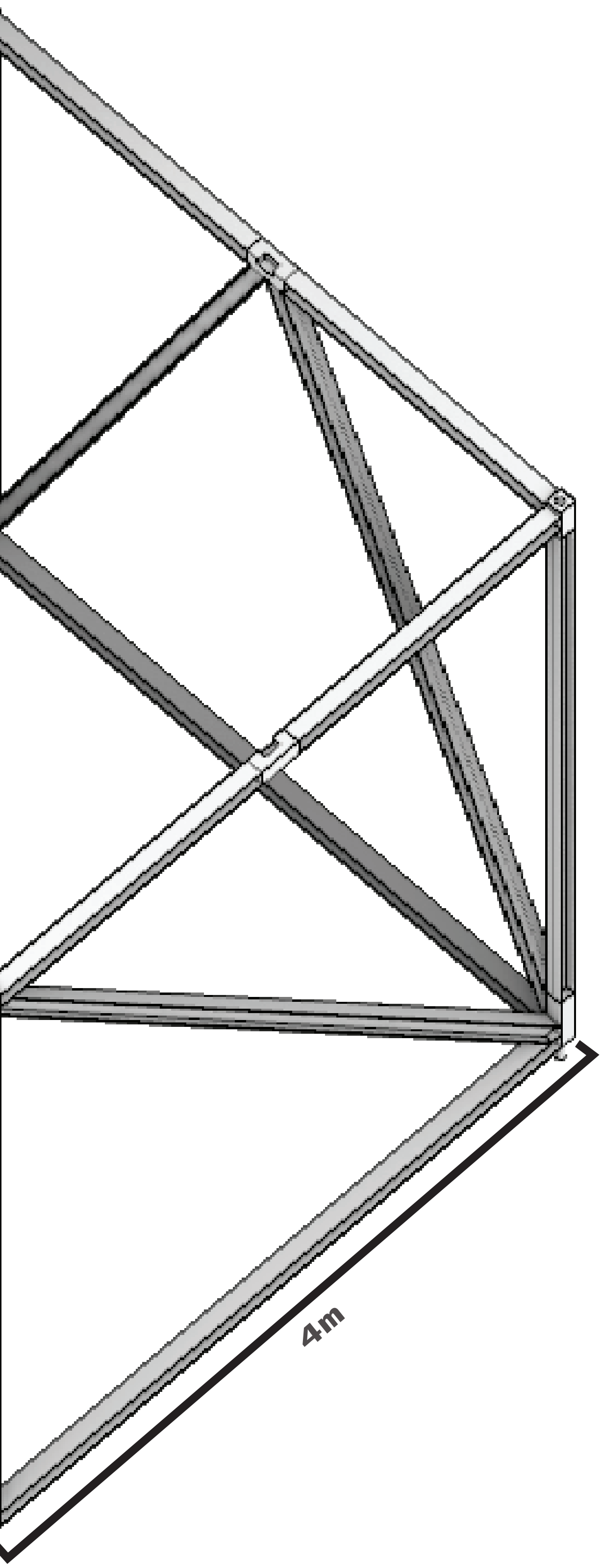
The 4x4x4 meter dimensions of the cubes are based on the conclusion that:

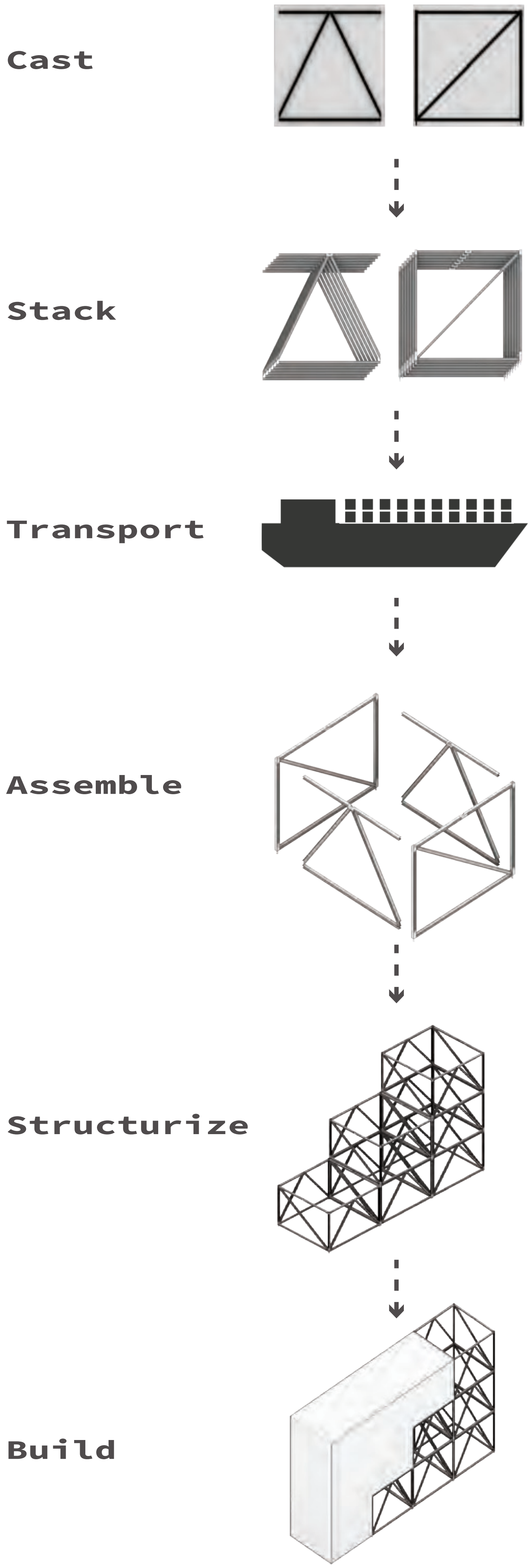
- Due to the length and height of the wall, larger cubes will cover more ground and height, resulting in less cubes needed and therefore less material used.

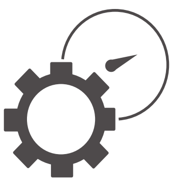
- A 4x4 meter space in terms of housing translates to rooms, so the cubes can serve as a foundation for housing.

Mentionable contenders were hexagons and triangles, as they also can be structured with ease, yet their drawback is that they require more material and also are less flexible when it comes to building upon them, in particular hexagons.

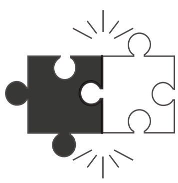








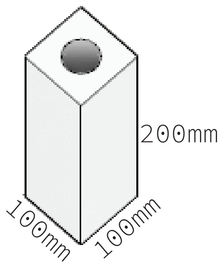
Readily producible



Building compatible

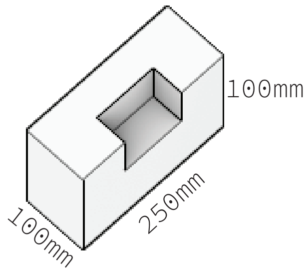
4.5 CUBE ANATOMY

Top Corners



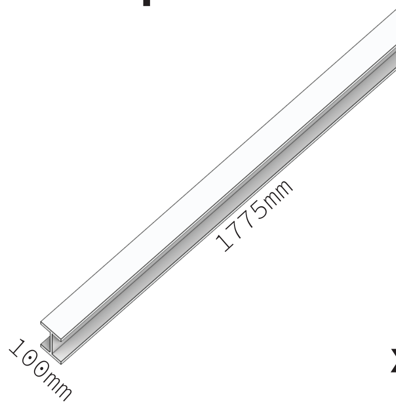
x4

Middle Niches

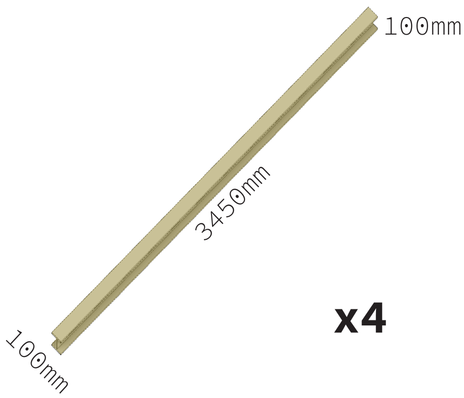


x4

Top frames

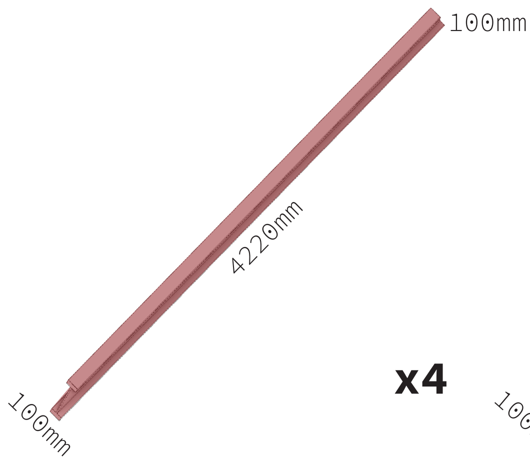


Frame corners



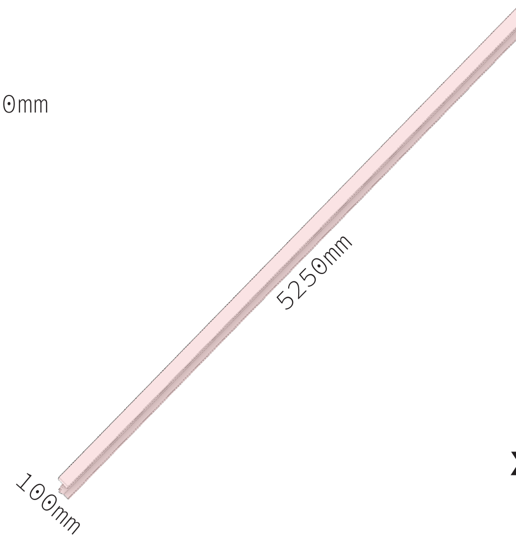
x4

Central supports

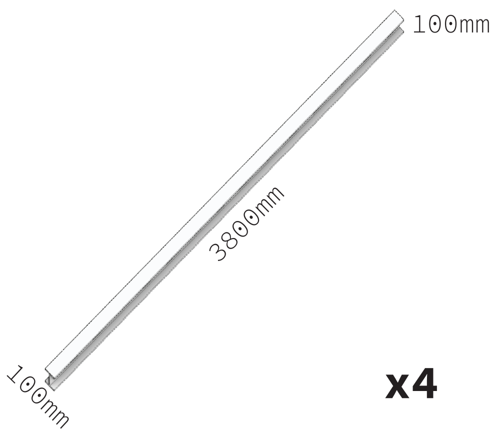


x4

Diagonal support

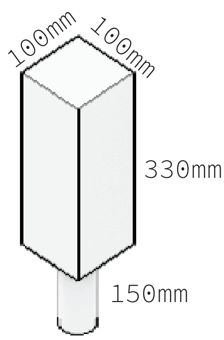


Bottom frames



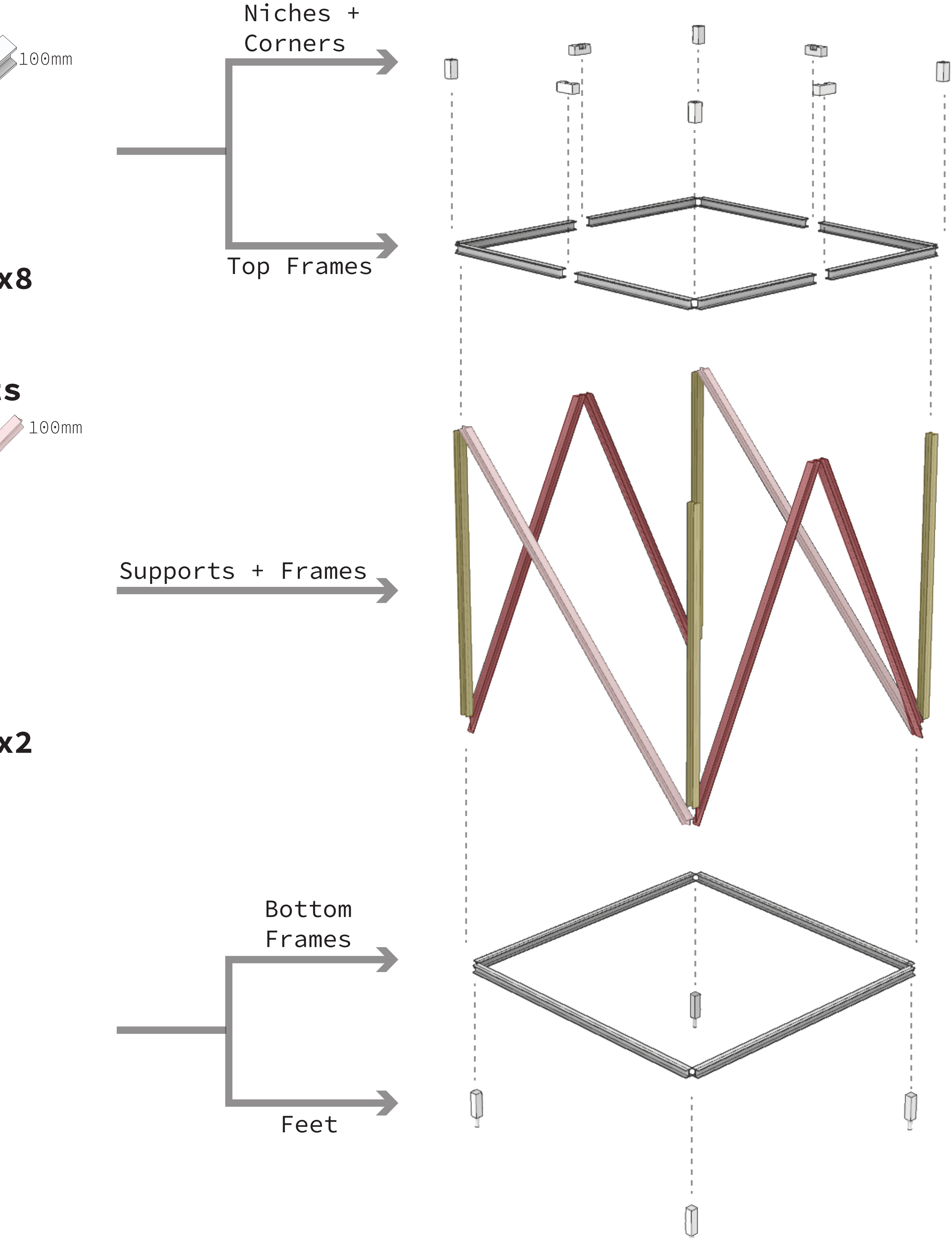
x4

Feet

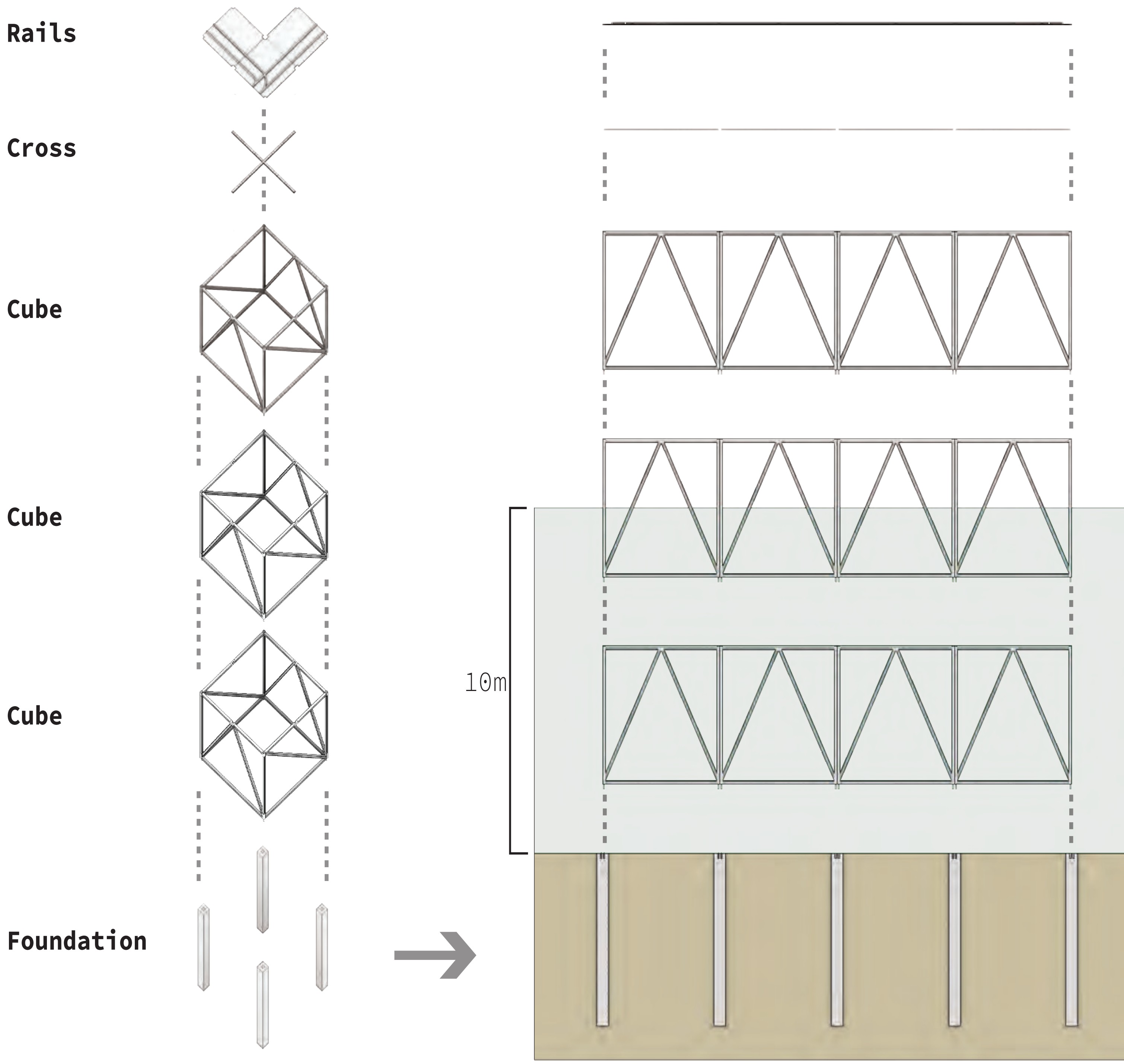


x4

Steel per cube
0.227 m³

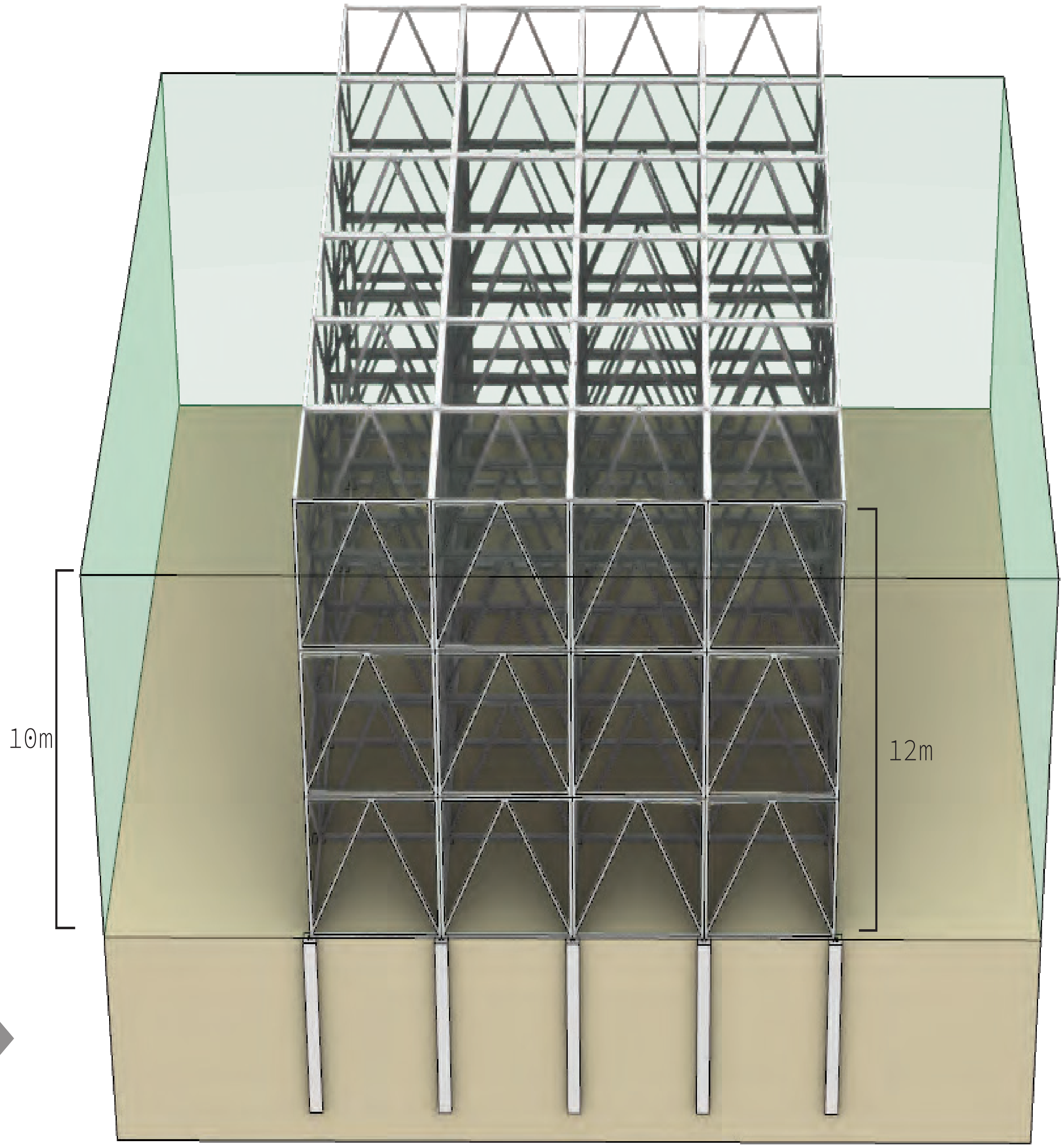


4.6 CUBE TO STRUCTURE



In order for the cubes to be anchored at the bottom of the sea, a grid of foundational pillars need to be placed in the sea floor. The cubes are designed to fit on top of each other, so

once the grid is in place, stacking the cubes is a straightforward process. A cross and rail can be placed on the upper side of the cube, and the rails are a means of automated logistics to fill the structure with sediment. As the cubes are



placed layer by layer, they will initially be arranged side by side. The integrity of the whole structure can be amplified if the cubes are welded together. When three layers of cubes have been stacked on top of each other, they will reach 2 m above current sea levels. When this is done on the whole barrier, phase 0 is completed.

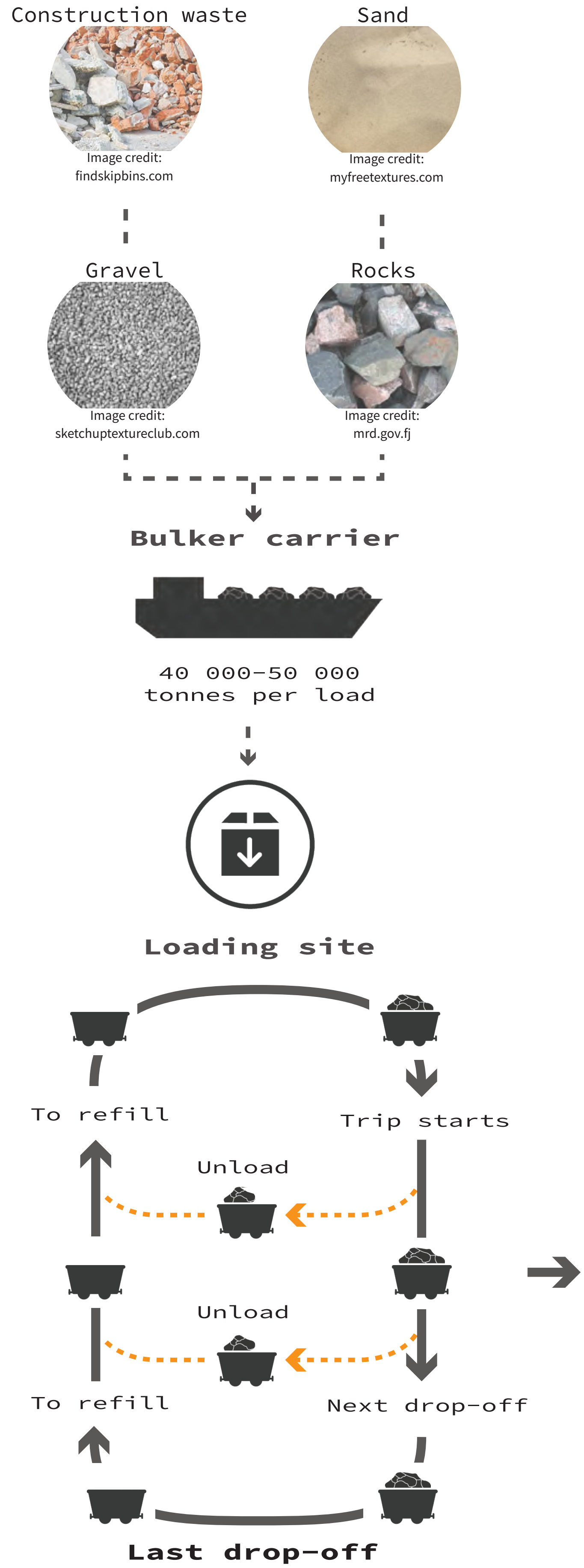
4.7 FILLING THE STRUCTURE

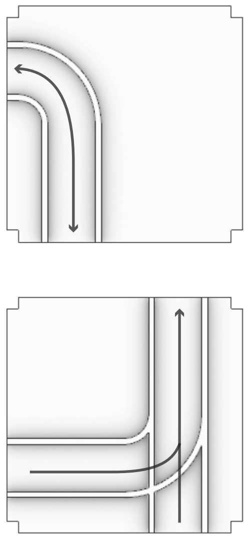
Annually, around 4.7 million tonnes (36%) of construction waste in Sweden ends up in landfills (naturvårdsverket, 2020). This type of waste is composed of wood, concrete, bricks, ceramics and metals. Since this waste is safe for the environment, it is a suitable material for filling up the barrier. To ensure the structure is watertight, smaller sediment such as sand, gravel and rocks should be poured into the structure as well. To ensure complete watertightness, liquid concrete may be necessary too.

To transport the huge amount of material needed to the site, a group of bulker carriers would be the most viable option, as they can carry vast loads fairly cheap, and because the site is located at the coast.

When the ships arrive in Malmö, they can either unload directly onto the wall where possible, or proceed to unload the materials at the drop off/loading site.

At the loading site, a legion of material transport rail carts stands ready to pour the material into the structure. For efficiency, the carts unload the cargo and take the shortest route back to the loading site. This system can likely be completely automated. Sensors that measure the height of the debris can be placed on the structure, with the purpose of instructing the carts where material is needed. To complete each phase in the calculated timespan, the carts would have to pour a total of 14 000 - 16 000 tonnes a day. Drones are an alternative automated option to complete this task, yet not with current technology. Perhaps in the future.





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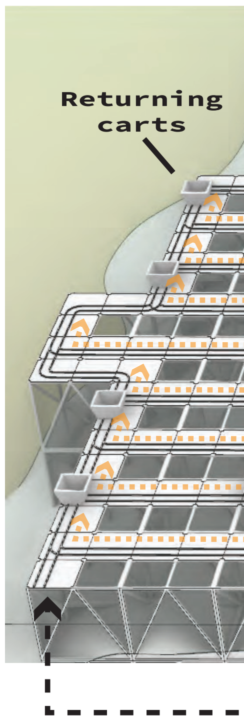
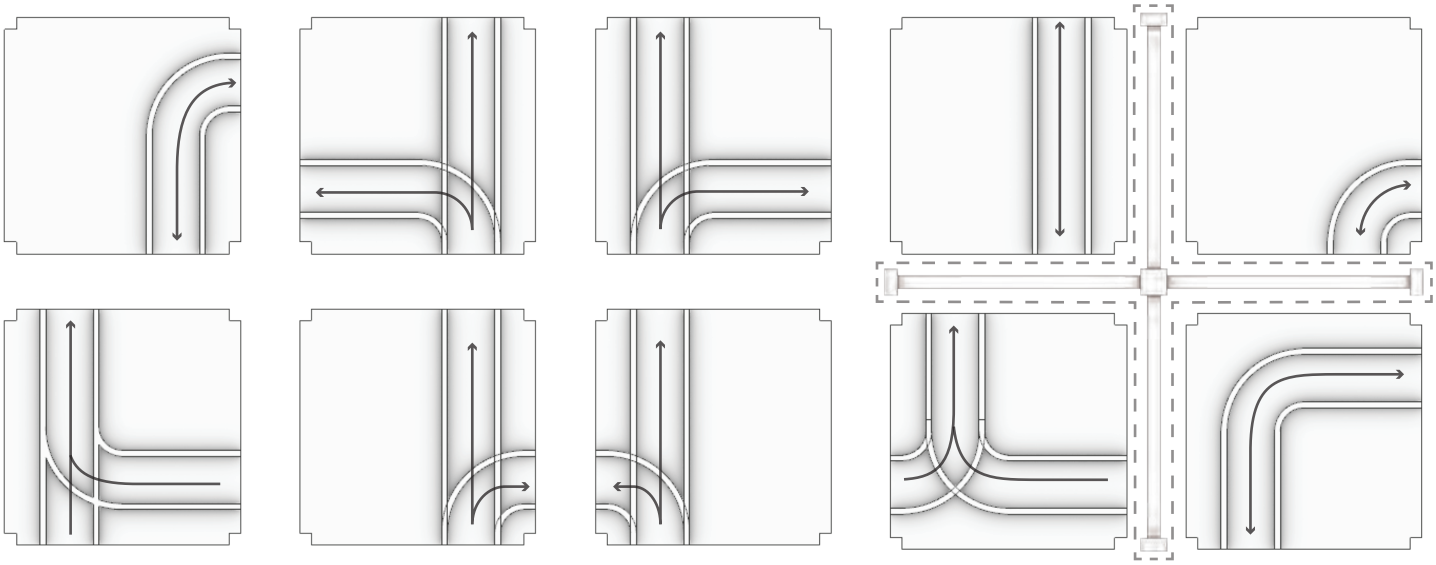


Track variations



lated form and
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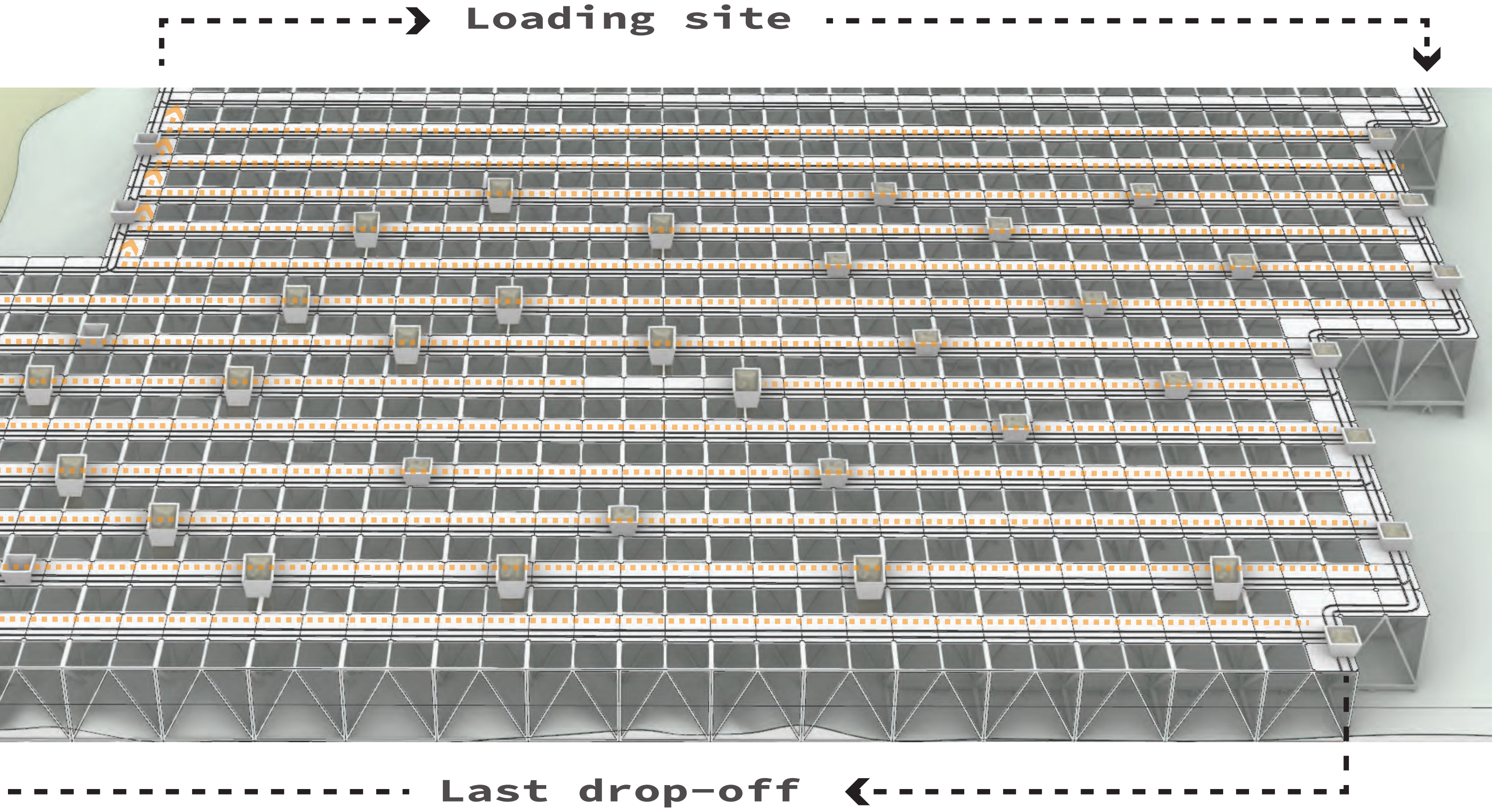
ed.

These twelve types of tracks overcame any directional problems that I encountered while experimenting with how the carts would have to pilot on the barrier. The rail carts can loop efficiently on the structure.

To place the tracks onto the cubes, a fitted cross is placed in the niches of the upper parts of the cube. The edges of the tracks are designed to fit the crosses and cubes, making tracks reuse-able in future phases.

Navigation example



1:32000

320m 1600m

N

In order to protect the entirety of Malmö from barrier stretches from the Öresund bridge, whic elevated slope in the south, onto the coast and northernmost part of the harbor. Ideally other Sweden would adopt the concept to protect their the barrier could extended along the coast inde other EU countries will connect to it as well.

A **sea sluice** is optional as it would come with pros and cons.

Pros:

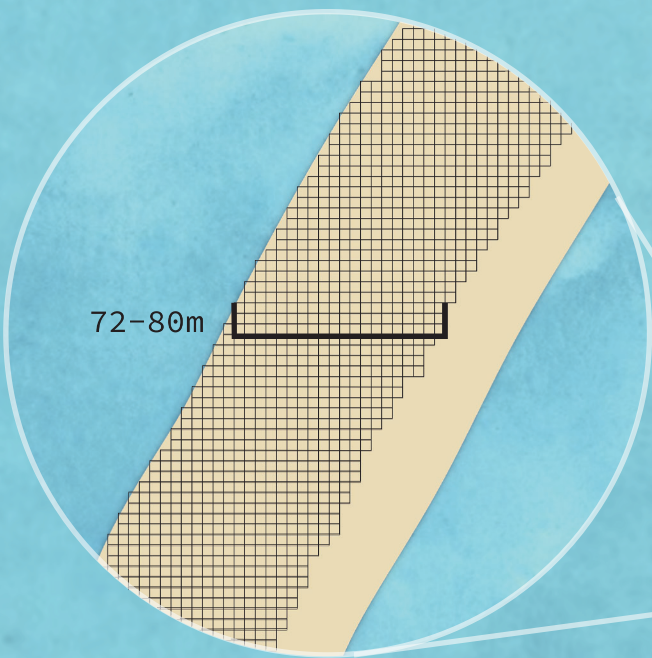
- Boats and ships can still access the city.
- A new harbor would not have to be constructed outside of the barrier.

Cons:

- Accessing the city would be slow.
- High maintenance and construction cost.

A habitable barrier

Cube based structure



rising sea levels, the
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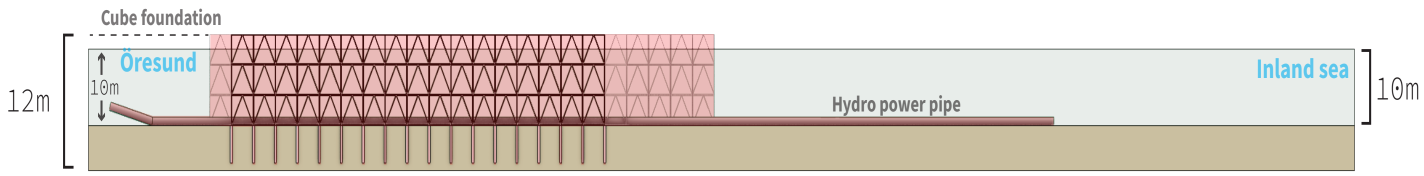
Completion prospects

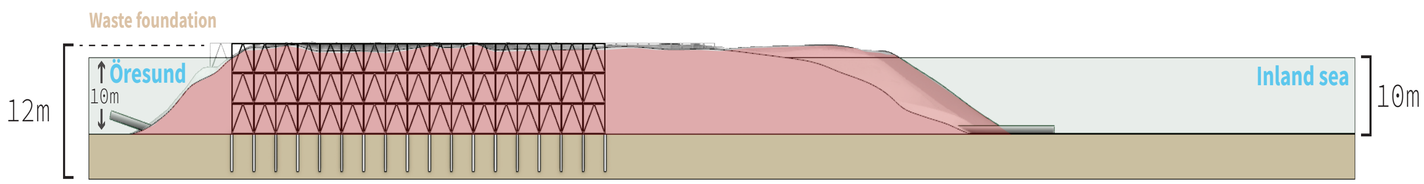
Wall length	**16 000 m**
Amount of cubes	**344 000**
Steel for cubes	**78088 m³**
Construction waste	**20 459 294 m³**
Land won	**1 101 062 m²**
Inland sea capacity	**11 572 841 m³**
Steel cost	**1.64 billion USD**
Fill up time frame	**7.8 Years**

4.9 Phase 0



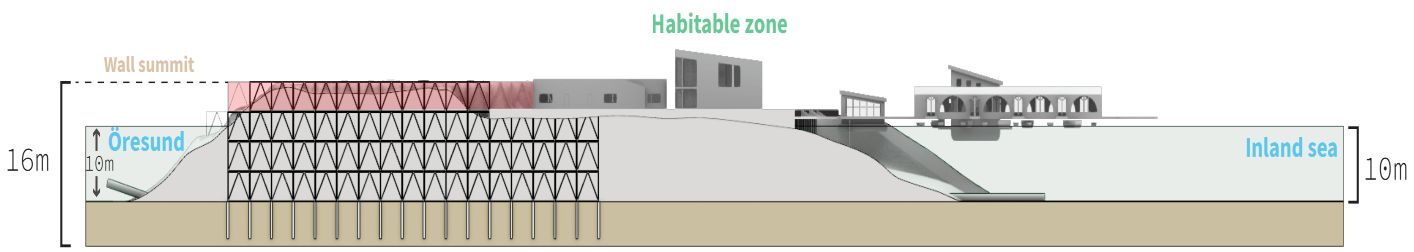
After the concrete foundation grid has been established in the seabed, three layers of cubes are stacked on top of each other to reach 2 m above the local sea level, serving as a frame for the rail tracks. Additionally, pipes are placed along the sea bed as a basis for hydro power or for controlling the water level of the inland sea in the future. When the rails are placed on top of the cubes, phase I can commence.

4.10 PHASE I

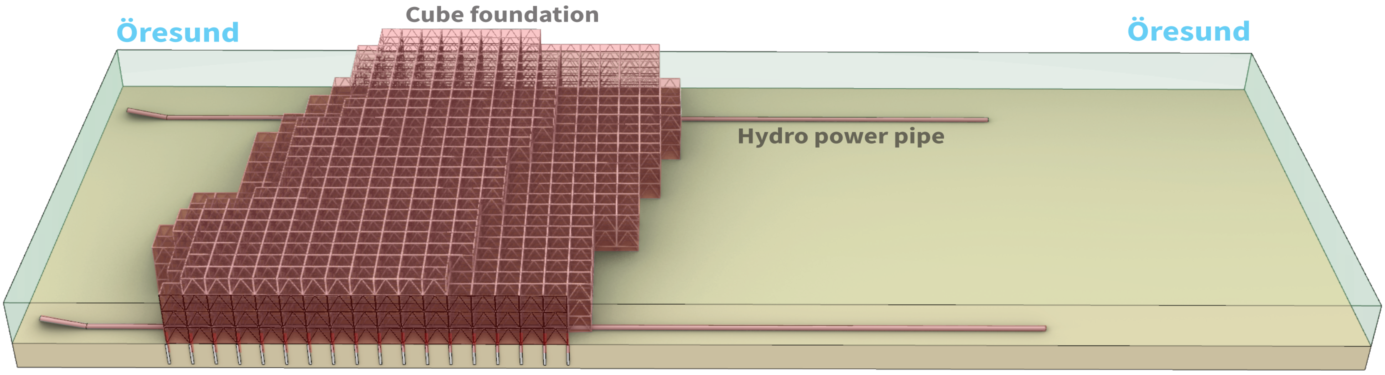


The goal of phase I is to fill the cube frame with building waste such as concrete, bricks, gypsum, wood, ceramics and rocks, gravel and sand to solidify an artificial barrier that separates coastal Malmö from Öresund. When completed, Malmö will have significantly reduced the risk flooding as well as having laid a foundation that can become a lucrative development area for the city. At this stage, the barrier consists mostly of debris, so it is likely not habitable yet.

4.11 PHASE II



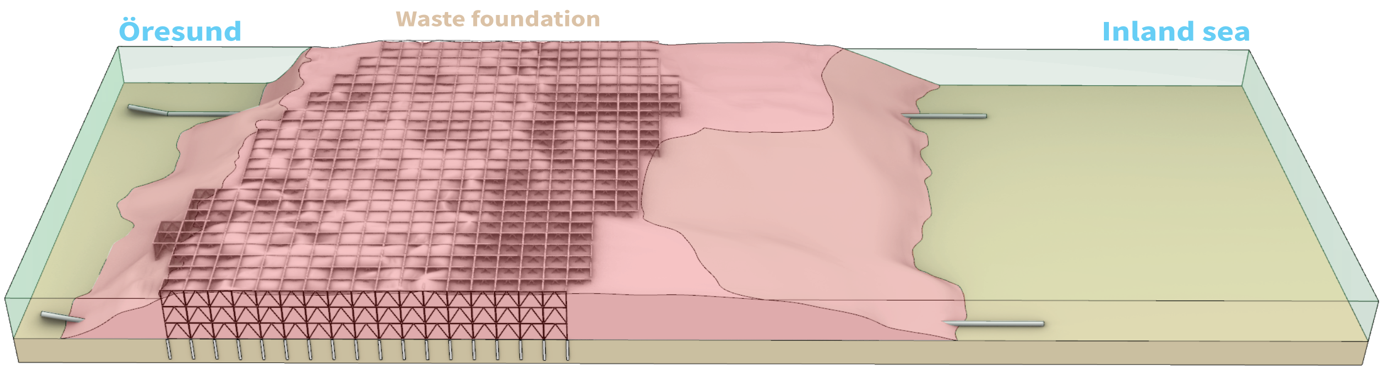
Phase II aims to provide an additional 4 meters of protection in anticipation for increased sea levels. By now, sand and dirt should cover the interior side of the barrier, making it somewhat habitable for people, animals and plants.



Amount of cubes
216 000

Construction waste
—

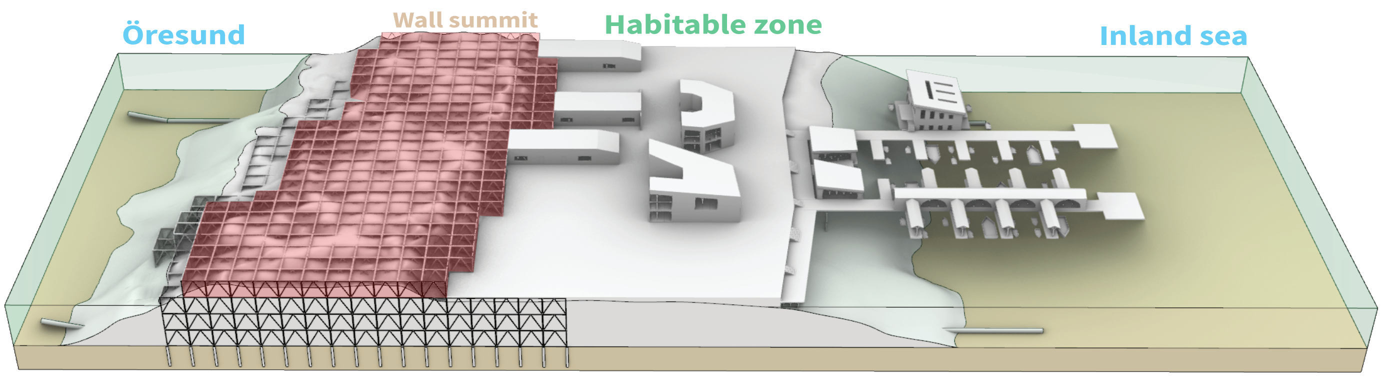
Fill up time
—



Amount of cubes
—

Construction waste
13 460 299 m³

Fill up time
5.15 Years

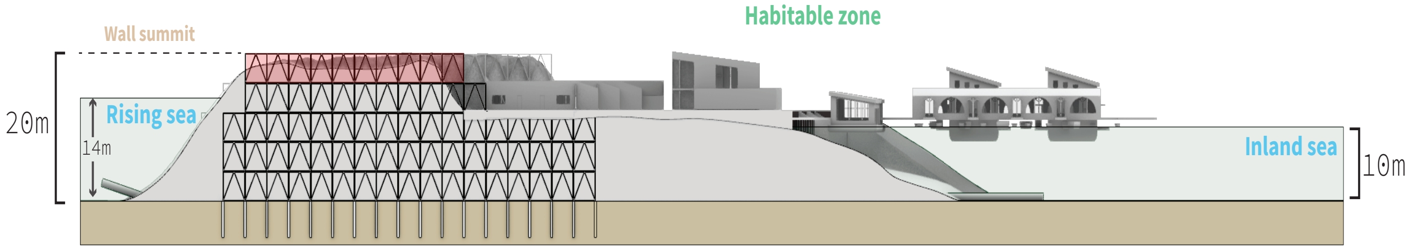


Amount of cubes
44 000

Construction waste
2 499 601 m³

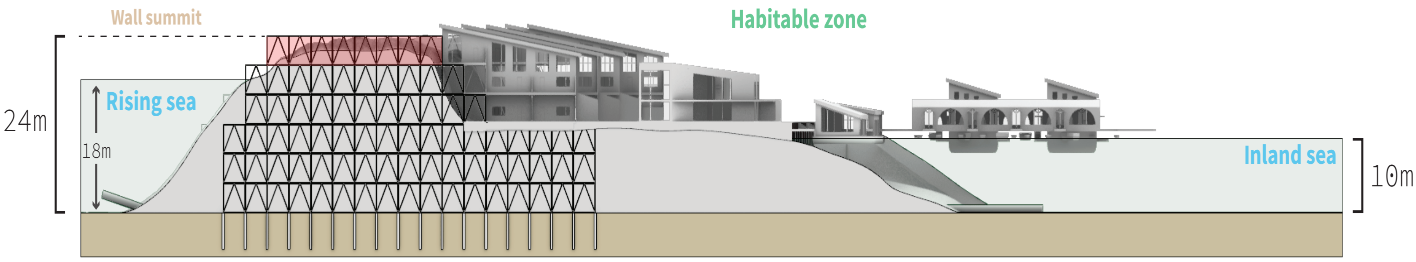
Fill up time
346 Days

4.12 PHASE III



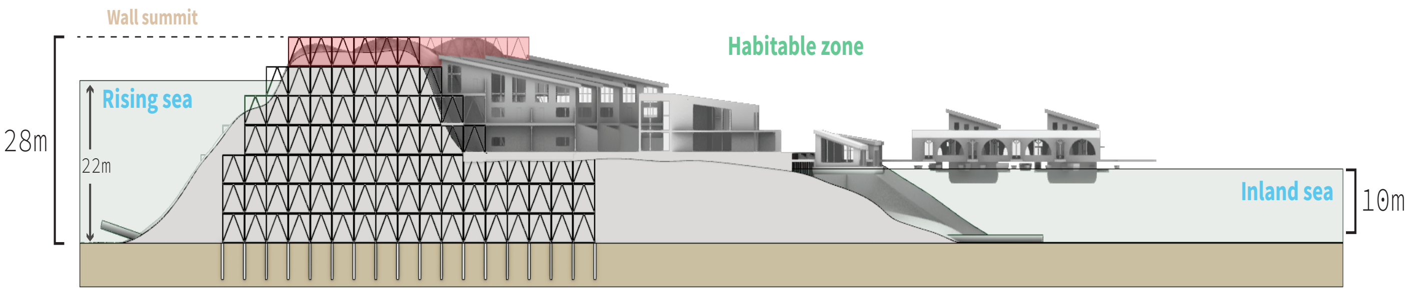
By phase III, the year is 2100, and global sea levels have risen by four meters. As the sea is expected to rise further, an additional layer of cubes is stacked on the existing structure, and the fill up process is continued. As the sea now is 4 meters higher than the inland sea, harvesting hydro power can commence.

4.13 PHASE IV

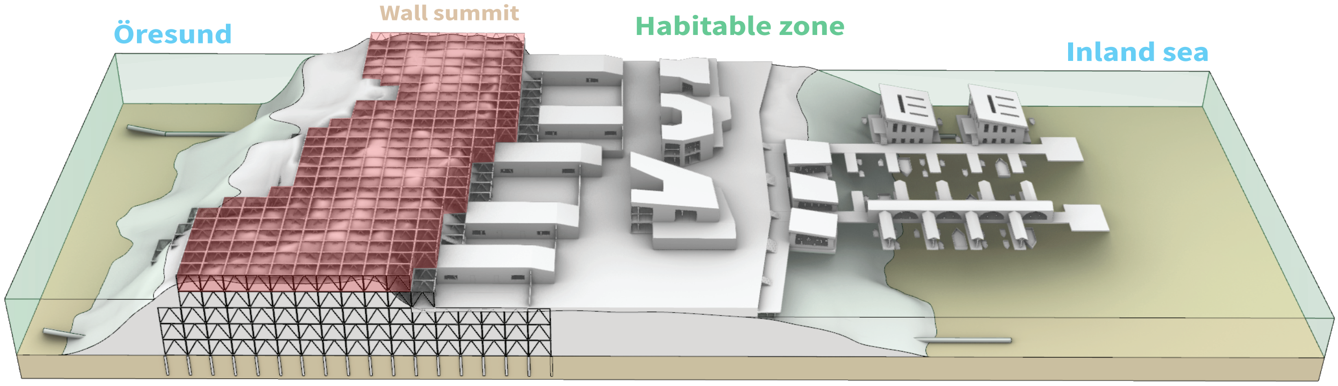


By phase IV, sea levels have risen 8 meters above current sea level. In anticipation for a further increase of 4 meters, an additional layer of cubes is placed on the existing structure. If the buildings on the barrier were designed with the height increase of the wall in mind, the next module can be placed on top. The barrier should be well populated at this point.

4.14 PHASE V



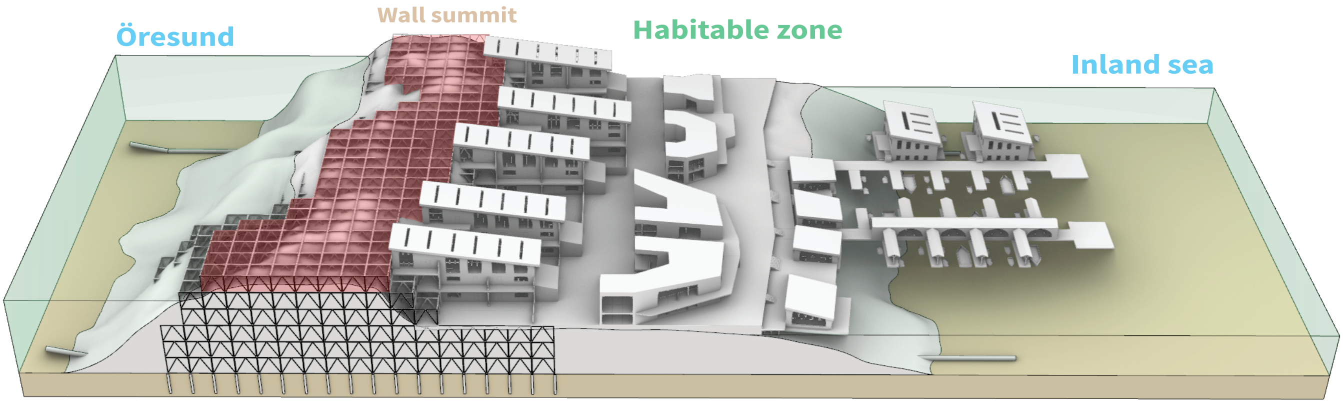
In phase V, the goal of protecting Malmö from a twelve meter increase in sea level has been achieved. In phase V, the barrier may be an active extension of Malmö.



Amount of cubes
36 000

Construction waste
1 999 723 m³

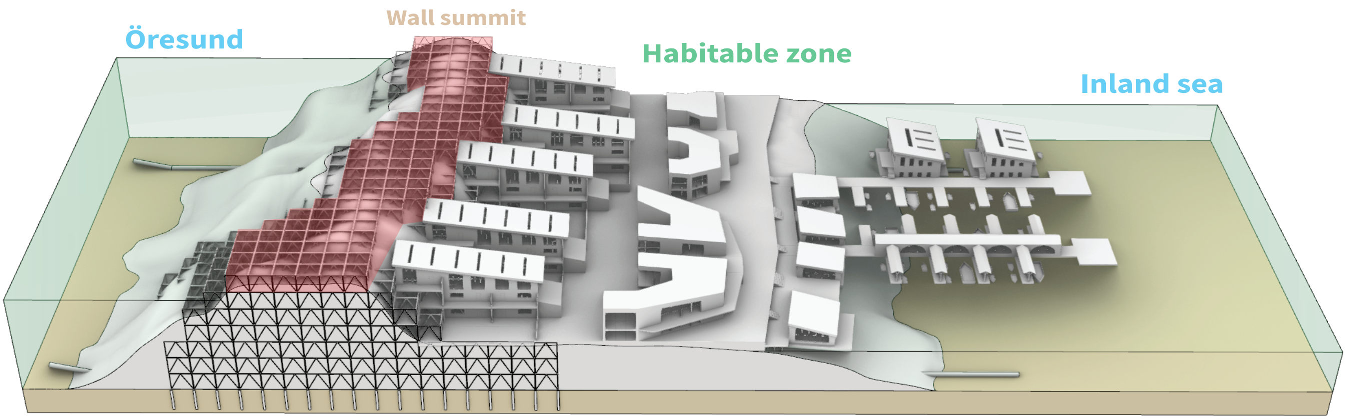
Fill up time
277 Days



Amount of cubes
28 000

Construction waste
1 499 828 m³

Fill up time
209 Days



Amount of cubes
20 000

Construction waste
999 843 m³

Fill up time
138 Days

4.15 TIME AND RESOURCE CALCULATIONS

Like any other infrastructure project, a habitable sea barrier would be time and resource-intensive. Another pressing question is whether this process and resulting structure can be completed before the year 2100.

Truthfully, I could not make a time estimate about how long it would take to build the skeletal structure of phase 0, as the number of workers and machinery, as well as their efficiency, is unknown in such a new and experimental process. Additionally, it is unlikely that I could give a realistic time frame for how long the preparation of the site as well as actual cube placement would take, as again, it is an experimental process.

However, it was possible to calculate the sediment volume needed to fill the structure, as well as the total cost of the steel cubes based on contemporary prices. Hence, this part of the essay presents the excell sheets that calculate the steel price and sediment pouring time in order to verify that the structure indeed is a financial and chronic option.

SEDIMENT REQUIREMENT CALCULATION

According to a 2020 report from the Swedish Environmental Protection Agency, Swedens' annual construction waste in 2018 was 13 million tonnes, of which:

- 840 000 tonnes (6%) is dangerous
- 6,1 million tonnes (47%) are recycled for construction
- 1,4 million tonnes (11%) are put into conventional recycling
- 4,7 million tonnes (36%) end up in landfills (Naturvårdsverket, 2020)

Since 4,7 million tonnes of construction waste ends up in nature anyhow, it seems like a cheap and readily available choice of material to fill up the structure with. The calculations for the filling process are based on the idea that these 4.7 million tonnes are provided for the barrier.

	Phase volume (m3)	Construction waste weight per m3 (kg/m3)	Construction waste needed (tons)	Years (4.7 mil tons /year)	Material poured (tons/day)
Phase 1	13 460 299	1800 (1.8 t)	24 228 538.2 tons	**5.15 Years**	14 745 tons
Phase 2	2 499 601	1800 (1.8 t)	4 499 281.8 tons	**0.95 Years**	15 408 tons
Phase 3	1 999 723	1800 (1.8 t)	3 599 501.4 tons	**0.76 Years**	14 115 tons
Phase 4	1 315 639	1800 (1.8 t)	2 699 690.4 tons	**0.57 Years**	14 832 tons
Phase 5	999 843	1800 (1.8 t)	1 799 717.4 tons	**0.38 Years**	16 510 tons
Total	20 459 294		36 826 729.2 tons	**7.8 Years**	

STEEL CALCULATION

For this proposal, the steel cost is based on the assumption that all cubes are made of steel. In fact, it would be possible to make the cubes within the wall out of wood, as this wood could manage to support the overlying cube structure until the material is poured into the wall. By the time the wood would rot, it would be surrounded by construction waste. Therefore, the price for the cubes may be lower than is presented here.

	Length of wall (m)	Amount of rows (in cubes)	cubes/ row	cubes/phase	Steel volume/ cube (m3)	Total steel needed (m3)	Cost per m3/steel (USD)	Cost of processing steel (x3) in USD
Phase 1	16 000	4 000	54	216 000	0.227	49 032	343 224 000	1 029 672 000
Phase 2	16 000	4 000	11	44 000	0.227	9 988	69 916 000	209 748 000
Phase 3	16 000	4 000	9	36 000	0.227	8 172	57 204 000	171 612 000
Phase 4	16 000	4 000	7	28 000	0.227	5 356	44 492 000	133 476 000
Phase 5	16 000	4 000	5	20 000	0.227	4 540	31 780 000	95 340 000
Total	16 000	4 000		344 000		78 088	546 616 000	1 639 848 000

A COST COMPARISON

In US dollars, the price for the steel required for the entire sea barrier is around 1.6 billion USD. In SEK, Sweden's currency, this amount is roughly SEK 16 billion. In comparison, the Öresunds bridge, a large-scale infrastructure project to connect Denmark and Sweden with a road and rail track, along with its city tunnel, cost a staggering SEK 46.3 billion (Wessman, J. 2015).

The Öresunds bridge

Image credit: oresundsinstituttet.org

It could be argued that the additional costs for the barrier that I could not account for may make the total price of the habitable sea barrier fall within the price range of the Öresunds bridge. Considering the cost-saving protection that the sea barrier would provide for Malmö, along with the urban development potential, the barrier is a solid infrastructure project.

5. ARCHITECTURAL PART

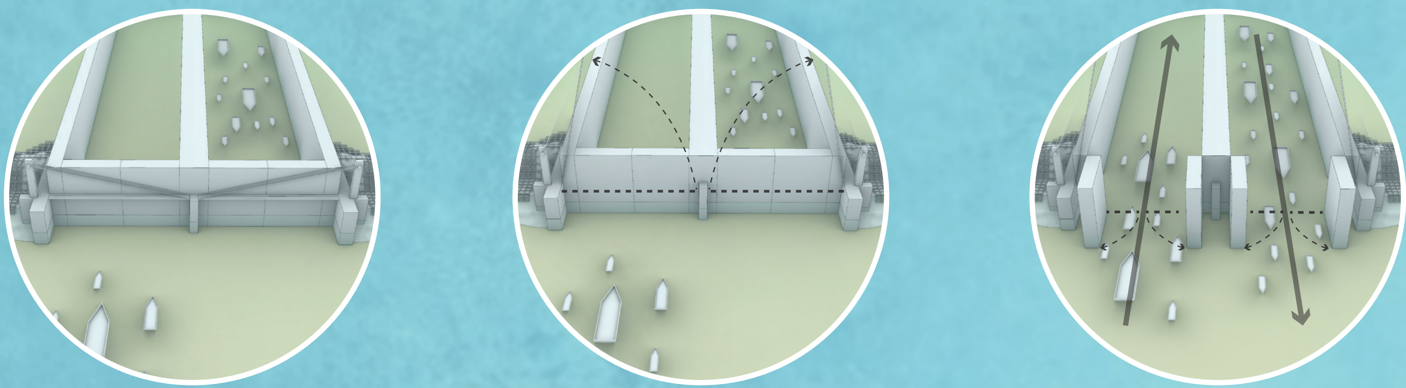
5.1 LOGISTICS & TRANSPORT

1:32000

320m 1600m

N

Sluice and transport cart solution



Closed gates   Tracks lifted   Gates opened

If a sluice is installed, it would certainly affect the looping of the material transport carts. Hence, a draw bridge can be placed in front of the sluice gates, which would lift up this section of the tracks before the sluice gates are opened. This would temporarily put the fill-up process on hold, yet this solution is likely the most feasible to ensure that the sluice and filling up process function properly.

“No” to motorized traffic

Due to environmental concerns and the development of self driving cars, motorized traffic is expected to progressively decrease in the future. Additionally, the slim width of the habitable zone on the barrier makes space for traditional motorized transport unsuitable. Hence, the concept of car traffic to, from and on the barrier is dismissed.

Instead, habitants and visitors of the barrier will commute with boats on the newly established inland sea. Private boat owners will experience a similar liberty as with cars, but of course there must also be a public option for transport.

Conventional transport

- Minor traffic roads
- Major traffic roads
- Coast stops

Maritime transport

- Transport between barrier and city
- Transport along barrier
- Sea barrier stops

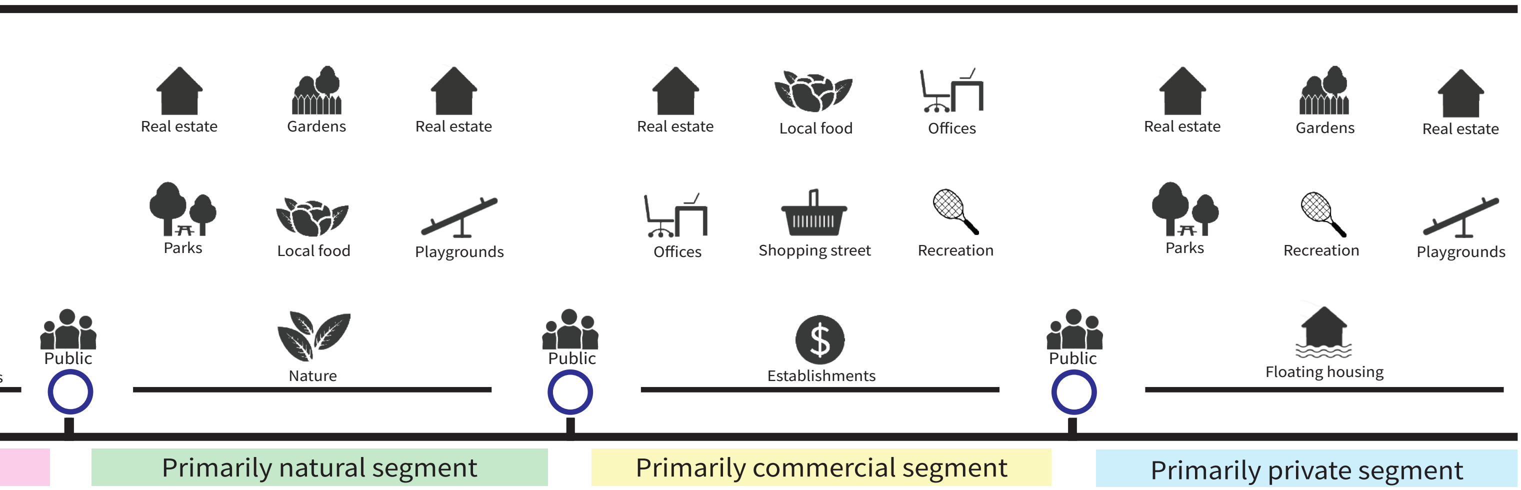
Drop off spot

- Material drop off for rail system

5.2 SEGMENT DIVISION

The public boat stops effectively divide the barrier into segments. On these individual segments, the development ven diagram can be applied. Some segments may be designed to serve a primary function, yet it is of course possible to make a segment that is truly mixed. Deciding on what segment should serve what purpose is a decision that Malmö as a city can make with expertise from city planners.

e segments



5.3 SUSTAINABLE COLONIZATION

Artificial Reef

Image credit: Reef Design Lab

Marine habitat

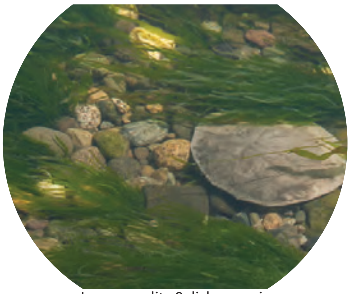
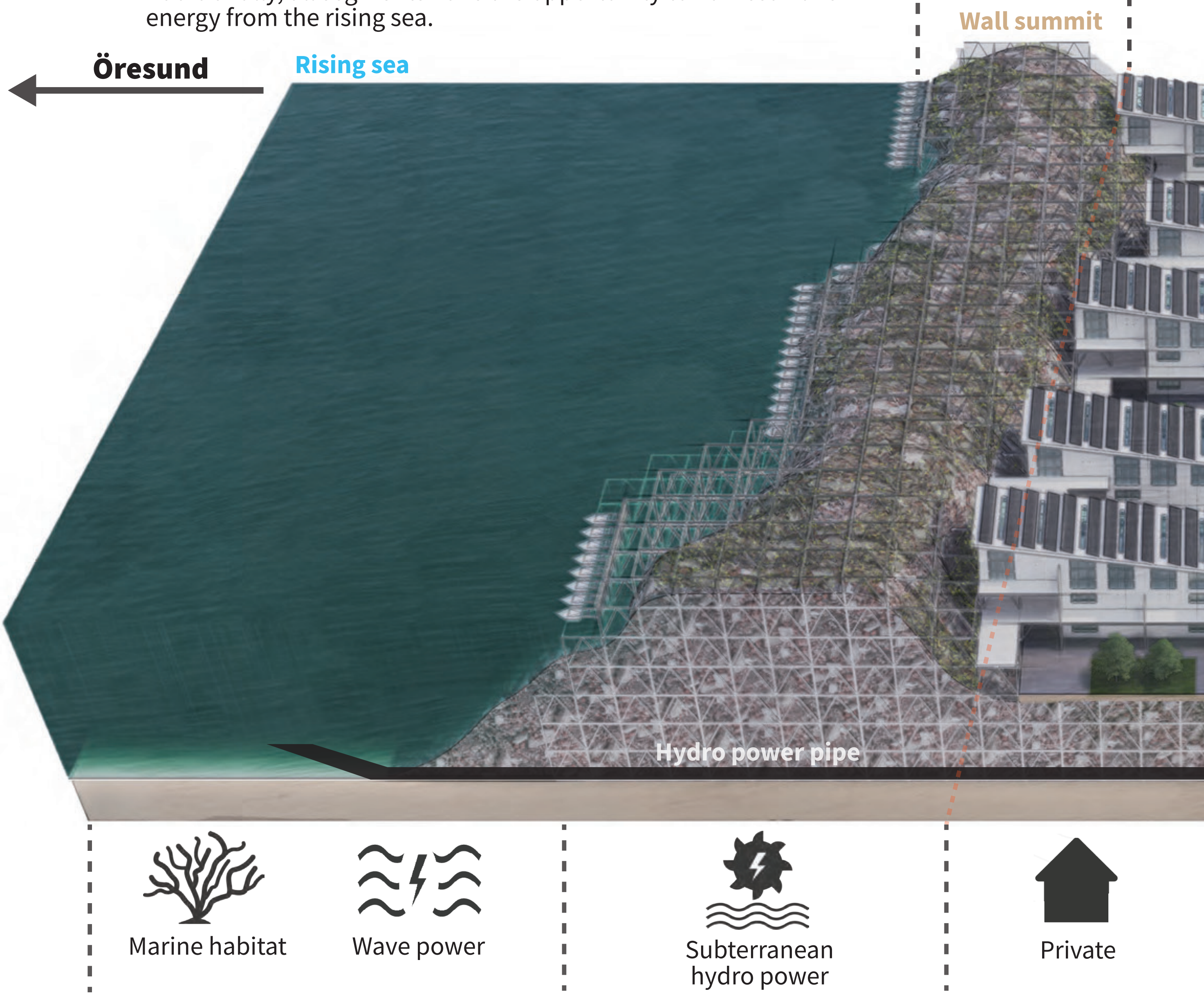


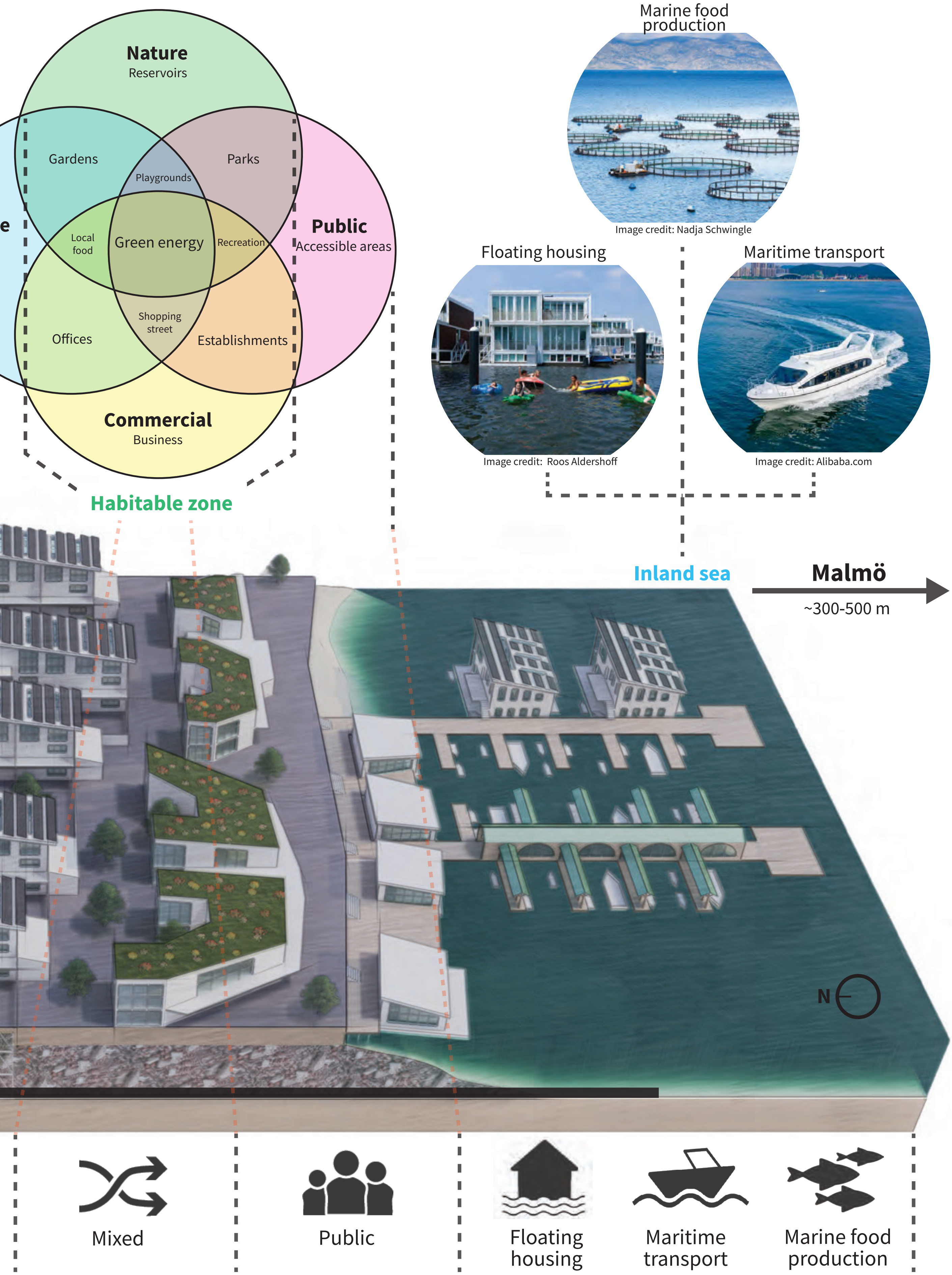
Image credit: Salishmagazine

Wave power

Image credit: Eco Wave Power

Due to the relatively slim width of the habitable zone, a guiding concept was required to ensure that private areas are private and public areas are public. Hence, the ven diagram can also be applied to the habitable zone, further ensuring variety and sustainable development in the built environment. In this visualization we see a primarily public segment, which is densely populated. Additionally, all segments have the opportunity to harvest wave energy from the rising sea.





Nature
Reservoirs
Gardens
Parks
Playgrounds
Local food
Green energy
Recreation
Public
Accessible areas
Offices
Shopping street
Establishments
Commercial
Business
Habitable zone
Marine food production
Image credit: Nadja Schwingle
Floating housing
Maritime transport
Image credit: Roos Aldershoff
Image credit: Alibaba.com
Inland sea
Malmö
~300-500 m
N
Mixed
Public
Floating housing
Maritime transport
Marine food production

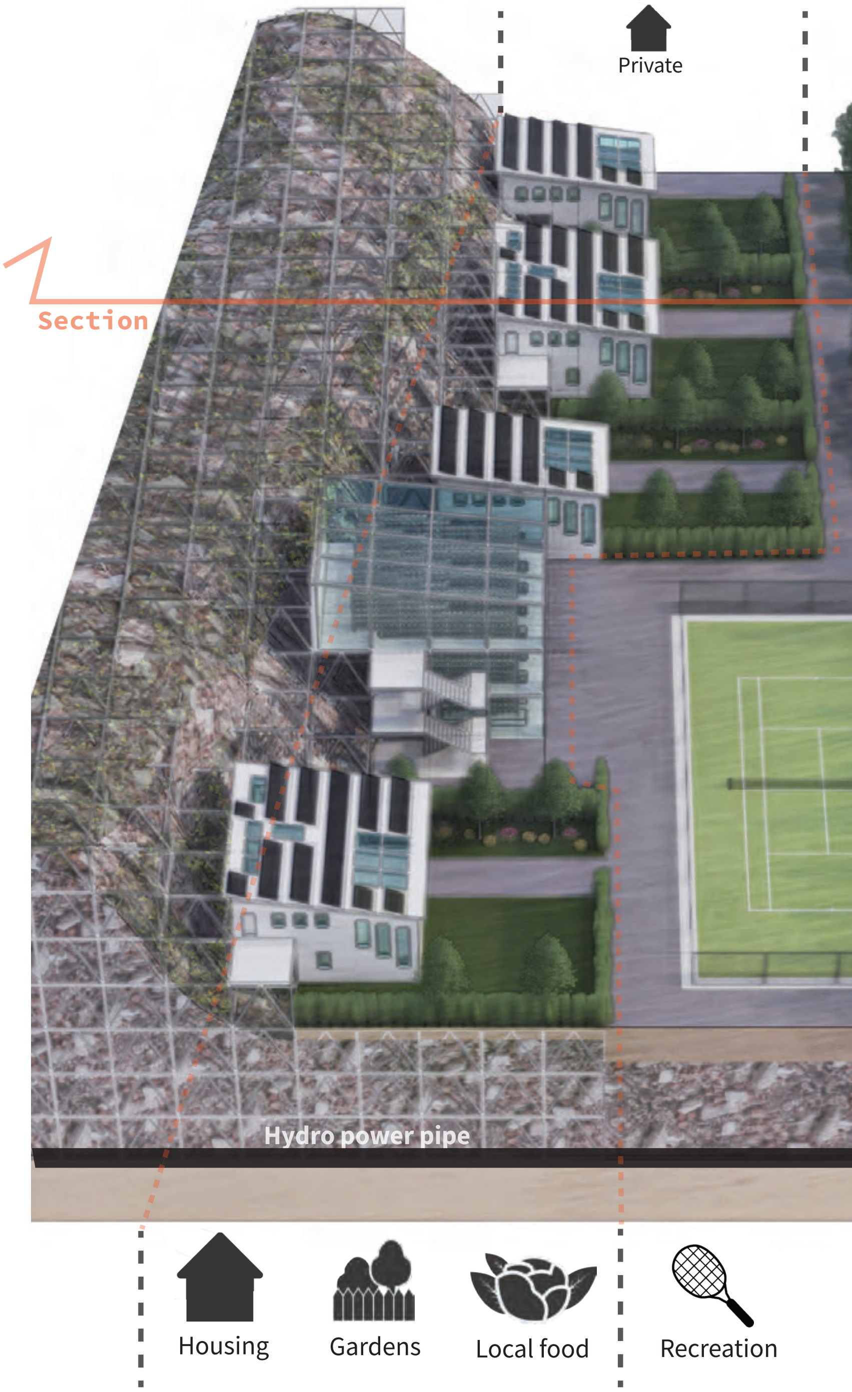
5.4 PRIVATE SEGMENT

A primarily private segment focuses on private ownership, privacy, local food production as well as vegetation.

In the **private area** of the segment, there is a focus on house ownership rather than compact apartment living. In my example, the housing that is built onto the barrier are two to four room lofts that vary from 92 to 108 square meters, each with a garden that is between 200-230 square meters. As lofts tend to have slanted roofs they are also an ideal choice for harvesting solar power. The roof windows are optional, yet their existence ensures plenty of daylight intake, as the southern side of the lofts faces the barrier. Another construction option is hydroponic greenhouses, as they become more efficient when built in height. Hence, they are perfect to be built directly onto the barrier. The greenhouse in this visualization can hold 1 860 crops.

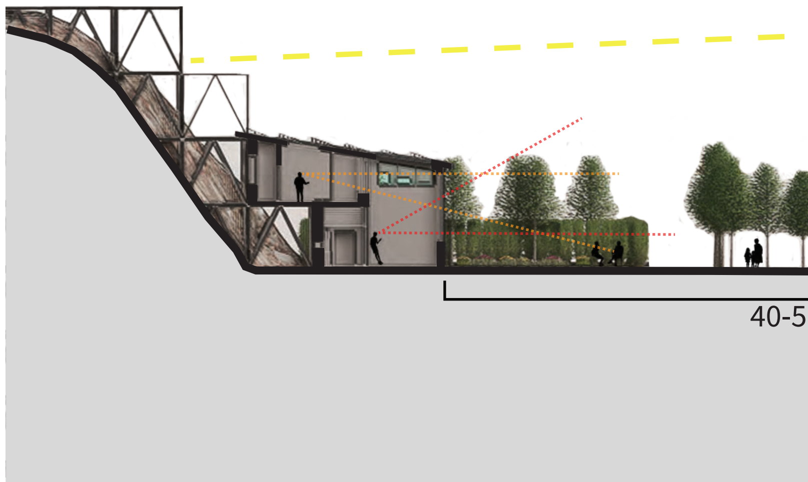
In the **mixed area** of the segment, there are parks, playgrounds and other recreation that is semi private and can be enjoyed by both inhabitants and visitors. The large amount of green areas is to ensure quality of habitation as well as biodiversity.

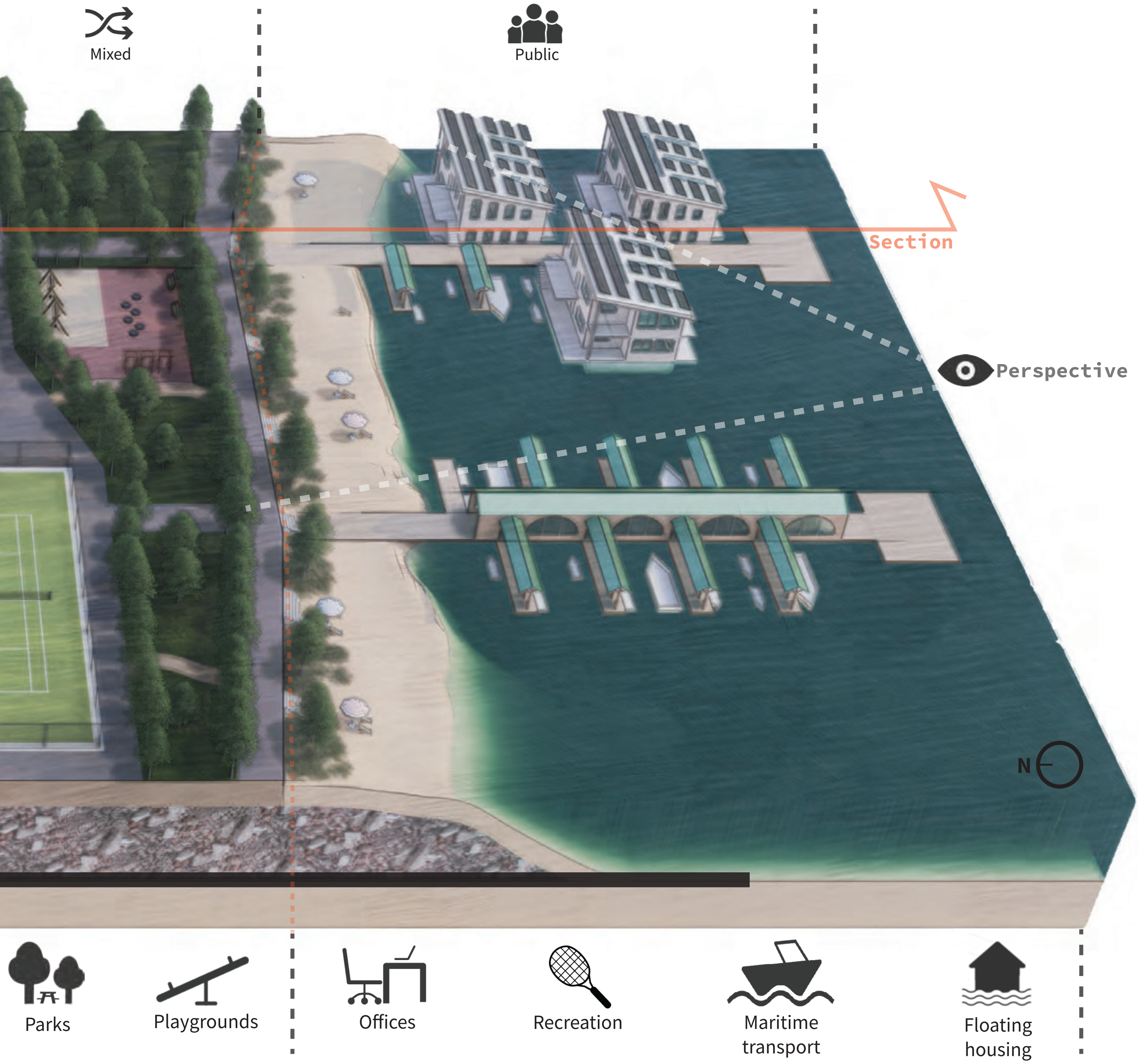
In the **public area**, there are beaches, public transport, marine based recreation and floating housing that can be additional homes or offices.

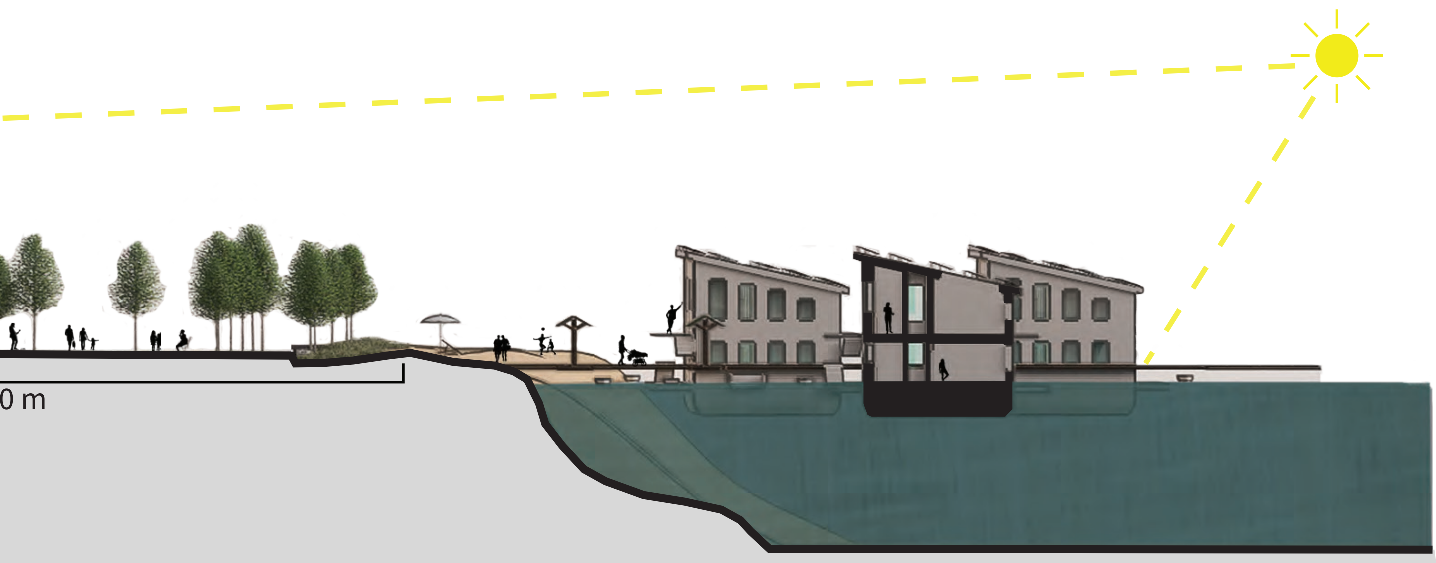


The section

The outward facing side of the lofts have two story windows that allow massive daylight while simultaneously offering a panoramic view to the garden, park vegetation and inland sea. All in all, the inhabitants of a private segment will enjoy quick access to a large variety of outdoor recreation, which can be most enjoyed in the summer. The beach is only 40-50 meters from their front door. People who dwell in floating housing will have a similar liberty, although they can go into the water from their doorstep.




Mixed
Public
Section
Perspective
N
Parks
Playgrounds
Offices
Recreation
Maritime transport
Floating housing


0 m

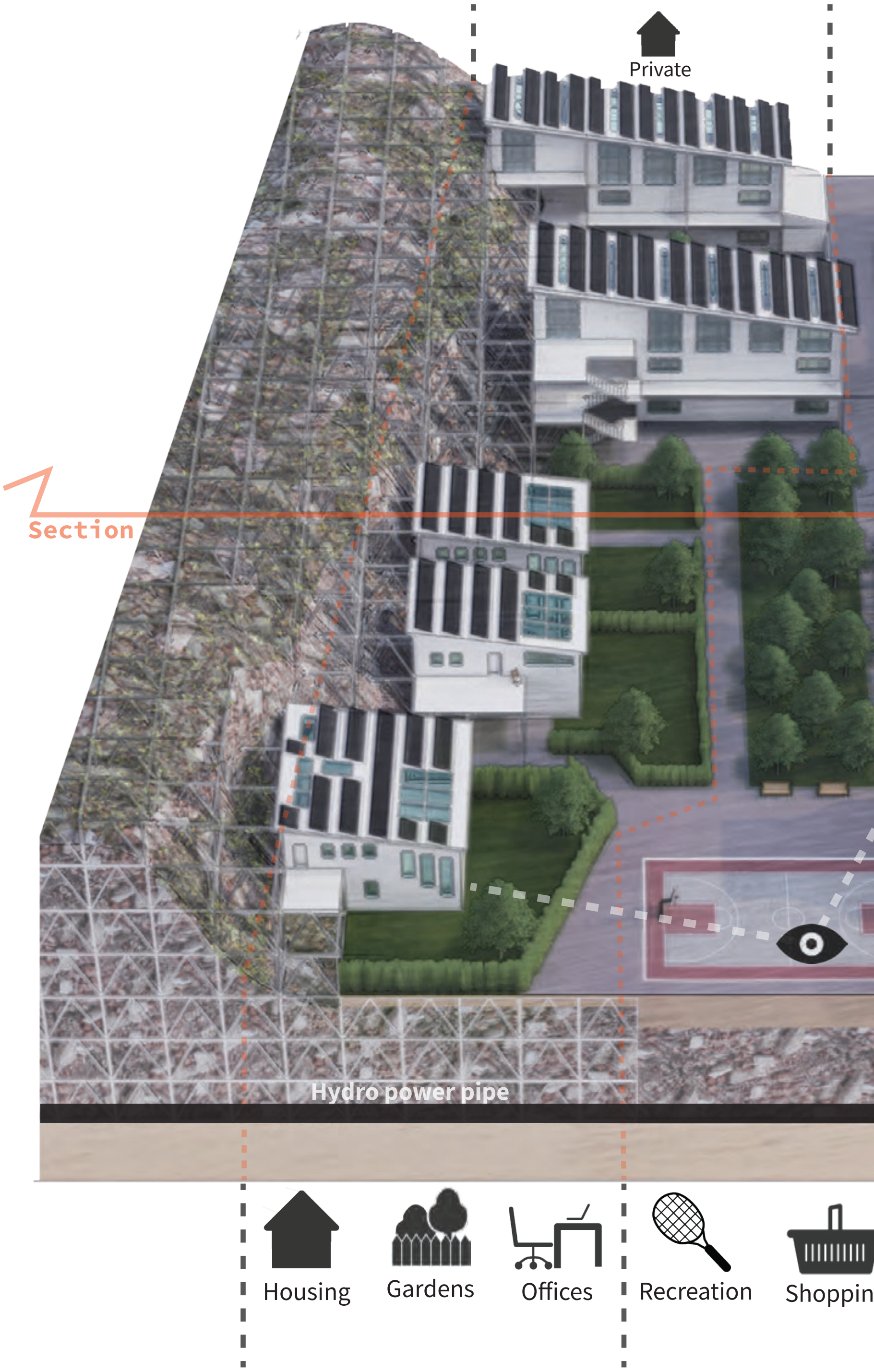
5.5 COMMERCIAL SEGMENT

A primarily commercial segment focuses on establishments, local production, recreation and offices.

In the **private area** of the segment, people are of course still able to obtain private homes in the form of apartments or lofts. Yet considering the purpose of a commercial segment, these structures are also suitable as offices. One loft or apartment can serve the needs of a small firm, while a larger firm may choose to rent or buy several adjacent buildings, which would result in a company having their own business district. While I did put gardens into this visualization, they are not a necessity. Their existence ensures quality breaks for potential office workers, but they can alternatively be replaced with more housing.

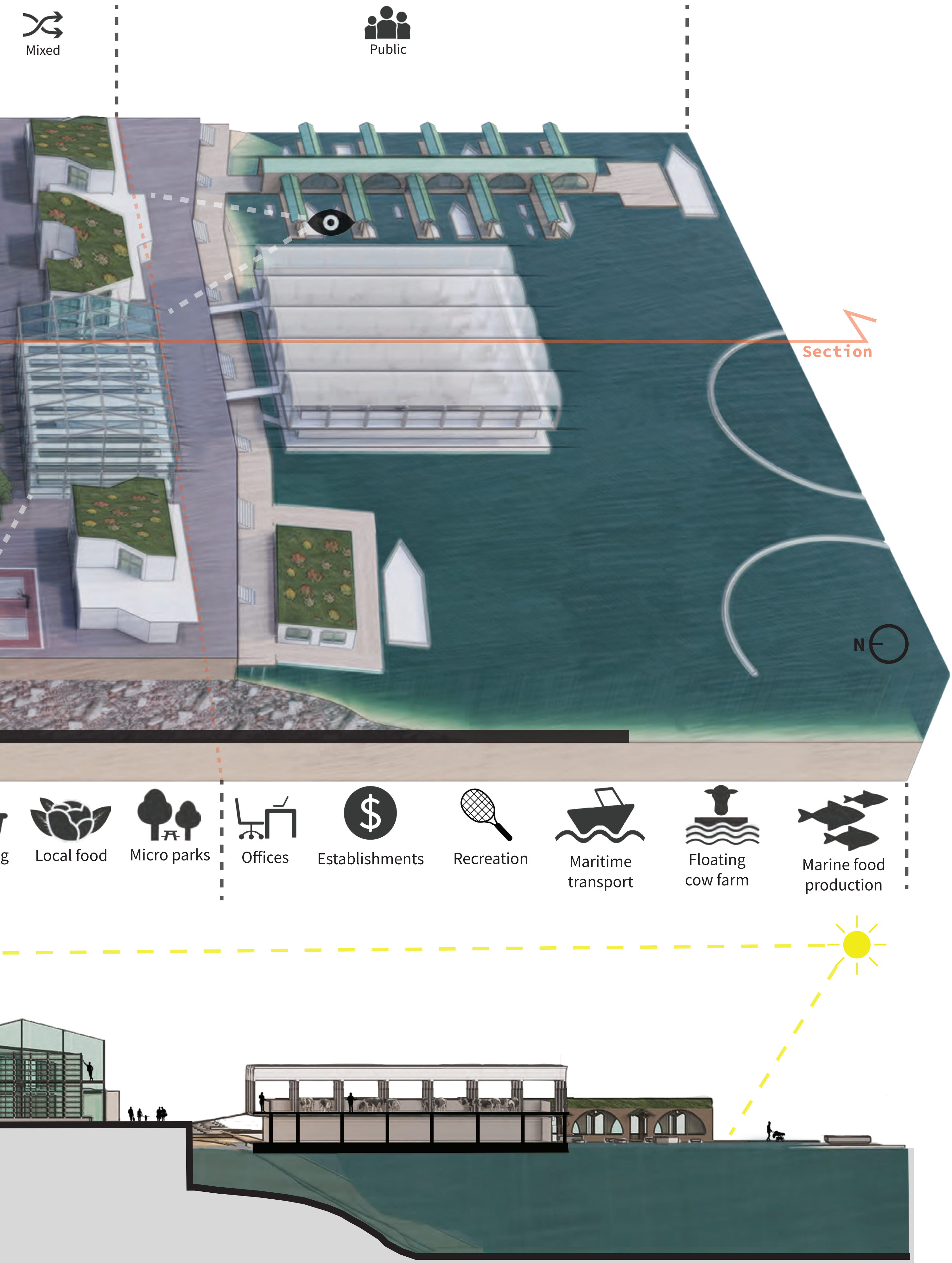
In the **mixed area** of the segment, there may be shopping streets, local food production, parks and micro parks, playgrounds or privatized recreation that can be a source of income for the owners.

The **public area** provides space for floating establishments, offices and maritime recreation. Although in this visualization, the focus for floating structures is local food production; an Amsterdam inspired floating cow farm, and further out into the inland sea, fish farms.

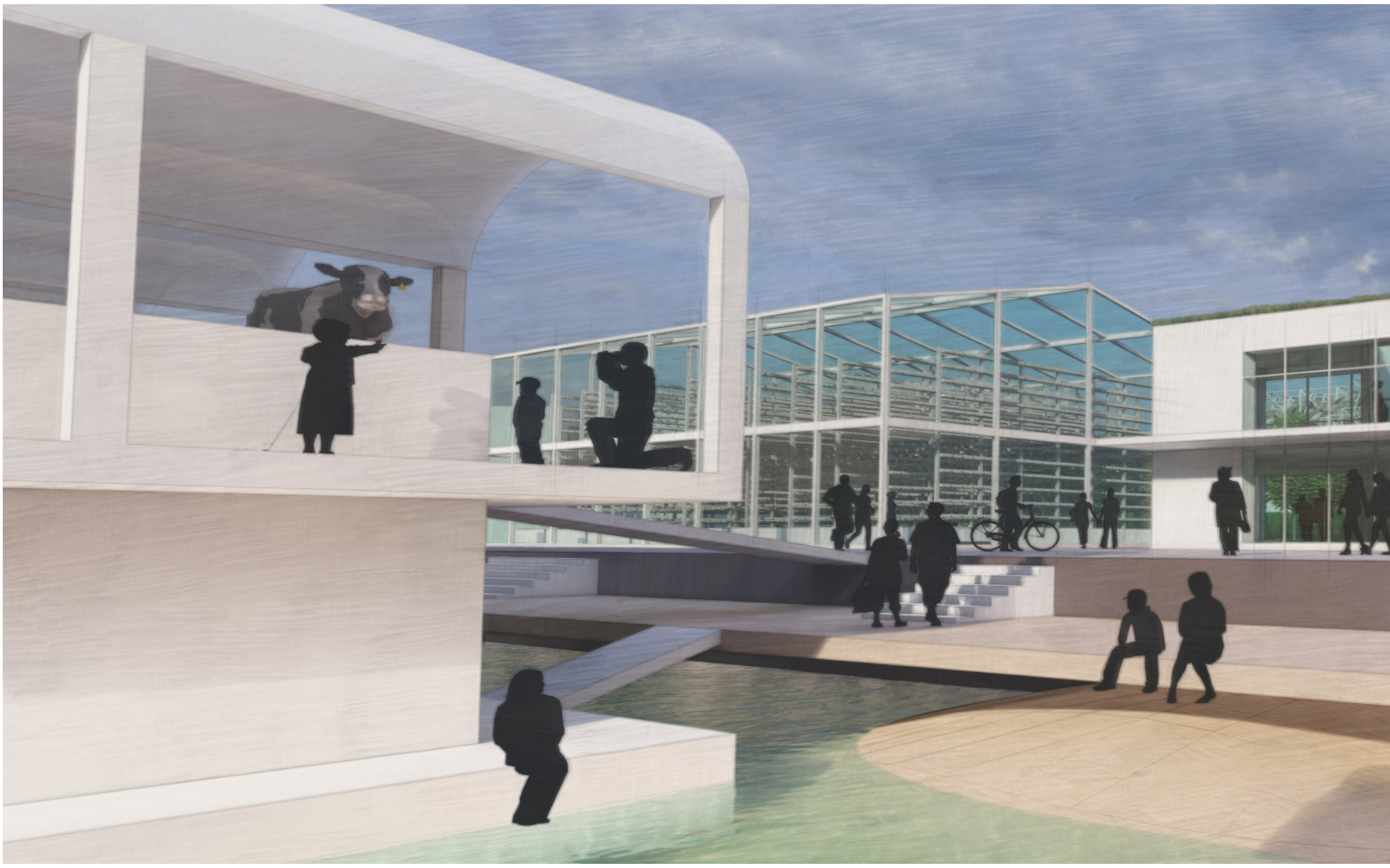


The section

Similar to the private segment, the outward facing side of the lofts offer massive daylight intake and a panoramic view. These structures have great potential to serve as offices for small to large firms. The greenhouse in this visualization can hold up to 3 640 crops, and the floating cow farm can hold up to 30 cows.



Mixed
Public
Section
N
g
Local food
Micro parks
Offices
Establishments
Recreation
Maritime transport
Floating cow farm
Marine food production



6. GREEN ENERGY POTENTIAL

Due to the massive size of the sea barrier, the potential energy rewards for implementing green energy technologies throughout the structure are enormous.

As Sweden has varying energy needs and daylight hours over the seasons, solar power would be prioritized in spring and summer. In autumn, where energy needs dramatically increase and the efficiency of solar panels decrease, hydro power can provide a significant portion of the energy. Switching between the two also makes sense because the inland sea has a limited water capacity. Wave power can provide energy year round.

Note

It is important to point out that the numbers below are very rough estimates. For instance, the solar energy yield is based on the assumption that all panels face south. Yet, the potential energy yield can be substantially higher than what is presented here, since sustainable energy technologies are expected to be vastly improved in the coming decades.

Solar power

If 40% of the barriers interior is dedicated to real estate, and this housing is directly built upon the cube structure, as well as that a similar amount of housing is placed in the water, and they all are equipped with solar panels that receive an average of five hours of sunlight a day, the potential power harvested could be **70 000 megawatts per year.**

Wave power

Eco Wave Power© is a leading company in harvesting sustainable power from ocean waves. Frankly I am impressed with their product, and since my concept provides a solid foundation for this technology, I decided to include it in my project. I received their technical brochure, which allowed me to make a rough estimate of the energy potential with their technology based on the sea conditions of the Öresund. Hence, if 80% of the exterior side of the barrier is equipped with Eco Wave Power© floaters, the yearly yield could be up to **140 160 megawatts per year.**

Hydro power

Due to the difference in height required for dam based hydro power to function, it would not be efficient until phase III. Anyhow, the water levels of the inland sea are suitable to be increased by up to one meter, which gives the inland sea an estimated capacity of 11 572 841 cubic meters. At a 4 meter difference in global sea levels and inland sea level, the potential energy to be harvested by filling the capacity of the inland sea is **257 385.6 megawatts.**

Total energy potential

If all technologies operate at ideal capacity, the expected annual yield could be up to

467 545 Megawatts per year

Which would provide enough energy for

18 680 Electrically heated villas/year

7. CRITICAL THOUGHTS

As this project is a massive, unprecedented approach, there of course exist a variety of implications that deserve to be addressed.

My new approach, “Utilize”, likely will not suffice by itself. The “utilize” approach must probably be combined with other current preventive strategies in order to not fall victim to erosion as well as additional protection against increasingly turbulent seas.

Since many of the current preventive strategies against sea-level rise affect the natural behaviour of the coast, the proposed mega structure would definitely do so as well. For example, when the Öresunds bridge still was a proposal, there were major concerns about how the bridge and artificial island that was to be built would affect the natural currents of the Öresund sea. Hence, if my proposed structure were to be built, governments should include oceanographers in the planning process, so that they can use their expertise to provide feedback that would limit the effect of the mega structure on natural currents along any coastlines where the structure is built.

The proposed trajectory of the sea barrier on the master plan is misleading. The trajectory is based on the idea that the first layer of cubes is placed at a depth of 10 meters, but the Öresund sea is actually extremely shallow. Hence, the trajectory of the wall should be adjusted to fall in line where the Öresund sea has a depth of 10 meters. Alternatively, one or two layers of cubes in Phase 0 can be excluded.

The trajectory itself should also have more variation, in terms of width and shape. The reason the trajectory of the barrier is presented as strictly following the width of 72-80 meters was in order to minimize the number of resources needed to construct the barrier as a whole, but also because the architectural part of this project focused on building directly upon the cube structure. The trajectory could have more variation in shape and direction, it should be more than just a line that is offset 300-400 from Malmös coastline.

An additional question also becomes, does the barrier really have to protect the whole coastline of Malmö? The northern, industrial harbour area may not need to be as important to protect as the more central, densely populated areas.

Finally, from an urban planning perspective, the barrier would not strictly follow the 72-80 meters width, or the proposed, fine line trajectory. If the barrier were to be built, it would be constructed with varying width and shape, especially in the inland sea, as this would allow for even greater variety in urban development. As I am advocating for mixed development, the way the project is presented actually implies the opposite, as the proposed segments communicate the idea of hundreds, if not thousands, of private homes with close beach access. From a realistic viewpoint, this would result in wealthy individuals and families settling on the barrier, while the barrier is intended to welcome all people.

8. THESIS CONCLUSION

Considering that rising sea levels are an enormous global threat, as millions of people would be displaced, millions of square kilometres of land would be lost with the global GDP losing billions of dollars, it requires a massive solution. The consequences of property loss, land loss and the displacement of hundreds of millions of people on a global scale may lead to an unprecedented crisis in modern history. Existing preventive strategies against sea rise are will not suffice, as they mainly are focused on solving contemporary issues such as beach erosion and flooding; they are not intended to deal with permanently increased sea levels whatsoever. What coasts and coastal cities need is a long-term solution that permanently protects the coast and built environment.

Malmö is one of many coastal cities that will most directly feel the effects of sea rise, and the city has already experienced a temporary two-meter increase in sea levels due to flooding when Storm Sven hit the Malmö in 2013. Öresund, the sea where Malmö is located, appears to offer a favourable setting for placing a megastructure that can act as a long-term solution for protecting Malmö and its coast against rising seas.

Through a new experimental process, coined **Continuous Algorithmic Aggregation (CAA)**, which is based on building an aggregatable structure rather than a traditional structure, the completion of the sea barrier becomes sequential, making it flexible and responsive to necessity. Additionally, the process appears to be as costly as other major infrastructure projects, although the resulting sea barrier, due to the process, offers vast opportunities for urban development and harvesting large quantities of energy through sustainable technologies, making it a promising long-term investment despite the initial costs associated with infrastructure projects. The materials needed to fill the structure, primarily construction waste, are readily available from a national point of view, as 4.7 million tonnes of construction waste end up in landfills in Sweden anyhow. The filling of the structure could be completed automated with existing and emerging technologies, making the process efficient and safe.

While the process still needs to be fine-tuned and tested, as well as finding out the potential effects it would have on the natural flow of sediment and water in öresund, it is a strong proposal to take the battle to the sea instead of retreating from it. The potential to continue extending the sea barrier along the coast may benefit other municipalities in Skane, eventually the whole of Sweden, and ultimately even other member states of the European Union. The project could galvanize the continent to mutually build protection for coasts, cities and people from the dire threat of permanently increased sea levels. Mutual goals for survival have the potential to foster unity between even the most disagreeable people, and a massive sea barrier can permanently symbolize the mutual effort needed to achieve that goal.

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