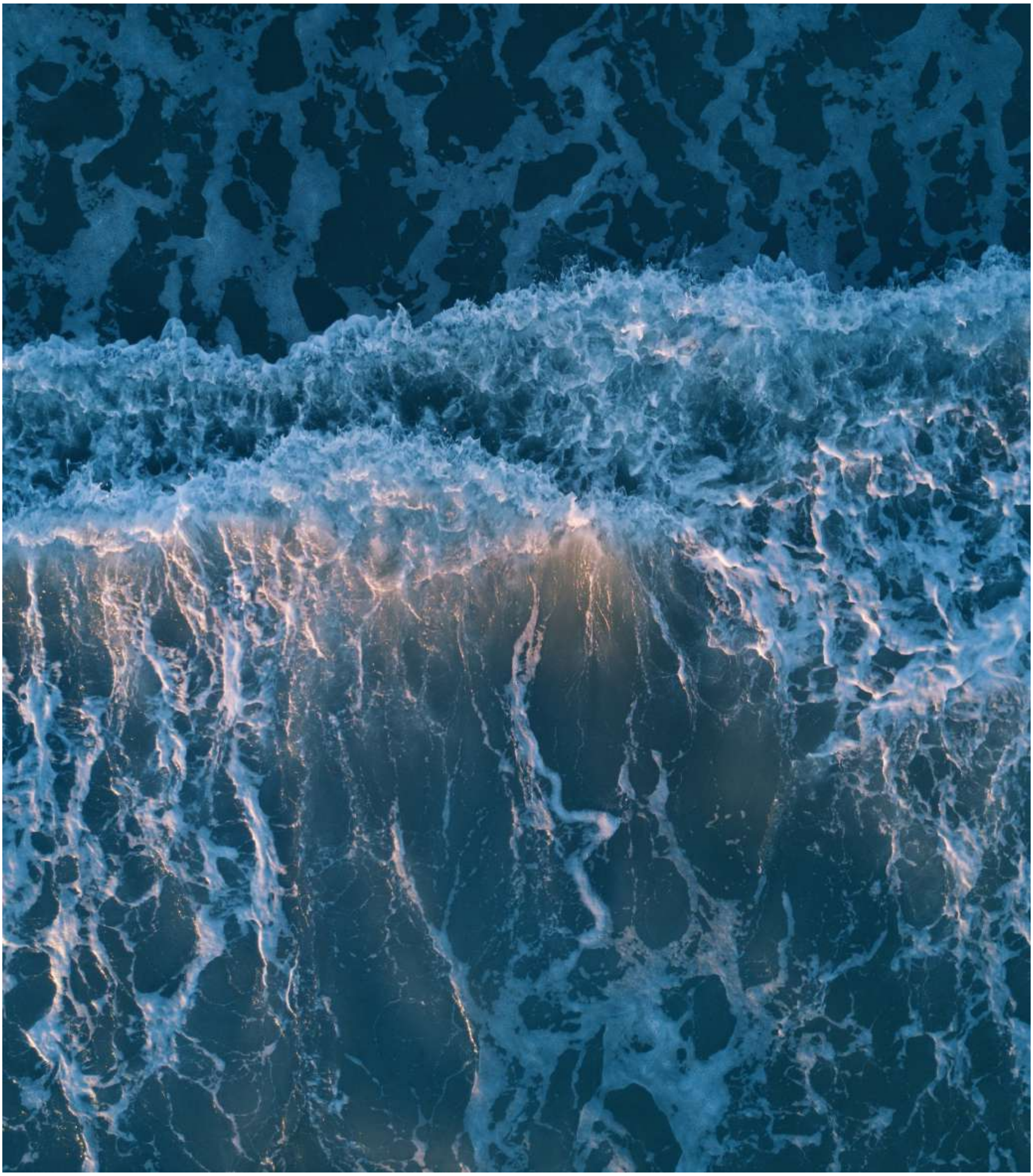


RESTORATIVE ARCHITECTURE

Designing for mutually supportive systems

'Sara Ekström & Alexandra Hansten
Chalmers School of Architecture
Department of Architecture and Civil Engineering
Master thesis, spring 2023
Examiner: Nils Björling
Supervisor: John Helmfridsson
ACEX35 Master thesis direction: Rurban transformations

Master thesis, spring 2023
Sara Ekström & Alexandra Hansten

Restorative architecture
Designing for mutually supportive systems

Chalmers School of Architecture
Department of Architecture and Civil Engineering
Architecture and Urban Design
Examiner: Nils Björling
Supervisor: John Helmfridsson

ABSTRACT

This thesis addresses the urgent need for a shift in how architecture relates to natural resource extraction in the face of the twin crises of climate breakdown and biodiversity loss. The aim of this thesis is to explore a system that responds to the twin crisis by sourcing biomass as rest products from ecologically restorative processes and implementing them as regenerative building materials. The purpose behind this is to highlight the architects' possibility of executing a holistic practice where our systemized approach to problem solving holds the potential to respond to complex societal issues.

The research focuses on coastal environments and covers three bioremediating marine species; blue mussels, reeds, and eelgrass, whose biological functions naturally help counteract eutrophication. The studies of these species result in a mapping of their biological function, occurrence, physical properties, and potential to perform as building materials. Traditional and modern case studies, interviews, and literature studies are used to support the research.

The thesis re-connects to the pressing issue of the twin crisis in the design phase where both program and building reflects and promotes a sustainable relationship between natural resources and human consumption in the rurban setting of Stora Dyrön. More specifically, the new addition contains a program that answers to an uneven seasonal activity by extending the tourism season through a sustainable experience-based restaurant that cultivates marine species through a local, small scale blue garden.

The outcome of this thesis provides insights in the possibilities and challenges with connecting material extraction to nature restoration. This has been done through the holistic approach of making visible systems and connections across different scales. It concludes that this practice would pose demands on the building sector in terms of attitudes, material sourcing and craftmanship. This would in contrast to todays linear resource use, depart from available supply rather than material demand where the environmental benefit of bio-based materials has to be elevated. By acknowledging that architects' systemized approach to problem solving could help tackle complex societal issues, and openess to cross-disciplinary collaboration and a curiosity towards new knowledge becomes important features of the modern architect.

Keywords: Regenerative design, Bioremedation, Eutrophication, Marine resources, Building materials

Sara Ekström

BSc Architecture
Chalmers University of Technology
2017 - 2020

Kaminsky Arkitektur, Gothenburg
Internship, 2021

Chalmers University of Technology,
MSc Architecture and Urban Design
2021 - 2023

Studio, fall term 2021:
ARK338: Material and Detail 1

Architecture exchange
École polytechnique fédérale de Lausanne,
Studio spring term 2022:
Studio Elii

Chalmers University of Technology
Studio, fall term 2022:
ARK123 Matter, space, structure 1

Alexandra Hansten

BSc Architecture
Chalmers University of Technology
2017 - 2020

Fredblad Arkitekter, Halmstad
Internship, summer 2019 - 2020

WE Architecture, Copenhagen
Internship, 2020 - 2021

Chalmers University of Technology,
MSc Architecture and Urban Design
2021 - 2023

Studio, fall term 2021:
AUT164: Residential healthcare

Studio, spring term 2022:
ARK137: Housing inventions

Studio, fall term 2022:
ARK123 Matter, space, structure 1

INTRODUCTION

PROBLEM STATEMENT

"The twin crises of climate breakdown and biodiversity loss are the most serious issue of our time. Buildings and construction play a major part, accounting for nearly 40% of energy-related carbon dioxide (CO2) emissions whilst also having a significant impact on our natural habitats" (Architects Declare, 2019).

The interconnectedness of climate change and biodiversity loss is a complex and pressing issue where one is affecting and exaggerating the other. Todays linear and depleting production ideology has caused severe impact on our climate, resulting in a series of consequences that strains our natural habitats, causing irreversible damage to Earth's ecosystems.

In terms of the building and construction industry's impact on climate change, the potential to work regeneratively is not only possible, but urgent. The building industry currently stands for around 40% of the emitted CO2 and has a large impact on natural environments (United Nations, 2022). The vast amounts of resources needed for construction currently accounts for almost 50% of all extracted material and the industry is responsible for over 35% of the EU's total waste generation (European Commission, n.d.).

The potentially catastrophic consequences of climate change could trigger large-scale abrupt and non-linear environmental changes, causing severe biodiversity loss. The nine planetary boundaries is a scientifically developed concept that identifies and estimates the limits within which human activity can operate safely within. The latest assessment by the Stockholm Resilience center reveals that four of the boundaries have already been breached, meaning that human activity is currently pushing Earth's system beyond what is considered safe, where restorative measures is not only needed, but vital for our future survival.

When looking at architecture in its contemporary context, it reflects todays linear and depleting production ideology. On the contrary, architecture has the potential to reflect complete other attitudes. "The assumption that the building industry can only fulfill humanity's needs with the irreversible exploitation of the environment, of people, and of the future, needs to be reconsidered" (Kritsouk, L., & Korody, N, 2021).

TWIN CRISIS

01/ climate breakdown
the building and construction industry's impact on climate change

02/ biodiversity loss
impact of climate change on natural systems and habitats

a dual response

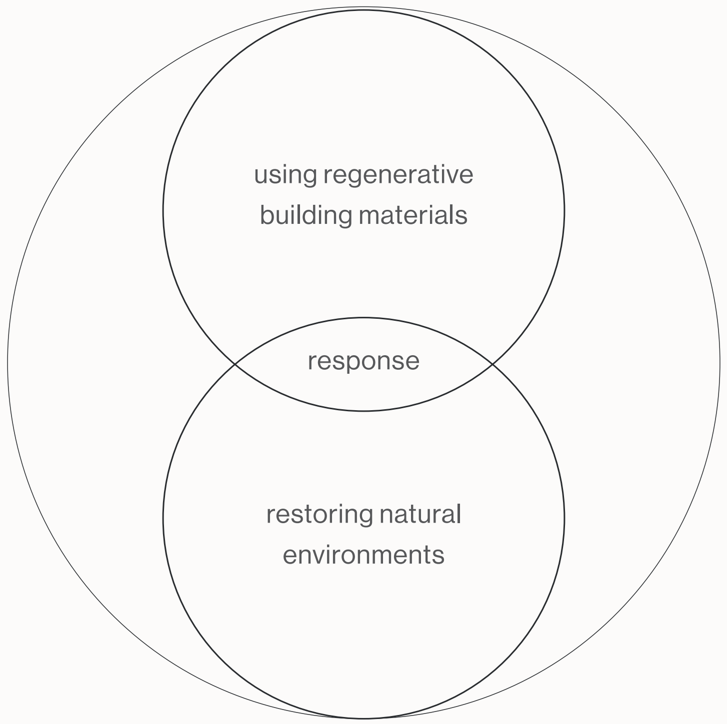


Fig. 1 - Twin crises and architecture

Research question

How could architecture respond to the twin crisis by sourcing rest products from ecologically restorative processes and implementing them as regenerative building materials?

How could these materials be showcased in the built environment on Dyrön?

Aim & Purpose

The aim of this thesis is to explore a system that responds to the twin crisis by sourcing rest products from ecologically restorative processes and implementing them as regenerative building materials. It aims to make visible the the possibilities and challenges that the biomaterials pose in terms of sustainability, material properties and architectural impact. The project further aims to re-connect the program to the twin crisis, in the way that allows people to engage in the cross-section between sustainability, food, climate and biodiversity. This is done through a program that aims to develop the rurban context of Stora Dyrön through sustainable experience-based tourism surrounding food consumption.

The purpose behind this is to highlight the architects' possibility of executing a holistic practice where the systemized approach to problem solving holds the potential to respond to complex societal issues.

Delimitations

This thesis makes visible systems across different scales, connecting the responsibility of architects to the twin crisis of climate change and biodiversity loss. It implements the theoretical framework of regenerative design in order to support a hollistic architectural proposal. It investigates the three marine species reeds, eelgrass and shells and their potential as bioremediative species. Additionally, it investigates the possibilities and challenges those species hold as building materials in terms of sustainability, material properties and architectural impact. Finally, it provides a deeper understanding of how the building proposal fits into and contributes to a wider system within the rurban context it is situtied in and suggests a program that re-connects to the twin crisis and responds to the local context.

This thesis does not pose itself as a definite solution, but rather aims to provide an objective investigation through the connection of systems. It does not discuss the financial aspects of such an implementation. The project proposal considers the architectural impact on the cultural heritage of Dyrön, but does not allow that heritage to determine the outcome of the design. The program does not provide an in-depth study of species cultivation in terms of food production but rather a focus on a general program and its sustainable development in its local context.

Methods

Research by design

The project is a result of an iterative process of scientific research in combination with design work and material explorations. Working iteratively means that the aspects of research and design will affect each other continuously.

Literature studies

The literature research has been fundamental for the project and our understanding of the wider discourse. The literature has been carefully reviewed to ensure that the knowledge is up to date and from reliable sources.

Cross-disciplinary collaboration

As the thesis aims to highlight the importance of cross-disciplinary collaboration in solving complex societal issues, our method has involved continuous contact with professionals from a variety of fields in order to give us a wider knowledge base for the project.

Case studies

To demonstrate historical and contemporary solutions that help inform the design, case studies have been made. The references have laid the base for the building design and influenced the chosen methods of construction.

Mapping

Mapping techniques for investigating site and conditions includes executing a site analysis that deepens the understanding of the physical, cultural , and social context.

Material investigation

Material investigations have been carried out in order to understand the physical and chemical properties of the material that will influence the proposed design. The investigation has not only given us an understanding of how commonly used materials work today, but what possibilities and challenges there are when shifting towards a sustainable substitute.

Model making

The building's construction and aesthetical expression has been investigated and developed through physical model making. Building models of different scales resulted in a deeper understanding of everything from construction to detail.

BACKGROUND

Background

Planetary boundaries

The nine planetary boundaries is a scientifically developed concept that identifies and estimates the limits within which human activity can operate safely without causing irreversible damage to the Earth's ecosystems. The nine boundaries include climate change, biodiversity loss, biochemical flows, land use change, freshwater use, ocean acidification, ozone depletion, atmospheric aerosol loading and chemical pollution. Exceeding the planetary boundaries could have negative and potentially catastrophic environmental consequences as reaching critical planetary thresholds could trigger large-scale abrupt and non-linear environmental changes .The latest assessment by the Stockholm Resilience center reveals that four of the boundaries have already been exceeded, meaning that human activity is currently pushing the Earth's system beyond what is considered safe. The four boundaries include climate change, land use, biodiversity loss and biochemical flows where the last two are the most pressing issues (Rockström et al., 2009).

An unsustainable field of practice

The built environment is a large contributor in pushing our planetary boundaries. The building industry currently stands for around 40% of the emitted CO2 and has a large impact on natural environments (United Nations, 2022). The vast amounts of resources needed for construction currently accounts for almost 50% of all extracted material and the industry is responsible for over 35% of the EU's total waste generation (European Commission, n.d.).

Non-renewable materials

The use of non-renewable materials such as metals, sand, concrete and gravel has a clear connection to a wide range of environmental consequences including climate change, acidification, energy demand, land use, human toxicity, ozone layer depletion, photochemical oxidation, terrestrial ecotoxicity and eutrophication. Non-metallic minerals such as limestone, gravel and sand also account for more than half of the total material use, heavily increasing their environmental impact (OECD, 2018). As global material use is predicted to have doubled by the year 2060, a search for sustainable and biodegradable alternatives is highly important in securing a sustainable future.

Bio-materials

The use of bio-materials is becoming increasingly popular among architects and designers thanks to their environmental performance in comparison to conventional alternatives. In contrast to non-renewable materials, biomaterials are materials that derive from living organisms such as plants, animals or fungi. They are usually biodegradable and lower the embodied carbon footprint of buildings through storing CO2 during their lifespan (Parkes, 2021). Increasing the use of biomaterials in architecture could therefore be one way to tackle the building industry's large environmental impact.

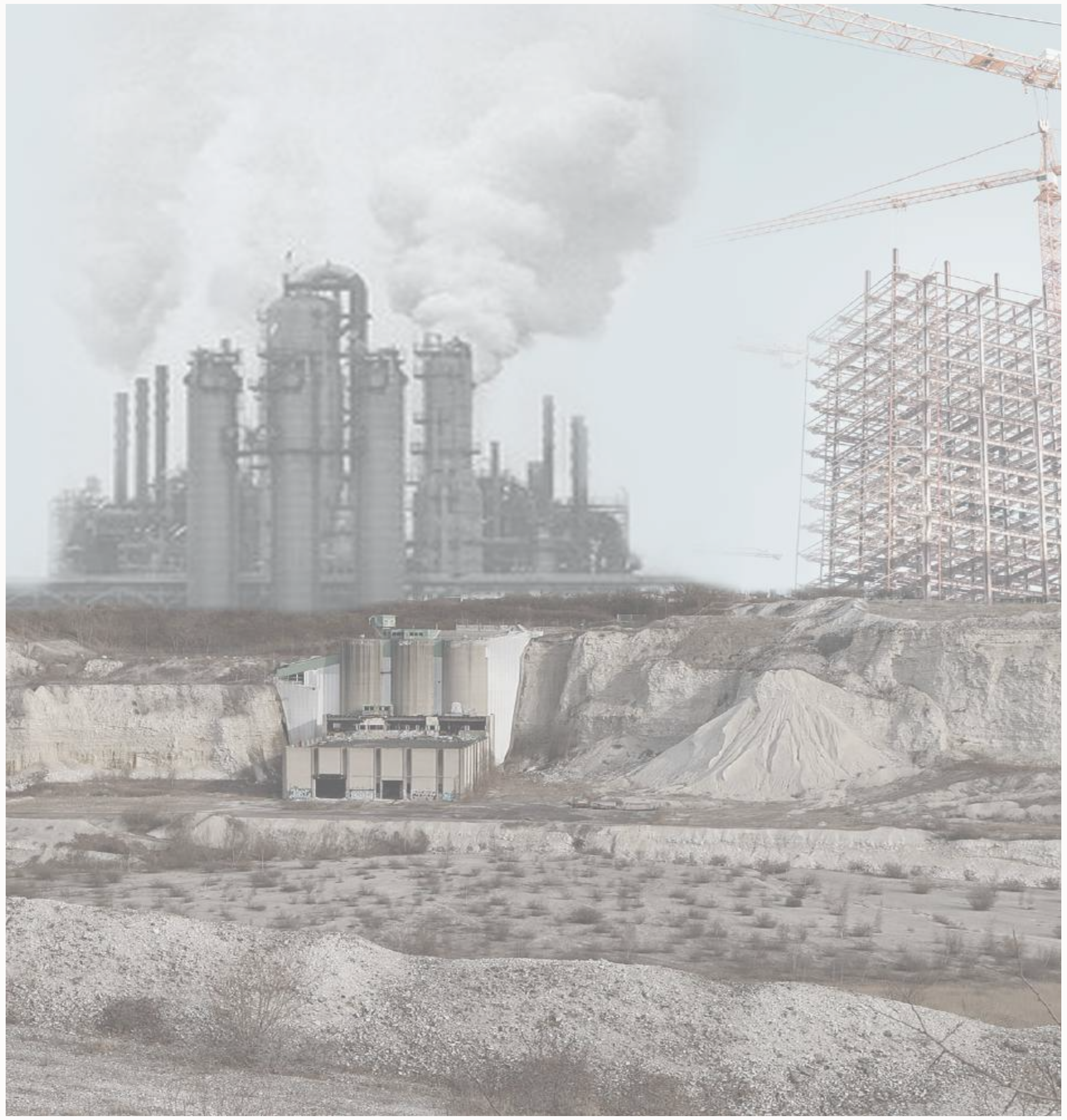
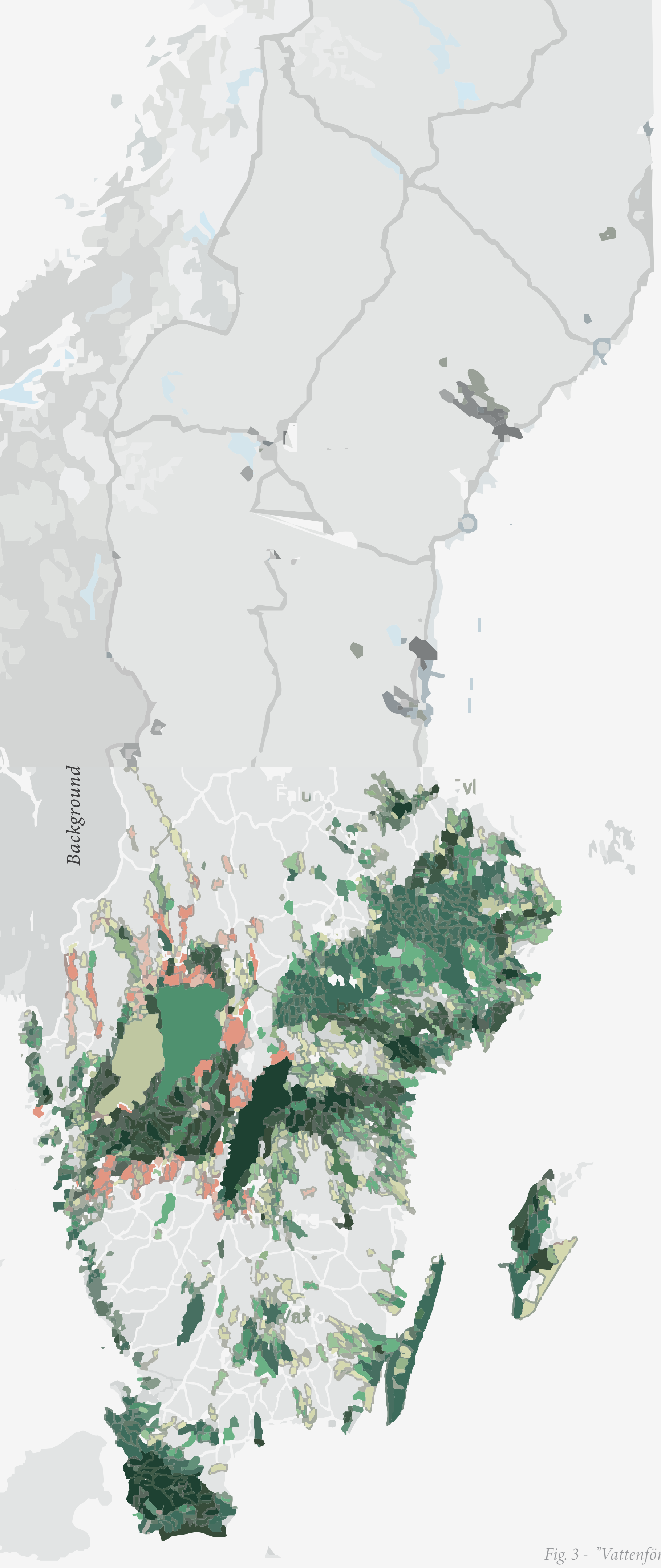


Fig. 2 - Building industry's impact on natural environments

01/ climate breakdown
the building and construction industry's impact on climate change

02/ biodiversity loss
impact of climate change on natural systems and habitats



"Anthropogenic pressures on the Earth System have reached a scale where abrupt global environmental change can no longer be excluded" (Rockström et al., 2009).

01/ climate breakdown
the building and construction industry's impact on climate change

02/ biodiversity loss
impact of climate change on natural systems and habitats

Fig. 3 - "Vattenförekomster med övergödningsproblematik" - Länsstyreslserna (n.d)

IMPACT OF CLIMATE CHANGE ON NATURAL SYSTEMS

Human activity altering the ecosystem balance

Ecosystems hold a strong resilience within itself, where a natural balance is found and maintained at its best capacity. Human interference with natural systems through rapid urbanization, deforestation and pollution is causing that same rescilience to be insufficient (Klenske, 2021).

Imapct of industrialized agriculture

In the 1950s, the use of commercial fertilizers increased tremendously and the global consumption went from 14 million tons in 1950 to 129 million tons in 1984. The commercial fertilizers contain large amounts of nutrient salts, mainly nitrogen and phosphorus which is released during agriculture (Haamer et. al.1999). Heavier rainfall due to climate change has drastically increased the run-off from land and is increasing the amounts of excess nutrients reaching the water. In combination with warmer water temperatures this is creating favorable environments for algae to thrive (Baden et al., 2022).

Biodiversity loss due to anthropogenic flow of biochemicals

Nitrogen and phosphorus cycles are crucial for plant growth and global food production, however an excess of these nutrients has a negative impact on the environment and causes severe biodiversity loss (Rockström et al., 2009). An excess of nutritions in the water leads to an over production of algae, an anthropologic strain which can not be balanced out by natrual filtering organisms. This causes insufficient light conditions and a lack of oxygen in the bottom sediments, a phenomenon called Eutrophication that today is a widespread problem in our coastal waters (Haamer et. al.1999).

Need for active restoration

Coastal ecosystems are crucial for our existence as they hold a large part of the world's biodiversity while also playing an important role for our societies through regulating oxygen levels, weather as well as supply of drinking water and food (Klenske, 2021). Restoring coastal environments is therefore highly important in order to secure a sustainable future.

Ideally a problem should be solved at its source, meaning that a reduction of emitted nutrients from human activity is urgent. However, even if the emissions of nutrient salts from human activity on land is limited, the problem might remain. Research has shown that nitrogen and phosphorus can accumulate in bottom sediments, continuing to be released over time (Ahlkrona, 2017). Complementary measures that actively remove nutrients from the water (such as bioremediation) are therefore considered favorable. Further, as phosphorus is a finite resource, it is important to contain and reuse it within a circular system.

THEORY - REGENERATIVE ARCHITECTURE

Regenerative architecture is the practice of engaging the natural world as the medium for, and generator of the architecture. It responds to and utilizes the living and natural systems that exist on a site that become the “building blocks” of the architecture (Littman, 2009).

REGENERATIVE DESIGN

”Less bad” is not good enough

The twin crisis of climate breakdown and biodiversity loss requires a paradigm shift in how we design built environments. The current idea of sustainability in architecture is oriented around an inadequate way of viewing buildings as isolated objects, rather than viewing the built environment as integrated parts of a ecosystem where the design allows for mutually supportive systems. (Gattupalli, 2023).

Reversing ecological damage

In contrast to sustainable design, regenerative design strives to reverse ecological damage, with and ambition of having a positive impact on our natural environments. It aims to counteract depletion of resources and increase the resilience of environments towards natural change (ARUP, 2020).Through the lens of regenerative design, architects and designers can shift towards a hollistic thinking, with a cross-disciplinary collaboration, where we recognize how the built environment exists within a wider social, environmental and economical net (Gattupalli, 2023).

Eco-effectiveness

Circular Economy Guide (n.d.) states that renewable materials are sources that naturally restore after human exploitation, and include examples like wood, bamboo, cork and straw. William McDonough and Dr. Michael Braungart developed the design framework of Cradle to Cradle®, as a systemic shift when thinking about material explotation. This goes beyond a sutainable approach where doing ”less bad” (eco-efficiency) turns into doing ”more good” (eco- effectiveness). Cradle to Cradle pushes for the notion of eliminating the idea of products as waste, where it instead is perceived as ”food” for a renewable cycle. Cradle to Cradle® identifies two material cycles: biological and technical.

BIOREMEDIATION

Bioremediation is a method for the restoration of ecological balance and lost environmental qualities. It utilizes biological means to naturally counteract environmental damage (Haamer et. al.,1999). When implementing bioremediation, it is important to understand that the costal ecosystem already holds a strong natural resilience within itself, where the natural occurance of nutrient salts in our waters are integral parts of the natural cycle. The urgent issue lies in the antropogen strain that has disrupted the natural balance, where an extensive increase in nutrient salts has caused that same natural rescilience to be insufficient. Bioremediation therefore makes use of an already rescillient system, in an amplified and directed intervention.

The main purpose behind bioremedation of eutrophicated water bodies is to reduce the plankton biomass by absorbing and extracting excess nutrients to prevent overproduction of algae and clear up the water. This can be done by increasing the occurrence of naturally filtering species to absorb excess nutrients. Naturally effective filtering species are for example, blue mussels, oysters, seaweed, and water grass such as reeds and eelgrass. These species filter waters from nitrogen and phosphorus through nutrient uptake, naturally decreasing phytoplankton’s capacity to increase, therefore balancing the system (Haamer et. al.,1999).

This type of bioremedation depends on regular harvest to permanently remove the nutrients from the system and current research focuses on ways to use the biomass to recycle the nutrients.,Many bioremedation methods also have a positive impact on the local biodiversity, as theymake up living habitats for other species (Haamer et. al.,1999).

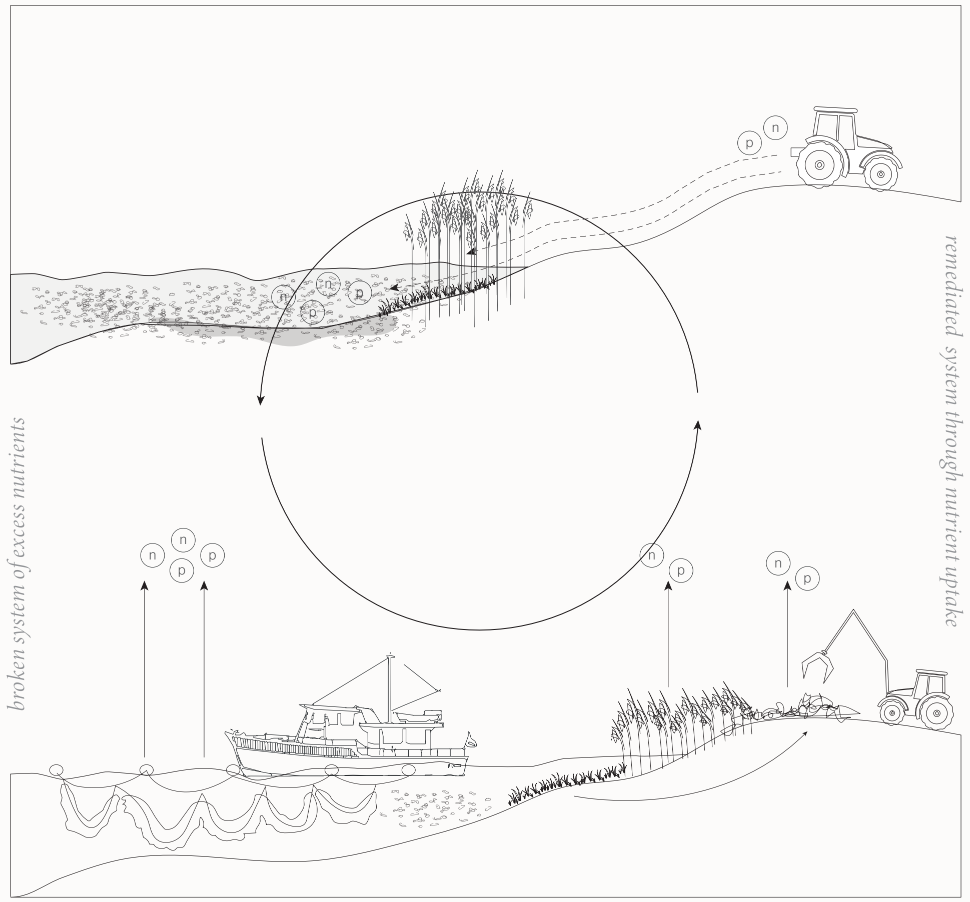


Fig. 4 - Bioremediation - Own illustration

ANALYSIS

BIOREMEDIATION THROUGH MUSSELS

Fig. 5 - Mussel farm - Own Illustration

Occurence: All parts of Sweden
Habitat: 0-10m depth
Size: 8-20cm

Species

The blue mussel is found in all Swedish waters but mainly along the west coast as the salt water is beneficial for its growth. The life of the mussel begins in the spring and is fully grown after 18 months. It originally occurs in different types of stock, one close to the shore in shallow waters with a depth of 0-2 m, and one in waters at 2-10m depth (Sveriges vattenmiljö, 2022).

Biodiversity

Mussel banks and farms make up living habitats for other species and have a large impact on the overall biodiversity of the ocean and increasing their occurrence could therefore be important for the overall biodiversity of the ocean (Sveriges vattenmiljö, 2022).

Bioremediation

The blue mussel is a filtering organism that lives on absorbing nutrients and phytoplankton from the water. In its shell, it has two openings, one which takes in nutritious water, and one that lets out the filtered water. Through this technique, one single mussel can filter several liters of water each hour and is often referred to as the ocean's "ecosystem engineer" (Baden et al., 2022).

Mussel farming has proven to be an effective method for restoring eutrophicated waters while simultaneously providing a source of sustainable food. The most favorable conditions for mussel growth is in salt water which is why most of the existing mussel farms are located on the Swedish west coast To extract the nutrients absorbed by the mussels, they need to be harvested and brought out of the water. This can be done after 18 months and up to 3 years (Haamer et. al.,1999). Mussels are harvested in the fall using boats. During good conditions, one hectare of mussel farming can generate around 300 tonnes of mussels each 18 months, extracting around 300 kg Phosphorus and 300kg Nitrogen (Lindahl & Kollberg, 2008).

BIOREMEDIATION THROUGH REEDS

Fig. 6 - Reeds - Own Illustration

Occurence: All parts of Sweden
Habitat: Shallow soft bottoms
Size: 2-4m

Species

Phragmites Australis is the largest species of grass in Sweden. It occurs all over the country but is less widespread in the northern parts. The Swedish coast has a reed stock of approximately 200,000 ha (SLU, 2021).The species reproduces vegetatively through long rhizomes in the bottom sediments and can grow in waters up to 2,5m depth. Reeds grow rapidly during the spring and bloom in August-September when they have reached a height of 2-4 meters (Våtmarksguiden, n.d).

Biodiversity

Reeds thrive in nutrient-rich environments and quickly spread to form large populations along the shorelines of ocean and lakes. Reed stands make up important living and breeding habitats for birds and fishes, however dense stands of reeds limits the access to the water from land and causes muddy environments with lack of oxygen which is disturbing the life and reproduction of fish and other animals in the shallow waters if not harvested regularly (Naturskyddsföreningen, 2021).

Bioremediation

Regularly harvesting reeds has proven highly effective in removing nutrients from eutrophicated waters. The large biomass production requires a large amount of nutrition and its rapid growth increases the speed of absorption (Våtmarksguiden, n.d). Harvesting reeds during the summer can remove up to 9 kg of phosphorus and 100 kg of nitrogen per hectare (Naturskyddsföreningen, 2021).

In August the amount of nutrients in the above-ground parts of the plant culminates which makes this the optimal time for harvesting for a maximum extraction of nutrients from the system If the reeds are not harvested at this point, the nutrients will transport back down to the rhizome or be released back into the water. When harvesting reeds with the purpose of eliminating nutrients from eutrophicated waters, it is important to cut the stems above the water surface. If the reed is cut below the surface, the plant will suffocate and might not grow back the next year (Orvestedt, 2013).

BIOREMEDIATION THROUGH EELGRASS

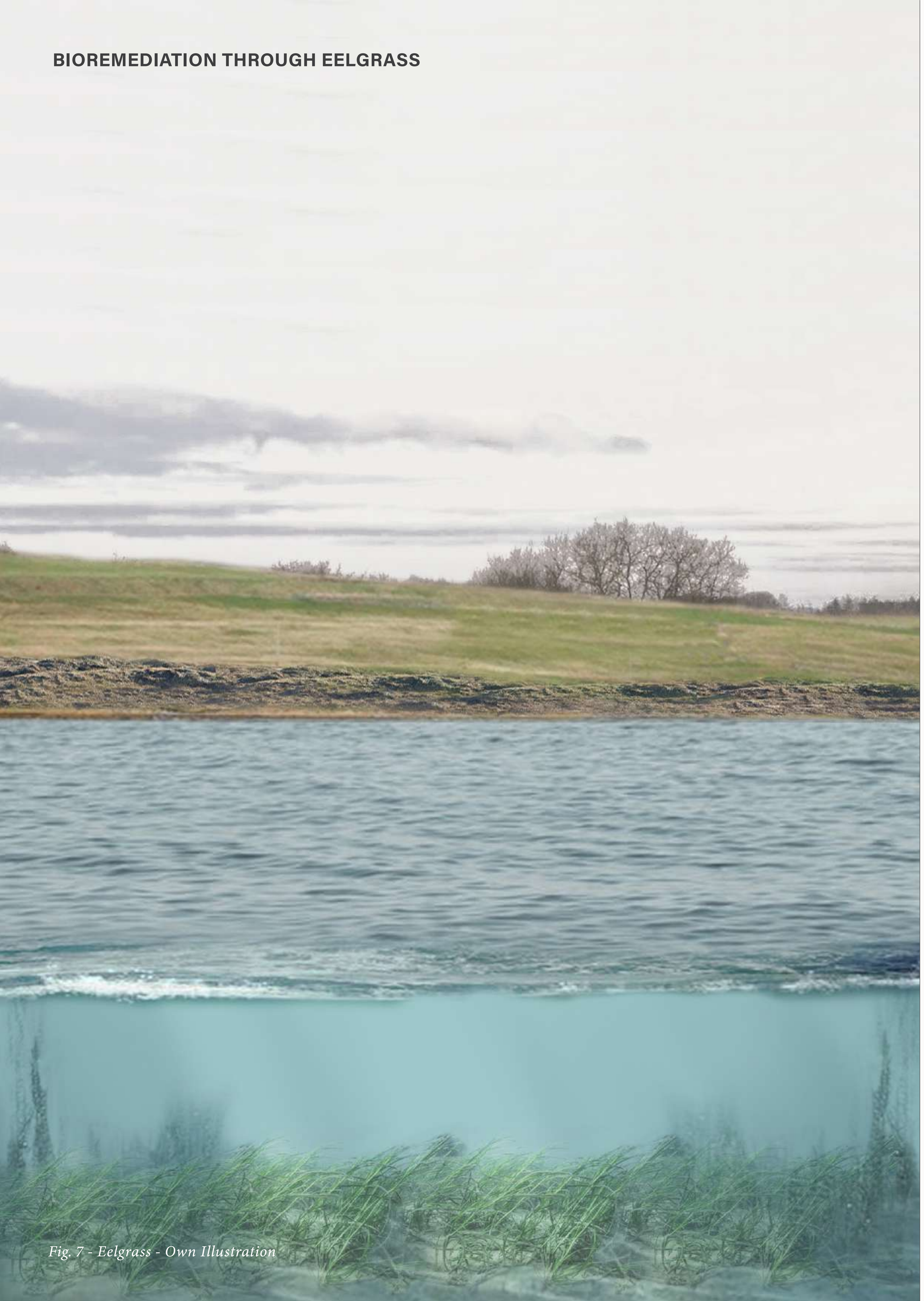


Fig. 7 - Eelgrass - Own Illustration

Occurence: All parts of Sweden
Habitat: 2-10m depth
Size: 30-60cm

Species

Eelgrass grows along the entire Swedish coast up to Uppland. It is usually found at depths between 2 and 4 meters but can occur to a depth of 10 meters. The species is a marine vascular plant and attaches to the bottom sediments through its roots. The plant has three to seven leaves on each shoot which are usually between 30-60 cm long and about 1 cm wide when fully grown. The eelgrass plant then overwinters using its rhizomes and can through this technique live for several years (Havsmiljöinstitutet, 2022).

Biodiversity

Eelgrass beds are providing shelter for many young fish and other species. It helps stabilize and reduce the erosion of bottom sediments through its large root systems. This helps create calm and clear waters which is beneficial to several species (Havsmiljöinstitutet, 2022).

Bioremediation

The eelgrass beds provide a number of ecosystem services and improves the water quality through filtering polluted runoff, absorbing excess nutrients and storing greenhouse gasses such as CO_2 (NOAA, 2014). In the autumn the plant loses its leaves which washes up on the beaches forming large piles along the shore, through removing the leaves the nutrients stored in them can be removed from the waterline, avoiding that they transport back into the water.

BIOMASS AS MATERIAL

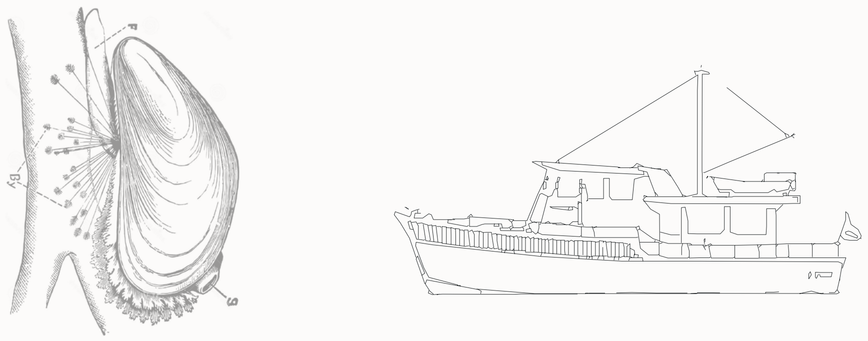


Fig. 9 - (Cooke et al., Molluscs, Brachiopods (Recent), Brachiopods (Fossil n.d.)

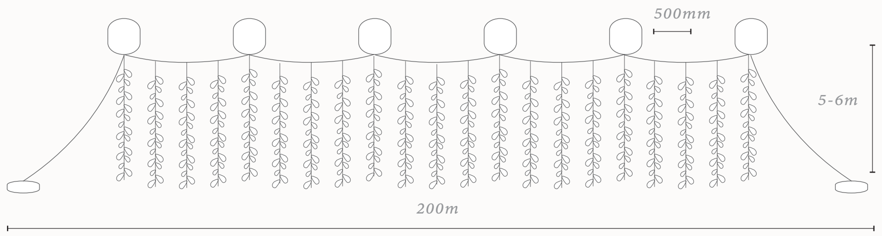


Fig. 10 - mussel harvest

Farming and harvest

There are several types of mussel farming methods where the most commonly used ove is the long-line method. This method consists of 200m long lines anchored in both ends and kept floating evenly distributed buoys. From each line hangs farming lines of approx. 5-6m with a distance of 500mm from each other (Lindahl & Kollberg, 2008). The mussels are harvested in the fall using boats.

Supply - shells as rest products

When mussels are harvested, around 1/3 of the harvest does not meet the demands for consumption and studies are searching for new areas of implementation for these rest products. The most researched appliactions are as fertilizers or animal food. If mussel farming becomes an even more commonly used bioremediation method, the amount of rest products will account for tens of thousands of tonnes (Lindahl & Kollberg, 2008). The rest products from mussel farming which we see potentially could be used as building material comes from three different sources: mussels non fitted for consumption, rest proucts from restaurants & shells left over from animal food production

Material properties

The shells have certain insulation value, are water repellent, wind resistant, posesses static strength and is a lightweight material. The most common use of the shells are as insulation and drainage, however they have also been seen as filling in walls and roof cladding (Nielsen, 2012).

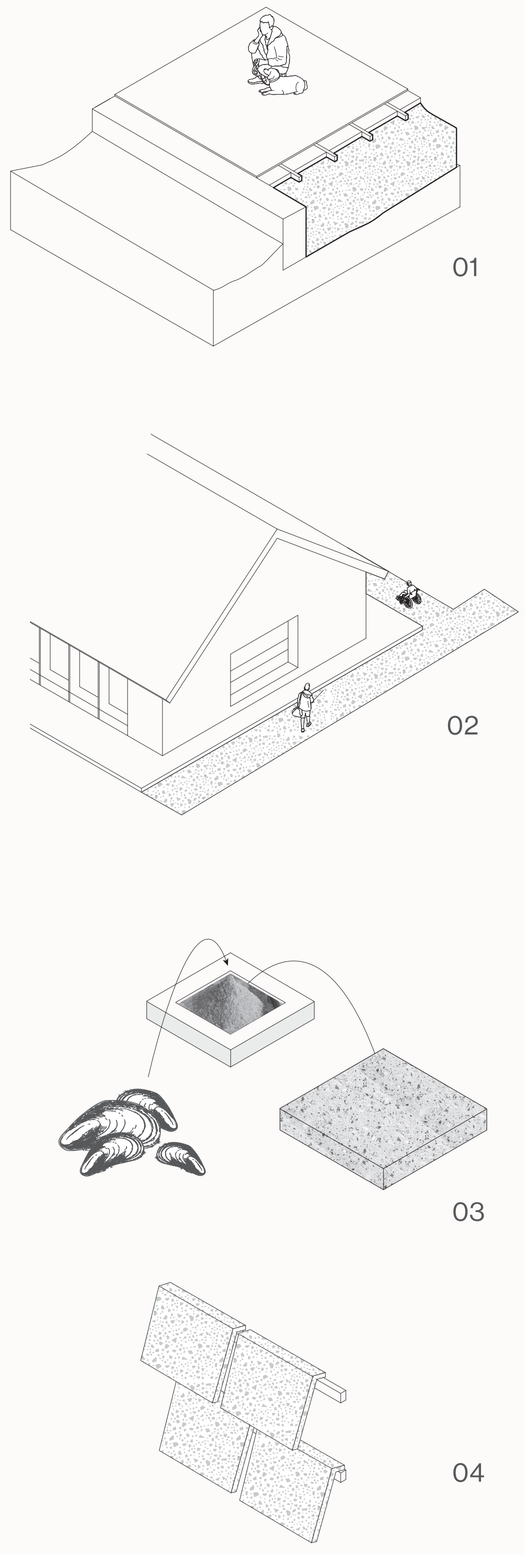


Fig. 10 - Architectural implementation -shells

Architectural implementation

Lambda: 0,112–0,135 W/mK
Acoustic properties: Low
Water resistance: Good
Durability: High
Most suitable for: Foundation/ drainage

01/ Foundation

Mussel shells can be used as insulation and draining material in foundations. As the insulation values are lower than conventional materials, the foundation needs to be at least 750mm.

02/ Drainage

Crushed mussel shells can be usd as a drainage and ground cover material. As they are naturally high in nitrogen and phosphorus, they can be used as a natural fertilizer in gardens on in agriculture.

03/04 Green binder

Mussel shells contain a high amount of $CaCO_3$ and research is currently made on how to replace limestone with mussel shells in order to create more sustainable cement. Crushed shells in different particle sizes can also act as a replacement for sand as an aggregate in concrete. Several companies are experimenting with this as a sustainable option to facade tiles.

Fig. 11 -Phragmites australis. Skoumalová, 2017

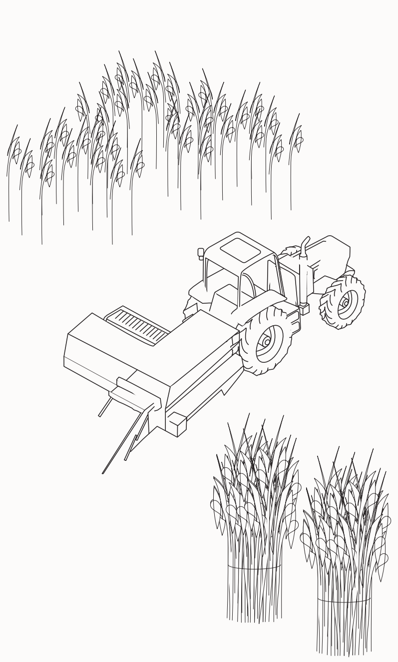


Fig. 12 - Reed harvest

Harvest & processing

Harvesting can be done both manually or using of machines, however, as the reed stocks make up important living and breeding habitats for both fish and birds, harvesting needs to be done consciously with environmental care (SLU, 2021). Usually the reeds for construction are harvested in the winter when the nutrients have transported down to the rhizomes, however, current research is exploring the possibility of harvesting earlier in the season to maximize the nutrient uptake. Once the reeds are cut, the old and brittle or damaged reeds are removed after which the reeds are transported ashore and bundled with a diameter of approximately 20-25 cm. In dense stocks, one ha of reeds could generate around 2000 bundles (Ljungberg, 2015).

Supply - a large renewing stock

The Swedish coast has a reed stock of approximately 200,000 ha which reproduces on a yearly basis. Despite the large stock of reeds along the Swedish coast, most of our reeds used in construction is imported from the Baltic countries or China (Ljungberg, 2015).

Material properties

The properties of the biomass makes it a flexible and durable material that can be used in construction. The hollow stem provides good sound and heat insulation properties. The reeds growing in coastal areas contains silicones wich increases the reeds resistance against the impact of the sun and wind (Central Baltic Interreg Programme, 2011)

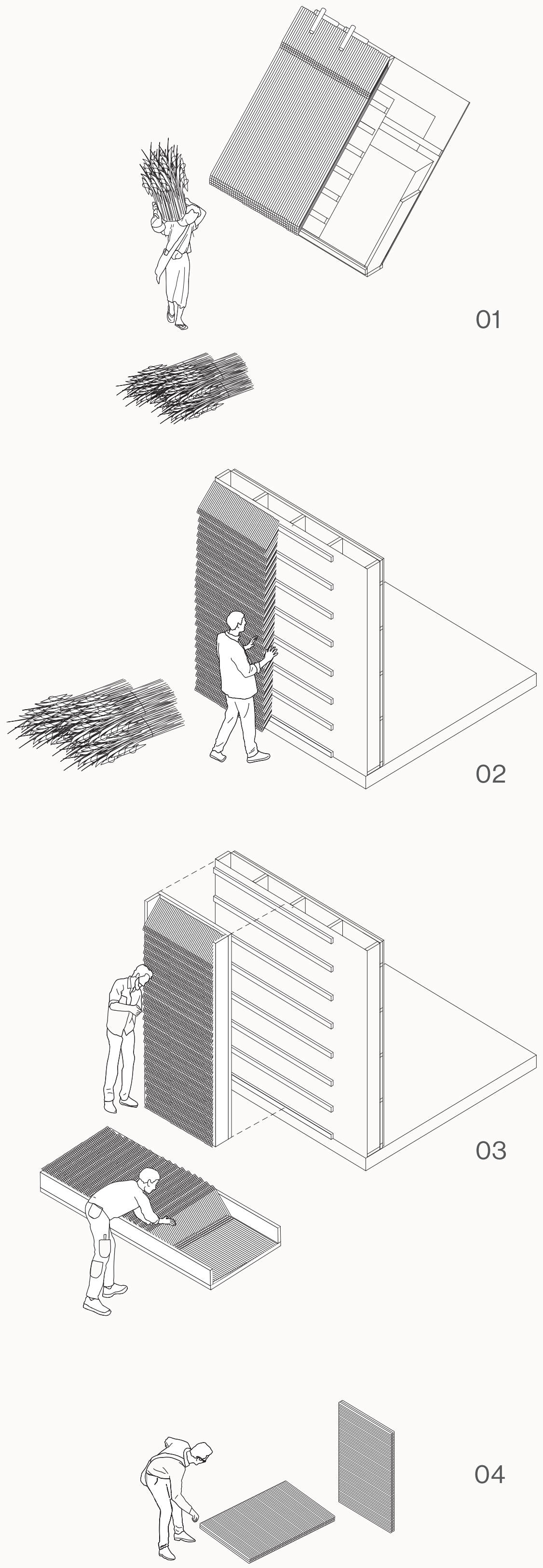


Fig. 13 - Architectural implementation - reeds

Architectural implementation

Lambda: 0.04-0.055W/mK
Acoustic properties: Good
Water resistance: Good
Fire resistance: Low
Durability: 30-70 years
Most suitable for: Roof/Facade

01/ Thatched roof

The most common use of reeds as building material is for thatching roof providing both external protection as well as insulation. One m^2 of thatched roof reqire around 10 bundles of reeds.

02/ Thatched facade

Thatched reeds can also be implemented vertically as facade cladding.

03/ Module facade

Experiments have been made where the reed is thatched in wooden casettes as prefabricated elements that can be easily mounted on site.

04/ Reed mats

Reeds can be used as insulation inside walls or as reveting mats. These mats are sparsely woven reeds held together by a steel wire. These mats can be used as a base for clay or lime plaster for wood panels as well as reinforcement in concrete.

POTENTIAL AS BUILDING MATERIAL - EELGRASS

Fig. 14 - Zostera marina, Douglas et al. (2001).

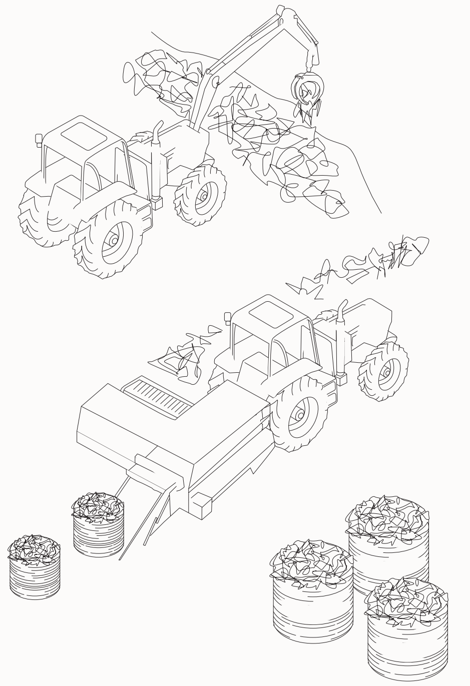


Fig. 15 - Eelgrass harvest

Harvest & processing

In the fall/winter the eelgrass is flushed up on beaches where it can be collected by machines. The eelgrass is then laid out on large fields for 2 weeks where the rain can wash away excess salts and then left to dry in the sun. Once the eelgrass is dry again, it gets collected into bales that can be stored until use (Realdania, 2013).

Supply - sensitive to climate change

The supply of eelgrass is uncertain as it depends on several environmental factors.Eelgrass are sensitive to climate change and the occurrence of it in Swedish waters has drastically deteriorated the past years. As the eelgrass beds have a great ecological importance, researchers are concerned about the environmental effects this will have on the overall coastal ecosystem. Several restoration programs for the eelgrass beds are currently in action and just last year a restoration outside of lilla askerö in Gothenburg archipelago suceeded where the 80.000 eelgrass plants that were planted has ten doubled and is now 860 000 plants (Nylén, 2022).

Material properties

Eelgrass as a building material has high potential. It is naturally impregnated with salts from the water which makes it both rot- and fire resistant. It has good thermal conductivity and is comparable to conventional insulation materials such as mineral wool. The plant absorbs significant amounts of CO_2 while growing and therefore serves as a carbon sink when used in construction (Realdania, 2013)

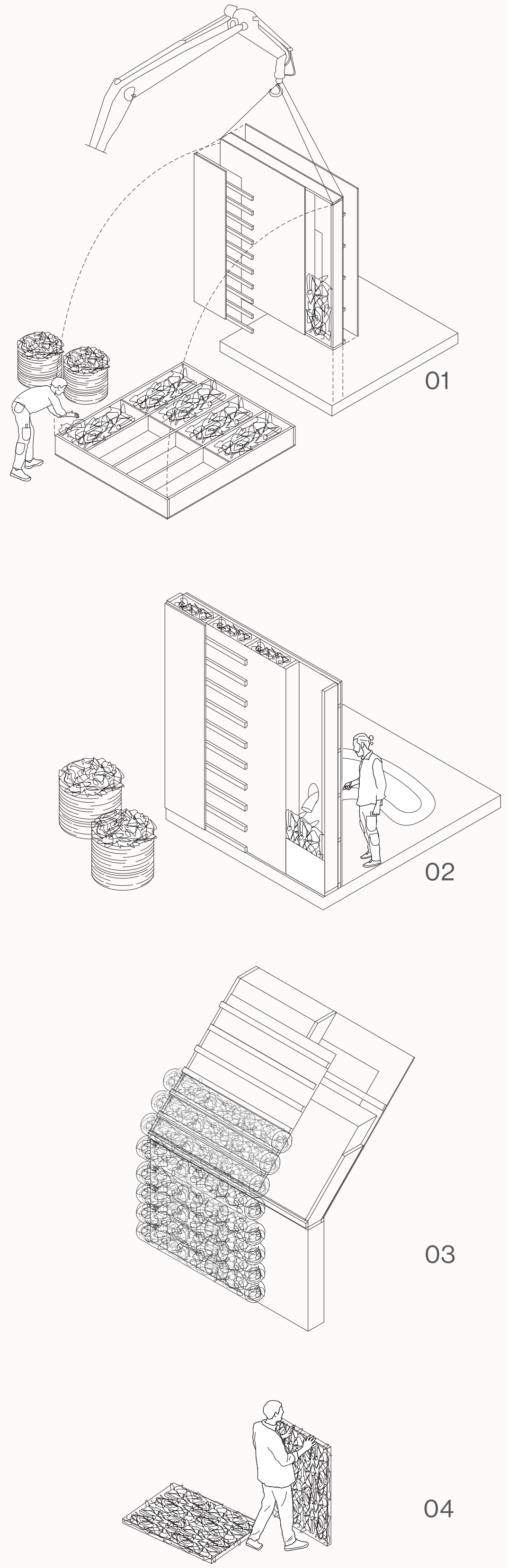


Fig. 16 - Architectural implementation -eelgrass

Architectural implementation

Lambda: 0,042 W/mK
Acoustic properties: Good
Water resistance: Good
Fire resistance: Good
Durability: 100+ years
Most suitable for: Insulation/roof

01/ Insulation

Eelgrass has a thermal conductivity of 0,042 W/mK and is well suited as insulation in prefabricated wall- and roof elements. The eelgrass is then manually pressed into the modules and weighed until preferred density.

02/ Loose insulation

Based on its material properties it could potentially be used as loose insulation which can be blown into the construction on site.

03/ Roof coverage

Eelgrass was historically a common roof coverage material in areas with abundance of it. Modern experiments using eelgrass as roof coverage and exterior cladding has been made by Vandkunsten Architects.

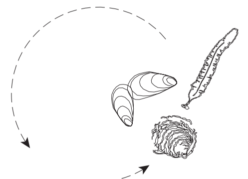
04/ Acoustic boards

The eelgrass can be grinded down and compressed into insulation mats similar to mineral wool mats. A similar process can also be done to create more compact acoustic boards for interiors.

A SYSTEMIZED APPROACH

Change in activity on land

change in activity on land in combination with climate change causes more emissions to reach the ocean



nutrient uptake through the natural recillience of the ecosystem

Increased algae growth

If the nutrient levels become higher than the natural filtering capacity, the result is an increase of algae

Over-fertlization

The increased amount of algae is worsening the light conditions and suffocates the botton mesdiments.

Eutrophication

Loss of oxygen in bottom due to sedimentation and worse light conditions

Biodiversity loss

The damaged ocean floor is resulting in inhabitable environments for important species along the coast and causes severe biodiversity loss.

biodegradable

01/ *better material use by building industry*

02/ *composted biomaterials can be re-introduced into agriculture as natural fertilizers, minimizing the anthropological strain and biodiversity loss*

bioremediation

Higher filtering capacity created through conscious interventions

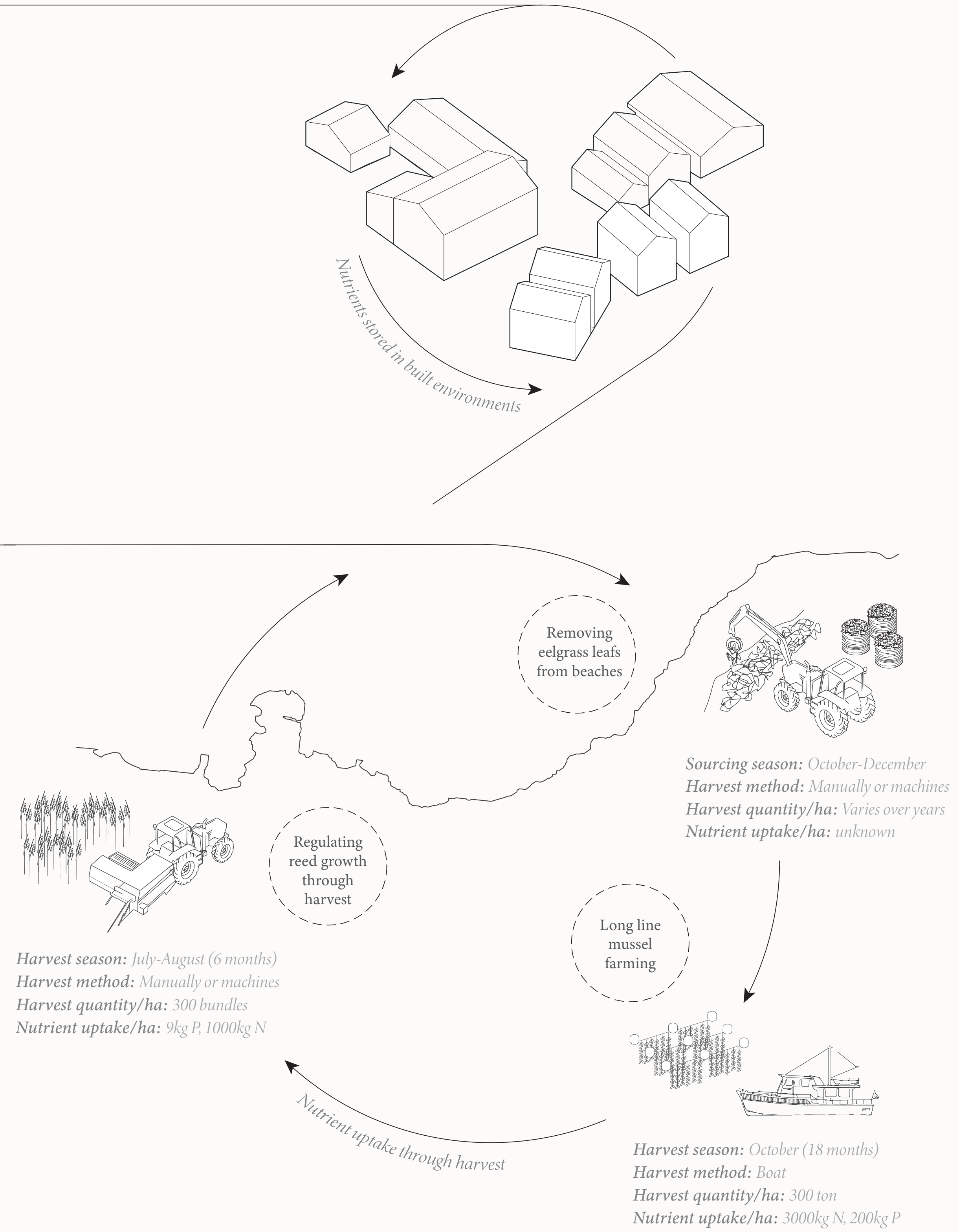


Fig. 17 - Explored system - Bioremediation to building material

CASE STUDIES

01/

Whaleback shell mould. Image: Peabody Museum of Archaeology and Ethnology

02/

Tabby concrete with whole oyster shells as aggegate. Image source: Rory Gardiner

03/

Facade made of oyster shells in Guangdong. Image: Life of Guangzhou

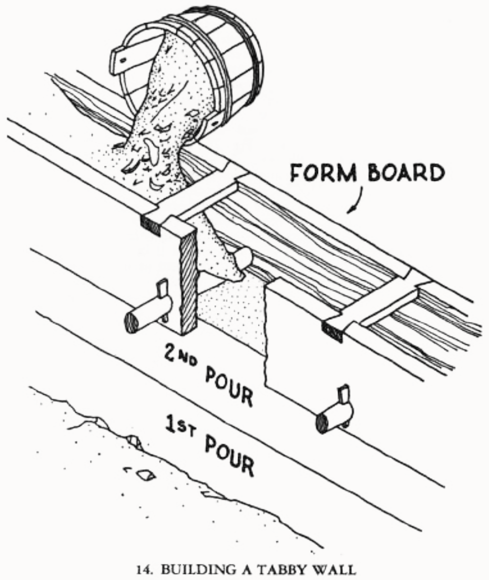


Fig. 18: Building a tabby wall. Image source: The houses of st. Augustine

01/ The concrete-like material "Tabby" was made through a mixture of equal parts shell, lime, sand, water and sometimes ash.

02/ The material was used to construct a variety of building components such as foundations, columns, walls, floors and roofs.

03/ Wall made up of oyster shells in the Guangdong pearl River Delta region in Cina.

"The process of transforming sea shells into building materials dates back over a thousand years. It has evolved from communities lacking certain natural resources for construction" (Local Works Studio, 2016).

Using shells for construction

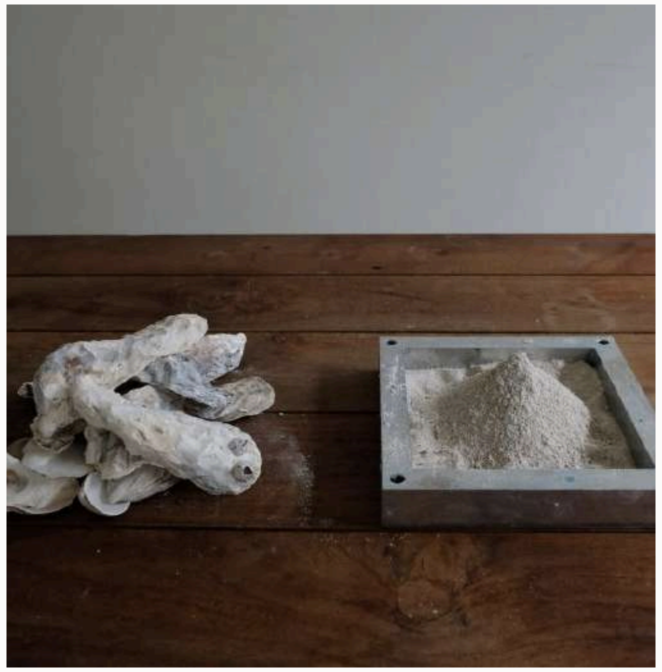
Already in the 1700's, shells from mussels, oysters and other species were used in construction. (Ahrenbeck et al., 2021). A concrete-like mixture called "Tabby" used equal parts shell, lime, sand, water and sometimes ash (Ahrenbeck et al., 2021). The ash is a rest product from burning of shells to create lime and works to harden the final product. The tabby mixture was traditionally poured into molds and could be used to make several building components such as foundations, columns, walls, floors and roofs. It is a durable material and if protected with stucco to withstand water better (Morris, 2009).

Replaced by cement

Along with the introduction of Portland cement in the 1870's, the use of Tabby decreased and cement mixtures became more commonly used. However there are still remains of old tabby buildings in various places. A re-introduction of the old technique but in a modified modern manner has also been seen recently , however this mixture often includes portland cement (Morris, 2009).

Cultural heritage in parts of China

In the Guangdong pearl River Delta region , building with shells is a special part of the cultural heritage. "The oyster shells are scaly and neatly laid in a 45-degree downward manner, which can facilitate the drainage of rainwater, avoid rainwater from entering the inner wall, and keep the room dry." - (Huang, 2021)



01/

Manually grinded shells. Image source: Newtab-22

02/

Tiles made from waste oyster shells. Image source: Local Works Studio

03/

Mussel shell drainage in foundation. Image: Bondegaard Rydbjerg

MODERN USE OF SHELLS

01/ Shells are becoming more common to experiment as a waste product. Because the shells consists mainly of Calcium carbonate, it has potential to act as a natural green binder in the replacement of limestone in cement

02/ Local works studio sources oyster shells as waste from restaurants in Brighton. Through blending this with other waste materials, they have created a palette of self-coloured mortars for casting as weatherproof external tiles.

03/ Mussel shells have good capillary breaking properties and drain well. This makes them a suitable material in building foundations.

Shells in buildings

The use of mussel shells in modern construction is mostly found in small scale self-building projects as well as in eco-housing. In Denmark, more than 100,000 tonnes of mussels are harvested each year making the quantity of shells as a waste product huge. "A residential building typically consumes 35 - 60 t of shells, depending on use and size."(Nielsen, 2012).

Material properties of shells

Mussel and oyster shells are completely water repellent and have good capillary breaking properties which makes them a good material for drainage. When stacked together the shells form small insulating pockets of air. Despite this, they have a lower thermal conductivity than conventional materials and need a thicker layer to reach the same insulating properties. The most common use of the shells are as foundation and drainage, however, examples have been found where the shells are used both as filling in walls and roof covering material where the shape of the shells make them resistant to impact of wind (Nielsen, 2012).

Using shells as a rest product

Shells are becoming more common to experiment as a waste product. Because the shell consists mainly of Calcium carbonate, it has potential to act as a natural green binder in the replacement of limestone in cement. Offices such as Local works and Newtab -22 have explored the possibility of converting mussel and oyster shells into tiles as well as facade cladding.

Local works studio writes that they source oyster shells as waste from restaurants in Brighton and blend this with other local waste materials, creating a palette of self-coloured mortars for casting as weatherproof external tiles (Local Works Studio, 2016). Newtab-22 has created a product named Sea Stone, a material that is made by grinding down shells that are destined for landfill before combining them with natural, non-toxic binders. This grants the Sea Stone a terrazzo-like aesthetic (Designwanted, 2021)

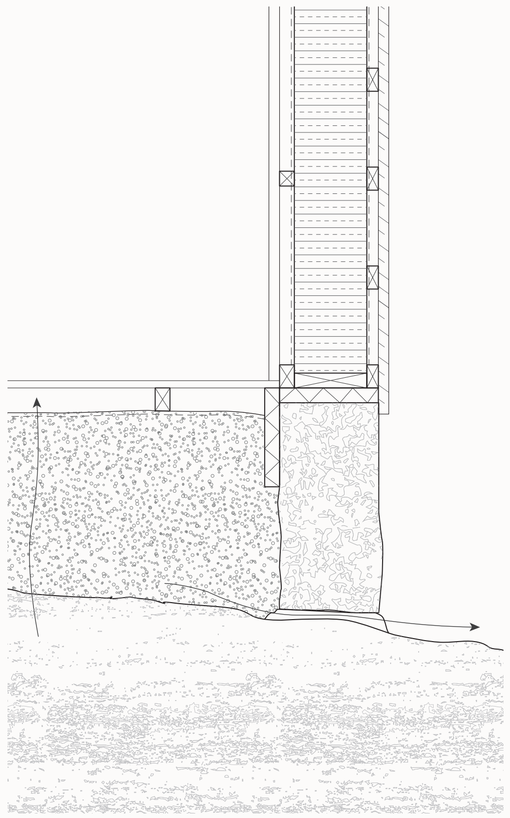


Fig. 19: Modern mullbänk. Own illustration.

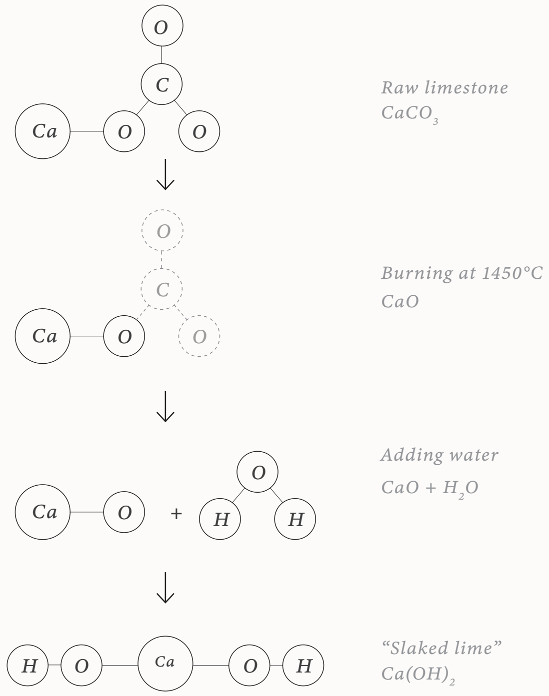


Fig. 20: Chemical reaction of slaked lime. Own illustration

01/

Roof covering with reeds. Photograph: Nilsson, Nils J/Kalmar Läns museum

02/

Thatched roof. Image source: Svenska Stråtaktäckarföreningen

03/

Detail of a reed/thatched roof on Öland. Image: Wikimedia Commons

01/ In Sweden, thatched roofs were common in all parts of the country. The materials used for thatching varied, along the coast, reeds were easily accessible while inwards land, straw was more commonly used (Dervishi & El-Zoubi, 2012).

02/ Using reeds put a certain demand on the construction. The roof pitch depended on the house's width and ceiling height in relation to each other and what material was being used. For straw and reed roofs this often required a 2:1 relation between the width and height of the house, ca 45 degrees (Dervishi & El-Zoubi, 2012).

03/ The ridge could be covered with loose reeds or seaweed and held together by branches.

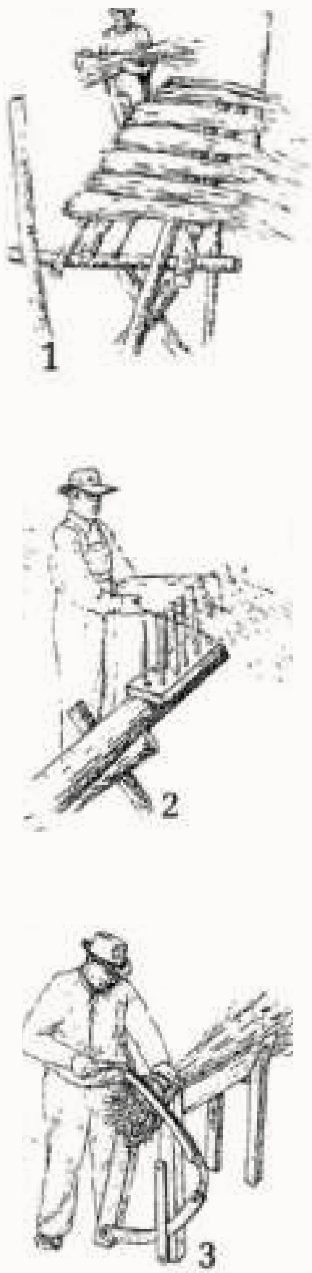


Fig. 21: Stages of the thatching process. Image source: Roman Fodchuk and Associates

In Sweden, thatching is one of the oldest roof covering methods. The material for thatching depended on the location where straw was common inland and reeds were used closer to the coast (Landsbygdens folk, 2019)

A traditional material

Building with reeds dates way back in history throughout different cultures around the world. The easy access to the material along with the material properties made it a popular building material especially for constructing roofs (Csaplovics et al., 2011).

Thatching techniques

Just as the materials varied in different parts of the country, there were also several different thatching techniques. In the southern parts of Sweden, the material was attached directly onto the horizontal battens of the roof and covered with loose material at the top kept together with branches. Further north the thatching technique involved a sparse net of long stick where the straw had to be attached (Dervishi & El-Zoubi, 2012).

Replaced by modern materials

In the end of the 1800s the thatched roof was gradually replaced by other materials. Clay tiles competed as a more attractive material, as they also contained better fire resistant properties.The industrialization of agriculture with new machines for harvesting caused the straw to be unusable for thatching roofs. The poor fire resistance of the materials along with a lack of proper knowledge about fireproofing were also a contributing factor to the declining use. This however is no longer an issue in modern thatched roofs (Dervishi & El-Zoubi, 2012).

01/

Naturum Tåkern. Image source: Inside Wingårdhs

02/

Thatched facade at Wadden sea center. Photograph: Rasmus Hjortshøj

MODERN USE OF REEDS

01/ Jonas Edblad, architect at Wingårdhs states that when arriving at Tåkern to look at the area, they immediately felt an urge to somehow use the large reed beds around the lake. After reading up on buildings with reeds, Edblad realized how durable the material is if it is treated properly. It then has the potential to become one of the most durable materials available. (Svenskt trä, 2012)

02/ The Wadden Sea center is a modern interpretation of the historically traditional building techniques and typology of the area. The exterior of the building consists mainly of thatched reed which gives the building high tactile qualities and a robustness often found in traditional crafts (Dorte Mandrup, n.d.)

Reed roofing

The most common use of reeds is for thatching roof and poses a certain demand on the construction. To ensure enough water run-off, the roofs require an angle of minimum 40 degrees. When ensured a suitable angle and during the right circumstances, a thatched roof can have a lifespan of 30- 70 years (Svenskt trä, 2012). A felt roof will have a life span of approximately 20 - 30 years in comparison (Westergren, E. B 2015). A reed roof can weigh 35-40 kilos per square meter, so a strong frame is needed (Dervishi & El-Zoubi, 2012). The reed roofs most critical point is its ridge. It is usually maintained every 7 years (Westergren, E. B., 2015). Modern examples implement a steel profile to better protect the ridge, extending the durability and lifespan of the roof.

Fire safety

A historical problem with reeds in construction was that it easily caught fire. In regards to fire safety of thatched roofs, there are two main methods in limiting the risk. The Dutch constructive method means fixing the reeds with wire directly on a sheet material like groove or the wind protection barrier. The aim is to limit the oxygen supply from underneath the construction. Without the air gap in the construction, the thatched roof acts as an additional insulator of the roof. The second thatching technique is the Danish method which is similar to the Dutch one with the exception of the addition of a fire proof sheet membrane that diminishes the fire risk from underneath the construction. The danish method usually uses an air gap in the construction, but does not benefit from the insulative properties of the thatched roofing (Dervishi & El-Zoubi, 2012).

Durability

The lifespan of a reed roof will depend on several factors. Sources of damage to a thatched roof consists of potential branches from surrounding trees hitting the roof, shaded or poorly oriented positioning that slows down the drying of the roof, as well as the construction and reed quality (Criteria for the Durability of thatched Roofs, 2017). According to Dervishi & El-Zoubi (2012), strong winds up to 30-40 m/s can damage the roof. In conclusion, this will pose demands on the construction, placement, orientation and roof pitch of the building.

Architectural impact

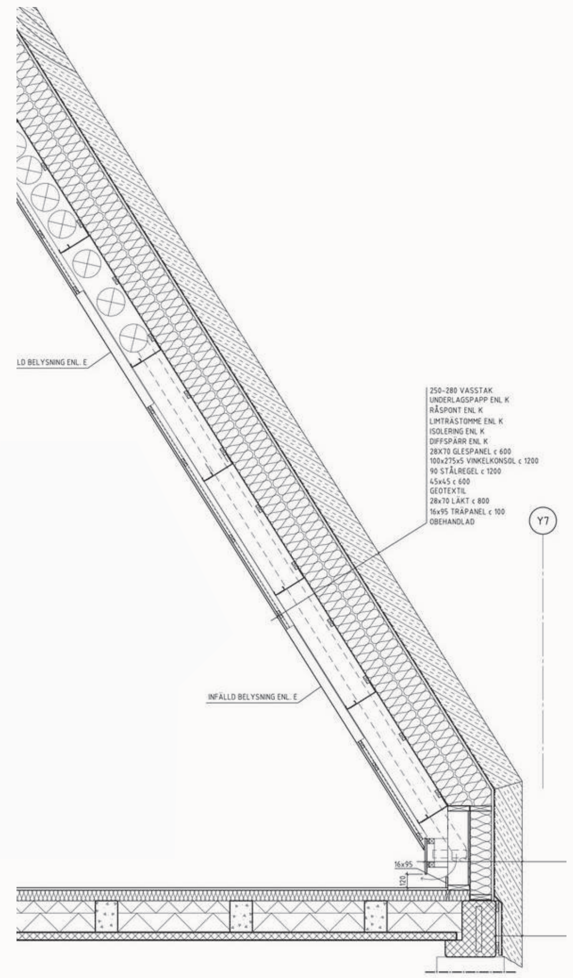


Fig. 22: Detail drawing Tåkern, Image: Svenskt trä

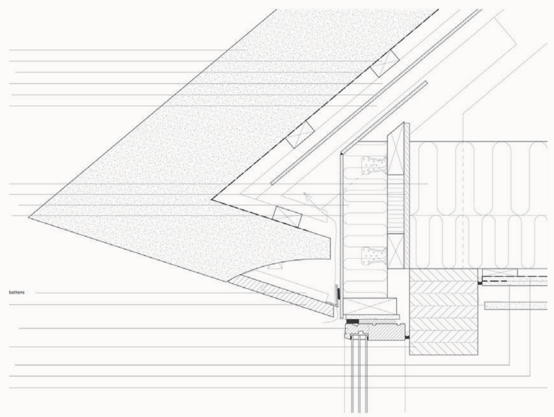


Fig. 23: The Wadden Sea Center, detail section, Image: EU Mies Award

01/

Eelgrass house in Østerby in 1906. – . Foto: H. Fr. Eiler.

02/

Eelgrass roof on Læsø. Image credit: Thomas Kyhn Rovsing Hjørnet/Alamy

03/

Eelgrass roof. Image: Designboom

01/ Traditionally on the island Læsø the eelgrass was collected by the women in the village.

02/ The eelgrass was usually stacked on the roof using a specific twirling technique until it was water tight. This gives the very unique expression of overflowed, chunky roofs.

03/ The eelgrass roofs can last for up to 300 years and today there are still eelgrass roofs present on the island.

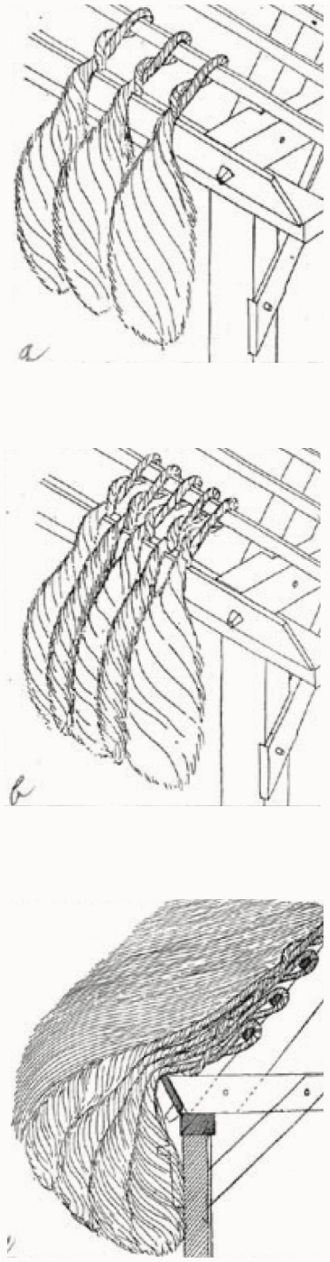


Fig. 24: Tangtagets konstruktion, Nationalmuseets arbejdsmark 1944

In Denmark there is a strong historical tradition of building with eelgrass as they have a large abundance of it on the beaches.

A danish tradition

On Laeso, an island on the Danish east coast, seaweed has been used traditionally as a locally sourced building material. Due to the lack of straw, the roofs of the buildings were covered in seaweed, that flushed up on the shores nearby (Realdania, 2013).

The women of Læsø

In an interview with Søren Nielsen, Architect and partner at Vandkunsten Architects (15 febuary 2023), he states that back in the days, when eelgrass was a more commonly used building material, it was collected mainly by the women in the village. The collected seaweed was dried and attached to the roof structure using a twirling techniqe. When the base was laid, large amounts of eelgrass was added on top until full coverage was reached. This often resulted in massive roofs of up to 1.5m thick.

In an interview with the National Museum's from 1949, Fr. Petersen, born 1858 in said: "At the place where the seaweed especially drifted ashore lived an elderly single woman. Her main source of nutrition was "to clear" the seaweed. The work consisted in when the seaweed was fairly dry "to shake it up", i.e. she shook sand and the like off the tongs with an ordinary three-pronged fork. When that had happened it was staked, and thus stood until the person who had ordered the load picked it up" - (Danish Cultural Heritage Agency, 2008)

The Modern Seaweed house. Photo: Helene Høyer Mikkelsen and Realdania Byg

01/

Eelgrass insulation in prefab wall. Image source: Realdania By & Byg, 2013

02/

Acoustic Boards made from eelgrass. Image source: Søuld

03/

MODERN USE OF EELGRASS

01/ "The Modern Seaweed House on Læsø is not only a tale of the renewed use of a remarkable material on a unique site with an extraordinary building history. It acts like a crystal ball that catches and illuminates many of the most important issues the construction industry is facing today." - Søren Nielsen, architect MAA, partner at Vandkunsten

02/ The properties of the eelgrass makes it suitable for insulation in exterior walls. Here the eelgrass is packed into a prefab wall element.

03/ Several companies have discovered this material and many products are now on the market, among these, sustainable acoustic boards by the company Søuld.

A durable and sustainable material

The interest for eelgrass has grown steadily the last few years and it is occurring in more and more modern projects. One of the material's most important advantages is its positive effect on the climate. It binds CO2 during its life and can be harvested and processed using very little energy. Traditionally the material was used for many purposes , however, today it is most commonly seen as a sustainable alternative to conventional wall insulation such as mineral wool. In the project The Modern Seaweed House by Vandkunsten Architects, three very different ways of using the material was developed: As insulation, as interior padded cladding, and as external visible cladding (Realdania 2013).

Material properties

The insulation properties of eelgrass is comparable to conventional alternatives and has almost the same thermal conductivity as mineral wool: 0.042 W/mK. It is naturally impregnated with lime and silicic compounds to withstand decay and has a high fire resistance thanks to the salt. It is a durable material that doesn't rot (Realdania, 2013).

Lacks form-binding capacity

Søren Nielsen, architect and partner at Vandkunsten Architects describes in an interview on the 15th of february, the design process behind the project and brings up the facade and roof cladding rolls. As the seaweed itself has no particular form binding capacity and therefore requires a supportive construction that holds it together when used for other purposes than as loose insulation. Here he describes how the team at Vandkunsten tried out many possible designs and ended up with a design made out of yarn tying rolls of seaweed together like a net. The reason behind this was to honor the historically female dominated craftsmanship, implementing features of fabric, threads and knitting techniques into the design. When revisiting the project, the yarn rolls had dissolved by rain, showcasing a need for further explorations in using it as facade cladding.

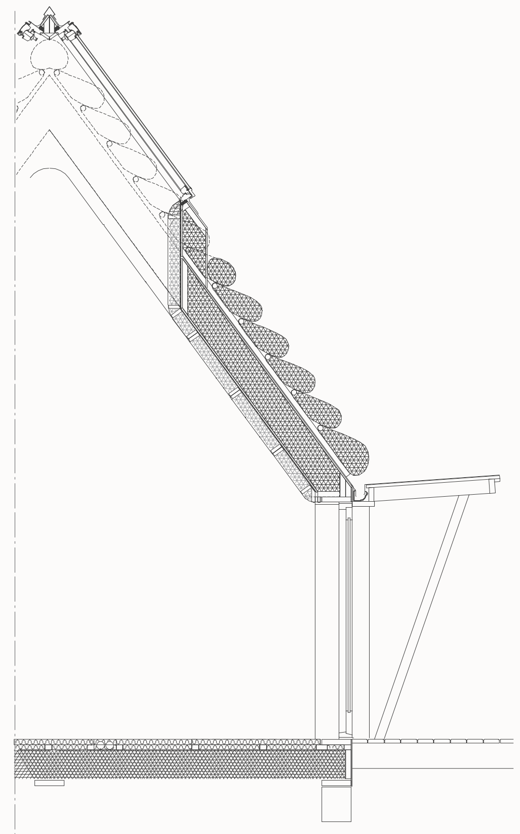
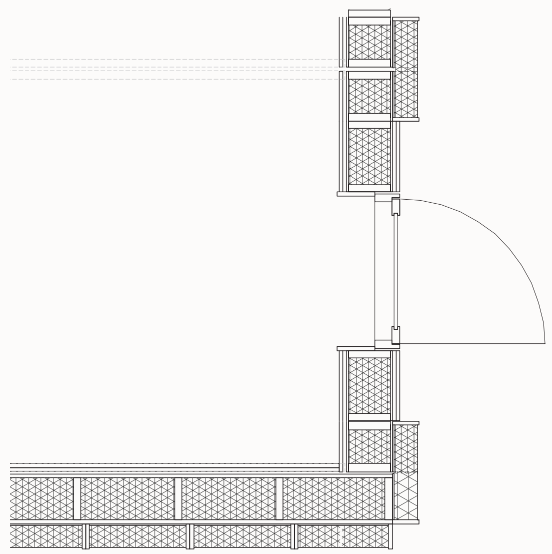


Fig. 25-26: Drawings of The Modern Seaweed House, Vandkunsten Architects



MATERIAL INVESTIGATION

Cross-disciplinary collaboration

In order to deepen our own personal knowledge about conventional building materials and understand what are the key factors to their negative impact on the environment we wanted to investigate this in a more practical manner. Through this part of the project we had fantastic help from Arezou Baba Ahmadi as well as Kathryn Larsen who both has been of great assistance in helping us understand the science behind implementing marine based resources in conventional materials. Arezou is a researcher with a PhD in building materials and a background in civil engineering, materials chemistry and concrete technology. Kathryn is an Architect and architectural technologist with a specified knowledge and interest in marine biomaterials.

Possible use of shells as a replacement in cement

Concrete is currently the most commonly used material worldwide and its production is a major contributor too the yearly emissions of the building industry. Much of the environmentally straining aspects of concrete comes from the production of the cement. (Ahrenbeck et al., 2021) The production of cement includes quarrying and burning of limestone which has a high environmental impact both in terms of emissions as well as destruction of natural environments. The global production of cement is estimated to be responsible for 9% of the worlds total CO_2 emissions (Naturskyddsföreningen, 2022).

The biggest contributor to conretes negative environmental impact is the quarrying and burning of limestone to extract calcium carbonate ($CaCO_3$) in order to make cement (Naturskyddsföreningen, 2022). Studies have shown that the shell of blue mussels consists of around 90% $CaCO_3$ (Ahrenbeck et al., 2021) and the last couple of years research has been carried out in the department of Architecture and Civil Engineering here at Chalmers University, on the possibilities of utilizing shells as a replacement for the limestone in cement production.

Laborations

As shells can be sourced as a waste product leaving little to no environmental footprint, we here see a great opportunity to explore possible areas of implementation further.

During the thesis process we were able to ourselves experiment with this material in the lab at Chalmers. In this laboration we were trying to find a possible mixture that would replace as much of the non-renewable materials as possible with mussel shells. The mixture that ended up working the best is a recipie similar to the one for rammed earth blocks used for construction in many places of the world.

Fig. 27: Test mixture - Own image

01/

02/

03/

04/

01/ Raw material - Mussel shells sourced from a local restaurant
02/ Crushed shells - larger particle size for texture
03/ Grinded shells - smaller aprticle size similar to sand
04/ Calcinated shells - CaCO3 based binder

Utilizing waste products

The first and perhaps most important aspect of the experiment was making sure that the calcinated shell could achieve the same type of chemical reactivity as regular limestone. This was tested before conducting the mixing of compounds. The test was made through mixing the calcinated mussel shells with water and through PH-measuring, we could conclude that a chemical reaction had happened. This in theory means that the calcinated shells on a chemical level, has the same chemical attributes as limestone in terms of reactivity, hence could therefore be seen as a potential binder.

The aim with the explorations was to create a mixture that utilized as much of the waste shell as possible. For this reason, the recipes tried out were made without the implementation of any cement or non-reneweable resources. Since we knew that the calcinated shells posessed the ability to chemically react with water in a similar way to limestone, we could assume that this component could be replaced and still ensure a reaction. A recipie for a concrete mixture was then used were an attempt was made to replace all components with bio-based rest products, using as much shell as possible. As cement contains other reactive comounds such as silicates, aluminum and iron ore, we needed to find a bio-based or waste-product that could work as an alternative to this. For this pupose two types of components was used in the mixture.; volcanic ash (sourced naturally from iceland) and waste clay from construction sites in Norrköping, Sweden.

Outcome

Two types of recipies were tried out, one similiar to regular concrete and one closer to the one used for constructive earth blocks. We also experimented with increasing the amount of reactive substance. The tests were put into wooden and silicone molds and placed in a humid environment to harden.The outcome of the tests had varied results. The recipie which closer resembled the earth-blocks was more sucessfull than the others and we chose to use that recipie for two largers tests. This time we added pressure to the molds in the same way which earthblocks are traditionally made. The results are still not taken out of their molds, however when checking them , the pressure seemed to have helped the hardening process

Reflection

As this is an architectural thesis and we have limited possibilities in scientifically testing the structural and environmental properties of this, the result can not say with certainty that replacing concrete components entierly with shells while still remaining its material properties is possible at this point. However, it provide insights into possibilities for a wider utilization of shells as rest products from ecologically restorative processes. This supports the Cradle to Cradle perspective of eliminating the idea of products as waste and seeing them as "food" for a new renewable cycle.

Fig. 28: Samples from laboration - Own image

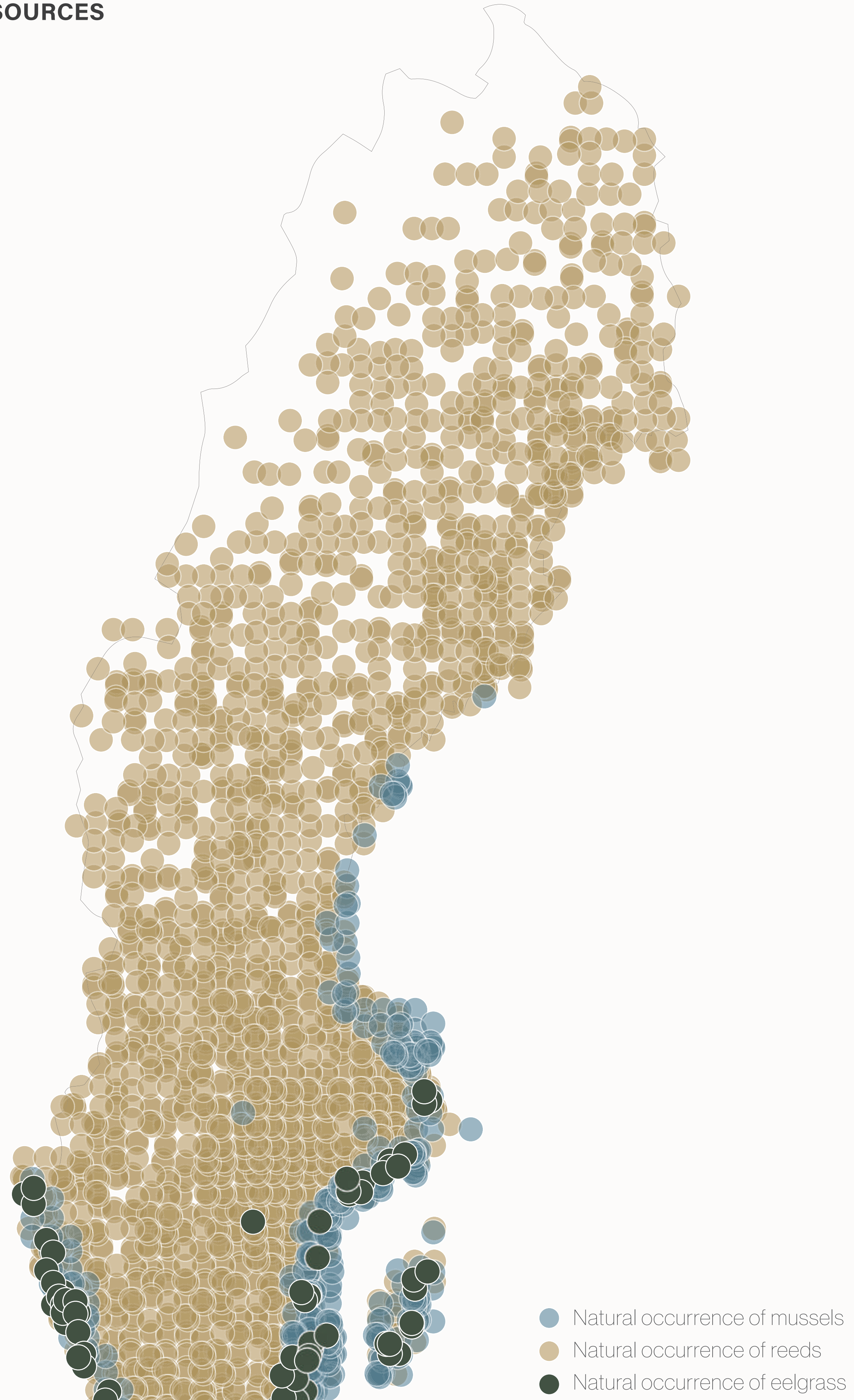


Fig. 29: Natural occurrence of species based on info from "artdatabasen" - Own Illustration

Departing from the supply

A precondition for establishing a sustainable relationship between resource extraction and natural balance is to understand that the material demand has to be subordinated the available supply. Further, limiting the material use should always be considered as we only have a limited supply of resources to share to stay within our planetary boundaries.

As the need for extended bioremediation of eutrophicated waters is large, new areas of implementing the rest products could be beneficial in a financial aspect where a demand for the output could give more means to a greater implementation of restorative interventions. Hence a shift towards a more common use could result in a larger and somewhat more controlled supply. For example, increased initiatives for mussel farming could increase the supply of shells as a rest product.

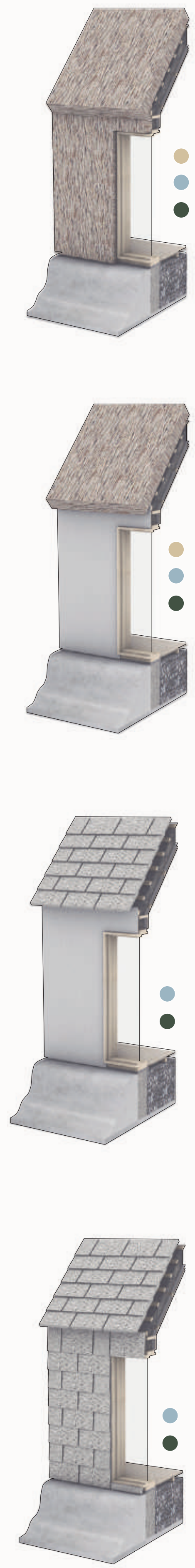
Today the natural occurrence of the studied species varies drastically where the reed stock is by far the most widespread. Utilizing reeds to a larger extent would therefore be a beneficial choice in most parts of the country.

Replacing normative materials

The use of the studied species in modern construction could significantly limit the environmental impact connected to material extraction and can be applied in various ways in a building leading to a variety of architectural expressions. The aim of this thesis has been to emphisise the fact that a shift towards more bio-based materials does not neccesarily have to be made at the expense of current architectural ideals.

Depending on what materials are being replaced, the architectural expression can be more or less similar to "conventional" buildings. Replacing for example only mineral wool to eelgrass insulation gives little impact on the exterior expression, whereas a thatched roof might have a more obvious character. While eelgrass and reeds through case studies has proven to be successfully implemented, the shell-based concrete/tiles is still being developed through research and has not yet proven to be durable enough to replace conventional concrete.

IMPACT OF MATERIALS



PROJECT IMPLEMENTATION

A dually responsive program

The duality of the twin crises demands a behaviour shift in all aspects of life and applies not only to the resource use of the building industry but the food sectors' as well.

Blue cultivation

The food sector alone stands for about a third of the world's total greenhouse gas emissions and it is the biggest driver of nature loss. Producing food requires large amounts of farmland and currently 40% of our habitable land is occupied with food production which has caused 80% of the global deforestation and 70% of the biodiversity loss (United Nations, 2022). Industrialized agriculture is also one of the largest contributor to ocean eutrophication. There is therefore an urgent need to explore alternative sources of food that does not deplete our natural environments.

An increase of interest

Recently there has been an increase in the interest for blue foods. The many benefits, both for the environment and overall health has caused people to reconsider their food consumption. In Denmark, the interest for blue cultivation is large and the community "Havhøst" has established several blue gardens around the country. The purpose of these gardens is to "get people actively engaged in a practice in the cross-section between sustainability, food climate and biodiversity" (Havhøst). In these blue community gardens, three aquatic species are cultivated; Blue mussels, Oysters and Seaweed which are described as the power trio of the regenerative era thanks to their multi-functional properties (Hjerl, 2021). In a swedish contex, Maria Bodin at the University of Gothenburg says that there is a lot of potential in further development of these kinds of projects (Bodin, 2021). Helsingborgs kommun announced an opportunity for the public to get involved in a similar initiative. Here individuals can announce their interest in getting their own "marin kolonilott" where they can grow mussels and other species.

Reference program

"From my house, at the hill above here, you can clearly see how the mussels clean the water. It is always clear and nice closest to the plantations" (Stawreberg, A.-M., 2020).

Musselbaren is a Swedish restaurant with two establishments on the Swedish west coast, one in Smögen and one in Ljungskile. When it opened, it was a great success with a big interest. Janne Bark, the owner, describes how more and more people have realized that mussels are the food of the future, both for the surface-efficient cultivation method and for the high nutrient content, but primarily for the positive environmental effects. Anton Ingildsen Kämpe insists on the fact that cultivating mussels is a enormous environmental favour. "It is the most climate-smart thing you can eat. The more mussels you harvest, the greater the benefit. Because mussels filter enormous amounts of water. It counteracts eutrophication, nitrogen and phosphorus" (Stawreberg, A.-M., 2020). In the Ljungskile establishment the restaurant has an experience package where you through a booked tour get the opportunity of joining the fishermen on a 4h boat ride to harvest, clean and prepare your own mussels directly from their long-line farming in the fjord system. Once back at the restaurant you get to see and be a part of the cooking of the newly harvested mussels, in this way experience the entire process from farming to eating (Stawreberg, A.-M., 2020).

01/ *Mussel farming, Image source: Kent Eng*

02/ *Harvesting experience, Image source: Jonas Ingman*

A SUSTAINBALE PROGRAM AT DYRÖN

The project further suggests a program with inspiration from the references of Havhost and Musselbaren. This re-connects the program to the twin crisis, in the way that allows people the opportunity of engaging in the cross-section between sustainability, food, climate and biodiversity. In the search for a suitable site for this program, Dyrön was found as a rurban context which could respond well to this type of initiativ.

Stora Dyrön - a rurban context

Dyrön is one of six islands in the archipelago of Tjörn on the Swedish west coast that has a year-round population of around 170 inhabitants. When describing Stora Dyrön as a rurban context, it is best done so by considering the complexity of its geographical location in combination with its very polarized activity over the seasons. The island is small in its scale and population, giving it a clear sense of rural attributes, meanwhile it lies in a close proximety to Gotheburg that offers a strong influence of urbanization. With its seasonal shift, Stora Dyrö increases in population by approxiamtely 300% during the summer, caused by an influx of tourists and summer residents, raising the demand for services and recreational activities. The calm and quiet winter season experience a drastic decrease in activity and residants. This seasonal shift highlights the interplay between the island's rural and urban features, giving it 'rurban' attributes both in terms of spatial, geographical and temporal conditions.

Building beyond an urban norm for sustainable futures

The design framework of rurban transformations can provide Dyrön with new opportunities for a sustainable and a more even seasonal development. This is done through a hollistic and regenerative approach, that re-connects the program to the twin crisis, in the way that allows people the opportunity of engaging in the cross-section between sustainability, food, climate and biodiversity, through the built environment. This would be possible by the strengthening of a loal context through a local resource use both regarding material and food consumption. In a shift towards a sustainable future, this means going beyond the urban norm that departs from material demand, and instead focuses on the material supply and the environmental demand of regenerative materials.

Fig. 30: Map of Dyrön

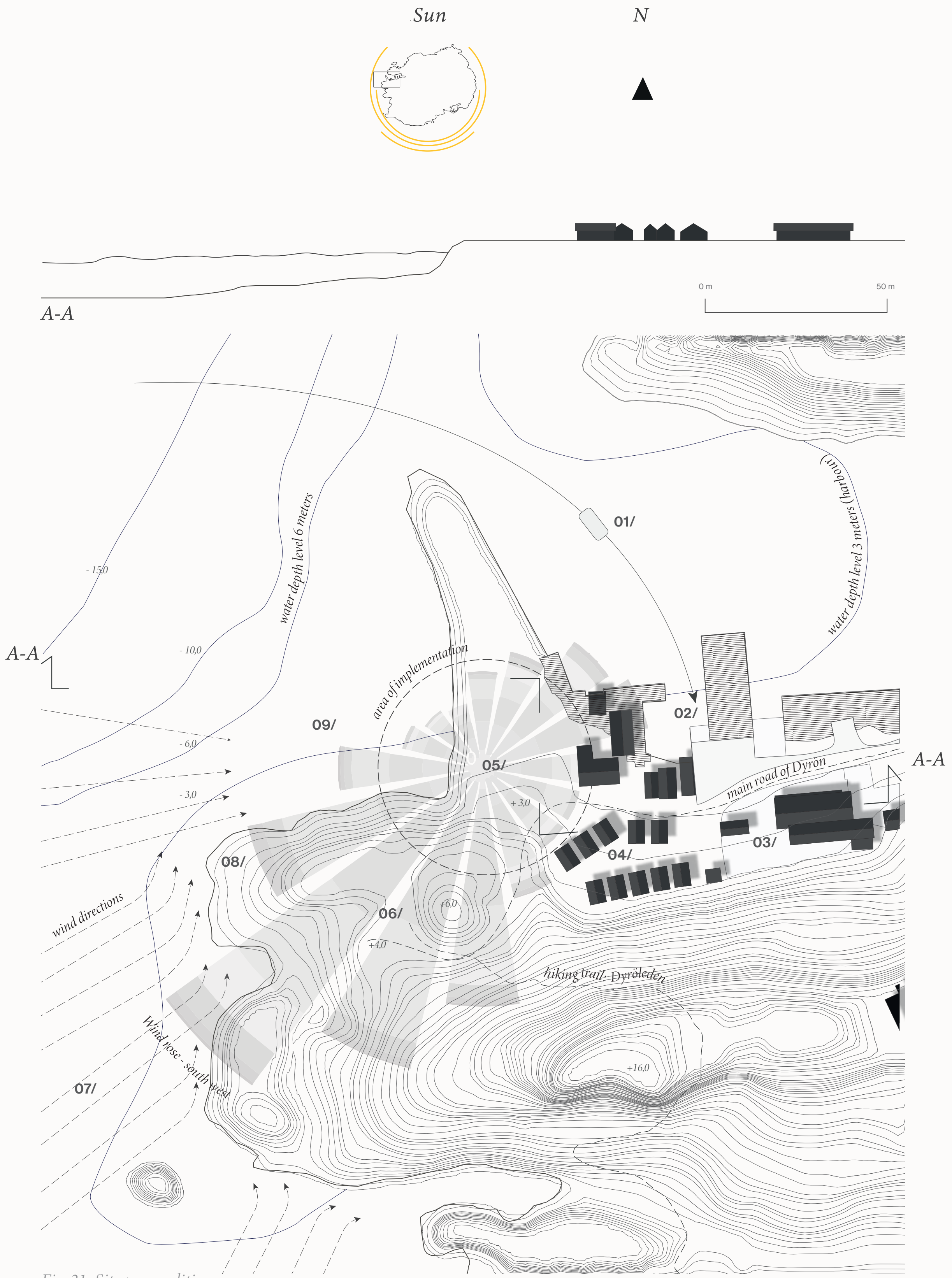
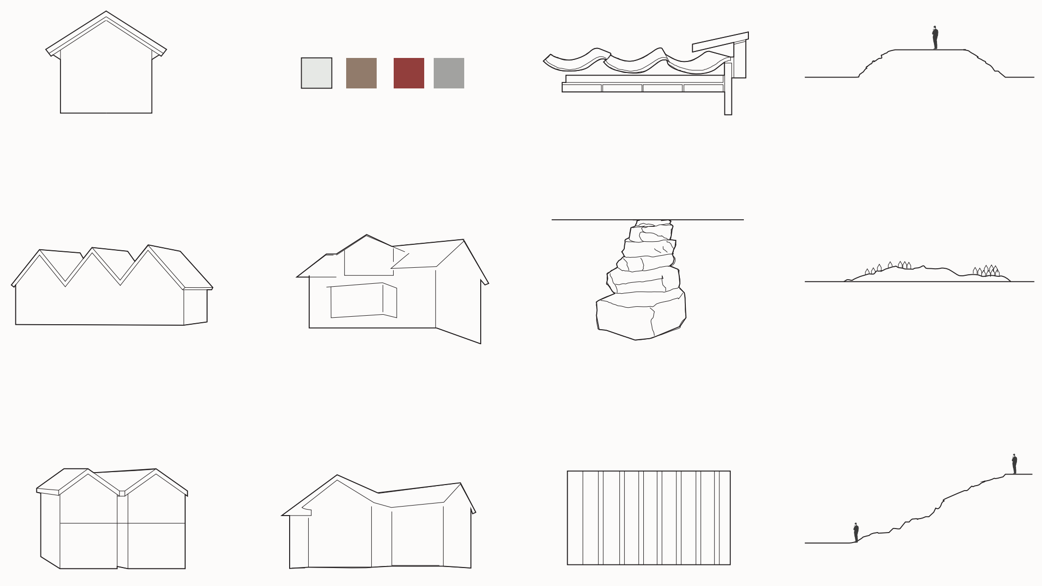


Fig. 31: Site preconditions

1. ferry (north harbour stop) 2. ferry stop 3. Trålverket 4. New hotel cabins 5. Site of interest for project implementation 6.sun set spot 7. Strong winds from south/south west. 8. Cliffs break the heaviest waves from the strongest winds 9. Exposed open area towards west

Architectural inventory



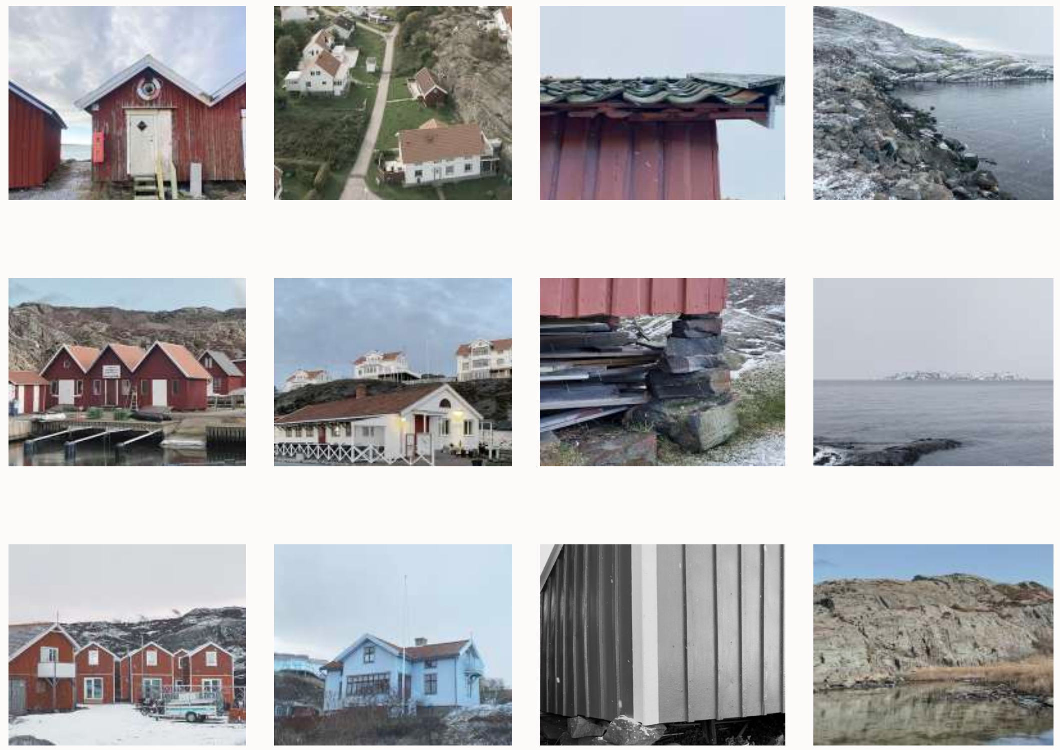
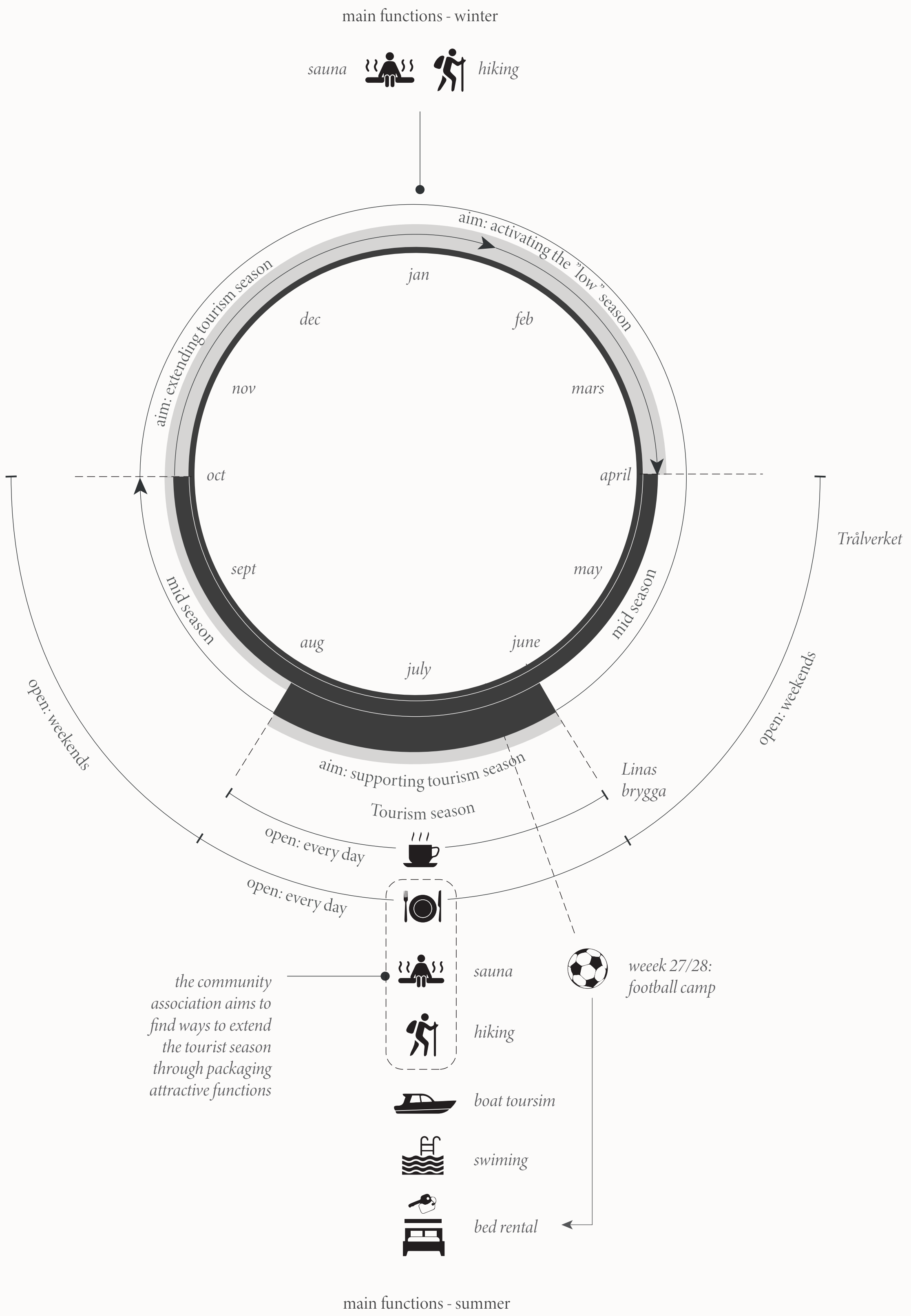


Fig. 32: Character mapping

General character: Traditional 33 degree roof/ 45 degree roof/ Two story newly built huts/ Color mapping/ Volumes, white facades/ Clay roofing tiles/ Stone foundation/ Vertical facade/ Pier section/ View of åstol/ Cliffs

Fig. 33: Activity mapping - present



Intervju with Dyrön comunity association

With this program in mind, the aim was to further tailor this, through an interview with the community association. In an interview with Sören Holm (on april, 2023), a representative from the community association of Dyrön., he is posed with the question if private "marina kolonilotter" would be of an interest. On this question, he responds that he has a difficulty in seeing that program as successful, due to the fact that the island "lives on a tradition of crass survival" and that Dyröns vitality is based on its tourism season. He mentions an interest in oysters as contribution to tourism if anything, but presses the matter of creating attractive new functions that could extend the toursim season.

Describing Dyrön

When asked how Sören Holm would describe the island in general, he states that its a small scale island with a year around open store, pharmacy as well as 2 ferry stops, the main one found in the North harbour. The island has one main restaurant called Trålverket, as well as Linas brygga and Dyrön södra, a café and a pop- up restaurant. The North harbour has very recently been developed with 12 new hotel cabins that are possible to rent. An important attraction of year-round tourists, is the scenic 4.5 km long hiking trail around the island, as well as the public sauna, which is Dyröns main attractive function.

Heavy seasonal shifts

Between October and April, the island is mainly occupied by year-round inhabitants with occasional visitors, this is in the thesis refered to as the "low-season". The activity increases somewhat between Easter until midsummer, where it peaks. The island then experiences a population increase of around 300% and all extra beds and rental housing is usually fully booked. Around midsummer, a yearly football camp is held and the island is filled with 200 children from around the area. During this time they also host an annual midsummer party which last year attracted as many as 850 guests. During the summer, the island is also heavily depended on its boat tourism, where Sören estimates around 50 guest boats per day with approximately 150 additional visitors. The tourism peak lasts until around mid august. During late august and September, majority of the summer tourists have left and the activity decreases a bit again before going back to low-season again.

A wish to extend the tourism season

This drastic shift in activity of the island is a challenging situation. As the island is very dependent on its summer tourism, Sören Holm (2023) states that the community association is continuously working on ways of prolonging the tourism season to achieve a more evenly distributed activity level of the island. He describes how the association notes the instant decrease in Trålverkets guests, when the sauna is down, and the functions of the island in that way is heavily interconnected. In this he sees a very important potential in "packaging experiences" where people can combine activities on the island. This could also work as a tactic to extend the tourism season.

PROGRAM

Introducting a program that aims to both support and extend the tourism season through a sustainable, flexible and experience-based restaurant.

Reflecting the interview and reference projects

The program that will define the building will reflect the interview with the community of Dyrön, the reference projects, as well as the site mappings of Dyrön and existing functions. The program recognizes the challenges of an island which has a very polarized activity depending on its season. It recognizes this by a response that aims to implement functions that both support existing ones, the year around community, as well as implementing functions that aim to extend the tourist season. This is primarily done based on the need of a dual response towards the twin crisis.

Experience based restaurant

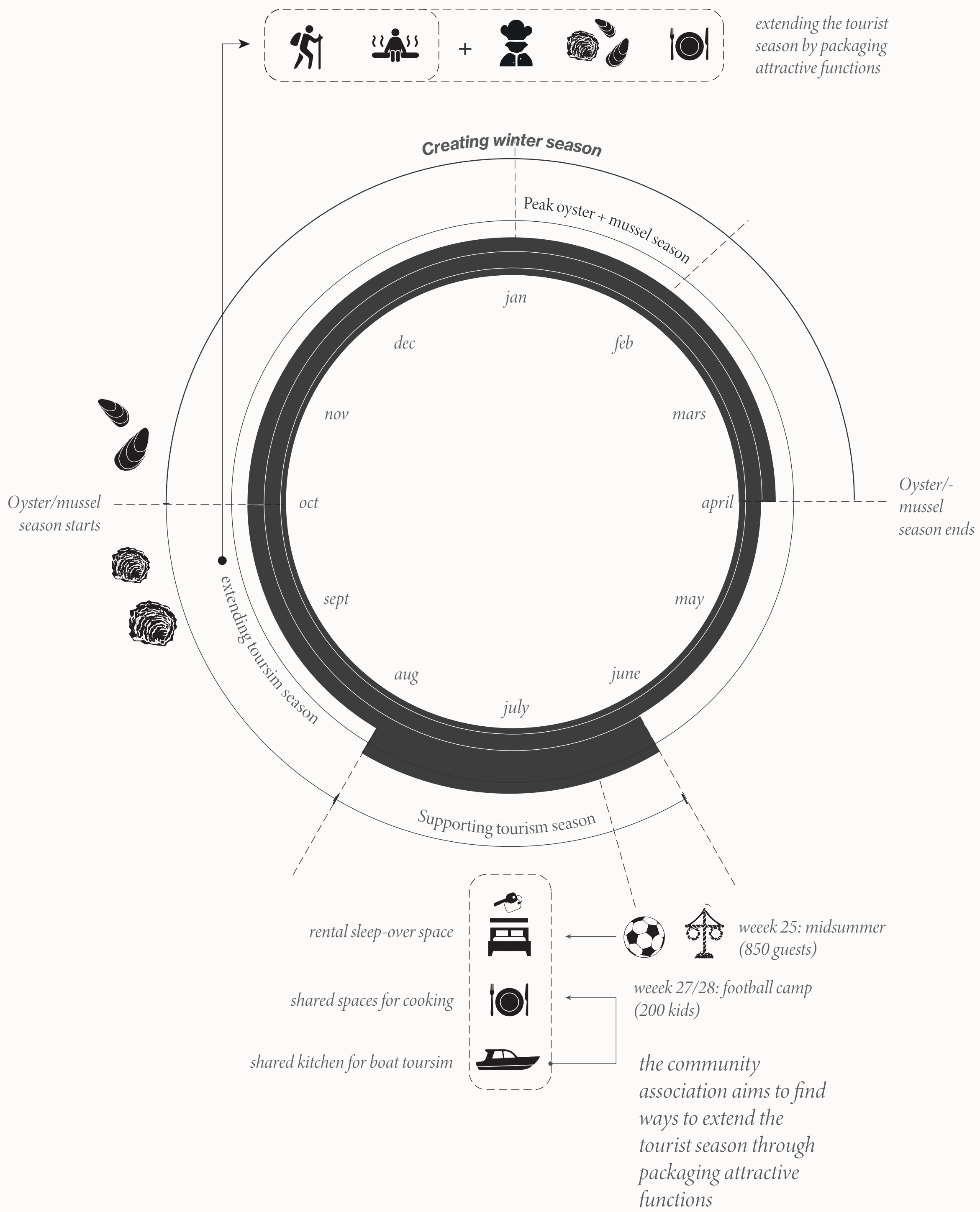
This tourism extension will be designed as a sustainable and experience based restaurant that cultivates marine species through a local, small scale blue garden. This experience-based program would have the support of the similar and successful Musselbaren. Here, the ritual of cultivating, harvesting, sorting, cooking and eating marine foods, will be translated into a building where the sequence of the ritual will be reflected in the plan. The potential to extend the tourist season until autumn lies in the cultivated species natural harvesting cycles. The absolute prime oyster and blue mussel season are late winter, around jan/feb. Following the community associations ideas about extending the season, a packaging experience including the sauna, hiking, as well as a restaurant visit surrounding marine specie culinary experience, could lengthen the tourism season until autumn, while creating a winter season spike in activity on the island. In this way, the mid season in between could also be strengthened.

A flexible space

During the less active season of the experience based restaurant, the space may be converted into a normative scale kitchen for rental use. The supporting functions for the restaurant such as seating spaces will be designed as a flexible open space that can be use all year around by for example inhabitants as well as new meeting spaces for the community association, something that is lacking today. The very scenic and attractive dining space could also be utilized for larger events and gatherings. During the summer season, the open and flexible space could be rented to support for example the football teams with a place to sleep and cook. The shared kitchen could also be utilized by boat tourists for a proper meal cooking facility, something that could support and strengthen the island as an attractive stop. It may also support other festivities like midsummer.

Diagram of and extended tourism season based on activity

Fig. 34: Activity mapping - future



From sea to table

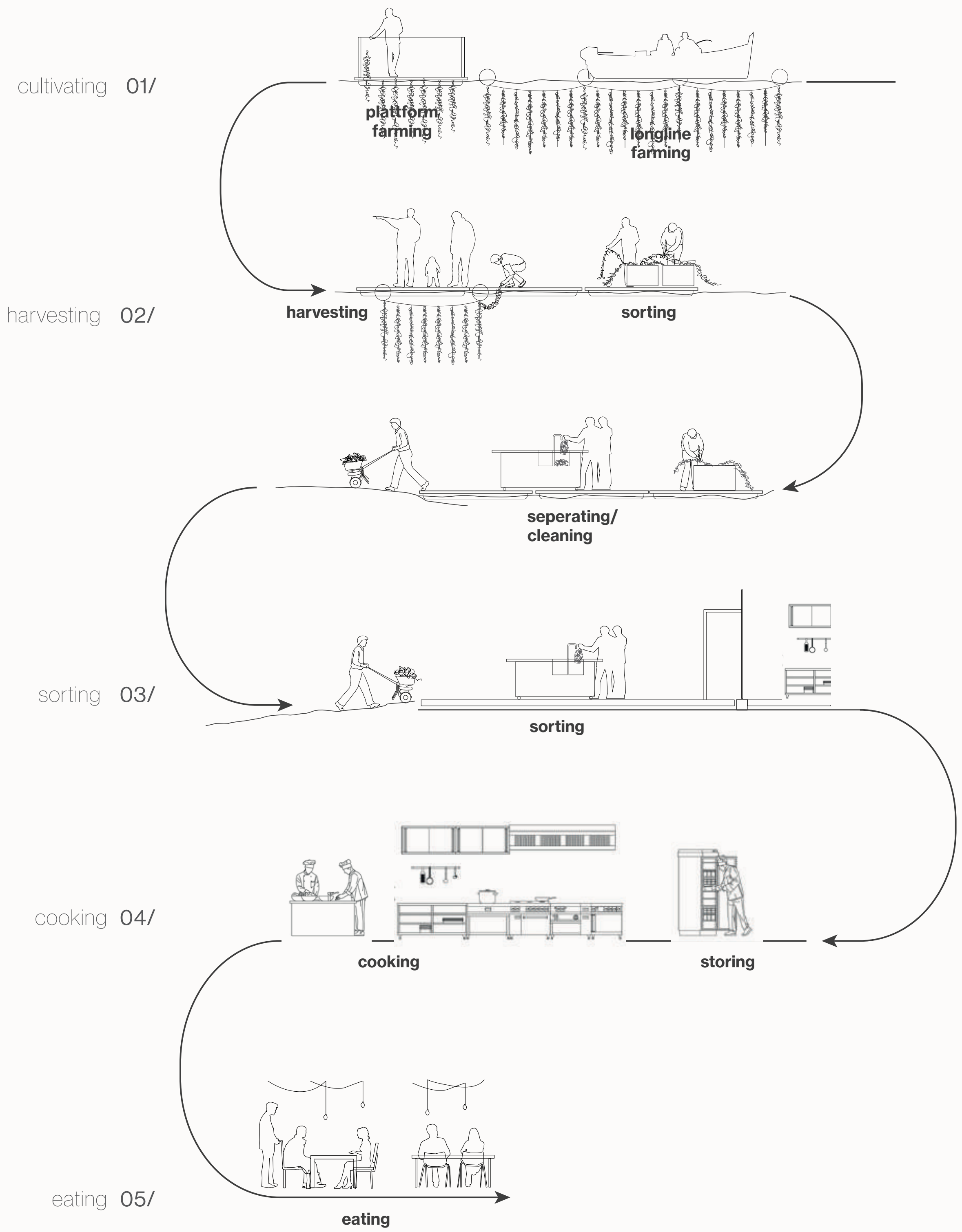
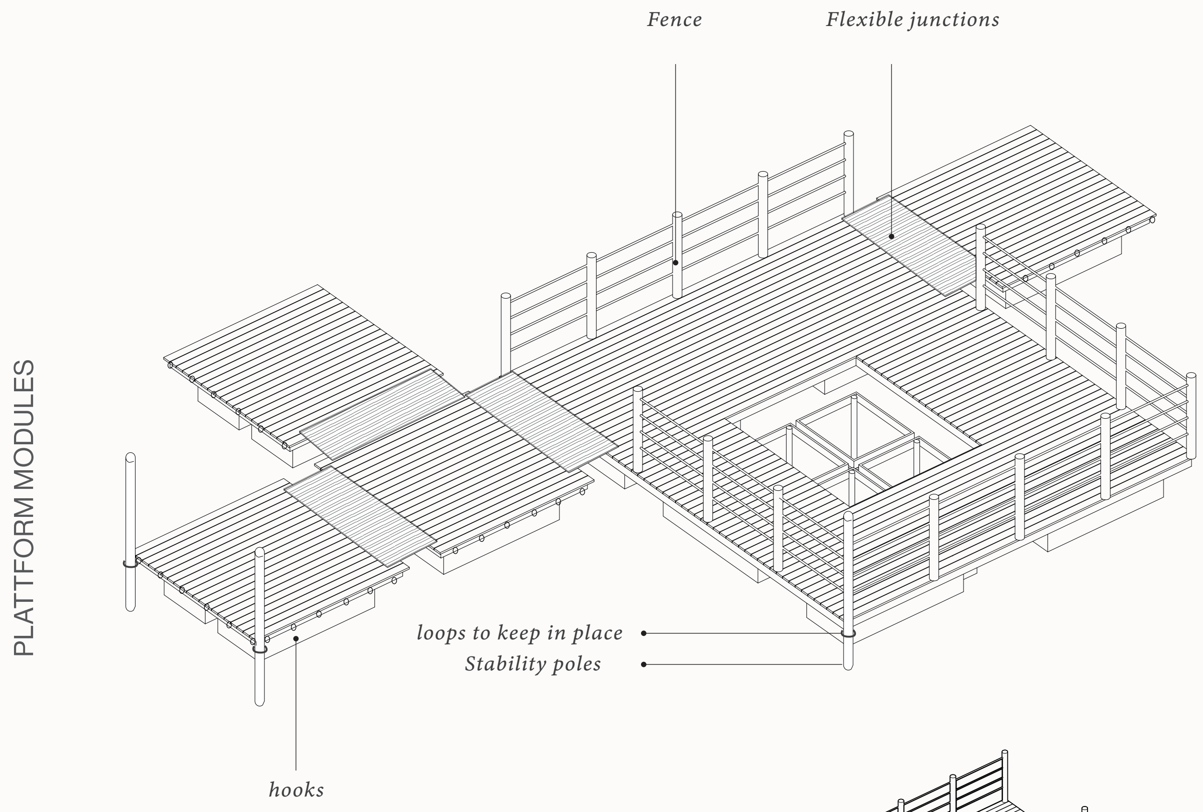
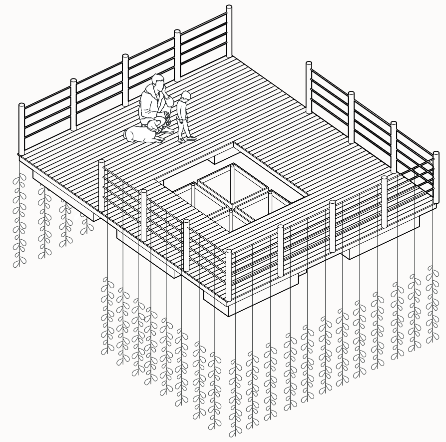
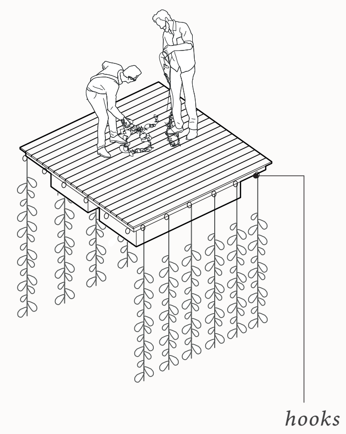


Fig. 35: Function diagram - from sea to plate



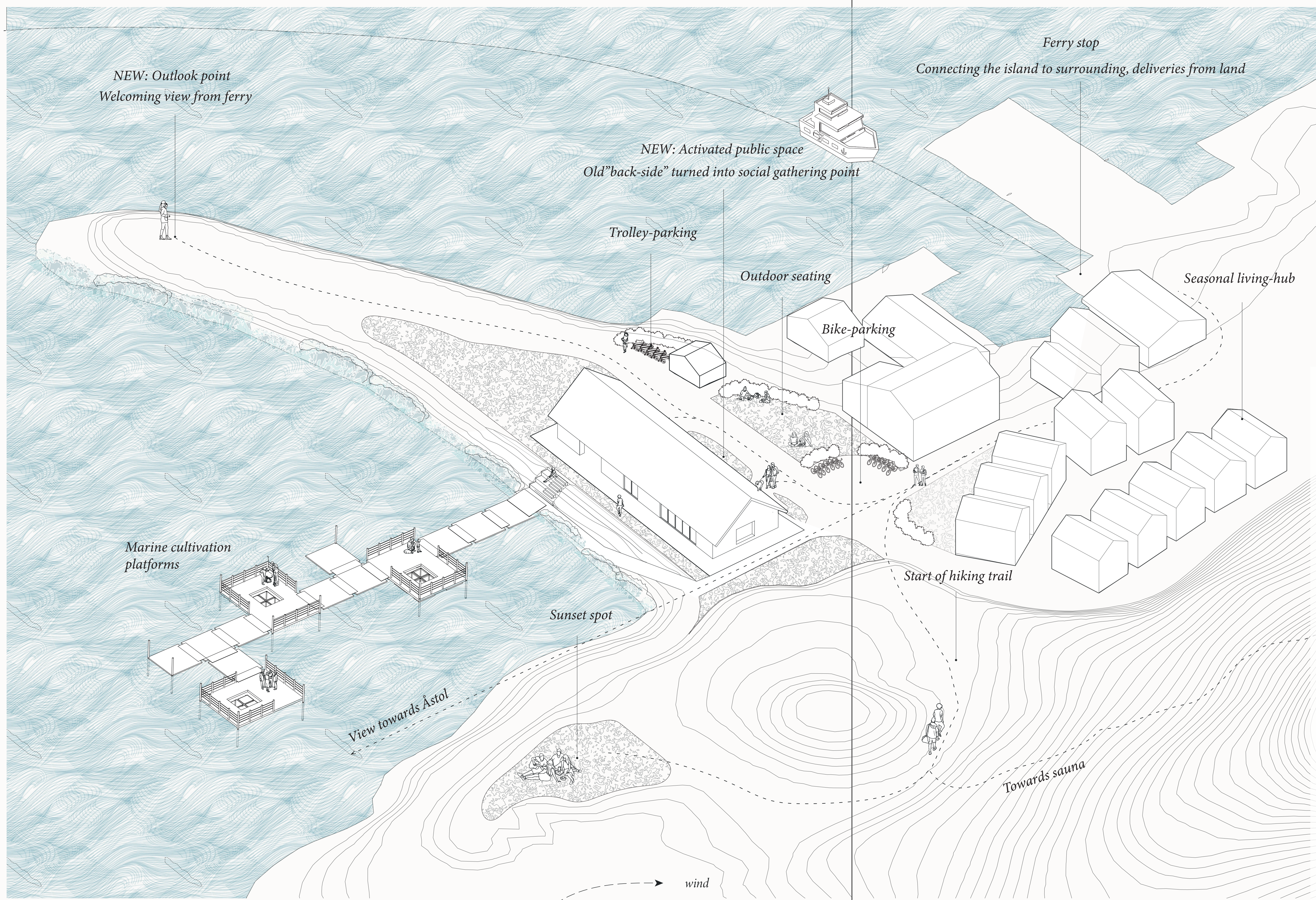


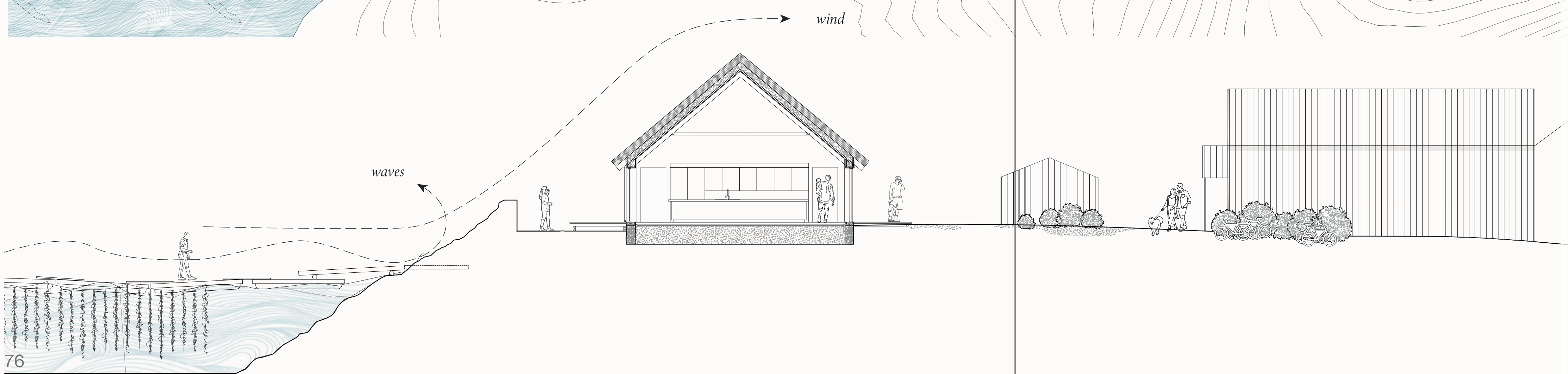


BLUE GARDEN SEQUENCE

The ritual of blue farming consists of several steps taking the visitors on a journey from sea to table. The first activity involves harvesting of the species. The harvesting platform needs to be accessible and easy to reach. For this project we have chosen to work with platform farming as this is an easy access solution that allows the visitors to themselves pull out the ropes from the water up on the floating deck. This also allows people to continuously see the species growing when visiting during the year.

The species are harvested from the platforms by hand and brought out of the water after which they are collected in boxes and transported on trolleys up to the cleaning station. In the cleaning station the species are separated from the farming lines and cages and all eventual rest products and damaged harvest is sorted out. Thereafter the mussels are cleaned and prepped for cooking. The cooking can be an interactive part of the experience where the guests can help cooking in the common- or outside kitchen.





TRANSFORMING THE NORTH HARBOUR

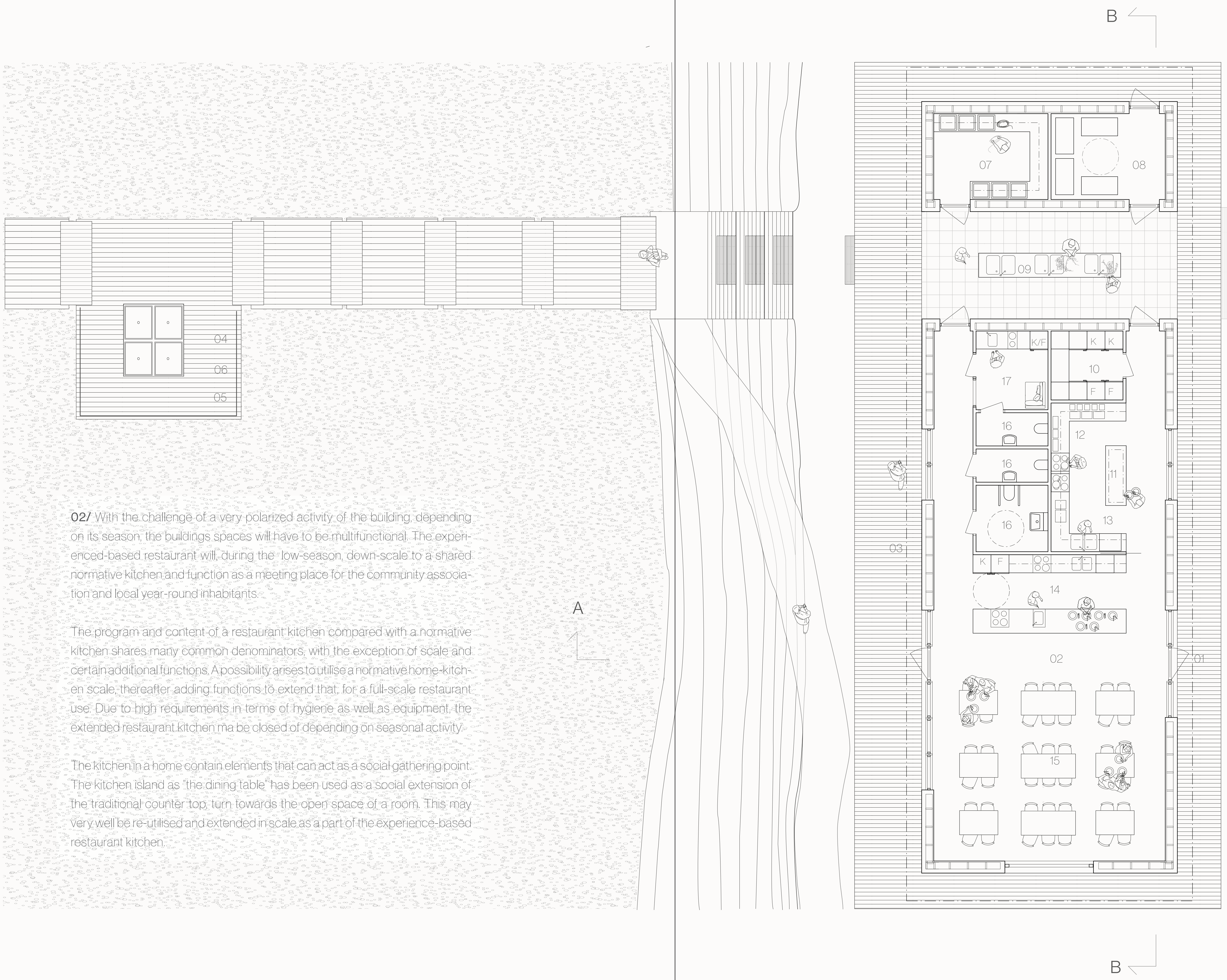
As the cultivated species require a certain depth and flow of water, the building is placed on the man-made pier that protects the harbour. The new addition helps strengthening the local site through transforming the it from a strictly functional space to a gathering for social interaction along with necessary functions. It is situated close to the ferry stop making it a obvious part in the every day life of the inhabitants of the island. The new square connects to the newly built rental houses and enhances the beginning (or end) of the hiking trail around the island.

An exposed environment

The development plans for the island is pointing out this plot as interesting for new development, however, placing a building on this site pose certain demands on the construction. The building will have to withstand pressure both from land and sea.

The site is protected from the strongest winds from south west thanks to the islands shape and terrain, however the pier is still exposed to wind and waves coming in from west. Measures have been taken through shaping the terrain in front to the building to minimize the worst wave and wind impact. A module design for the platform farming with flexible junctions and additional support structure that will work to keep the structure in place while also allowing necessary movement.

FLOORPLAN



02/ With the challenge of a very polarized activity of the building, depending on its season, the buildings spaces will have to be multifunctional. The experienced-based restaurant will, during the low-season, down-scale to a shared normative kitchen and function as a meeting place for the community association and local year-round inhabitants.

The program and content of a restaurant kitchen compared with a normative kitchen shares many common denominators, with the exception of scale and certain additional functions. A possibility arises to utilise a normative home-kitchen scale, thereafter adding functions to extend that, for a full-scale restaurant use. Due to high requirements in terms of hygiene as well as equipment, the extended restaurant kitchen ma be closed of depending on seasonal activity.

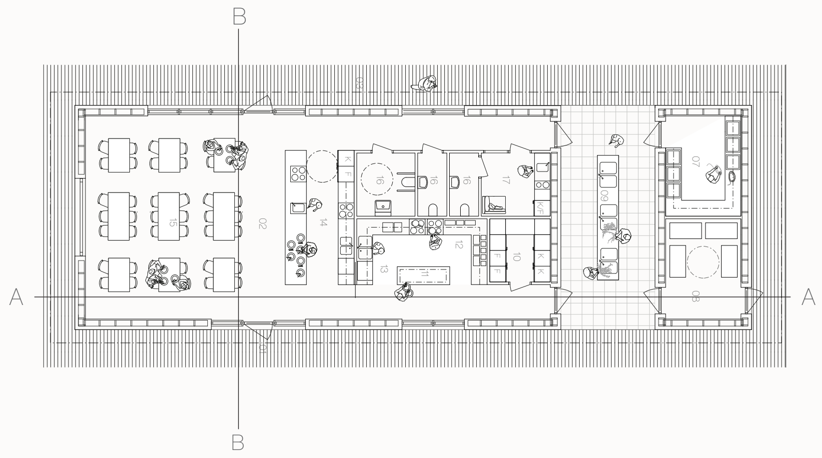
The kitchen in a home contain elements that can act as a social gathering point. The kitchen island as "the dining table" has been used as a social extension of the traditional counter top, turn towards the open space of a room. This may very well be re-utilised and extended in scale as a part of the experience-based restaurant kitchen.

FLOORPLAN

1. entrance
2. restaurant
3. terrace
4. cultivation
5. harvest
6. sorting station
7. storage
8. garbage
9. cleaning/sorting
10. fridge/freezer/ storage room
11. restaurant kitchen
12. prep
13. washing
14. shared kitchen
15. dining room
16.WC
17. Staff room

A RITUAL

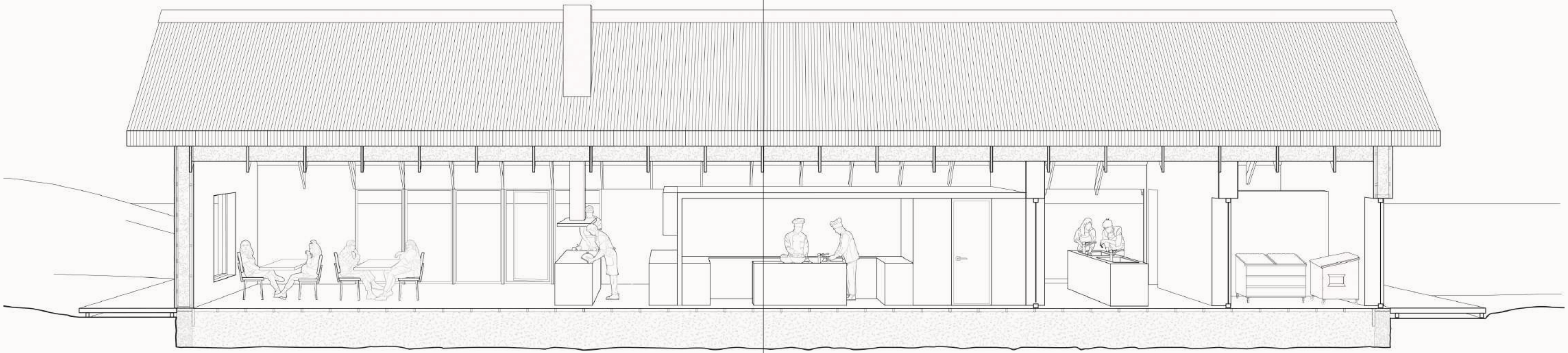
03/ The journey from sea to table is reflected in the movement through the structure. As a visitor you pedagogically follow the species from the uptake, through preparation and cooking to finally end up on the plate in the scenic dining space overlooking the farm. The aim is to shine a light of the processes behind our consumption patterns giving rise to reflection on sustainable living.



sections

INTERIOR PERSPECTIVE

Project implementation



Section A-A 1:100

Reflecting the research

04/ The chosen materials and construction reflect a design based on research that acknowledges the importance of the materials bio-remediating effect, while also undertanding the material properties' impact on the architectural expression. The architectural expression of Dyrön varies in terms of color, materiality and shape over the island but the general expression of the buildings is wooden buildings with tile roofs. Here the main conflict has laid in designing a building that may not resonate clearly with the closest surrounding buildings. This discussion however is something that has led us to reflect upon architectural(/traditional) ideals in contrast to a sustainable building practice where the first may have to become subordinated for the benefit of a sustainable future.

Departing from supply

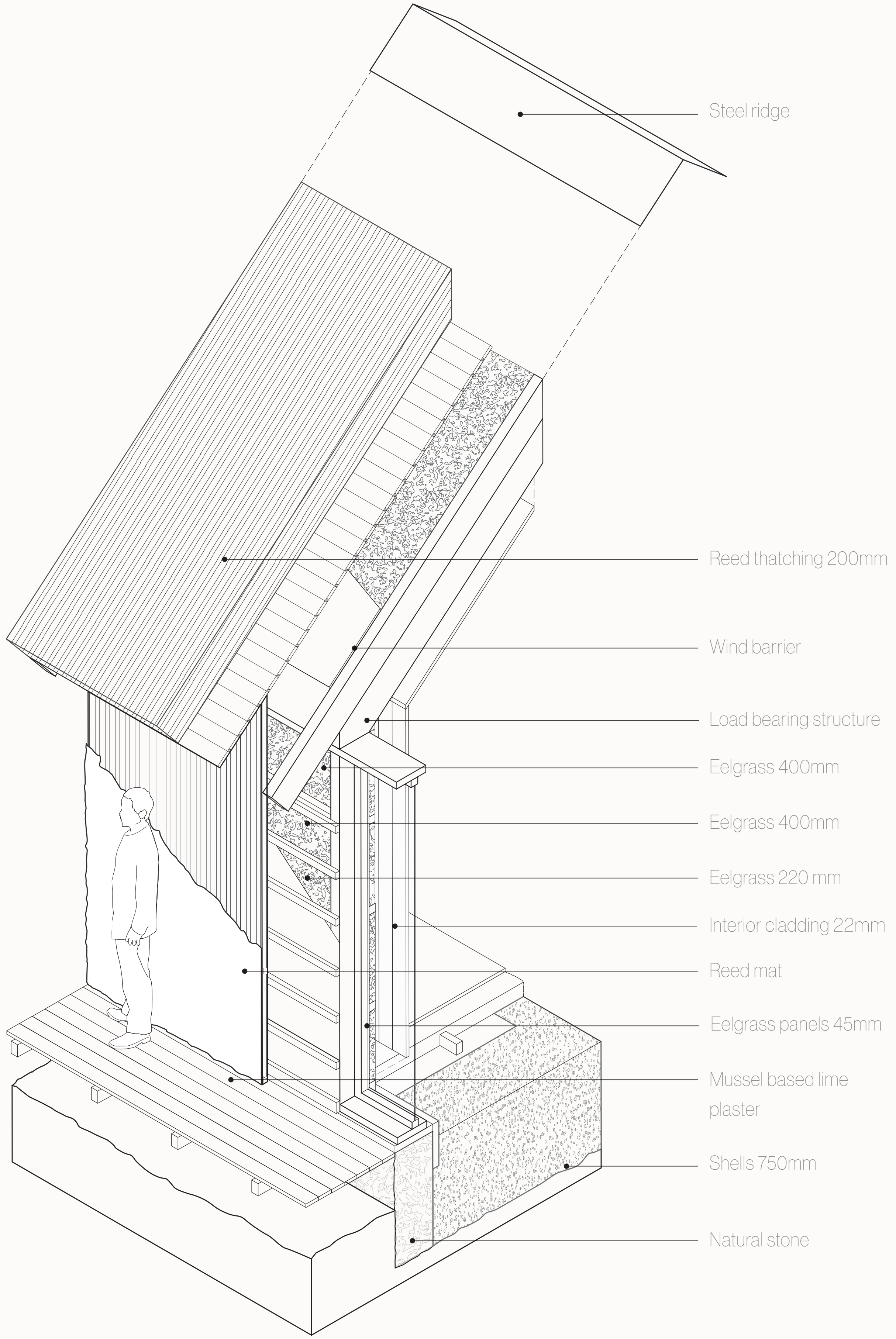
The building utilizes reed for the roof as this require a large ammount of material which would match the natural supply of resource. The thatched roof has an impact on the architectural expression as it affects the pitch angle. As the building sits in an exposed environment, the question of durability comes into play. As previously mentioned, thatched roofs were traditionally used along the coast and the construction can withstand winds up to 40m/s. However to improve the durability of the roof, a steel ridge has been added to reinforce the weakest point of the roof.
The reed roof provides certain insulation which has an impact on the ammount of insulation needed inside the roof construction.

Locally sourced material

The facade consists of reed mats with a shell-based plaster giving the building a uniform and calm facade expression that highlights the volume. The wall- and roof insulation consists of eelgrass which can be sourced locally. As the insulation properties of eelgrass is comparable to the one of mineral wool, it does not affect the building expression in any significant aspect. The foundation is insulated withlocally sourced mussel shells with a thickness of 750mm. As the building sits on a man-made pier, the foundation can be dug into the ground, leaving the ground rock untouched.

Complimentary materials

The buildings load bearing construction is made of wood wich is a local an reneweable resource that similar to the marine bio-materials, has a positive environmental effect on its close surroundings through absorbing CO_2 and transforming it through photosyntesis.



MODEL BUILDING

To understand the materiality and its effect on construction and the architectural expression, explorations through model building has been carried out.

Model explorations: the 3d dimensions of the site, from land to water

Model explorations: 1:5 construction section, exploring details

Reflection

Materials

The use of bio-based materials specifically obtained from bioremediating processes has many environmental benefits. The extraction of materials, in comparison to many of the currently most used building materials, has a positive impact on natural environments and ecosystem stability. The materials discussed in the thesis is extracted as rest-products meaning that the environmental impact in terms of material extraction is low.

Possibility of returning to a renewable cycle

Bio-based materials ability to be recycled is important for the nutrient cycles. The fact that the materials at the end of their life cycle are biodegradeable and returned to the agricultural land in sthe shape of fertilizers, ensures a sustainable cycle of nutrient flow while also limiting the amount of waste generated from the building industry.

Supply and demand

As the need for extended bioremediation of eutrophicated waters is large, new areas of implementing the rest products could be beneficial in a financial aspect where a demand for the output could give more means to a greater implementation of restorative interventions. A direct result of relying on natures own ability of producing materials is a less controllable supply as it is more easily affected by natural change and environmental circumstances. However, in order to secure a sustainable future the choice may have to be to buildwith natural material when and if they are available or to not build at all.

Craftmanship

As much of the discussed materials are not standard practice in the building and construction field today, a shift would need to happen in terms of craftmanship and technology. This however could potentially help transitioning the building industry into a sustainable future.

Understanding the whole system

Much of the reason behind the low impact of the materials depends on the use of eco-friendly equipment. (Ex. mussel farming has a net-positive impact on the climate but the boats used for harvesting needs to be operated in a sustianable way in order for the process to be considered environmentally friendly). For this aspect it is important to take into consideration the entire process, and use for example LCA analysis where all aspects of the materials life cycle is accounted for.

Maintaining a conscious resource use where assets are shared

There is always a risk of systemizing things on a larger scale. In order for this type of materials to become more commonly used, a certain level of systemization or standardization needs to take place. However this needs to be done with a continous environmental care where eco system stability is the main priority and extraction is made based on available supply. While the materials covered by this thesis could be considered having a net positive impact on the climate, conscious resource use still has to be stived for where we both aim to limit the amount of resources we use as well as share the available supply.

Conclusion & Discussion

The outcome of this thesis has provided insights in what it means to support a regenerative practice in an architectural proposal. This has been done through the hollistic approach of making visible systems and connections across different scales. Through the lens of regenerative design, it has also provided a deeper understanding of how the proposed project fits into and contributes to a wider system within the context it situatied in.

By making visable the interconnected system of the building industrys effect on our climate as well as the excess biochemical flow's impact on biodiversity loss, the design framework of regenerative design provided a dual response in the form of bioremediation. By using the obtained biomass from bioremediating processes as building materials, it holds the potential to limit the building industrys material emissions, simutaniously benefitting the restoration of natural habitats.

The thesis explores the possibilities and challenges when implementing reeds, shells and eelgrass as building materials, through the mapping of natural occurance, specie growth cycles, method of extraction, method of production, material properties as well as architectural impact in a rurban context. Using natural resources through this method, means understanding that the extraction of the material has to be done on the premises of the species growth cycle and natural occurance. This method would pose demands on the building sector in terms of attitudes, material sourcing and craftmanship, amoungst others. This would in contrast to todays linear and depleting resource use, depart fom the available supply rather than material demand. This also means understanding that the architectural impact of these materials will be subordinated for example cultural heritage, where the environmental benefit of bio-based materials is elevated.

References

Ahlkrona, M. (2017). Phosphorus in a biogeochemical lake model. SMHI Reports Hydrology, 17. Retrieved from: https://www.smhi.se/polopoly_fs/1.165168!/RH_17%20Phospherous%20in%20a%20Biogeochemical%20Lake%20Model..pdf

Ahrenbeck, M., Benskiöld, A., Gannholm, A., Nilsson, E., Storm, C.-F., & Strand, R. (2021). Blåmusselskal – ett hållbart alternativ till den kontroversiella cementen, En jämförande studie av substitution med kalcinerat blåmusselskal vid tillverkning av hydrauliskt bindemedel. Kandidatarbete inom Samhällsbyggnadsteknik (thesis). Chalmers University of Technology, Gothenburg.

ARUP. (2020). (rep.). Arup Explores Regenerative design. Retrieved May 7, 2023, from https://www.arup.com/perspectives/publications/research/section/arup-explores-regenerative-design.

Baden, S., Hernroth, B., & Lindahl, O. (2022, May 24). Jakten på de Försvunna Musslorna. Sveriges vattenmiljö. Retrieved May 7, 2023, from https://www.sverigesvattenmiljo.se/content/jakten-pa-de-forsvunna-musslorna

Baden, S., Hernroth, B., Lindahl, O., Kungl. Vetenskapsakademin, & Göteborgs universitet. (2022, May 25). Blåmusslan – en populär men hotad ekosystemingenjör. Sveriges vattenmiljö. Retrieved November 7, 2022, from https://www.sverigesvattenmiljo.se/content/blamusslan-en-popular-men-hotad-ekosystemingenjor

Central Baltic Interreg Programme. (2011). COFREEN-Concepts for using reed biomass. Retrieved March 29, 2023, from https://www.youtube.com/watch?v=W870tsu_L0Y&list=UUVTulCqGDk-GVyn-AitDErA.

Criteria for the Durability of thatched Roofs. (2017). HISS REET. Retrieved April 29, 2023, from https://www.hiss-reet.de/en/thatched-roof/reed-the-material/durability/criteria-for-the-durability-of-thatched-roofs

Csaplovics, E., Schmidt, J., Zámolyi, F., & Herbig, U. (2011). Reed as building material – renaissance of vernacular techniques. In International Symposium on Advanced Methods of monitoring reed habitats in Europe (pp. 83–108). essay, Rhombos-Verl.

Danish Cultural Heritage Agency. (2008). Report regarding Læsø seaweed farms [Rapport vedrørende Læsø tanggårde]. Retrieved May 10, 2023, from http://www.tangtag.dk/upl/website/rapporter/2008.09.08LsTanggrderapportPeterCarstens.pdf

Dervishi, A., & El-Zoubi, S. (2012). Vass- och tegeltak – En studie om användningen av vass och tegel då, idag och i framtiden (thesis). Lund University, Lund.

DesignWanted. (2021, May 31). Newtab-22: A sustainable alternative to traditional building materials. Retrieved May 10, 2023, from https://designwanted.com/newtab-22-sea-stone/

Dorte Mandrup. (n.d.). The Wadden Sea Centre, Denmark. The Wadden Sea Centre, Denmark | Dorte Mandrup. Retrieved March 5, 2023, from https://www.dortemandrup.dk/work/wadden-sea-centre-denmark

European Comission. (n.d.). Buildings and construction. Internal Market, Industry, Entrepreneurship and SMEs. Retrieved May 7, 2023, from https://single-market-economy.ec.europa.eu/industry/sustainability/buildings-and-construction_en

Gattupalli, A. (2023, March 5). What is regenerative architecture? limits of sustainable design, System Thinking Approach and the future. ArchDaily. Retrieved May 7, 2023, from https://www.archdaily.com/993206/what-is-regenerative-architecture-limits-of-sustainable-design-system-thinking-approach-and-the-future?ad_source=search&ad_medium=search_result_all

Haamer, J., Holm, A. S., Edebo, L.,Lindahl, O., Norén, F., Hernroth, B., & Karås, P. (1999). Strategisk musselodling för att skapa kretslopp och balans i ekosystemet - kunskapsöversikt och förslag till åtgärder : Rekryteringsmiljöer för kustbestånd av abborre, gädda och gös. Retrieved from Fiskeriverket website: http://urn.kb.se/resolve?urn=urn:nbn:se:havochvatten:diva-280

Havsmiljöinstitutet. (2022). Ålgräs. Livet i Havet. Retrieved March 31, 2023, from https://www.havet.nu/livet/art/algras

Huang, H. (2021). Architecture Material: Oyster-shell. Göteborg: Chalmers University of Technology.

Klenske, N. (2021, November 1). Nature and climate crises: Two sides of the same coin. Horizon Magazine. Retrieved March 4, 2023, from https://ec.europa.eu/research-and-innovation/en/horizon-magazine/nature-and-climate-crises-two-sides-same-coin

Landsbygdens Folk. (2019, January 31). Dags att återuppliva kunskapen om traditionella vasstak [Time to revive the knowledge of traditional thatched roofs]. Retrieved May 10, 2023, from https://www.landsbygdensfolk.fi/nyheter/dags-att-ateruppliva-kunskapen-om-traditionella-vasstak/

Lindahl, O., & Kollberg, S. (2008). Musselodling som miljöåtgärd från idé till verklighet. Musselodling som miljöåtgärd - från idé till verklighet. Retrieved May 7, 2023, from https://cms.it.gu.se/infoglueDeliverWorking/digitalAssets/1575/1575671_musselsve.pdf

Littman, Jacob A., "Regenerative Architecture: A Pathway Beyond Sustainability" (2009). Masters Thesis 1911 - February 2014. 303. Retrieved from https://scholarworks.umass.edu/theses/303

Ljungberg, M. (2015). Potential high value products from production wetlands. Journal of Water Management and Research. Retrieved May 8, 2023, from https://www.tidskriftenvatten.se/wp-content/uploads/2017/04/48_article_4766.pdf.

Localworks Studio. (n.d.). Shellcrete: Transforming sea shells into low-carbon materials. Retrieved May 10, 2023, from https://localworksstudio.com/projects/shellcrete-transforming-sea-shells-into-low-carbon-materials/

Morris, S. D. (2009, December 10). Tabby - New Georgia Encyclopedia. Tabby. Retrieved March 5, 2023, from https://www.georgiaencyclopedia.org/articles/history-archaeology/tabby/

Naturskyddsföreningen. (2021, March 26). Viva vatten – skörda vass. Retrieved March 29, 2023, from https://www.naturskyddsforeningen.se/inspiration-tips-och-verktyg/viva-vatten-skorda-vass/

National Oceanic and Atmospheric Administration (NOAA). (2014). The importance of eelgrass. Retrieved from https://www.fisheries.noaa.gov/feature-story/importance-eelgrass

Nielsen, J. (2012, January 13). Muslingeskaller Som Byggemateriale. Tips fra DR. Retrieved April 4, 2023, from https://www.dr.dk/levnu/tips-fra-dr/muslingeskaller-som-byggemateriale

Nylén, K.-J. (2022, September 30). Succé för ålgräsplantering I sand. Succé för ålgräsplantering i sand. Retrieved April 3, 2023, from https://www.gu.se/nyheter/succe-for-algrasplantering-i-sand

Organization for Economic Cooperation and Development (OECD). (2018). Raw materials use to double by 2060 with severe environmental consequences. Retrieved May 7, 2023, from https://www.oecd.org/environment/raw-materials-use-to-double-by-2060-with-severe-environmental-consequences.htm

Orvestedt, S. (2013). Out of the Baltic See through the reed – description of the eutrophication problem and optimization of a method based on harvest of water plants (thesis). SLU, Sveriges lantbruksuniversitet, Uppsala.

Parkes, J. (2021, December 9). Dezeen guide explores potential of biomaterials in architecture, design and interiors. Dezeen. https://www.dezeen.com/2021/12/09/dezeen-guide-biomaterials-architecture-design-interiors/

Realdania (2013, October 2). The Modern Seaweed House [Video]. YouTube. Retrieved April 29, 2023, from https://www.youtube.com/watch?v=quyrglWd7vw

Riksantikvarieämbetet . (2013). (rep.). Materialguiden - Rapport från Riksantikvarieämbetet . Riksantikvarieämbetet . Retrieved May 8, 2023, from https://www.diva-portal.org/smash/get/diva2:1235014/FULLTEXT01.pdf.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., … Foley, J. A. (2009). Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecology and Society, 14(2), 32. https://doi.org/10.5751/es-03180-140232

Stawreberg, A.-M. (2020, February 28). Janne driver succérestaurangen Musselbaren: "Det är framtidens mat". Land. Retrieved May 7, 2023, from https://www.land.se/mat-dryck/musselbaren-lyckorna-ljungskile/?fbclid=IwAR19KPi5uPCTCFtooLG40xsba6pSiENCr97ZpVqYMpsPahzjOPbWuH0YaD8

Svenskt Trä (2016.). Ett modernt naturum med gammal teknik vid sjön Tåkern - Tidningen Trä.https://www.svensktтra.se/publikationer-start/tidningen-tra/2012-3/ett-modernt-naturum-med-gammal-teknik-vid-sjon-takern/

Swedish University of Agricultural Sciences (SLU). (2021, January 25). Vass - Framtidens Nyttogröda. SLU.se. Retrieved May 7, 2023, from https://www.slu.se/fakulteter/vh/forskning/forskningsprojekt/vilt-och-fisk/vass-framtidens-nyttogroda/

UK Architects Declare Climate and Biodiversity Emergency. (2019, May 30). UK Architects Declare Climate and Biodiversity Emergency. Retrieved April 20, 2023, from https://www.architectsdeclare.com/

United Nations. (2022, November 9). CO2 Emissions from Buildings and Construction Hit New High, Leaving Sector off Track to Decarbonize by 2050: UN. Retrieved March 3, 2023, fromhttps://www.unep.org/news-and-stories/press-release/co2-emissions-buildings-and-construction-hit-new-high-leaving-sector.

Våtmarksguiden. (n.d.). Bladvass. Våtmarksguiden. Retrieved March 29, 2023, from http://vatmarksguiden.se/projekt/bladvass/

Westergren, E. B. (2015). Underhålla taket. Olika Taktyper | Byggahus.se. https://www.byggahus.se/renovera/underhalla-taket-olika-taktyper

Images:

Image of isolating mussel shells in foundation, Bondegaard Rydbjerg. Retrieved 4th May, 2022
from http://www.bondegaard-rydbjerg.dk/lindovej.html.

Tiles made from waste oyster shells, Local Works Studio. Retrieved 25th May, 2023 from https://localworksstudio.com/projects/shellcrete-transforming-sea-shells-into-low-carbon-materials/

Manually grinded shells, Newtab-22. Retrieved 25th May, 2023 from https://www.newtab-22.com/%EB%B3%B5%EC%A0%9C-material-sea-stone

Whaleback shell mound - Courtesy of the Peabody Museum of Archaeology and Ethnology, Harvard University, PM #2005.3.61.4 Retrieved 25th May, 2023 from http://outsideinradio.org/shows/tag/History

Facade made of oyster shells in Ancestral temples and dwellings in Guangdong , Life of Guangzhou.
https://www.lifeofguangzhou.com/

Building a tabby wall. The houses of st. Augustine. Retrieved 25th May, 2023 from https://preservedowntownstaugustine.wordpress.com/2013/03/29/the-gallegos-house/tabby-concrete/

Tabby concrete with whole oyster shells as aggegate, Rory Gardiner. Retrieved 25th May, 2023 from https://architecture-today.co.uk/shells-and-core/

Roof covering with reeds, Nilsson, Nils J / Kalmar Läns museum. Retrieved 25th May, 2023 from https://digitaltmuseum.se/021017095154/taktackning-med-vass-pa-elias-gustavssons-gard

Thatched roof, Svenska Stråtaktäckarföreningen. Retrieved 25th May, 2023 from https://stratak.info/stratak/

Detail of a reed/thatched roof on Öland, Wikimedia Commons. Retrieved 25th May, 2023 from https://commons.wikimedia.org/wiki/File:Detalj_av_vasstak_p%C3%A5_%C3%96land.jpg

Stages of the thatching process , Roman Fodchuk and Associates. Retrieved 25th May, 2023 from https://journals.lib.unb.ca/index.php/MCR/article/view/17399/22611

Thatched facade at Wadden sea center, Rasmus Hjortshøj. Retrieved 25th May, 2023 from https://divisare.com/projects/395006-dorte-mandrup-rasmus-hjortshoj-wadden-sea-center

Naturum Tåkern , Inside Wingårdhs. Retrieved 25th May, 2023 from http://inside.wingardhs.se/takern-wingardh-arkitekter/

Detail drawing Tåkern, Svenskt trä. Retrieved 25th May, 2023 from https://www.svensktтra.se/siteassets/3-inspiration/trapriset/4-traprisbockerna/1.-ritningar/detaljritningar-naturum-takern.jpg

The Wadden Sea Center, detail section, EU Mies Award. Retrieved 25th May, 2023 from https://miesarch.com/work/4988

Tangtagets konstruktion, Nationalmuseets arbejdsmark 1944. (2008). Læsø tanggårde. Arkitekt m. A.A. Erik Einar Holms tegnestue aps. Retrieved May 24, 2023, from http://www.tangtag.dk/upl/website/rapporter/2008.09.08LsTanggrde-rapportPeterCarstens.pdf.

Eelgrass house in Østerby in 1906. Foto: H. Fr. Eiler. Retrieved 25th May, 2023 from https://www.kristeligt-dagblad.dk/kulturhistorie/saltsydernes-land

Eelgrass roof on Læsø. Image credit: Thomas Kyhn Rovsing Hjørnet/Alamy. Retrieved 25th May, 2023 from https://www.bbc.com/travel/article/20200805-denmarks-300-year-old-homes-of-the-future

Eelgrass roof. Designboom. Retrieved 25th May, 2023 from https://www.designboom.com/architecture/seaweed-roof-laeso-denmark-07-25-18/

The modern Seaweed house, Helene Høyer Mikkelsen and Realdania Byg. Retrieved 25th May, 2023 from https://www.dezeen.com/2013/07/10/the-modern-seaweed-house-by-vandkunsten-and-realdania/

Acoustic Boards made from eelgrass. Søuld. Retrieved 25th May, 2023 from https://www.sould.dk/acoustic-boards

Eelgrass insulation in prefab wall. Realdania By & Byg, 2013. Retrieved 25th May, 2023 from https://www.youtube.com/watch?v=quyrglWd7vw

Drawings of The Modern Seaweed House, Vandkunsten Architects. Retrieved 25th May, 2023 from https://vandkunsten.com/en/projects/seaweedhouse

Mussel farming, Kent Eng Retrieved 25th May, 2023 from https://www.land.se/mat-dryck/musselbaren-lyckorna-ljungskile/

Harvesting experience, Kent Eng Retrieved 25th May, 2023 from https://www.land.se/mat-dryck/musselbaren-lyckorna-ljungskile/

Illustrations:
Fig. 1: Twin crises and architecture - Own Illutsration
Fig. 2: Building industy's impact on natural environments - Own illustration
Fig. 3: Länsstyrelserna. (n.d.). Vattenförekomster med övergödningsproblematik. LST WebbGIS Övergödningskartan. Map. Retrieved May 7, 2023, from https://ext-geoportal.lansstyrelsen.se/standard/?appid=85131fe1a5c0443ca0b26e3f0a904c67.
Fig. 4: Bioremediation - Own illustration
Fig. 5: Mussel farm - Own illustration
Fig. 6: Reeds - Own illustration
Fig. 7: Eelgrass - Own illustration
Fig. 8: - Blue mussel. Cooke, A. H., Shipley, A. E., & Reed, F. R. C. (n.d.). Molluscs, Brachiopods (Recent), Brachiopods (Fossil. University Libraries - University of Washington. Freshwater and Marine Image Bank. Retrieved May 8, 2023, from https://digitalcollections.lib.washington.edu/digital/collection/fishimages/id/48580.
Fig. 9: Long line farming - Own illustration
Fig. 10: Architectural implementation shells - Own illustration
Fig. 11: Phragmites australis. Skoumalová, A. (2017). . Biological Flora of the British Isles: Phragmites australis. Brittish Ecological Society - Journal of Ecology. Retrieved May 8, 2023, from https://besjournals.onlinelibrary.wiley.com/doi/10.1111/1365-2745.12797.
Fig. 12: Reed harvest - Own illustration
Fig. 13: Architectural implementation reeds - Own illustration
Fig. 14: Zostera marina, Douglas et al. (2001) Retrieved May 8, 2023, from:https://www.semanticscholar.org/paper/Absence-of-recovery-in-a-degraded-eelgrass-(Zostera-Wilson-Garbary/b320c8d262f8121069922df38ea3a9ff86bdb36f/figure/0
Fig. 15: Eelgrass harvest - Own illustration
Fig. 16: Architectural implementation eelgrass - Own illustration
Fig. 17: Explored system - Bioremediation to building material - Own illustration
Fig. 18: Building a tabby wall. The houses of st. Augustine. Retrieved 25th May, 2023 from https://preservedowntownstaugustine.wordpress.com/2013/03/29/the-gallegos-house/tabby-concrete/
Fig. 19: Modern mullbänk. Own illustration.
Fig. 20: Chemical reaction of slaked lime. Own illustration
Fig. 21: Stages of the thatching process. Image source: Roman Fodchuk and Associates
Fig. 22: Detail drawing Tåkern, Image: Svenskt trä
Fig. 23: The Wadden Sea Center, detail section, Image: EU Mies Award
Fig. 24: Tangtagets konstruktion, Nationalmuseets arbejdsmark 1944
Fig. 25-26: Drawings of The Modern Seaweed House, Vandkunsten Architects
Fig. 27: Test mixture - Own image

APPENDIX

Interviews & Lab explorations

INTERVIEW: SØREN NIELSEN

The following texts are summarized based on an interview with Søren Nielsen (personal communication, 5 february, 2023).

The Modern Seaweed House on Læsø is not only a tale of the renewed use of an remarkable material on a unique site with an extraordinary building history. It acts like a crystal ball that catches and illuminates many of the most important issues the construction industry are facing today." - Søren Nielsen, arkitekt MAA, partner at Vandkunsten

The Modern Seaweed House is an experimental project made by the Danish architectural office Vandkunsten for a competition initiated by the Realdania byg foundation in 2010. The competition was an initiative to preserve old building traditions on the Danish island Læsø, an island with a strong historical tradition of using seaweed, or more precisely "eelgrass" for roof construction. Eelgrass is an aquatic plant that flushes up in an abbundance on the beaches of Læsø. Søren describes that the project is one of their smallest projects in scale but perhaps the most published one. The interest in the seaweed house has been huge both in and outside of Denmark.

Image source: Vandkunsten Tegnestue

The Modern Seaweed house. Photo: Helene Høyer Mikkelsen and Realdania Byg

The modern seaweed house explores the material properties of eelgrass using it both on the interior and exterior

"The Modern Seaweed House"

Søren describes a bit about the design process behind the project and brings up the peculiar rolls that holds together the facade and roof cladding. As the seaweed itself has no particular formbinding capacity, it reqires a construction that holds it together when used for other purposes than as insulation. Here he describes how the team at Vandkunsten tried out many possible designs and ended up with a design made out of yarn tying rolls of seweed together like a net. The reason behind this was to honour the historically female dominated craftmanship, implementing features of fabric, threads and knitting techniques into the design.

Back in the days when eelgrass was a more commonly used building material it was collected mainly by the women in the village. The collected seaweed was dried and attached to the roof structure using a twirling techniqe. When the base was laid, large amounts of eelgrass was added on top until full coverage was reached. This often resulted in massive roofs of up to 1.5m thick. The ambition with the modern design was to showcase the material as much as possible, using it both on the interior as well as exterior. This entire project was an experiment of the material properties and the yarn design ended up not working well. However the building is still a great example of sustainable design in balance with nature.

When asking about the possibility of upscaling the use of seaweed, Søren sees certain challenges. We have made manual labour and craftmanship into one of the most expensive things we have, something that traditionally was free and sustainable. Revivng traditional craftmanship would be important, as well as shifting the industry's attitudes. As of now, there if too little of this material for big scale use, and perhaps one could cultivate it which would be great.

INTERVIEW: KATHRYN LARSEN

The following texts are summarized based on an interview with Kathryn Larsen (personal communication, 27 February 2023).

Kathryn Larsen is an architect and architectural technologist with a special interest for marine biomaterials and her research has been widely published. During her last years of studying, she founded her own practice with a focus on research of marine biomaterials. Studio Kathryn Larsen consists of Kathryn herself and marine biologist & biogeochemist Shannon Hanson, PhD. Their studio work a lot with design installations, residential architecture and commercial interiors along with consultancy on larger projects.

Meeting in her studio

We met up with Kathryn at her studio space in Østerbro, Copenhagen to learn about her research and gain some deeper knowledge about the material properties and possible areas of implementation in buildings. The meeting was increadibly inspiring and we got to see a variety of material tests for different applications and hear about the process behind the research during her time at TU Delft. Her process book contained everything from studies of traditional thatching methods to coloured sheets of "seaweed paint" and bioplastics.

Image: Kathryn Larsen

Material samples of bioplastics and shellcrete from Studio Kathryn Larsen.

Image source: Kathryn Larsen Studio

A curious approach

When talking to Kathryn it quickly becomes clear that she enjoys the explorative practice. She points out how there is a restricting point of view within architectural practice that everything has to work perfectly for it to be interesting. She however encourages a more curious approach where "mistakes" give means to further research.

The material investigations done at her studio targets different structural and aesthetic values and she is continuously discovering new possibilities with the material. Among the test samples she brought to the meeting there were a variety of hard and soft plastics, paint of different colours and bricks of compressed shell and natural binders. To the touch the material samples resembles conventional materials to a high extent. Most of her test has been carried out in her own kitchen, using what she had access to, laborating with a variety of natural binders and techniques to find ways of working that does is not harmful to the environment. Kathryn's educational background in chemistry and physics comes in handy here, yet the process include a lot of trial and error.

INTERVIEW: MARIA BODIN

The following texts are summarized based on an interview with Maria Bodin (personal communication, 21 November 2022).

Maria Bodin is a marine biologist at the University of Gothenburg. Maria is the person behind the pilot project "Marina kolonilotter" at Tjärnö marina laboratorium. Early in the process we conducted an interview with Maria over zoom to learn more about this initiative. The general idea behind the project was to create a technique for individuals to grow their own "blue foods".

The idea is insipred by the danish initiative "Havhøst" where aquatic species are farmed in small scale installations to engage people in blue cultivation. In Tjärnö Maria hung out ropes from piers in the area in an attempt to grow mainly mussels, oysters and algea. The project was sucessful and has got a lot of publicity both from actors and the public. The idea was originaly to create a system for people to grow their own blue foods at their own deck. However as not everyone has access to a private deck, the focus is now more aimed at creating "community farms". To find suitable locations for these kinds of practices they work together with "ocean planners" to find where the species will grow well.

Maria Bodin. Photo: Johan Wingborg

Edible seaweed. Photo: Johan Wingborg

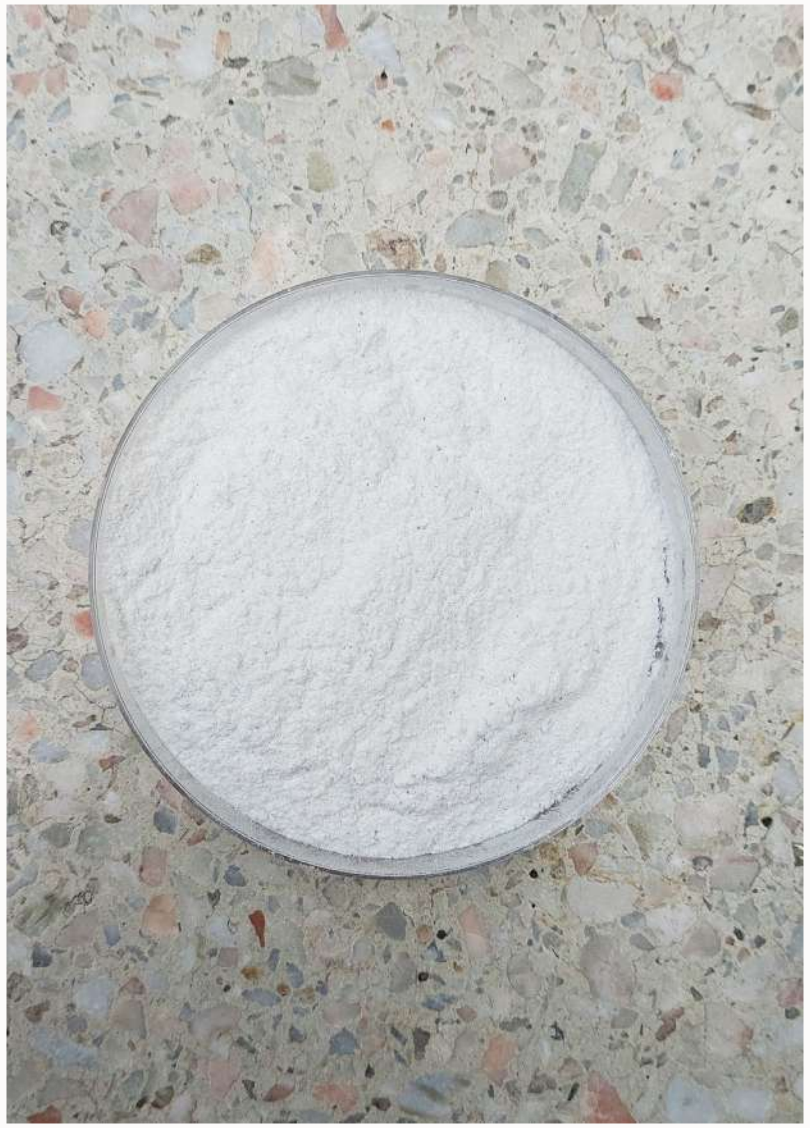
"we currrently eat a very limited part of what we actually could consume from the water"
- Maria Bodin

Marina kolnilotter

Maria was recently asked to do a test installation in Frihamnen, Gothenburg in their so called "omställlningslab" where they together with the public will create a space for gatehering and learning about cultivation of the ocean. We asked Maria about this inastallation an if she saw any potential in a development of some sort of placemaking to support this. She responded that she would love to see some kind of outdoor classrooms and outdoor kitchen where visitors could come and participate and learn about marine cultivation practically, simliar to Havhøst.

She points out how we currrently eat a very limited part of what we actually could consume from the water and wants to increase the interest for trying other kinds of blue food. The fact that the farms also have a positive impact on the local environment through nutrient uptake is another great reason for establishing these kinds of farms. She brings up the planned reconstrction of Malmö harbour as an example of a current development project where a sustainable relationship to the ocean is desired. She here sees a potential in impleminting this in a wider scale where more harbour areas could benefit from the implementation of blue farming both for environmental reasons as well as social and sustainable reasons.

shell-based lime



The mussel shells are crushed, calcinated at high temperatures, ground and sieved to achieve a reactive powder that acts as a green binder.

reactivity

The reactivity of mussel shell based lime is the same as limestone, giving it good qualities as a sustainable replacement derived from waste products *crushing shells*

For shell based aggregate, the machine crushes the shells at different particle sizes depending on purpose

mixing

Different mixtures depending on the recepie is prepared. The mixtures are based on crushed shells, shell- based sand, water and reactive compounds such as lime and volcanic ash or clay.

components

The volcanic ash and the clay (a rest product from building sites in Norrköping) are both highly reactive as a green binder.

moulding trial 1

Pressing the mixture into smaller moulds for a first trial *curing*

The mixture needs to harden and here different moulds and mixtures where tried out. The wood one was most successful as it hardened the best. Some mixtures where wetter and needed a longer time to curate.

samples

Different hardened samples based on different recepies. Hardened but fragile.

mixing trial 2

Mixing the components by machine in the final trial

moulding trial 2

Two larger tiles are made by pressing two different mixtures into moulds. The different character of the reactive compounds give the tiles different colours *pressing*

Pressing the tiles when moulded to ensure a favourable environment for the tiles to harden in

LAB-INSTRUCTIONS

PART 1 - CALCINATING SHELLS:

1. Wash and rinse
Wash and rinse the shells with a steel brush to remove organic material, sand and salts

2. Roughly crush the shells
Crush the shells roughly with a hammer

3. Dry in oven overnight
Let dry in a drying oven at 105°C overnight

4. Crush in machine
Crush the shells in a crushing machine

5. Grind the shells
Grind the crushed shells in a machine to a fine powder.

6. Sieve the shell powder
Sieve the powder through a 500 µm sieve.

7. Calcinate shell powder
Calcinate by putting small portions of powder in glazed ceramic moulds and put in the oven. Set the temperature at 800°C and turn off after 5 hours.

8. Let cool overnight
Leave the shells in the oven overnight to cool off and remove them after.

PART 2 - MIXING OF MORTAR

1. Sieve sand
Sieved sand through a 4 mm sieve

2. Mix mortar
Standard recipe: 50% water, 50% sand 50% CaO_2 from mussels, 50% pozzolanic ash?

3. Experiment with different ash?

PART 3 - CREATE SAMPLES

1. Pour mixture into moulds
Fill prisms of suitable dimensions(?) with the different mixtures.

2. Add vibration?
Place the prisms on a vibration table to compact the mixture

3. Leave to harden
Leave the moulds to harden under a plastic sheet for 24 hours.

4. Place in water bath?
Place in a water bath for 7-28 days

LAB-RECIPIES

CaO	CaO(shell)	Ash 35.1g	Water	Sand	Crushed shell	
35.1g	*0g*	*Volcanic*	*117g*	*838.5g*	*0g*	*Standard recipie*
0g	*35.1g*	*Volcanic*	*117g*	*838.5g*	*0g*	*Replace lime*
0g	*35.1g*	*Volcanic*	*117g*	*0g*	*838.5g*	*Replace lime+sand* *small pieces*
0g	*35.1g*	*Volcanic*	*117g*	*0g*	*838.5g*	*Replace lime+sand* *small +large pieces*
0g	*35.1g*	*Oak (bio-ash)*	*117g*	*0g*	*838.5g*	*Replace ash*
0g	*35.1g*	*Calcinated clay*	*117g*	*0g*	*838.5g*	*Replace ash*

Dimensions prisma:
40x40x160mm = 4x4x16cm= 256cm3

Recepie based on 3 prismas:
256cm3 x 3 = <u>768cm3</u>

CaO: 70g/768cm3 = 0.09g/cm3
Ash: 70g/768cm3 = 0.09g/cm3
Water: 225g/768cm3 = 0.3g/cm3
Sand: 1650g/768cm3 = 2.15g/cm3

Our casts:
26x15x100mm=2,6x1,5x10cm=
<u>390cm3</u>

CaO: 0.09g/cm3 x 390cm3 = 35.1g
Ash: 0.09g/cm3 x 390cm3 = 35.1g
Water: 0.3g/cm3 x 390cm3=117g
Sand: 2.15g/cm3 x 390cm3=838,5g

Material use:

Per test:
CaO: = 35.1g
CaO shell: 35.1g
V-Ash: = 35.1g
O-Ash: = 35.1g
C-Ash: = 35.1g
Water: = 117g
Sand: = 838,5g

Total (6 tests):
CaO: = 35.1g
CaO shell: 175.5g
V-Ash: = 140.4g
O-Ash: = 35.1g
C-Ash: = 35.1g
Water: = 702g
Sand: = 5031g