ZOSTERA MARINA: REUSING HISTORY FOR A SUSTAINABLE FUTURE

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Architecture and Design
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Group 2
Anne-Mette Rosenkilde Hansen
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provided by Møn Tang.

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Anne-Mette Rosenkilde Hansen

TITLE PAGE

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ABSTRACT

As the climate changes continuously become more evident, it is clear that action is necessary. With the building industry being one of the big contributors to the global energy consumption and CO_2 emissions, the industry is an important parameter in the reduction of the global energy consumption and CO_2 emissions. This thesis therefore investigates the use of eelgrass as a bio-based building material. The report determines advantages and disadvantages of eelgrass as a building material, based on analysis of historic and current use, of material properties, and by comparing the existing eelgrass products with similar building products.

The possible utilisations of eelgrass as a building material are showcased by presenting examples of the material applied in renovations as well as in new build. For the new build example, a small exhibition building showcasing and raising awareness of eelgrass is designed.

Through the works of the thesis, it is established that eelgrass products have properties similar to or even better than existing biobased and mineral materials. On some parameters the eelgrass materials perform better than both biobased and conventional building materials. The eelgrass performs well on parameters such as thermal- and acoustic insulation, and additionally has a low Global Warming Potential.

The biggest challenge of upscaling the use of eelgrass in the building industry is the lack of resource, due partly to the oxygen depletion of the Danish waters.

CONTENTS

READING GUIDE

This report consists of a Prologue introducing the project, followed by the Background, presenting the background for the problem explored in the project. Next the method is explained. The method consists of descriptions of design methodologies, a table of tools used in the project work and detailed descriptions of selected tools.

After the Methodology section, the main part of the report begins. The main part of the report is sectioned into three parts, respectively Material, Renovation and Design. For each section both analysis, synthesis and evaluation are performed.

The Material section covers the history of the use of eelgrass in buildings, the properties of the material and the production methods. Furthermore, eelgrass products are compared with other building materials and recommendations for applications are presented.

In the Renovation section existing constructions of Danish buildings are investigated, regulations and recommendations regarding renovation is established. The section seeks to present two different cases of eelgrass applied in renovations. For this purpose, preceding experiences of reinsulating with eelgrass are explored.

The purpose of the Design section is to investigate how the eelgrass can be utilized in a new exhibition building, which can showcase the material and raise awareness of environmental challenges of the building industry as well as the state of the Danish waters. To solve this design task, the section investigates exhibitions, constructions and a vary of design proposals.
The result of the Design section is presented in the chapter Presentation.

Following the Presentation is the Epilogue, which contains a Conclusion on the Problem of the project, along with a Reflection on advantages and disadvantages of using eelgrass as a building material.

MOTIVATION

Growing up near the coast of south-eastern Zeeland I witnessed the, at times massive, amounts of seaweed that washed up on shore.
With my following increasing interest in environmentally sustainable buildings and biobased materials, I started to wonder why the marine material was viewed as waste and complications rather than a great resource.
Being constantly made aware of the severity of the climate changes and being aware of the building industry's impact on this matter, this has led me to being interested in investigating how the seaweed can be utilised in, and positively influence the emissions of the building industry.

INTRODUCTION

This thesis is conducted as a final project on the fourth master semester of Architecture and Design at Aalborg University. The thesis investigates the possibilities of using eelgrass, also known as Zostera Marina, in the building industry, as a solution to decrease the energy consumption and emissions from the building industry.
The building industry is a huge contributor to the global emissions and energy consumption, and thereby possess great opportunities to improve its impact on the global resource- and energy consumption. Lowering the embodied carbon of buildings is one strategy to improve the environmental impact of the building industry. Using biobased materials in general reduces the embodied carbon of buildings, and this thesis therefore investigates the biobased material eelgrass.
Using eelgrass in buildings is historically an international tendency, however Denmark has a unique regional tradition for using eelgrass, in the eelgrass thatched roofs of the buildings of the island Læsø. The project will be investigating and seeking inspiration outside the Danish borders, but the solutions will be based on Danish conditions.
As the thesis investigates eelgrass and its qualities and disadvantages as a building material, the project is material driven rather than design driven as usually. The project does however contain a building design. The report consists of three main focal points. First off, the material and its properties, along with its historic and current use is investigated. Different eelgrass materials are investigated to understand their properties and application possibilities. The eelgrass products are compared to similar products, to determine their place in the market.
The report additionally investigates the use of eelgrass in renovation cases, as renovation is considered to be more efficient, considering both economic and ecological sustainability, than building new. The thesis analyses existing Danish building typologies and their constructions along with previous use of eelgrass in renovations, to determine possible renovation solutions.
The project culminates in a design proposal of an exhibition building, showcasing the possibilities of eelgrass and raising awareness of the state of the environment and marine environment of Danish waters. The exhibition building hosts an exhibition, while simultaneously being part of the exhibition itself.

AIM

The aim of this thesis is to investigate if eelgrass can be a valuable sustainable product in the building industry, by investigating the historic use, the existing products, and ways of implementing it in new build as well as in renovations.

PROBLEM

With the consequences of climate change being increasingly more evident and the building industry being responsible for almost 40 percent of the energy related carbon dioxide emissions, the processes of the building industry need to be revolutionised. Therefore, this thesis will investigate the possibilities of eelgrass becoming a sustainable and valuable resource in the building industry, to bring down the climate impact of the industry.

VISION

The vision of this project is to investigate the useability of eelgrass as an alternative biobased building material in different use cases. The different use cases should inspire the industry to improve and build more sustainable, by implementing new renewable solutions. Furthermore, the thesis should investigate the possible advantages of building with biobased materials, regarding both the emissions and energy consumption, as well as for the indoor climate.

EXPECTED OUTCOME

The thesis should terminate in a catalogue of different applications and recommendations for the use of eelgrass as a building material. Furthermore, application solutions for both renovation and new build should be detailed and presented, to showcase specific solutions. Lastly, a small architectural design for the new build, which showcases eelgrass as a building material, provides know-ledge and inspire lay persons as well as homeowners to choosing bio-based materials and improving the building industry will be carried out.

Illu. 1. Photography of seaweed on the coast of Kegnæs.
Photography by Anne-Mette Rosenkilde

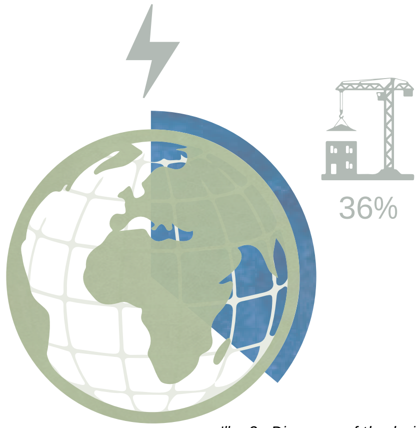
BACKGROUND

In the background section, the background for the problem of the project is investigated. The background section presents challenges of the environmental impact of the building industry and the measures taken to decrease the impact. Additionally, the background section investigates the state of the marine environment of the Danish waters, along with qualities and challenges of eelgrass.

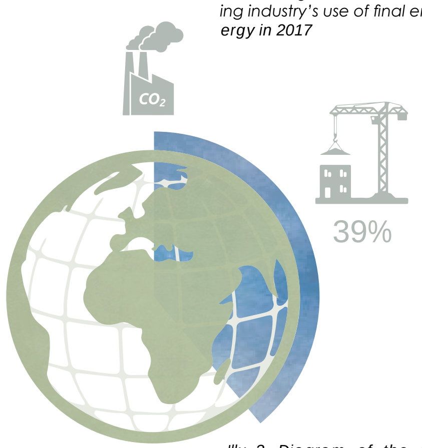
THE BUILDING INDUSTRY AND CLIMATE CHANGE

Emissions from the building industry

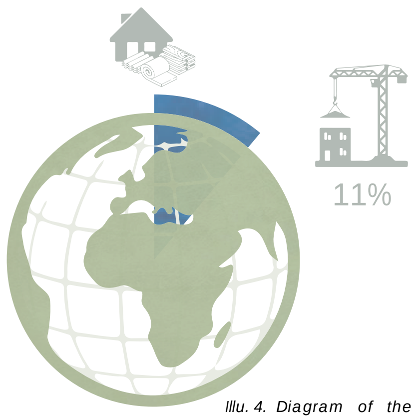
According to the 2018 Global Status Report by the Global Alliance for Buildings and Construction, the construction and operation of the building industry accounted for 36% of the global use of final energy in 2017. While being responsible for 39% of the energy related carbon dioxide emissions in 2017 as well. This results in the building and construction sector being the largest contributor to energy consumption and carbon dioxide emissions. (Abergel, et al., 2018)
With an anticipated continuous increase in the global population, the global building stock is expected to increase as well. In fact, it is expected to double in size, potentially consuming great amounts of resources and further increasing the emissions of the sector. Therefore, new approaches need to be implemented and ideally as fast as possible. (Adams, et al., 2019)
Since the oil crisis in the 1970's there has in Denmark been a focus on minimizing the energy use of our buildings, in new build as well as renovation. The effort has been effectful and the energy use per square meter has decreased from more than 350 kWh per square meter dwelling in 1961 to an average use of approximately 30 kWh per square meter dwelling in 2020.
However, while the energy use per square meter has decreased, the floor area of new dwellings has simultaneously increased, minimizing the effect of the efforts. From 1992 till 2017 the building area per person in Denmark has increased by 11%, correspondent to an increase from 47 m² to 52 m² per person. This is an average and the floor area for some building typologies have increased even more. (Wied & Madsen, 2023)



Illu. 2. Diagram of the building industry's use of final energy in 2017



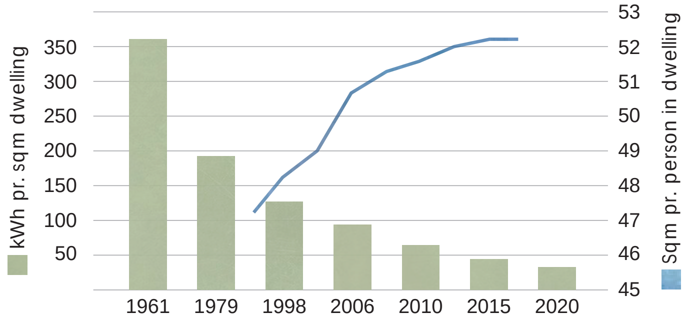
Illu. 3. Diagram of the building industry's emission of carbon dioxide in 2017



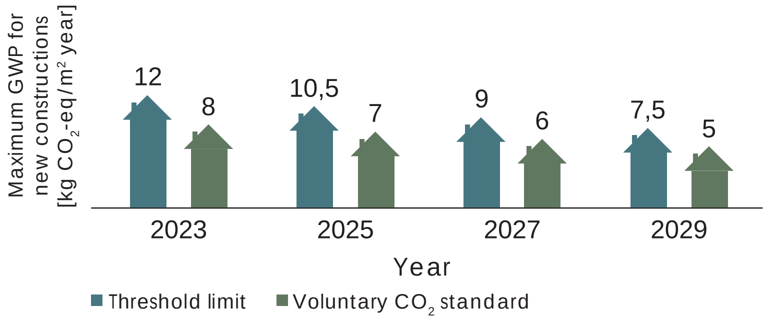
Illu. 4. Diagram of the embodied carbon in constructions

EMBODIED CARBON

As the energy use for the operation of buildings decreases, the embodied carbon of the construction gains greater impact on the total energy consumption of the building.
The term embodied carbon covers the carbon emission from all phases of the building's lifetime, such as manufacturing, transportation, construction and end-of-life phases. (Adams, et al., 2019)
At present the embodied carbon of constructions make up for 11% of the total global carbon emissions (Adams, et al., 2019), while 10% of the Danish carbon emissions are due to the production of building materials and the construction processes. (Wied & Madsen, 2023)



Illu. 5. Graph of decrease in energy consumption compared to increase in floor area. Based on data from (Wied & Madsen, 2023).



It is predicted that the carbon emitted before the construction is ready for use, the upfront carbon, will constitute to half of the overall carbon footprint of new constructions in the period from now till 2050. (Adams, et al., 2019)

LCA REGULATIONS

In Denmark the focus on the embodied carbon of buildings is slowly increasing.
From the beginning of 2023 it is required by the Danish Building Regulations that a LCA must be conducted for all new buildings in Denmark.(Social- og Boligstyrelsen, 2023)
LCA is an abbreviation of Life Cycle Assessment and is a comprehensive calculation of all carbon emissions during the building's lifetime. Including those phases previously mentioned.
New buildings exceeding 1000 m^2 must document with a LCA calculation that they comply with the demands of a maximum of 12 kg CO_2-eq/m^2/year. In 2025 the demands will apply to all new buildings, while the maximum allowable Global Warming Potential is simultaneously lowered to 10,5 kg CO_2-eq/m^2/year. Towards 2029 the demands will gradually be tightened. (Social- og Boligstyrelsen, 2023)
With the implementation of LCA requirements in the Danish Building Regulations, the Danish building industry is forced to consider the embodied carbon of new buildings.
The means to reducing the embodied carbon are among others to limit the use of materials with high emissions and energy consumption related to the manufacturing. Reducing the use of mineral building materials and implementing renewable materials as an alternative or using local materials rather than materials transported over great distances, are strategies to lower the embodied carbon of buildings. (Adams, et al., 2019)

CHALLENGES

Parts of the building industry are ready for the implementation of new and sustainable solutions. However, the green transition of the sector is facing some challenges.
First of all, it is necessary to change the trend of living bigger, as the increased personal square meters swallow up the efforts of reducing the carbon footprint of buildings.
Additionally, studies show that sustainable solutions are often deselected due to greater cost than traditional construction methods.
A study investigating the cost of green buildings, compared 336 green buildings to 2060 conventional buildings. The study showed that on average a green building is only 6,5 percent more expensive than the conventional building. (Chegut, et al., 2019)
Additionally, the study shows that especially the design fee of the green buildings is high. The design cost of a green building proves to be 31 percent higher than that of conventional buildings. Together with the extra design cost being placed in an early and thereby uncertain phase of the building process, makes building green a risk, that few developers are willing to take and is therefore often a factor in the deselection of green buildings. (Chegut, et al., 2019)
However, a report from 2020 investigating the impact of green certificates on property cash flows and values, shows that a green building certification on average increases both the rental income and the occupancy with approximately six percent and increases the sales prices with approximately 15 percent. (Leskinen, et al., 2020)

Sub conclusion

To decrease the emissions and energy use from the building sector in the future, it is necessary to increase the attention to using more sustainable materials in the building industry in order to bring down the carbon emissions from embodied carbon.
Furthermore, the green solutions need to be designed for easy implementation in the design phase as well as in the construction, to ensure that neither economic nor timely cost are the factors that make the green solutions unable to compete in the market.
Additionally, with the need for new housing, smaller dwellings should be promoted. The trend of living big needs to be reversed. Designers and architects should be invested in proving that you can live large in a smaller space.

SUSTAINABILITY

KLIMALOVEN

In 2020 the Danish government passed the 'Klimalov' [Climate legislation]. With the Climate legislation, the Danish government aims to reduce greenhouse gas emission by 70 percent by 2030, compared to the emissions of 1990. (Klima-, Energi- og Forsyningsministeriet, 2021) In 2022, the Danish greenhouse gas emissions had been reduced by 41 percent, compared to the 1990 emissions. (Danmarks Statistik, n.d.)
The Climate legislation was passed in order to reach the goals of the Paris agreement, aiming for a carbon neutral society by the year 2050, thereby ensuring that the global temperature increase doesn't exceed 1,5 degrees Celsius. (Klima-, Energi- og Forsyningsministeriet, 2021)

PILLARS OF SUSTAINABILITY

The focus on sustainability rises steadily, as the all-encompassing effects of the climate changes become more evident. However, there has been a focus on building energy efficient since the oil crisis in the 1970's.
Since 1987, when the report 'Our Common Future' also known as the 'Brundtland report' was released, the focus on sustainable development has been more widespread. One of the most quoted definitions of sustainability, is defined in the report by the UN and goes as:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
(United Nations, 1987, p.37)

The Brundtland report puts focus on all aspects of sustainability, as it should concern all professions. It urges the governments to take action and attempts to set guidelines for the sustainable development. Apart from focusing on application in all fields, the Brundtland report also focuses on the different aspects of sustainability. It applies to both environmental, social, and economic sustainability and carefully displays how environmental sustainability is not possible without paying attention to the social and economic development, and vice versa. The report presents the delicate and complex interplay of all three pillars of sustainability. (United Nations, 1987)

Sustainable Environmental Development

As previously mentioned, the building industry constitutes a great deal to global energy use and emissions, and it is therefore important to improve the environmental impact of the building industry and decrease the overall environmental impact.

Ceasing all construction and not building any new buildings would be the most sustainable environmental solution. However, with the anticipated increase in the global population, new dwellings as well as other institutions are a necessity. (Adams, et al., 2019)
In the report 'Bringing embodied carbon upfront' by the World Green Building Council, four different principles for reducing the carbon emissions of the building industry are proposed. The best but simultaneously most challenging principle is called Build nothing and proposes to explore alternatives to building new or might just explore alternatives to some materials. The second principle is Build less and encourages to maximise the use of existing assets. As the third principle Build clever is presented. Build clever propose to optimise the material use and use materials with a low carbon footprint. The last principle is called Build efficiently and focuses on the production of building and building materials. Build efficiently encourages the use of low carbon construction technologies and focus on bringing down waste of the building process. (Adams, et al., 2019)

BUILDING LESS

One strategy to a more sustainable building industry, is renovating rather than tearing down and building new.
The report 'Analyse af CO_2-udledning og totaløkonomi i renovering og nybyg' [Analysis of CO_2-emission and total economy in renovation and new build] by the global engineering and consultant company Rambøll investigates the advantages of renovating instead building new. The report demonstrates that it is better to renovate than build new, both for environmental and economic reasons. The report investigates 16 different cases and analyses the environmental and economic effects of four different scenarios for each case, comparing renovations to new build.
The study shows that renovating roof and outer wall or roof, outer wall and installations is more

beneficial than building new, both regarding environmental impact and cost. Additionally, the report shows that only renovating the roof and building new has almost the same environmental impact, yet the cost of renovating is much lower. All the renovation scenarios have higher energy use for operation than the new build. However, the embodied carbon for building materials for the new build, eats up the advantage and makes new build the least sustainable solution of the four scenarios presented in the report. (Sørensen & Mattson, 2020)
However, it is a tendency in Denmark to buy older buildings with the purpose of tearing them down to build new. This is further encouraged by the fact that it is often easier to get a loan if you're planning to build new, than it is to get a loan for renovating. (From & Dohm, 2024)

Another strategy to building less is to transform existing buildings into fulfilling new required functions. In the report 'Analyse af CO_2-udledningen for forskellige typer byudvikling' [Analysis of CO_2-emissions of different types of urban development] by Viegand Maagøe the CO_2 emissions of three different urban development strategies are compared. The comparison shows that it is better for the environment to build new row houses compared to building new single-family houses, but it is even more advantageous to transform former industrial buildings into residential buildings.
The study of the report shows that the build area has the greatest effect on the total CO_2 emission in all cases. The single-family houses, with high floor area per person, take up more space than the other two cases and emit more than double the amount of CO_2.
Transforming industrial buildings into dwellings, which is the case in the study, emits almost as much CO_2 as building new row houses. Whereas the report claims that transforming buildings which are closer to fulfilling the energy requirements of the Danish Building Regulations, would presumably have a lower emission as the changes would be less comprehensive. (Wied & Madsen, 2023)

BUILDING CLEVER

When constructing new buildings, a lot of factors play a part in determining the environmental sustainability of the building. For example, it was previously mentioned how the embodied carbon of buildings play a continuously greater part in the overall assessment. This was manifested by the analysis in 'Analyse af CO_2-udledningen for forskellige typer byudvikling' report, investigating the environmental impact of different strategies for urban development. The analysis found that replacing heavier building materials, such as concrete and steel, in the single-family house, with timber solutions reduced the total CO_2 emission of the development area with 8 percent, and the CO_2 emission of materials declined by 17 percent. (Wied & Madsen, 2023)

Furthermore, the report proved that the typology of new build is very important, since the low-rise terrace houses emitted less than half of the CO2 emitted from the single-family houses. With a denser settlement, less energy and material were needed for construction of mobility systems. Additionally, the built square meters proved to be the biggest influence on emissions. The study showed that reducing the area of the single-family houses from 205 square meters to 120 square meters, reduced the emission from building materials with 34 percent and a reduction in energy use of 36 percent. Resulting in a total reduction of CO_2 emission of the development area with 24 percent. (Wied & Madsen, 2023)

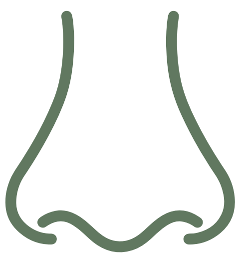
BUILDING EFFICIENTLY

To build efficiently the 'Bringing embodied carbon upfront' report encourages to optimise the processes of construction to lower the energy use and waste materials. One strategy for reducing the energy consumption of construction and the material waste, is to use prefabricate elements. Apart from being more time and cost efficient, the use of prefabricated elements for construction of buildings have also proven to decrease the material waste generated, compared to building conventional buildings on site (Subramanya, et al., 2020). The report 'Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong' found that waste reduction was one of the main benefits of using prefabricated elements. In fact, the report determined that on average the amount of waste can be reduced with 52 percent, when using prefabricated constructions compared to conventional on-site construction. (Jaillon, et al., 2009)

Social Sustainability Criteria

Social sustainability is often divided into qualitative and quantitative aspects. The qualitative aspects cover topics such as inclusive design and designing for social interactions. The quantitative aspects cover the measurable values of the indoor environment.
As the average person spends approximately 90 percent of their time indoors, the indoor environment of our buildings is quite important (Leesman, 2015). In the following section, the quantitative aspects of social sustainability such as air quality, daylight, and acoustics, and their effect on the human body are investigated.

AIR QUALITY
An important aspect of a good indoor environment is the air quality. The air quality is affected by many factors and to ensure good quality one should among others be aware of the material choices, as building materials give off chemical gasses, some more than others. These toxins from the building materials can cause health issues such as asthma, skin, nose and throat irritation, headache and in some cases even be related to cancer and reproductive impairment. (Fernando Pacheco-Torgala, 2010) To prevent a toxication of the indoor climate the use of toxic materials should be minimized (Social- og Boligstyrelsen, 2024).
To further improve the indoor climate, the building should be well ventilated, to get rid of chemicals and pollutions.
In new dwellings it is a requirement that the air change is 0,30 l/s pr. m^2, which in rooms with standard height equals to 0,5 h^{-1}. (Social- og Boligstyrelsen, 2024)
Often, we want to get rid of moist and polluted air by ventilation, mechanical or natural. However, it is becoming a tendency that the ventilation of new buildings removes too much moist from the air, leaving the occupants with a feeling of the air being uncomfortably dry, resulting in the mucous membranes drying up. A too dry indoor climate often occurs in the winter period and is especially noticeable in buildings with a recovery plant. (Boding, 2023)



ACOUSTICS
Another factor affecting the indoor climate is the acoustics of spaces. The Danish Building Regulations prescribe that the acoustic conditions of a building should both be healthy and comfortable. When designing for satisfying acoustic environment, one should both remember to consider noise transmission between rooms, noise from technical installations, noise from outside mobilities and the reverberation time. (Social- og Boligstyrelsen, 2024)
The acoustics are dependent on the dimensions of a space and the surfaces of the boundaries and interior. In private dwellings the acoustics are rarely a problem since they can be controlled with furniture, carpets, and curtains.
However, in offices this isn't always a possibility and unfortunately many employees experience bad acoustic environments at their workplace.

The report 'Leesman review' gathers multiple studies of noise and the impact on productivity. In a study questioning 100.000 office workers, 77 percent answered that the noise level is an important feature of their workplace. However, 46 percent also answered that they were dissatisfied with the noise levels. In open plan offices the satisfaction is even worse, as only 28 percent are satisfied with the acoustic conditions of their work environment. (Leesman, 2015)

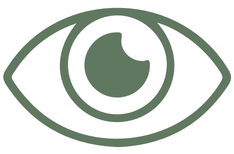
In another study from 2005, 99 percent of the participants answered that their concentration is impaired by noise from the office, and another study found that the performance of the employees drops with 66 percent when they are exposed to different background noises. (Leesman, 2015)

Allegedly noise is one of the most widespread stressors of the physical work environment and a study by The Stress Research Institute in Stockholm showcases how an improvement of acoustics can reduce cognitive stress and improve focus, memory and decision making of the employees by 11 percent. (Echophon, 2020)

DAYLIGHT

Another aspect of the indoor environmental conditions is the daylight. Daylight is very important for the human health and efficiency.
For thousands of years the human body has adapted to the circadian rhythm of a 24-hour day. However, for the past decades this rhythm has been twisted by the use of artificial light. Not being able to follow the course of the day by experiencing the natural daylight disturbs the circadian rhythm and often leads to a reduced quality of sleep. A reduced quality of sleep affects both physical and mental health. (Mohamed Boubekri, 2014)
This is proven by the Seasonal affective disorder, also known as SAD. SAD is a form of depression triggered by the seasonal daylight conditions. (Johns Hopkins Medicine, n.d.) The Seasonal affective disorder is often seen in the Northern hemisphere, in winter, when the nights are long and the daylight hours are few.
Additionally, sufficient daylight has proven to improve the performance of students (Lisa Heschong, 2002) as well as it is found that higher levels of daylight illumination positively affect the attention span and short-term memory of office workers. (California Energy Commission, 2003)

With the importance of daylight in our buildings, the Danish Building Regulations of course define some requirements for the daylight conditions. It is required that the glass area of a room constitutes to at least ten percent of the floor area or that the indoor daylight illuminance is at least 300 lux on minimum half the relevant floor area in at least half of the daylight hours. (Social- og Boligstyrelsen, 2024)



Illu. 6. Illustrations of the human sensors affected by the indoor environment.

Sub conclusion

In order to further improve the environmental sustainability of the building industry it is necessary to promote renovation and transformation instead of new build when possible. When designing new build the architect should attempt to decrease the floor area per person and optimize the functionality of the square meters instead. Not only the single building, but the overall build area should be minimised, and the focus should be on developing compact typologies, rather than single -family units.
In both new build, renovation, and transformation the designer should be aware of material choice, both for the purpose of reducing the embodied carbon as well as for providing a healthy indoor environment by reducing the toxins from building materials.
Furthermore, the social sustainability should be enhanced by being aware of designing a comfortable acoustic environment and ensuring sufficient daylight in the spaces.

Illu. 7. Photography of eelgrass plant with rhizomes.
Photography by Anne-Mette Rosenkilde

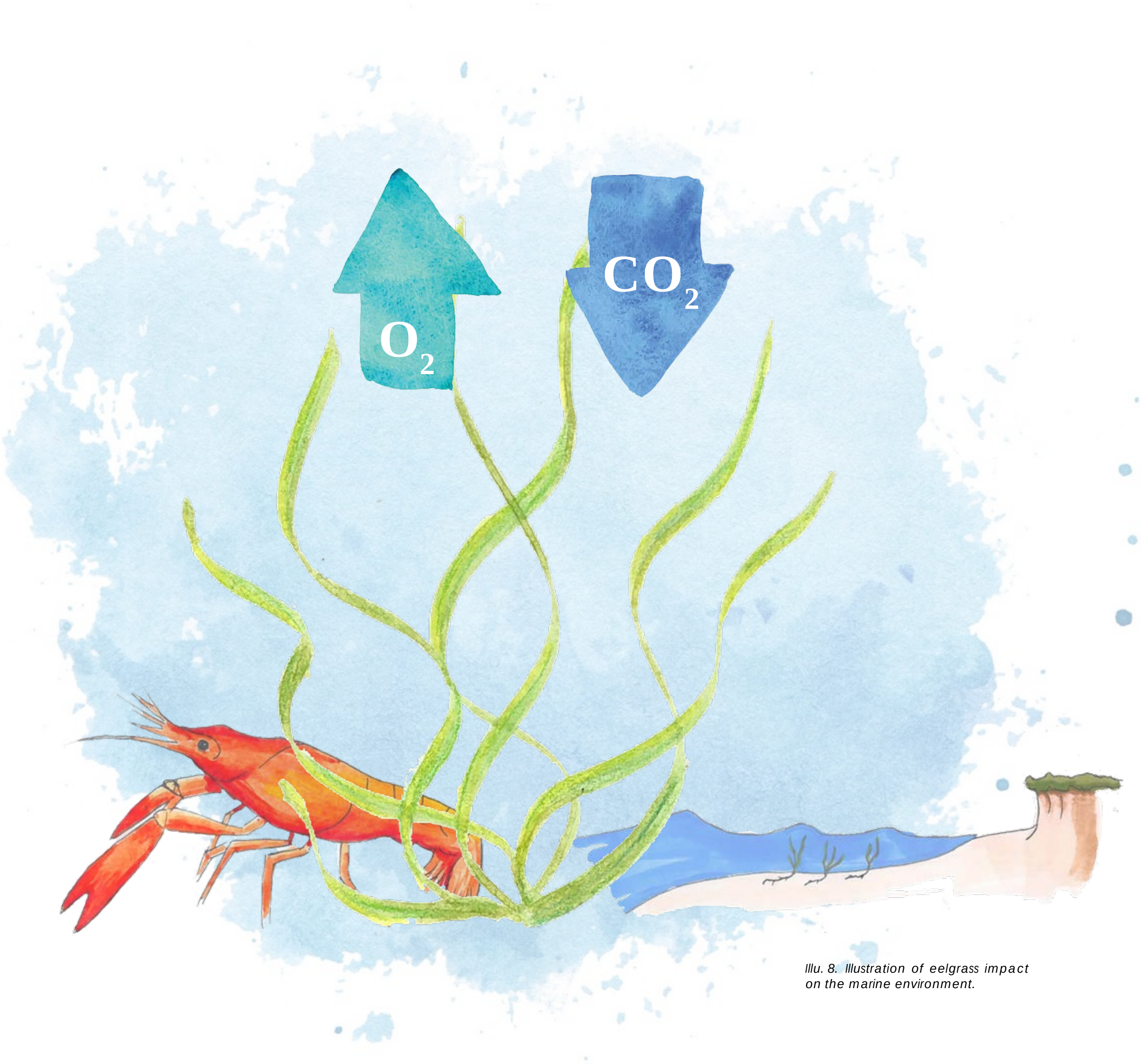
EELGRASS
[Zostera Marina]

Eelgrass, also known as Zostera Marina, is an underwater plant which thrives along the Danish shores. The stems are between 50-100 cm and mostly grow on shallow waters. With good lighting conditions the plant can grow in depths of five meters. (Pallesen, 2018)

Eelgrass is a seagrass, not to be confused with seaweed.

Seaweeds are macro algae, whereas seagrass is a rooted flowering vascular plant. Seagrasses originated from the sea, evolved to life on land and moved back into the sea. The plants are pollinated by crabs and shrimps. This makes seagrass the only true plant in the ocean. (Potouroglou, et al., 2022)
On the opposite, seaweed lives on rocks and other hard surfaces and is a primitive group of marine photosynthetic organisms. All algae and seagrasses can sequester CO_2 by photosynthesis, but seagrasses can store the CO_2 in the roots.
There are approximately 5.000 to 6.000 species of seaweed, in three different groups; red algae, brown algae and green algae, compared to 72 species of seagrass. (Potouroglou, et al., 2022)

Eelgrass grows in meadows and wash up on shore when the stems break of the plant. When the stems break, the plant survives and regrows, (Appendix 01) making eelgrass the waste of a renewable material resource.



Illu. 8. Illustration of eelgrass impact on the marine environment.

Marine Environment

ECOSYSTEM

Eelgrass is an important resource for the marine environment, as it is part of a delicate ecosystem. As the plant grows from the seabed, the eelgrass meadows can provide shelter for smaller fish and crayfish living at the seabed, thereby enhancing the biodiversity of the marine environment.
The seagrass also poses an important role in climate resilience since it protects our shores from erosion and facilitates sediment surface elevation. Allegedly, the leaves of seagrass can reduce the force of waves with up to 40 percent, before hitting the shore. (Potouroglou, et al., 2022)
Furthermore, studies show that the seagrasses can trap sediment and thereby raise the elevation of the seabed. This is an important ability, both with anticipated rise of water levels but also for preserving the carbon stored in the sediment of the seagrass meadows. (Potouroglou, et al., 2017)
Additionally, the seagrass sequesters CO_2 and other nutrients by photosynthesis and release Oxygen to the water instead, which the marine species can benefit from. (Potouroglou, et al., 2022)

CO_2 Sequestration

The ocean covers 70 percent of the earth's surface and sequesters 23 percent of the global CO2. (Matheson, et al., 2022) This is due to its important ecosystems, one of these being seagrass meadows.
Seagrass is the second most efficient ecosystem for carbon storage on earth, whilst tropical forests are in a fifth place (Svennevig, 2018). Additionally, seagrass is the most efficient blue carbon ecosystem, storing amounts of Carbon corresponding to the total sequestration of the two other main parts of blue carbon ecosystems, marine tidal marshes and mangrove forests. (Potouroglou, et al., 2022)
In fact, studies show that the contribution of seagrass meadows to carbon accumulation is up to three times as great as that of terrestrial soils. (Röhr, et al., 2018)

Contrary to the carbon storage of terrestrial plants, the main carbon storage of costal vegetated habitats is found in the soil. (Fourqurean, et al., 2012)
The average carbon storage of seagrass sediment is estimated to be 83.000 Mg/km^2, which equals to a total global blue carbon storage of 19.9×109 Mg.

Seagrasses decompose slowly compared to other marine angiosperms and algae due to the hypoxic seagrass sediments. The slow decomposition of seagrass entails longer carbon storage, in the case of Zostera Marina, up to several centuries.
The carbon storage of Zostera Marina varies a lot. In the study of the report 'Blue Carbon Storage Capacity of Temperate Eelgrass (Zostera marina) Meadows', the organic carbon stock of the top 1 meter of the eelgrass sediment ranged between 23.1 and 351.7 Mg C/ha, with an average of 108,9 Mg C/ha. The projected organic carbon stock for the Kattegat-Skagerrak area was 194.5 Mg C/ha, the highest carbon stock for an area, except for one site in the Mediterranean Sea reaching an organic carbon stock of 351,7 Mg C/ha.

It was found that some of the most important factors influencing the carbon storage of the seagrass was the sediment mud content, dry density, the degree of sorting, salinity, and water depth.
The highest total organic carbon stock of a region was, as mentioned, found in the Kattegat-Skagerrak region and the highest carbon storage of all sites was found at the site Thurøbund, which is located in a creek of the archipelagos of Southern Funen. In fact, the study found that 9 out of 10 of the sites with the highest carbon stocks were found in the Kattegat-Skagerrak region. (Röhr, et al., 2018)

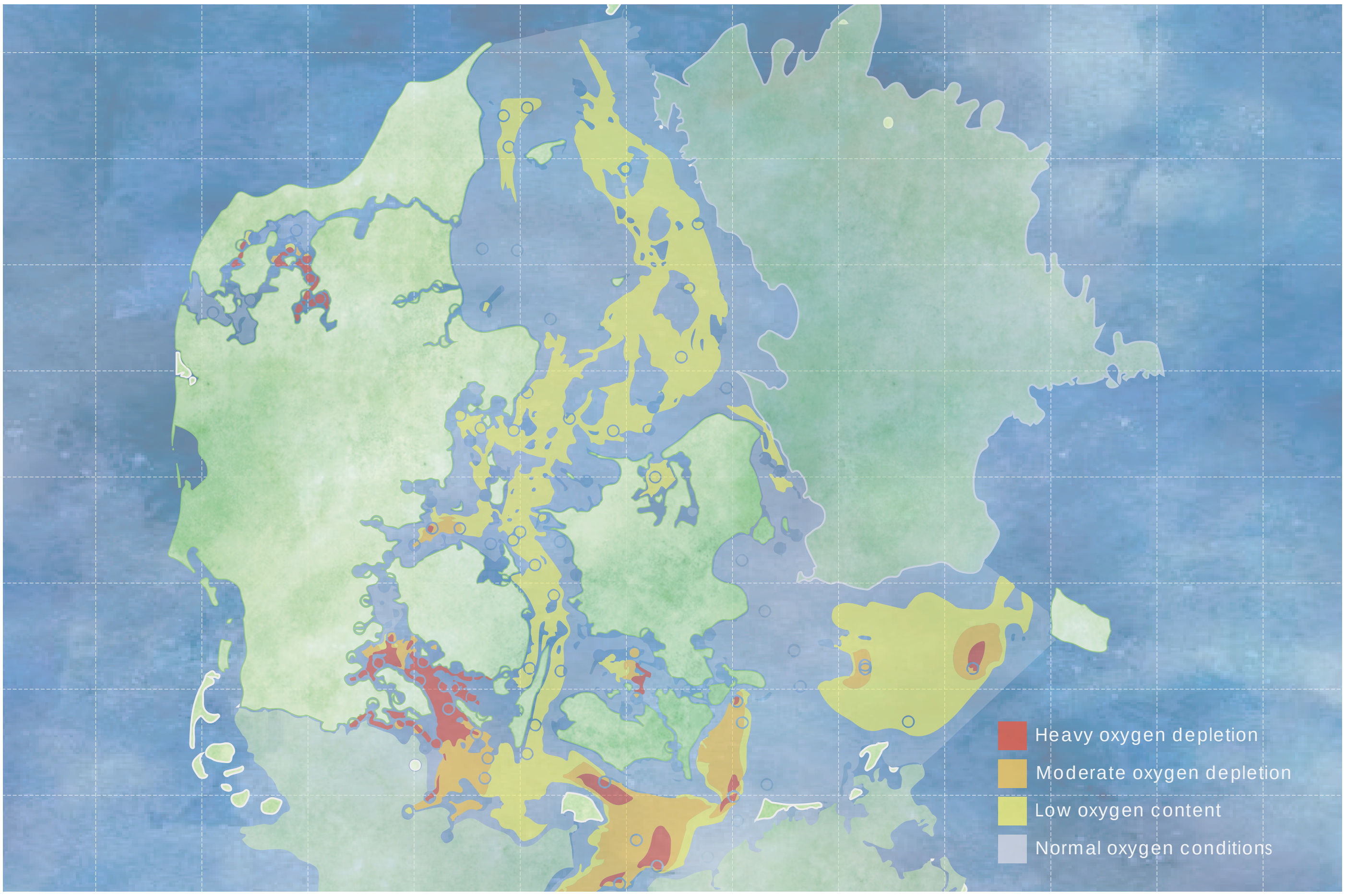
Blue Carbon

"Blue carbon is the term for carbon captured by the world's ocean and coastal ecosystems." (National Oceanic and Atmospheric Administration, 2023)

The costal ecosystems include Sea grasses, mangroves, and salt marshes. These ecosystems function as carbon sinks. The blue carbon ecosystems can sequester carbon at much faster rates than forests on land even though they are much smaller. The nutrients sequestered by these ecosystems are stored in the system for many centuries. (National Oceanic and Atmospheric Administration, 2023)

In the report 'Bæredygtige Tangisoleringsmåtter fra ålegræs' it is estimated that the Danish eelgrass meadows can sequester 44,9 tons of CO_2 pr. ha. (Pallesen, 2018) With an estimate of 673 km^2 to 1345 km^2. (Boström, et al., 2014) of eelgrass in Denmark, that is equivalent to the Danish eelgrass storing between 3.021.770 to 6039.050 tons of CO_2.

However, in the report 'Capturing of organic carbon and nitrogen in eelgrass sediments of southern Scandinavia' another study investigating the capturing of organic carbon and nitrogen in eelgrass sediments of southern Scandinavia, estimates that the mean acceleration rate of Carbon sequestration in eelgrass is 22 g C m^2 yr^{-1} and thereby indicates that with the state of the current eelgrass meadows of Denmark, eelgrass would only be able to capture approximately 0,7 percent of the of annual CO_2 emissions by Denmark. Necessitating the restoration of eelgrass meadows to the size of former time, in order to have impact on the reduction of Carbon in the atmosphere. (Leiva-Dueñas, et al., 2023)



Illu. 9. Map of oxygen depletion in Danish waters.

OXYGEN DEPLETION

Recently the oxygen depletion of the Danish waters has been a topic for public discussion.

Oxygen depletion is defined as the oxygen concentration of the water being below 4 mg/L. If the oxygen level reaches below 2 mg/L, it is defined as severe oxygen depletion. At a moderate oxygen depletion, the marine creatures will search for other habitats, whereas at severe oxygen depletion the plants and benthic animals suffer or might even die.

The oxygen depletion is caused by a vary of factors, but the main one at the moment being eutrophication. Especially the agricultural industry is made a scapegoat of recently.

The oxygen depletion occurs when nutrients from agriculture, household and industry is washed into the waters by the rain. The increased amounts of nutrients in the waters, result in an increased amount of plankton. The plankton blocks the sunlight, hindering photosynthesis for the plants in the seabed, as well as the dead plankton consumes oxygen when it sinks to the seabed and is decomposed by microorganisms. (Miljøstyrelsen, 2023)

Another factor affecting the oxygen depletion is the microclimatic conditions. Calm and warm weather in the late summer and early fall, result in high levels of oxygen depletion, whereas cold and stormy weather slow down the oxygen depletion. (Miljøstyrelsen, 2022)

Studies show that the oxygen depletion has been quite staple for the last decade, with higher deviations in the year 2016, 2020 (Miljøstyrelsen, 2023) and 2022. In 2022 the oxygen depletion was nearly double the size of the depletion in 2021, but 20 percent less than in 2020 (Miljøstyrelsen, 2022) and not nearly as severe as in 2002 which is a record year regarding area prevalence of oxygen depletion. (Miljøstyrelsen, 2023)

The oxygen depletion typically occurs in the season from July till November and is most comprehensive in September. Eventhough the oxygen depletion levels aren't as comprehensive as seen in the past, the duration of the season of oxygen depletion has increased.

Making it more of a hazard for the marine environment, since the longer the duration of the oxygen depletion is, the more damage it does to the life in the seabed. (Miljøstyrelsen, 2023)

The area prevalence of oxygen depletion in 2022 reached 2.800 km^2 in August. The studies present that some areas are more affected than others. Especially the southern part of Lillebælt, the fjords of eastern and southern Jutland, the Limfjord and the archipelago of southern Funen is heavily taunted by oxygen depletion. (Miljøstyrelsen, 2023)

Eelgrass has a positive effect on the marine environment, since it sequesters Carbon and emits Oxygen, which the marine environment is in need of, by photosynthesis. Additionally, eelgrass also sequesters Nitrogen which is one of the main emissions of the eutrophication. Both abilities help improving the marine environment and decrease the oxygen depletion. In fact, studies show that the current population of eelgrass in Denmark, could sequester approximately 0,005 Tg of nitrogen annually, which corresponds to 6,9 percent of the total terrestrial nitrogen load by Denmark in 2019. (Leiva-Dueñas, et al., 2023)

Occurence

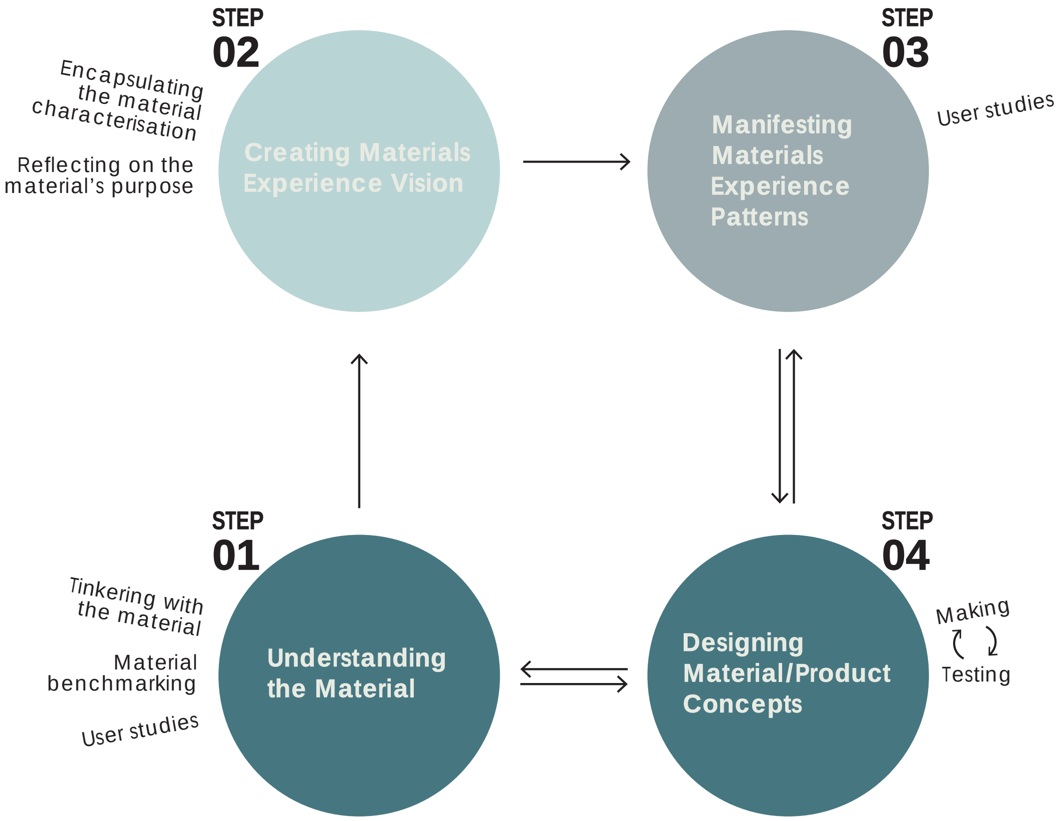
Seagrass meadows can be found along the coast of most continents and the Danish waters are a hotspot for eelgrass in Scandinavia (Leiva-Dueñas, et al., 2023).
The report 'Distribution, structure and function of Nordic eelgrass ecosystems' shows that eelgrass occurs in most of Denmark, except for the Western coast, and is heavily represented in Mariager Fjord, Isefjorden, at the Funen archipelago and around Als. (Boström, et al., 2014) However, the eelgrass today is mainly harvested along the shores of Møn, Bogø and Tærø (Pallesen, 2018). Implying that there would be more possible gathering places.
The depth limits of eelgrass in the Danish waters have drastically decreased since the 1900. In the period from 1880 till 1930 the average depth limit along open coasts was 7 meters, whereas in the period from 1989 till 2010 the average depth limit was only between 4,3 meters to 5,4 meters. With the decrease in depth limit follows a decline in the area distribution of eelgrass. (Boström, et al., 2014)
In 1900 the Danish national eelgrass area was estimated to be approximately 6726 km^2. However, the occurrence has heavily declined over the last century. The distribution of eelgrass took a drastic decline in the 1930's due to a wasting disease.
It is estimated that the present Danish eelgrass area amount to only 10 to 20 percent of the eelgrass area of 1900. Which equals to an approximate area between 673 km^2 and 1345 km^2. (Boström, et al., 2014)
The decline in eelgrass is expected to continue and might even accelerate (Röhr, et al., 2018). Emphasising the need to take action for preserving the important marine ecosystems.
This explains the decline in eelgrass harvesting as well. In an interview with Kurt Schierup, the owner of Møn Tang (Appendix 01), he tells stories of how they in 1914 gathered eight million tons of eelgrass in Denmark, as compared to the 90 tons per gathering place in average nowadays. The maximum of gathered eelgrass for one year in recent years is 150 tons dry eelgrass from one farmer. Together with the practise being forgotten, Kurt presents the acquiring of enough eelgrass as being the biggest challenge of the revival of the eelgrass utilisation.
This is also why he is involved in inviting and teaching more people the trade, in order to distribute the profession and being able to gather more of the Danish eelgrass which wash up along the shores.

RESTORATION

With the expected continuous decline in the occurrence of eelgrass and the evidently great importance for the marine environment and ecosystems, it is necessary to promote and continuously practice the restoration of eelgrass meadows.
Many attempts have been made in order to restore the eelgrass meadows. A Danish experiment performed by scientists of Syd Dansk University (SDU), investigated the effectiveness of planting eelgrass shoots in Horsens Fjord. For the experiment 14.400 shoots were planted in a field measuring 51x78 meters. The eelgrass was for this experiment planted as shoots, since other experiments have attempted to sow eelgrass seeds instead. In these experiments up to 99,9 percent of the seeds were lost.
The experiment had much greater success than anticipated by the researchers. In two years, the plant density was 70 times greater than at the beginning of the experiment, the 14.400 shoots had turned into more than one million shoots. (Svennevig, 2022)
However, another study, presented in the report 'Blue Carbon Storage Capacity of Temperate Eelgrass (Zostera marina) Meadows' shows that the global success rate for restoring seagrass meadows is only 37% (Röhr, et al., 2018).

Sub conclusion

Eelgrass is a sustainable resource, as it sequesters and stores CO_2 and additionally it is often viewed as a waste material and thereby an unused resource.
The potential of eelgrass salvage is much greater than what is collected today, and by spreading the interest and advantages of eelgrass salvage the collected amount of eelgrass could increase.
As it has great importance to the marine environment it is important to preserve and restore the eelgrass meadows. Additionally, it is important to raise awareness of the conditions and importance of the eelgrass meadows for both the climate and the marine environment.



Illu. 10. Figure of Material Driven Design process. Reproduction, based on (Karana, et al., 2015).

METHODOLOGY

Design Process

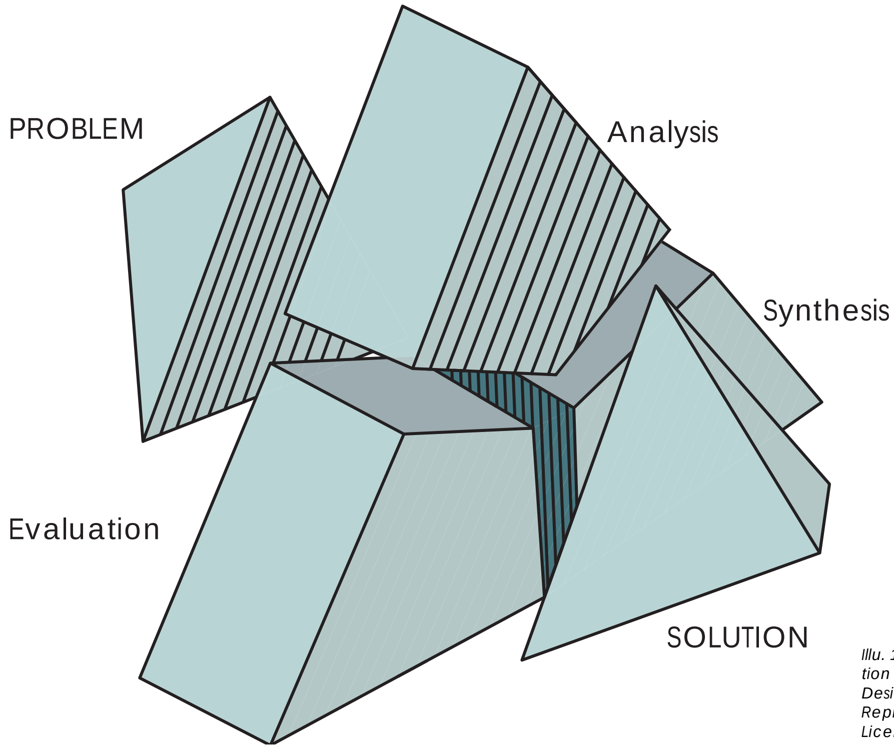
This project will be formed by an iterative process. In order to end up with a well thought design proposal, the design needs to undergo a number of iterations, improving the design and removing mistakes.

MATERIAL DRIVEN DESIGN

This thesis will be conducted on the basis of two design methodologies. Since, the project is material driven, it will depart from the Material Driven Design (MDD) methodology, drawn up by Elvin Karana, Bahareh Barati, Valentina Rognoli, and Anouk Zeeuw van der Laan. The Material Driven Design method is a method developed for designing material experiences.
The method seeks to establish both a technical and experimental approach to material design. As the method is developed for product and material design rather than architectural design, the thesis doesn't slavishly follow the method, but rather draws inspiration from the methods used to design with a material as a driver.
The Material Driven Design method consists of four steps; First is Understanding the material. In the first step the designer acquires knowledge of the material, both technically and experientially to gain a wholesome understanding of the material. The knowledge of the material is acquired through tinkering with the material, to explore the properties of the material; material benchmarking, to compare the material to alternative materials; and user studies, to understand how people perceive the material.

The first two are classified as Technical characterisation of the material where as the user studies provides Experiential characterisation of the material. (Karana, et al., 2015) The Technical characterisation of this project is primarily acquired through literature studies and little tinkering with material. The Experimental characterisation of the material has been acquired by interviewing experts with first hand experiences of the material.

The second step is named Creating Materials Experience Vision and is highlighted as the ultimate aim of the design process. In the second step the findings of the first step are summarised and evaluated to lay ground for a vision of the material experience. Besides from reflecting on findings in the previous step, the second step should also investigate the societal values of the material, its history and its current status.



Illu. 11. Figure of the Problem/Solution space. Illustration from 'How Designer Think' by Bryan Lawson. Reproduced with permission of The Licensor through PLSclear.

The creation of Material Experience Vision among others seeks to answer the following questions:

• What are its unique technical/experiential qualities to be emphasized in the final application?
• In which context would the material make a positive difference?
• What would the materials unique contribution be?
• How would it be sensed and interpreted?
• What would be the material's role in a broader context?
(Karana, et al., 2015, p.43)

The third step of the Material Driven Design method is Manifesting Material Experience patterns. Meaning that the third step investigates how users experience and interact with the material. Additionally, the third step is used for investigating what the users associate with the envisioned experience of the material. (Karana, et al., 2015)
In this thesis the Experience patterns have been investigated observing users' interaction with similar materials and designs and based on own material experiences.

The last step is Creating Material/Product Concepts. This is the step where the learnings from the previous steps are synthesized into a design concept for the material experience. The concepts created based on the preceding knowledge are tested and evaluated. (Karana, et al., 2015)

PROBLEM/SOLUTION SPACE
Reaching the Design Material/Product Concepts step the design process will be carried out according to the description of the Problem-Solution space by Bryan Lawson. In the Problem-Solution space some of the typical phases of the design process, such as analysis, synthesis and evaluation, occur. However, in Bryan Lawsons perspective the phases cannot be seen as individual phases on a linear timeline, as he believes that the phases of the design process are often intertwined and occur simultaneously.
Lawson believes that in a design process the problem and the solution often emerges simultaneously and that it is sometimes necessary to determine the solution before the problem is fully understood. Lawson describes the design process as a back-and-forth negotiation between problem and solution. In the negotiation process both analysis, synthesis and evaluation take place. The illustration is not to be understood as too literal, as the real process of design is too complex to illustrate, but rather seeks to illustrate that there are no predetermined movement between the phases and that the process can move back and forth between the phases as much as necessary to reach the solution. (Lawson, 2005)

As the design process is a complex task making use of a vary of analysis-, synthesis- and evaluation tools, the following tables seek to map out the tools used in the different phases, in order to provide a greater understanding of the process.

Chart of tools

Phase	Tool	What?	How?	Why?
Analysis	Literature studies	A study of relevant literature.	Finding and reading relevant literature on a topic and comparing multiple sources on one topic.	To gain understanding of a topic and to establish a discussion or verify information.
	Case studies	Analysis of existing design or structure.	By desktop analysis of relevant design exploring plans, constructions, materials, and experiences.	To gain knowledge from existing designs on design strategies that work and those that don't.
	Interviews	An interview with a loose structure.	Visiting or calling experts and asking pre-formulated questions in a loose interview form. Noting points, numbers and quotes from the interview. Supplementing with pictures from the visit.	To gain qualitative expert information and different perspectives on the topic.
	Registration	Registration of existing use of eelgrass.	Searching the internet, conventions and exhibitions, for existing use of eelgrass. Noting properties and techniques applied.	To gain knowledge of the resource as a material. Collecting existing knowledge on its qualities. Learn from others' experiences.
	Physical samples	Physical samples of constructions and products.	Acquiring or producing physical samples of products and materials.	To gain understanding of the product or material at hand and making decisions based on the experience of the sample.
Synthesis	Design Criteria	A list of criteria for the design.	Listing criteria for the design based on analysis, studies, and theory.	To stick out a direction for the project and to make informed decision based on required knowledge.
	Hand sketching	Drawing by hand on paper.	Sketching ideas on paper by hand with pencil, pen or marker. Sometimes sketching on top of existing pictures to create new appearance quickly.	To quickly transform ideas into concrete visible proposals.

Phase	Tool	What?	How?	Why?
Synthesis	Plan drawing	A drawing in 2D of the building or a space.	Drawing in 2D by hand or in AutoCAD	To test layouts and dimensions of design proposals and getting an understanding of necessary room for functions.
	Sections	A two-dimensional section drawing	Drawing in 2D by hand or in AutoCAD.	To test ideas of heights, widths and relation of spaces.
	Physical modelling	A physical model of the building design, volumes, or details.	Building models of relevant scale.	To test ideas, appearances constructions and similar.
	Digital 3D modelling	A three-dimensional digital model	Modelling the building design or details of the design.	To evaluate the appearance, volumes, light and construction.
Evaluation	Benchmarking	A comparison of similar products.	Comparing values such as properties, GWP, cost and appearance for different products	To determine if the product of interest has potential to compete with the existing products
	LCA	An assessment of the building's or building part's emissions during its lifetime.	Investigating EPDs of products. Modelling the building in LCA Byg based on quantities and EPDs	To have a value allowing for comparison with other materials, building parts or buildings.
	Be18	A calculationof the energy consumptionof a building.	Modelling the building in the calculation software Be18.	To evaluate the energy consumption of a building and to gain knowledge of where improvements could be applied.
	Ubakus	Calculations of performance of a building construction	Modelling the layers of the construction in the online software.	To investigate thermal properties, condensation and GWPs, to use for comparison of constructions or improvements of a construction.
	Daylight simulation	A simulation of the daylight in the building	Modelling the building in Rhino and using the Grasshopper plugin to simulate.	To gain knowledge of the effect of the window design and be able to change them based on quantitative data.
	Natural ventilation calculation	A calculation of the natural ventilation of a design proposal.	Determining the necessary air flow and dimensioning openings by calculations in an Excel sheet.	To evaluate if the design provides the necessary natural ventilation and to redesign if it doesn't.

Interviews

As eelgrass is a quite unexplored material compared to many conventional building materials, finding literature on some topics has been challenging and interviews with persons with first hand knowledge and experience has therefore been performed to establish a wider knowledge base.

The interviews have been conducted both in physical meeting, by phone and in writing. However, all interviews have had a loose interview form. For the interviews questions were prepared in advance. The questions were prepared to ensure that all intended topics were discussed, but as the interviews were loose, the interviewed was invited to answer freely and to get of topic. At some points in the interview the conversation was brought back on track by returning to some of the predetermined questions.

The interviews can be found appendixes. Note that all interviews were performed in Danish, but have been translated when used in the report.

Benchmarking

In the report three benchmarks have been performed in order to compare several eelgrass products to similar products. Benchmarking is a strategic process, typically used by organisations, to compare their product to industry standards or similar products from leading companies.

In this report the products of the benchmarks are divided into three categories, Exterior material, Insulation material and Interior product. In all categories two eelgrass solutions are presented in the benchmark. The eelgrass products are then compared to products with similar function, but one other biobased solution and one mineral solution. The products are compared on parameters such as their Global Warming Potential, expected lifespan, thermal conductivity, fire classification, cost and appearance.

Ubakus

Ubakus is an online calculation and visualisation platform, used throughout the project to quickly evaluate performances of building constructions. It is used both to determine the performance of existing constructions in the Renovation section, but also for evaluating new constructions and determine necessary change. With Ubakus it is possible to determine the thermal transmittance, thickness and weight, heat storing capacity and resistance to moisture diffusion of a construction. The tool determines heat loss, condensation in the construction and an estimated greenhouse gas potential. The calculations are based on the properties of predefined materials in the platform's library. It is additionally possible to create your own materials, which has been the case for all eelgrass materials, as the few seagrass materials in the library didn't match the properties of the utilised eelgrass materials.

Be18

Be18 is a calculation software, which determines the energy use of a building. Be18 is used for documenting that the building fulfils the requirements of the Danish Building Regulations. For the software to

perform the calculation, it must be informed of the construction properties and the properties of operation of the building. The construction properties are values such as floor area, wall and roof area, and the u-values of these. Also, the amount, size and orientation of the windows should be implemented. For the properties of operation, aspects such as use time, heating source and occupants should be applied.
Be18 has been used in the project for evaluating the energy use of the building dependent on the variation of constructions. Thereby it has been possible to determine whether the tested constructions are satisfactory together.

Life Cycle Assessment – LCA

Is an assessment of emissions during the lifetime of a building or a building part.
The lifetime of the building is divided into five different stages, Product, Construction, Use, End-of-life and Beyond the system boundary. The product stage assesses the emissions from the extraction of the raw material, the transport and the manufacturing. The Construction process includes emissions from transport to the site and the installation process. The Use stage covers all of the emissions from the buildings functioning lifetime, such as operation, maintenance and repair or replacement. The End-of-life stage includes demolition, transport to waste handling facilities, waste processing and disposal. The last stage, Beyond the system boundary, indicates the potential emission savings of reusing, recycling or incinerating the material.

The LCA provides results for the emissions of many different substances, however in this thesis, the focus will be on the values of the Global Warming Potential.

GLOBAL WARMING POTENTIAL - GWP

The Global Warming Potential is the emissions from the building, building part or building product given in kg CO_2 equivalents.

ENVIRONMENTAL PRODUCT DECLARATION - EPD

An EPD is a declaration of a products emissions during its lifetime. The EPD is divided into the same stages as the LCA and GWP. Most often, only the stages Product, End-of-life and Beyond the system boundary are included in the EPDs

LCA BYG

LCA Byg is a software for performing LCA calculations. In the software the constructions are added to the building model. Based on the building model, the software determines the LCA of the building.
The software contains generic data for some constructions and building products. Additionally, it is possible to create constructions and building products if they should be based on a specific EPD.
LCA Byg has mainly been used for evaluating the GWP of the building design and the separate constructions. Additionally, it has been used to compare the energy consumption for operation of the building to the embodied energy of the building.

Illu. 12. Photography of fresh eelgrass close up. Photography by Anne-Mette Rosenkilde.

01

MATERIAL

The material section explores eelgrass as a building material, by investigating the historic and contemporary use of eelgrass. The value of eelgrass is in this section evaluated by comparing eelgrass products to similar building products and investigating possible applications while fulfilling the requirements of the Danish Building Regulations.

Illu. 13. Photography of eelgrass thatched house on Læsø. Photography provided by Læsø Museum.

HISTORIC USE OF EELGRASS IN BUILDINGS

~1200

Læsø Tanghuse

[LÆSØ SEAGRASS HOUSES]

In Denmark the use of eelgrass as a building material is a part of the building heritage, in the form of the eelgrass thatched houses of Læsø.
The oldest roofs still functioning in the present is assumed to be approximately 300 years old and the practice of thatching with eelgrass is believed to have been existing since the 1200 and is most commonly associated with the 1600. (Holm, 2008) (Kibsgaard, et al., 2012)
In Læsø they built with seagrass since it was one of the only available materials at the secluded island. All wood was utilized for the open-pan salt making, so the only construction materials available at the island was timber from the shipwrecks that washed up at shore. (Kibsgaard, et al., 2012)
This made roofs thatched with seagrass the most prominent on the island.

DECREASE

Once there were approximately 300 eelgrass thatched houses on the island, but the building technique have faced a serious decrease in the past centuries (Kibsgaard, et al., 2012). From 1974 till 1986 the number of buildings with thatched seagrass roof, decreased from 90 to 57 buildings (Holm, 2008). Today there is only 33 seagrass houses left at Læsø (Læsø Museum, 2020).
The decrease is partly due to difficulties of keeping the roofs watertight, but also due to the lack of knowledge and skill for thatching the roofs with the special technique. But mostly the decrease in number of eelgrass thatched roofs is due to the challenge of acquiring enough eelgrass of the right quality.
The occurrence of eelgrass in the surrounding waters of Læsø is quite well, however the quality of the eelgrass makes it unsuitable for thatching roofs, since the tensile strength is too low, and the fibers are too short.
Furthermore, several attempts have proven that it is very difficult, closer to impossible, to repair an defective roof. In most cases the only solution is to tear down all of the roof and start over. In some cases, even the roof construction needs to be replaced in order to carry the heavy load of the thatched roof. But if the roof construction and the 'vaskervold' is intact it is possible to repair the roofs by darning new eelgrass into the existing roof, using a special tool. (Holm, 2008)

PRESERVATION

However, in recent years there has been a strong focus on restoring the seagrass houses of Læsø. A two-figured million amount has been sponsored to the project of restoring the houses. So far, this has ensured the restoration of 24 seagrass houses out of the 33 remaining on the island. (Læsø Museum, 2020)

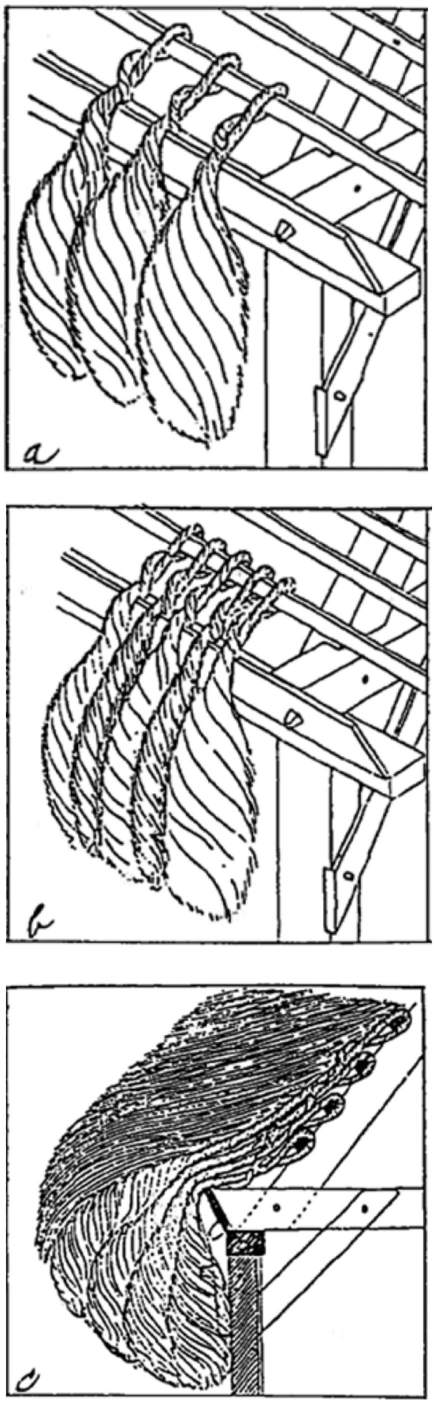
In the attempt of preserving the seagrass houses of Læsø, Læsø Tang-bank [Læsø Seagrass-bank] was founded. The purpose of the seagrass-bank is to ensure the possibility of restoration of the seagrass thatched roofs. The bank imports high quality eelgrass from Bogø and Møn and stores it on the island for forthcoming projects. The aim of the seagrass bank is to always have enough eelgrass stored to renovate two roofs. This equals to an amount of 100 tons of eelgrass in store. (Læsø Museum, 2022)

CONSTRUCTION

Seagrass has been utilized as a roof material in other locations, but the technique of the Læsø roofs is unique. The seagrass houses of Læsø is thatched in a special manner originating from the island. The houses are thatched by wringing long wisps of eelgrass into what is called ‘vaskere’. The vaskere was hung around the lowest lath of the roof and the gaps in between were filled with ‘gumlinger’, which is a smaller version of vaskere. This process was continued on the lowest three to four laths and created what is called a ‘vaskervold’. The purpose of the vaskervold is to keep the rest of the eelgrass of the roof from sliding down, since this is simply placed on the roof, traditionally on a layer of rye straw or birch twitches, without any fastening. (Holm, 2008) (Kibsgaard, et al., 2012)

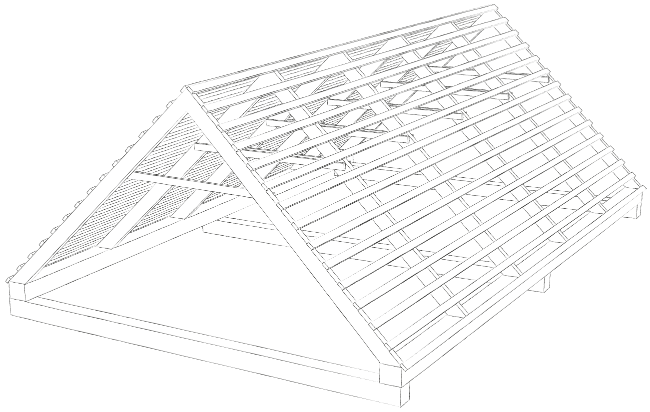
The origin of this special technique is credited to the women of the island, since Læsø was dominated by women and the technique resembles the technique of spinning (Holm, 2008). Due to the special technique more of the houses of Læsø are protected by conservation laws (Holm, 2008).

The dense layer of eelgrass on the roof becomes naturally watertight over time, due to the natural decomposition of the natural material. When the eelgrass is decomposed by warm temperatures and moist, the carbon of the material turns into CO_2, which is released to the atmosphere. The decomposition leaves the eelgrass as a compressed organic ash which makes the eelgrass roof watertight. (Kauschen, 2015)



Illu. 15. Drawing of construction of a ‘vaskervold’. Illustration by architect Hans Henrik Engqvist 1944 (Brought in ‘Nationalmuseets arbejdsmark 1944’).

Illu. 14. Drawing of women making ‘vaskere’. Drawing by Bjarne Stoklund, Skalk 1960:3.



Illu. 17. Drawing of the roof construction of the original Læsø eelgrass houses.

The typical house of Læsø is five to six meters wide and the inclination of the roof is typically 45 degrees.
Based on a newly thatched seagrass roof it is estimated that one square meter of the roof weighs approximately 160 kg. (Læsø Museum, 2022) Thereby, a roof of standard size thatched with eelgrass can easily weigh up to 35 tons (Læsø Museum, 2022).
One vasker in itself weighs between 7 kg and 12 kg and one meter of vaskervold consists of roughly 15 vaskere. The weight varies across the roof since there is a thicker layer of eelgrass in the gable and at the valley, approximately 1,7 meters and a thinner layer over the ridge, 1,4 meters. (Læsø Museum, 2022)
As mentioned, the houses of Læsø were often constructed of timber from shipwrecks. On the photographies in illustration 16, the roof construction of the eelgrass thatched houses can be seen. The roof construction appears to consist of a variation of collar beam trusses. On the exterior side of the trusses, the laths for carrying the eelgrass can be seen.

Illu. 16. Photographies of roof construction of original Læsø eelgrass houses. Photographies provided by Læsø Museum.

Illu. 18. Collage of illustrations of Cabot's quilt from the brochure 'Build Warm Houses with Cabot's Quilt' from 1928.

Illu. 19. Photography of Kalvehave Tangexport from approximately 1950. Photography provided by Langebæk Lokalhistorisk Arkiv.

1891
Insulation Material

CABOT'S QUILT

Eelgrass is known to have been used as an insulation material for centuries. Especially in the coastal locations of New England, the buildings were insulated with eelgrass. One of the earliest being the Pierce House from 1683.

In 1891 an actual insulation product using eelgrass was patented in USA. (Archipedia New England, 2020) The product was called Cabot's quilt and was invented by Samuel Cabot. Cabot's Quilt was a mat with an insulating layer of Zostera marina stitched between sheets of strong craft paper. The mats were produced in various thicknesses and were said to be applicable in both new build and as an application in buildings already constructed. A brochure advertising Cabots Quilt from 1928 states that installation of the insulation quilt lowers the heat loss and sound proofs the building. The brochure presents test results of the quilts from Massachusetts Institute of Technology, which shows that on average the heat loss is reduced by 27 percent when installing Cabots Quilt. Additionally, the brochure claims that the eelgrass insulation keeps the building cool in summer. (Samuel Cabot Incorporated, 1928)

In 1942 Cabot Company abandoned the production of Cabots quilt due to lack of resources caused by the wasting disease in 1930 and the outbreak of World War II. (Archipedia New England, 2020)

1918
Insulation and Mattress fill

KALHAVE TANGEXPORT

Today the main export of eelgrass in Denmark comes from the Danish island Møn. Møn has rich history for making money on eelgrass. In 1918, Kalvehave Tang Export was established. The company collected eelgrass when it washed up at shore and prepared it for sale. At its peak the company exported eelgrass to Norway, Sweden, Belgium, Holland, England, and Germany. The eelgrass was used as insulation as they found that it didn't decompose, and it wasn't infested by vermin. The eelgrass was sown into large matts, which could then be installed in buildings. Additionally, the eelgrass was used as stuffing for mattresses, for the same reasons. (Langebæk Lokalhistoriske Arkiv, 2024)

Illu. 20. Photography of Søuld acoustic mats. Photography provided by Søuld.

Illu. 21. Photography of Notech ventilation solution by Windowmaster. Photography by Anne-Mette Rosenkilde.

2010
Acoustic Insulation Material

SØULD
Søuld is a Danish company who produces mats for acoustic insulation out of eelgrass. The company was founded in 2010 with the aim of producing functional, sustainable, and beautiful alternatives to traditional building materials.
The acoustic mats are produced by shredding the fibers of the sorted eelgrass into shorter standardized fibers. The fibers are then impregnated with a flame retardant and mixed with a binder before it is made into batts with air laid technology. Lastly the batts are compressed into mats and cut to standard sizes. (Søuld, n.d.)
Søuld was formerly known as Læsø Zostera who produced insulation batts of eelgrass, but in 2020 the company changed name and focus (Lasso X, 2020).

According to Kirsten Lynge, co-founder of Søuld, the company abandoned the production of eelgrass insulation batts as the expenses of gathering eelgrass and producing in small scale were too great. This made them unable to compete with other products on the market.

2020
Ventilation

NOTECH
Notech is a solution for improving natural ventilation. It is a panel to be installed in the façade, lined with an eelgrass filter in between an interior lamella panel and the exterior façade cladding. The solution started as part of a research project and was done in 2020. Currently the panel is being further tested by Realdania at Teknologisk Institut [Institute of Technology].
The panel allows for natural ventilation while decreasing some of the known downsides of natural ventilation. Among others the eelgrass filters the air passing through, removing larger particles, cooling the air, and absorbing moist and smell. Furthermore, the large surface of the eelgrass filter works as a noise reduction for the outdoor noise pollution. A sound measurement of the effect of a panel implemented in Feldballe Skole, showed that the panel reduced the outdoor noise with 57 percent.
Lastly, the panel allows for natural ventilation without leaving any openings in the facade, providing a greater sense of safety. (Roth & Volf, 2024)

Process

SOURCING
The eelgrass is gathered when the broken of stems naturally washes up at shore. When it is storming, more eelgrass wash up and for that reason there will in some seasons be more eelgrass than others (Appendix 01). The eelgrass needs to be gathered as soon as it washes up, to prevent it from being mixed with other plants, insects and sand, in order to get as clean a product as possible. For the same reason, the shores from which the eelgrass is collected, needs to be kept clean from other washed-up materials.
The eelgrass is gathered by using a hay turner, picked up by a beach cleaner and transported to a nearby grass field, where it is scattered and left to dry naturally.
When the eelgrass is scattered at the field it should be washed through by at least 5 mm of rainwater to remove excess sand and salt. When the eelgrass is washed through and dried out to a water percentage of 15 to 20 percent, it is gathered and pressed into round bales.
The drying process in itself doesn't require any energy, but the eelgrass needs to be turned during the drying process. Therefore, the part of producing the eelgrass having the greatest emission, is gathering, turning and packing the eelgrass using farming equipment. (Pallesen, 2018)

SORTING
The dry eelgrass is sorted, to remove the last alien plant material and to separate the different qualities of eelgrass. The length of the eelgrass fibre determines what it is best used for. The shortest fibres are used as fertilizer for gardens, the longer fibres are used for stuffing for pillows and similar products and the longest fibres are used for insulation. (Appendix 01)

Illu. 22. Photographies of eelgrass being harvested and pressed into bales. Photographies provided by Møn Tang.

Illu. 23. Drawing of eelgrass process, from sea to storage.

Illu. 24. Photographies of eelgrass variations. From the top: eelgrass loose fill long fibres, eelgrass loose fill fine fibres, eelgrass granulate, eelgrass pellets. Photographies by Anne-Mette Rosenkilde

EELGRASS AS A BUILDINGMATERIAL

Raw Materials

LOOSE FILL

When sorted, the eelgrass can be used directly as loose fill insulation, for both wall cavities, flooring structures and ceilings. When used as insulation a density of 55 kg/m^3 is aimed for. The cost of the eelgrass is 9 kr per kg, adding up to 495 kr/m^3, as the eelgrass is paid by weight. (Appendix 01) The natural eelgrass has a thermal conductivity of 0,043-0,045 W/mK when dry (Seegrashandel, 2018), which is quite high compared to contemporary insulation materials. The loose fill eelgrass is installed manually by hand and is mostly used as insulation for renovations as it allegedly eliminates the need for installation of a vapor barrier in the old constructions. (Appendix 01) Eelgrass has high sorption dynamics (Frandsen, et al., 2020) which is why the use of eelgrass in renovations can in some cases eliminate the need for a vapour barrier.
As eelgrass is a plant which stores CO_2 before it washes up at the shore, and it is a natural product with no processing, besides from being gathered, the GWP of loose fill eelgrass is one of its great advantages. In an LCA report for the Modern Seagrass House, the GWP of eelgrass is determined to be -0,349 kg CO_2-eq/m^2 year. The GWP of loose fill eelgrass is determined in the LCA report from 2013, as there was no data on this prior to the report. (Kauschen, 2015)

GRANULATE INSULATION

It is possible to turn eelgrass into a granulate which can be used as insulation of cavities by blowing it in, as known from for example cellulose fibres. The eelgrass can thereby also be utilised as insulation in renovation cases. However, experiments with the granulate insulation have proven that insulating with the eelgrass granulate became heavy and thereby more expensive than loose fill, as the eelgrass material is paid per kilogram. (Appendix 01)

BIO-PLASTIC

At Møn Tang they were additionally experiencing with converting the eelgrass into pellets for making bioplastic. Before making the pellets, the eelgrass was shredded into a granulate. The pellets were made on a regular wood pellet press, however the process was heavy on the equipment and at Møn Tang they didn't plan on continuing the production, since there are larger companies specialized in making pellets. (Appendix 01)

Advantages of Removing Eelgrass

MARINE CONDITIONS

Removing the eelgrass from the shores, helps improving the conditions for the eelgrass in the waters. If the eelgrass is left at the shores, nutrients from the eelgrass will wash into the ocean, changing the nutrient balance and risking that other seaweeds with different needs oust the eelgrass. (Pallesen, 2018)

ECONOMY

Additionally, many plot owners and municipalities who have shores where the eelgrass wash up, are interested in the possibility of providing the eelgrass for gathering and utilization, since the removal of eelgrass to keep the beaches clean, is a great expense for the municipalities. For example, Odsherred Municipality spends 200 kr. pr. ton of eelgrass removed from their beaches, while in Køge Municipality up to 22.000 tons of eelgrass are removed from the beaches annually. (Pallesen, 2018)

Challenges

ECONOMY

To ensure a high quality of eelgrass, the shores on which it washes up needs to be kept clean from other washed-up materials at all times. Keeping the shores clean, is costly regarding time as well as money. This drives the cost of eelgrass up and creates a disadvantage compared to mineral wool and other insulation materials. Currently eelgrass insulation is approximately twice as expensive as hemp insulation. To lower the cost of eelgrass both supply and demand needs to increase simultaneously. (Pallesen, 2018)

RESOURCES

The biggest challenge of propagating the use of eelgrass as a building material is the lack of sourced eelgrass. Even though the eelgrass occurrence is in decline, the Danish shores are filled with a lot of unused eelgrass. Since the potential of eelgrass and the sourcing of it is much greater than what is utilized at present, existing farmers are attempting to scout more farmers for eelgrass gathering. (Appendix 01)

Sub Conclusion

Eelgrass has through history proven its functionality for different purposes in buildings. Today tests of the physical properties of eelgrass are there to support the claim of eelgrass being a functional material for use in buildings. The thermal conductivity of loose fill eelgrass isn't fully on height with that of current insulation materials. However, the low GWP and high sorption dynamics of eelgrass make up for some of the disadvantages. Additionally, the eelgrass is a renewable waste resource and removing it from the shores improves the marine conditions. Therefore the use of eelgrass for construction purposes only have positive effects. The greatest challenges of using eelgrass as a building material currently, is the high cost and lack of resources.

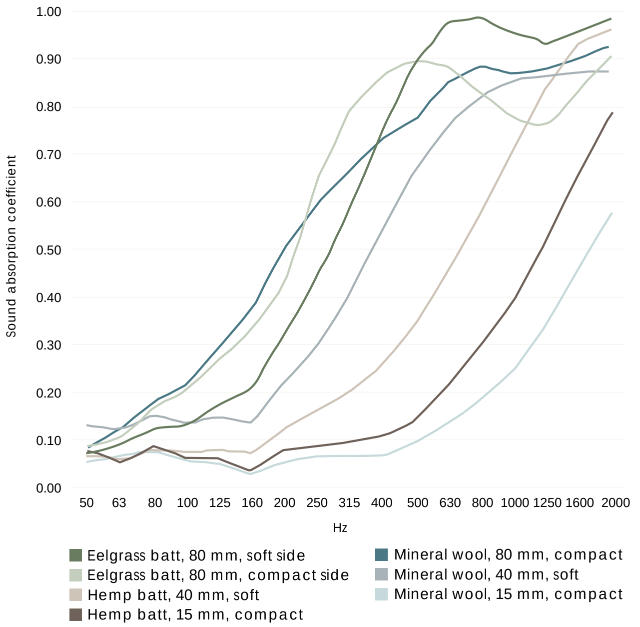
Eelgrass Insulation Batts

From 2015 till 2017 Miljø- og Fødevareministeriet [the Danish Ministry of Environment and Food], conducted an experiment, utilizing eelgrass for insulation batts. The experiment and results are presented in the report 'Bæredygtige Tangisoleringsmåtter fra ålegræs' [Sustainable seaweed insulation batts from eelgrass]. The report claims that the eelgrass insulation batts are as qualified as conservative materials, regarding thermal insulation, fire classification and adsorption of sound.
Used as insulation the insulation batts of eelgrass have a thermal conductivity of 0,037 W/mK, which means that it can reach same insulating value as mineral wool.

The insulation batts are produced with the CAFT-technology (Carding Airlaid Fusion Technology). The technology is a dry laid process where the fibres are air carted by rotating rollers with spikes. Beneath the fibres there is a suction securing the uniformity of the batts. Since the eelgrass fibres are long and stiff, the fibres are pre-processed and shredded. The batts are then passed into an oven where the binders melt and fixes the batts. The eelgrass batts consist of approximately 10 percent binders and the preferred fibres are thermoplastic polymers in the form of BICO-fibres, which consists of polyethylene/polypropylene. The addition of oil-based binders hinders the possibility of utilising the eelgrass as fertilizer after the End-of-life. Instead, the eelgrass batts can be reused for production of new eelgrass batts with less binders added. (Pallesen, 2018)

The natural salt content in the material results in the insulation being fire-retardant without the addition of fire impregnation and being able to reach a fire classification E without fire retardant additives. The addition of the binders, BICO fibres, decreases the fire-retardant abilities of the eelgrass batts and without the addition of these fibres it is assumed that the eelgrass could receive a higher fire classification. Additionally, the high salt content in the eelgrass prevents it from being infested by vermin. The porous material also works well as an acoustic dampener. Tests of the acoustic and noise reduction in the material shows that the eelgrass insulation performs slightly better than mineral wool and hemp insulation at the highest frequencies (See illustration 26). At the lower frequencies the sound absorption of the soft side of the eelgrass insulation batts resembles those of soft mineral wool. (Pallesen, 2018)

Illu. 25. Photography of eelgrass insulation batt. Photography by Anne-Mette Rosenkilde



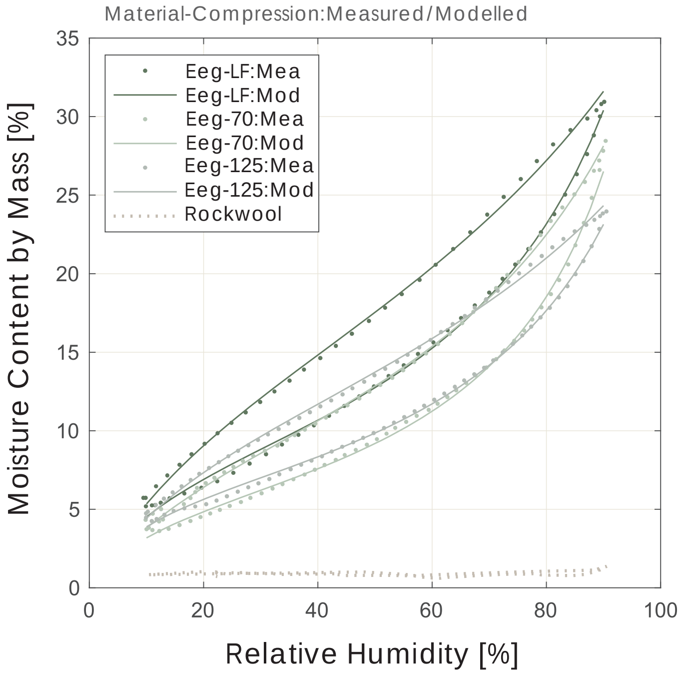
Illu. 26. Graph of sound absorption in insulation materials. Reproduced, based on graph from the report 'Bæredygtige Tangisoleringsmåtter fra ålegræs' by Pallesen et. al.

As mentioned in the description of loose fill eelgrass, eelgrass has great moisture buffering capabilities, which possibly can reduce the energy consumption and improve the indoor environment.
The report 'Water vapor sorption dynamics in different compressions of eelgrass insulation' carried out by the Department of the Built Environment at Aalborg University, investigates how the compression and addition of binders, which occur when the eelgrass is transformed into insulation batts, affects the water vapor sorption dynamics of eelgrass. The report finds that eelgrass, natural and compressed, in general performs better than mineral wool, regarding the sorption dynamics. Additionally, the report informs that the natural eelgrass fibres have higher sorption dynamics than the eelgrass batts, due to the compression and added binders. The lower sorption dynamics of the eelgrass batts was especially evident in the range of 70% RH and above. (Frandsen, et al., 2020)

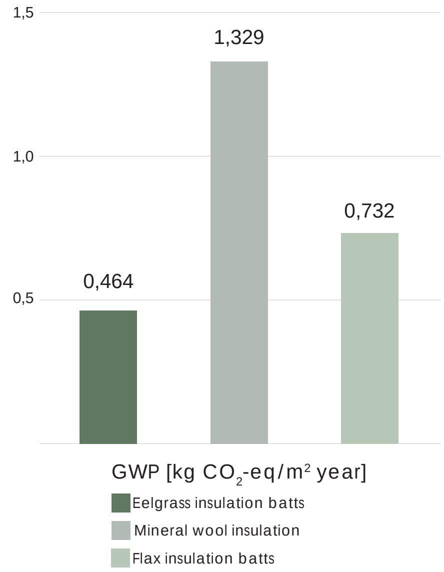
The report of the eelgrass insulation batts carried out a LCA analysis of the eelgrass insulation batts which determined that the global warming potential of the batts is 0,464 kg CO_2-eq. pr. kg final product. This is a low value compared to the 1,329 kg CO_2-eq. pr. kg final product for mineral wool and 0,732 kg CO_2-eq. pr. kg final product for flax batts, as stated in the report. (Pallesen, 2018)
However, the Global Warming Potential of the eelgrass batts is based only on the product stage and doesn't take into account the emissions at End-of-life stage. Additionally, the CO_2 stored in the material doesn't seem to be included in the determination of the GWP.
Lastly, the eelgrass insulation batts doesn't contain any harmful additives and is 100% recyclable and can thereby be part of a circular economy and have proven so by being the first Danish insulation product certified with the GOLD level in Cradle to Cradle. (Pallesen, 2018)

Sub Conclusion

In conclusion, the thermal- and acoustic properties of eelgrass batts are fully on height with the properties of conventional insulation materials. Additionally, according to the report 'Bæredygtige Tangisoleringsmåtter fra ålegræs' the GWP of the eelgrass batts is low compared to the other insulation materials presented. Being renewable and derived from excess material, utilizing eelgrass does more good than harm, especially considering its positive impact on coastal ecosystems. However, the eelgrass is an expensive material, and the current state of eelgrass meadows makes it difficult to upscale the production.



Illu. 27. Graph of sorption dynamics in different compressions of eelgrass. Reproduced, based on graph from the report ' Water vapor sorption dynamics in different compressions of eelgrass insulation' by Frandsen et. al.



Illu. 28. Graph of GWP values for insulation materials. Based on values from the report 'Bæredygtige Tangisoleringsmåtter fra ålegræs' by Pallesen et. al.

Illu. 29. Photography of The Modern Seagrass House on Læsø. Photography by Helene Høyer Mikkelsen.

DET MODERNE TANGHUS

[The Modern Seaweed House]

by Vandkunsten

A CASE STUDY OF LOOSEFILL EELGRASS IN A MODERN CONTEXT

Year: 2013
Function: Holiday house
Location: Østerby, Læsø, Denmark
Size: 90 m^2

The Modern Seagrass House is located on Læsø and designed by Vandkunsten. The building is a holiday house and was finished in 2013. The building is an attempt to revive the eelgrass material while interpreting it in a modern style and using modern and technical solutions. (Vandkunsten, n.d.)
The case study of the Modern Seagrass House investigates the possible use of loose fill eelgrass in a contemporary building, and how the different uses affect the material and the building.
Eelgrass is used in many parts of the construction of the Modern Seagrass House. For example, eelgrass is used as insulation in both floor, outer wall, and roof. It is used for cladding on both the façade and the roof. Furthermore, the eelgrass is used in the upholstered ceilings, inspired by the historical use of eelgrass as stuffing for pillows and mattresses. (Vandkunsten, n.d.)
The façade and roof are cladded with eelgrass in net sacks. The sacks are knitted of wool on a homemade large scale knitting mill by voluntary elder women (Appendix 01). The eelgrass net sacks don't provide enough protection from the elements, and roofing felt is therefore applied beneath the eelgrass. The eelgrass sacks do however protect the roofing felt and should be able to increase the lifespan of this. (Kauschen, 2015)
The roofs of the original seagrass thatched houses were watertight because of the massive amounts of eelgrass. However, at the Modern Seagrass House the eelgrass of the roof is used to protect the underlying layer of asphalt roofing and thereby the eelgrass isn't used for waterproofing. With this approach it was possible to thatch the roof with only a tenth of the material used on the original roofs. (Nielsen, et al., 2013) However, the massive density of the original eelgrass roofs, were also an important factor for the long durability of the roofs. Reducing the mass of the roof to ten percent of the original, simultaneously reduces the expected lifetime of the eelgrass roof. In fact, the expected lifetime for the light eelgrass roof on The Modern Seagrass House, is estimated to be between 10 to 25 years. (Kauschen, 2015)
For the eelgrass used as insulation, the lifetime expectancy are higher, as eelgrass, which is kept dry, doesn't decompose. The lifetime of the eelgrass insulation in The Modern Seagrass House, is therefore expected to be dependent on the lifetime of

Illu. 30. Photography of the knitted eelgrass stuffed sacks on the Modern Seagrass House. Photography by Helene Høyer Mikkelsen.

Illu. 31. Photography of the upholstered ceiling in The Modern Seagrass House on Læsø. Photography by Helene Høyer Mikkelsen.

the façade cladding, which has an expected lifetime of minimum 45 years. (Kauschen, 2015)

As The Modern Seagrass House to a high degree consists of eelgrass and timber, the biobased materials of the Modern Seagrass House allegedly store an amount of CO_2 equivalent to the CO_2 emission of ten years use of the house. (Vandkunsten, n.d.)
In the report 'Livscyklusvurdering af projektet "Det Moderne Tanghus på Læsø"' the LCA of the Modern Seagrass House has been determined. The report shows that the Global Warming Potential of the Modern Seagrass House has been determined to have a negative value of -2,00 kg CO_2-eq pr. m_2/year when only the materials are considered. However, when looking at the LCA scenario with the energy consumption for operation included and the energy supply being DK GridMix, the GWP reaches 26,13 kg CO_2-eq pr. m_2/year which is quite high. In this scenario the energy for operation constitutes to 92 percent of the GWP, while the last eight percent from the material use has a negative GWP. In the intermediate scenario, where operation is included, but the energy is supplied by wind power, the Modern Seagrass House has a GWP of -1,32 kg CO_2-eq pr. m_2/year. The hotspot analysis of the report identifies the roofing felt and the vapour barrier as two of the big negative influences on the LCA of the Modern Seagrass House. (Kauschen, 2015)

In the Modern Seagrass House, the use of prefabricated elements has been implemented to cut down cost, in order to save money for the special elements, such as the upholstered ceilings and energy reducing installation, which has a high cost. (Vandkunsten, n.d.)
The prefabricated elements consist of the wall elements, where wooden frames have been filled with eelgrass by hand before being transported to the building site. The frames have been filled with eelgrass with a density of 50 kg/m^3. (Kauschen, 2015)
With the more stringent process of prefabrication, it is possible to ensure the quality of the building elements (Vandkunsten, n.d.) as well as it makes the process more time efficient.
As a final remark it must be noted that the eelgrass on roof and facades were removed in 2016, due to a moisture-induced damage on the roof boarding. The damage wasn't related to the expirmentation with eelgrass. (Realdania, n.d.)

Sub Conclusion

In conclusion, the Modern Seagrass House showcases new and innovative use of eelgrass, while simultaneously drawing references to the historic use of eelgrass. The eelgrass proves to has a positive effect on the LCA of the building. Additionally, working with prefabricated building elements, decreases the time spend on construction and while increasing the quality.
However, the eelgrass net sacks on the façade doesn't appear to be optimal use of the material, as their lifespan is short, additional protection is needed and the building can function without it.

Illu. 32. Photography of EcoHousing. Photography by Katrine Becher Damkjær.

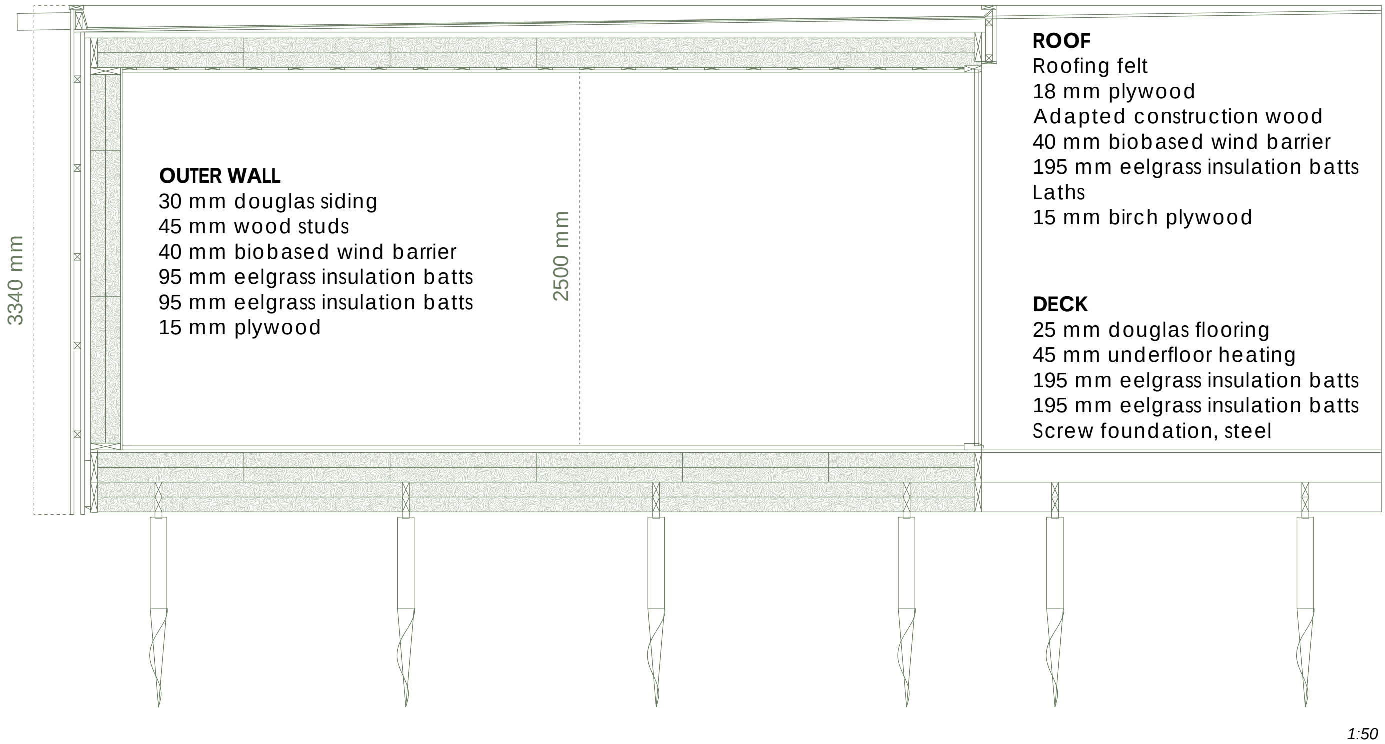
ECOHOUSING
by Carlo Volf

A case study of construction with eelgrass insulation batts

Year: 2021
Function: Holiday house
Location: Mols Bjerge, Djursland, Denmark
Size: 86 m²

EcoHousing is a holiday house designed by architect Carlo Volf. It is an experimental building, testing new materials and construction principles.
The holiday house is explored through a case study, to learn of the possible applications of eelgrass insulation batts and the effects of implementing the insulation batts in the building construction.

The holiday house is 86 square meters and located in Mols. EcoHousing is insulated with eelgrass insulation batts in floor, roof and outer wall and doesn't make use of a vapor barrier. (Agnes Garnow, 2023) The vapor barrier is deselected in attempt to provide a healthy indoor climate without the need for mechanical ventilation. (Agnes Garnow, 2023) Instead, the water vapor sorption abilities of eelgrass and graduating moisture diffusion resistance throughout the construction are utilized to control the moist of the construction and for ventilation, the Windowmaster natural ventilation panel is utilized. (Appendix 02)
Additionally, the eelgrass insulation batts were chosen to add thermal mass to the building, to prevent overheating in summer. As the density and specific thermal capacity of the eelgrass batts are twice as high as those of mineral wool. According to Carlo Volf, the architect and owner of the holiday house the strategy of using the properties of eelgrass to fight overheating works well and the temperature of the holiday house has allegedly never been more than 27 degrees Celsius. (Appendix 02) However, as the eelgrass is considered to be an insulation material, with a thermal conductivity lower than 0,1 W/mK, the material is not considered to contribute to the heat capacity of the building. The experienced, well-balanced temperatures must therefore be assumed to rely on a well-insulated building envelope and correct ventilation.
Carlo additionally explains how he clearly experience the difference of the indoor climate between a conventional construction with vapour barrier, and the indoor climate of EcoHousing. Actually, he says that the two conditions aren't even comparable. Carlo explains how the lack of vapour barrier and the use of the hydroscopic material allows the construction to help adjusting the



Illu. 33. Section of EcoHousing. Reproduced. Section provided by Carlo Volf.

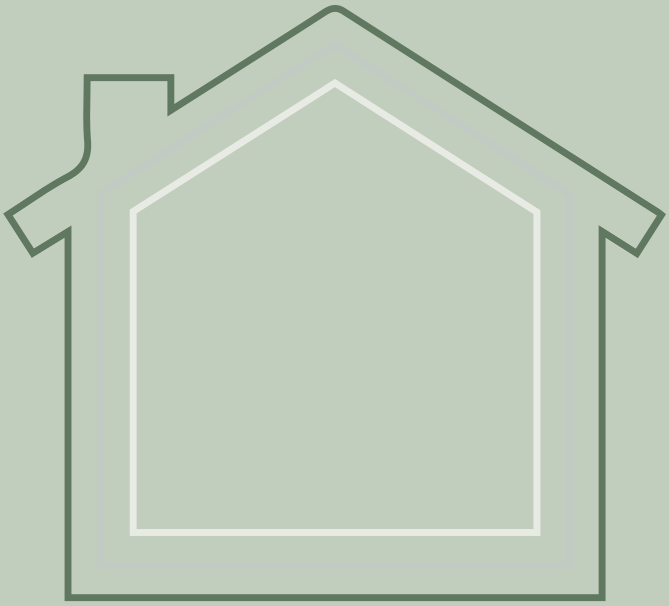
humidity. (Appendix 02)
The façade of the building is cladded with non-treated timber. (Agnes Garnow, 2023) The wooden façade is ventilated to protect the non-treated timber cladding from rot and fungus. (Appendix 02)
To minimize the footprint of the building and to avoid the use of concrete, the holiday house is placed on a screw foundation. EcoHousing has a flat roof, which is covered with asphalt roofing, one of the few non-biogenic choices of the design.
As mentioned EcoHousing is an experimental building and the building is part of the report 'Boligbyggeri fra 4 til 1 planet: 25 Best Practice Cases' [House building from 4 to 1 planet: 25 Best Practice Cases] by BUILD, Department of the Built Environment, Aalborg University. In the report LCAs of 25 different cases are showcased. The LCA calculations of the holiday house shows that the building has a Global Warming Potential of 4,17 kg CO_2-eq. pr. m_2/year, which is approximately a third of the allowable emission according to the LCA requirements of 2023. This shows that the use of biogenic materials and the minimizing of non-biogenic materials has a huge impact on the GWP of the building. The LCA results additionally present how the GWP in kg CO_2-eq of the biogenic materials is equivalent to approximately 1/6 of the actual mass of the materials. Whereas, for the foundation screws, the GWP in kg CO_2-eq is higher than the mass of the material. Additionally, the report shows that the roof construction with the asphalt roofing is the most influential of all building parts. (Agnes Garnow, 2023)
For the 86 square meters of building 2641 kg of eelgrass insulation have been utilized. (Boding, 2022) Approximately, 30 kg per square meter of the floor area doesn't seem like a lot. However, with the current status of the Danish eelgrass meadows, replacing all conventional insulation with eelgrass insulation isn't currently a possibility, but rather an option in 30-40 years if we start taking better care of our marine environment and raise awareness of the importance of eelgrass as an ecosystem. (Appendix 02)

Sub Conclusion

The case-study of EcoHousing shows that eelgrass batts can be applied in a vary of constructions and can have a positive effect on indoor climate. The application of eelgrass in the construction allowed for a diffusion open construction with moisture buffering abilities. However, one must be aware of the shortage of eelgrass and a sudden revolution in insulation materials cannot be expected.
The insights from EcoHousing showcase that the negative effect of constructions with non-biogenic materials have a great impact on the total GWP of the building. Therefore, as many biogenic materials as possible should be applied.

BENCHMARK

In order to investigate the qualities and challenges of eelgrass as a building material, the existing eelgrass materials will be compared with conventional building products and other biobased materials with similar function.
The products will be evaluated in three different categories: Protecting layer, Insulating layer and Interior layer. The products will be compared on different parameters corresponding to the application of the products.
The protecting layer is for example compared on factors such as Global Warming Potential, typical use per square meter, durability, appearance, and cost. The insulating layer is compared by its properties of density, GWP, thermal conductivity, heat capacity, moisture, fire class, sound insulation, lifespan and cost. Lastly, the interior layer is compared by factors as GWP, daylight, acoustic properties, appearance, density, fire classification, life span and cost.



Illu. 35. Illustration of the three categories of the benchmark.

Protecting Layer	Eelgrass Thatch	Eelgrass Modern	Reed Thatch	Ceramic Tiles
GWP Total [kg CO_2-eq] pr m²	-12,56 [1]	-8,91 [4]	16,15 [6]	67,5 [10]
Lifespan [years]	200-300 [2]	15 [4]	20-60 [7]	80-100 [11]
Typical use [kg/m²]	160 [3]	34,6 [4]	30-50 [8]	35-40 [12]
Appearance	Nature, heavy, unstructured	Nature, structured, soft	Nature, tradition, sculptural	Structure, pattern, hard, smooth
Cost [kr/m²]	2400 [1]	n.d. [5]	930 [9]	875 [11]

Illu. 34. 1. Appendix 03), 2. (Holm, 2008), 3. (Læsø Museum, 2022), 4. (Kauschen, 2015), 5. The roof is constructed by volunteers and there is therefore no data on cost. 6. (Kauschen & Granby-Larsen, 2020), 7. (Tagrenovering.dk, 2024), 8. (Vadstrup & Høi, 2011), 9. (Stråtag ved Service Fyhn, n.d.), 10. (Trafik-, Bygge- og Boligstyrelsen, 2021), 11. (Randers Tegl, n.d.), 12. (Nyt-tag.com, 2024)

For the protecting layer, four different roof constructions have been assessed. First of the roof thatched with eelgrass, the roof of the Modern Seagrass House, also a roof thatched with reed and lastly a roof with ceramic tiles. For the roofs, the GWP for all of the roof construction has been compared, since the eelgrass thatch is very heavy and would need a stronger construction. The benchmark shows that a lot more material is used when thatching with eelgrass compared to with reed. However, the roof construction with eelgrass has a negative global warming potential and a much longer lifespan, meaning that the extra material use might be worth it in the long run. The reed for the thatched roof in itself has a negative GWP, but the construction and fire protection affect the GWP negatively. (Kauschen & Granby-Larsen, 2020) With the shorter lifespan of reed thatch, some of the reed would need to be replaced during the 50-year lifespan, adding to the GWP. The same is the case for the roof of the Modern Seagrass House. The roof is constructed to only use approximately 10 percent of the eelgrass used in the original eelgrass roofs. However, the expected lifespan of the roof is very short, since it is the great mass of the original eelgrass thatched roofs that give them their long lifespan. (Kauschen, 2015)
Even though the ceramic tiles have a relatively long lifespan, the GWP of the construction is correspondently higher, and can't compete with the thatched constructions. Additionally, both eelgrass and reed provide thermal insulation to the roof, contrary to the ceramic tiles. (Kauschen & Granby-Larsen, 2020)
The cost of the eelgrass thatched roof is based solely on the cost of the material and do not include the pay for labour, nor structural timber. The cost of the eelgrass thatch is therefore not directly comparable to the two other roof claddings, since they include all expenses. However, we still see that the eelgrass thatch has a much higher cost, even without the cost of labour and structural timber added.

Insulating Layer	Eelgrass loosefill	Eelgrass batt	Steico flex 36	Rockwool flexibatts 37
GWP Total [kg CO2-eq] pr m3	-7,20E+00 [1]	1,02E+01 [4]	3,02E+00 [7]	4,78E+00 [11]
Density [kg/m3]	55 [2]	70 [5]	60 [8]	33 [11]
Thermal conductivty [W/mK]	0,043-0,045 [3]	0,037 [5]	0,036 [8]	0,037 [12]
Specific Thermal Capacity [J/kgK]	2000 [3]	2000 [3]	2100 [8]	1030 [12]
Water vapour diffusion resistance factor	1-2 [3]	1-2 [3]	2 [8]	1 [12]
Fire classification	D [4]	E [5]	E [8]	A1 [12]
Life span [years]	45 [1]	45 [1]	>50 [9]	>65 [13]
Cost [kr/m2]	309 [4]	n.d. [6]	105 [10]	74 [14]

Illu. 36. 1. (Kauschen, 2015), 2. (Appendix 01), 3. (Seegrashandel.de, 2018), 4. (Appendix 03), 5. (Pallesen, 2018), 6. The product is not marketed, and there is therefore no data on cost, 7. (Institut Bauen und Umwelt, 2020), 8. (STEICO SE, 2020), 9. (EcoTes, 2024), 10. (Zepa.dk, n.d.), 11. (epd-norge, 2023), 12. (Rockwool, 2022), 13. (Rockwool, 2022), 14. (Silvan, n.d.)

For the insulating layer, insulation materials with almost similar thermal conductivity, except for the loose fill eelgrass, have been compared in order to make it easier to compare the remaining factors.
The benchmark shows that the thermal conductivity of natural insulation materials can be at height with the mineral materials. However, it also shows how insulating with natural materials has challenges regarding the fire classifications.
The natural eelgrass is classified as a B2 material, according to the German standard DIN 4102-1, which is correspondent to D classification of the Euro class (Mahmood, n.d.). The eelgrass insulation batts reach a fire classification E, without any flame retarding additives. In fact, the added binders compromise the natural flame retardant of the high salinity in the product (Pallesen, 2018) .
The Steico flex batt of wood fibres also reach a fire classification E. This is reached by adding 7 percent ammonium salts to the product. (Institut Bauen und Umwelt, 2020)
A LCA has been conducted for the eelgrass insulation batts. However, in phase A1 only the negative effect of salvaging the eelgrass is included and not the positive effect of the eelgrass storing CO_2. Furthermore, only the Product stage is included and not the End-of-life stage. (Pallesen, 2018)
The GWP of eelgrass batts therefore takes its point of departure from the EPD for Søuld mats without added flame retardant, since the material content and production method are the same, except for the insulation batts being compressed to a lower density (See Appendix 03, for more information).

GWP	A1-A3	C2	C3	C4	D	Total
Eelgrass batt	-5,23E+01	1,42E-01	1,10E+02		-2,46E+01	**3,32E+01**
Steico Flex 36	-2,83E+01	1,45E-01	7,83E+01		-4,01E+01	**1,00E+01**
Rockwool Flexibatts 37	1,15E+01	1,18E-01		4,43E-01	-7,59E-01	**1,13E+01**

Illu. 37. The included phases of the GWP from the EPDs of the insulation materials, except for loose fill eelgrass, as the GWP is only presented as a total.

The Global Warming Potential of the eelgrass insulation batts prove to be the highest. This is opposite to what was expected.
C3 is the most influential phase for the eelgrass batts and has a negative effect on the GWP. It is assumed that the eelgrass batt is incinerated at the End-of-life. In C3 is the emissions of the incineration and in phase D is the energy gained from the incineration. However, it is clear to see that the gain doesn't reflect the emissions. (Sørensen, 2022) This is due to eelgrass lacking ability to burn because of the salinity of the material. Instead, the eelgrass should be reused for new production, as the manufactures claim is possible. Unfortunately, the eelgrass fibres are mixed with an oil-based binder in the manufacturing phase, (Pallesen, 2018) and the eelgrass can therefore only be reused in the production of new batts and not utilised for other purposes.
On the contrary the GWP for loose fill eelgrass is lowest, with a negative value. For Rockwool the value of stage D is due to the incineration of the wood pallets on which the product is transported and not the material itself. Rockwool is deposited at a landfill at the End-of-life. Since the material isn't incinerated, the emission of the End-of-life stage is low, however the material doesn't have any reuse or recovery advantages, as it is simply landfill. (epd-norge, 2023)
The Steico insulation batts which are made of wood fibres were expected to resemble the GWP of the eelgrass batts the most. However, the GWP of eelgrass batts is more than three times higher than the GWP of Steico. The most substantial differences in these materials are seen in the End-of-life stages. Both materials are expected to be incinerated, however the incineration of eelgrass has a much higher emission. Additionally, the incineration of the eelgrass has only half of the potential gain in stage D, due to its poorer ability to burn.

Interior	Søuld	Søuld FR	Troldtekt (Light natural)	Tyst
GWP	2,27E+00 [1]	3,65E+00 [1]	1,08E+01 [4]	1,19E+01 [8]
Acoustic classification	A [2]	B [2]	A [5]	A [9]
Alpha coefficient (aw)	0,95 [2]	0,85 [2]	0,9 [5]	0,95 [9]
Noise Reduction Coefficient (NRC)	0,9 [2]	0,9 [2]	0,9 [5]	0,9 [9]
Surface	Soft	Soft	Textured	Soft
Appearance	Muted greens/warm browns, textured [2]	Silvery greys/warm browns,textured [2]	Natural, texture	Colourful
Cost [kr/m²]	1.136 [3]	1.136 [3]	312 [6]	n.d.
Density [kg/m³]	120 [2]	133 [2]	409 [4]	126 [8]
Fire class	No fire classification [2]	D-s1,d1 [2]	B-s1,d0 [7]	B-s1,d0 [10]
Thickness [mm]	40 [2]	35 [2]	35 [4]	40 [8]

Illu. 38. 1. (Sørensen, 2022), 2. (Søuld, n.d.), 3. (Byggeladen.dk, n.d.), 4. (Institut Bauen und Umwelt, 2022), 5. (Troldtekt A/S, 2020), 6. (Stark.dk, n.d.) , 7. (Troldtekt A/S, 2023), 8. (Sørensen, 2023), 9. (PC Sound & Acoustics, 2023), 10. (Tyst ApS, 2023)

For the interior layer, four different acoustic solutions are compared. Søuld, a panel of compressed eelgrass, Søuld FR is the flame-retardant version of the acoustic panel, Troldtekt is a panel of wood fibres and cement and lastly Tyst is a panel of mineral wool covered with textile.

The eelgrass panels, have the lowest Global Warming Potential of the four acoustic solutions. Based on the GWP and the acoustic properties, the Søuld mat without flame-retardant performs best of the two. However, the lack of flame-retardant means that the panel has no fire classification. On the acoustic properties all the materials perform quite equally, except for the Søuld FR which has an acoustic classification B. The remaining differences are to be found in the appearance and the density of the product. Containing concrete, makes the Troldtekt panels the absolute heaviest panel, and the three lighter products must be considered easier to handle during installation.

The appearance of the panels is very different. Troldtekt has a rough textured surface and often comes in light colours. Tyst has texture to the surface due to the textile, but not as much as Troldtekt, and comes in a great variety of colours. Søuld has a soft and little textured surface. The appearance of Søuld is dark due to the natural appearance of dried eelgrass, and the colours of the panel shimmers due to the visible strands of eelgrass. Tyst has a versatile appearance and can be customized and Troldtekt has a bright appearance, whereas Søuld is the darkest of the panels, and creates a certain atmosphere when applied. It is possible to dye the Søuld panels with natural dyes and linseed oil, however it isn't possible to buy dyed panels, yet. (Søuld.dk, n.d.)

Sub Conclusion

The Global Warming Potential of both the eelgrass roof constructions, the eelgrass loose fill and the eelgrass acoustic panels were as expected low compared to the other constructions and products. However, the GWP of the insulation batt was higher than anticipated and should be further investigated before being written of.

Additionally, the lack of knowledge of the price of eelgrass products and the known higher cost is a challenge for the eelgrass to take off as a widespread building material.

Besides from the factors listed above, the benchmark shows that the eelgrass products can work fully on height with the conventional and well-established building materials.

One last important factor of the eelgrass products is the appearance, which is quite distinct from other known materials, with its darker, heavier and unstructured appearance. Deciding on eelgrass materials therefore has to be a stylistic choice implemented early in the design process.

EXPERTS' THOUGHTS ON EELGRASS

To gain insights into advantages and challenges of working with eelgrass and a broader understanding of the material, three different professions who are involved in the eelgrass process have been interviewed.

Illu. 39. Drawing of eelgrass farmer.

Illu. 40. Drawing of architect.

Illu. 41. Drawing of carpenter.

THE FARMER

To understand the material from the farmers point of view, a visit to Møn Tang was made, to see the different materials and to interview the founder, Kurt Schierup.

In the interview Kurt tells the story of how Møn and Bogø are known for making a business out of harvesting and selling eelgrass. Kurt tells how eelgrass have been used since the bronze ages and have been a commodity since 1914. 1914 was also the record-breaking year, where 8 million tons of eelgrass were salvaged in Denmark.

Today Møn and Bogø are still the main suppliers of eelgrass. The eelgrass is mostly used as loose fill and applied in renovations, since you avoid applying a vapor barrier.

The biggest challenge currently is to procure more eelgrass. On average one eelgrass salvaging farmer can collect 90 tons in one year, and the record year for Møn Tang was 150 tons of eelgrass salvaged in one year. In attempt to get more farmers involved Kurt is reaching out to farmers all over Denmark and instructing the interested farmers in salvaging eelgrass.

Additionally, it is an advantage to remove the eelgrass from the coasts, since it contains nitrogen, which would otherwise be emitted to the sea.(Appendix01)

THE ARCHITECT

To understand the architect's initiative to use eelgrass in the design, an interview with architect Carlo Volf was performed.

Carlo Volf has a vision of creating a better indoor climate and saving our climate at the same time. That is why he has used eelgrass batts as insulation in his holiday house and have designed a natural ventilation panel using eelgrass as well. The use of eelgrass in the construction, has allowed him to leave out the vapour barrier. And Carlo explains how he clearly experience a difference in the indoor climate, compared to conventional constructions, with mineral wool and vapour barrier.

Carlo explains that you need to learn to cut the eelgrass batts differently than with conventional insulation materials. But when it is learned, it is more pleasant to work with eelgrass insulation since it doesn't itch afterwards, as you would experience with mineral wool.

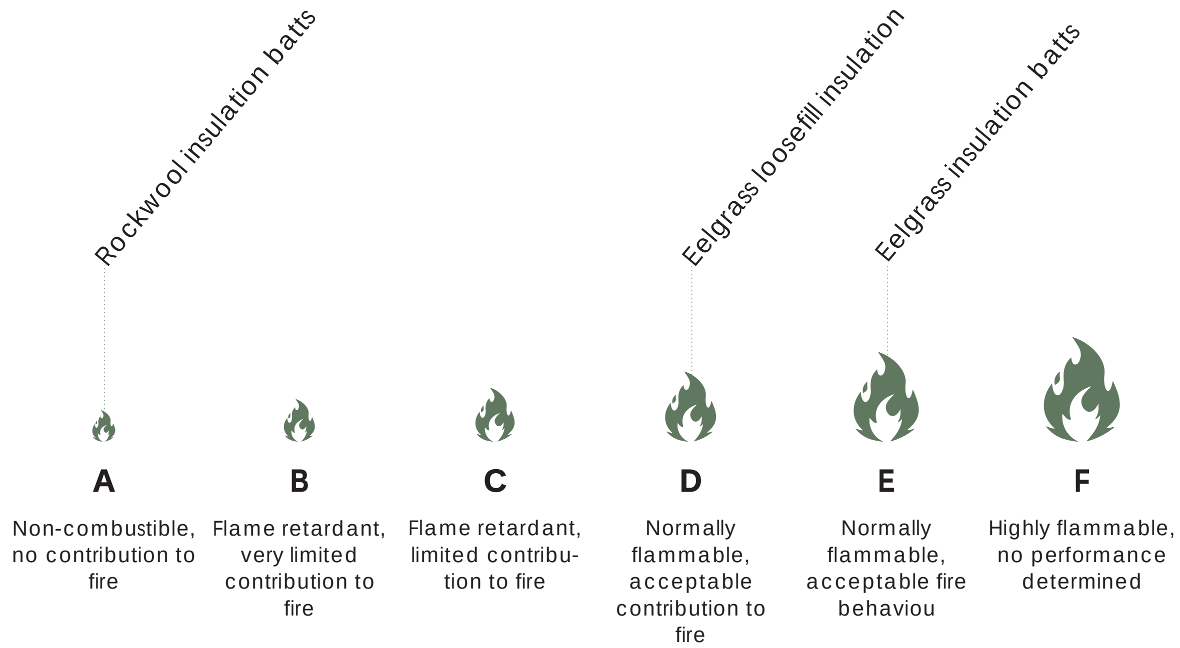
Carlo doesn't think that there is enough eelgrass to use it as an insulation material at the moment. He believes that it will be approximately 30 to 40 years before the eelgrass meadows have been restored, to provide enough resources. (Appendix 02)

THE CARPENTER

To understand the perspectives of the contractor, the carpenter company Tømrermester Søren H. Rasmussen who has formerly build with eelgrass was contacted.

They could inform that they have worked with loose fill eelgrass and applied it in roof- and wall constructions. They have only used the eelgrass for renovations.

They found the material nice and comfortable to work with, since there is no dust nuisance from the eelgrass, as there is from conventional insulation materials. However, they found insulating with eelgrass to be a time-consuming process and additionally the packaging of eelgrass in large big-bales made the material difficult to handle. The company have used the eelgrass insulation a few times afterwards, however they predict that the future of eelgrass as a building material is limited, due to the lack of resources. (Appendix 04)



Illu. 42. Descriptions of fire classifications for materials.

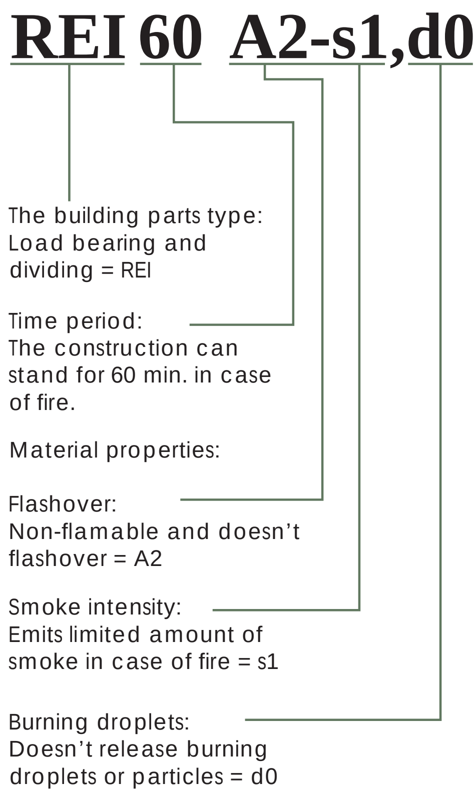
APPLICATION REGULATIONS

Requirements Regarding Fire

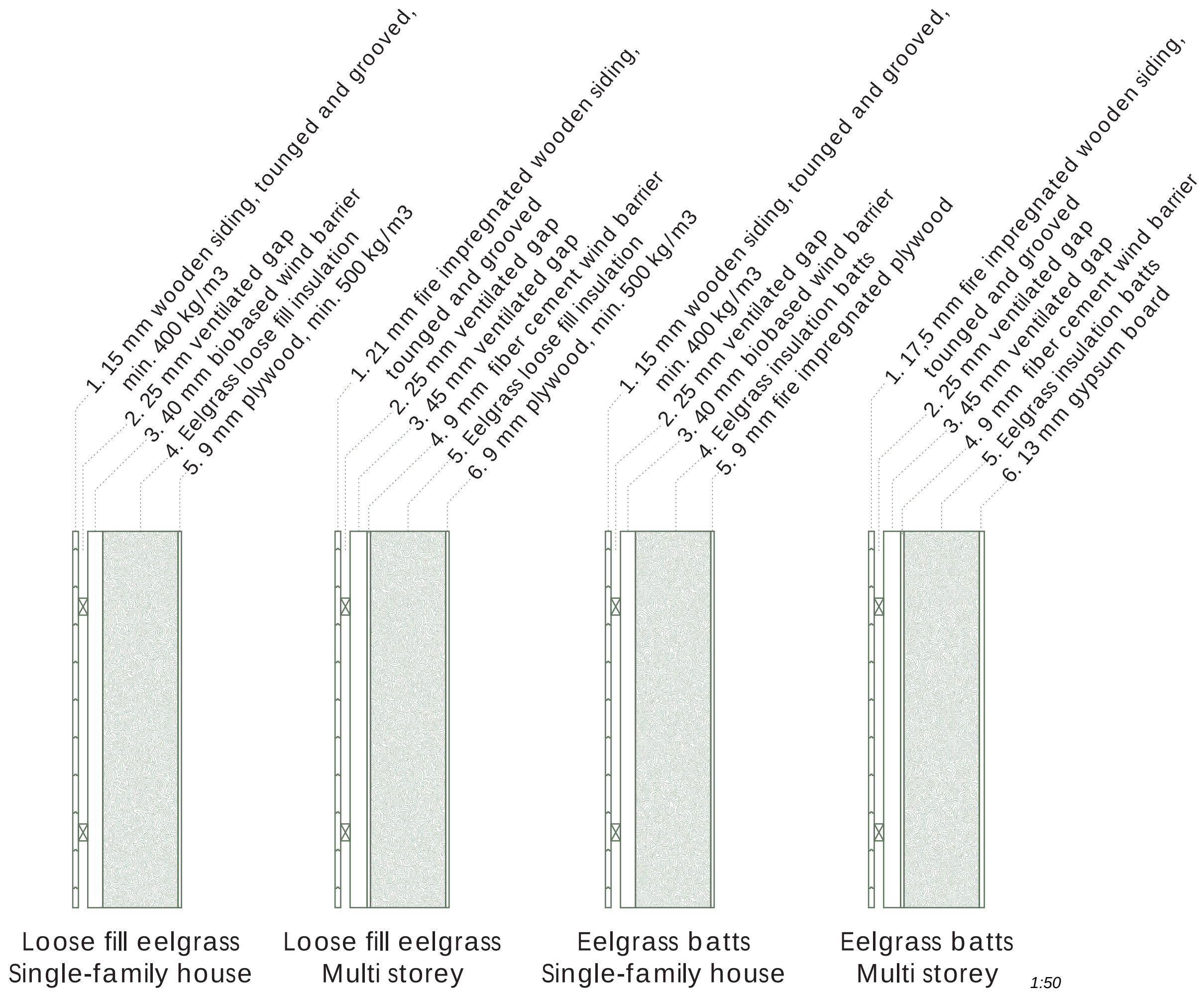
Since loose fill eelgrass is classified as class D material and the eelgrass batts currently only reach a fire classification E, it will be investigated which limitations of application this causes.
The following section will address fire regulations for dwellings only, and thereby focus on usage category 4, which include buildings with sleeping accommodations and users who can bring themselves to safety (Social og Boligstyrelsen, 2024), such as single-family houses, apartment buildings and row houses. (Trafik-, Bygge- og Boligstyrelsen, 2019)

For insulation materials with a minimum classification of D-s2,d2, the standard rules for exterior cladding and interior surfaces apply. This means that for a single-family house with loose fill eelgrass insulation the outer wall cladding should be at least cladding classification $K_1$10/D-s2,d2 or material classification D-s2,d2. The interior surfaces of walls and ceilings must be at least $K_1$10/D-s2,d2 classified cladding. (Social- og Boligstyrelsen, 2024)

For a multi-storey residential building where the upper floor is no higher than 22 meters, the external surfaces must be a classification $K_1$10/B-s2,d0 cladding. If a rain shield is installed on top of the exterior surface with an underlying cavity, the material of the rain shield must be at least material class B-s1,d0. The interior wall surfaces in residential



Illu. 43. Instruction in reading the fire classifications.



Illu. 44. Examples of constructions fulfilling the requirements. The wood studs of the ventilated layers have for illustrative purposes been turned 90 degrees, to showcase the dimensions.

buildings where the upper floor doesn't exceed 22 meters, must be a cladding class $K_1$10/D-s2,d2. For the ceiling surfaces the requirements differ according to the building height. For single story buildings the ceiling surfaces can be a class $K_1$10/D-s2,d2 cladding. Whereas the ceiling surfaces of a multi-storey building where the upper floor is maximum 22 meters, must be a class $K_1$10/B-s1,d0 cladding. (Bolig- og planstyrelsen, 2021)

For insulating with the eelgrass insulation batts, the requirements are stricter as the material has a lower fire classification. However, for single family houses the same requirements apply regarding the exterior cladding. For the interior surfaces of walls and ceilings, a class $K_1$10/B-s1,d0 cladding is required. The interior cladding must cover both sides of a vertical building part or the underside for a horizontal or inclined building part. (Social- og Boligstyrrelsen, 2024)
When using the eelgrass insulation batts in a multi-storey residential building where the upper floor is no higher than 22 meters, the external surface must be a class $K_1$10/B-s1,d0 cladding and a potential rain shield must be a B-s1,d0 classified material. The interior surfaces of walls and ceilings must consist of a EI30/A2-s1,d0 classified building part. The insulation material in vertical building parts must be covered on both sides. Additionally, there is for the multi-storey building, requirements for the flooring material if the insulation material is used in a partition deck. In this case the partition deck must be a REI60/A2-s1,d0 building part and the flooring should be a class Dfl-s1 flooring. (Bolig- og planstyrelsen, 2021)

Sub Conclusion

It is possible to use eelgrass insulation in both single-family houses and multi-storey buildings. However, the poor fire classification of eelgrass, requires extra awareness of the remaining constructions and material use, to ensure that the building fulfil the requirements for fire safety.

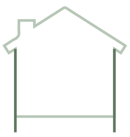
Requirements Regarding Thermal Insulation

U-VALUE

To minimize the energy consumption of buildings, the Danish Building Regulations require minimum insulation of different building parts. The minimum requirements for the heat loss coefficient of new build are found in the table below.

The required U-values of the Danish Building Regulations are quite high and reaching the requirements for the energy frame of 30 kWh/m$_2$ pr year (Social- og Boligstyrrelsen, 2024), will be impossible if all constructions of the building aim for the maximum U-value. However, the relatively high U-values allows the designer to work more freely with some construction parts and putting more effort into the thermal insulation of others.
To fulfil the demands of the energy frame it is recommendable to aim for the U-values presented in the third column of the table.

As the eelgrass insulation batts have a thermal conductivity of 0,037 W/mK, similar to the thermal conductivity of most mineral wool, fulfilling the recommended U-values isn’t considered to be a problem. However, for the loose fill eelgrass insulation the thermal conductivity is approximately 0,045 W/mK, which is higher than the other two materials. Therefore, insulating with loose fill eelgrass insulation will require a thicker construction to reach the same U-value. For a outer wall construction insulated with loose fill eelgrass, the insulation layer should be 321 mm to reach the recommended U-value of 0,14 W/m^{2}K, compared to 264 mm if eelgrass insulation batts are used.

	Building Part	Requirements for new build U-value [W/m2K]	Recommendations for new build U-value [W/m2K]	Requirements for renovation U-value [W/m2K]
	Outer wall and basement wall towards ground	0,30	0,14	0,18
	Decks and partition walls towards rooms, with a temperature difference of 5 C or more	0,40	0,10-0,15	0,40
	Ground deck, basement floor towards ground and decks towards the open air or ventilation space	0,20	0,10	0,10
	Ceiling- and roof constructions, including wall separating habitable room from roof space, flat roofs and sloping walls directly aginst the roof	0,20	0,10	0,12

Illu. 45. Table of U-values for new build and renovation.

RENOVATION

When renovating, the Danish Building Regulations require reinsulating in cases where it is profitable. The regulations divide renovation into three categories. The first category is ‘Repair’, and covers the replacement of smaller construction parts, such as repair of roof tiles or smaller damages to the façade. Repairing the building doesn’t come with any requirements to reinsulate.

The second category is ‘Building alteration’, covering the modification of whole building parts, such as changing the roofing or siding. When altering the building, the Danish Building Regulations demand reinsulating if it is profitable and doesn’t pose issues for the existing construction. As a rule of thumb, it is in general profitable to re-insulate buildings build before 1979, when the more stringent insulation requirements were implemented.

The third category is ‘Replacement of a building part’. This covers the replacement of a whole building part, including the construction. When building owners are replacing a building part, the new building part must always be insulated to satisfy the requirements for the thermal loss for renovations, whether it is profitable. (Social- og Boligstyrelsen, 2022)

For renovations different requirements for the thermal loss are defined in the Danish Building regulations. For re-insulation, the values of the fourth column of the table apply, for the maximum heat loss coefficient.

CAVITY WALL

The Danish Energy Government Agency mentions that it is important that the insulation of a cavity wall is hydrophobic since moist in the construction decreases the thermal resistance of the insulation. Furthermore, it is recommendable to choose an insulation with a high thermal resistance, since the thickness of the insulation in cavity walls are often limited. (Energistyrelsen, 2018) These recommendations, make eelgrass unfir for insulation of cavity walls, as eelgrass is a hygroscopic material (Frandsen, et al., 2020).

However, these aspects are not mentioned as requirements in the Danish Building Regulations.

EXCEPTIONS

If a re-insulation isn’t profitable the municipality can grand dispensation, if it can be demonstrated that reinsulating is inappropriate.

For example, a dispensation can, be granted if reinsulating creates risk of moisture problems in the construction. Furthermore, a dispensation can be granted if reinsulating creates architectural or constructional issues. This could be a special architectural appearance that the owner wants to preserve, or the roof overhang not being wide enough to cover the construction, it could be interior reinsulating hindering the possibility of fulfilling the requirements for room heights or lastly the re-insulation exceeding legal boundaries of the plot. (Social- og Boligstyrelsen, 2022)

Sub Conclusion

Since the eelgrass insulation can reach same thermal properties as conventional insulation materials, using eelgrass for insulation of new build is no issue regarding the requirements. For renovations however, it must be noted that eelgrass isn’t recommendable for insulating cavity walls due to its hygroscopic properties. Lastly, using eelgrass insulation for interior re-insulation could be beneficial, since the challenges of interior re-insulation are often related to moisture, which is abated by eelgrass.

APPLICATION

To inform of where the eelgrass products can best be applied, the following tables will present the possibilities of application. The tables will differentiate between possible application and recommendable application. The possible applications are marked with a X, while the recommendable applications are marked with an O. The evaluation of the application of eelgrass products is based on requirements, method of application, and function of the product, which has been presented previously in the report.

Protecting	Building part	Original Thatch	Sacks
New Build	Roof	x	x
	Ceiling		
	Flooring structure		
	Outer wall		x
	Inner wall		
	Ground deck		
Renovation	Roof	o	x
	Ceiling		
	Flooring structure		
	Outer wall		
	Inner wall		
	Ground deck		

Illu. 46. Table of applications for exterior eelgrass products.

The only recommendable use of eelgrass on the exterior of a building is in renovations of the original eelgrass roofs of Læsø.

Since the original eelgrass thatched roofs are particularly heavy, a strong roof construction is necessary if the construction were to be applied in new build. Additionally, the great use of eelgrass for the thatched roof, doesn't provide the necessary thoughtfulness of use of eelgrass, as is needed currently with the low occurrence and intensive attempts of restoration of eelgrass and using eelgrass thatched roofs for new build is therefore not recommendable.
Additionally, it is worth noticing that the unstructured and heavy eelgrass roofs were used due to lack of other building materials, they were simply the only option.

The case study of the Modern Seagrass House shows that the eelgrass net sacks can be applied in new build, and as it extends the lifespan of underlying materials it could probably also be applied to roofs during renovations. However, it isn't recommendable as the sacks proved to have little effect and needed underlying protection.

Insulation	Building part	Loose fill	Insulation batts	Granulate
New Build	Roof			
	Ceiling	o	o	x
	Flooring structure	o	o	x
	Outer wall	o	o	
	Inner wall	o	o	
	Ground deck			
Renovation	Roof			
	Ceiling	o	x	x
	Flooring structure	o	x	o
	Outer wall	o	o	
	Inner wall			
	Ground deck			

Illu. 47. Table of applications for eelgrass insulation products.

Currently the loose fill eelgrass is utilised for reinsulating flooring structures, ceilings, and outer walls in renovations (Appendix 01), in renovations it could therefore be used in these known constructions. If the floor is changed during a renovation or transformation, the loose fill eelgrass can be added beneath the floorboards. Loose fill eelgrass is also a simple and effective solution for reinsulating the upper ceiling. It could be used in the inner walls and partition decks as well to provide acoustic insulation. Additionally, the loose fill eelgrass can be applied in new build as seen in the case study of the Modern Seagrass House.

The case-study of EcoHousing has proven that the eelgrass batts are applicable in both ceiling, floor and outer wall of new build. The same applications are presumed possible for renovations. However, installing batts in the upper ceiling can prove to be more demanding than the application of loose fill.

The granulate of eelgrass can be blown into cavities, such as flooring structures or unutilized ceiling space, and would therefore be suitable for less comprehensive renovations. However, it is worth noticing the risk of extra cost, since the density of eelgrass granulate is higher than the density of loose fill, which can result in a higher price. Furthermore, sources suggest that eelgrass granulate isn't suitable for insulating cavity walls, since the insulation of cavity walls should be hydrophobic, and eelgrass is the opposite.

When applying eelgrass insulation in buildings, attention must be given to fulfilling the fire regulations, as eelgrass materials have poor fire classifications.

Interior	Building part	Søuld	Søuld FR	Upholstered
New Build	Roof			
	Ceiling	o	o	x
	Flooring structure			
	Outer wall			
	Inner wall	o	o	x
	Ground deck			
Renovation	Roof			
	Ceiling	o	o	x
	Flooring structure			
	Outer wall			
	Inner wall	o	o	x
	Ground deck			

Illu. 48. Table of applications for interior eelgrass products.

Both the Søuld mats and the upholstered panels can in principle be used on both ceiling and wall surfaces, except for in wet rooms. The application will of course be dependent on the function of the room and the desired atmosphere. For example, the upholstered surfaces might be difficult to keep clean on the walls of kindergartens and other institutions.

Both solutions have great impact on the indoor environment as they absorb noise and have great water buffering abilities. The Søuld mats are recommendable both in new build and renovation, as they improve the indoor environment and has low GWPs. However, the Søuld mats without flame-retardant can have limitations in applications in combination with other biobased materials regarding fire regulations and must be investigated thoroughly before application. The upholstered panels have proven to be effective in the Modern Seagrass House, however the information on these are limited and the application of these is therefore only determined to be possible and not recommendable, without further knowledge.

SUMMARY

Limitations of Material

As eelgrass is a sparse resource, reviving the eelgrass thatched roofs might not be the way to go with the material, since the material use of the eelgrass thatched roof is 30 to 40 tons per roof. Therefore, it must be assessed how the eelgrass, and its qualities are best utilized in the building industry.

Best Application

Currently, there is not enough raw material for eelgrass to be the new main insulation material of Denmark. However, the analysis has shown that using eelgrass in buildings has a great ability to affect the indoor environment, as it has high sorption dynamics, which can help balance the relative humidity of a space, and an acoustic sound absorption on height with other insulation and acoustic regulating products, providing a comfortable acoustic environment. Additionally, when kept dry as if used in the construction or inside the building, the eelgrass doesn't decompose, elongating its lifespan, compared to applying the eelgrass on the exterior of the building.

With this argumentation it seems logical to recommend that eelgrass is used in the construction or inside the building.

If a recommendation is to be made of either eelgrass loose fill or eelgrass insulation batts, the loose fill would in many cases be recommended, as the density of loose fill eelgrass is lower, meaning that less material is used. Even when considering the need for extra thickness due to the higher thermal conductivity of loose fill, the material use is still lower. Additionally, the loose fill is a natural product with no additives, together with the little processing, resulting in a negative Global Warming Potential. Lastly, the fire resistance is slightly better for loose fill than eelgrass batts.

Illu. 49. Photography of dry eelgrass on land in Faxe Ladeplads.
Photography by Anne-Mette Rosenkilde.

02 RENOVATION

The renovation section explores how eelgrass can be implemented in renovations. To determine the possible applications, the constructions of Danish building typologies are investigated, along with existing examples of renovating with eelgrass and the regulations which apply when renovating.

HOW TO RENOVATE

Renovations constitute to more than half of the total production in the Danish building industry. Therefore, it is relevant to investigate how these processes can be made even greener. (Realdania, n.d.)

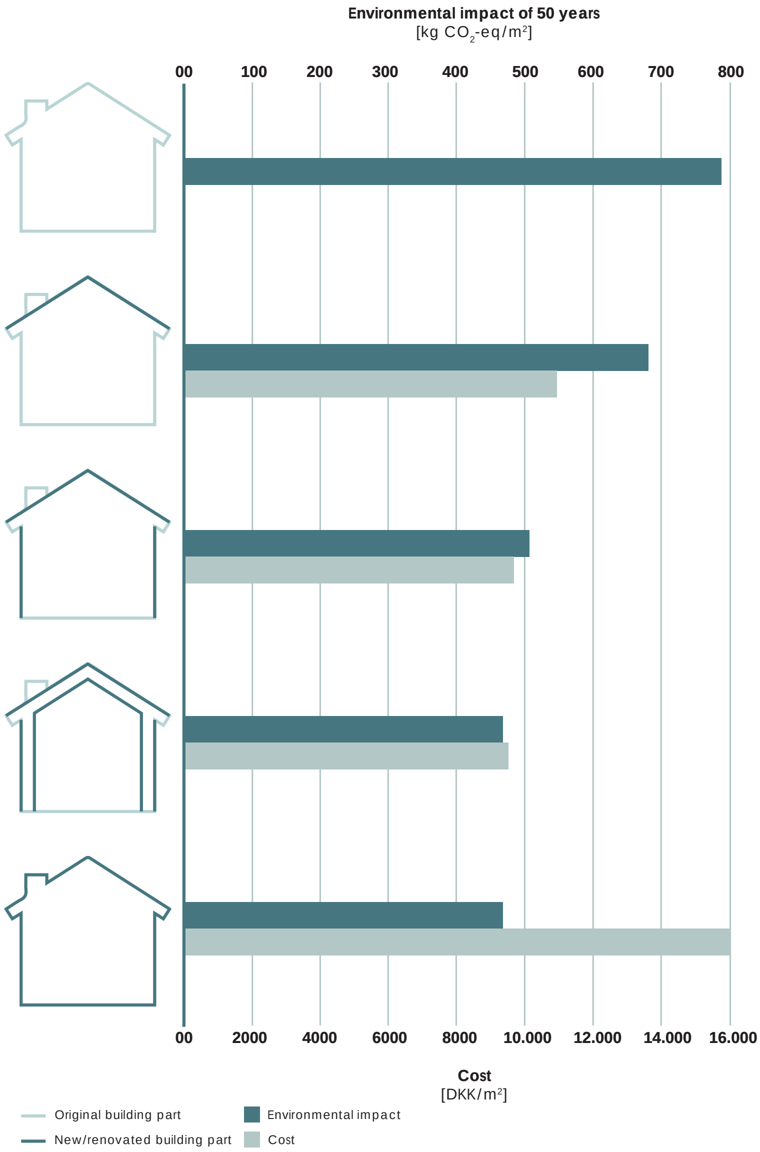
BUILDING PARTS

As formerly mentioned, the practice of renovation and transformation is green compared to building new. This is showcased in the formerly introduced report 'Analyse af CO_2-udledning of totaløkonomi i renovering og nybyg' by Rambøll investigating the advantages of renovating instead of building new and the report 'Analysis of CO_2-emissions of different types of urban development' by Viegand Maagøe, comparing the CO_2 emissions of three different urban development strategies, new build single-family housing and row housing and transformation.

Before renovation, many older buildings will often use a lot of energy on operation, since the building envelope is often inadequately insulated. In new buildings the energy needs for operation are usually low, while the energy for materials and construction is often high. When renovating an old building it is possible to lower the energy use for operating, while keeping the material related energy down.

The report 'Analyse af CO_2-udledning of totaløkonomi i renovering og nybyg', shows that in all 16 cases investigated in the report, it is better regarding the environmental effect to renovate roof and outer walls or roof, outer walls, and installations, than building new. Regarding cost, the most beneficial for all 16 cases prove to be renovation rather than new build. However, the lowest cost is spread out on all renovation cases, with the simple renovation of only the roof being the least costly in half of the cases.

The report shows that renovating apartment buildings and public buildings, has a greater positive impact on the environmental aspect, compared to single-family housing and row houses, where the environmental effect is almost identical of the new build and the two renovation cases where roof and outer wall is renovated. However, in the cases of single-family housing and row houses the cost of renovating is very beneficial, compared to building new. (Sørensen & Mattson, 2020)



Illu. 50. Graph of environmental- and economic effect of renovating different building parts of single-family houses and row-houses. Reproduced, based on graph from 'Analyse af CO_2-udledning og totaløkonomi i renovering og nybyg' by Sørensen og Mattson, 2020.

REINSULATING

When renovating, the building can be reinsulated in various ways, and it is important to be aware of the effect of the different methods.

There are three overall methods for reinsulating. There is cavity wall insulation, which was earlier found not to be suitable for eelgrass insulation, there is insulation of the exterior and insulation of the interior.

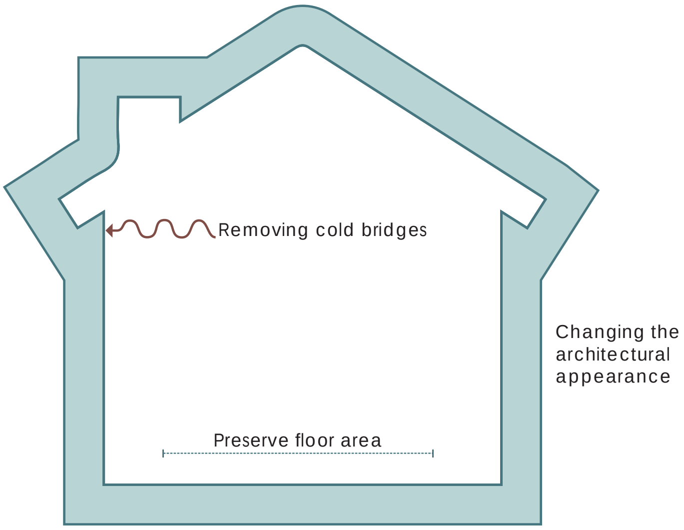
Reinsulating on the exterior side of the wall is the most effective. In fact, it is 30 percent more effective than insulating on the interior side. Additionally, insulating the exterior doesn't decrease the floor area of the building and it isn't necessary to move the installations. (Energistyrelsen, 2024)

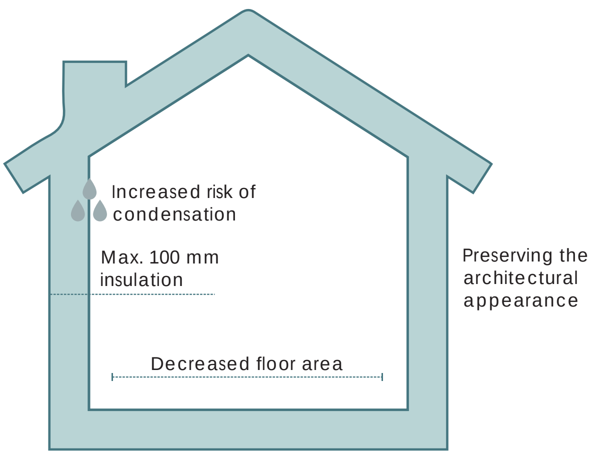
However, when insulating on the exterior side of the wall, there are a few cautionary notes.

First of all, one must be aware of the roof overhang and whether or not it exceeds the new insulation. If not, it is necessary to change either the slope of the roof overhang in the bottom of the roof or have a completely new roof construction. Furthermore, it can be necessary to change the placement of the windows and doors to fit the new dimensions of the wall, making it a costly process. (Energistyrelsen, n.d.)

Lastly, but very importantly, the exterior architecture of the building will disappear with the addition of an exterior layer of insulation. Therefore, exterior insulation is not suitable for all older buildings, and the owners must carefully consider if it is desirable to change the appearance of the building. (Energistyrelsen, 2024)

Insulating on the interior side of the wall might be a necessity for some buildings in order to preserve a desirable appearance, even though it does decrease the interior floor area. Insulating the interior comes with a vary of special demands for the execution. First of all, the installations need to be moved. Additionally, it takes great focus on the moisture properties of the construction to insulate on the interior side. The insulation should be between 50 to 100 mm, to save space and to avoid the risk of the moisture content condesating in the construction. Furthermore, typically a vapour barrier should be applied to avoid moist in the construction as well. Lastly, the heat capacity of the inner wall will typically be decreased when adding a layer of insulation. (Energistyrelsen, n.d.)





Illu. 51. Illustration of advantages and disadvantages, when reinsulating the exterior and interior.

NOISE

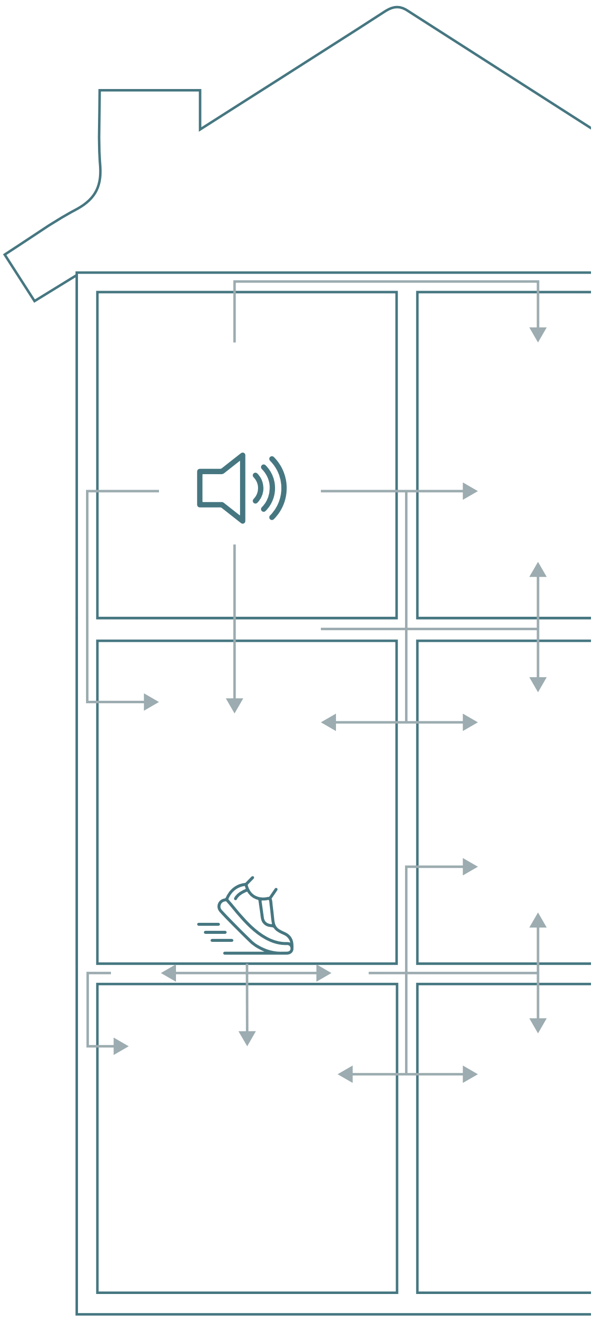
In 1961 the first requirements for sound insulation between dwellings were implemented, which means that before 1961 there were no requirements. More than half of the apartment buildings in Denmark, were built before the implementation of these regulations. This has led to almost 50 percent of the floors in Danish apartment buildings being constructed only in wood, which is one the worst materials for reducing sound transmission, resulting in 35 percent of dwellers of Danish apartment buildings being disturbed by noise from their neighbours. (Rasmussen, 2021)

When restoring old apartment buildings, it is therefore important to investigate and if necessary, improve the sound insulation between apartments.

The current requirements for sound insulation between dwellings were implemented in 2008 and dictates maximum values for both airborne sound insulation and for the footfall sound level. The airborne sound is sound from for example a speaker or conversation and it moves through constructions, leaks and ventilation ducts. The Danish Building Regulations require that the airborne sound insulation between dwellings should at least be 55 dB. The footfall sound is created by steps in neighboring dwellings and travels through the constructions of the building. The Danish Building Regulations require that the footfall sound level is maximum 53 dB. (Rasmussen, 2021)

In a pamphlet by BUILD, the institute of construction, urban planning and environment at Aalborg University, it is proposed that the acoustics of the older apartment buildings is improved during renovation by implementing sound insulation in the form of a new insulated cantilevered ceiling and new freestanding additional wall.

By applying these solutions in a renovation, it is expected that the buildings from the period 1830 till 1930, with a current sound classification F, can at least reach a sound classification D. For the building from the period 1930 till 1960 it is expected that the current construction with a sound classification E can at least reach a sound classification D when sound renovating with the described solutions. (Rasmussen, 2021)



Illu. 52. Noise transmission in old apartment buildings.

Sub Conclusion

Renovation is always a beneficial solution compared to building new, regarding both environmental impact and cost. When renovating, the building envelope should be improved by re-insulating. However, one must be aware of the effect of the different reinsulating methods and what the aim and limitations are of the renovation. Reinsulating on the exterior side is most effective, whereas reinsulating on the interior side can preserve the architectural appearance of a building. When renovating attention should also be given to the noise conditions of the building, especially in multi-storey buildings.

RENOVATING WITH EELGRASS

To determine how eelgrass can be used in renovations, former cases of reinsulating with eelgrass will briefly be examined. Eelgrass is a well-known material in renovations, in Germany more than Denmark. The eelgrass used in Germany is often exported from Denmark. (Læsø Museum, 2022)

When visiting Møn Tang, Kurt Schierup proclaimed that the use of eelgrass in renovations, prevented the need for installation of a vapour barrier in the old houses.

In a renovation project performed by the carpenter firm Tømrermester Søren H. Rasmussen, the loose fill eelgrass is used to insulate on the interior side of the wall. To apply the eelgrass, interior vertical wooden joists are installed. In between the joist the eelgrass is added in small steps by hand, held in place by the vertical boards which are applied gradually as the frame gets filled. As seen in illustration 53, this construction doesn't make use of a vapour barrier. Working with eelgrass loose fill applying it by hand in small steps is a time-consuming process as explained by Michael Kiil, from Tømrermester Søren H. Rasmussen.

The eelgrass loose fill can also be used to reinsulate on the exterior side, and cases of the utilization has been documented by the German eelgrass provider and informant, Seegrasshandel. Seegrasshandel showcases multiple cases of eelgrass used in both new build and renovation. On illustrations 54 and 55 is showcased two examples of reinsulating on the exterior side with eelgrass. In both cases the eelgrass is installed by adding wooden framing to the existing wall. In illustration 54 the eelgrass is held in place by a jute net. On top is applied reed mats, which allows for the application of plaster as cladding.
In the other case, illustration 55, the eelgrass is held in place by a wood fiber board and finished of with a wooden cladding.

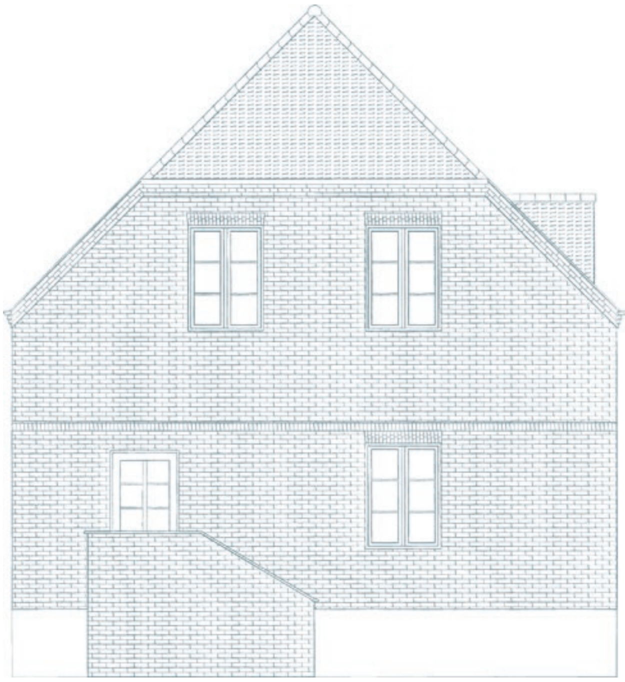
Additionally, Seegrasshandel also have examples of reinsulating an upper ceiling and a sloping roof with eelgrass loose fill. The insulation of the upper ceiling is described as simple, as the eelgrass insulation can simply be added in between the existing rafters and left open, if the attic space isn't utilized.
Insulating the inside of a sloping roof is a bit more demanding, as one must establish a ventilation level between the roof and the insulation. This can be done by installing either a layer of foil or precisely cut fiber board between the rafters. The insulation can then be added and finished of with for example wooden boards and plaster, as in some of the previous examples. (Seegrashandel, 2018)

Illu. 53. Photography of eelgrass loose fill in interior renovation. Photography provided by Tømrermester Søren H. Rasmussen.

Illu. 54. Photography of eelgrass loose fill in exterior renovation. Photography provided by Seegrashandel.

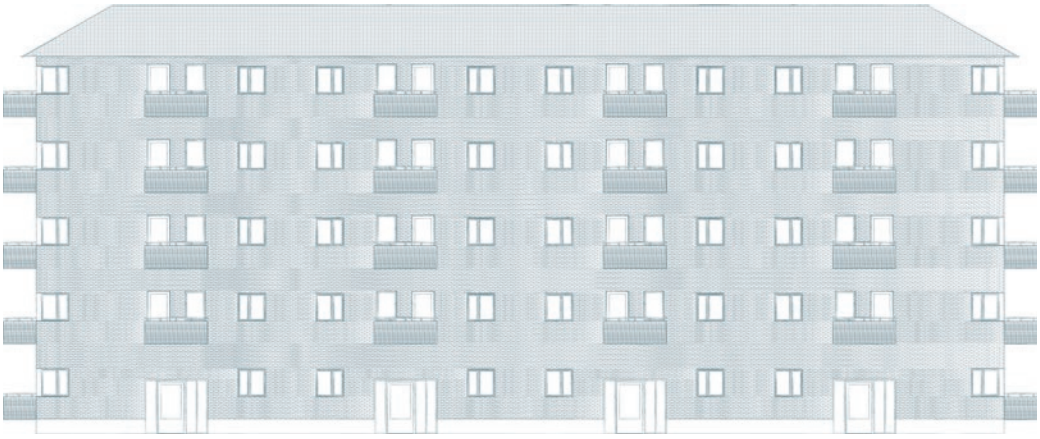
Illu. 55. Photography of eelgrass loose fill in exterior renovation. Photography provided by Seegrashandel.

Illu. 56. Photography of eelgrass loose fill in sloping ceiling renovation. Photography provided by Seegrashandel.



Illu. 57. Single-Family House 1851-1930 *1:100*

Illu. 58. Apartment Building 1851-1930 *1:200*



Illu. 59. Apartment Building 1931-1950 *1:300*

MAPPING EXISTING CONSTRUCTIONS IN DANISH BUILDINGS

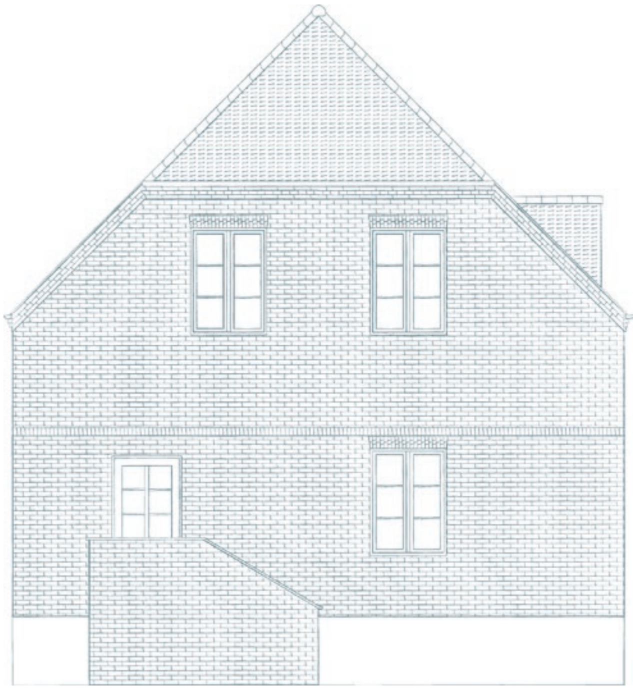
TABULA

To assess the value of renovating using eelgrass materials, the constructions and possible improvement of different Danish typologies will be assessed by information from TABULA.
TABULA is an abbreviation of Typology Approach for Building Stock Energy Assessment. The Danish Building Research Institute has contributed to TABULA with the report ‘Danish building typologies’. The report assesses the Danish residential building typologies. The typologies are divided into three main building types: Single-family houses, terraced houses and apartment blocks. Additionally, the typologies are divided into nine time periods, defined by changes in building tradition or shifts in energy requirements.
Based on data from TABULA, of the biggest impact of energy savings and the greatest national percentage of square meters, the building typologies used for the renovation example will be chosen.

	SFH 1851-1930	ABB 1851-1930	ABB 1931-1950
Percent of the total Danish heated floor area of the category (%)	27	30	18
Total heated floor area in Denmark (million m^2)	48,3	23,5	14,4
Maximum improvement pr. m^2 (kWh/m^2)	213	71	124
Yearly savings for standard case (kWh)	23.800	39.900	34.270
Yearly total saving for all area in Denmark (kWh)	10.287,9	1.668,5	1.785,6

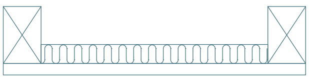
Illu. 60. Table of selected values of the three typologies. Based on data from ‘Danish building typologies’ by Wittchen & Kragh, 2012.

The table shows the general values for three different typology examples, chosen for comparison. The three typologies are chosen between the 27 building typologies of the report, as they had the greatest floor percentage of total floor are within their categories, and thereby can have the greatest effect. The chosen typologies are Single-family House from the period 1851 till 1930, Apartment Building Blocks from the periods 1851 till 1930 and 1931 till 1950. The comparison is performed to determine which typology has the biggest possible decrease in emission and energy use, when renovating. Therefore, among others, the total area of each building typology in Denmark and the maximum energy saving per square meter calculated in the report ‘Danish building typologies’, are used to determine the total possible energy savings.
To provide two different examples for further investigation, the Single-family houses from 1851 till 1930 and the apartment buildings from 1931 till 1950 are chosen, since they have the greatest possible energy savings, while simultaneously having quite diverse constructions and appearances.
The constructions and possible improvements will be investigated by building the constructions in Ubakus, an online construction property calculator, aiming for u-values reassembling those of the proposed renovations in the report ‘Danish building typologies’, in order to compare the difference in embodied energy.



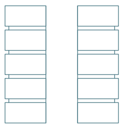
Illu. 61. SFH 1851-1930, facde. *1:100*

According to the report 'Danish building typologies' a Single-family house built between 1851 and 1930 would consist of constructions resembling the following illustrations.



Illu. 62. Illustration of SFH 1851-1930 ceiling construction.

The ceiling would often consist of a frame of joists insulated with 50 mm of mineral wool.



Illu. 63. Illustration of SFH 1851-1930 outer wall construction.

A typical outer wall would be 300 mm cavity wall with no insulation.

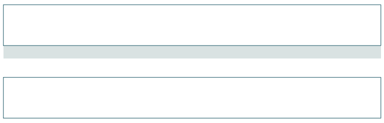
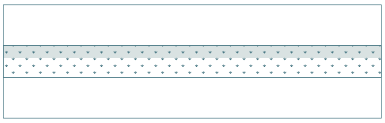
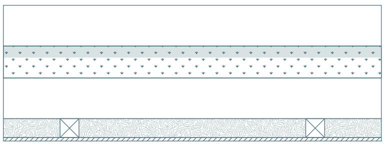
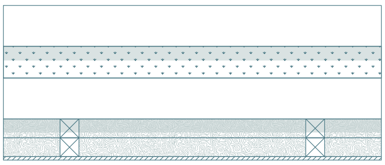
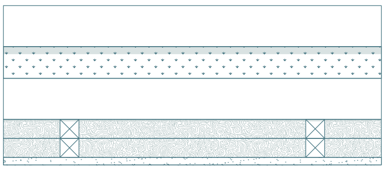
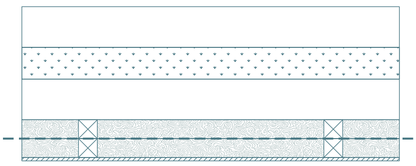
Illu. 64. Illustration of SFH 1851-1930 floor construction.

The floor would typically consist of boards placed on joists with an underlying clay pugging.

RENOVATION

As the building has an uninsulated cavity wall, the first task would be to insulate this cavity. However, as we learned from previous sections, eelgrass isn't suitable for insulating cavity walls as it requires a hydrophobic material. Instead, the cavity can be insulated with for example paper granulate insulation. (Bisp & Christensen, 2020)

To preserve the historic quality of the exterior, the building is insulated on interior side of the exterior wall. When insulating on the interior side it is recommended not to exceed 100 mm of insulation to avoid condensation in the construction. Furthermore, a vapour barrier should be added. (Kjerumgaard & Clasen, 2021) However, eelgrass is known for its moisture buffering properties and it will therefore be investigated if the vapour barrier could be left out, when reinsulating with eelgrass on the interior side.

	Construction (Out / In)	U-value [W/m^2K]	GWP [kg CO^2-eq/m^2]	Condensation [kg/m^2]
Original		1,477	0,0	1,7
Insulated cavity		0,369	-6,5	1,6
50 mm eelgrass		0,254	-5,7	1,5
100 mm eelgrass		0,195	-6,6	3,7
Clay board		0,191	-8,1	1,2
Vapour barrier		0,194	-4,8	0,0

Illu. 65. Table of iterations of insulation for the outer wall construction.

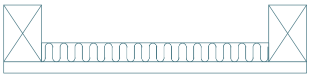
When insulating the cavity wall with cellulose fibres a condensation occurs on the inside of the outer brick wall.
Adding 50 mm of eelgrass insulation batts, the condensation still occurs on the inside of the outer brick wall. However, with 50 mm insulation added, the construction still doesn't fulfil the demands of the Danish Building Regulations, regarding thermal insulation.
Adding an extra 50 mm of eelgrass insulation batts, the construction comes closer to fulfilling the thermal requirements. With 100 mm eelgrass, the condensation now occurs on the inside of the interior brick wall as well.
Adding a clay board on the inside reduces the condensation on the inside of the interior brick wall, while preserving the 100 mm of eelgrass insulation. However, condesation still occurs on the inside of the outer brick wall.
Adding a vapour retarder to the construction would solve the issues of condensation. The vapor retarder must have an sd-value of at least 20 m.
As a downside, the addition of the vapour barrier, increases the GWP for the construction.

From previous sections, we know that renovating roof and walls is the most profitable combination. Therefore, it will also be investigated how the ceiling could be reinsulated.
In the ‘Danish building typologies’ report, it is proposed to reinsulate with 350 mm of mineral wool to reach the low energy class (Wittchen & Kragh, 2012). As mineral wool and eelgrass has almost the same thermal conductivity, it is assumed that reinsulating with 350 mm of eelgrass would work as well.
Using loose fill eelgrass, the thickness of the re-insulation layer would have to be approximately 380 mm.
To ensure that the fire safety fulfils the requirements of the Danish Building Regulations, the underside of the ceiling should be cladded with a $K_1$10/B-s2,d0 cladding (Social- og Boligstyrrelsen, 2024). This could for example be a 9 mm gypsum board or a 9 mm fireproofed plywood-board (Træinformation, 2021).
Lastly, the floors of the single-family house from 1851-1930 is often uninsulated and with an underlying layer of clay pugging. (Wittchen & Kragh, 2012) The layer of clay pugging is installed in partition floors from 1796 till 1950. They function both as fire protection and sound insulation. (Johansen, et al., n.d.) Additionally, the clay pugging can help balancing heat and moisture in the building, as it can absorb and emit both heat and moisture. However, the clay layer has poor thermal insulation properties. (Bisp, 2020) Changing a flooring construction with a layer of clay pugging is therefore a large interference with the building physics and must be performed with care.
Eelgrass has some of the same qualities, as it also provides sound insulation and can help balancing the moisture of the building. Additionally, eelgrass has great thermal insulation properties, as opposed to the clay pugging. However, using eelgrass in the partition floor will require extra fire preventions.
Therefore, if the partition floor is partitioning two spaces of same temperature, it is most optimal to preserve the existing partition floor. If the partition floor however is separating a heated- from an unheated space, it is worth considering reinsulating it with eelgrass. In this case one has to be aware of taking additional measures to ensure the fire safety.
In the table to the right, the final eelgrass renovation constructions are presented along with the original constructions and the renovation constructions proposed in the ‘Danish building typologies’ report.

	Ceiling	Wall	Floor
	Out / In	Out | In	In / Out

Original

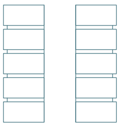
Ceiling (Out / In)



Construction:
1. Wooden ceiling 20 mm
2. Timber beam 100x150 mm
3. Insulation 50 mm

U-value: 0,727 W/m2K
Thickness: 170 mm
Heatloss: 56 kWh per m^2
Area: 94 m2

Wall (Out | In)



Construction:
1. Brick 108 mm
2. Uninsulated cavity 84 mm
3. Brick 108 mm

U-value: 1,477 W/m2K
Thickness: 300 mm
Heatloss: 115 kWh per m^2
Heat capacity: 122 kJ/m2K
Condesation: 1,7 kg/m2
Area: 98 m2

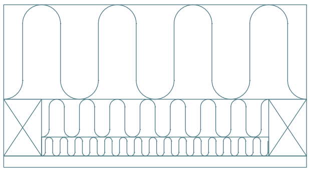
Floor (In / Out)

Construction:
1. Wooden flooring 20 mm
2. Timber beam 100x150 mm
3. Air gap 30 mm
4. Clay pugging 50 mm
5. Wooden boards 20 mm

U-value: 1,244W/m2K
Thickness: 170 mm
Heatloss: 96 kWh per m^2
Heat capacity: 32 kJ/m2K
Condesation: 0,0 kg/m2
Area: 66 m2

Conventional proposal

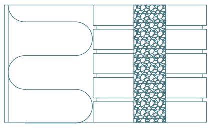
Ceiling



Construction:
1. Wooden ceiling 20 mm
2. Timber beam 100x150 mm
3. Insulation 50 mm
4. Mineral wool 350 mm

U-value: 0,102 W/m2K
Thickness: 420 mm
Heatloss: 8 kWh per m^2
Area: 94 m2
GWP: 11 kg CO_2 eq./m^2

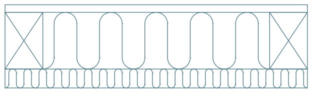
Wall



Construction:
1. Brick 108 mm
2. Perlite insulatiom 84 mm
3. Brick 108 mm
4. Mineral wool 225 mm
5. Facade plaster 2 mm

U-value: 0,116 W/m2K
Thickness: 527 mm
Heatloss: 9 kWh per m^2
Heat capacity: 292 kJ/m2K
Condesation: 0,0 kg/m2
Area: 98 m2
GWP: 25 kg CO_2 eq./m^2

Floor

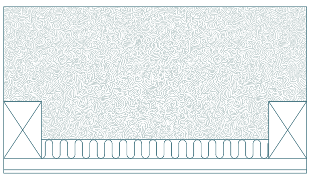


Construction:
1. Wooden flooring 20 mm
2. Timber beam 100x150 mm
3. Mineralwool 200 mm
4. Gypsum board 9,5 mm

U-value: 0,212 W/m2K
Thickness: 230,5 mm
Heatloss: 17 kWh per m^2
Heat capacity: 26 kJ/m2K
Condesation: 0,0 kg/m2
Area: 66 m2
GWP: 4,8 kg CO_2 eq./m^2

Eelgrass proposal

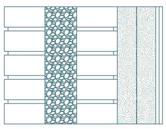
Ceiling



Construction:
1. Gypsum board 9,5 mm
2. Wooden ceiling 20 mm
3. Timber beam 100x150 mm
4. Insulation 50 mm
5. Eelgrass loose fill 350 mm

U-value: 0,108 W/m^2K
Thickness: 429,5 mm
Heatloss: 8 kWh per m^2
Area: 94 m^2
GWP: -4,9 kg CO_2 eq./m^2

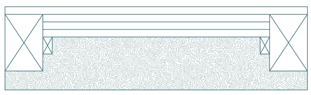
Wall



Construction:
1. Gypsum board 9,5 mm
2. Plywood 9 mm
3. Eelgrass batt 50 mm
4. Vapour barrier
5. Eelgrass batt 50 mm
3. Brick 108 mm
4. Uninsulated cavity 84 mm
5. Brick 108 mm

U-value: 0,194 W/m2K
Thickness: 410 mm
Heatloss: 15 kWh per m^2
Heat capacity: 105 kJ/m2K
Condesation: 0,0 kg/m2
Area: 98 m2
GWP: -6,3 kg CO_2 eq./m^2

Floor



Construction:
1. Wooden flooring 20 mm
2. Timber beam 100x150 mm
3. Air gap 30 mm
4. Clay pugging 50 mm
5. Wooden boards 20 mm
6. Eelgrass batt 120 mm
7. Gypsum board 9,5 mm

U-value: 0,262 W/m2K
Thickness: 261,5 mm
Heatloss: 20 kWh per m^2
Heat capacity: 108 kJ/m2K
Condesation: 0,0 kg/m2
Area: 66 m2
GWP: 1,4 kg CO_2 eq./m^2

Illu. 66. Table of original constructions and renovation constructions with mineral and eelgrass solutions. Values are based on Ubakus models of the constructions. All constructions are presented from inside to outside.

EXAMPLE

Single-family House 1850-1930

CEILING

The ceiling is insulated with 400 mm of eelgrass loose fill and thereby reaches a U-value of 0,112 W/m²K, which means that it fulfils the requirements of a U-value of 0,12 as required in the Danish Building Regulations. Beneath the existing ceiling, a gypsum board is installed, to secure the insulation material from fire.

PARTITION FLOOR

The partition floor is left untouched, since the clay pugging should provide noise insulation and fire protection to the construction. Since the temperature of the two spaces the partition floor is separating have the same temperature, the thermal insulation eelgrass could provide isn't necessary.

BASEMENT CEILING

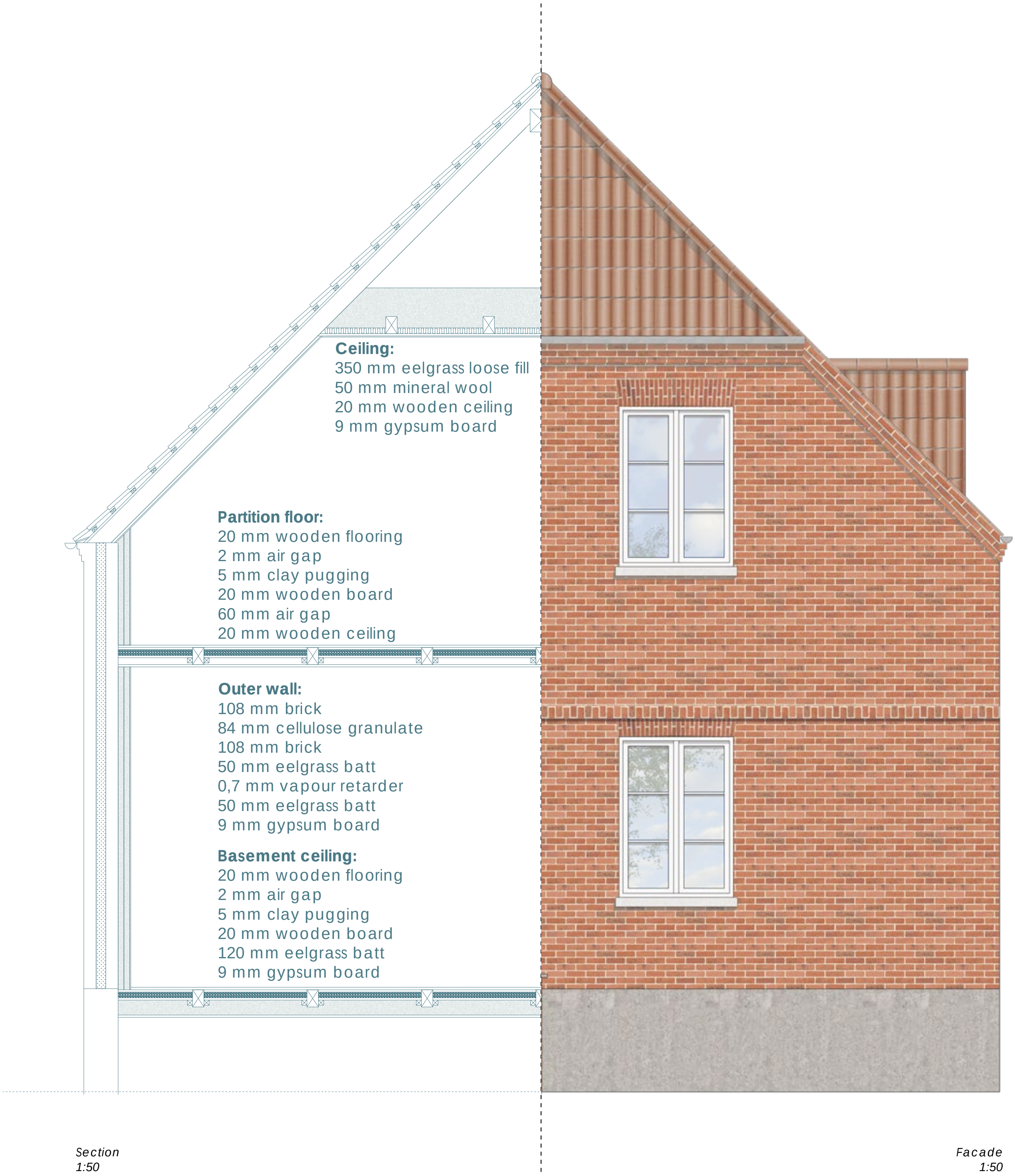
For the partition floor towards the basement the floor is however reinsulated as it is assumed that the basement is unheated and thereby is more than five degrees colder than the living space. For decks separating spaces with a temperature difference of more than five degrees, the Danish Building Regulations require that the U-value after renovating is at least 0,4 W/m²K (Social- og Boligstyrelsen, 2022). These requirements are fulfilled by insulating with 120 mm of eelgrass batts underneath the clay pugging, meaning that the room height of the basement will be decreased. Beneath the eelgrass insulation a gypsum board of 9,5 mm is installed to ensure the fire safety. The renovated construction reaches a U-value of 0,262 W/m²K, compared to the original U-value of 1,244 W/m²K. In this case the basement ceiling was insulated from beneath since the room height of the basement is easier to sacrifice than the room height of living spaces. The eelgrass batts were utilised in this case, since it is simpler to instal in the ceiling. However, if one is to change the flooring, the basement ceiling could just as well have been insulated from above. In that case eelgrass loose fill could also have been utilized.

OUTER WALL

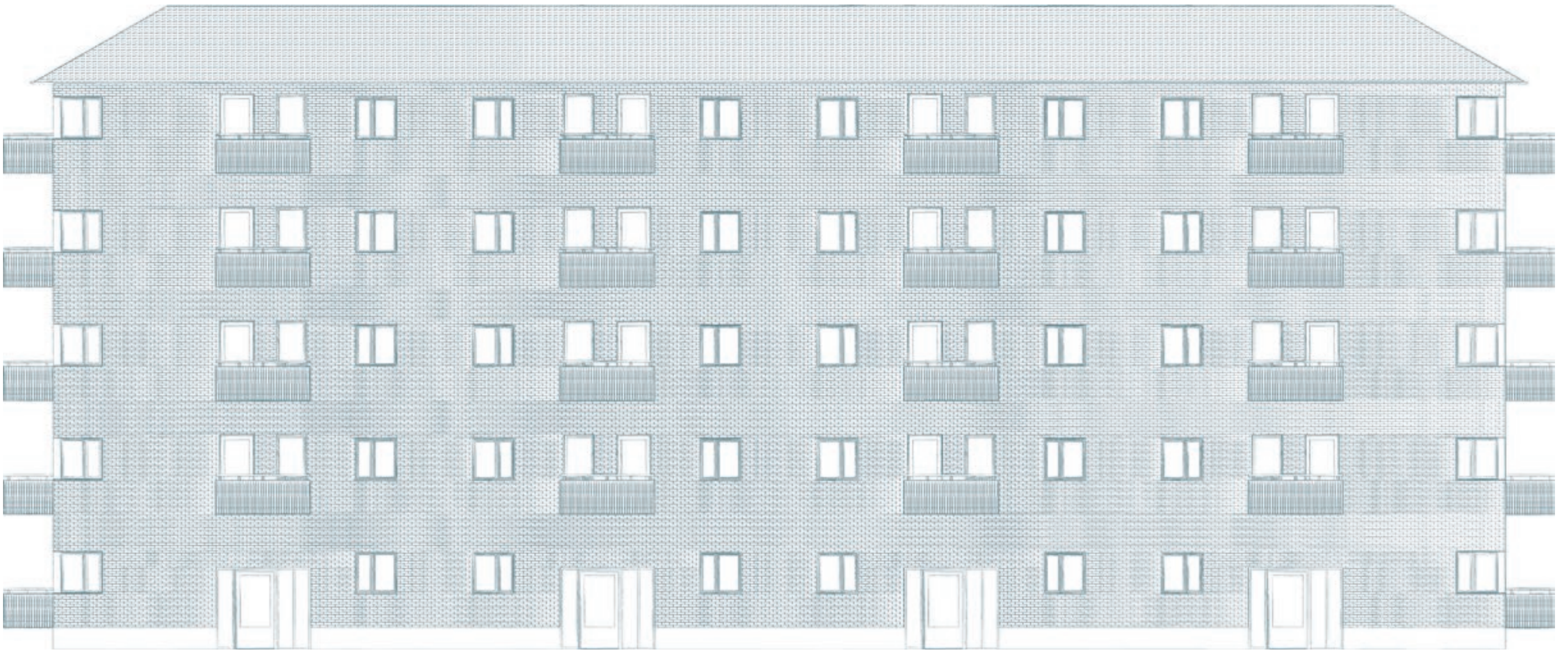
When insulating on the interior side, it is recommended to maximum reinsulate with 100 mm of insulation, to not cause condensation in the construction. The outer wall is therefore insulated with 100 mm eelgrass batts. The eelgrass batts are chosen over loose fill eelgrass, as the batts have a lower thermal conductivity, which is preffered when there is a limitation to the thickness of the insulation. The batts are covered with a gypsum board to fulfil the fire requirements. 50 mm into the insulation layer, it was necessary to install a vapour barrier, since the calculations proved condensation in the construction otherwise. With the limitations of insulating on the interior side, the outer wall is the only construction that doesn't fulfil the requirements of the Danish Building Regulations, regarding U-value. The required U-value of the regulations is 0,18 W/m²K for outer walls (Social- og Boligstyrelsen, 2022), whereas the construction reaches a U-value of 0,194 W/m²K. If the exterior appearance of a building is worthy of preservation, the municipality can grand dispensation from the regulations (Social- og Boligstyrelsen, 2022). Even though, the renovation doesn't fulfil the requirements, the re-insulation of the outer wall does decrease the energy use for heating with approximately 100 kWh per sqauremeter wall yearly.

Summary

Reinsulating with eelgrass on the interior side theoretically is meaningful, as problems with moisture is often an issue faced when reinsulating on the interior side, and this is an aspect which eelgrass handles better than conventional insulation materials. However, in the calculations performed, the eelgrass insulation didn't have the expected effect on the condensation of the wall construction, and it was necessary to add a vapour retarder to solve the issues. It might be the calculation software that isn't appropriate for the calculations, as interior re-insulation with eelgrass without the application of a vapour barrier has proven to function in praxis (Appendix 04). Through the investigation of reinsulating on the interior side of the building it is also found that the low possible applicable thickness of eelgrass hinders the renovated construction from fulfilling the requirements of the Danish Building Regulations.

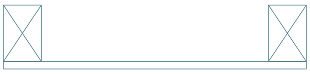


Illu. 67. Illustration of renovation solutions shown in a section, paired with a facade illustration showcasing the exterior appearance.



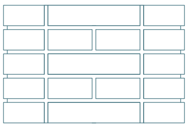
Illu. 68. ABB 1931-1950 facade. 1:200

According to the report 'Danish building typologies'a typical Apartment Building built between 1931 and 1950 would consist of constructions resembling the following illustrations.



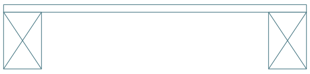
Illu. 69. Illustration of ABB 1931-1950 ceiling construction.

The ceiling would often consist of an uninsulated frame of joists.



Illu. 70. Illustration of ABB 1931-1950 outer wall construction.

A typical wall would be a massive 480 mm brick wall with no insulation.

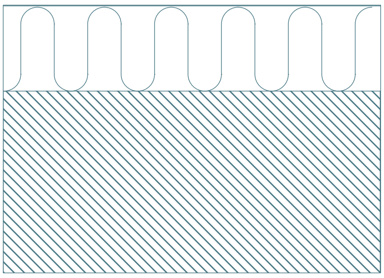


Illu. 71. Illustration of ABB 1931-1950 floor construction.

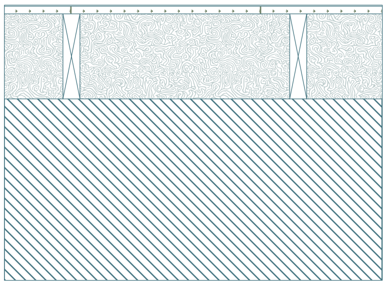
The floor would typically consist of boards placed on joists with no insulation.

RENOVATION

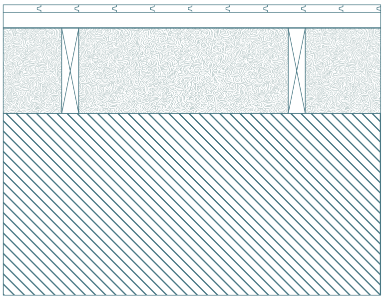
For the sake of the example the, the apartment building from 1931 to 1950 will be renovated by reinsulating on the exterior side of the wall. Insulating on the outside is more efficient regarding thermal insulation and doesn't present the same issues with moist in the construction as reinsulating on the inside, since the construction becomes more diffusion open towards the outside. Therefore, when it is acceptable to change the exterior appearance of the architecture, it is recommendable to reinsulate on the exterior side. However, one must be aware that the roof overhang still covers the construction and that the interior spaces are still provided with enough daylight, since the walls and thereby openings are getting deeper.



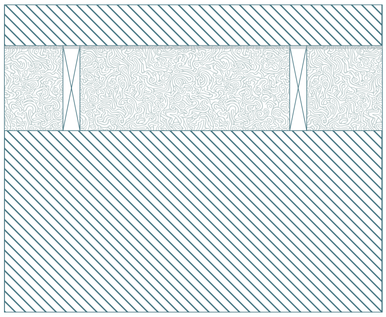
Plaster on mineral wool
Thickness: 707 mm
U-value: 0,153 W/m^{2}K
GWP: 7,9 kg CO_2-eq/m^2
Condensation: 0,00 kg/m^2



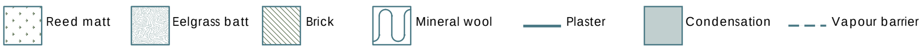
Plaster on eelgrass
Thickness: 728 mm
U-value: 0,154 W/m^{2}K
GWP: -7,7 kg CO_2-eq/m^2
Condensation: 0,00 kg/m^2



Wooden cladding
Thickness: 790 mm
U-value: 0,160 W/m^{2}K
GWP: -16 kg CO_2-eq/m^2
Condensation: 0,00 kg/m^2



Additional brick
Thickness: 813 mm
U-value: 0,158 W/m^{2}K
GWP: 9,1 kg CO_2-eq/m^2
Condensation: 0,46 kg/m^2



Illu. 72. Illustrations of four different solutions for reinsulating a facade. In plan view. Scale, 1:20.

When reinsulating with mineral wool on the outside, the insulation is often finished with a layer of plaster. For this, a special façade insulation, which is designed for this solution, is used. When reinsulating with eelgrass it is also possible to have plastered finish, by adding reed mats on top of the insulation. The plaster can then be applied on the reed mats. However, in this case a solution with an additional wooden cladding is chosen.

The additional wood cladding will make the already thick construction even deeper. However, simple calculations in Ubakus showcase that, even though it requires more material, reinsulating with eelgrass insulation batts has a lower GWP than the solution with mineral wool and finishing plaster.

Adding an additional layer of bricks would mime the existing façade.
However, adding the brick layer on the cold side of the construction poses issues with condensation in the construction.
Applying a wooden cladding on top of the eelgrass insulation, creates a construction with lower diffusion resistance on the cold side, which prevents the condensation. Additionally, the wooden façade has a negative GWP, whereas using bricks will have a positive GWP.

As previously stated, fire safety requires extra awareness when working with eelgrass insulation. As mentioned in the section Requirements – Fire, there are requirements for both the cladding and the underlying protecting layer if the external cladding is to be constructed with an underlying airgap. In buildings where the upper floor doesn't exceed 22 meters in height, the cladding must be a material class B-s2,d0 and underlying protecting layer must be a class $K_1$10 B-s1,d0. (Træinformation, 2021)
Today most façade wood distributors provide different solutions for products of the required fire classification. The fire classification, class B-s2,d0, is reached for wooden facades by using fire impregnated wood that are part of a closed façade system. Some wooden façade claddings can even reach a fire classification B-s1,d0 depending on the wood species. (Frøslev, 2023) For the underlying protecting layer the wind barrier will also function as fire protection as many wind barriers can be acquired as a B-s1,d0 material.

As previously explained, when renovating it is important to consider if the renovation should also include noise reducing solutions, as the partition floors in many older buildings are constructed only in wood. This is the case for the example of an apartment building from 1931 to 1950, therefore solving noise issues of this case is very important, to enhance the quality of living for the residences.
To improve the noise conditions of the building, the floors will be insulated with eelgrass insulation batts as they have a high density, which is effective in the reduction of noise transmission. Additionally, the eelgrass provides thermal insulation between the spaces.

Ceiling (Out / In) — Wall (Out | In) — Floor (In / Out)

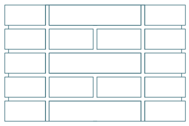
Original

Ceiling

Construction:
1. Wooden ceiling 20 mm
2. Timber beam 100x150 mm

U-value: 2,826 W/m2K
Thickness: 170 mm
Heatloss: 220 kWh per m^2
Area: 556 m2

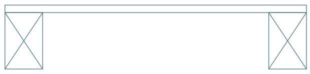
Wall



Construction:
1. Brick 480 mm

U-value: 1,114 W/m2K
Thickness: 480 mm
Heatloss: 87 kWh per m^2
Heat capacity: 304 kJ/m2K
Condesation: 0,052 kg/m2
Area: 1516 m2

Floor

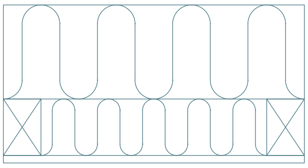


Construction:
1. Wooden flooring 20 mm
2. Timber beam 100x150 mm

U-value: 2,399W/m2K
Thickness: 170 mm
Heatloss: 271 kWh per m^2
Heat capacity: 2,8 kJ/m2K
Condesation: 0,0 kg/m2
Area: 556 m2

Conventional proposal

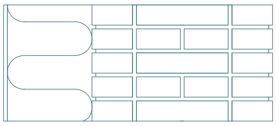
Ceiling



Construction:
1. Wooden ceiling 20 mm
2. Timber beam 100x150 mm
3. Mineral wool 400 mm

U-value: 0,102 W/m2K
Thickness: 420 mm
Heatloss: 8 kWh per m^2
Area: 556 m2
GWP: 12 kg CO_2 eq./m^2

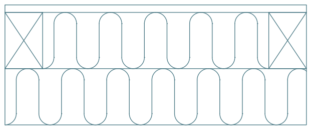
Wall



Construction:
1. Brick 480 mm
2. Mineral wool 225 mm
3. Facade plaster 2 mm

U-value: 0,153 W/m2K
Thickness: 707 mm
Heatloss: 12 kWh per m^2
Heat capacity: 658 kJ/m2K
Condesation: 0,0 kg/m2
Area: 1516 m2
GWP: 7,9 kg CO_2 eq./m^2

Floor



Construction:
1. Wooden flooring 20 mm
2. Timber beam 100x150 mm
3. Mineralwool 200 mm

U-value: 0,216 W/m2K
Thickness: 210 mm
Heatloss: 17 kWh per m^2
Heat capacity: 22 kJ/m2K
Condesation: 0,0 kg/m2
Area: 556 m2
GWP: 5,6 kg CO_2 eq./m^2

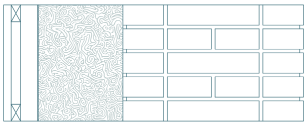
Eelgrass proposal

Ceiling

Construction:
1. Gypsum board 9,5 mm
2. Wooden ceiling 20 mm
3. Timber beam 100x150 mm
4. Eelgrass loose fill 400 mm

U-value: 0,109 W/m^2K
Thickness: 429,5 mm
Heatloss: 8 kWh per m^2
Area: 556 m^2
GWP: -5,8 kg CO_2 eq./m^2

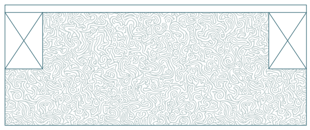
Wall



Construction:
1. Brick 480 mm
2. Eelgrass batt 225 mm
3. Wind barrier
4. Ventilated airgap 40 mm
5. Wood cladding 40 mm

U-value: 0,160 W/m2K
Thickness: 789 mm
Heatloss: 12 kWh per m^2
Heat capacity: 671 kJ/m2K
Condesation: 0,0 kg/m2
Area: 1516 m2
GWP: -17 kg CO_2 eq./m^2

Floor



Construction:
1. Wooden flooring 20 mm
2. Fire retardent plywood 9,5 mm
3. Timber beam 100x150 mm
4. Eelgrass batt 200 mm

U-value: 0,199 W/m2K
Thickness: 232 mm
Heatloss: 15 kWh per m^2
Heat capacity: 46 kJ/m2K
Condesation: 0,0 kg/m2
Area: 556 m2
GWP: -3 kg CO_2 eq./m^2

Illu. 73. Table of original constructions and renovation constructions with mineral and eelgrass solutions. Values are based on Ubakus models of the constructions. All constructions are presented from inside to outside.

EXAMPLE

Apartment Building 1931-1950

CEILING

The ceiling of the apartment building is insulated with eelgrass loose fill as the single-family house. Since there were no insulation in the existing construction, 400 mm insulation is applied in this case. For fire protection a gypsum board is installed beneath the existing ceiling. The U-value of the renovated construction is thereby 0,113 W/m^{2}K, which means that it fulfils the requirements of the Danish Building Regulations of a U-value of 0,12 W/m^{2}K.

PARTITION FLOORS

As the existing partition floors consist only of wooden floors and joists, it is assumed that noise between apartments is an issue, and the floors should therefore be insulated. The partition floors are insulated with 150 mm eelgrass batts between the joists. The batts are chosen over the eelgrass loose fill, as the batts has a higher density, which makes it better for breaking noise transmission through the construction. Additionally, the eelgrass batts provide load bearing capacity itself, compared to loose fill. If the eelgrass granulate become more common in the future, it would also be ideal for partition floors, as it has a higher density and can be blown in, which makes the operation easier and faster. Additionally, insulating the partition floors will help the lower apartments to preserve their heat.
When insulating the partition floors with eelgrass it is necessary to add cladding of fire classification $K_1$10/B-s2,d0 on both sides of the insulation. On the upper side a fire retardant plywood board is applied beneath the flooring. On the lower surface, the eelgrass is covered by a gypsum board.

BASEMENT CEILING

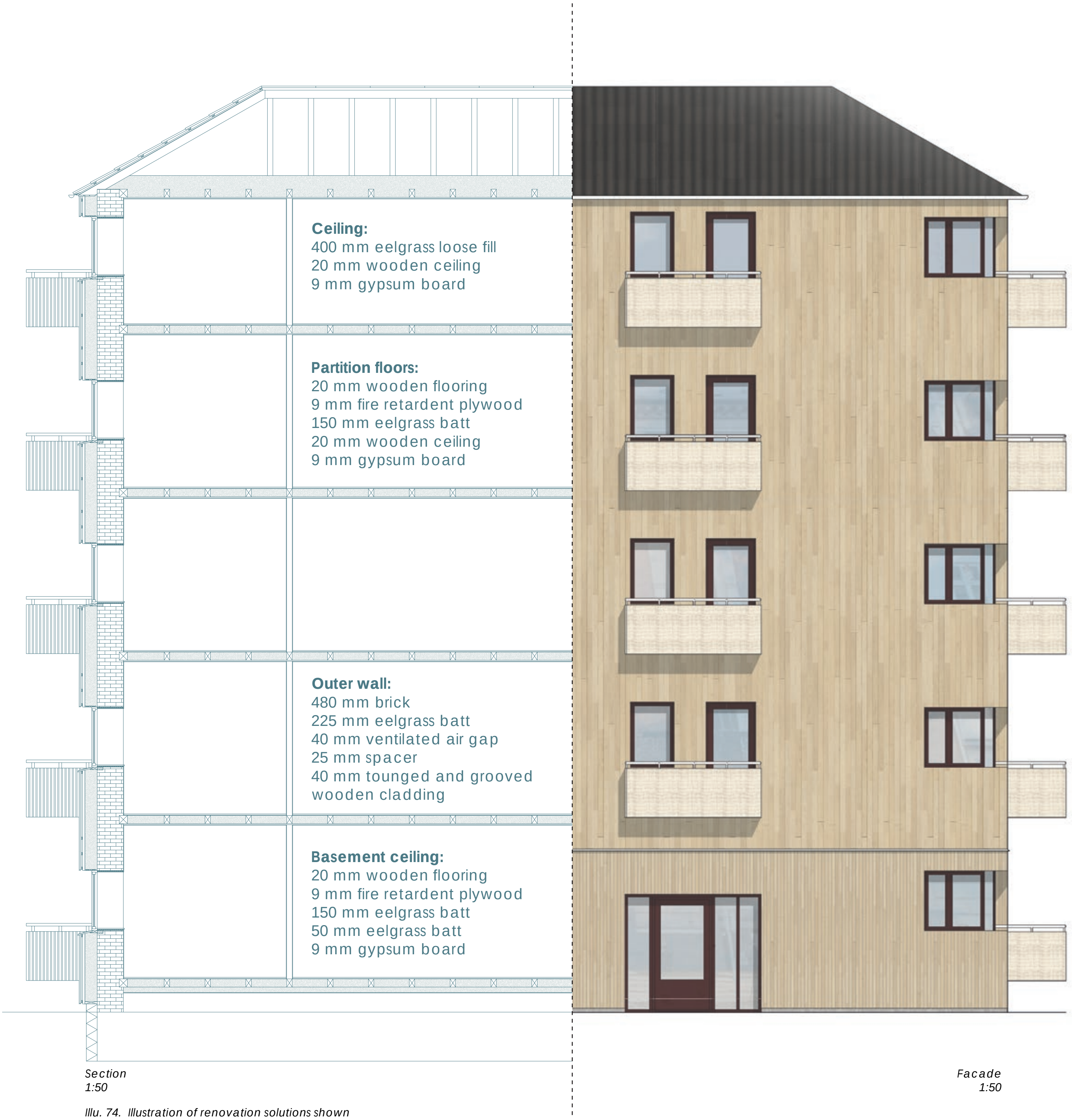
To hinder the heat from the lowest apartments to transmit through the construction to the basement, the basement ceiling is insulated with an extra layer of insulation, compared to the partition floors. The air gap between the existing joists is insulated with eelgrass batts as the partition floors. Beneath this layer an additional 50 mm layer of joists an insulation is added. The basement ceiling is finished of with a gypsum board to fulfil the fire requirements.

OUTER WALL

The existing outer wall consisted of 480 mm massive brick wall, leaving it with a U-value of 1,114 W/m^{2}K. As the requirements for U-values of the outer wall in renovations is 0,18 W/m^{2}K, the outer wall needed to be reinsulated. The outer wall in this case is insulated on the exterior side, which means that more insulation can be added without risk of condensation. However, the exterior insulation poses other awareness points. One has to make sure that the roof overhang covers the additional insulation, and that the daylight is sufficient in the dwellings when adding more depth to the wall.
In this case the existing outer wall is insulated with 225 mm of eelgrass insulation batt. The insulation is protected by wooden cladding with an underlying airgap, resulting in high requirements for the façade cladding. The wooden siding is fire impregnated and part of a closed façade system to ensure the fire safety.

Summary

The comparisons of constructions show that in general the eelgrass constructions have a lower GWP than the conventional constructions. However, the lower GWPs of the eelgrass constructions, are highly affected by the negative values of the wooden joists and boards added in these constructions, as the eelgrass insulation batts have a higher GWP than expected.
Reinsulating with eelgrass is possible regarding fire, however it does need more attention than in conventional constructions.
When reinsulating on the exterior side with eelgrass one doesn't make the same use of the positive properties of eelgrass, such as moisture buffering and sound absorption, as is some the great qualities of eelgrass as a building material. However, using the eelgrass in the partition floors makes great sense, as it has higher density than conventional insulation materials and thereby greater effect on the noise insulation.



Illu. 74. Illustration of renovation solutions shown in a section, paired with a facade illustration showcasing the exterior appearance.

Illu. 75. Photography of fresh eelgrass on the coast.
Photography provided by Seegrashandel.

03 DESIGN

In the design section a design proposal which can raise awareness of the importance of biobased materials and of caring for the marine environment is designed. The design section present theory and case studies applied to the design, along with the design process and the presentation of the final design proposal.

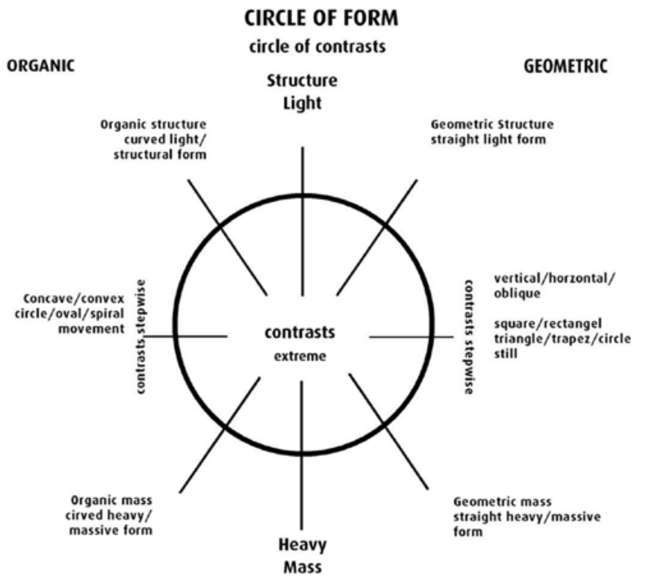
MODSÆTNINGER [OPPOSITES]

Theory of Contradistinctions

Looking at the original seagrass houses of Læsø, it is clear that the building heritage is one of a kind. The thick and heavy eelgrass roofs almost consume the exterior walls of the building and the proportions of roof to wall seems unnatural compared to conventional buildings. The great mass of the eelgrass thatched roof is distinctive to the Læsø houses, and working with playing up against this great mass in order to enhance the experience of it is found interesting. Therefore, working with contradistinctions will be part of the design process of the eelgrass exhibition.

SUSPENSE

To gain understanding of contradistinctions and how to work with these the theory of contradistinctions as explained by Thomas Arvid Jaeger in the books Modsætninger, has been investigated.
In literature an antithesis is often used to enhance the thesis. The same is evident in design and architecture. According to the literature, opposites put focus on the distinguishing of shapes. For example, a known technique is to emphasize one object by putting it up against its contradistinction. According to the book working with contradistinctions creates a suspense in the understanding of the relation. The suspense is defined as a conception of the experience of witnessing something contradicting and incompatible, turn into a whole. It is established by Arnheim that we as humans react to visual imbalances and that these imbalances create an impression of suspense. The suspense is therefore relative and is understood by the physics of our own body.
A central figure in illustrating opposites is the black circle in a white square, a figure by Arnheim.
Working with opposites is paradoxical, as one must recognize that two contradicting elements, in fact are very closely related. Not all shapes or phenomena can be put together and be contradistinction. The pairs of opposites must have a relation, while simultaneously being polar occurrences of this relation. Contradistinctions work as a whole, while emphasizing the component. (Jaeger, 2010)



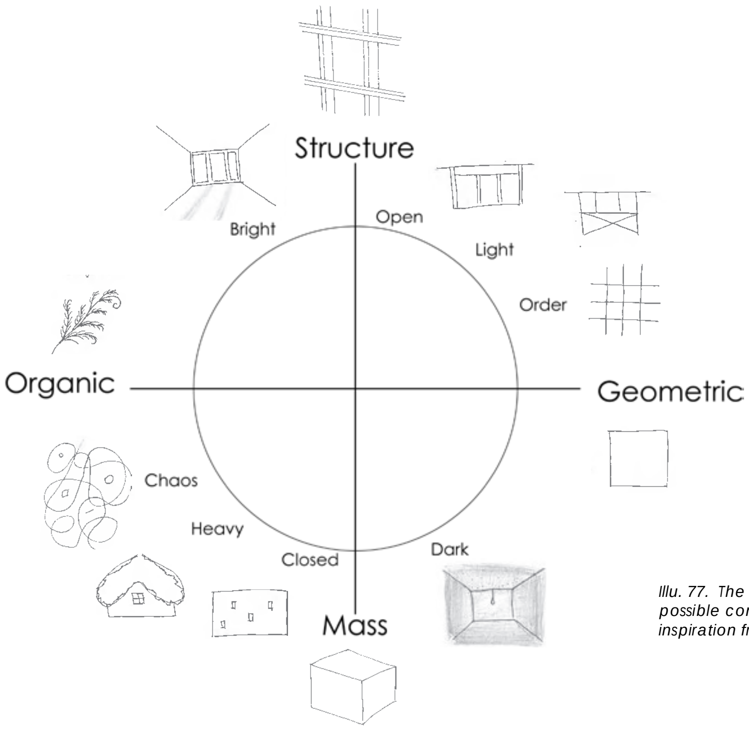
Illu. 76. Circle of form and contrast, from the book Modsætninger, by Thomas Arvid Jaeger.

THE CONTRAST CIRCLE

Contradistinctions are to be found in colours as well. However, the chromatology is more widespread and commonly known and the tools to working with colours are more well defined. When working with colours the colour circle set up by Goethe is a well-known system that present the opposing colours against each other over the middle axis of the circle, while gradually fading the colours into each other along the circles perimeter.
In the book the same systematisation is attempted for contrasting shapes, by inserting both simple- and complex elements into the so called Kontrastcirkel [Contrast circle]. The circle consists of two main pairs of opposites, one pair on each axis in the two-dimensional system. These pairs are organic and geometric on the x-axis and structure and mass on the y-axis. In between the main pairs the phenomena are placed along the circle gradually resembling each other. (Jaeger, 2010)

OPPOSITES

Working with opposites in design can be performed with a vary of effects. Many philosophers and artist have attempted to map out the contradistinction pairs of shapes, design and compositions. Speaking of shapes, these are in the book divided into two sub-categories, the simple- and the complex shapes. The simple shapes are identi-



Illu. 77. The illustration attempts to map the possible contradistinctions of the design, with inspiration from the contrast circle.

fied as shapes that can't be dissected further into sub-shapes. Simple contradicting shapes could for example be heavy and light, mass and structure or straight and curved. The complex contradistinctions are elements such as geometric and organic, calm and movement or order and chaos.
In the following some of the contradistinction pairs will be elaborated.
As mentioned, the two main pairs of opposites in the book are geometric versus organic and mass versus structure.

Geometric against organic is a complex pair of contradistinctions and covers many sub-components such as curved and straight. However, the two phenomena have through time as a general been understood as the geometric shape being unnatural and has often been used by artist attempting to dissociate from nature. Whereas the organic shape is considered to be harmonic and balanced. Additionally, this leads to the common understanding of organic being more free than geometric.
In general, geometric shapes are simple geometric elements which can be described by relatively simple mathematics. Organic shapes however are much more complex and sometimes impossible to describe with words. Also, the mathematics of the organic seems to be complex. The understanding of organic in itself is complex, as geometric shapes can be interpreted as organic if they are placed in an organic system of continuity and coherence.
The other main pair of opposites is as mentioned the contradistinctions, mass and structure. These are two very disparate directions in the design of architecture. The structural shape is open, sequential and line based. Whereas the mass shaping is closed, understood as a whole and based on surfaces. Mass and structure aren't shapes in themselves, but to be understood as a characteristic of either an organic or geometric shape. (Jaeger, 2010)

Order and chaos is another of the well-known pairs of contradistinctions. While some work only with one of these poles, most seek to work in the span between the two poles, as order can fetter the work, while chaos allows for freedom. Many seeks to work in some freedom in a work of order. And as stated in the book, history proves that chaos often promotes the need for order, and vice versa, rules and order often provoke a lust for chaos.

The effect of materials is understood through the differences in structure and surface and some of the opposites occurring in the material is coarse versus fine, rough versus sleek and shiny against matt.
When working with opposites one must be aware of the transitions power of making the components seem either like a whole or as oppositions. In the transition itself contradistinctions are found, these are known as the phenomena either-or and more-or-less. Either-or contradistinctions are very strong opposites put up against each other, and the effect is pronounced and dramatic. In the span between the poles of either-or, the spectrum of more-or-less is found. Working with the more-or-less spectrum allows the designer to adjust the suspense between the opposites. (Jaeger, 2010)

BIOSACK
REX SKOV ARKITEKTER

A case-study of an eelgrass pavilion

Year: 2022
Function: Culture
Location: Moveable
Size: 12 m^2

Illu. 78. Photography of BioSack. Photography by Joakim Züger.

BioSack is a pavilion designed by RexSkov Arkitekter for the Chart Architecture competition of 2022, with the topic bio-architecture. The pavilion is inspired by the original seagrass thatched houses of Læsø and seeks to indulge spectators to reflect upon the use of biogenic architectural materials. The volume of the chaotic eelgrass on the roof, contrast the structural simplicity of the traditional timber construction. On the floor is laid out a layer of seashells. (Skov, 2022)

From personal experience from visiting the pavilion, it was clear that BioSack provided a multisensory experience. The intense sound of the shells cracking beneath your feet, the tactile sensation and the smell of the natural bare materials.
The pavilion received the first prize at the architecture competition, and Bjarke Ingels, one of the members of the jury, explained the first prize with the statement, that:

"The theme for this year was Bio Architecture, with an invitation to pursue innovation in the field of materials, learning or benefiting from the interplay between the man-made and the natural. Ultimately, the reason we decided on this pavilion was because the idea of seagrass as roofing has a great potential for innovation going forward." (Skov, 2022)

BioSack and the team behind, won the competition of using biogenic materials in innovative ways, by being retrospective and finding inspiration in former building techniques.

Michael Skov, one of the architects of the team proclaims:

"De seneste år er der opstået en forestilling om, at nyskabelse skal komme fra noget nyt. Midt i al den innovation, glemmer vi ofte traditionerne. Personligt tror vi på, at nyskabelse lige så godt kan komme fra at genbesøge gamle metoder. I vores pavillon genbesøger vi præmissen om at designe ud fra begrænsede mængder – ud fra det, der er tilgængeligt."

["In recent years, a notion has arisen that innovation must come from something new. In the midst of all the innovation, we often forget the traditions. Personally, we believe that innovation can just as well come from revisiting old methods. In our pavilion, we revisit the premise of designing from limited quantities – from what is available."]

Sub Conclusion

The case-study illustrates that using unconventional materials raises interest of the architecture. The multisensory approach enhances the experience of the pavilion, and the contrasts of the elements further enhances the appearance of the untraditional traditional architecture.
Lastly, looking back at old building techniques, might be the way to approach sustainable development in the future.

Illu. 79. Photographies of BioSack at the exhibition 'Super Dansk' at Utzon Center. Photographies by Anne-Mette Rosenkilde

Illu. 80. Photography of the Wadden Sea Centre. Photography by Adam Mørk.

VADEHAVSCENTRET [THE WADDEN SEA CENTRE]

DORTE MANDRUP

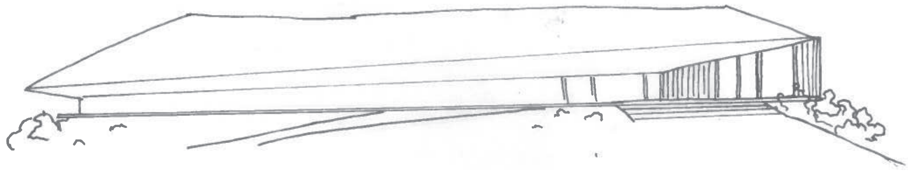
A case-study of reinventing a national building style

Year: 2017 & 2021
Function: Culture
Location: Okholmvej 5, Ribe

To learn of how to bring a regional and historic building material into our current architecture and to bring new interest on the material and the craftmanship of the material, a case study of a building doing just this is carried out. The case study will investigate how The Wadden Sea Centre, reinterprets a historic building material in a modern way.

The Wadden Sea Center is a transformation of the former Wadden Sea Center. The transformation is designed by the Danish architecture firm Dorte Mandrup. For the transformation the existing four-winged farm containing the center, was cladded with wood and reed on roofs and facades.
The thatched roof and facades are inspired by the surrounding vegetation, as well as the regional building customs. (Dorte Mandrup Arkitekter, n.d.) However, the appearance of the transformed Wadden Sea Centre is quite distant from the original reed thatched house that you will find in the area. First of all, the thatch covers not only the roof, as originally seen, but also all of the façade down to the plinth. Furthermore, the reed forms a vary of shapes, as it is all pointy in one meeting of the roof surfaces and in other meetings the angles are frustum. With simple but sharp horizontal and diagonal lines, the reed thatch is transformed from something old and well known to a modern, new and interesting architecture.
In a podcast Architect Dorte Mandrup, explains how the topography of the site was an important factor in the design process. The horizontal and diagonal lines are used in order to make the building grow out of the flat terrain, rather than contrasting it. (Skak & Bjørn, 2019)
Furthermore, the thatch takes additional distance from the regional inspirations, by combining the reed with new elements, such as untreated wooden cladding, large glass panes and sliding doors with lamellas. As chief editor of the Arkitekturforeningen [Architecture Association], Martin Keiding writes in a review of The Wadden Sea Centre

Illu. 82. Drawing of original thatched house.



Illu. 83. Drawing of the Wadden Sea Centre.

"The new architecture has connections to the regional ranch-style house with reed thatched roofs. Other elements resemble wooden barns in USA. Some facade sections are lamella doors, which can be moved back and forth, revealing pillars. This seems Japanese. But the way, reed and wood are joined, exists only here. The fact that facade and roof in some places is one material, is rare; everyone raise their hand to touch the stiff camel fur of the house." (Keiding, 2017)

Thatch is a commonly known method and quite often seen in Denmark. However, most people have never experienced the tactile sensation of the reed, since the material is placed on the roof, out of reach. Bringing the material down to the façade and all the way to the ground allows for a new tactile experience.
An experience which the visitors don't pass by. When visiting the Vadehavscenter it was clear that every fellow visitor seized the opportunity and touched the reed thatch on the façade, myself included.

Illu. 81. Photography of the tactile experience of the Waden Sea Center. Photography by Heidi Rosenkilde Hansen

Apart from being part of the national building heritage, the straw thatch has also proven to be a great material in regard of its embodied carbon, and the thatched surface has great thermal insulation properties (Kauschen & Granby-Larsen, 2020). Together with the reinvention of thatch and the showcased possibilities of creating a more contemporary appearance, the Wadden Sea Centre has, according to Stråtagetskontor, a joined trade office for Danish thatchers, helped increase the popularity of reed thatch in architecture (Stråtagetskontor, 2024). This is seen in buildings such as Sundby School be Henning Larsen Architects from 2022.

Sub Conclusion

To revive the interest in a historic building material, we learn from the case study of The Wadden Sea Centre, that implementing the material into a contemporary design is a start. Additionally, the design must challenge the material and showcase new possibilities of the material. Allowing the public to experience the material in new ways, such as the tactility helps raise the interest in the material. Lastly, reinventing a material, might be helped along by combining it with new materials, materials which add other associations.

THEORY OF EXHIBITION

The Smithsonians Guide to Exhibitions

PROCESS

In their guide 'A guide to exhibit development' the Smithsonian present processes, structuring tools and key factors to design an exhibition. According to the guide, the process of planning an exhibition consists of five stages.

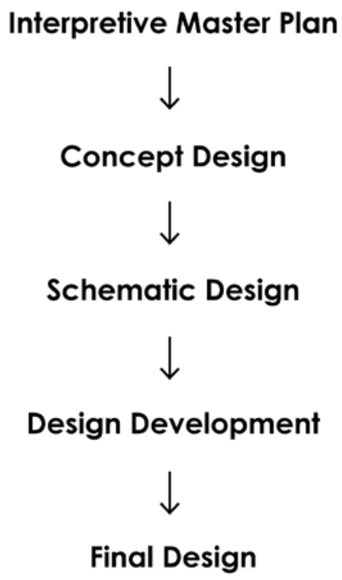
It starts off with the Interpretive Master Plan. In this phase the stakeholders, the targeted audience, the key goals and outlines are established.
It is recommended to create an Interpretive Hierarchy (see illustration 85) in the Interpretive Master Plan phase. The Interpretive Hierarchy consist of one big idea, which is based on the message the visitors should take with them from the exhibition. It then consists of the Key Messages, which are a small number of take-away statements. Lastly, the Interpretive Hierarchy consist of the so-called Critical Questions. These questions should relate to the Key Messages and should be questions which are answered by the exhibition. These make up a road map for the following planning.

The next phase is Concept Design. The Concept Design phase seeks to establish a concept for the exhibition and should result in a content brief, which includes among others overview of the exhibition and its main messages, and should present potential interpretive strategies, such as interactive and digital elements. It could also be considered whether the exhibition should be presented chronologically or thematically, and what the themes and subthemes could be.

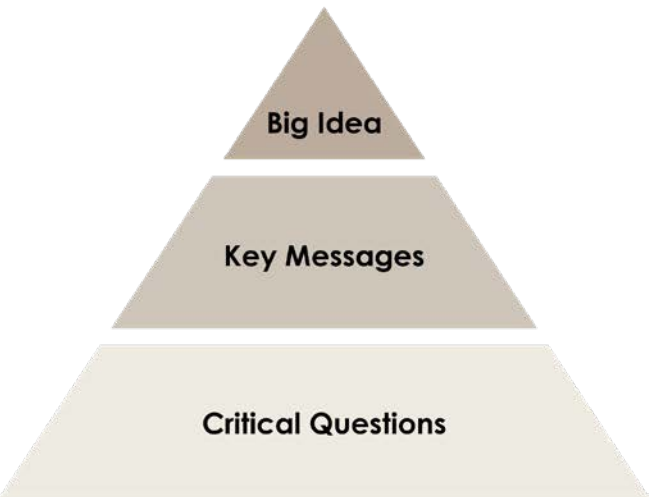
Next comes the Schematic Design phase. In the Schematic Design phase, the content of the exhibition, such as key objects, images, quotes and other elements are identified and divided into sections and subsections.

The next phase is called the Design Development phase, and seeks to transform the exhibition design from an outline to an Exhibit Script. The Exhibit Script contains ideas of presenting the content and of the narrative of the presentation.

Lastly, is the Final Design phase. In the Final Design phase, all the content is gathered, design details and layouts are determined, and the exhibition is finalized. (Smithsonian Exhibits, 2018)



Illu. 84. Phases of planning an exhibition.



Illu. 85. The Interpretive Hierarchy.

EXHIBITION CONTENT

When designing an exhibition, it is important to design for the expected audience and be aware that visitors have different interests, different ways of learning and are attracted to and entertained by different types of content. It is therefore important to design for different visitor types and different experiences. In the Smithsonian guide, the visitors are divided into four different categories based their preferred type of content.

The four categories are Ideas, which covers visitors who prefer conceptual and abstract thinking, People, for visitors seeking emotional connections, Objects, which includes visitors who are drawn to visual language and aesthetics and lastly, Physical, which covers visitors who seeks multi-sensory experiences.

To plan a successful exhibition, elements engaging all visitor types should be included. The visitors can be engaged by vary of elements and the content should be presented in different ways.

The list below presents some media through which the content can be presented.

Objects are what make exhibits unique. They lend authenticity and presence to exhibits.

Images provide visuals and illustrate ideas and concepts that may be difficult to explain in words. These include photos, maps, illustrations, charts, diagrams, etc.

Media elements, including video and audio presentations, add additional senses to the exhibit and help bring the content to life.

Interactives, including electromechanical and digital interactives, allow visitors to participate in the exhibit in a hands- and minds-on way and learn by doing.

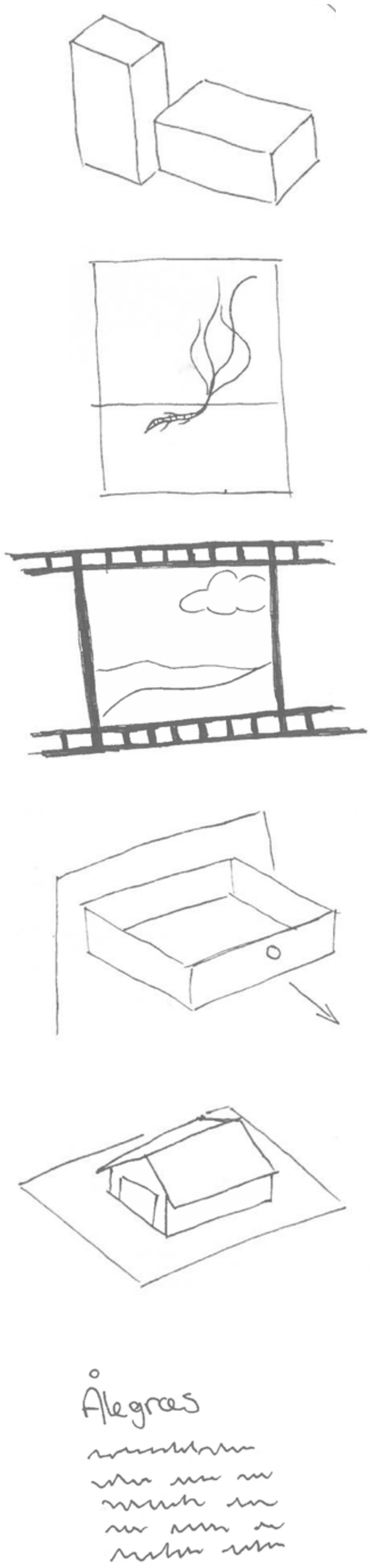
Models and tactile elements allow visitors to see and/or touch things that would not otherwise be accessible. Scale models enable visitors to interact with very large or small objects in new ways. A large object, such as a building or space shuttle, can be seen in its entirety. Conversely, the complexity of a tiny organism can be shown in an enlarged scale model.

Text is a key element, but it's important to remember that it's just one of many tools. Text is most effective when it's used strategically and graphically. Exhibits are not books on a wall. They should use all three dimensions of the space to tell the story. (Smithsonian Exhibits, 2018)(p.9)

Additionally, the visitor can be engaged by adding Talkback Labels, which are questions aimed towards the visitors, inviting them to share their opinions on different matters.

Just as important as it is to entertain and engage the visitor, it is to leave space for the visitor to reflect upon the learnings.

Lastly, the exhibition should help the visitor navigate, by designing for wayfinding. For wayfinding the flow of the exhibition can be designed to be intuitive, or wayfinding signage can be added. (Smithsonian Exhibits, 2018)



Illu. 86. Drawings of possible media for an exhibition.

Illu. 87. Water colour of eelgrass roof.

DESIGN PROCESS

The overall idea of the design is to design an exhibition which can inspire lay persons as well as civile, to implement more biobased materials in buildings, both in renovation, new build, or interior projects. Additionally, the exhibition should raise awareness of the state of the marine environments in Danish waters and emphasize the importance of eelgrass for the ecosystems.

To create a design which awakes attention and curiosity, the design should spark an interest just from looking at the exterior. To get attention and draw people in the main idea of the design, is to use the heavy and easily recognisable eelgrass thatched roof. This is despite the analysis conclud-ing that eelgrass roofs aren't the future. However, for the purpose of drawing attention, as well as historic parallels, the eelgrass thatched roof is just right.

Initial Design Criteria

	Criteria	Reasoning
Experience	The design must relate to the historic use of eelgrass	To tell the story of the material
	Must provide an experience through contradistinctions	To enhance the effect of the experienced elements
	Must provide a multi sensory experience	As it is one of the experiential qualities of natural materials
	The tactile experience of the materials shall be within reach	To invite the visitor to touch all surfaces and experience through their hands
	Must exhibit eelgrass constructions	To showcase the possible applications of eelgrass
Performance	The footprint of the building must be minimized as much as possible	To lower the energy and material use
	Must be closed insulated building	To showcase the insulation properties of eelgrass
	Must consist of the highest possible percentage of biobased building materials	To reach a low LCA and showcase the possibil-ities

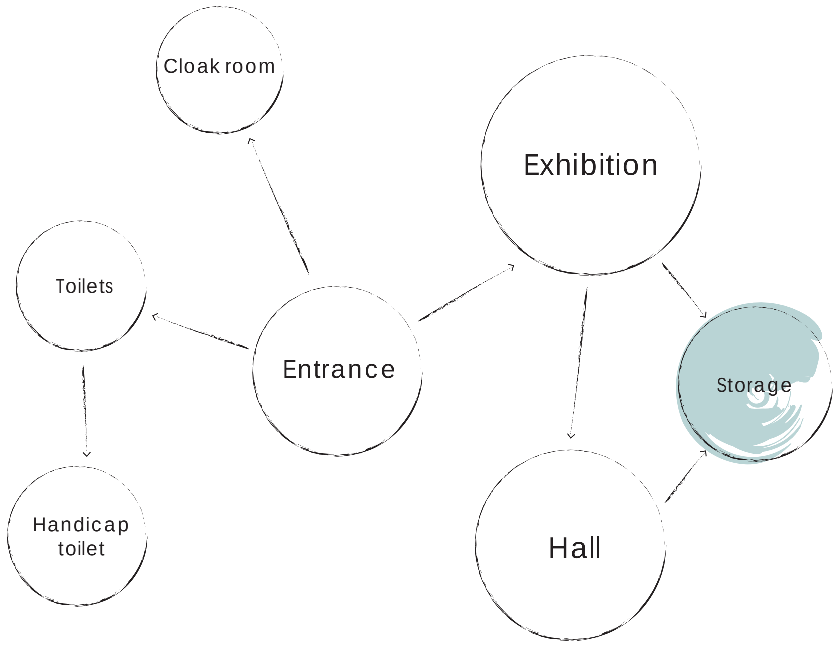
Room Program

Name	Number	Area	Function	Criteria	Atmosphere
Exhibition	1	50	Experience: Showcasing exhibition to public	Indirect light from north	Open, light, inviting
Hall	1	25	Experience: Room for lectures and projection of digital media	No flow through	Enclosed, dark, calm
Entrance	1	4	Experience/Practical: Entering and exiting, dividing practical from exhibition		Open, crossroad
Cloakroom	1	2	Practical: Room for coats and luggage		
Toilets	1-2	1,5	Pratical: Toilet	Toilet and sink in each stall	
Handicap toilet	1	4,8	Practical: Toilet		
Storage/ Technical	1	8	Practical: Storage for extra furniture, technical installations		
Hallway	+15%	15			
Total		115			

Function Diagram

To determine the desirable connections between the functions of the exhibition building, the functions are set up in a function diagram. The lines indicate the connections between the functions, while the size of the circles indicate the hierarchy of the functions. The coloured circles mark the functions to which the visitor should not access.

The entrance is the connection and divider of the practical and experience functions. There will be a flow through the exhibiton and the hall will be a dead end as the flow through should not disturb the calm atmosphere. The storage room should be connected to both exhibition and hall, to easily move interior back and forth.

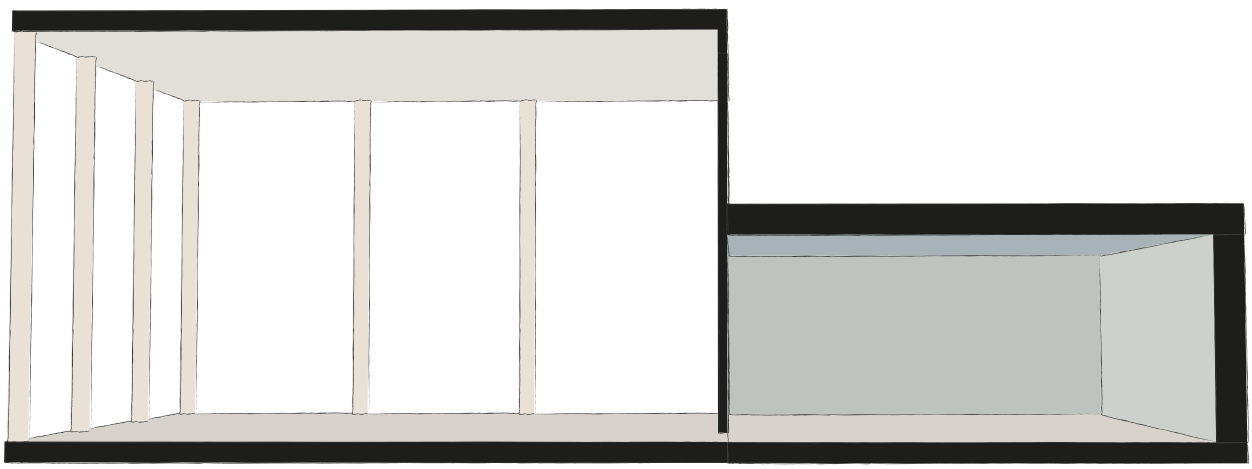


Illu. 88. Function diagram.

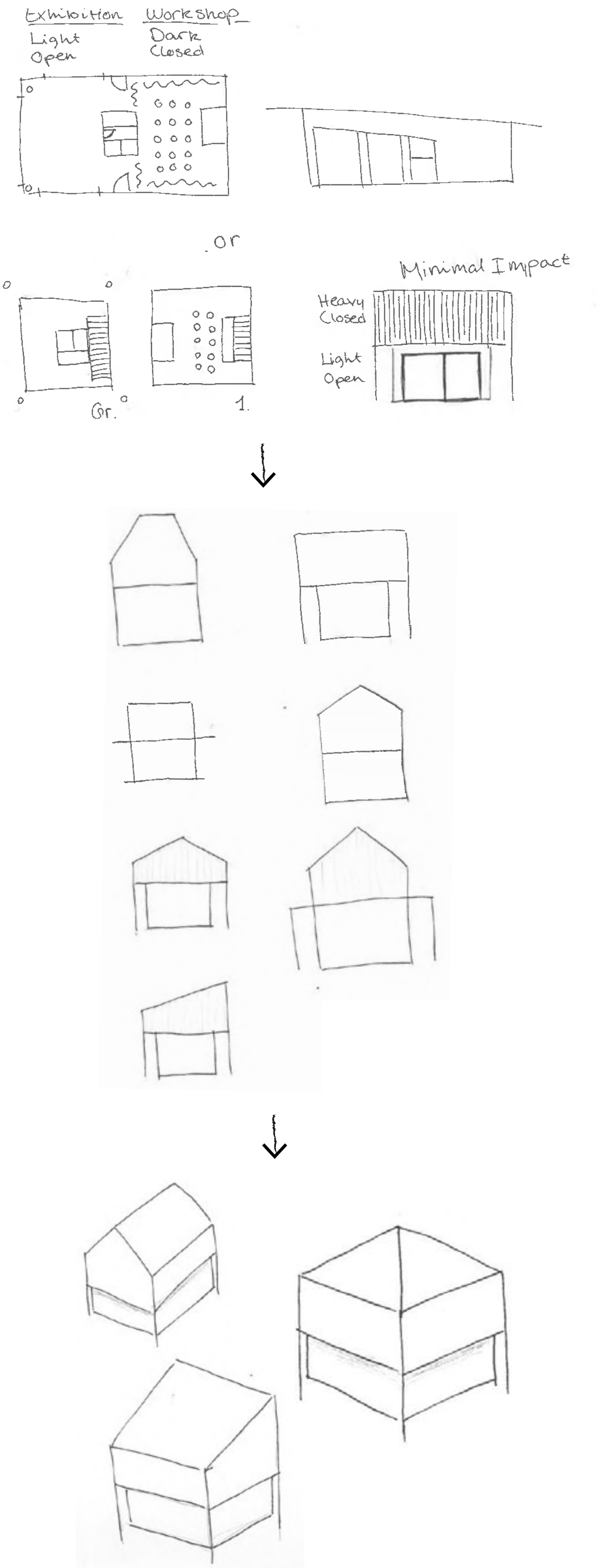
Atmospheres

The two main spaces, the exhibition and hall, should contrast each other, by providing different atmospheric experiences. As learned from the theory of contradistinctions, contrasts can enhance the experience of the respective opposites. The exhibition should be open and light, and invite to movement, conversation and interaction with the exhibition. Whereas the hall should be dark and enclosed, to create a calm and embracing atmosphere, facilitating quiet observation.

EXHIBITION	**HALL**
Inviting	Intimate
Open	Closed
High ceiling	Low ceiling
Bright	Dark
Light	Heavy
Conversation	Silent
Movement	Still
Interaction	Observation



Illu. 89. Illustration of contrasting spaces.



Illu. 90. Initial sketches.

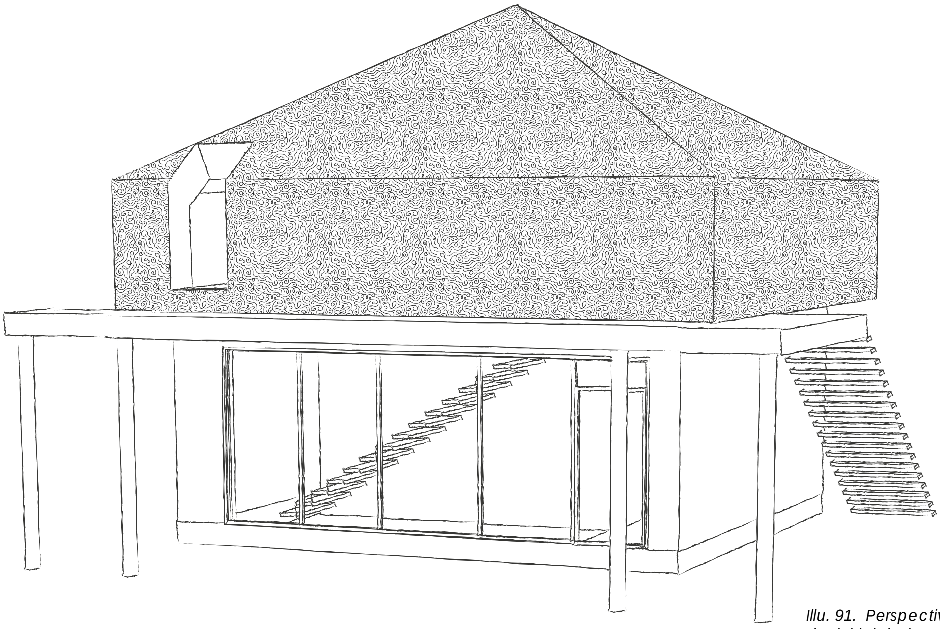
Initial Sketching

The initial sketching sparked of the design process. The initial sketches were based on the design criteria and initial room program. First, the initial sketching was used for experimenting with dimension and division of the exhibition and the hall. The sketching resulted in two proposals for dividing the contrasting spaces. In the first proposal the exhibition and hall are seperated by a central block, containing the practical functions.

In the second proposal, the spaces are divided by placing them on different levels. The seperation by levels creates a clear division of the atmospheres and provides a simple transition, in the form of a staircase. Additionally, building in two stories rather than one decreases the footprint of the building, which is an aim for the design, while preserving the total floor are.
It was decided to proceed with designing a two storey building.

By simple hand sketching, a vary of two dimensional shapes where brainstormed and evaluated. By the evaluation of the sketches it was decided that the roof should be sloping to relate to the eelgrass houses of Læsø. Additionally, a balcony should be added to the first floor to afford the tactile experience of the roof material. Furthermore, the bottom should seem light, to make the roof appear heavy.

Lastly, the sloping solutions were drawn in perspective, to gain an understanding of the possible volumes. The square shape with the pyramid top was found simple, while simultaneously the top seemed heavy. It was therefore chosen to proceed designing with this volume.



Illu. 91. Perspective drawing of the initial design proposal.

INITIAL DESIGN PROPOSAL

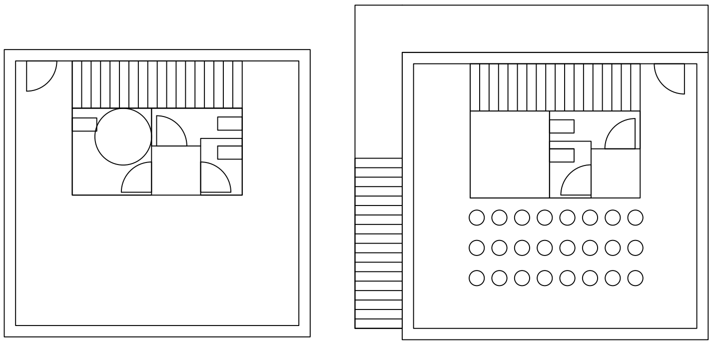
The initial design proposal is a two story building. The exterior of the upper floor is completely covered in eelgrass to make it appear as one heavy mass. The roof of the exhibition building slopes with an inclination of 45 degrees on all four surfaces. The exterior of the lower floor has a large opening towards south and should be cladded with a lighter material, to make the bottom appear light, contrasting the top.

The large opening provides light for the lower floor and the transition to the dark upper floor, which has no windows. From the upper floor it is possible to exit to the balcony, where the visitors can experience the roof material.

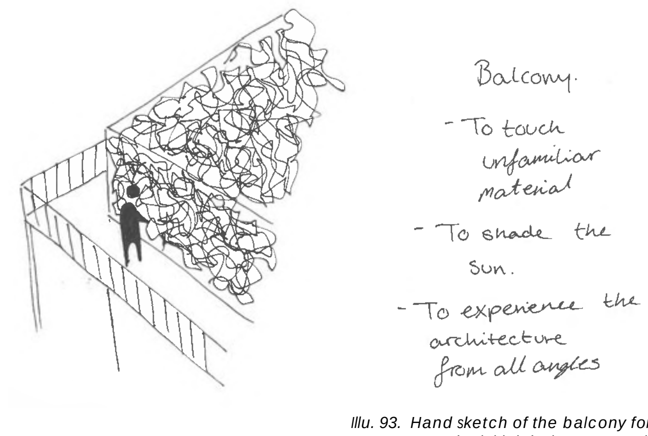
Evaluation

The initial design proposal contains clear contrasts in both appearances and experiences. The division of and the transition between the two atmospheres works well.

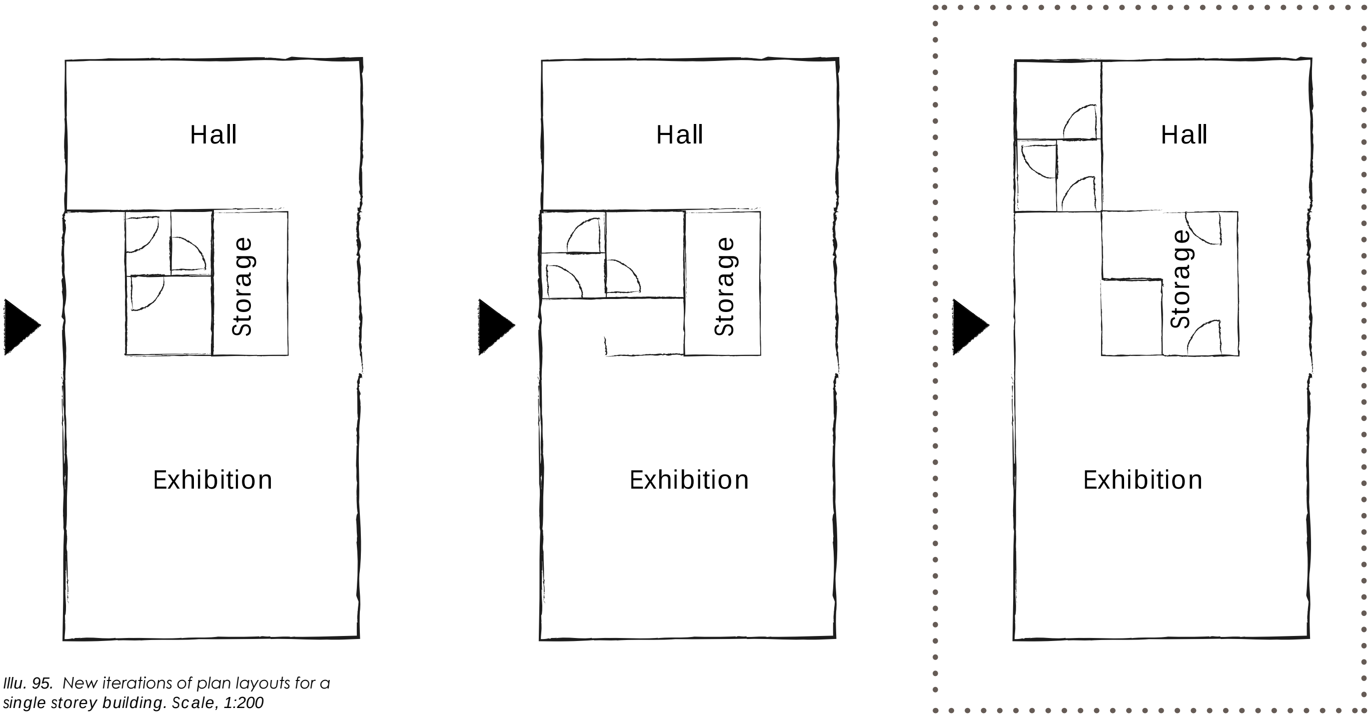
However, the two storied building creates difficulties for creating an accesiable design. Furthermore, the tactile experience of the roof material is placed too far from the ground, and the experience of the material by entering the balcony becomes superimposed.



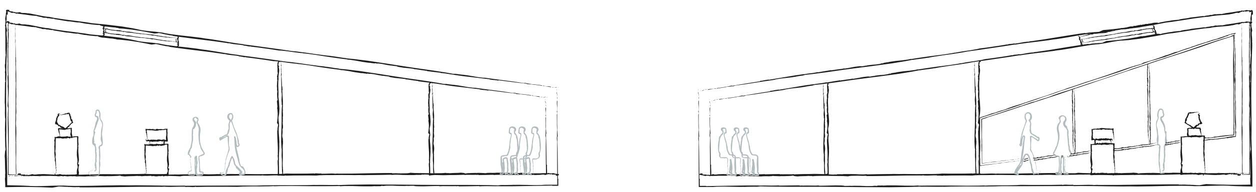
Illu. 92. Plan drawings of the initial design proposal.



Illu. 93. Hand sketch of the balcony for the initial design proposal.



Illu. 95. New iterations of plan layouts for a single storey building. Scale, 1:200

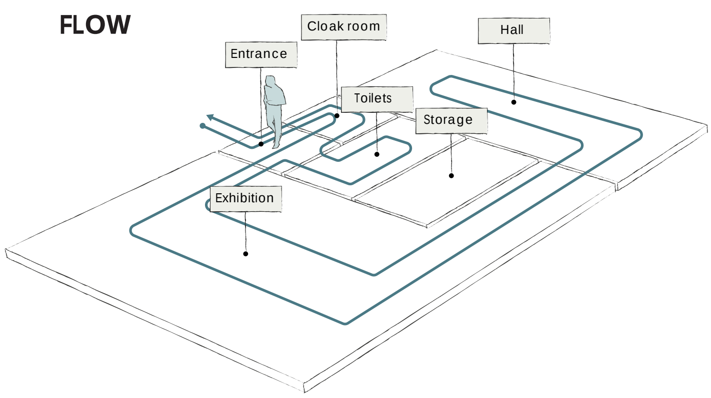


Illu. 96. New iterations of room heights and openings shown in sections. Scale, 1:200

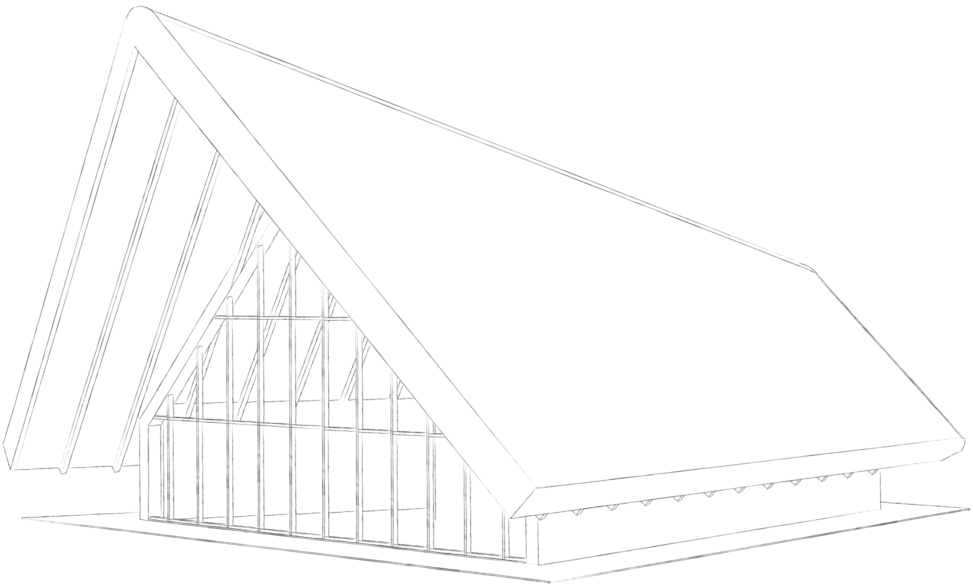
New plan layout

Moving the functions into one level instead of two, a new layout is needed as the stairs can no longer facilitate the transistion from one atmosphere to another.
For the new floor plan, the dimensions of the original Læsø houses gets to inspire the shape of the new design proposal.
For the new design propsal it is desireable to preserve the central core of practical functions. The central core will be used for dividing the exhibition space from the hall.
To fulfil these demands, three different proposals were created. In the first proposal all of the pratical functions is placed in one central block and the hall is seperated from the entrance by a single partition wall. The block doesn't contain a cloak room.
In the second proposal, the central block is extruded towards the exterior wall with the entrance, creating a functional seperation of hall and exhibition.
In the third proposal, the central block is divided in two and the toilets are moved to the corner, reducing the area of the hall, making it more intimate.
As seen in the sections, the roof declines towards the closed end, to provide an embracing and intimate atmosphere in the hall, compared to the atmosphere of the exhibition.

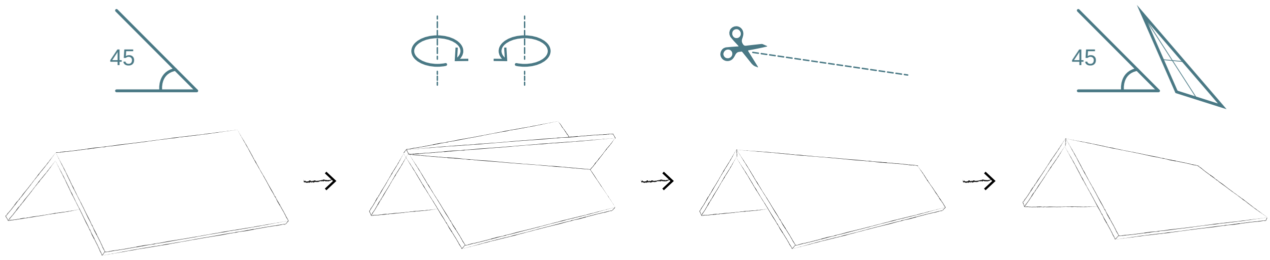
FLOW



Illu. 94. Example of possible flow of the plan layout. 1. Entrance -> 2. Cloak room -> 3. Exhibition -> 4. Hall -> 5. Exhibition -> 6. Toilets -> 7. Cloak room -> 8. Entrance



Illu. 97. Perspective drawing of the second design proposal.



Illu. 98. Evolution of the roof design.

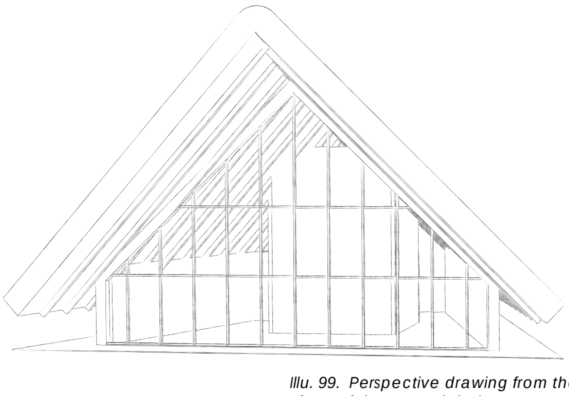
SECOND DESIGN PROPOSAL

In the second design proposal, preserving the roof inclination of 45 degrees as in the original eelgrass thatched houses and creating an open and a closed end has been the focuses.

As illustrated above, the roof shape started out as the original eelgrass roofs, without the thickness for now. The two roof surfaces have then been rotated around the Vertical axis to create an open and a closed end. The roof surfaces sticking out above have than been trimmed of, which gives the roof a slope towards the closed end. Lastly, the closed end has been closed of with a surface which has an inclination of 45 degrees as well. The open end is kept high and open.
Additionally, the idea of the central core with the practical functions dividing the exhibition from the hall is preserved in this design proposal.

Evaluation

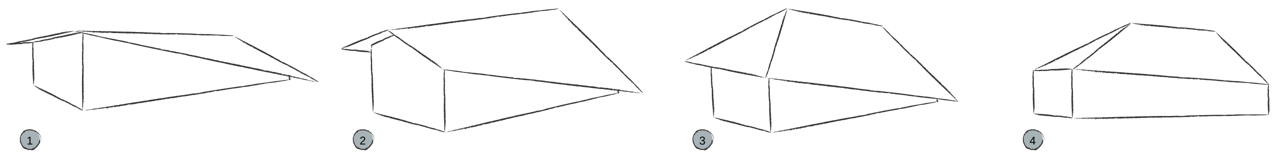
The shape of the roof is an interesting take on the original eelgrass roofs and creates a great overhang which can shade the sun in summer. However, the roof isn't contrasting the façade as is one of the design aims. The design will therefore need an extra iteration, with focus on creating contrasts in the exterior appearance.



Illu. 99. Perspective drawing from the front of the second design proposal.

Roof Study

The roof study is experimenting with approaches to shaping the roof surfaces. The aim is to come up with a strategy for preserving the roof inclination of the original eelgrass roofs of Læsø, while simultaneously making the roof seem heavier than in the second design proposal. Lastly, it is ideal if one end can be open and inviting, while the other end contrasts it by being dark and intimate.

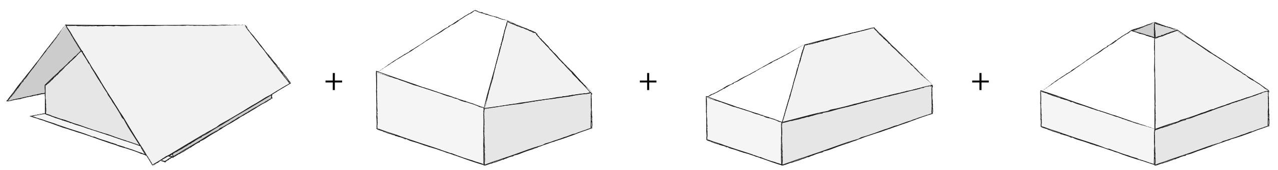


Illu. 100. Volumes for roof study.

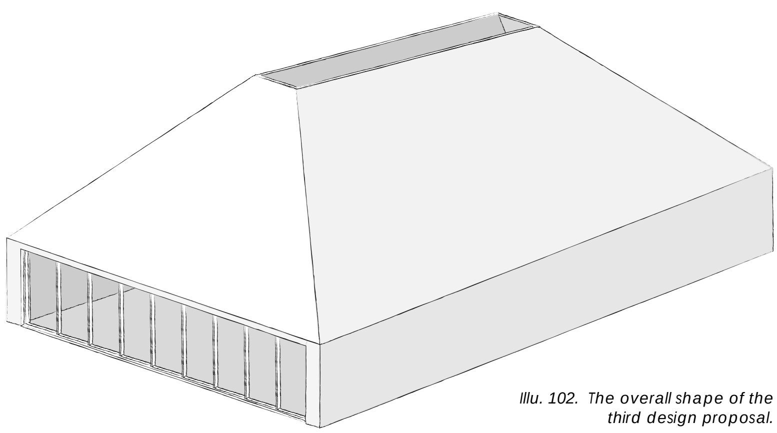
Evaluation

Working with the roof as free surfaces, as in the first two examples, rather than a predefined volume makes it easier to model interesting roof shapes. Volume 2 , which is the simplification of the second design proposal, has great contradistinctions between the two ends, however the roof appears-light and doesn't contrast the the construction in the open end.
The roof of the last two volumes seem heavier than the first two, and will create a greater contrast against a lighter construction.

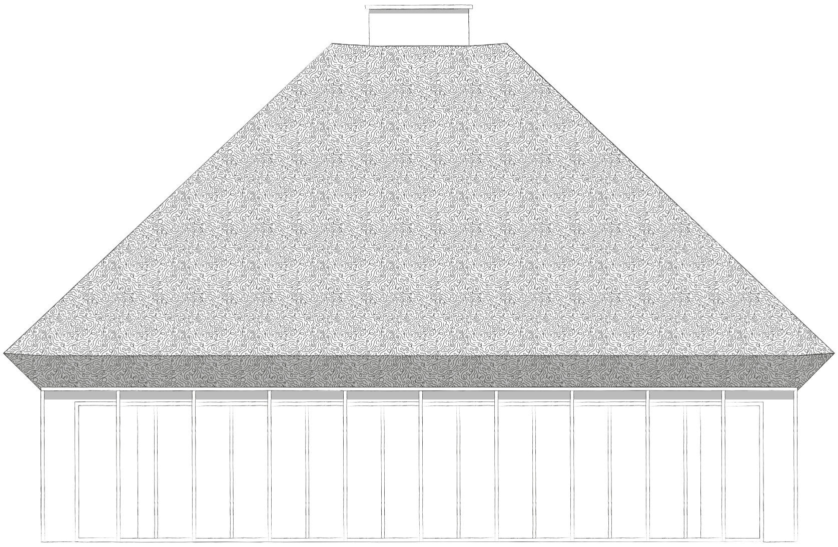
The approach to the ongoing design must based on this study be to work with each roof surface as an independent surface, but using the surfaces to create a mass rather than two to three joining surfaces.
This approach was following used to design a vary of roof volumes. Out of the new roof designs based on the approach, the three favourite shapes were chosen. All of these shapes had qualities and disadvantages. The qualities of the three shapes togehter with the roof of the second design proposal were combined. This resulted in a overall building shape for the third design proposal.



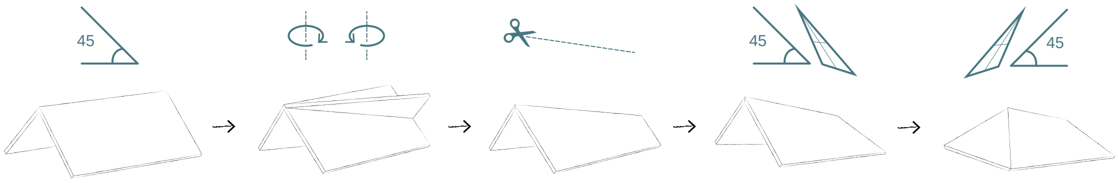
Illu. 101. The simplified volume of the second design proposal, along with the three favorite shapes.



Illu. 102. The overall shape of the third design proposal.



Illu. 103. Southern facade of the third design proposal.



Illu. 104. Evolution of the roof design.

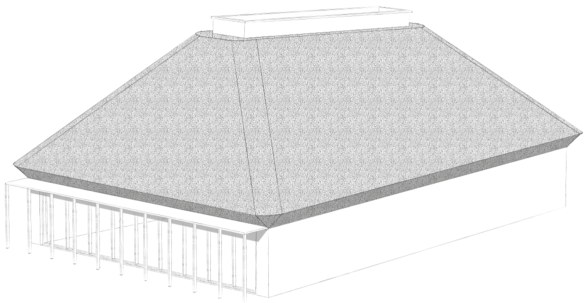
THIRD DESIGN PROPOSAL

The third design proposal continues with the idea of rotating the roof surfaces around the vertical axis, to differentiate the size of the open and the closed gable and to preserve the slope towards north allowing for a skywindow with diffuse light.
The southern gable is closed off with a surface tilting 45 degrees, to close the roof structure and have the it resembling one mass.
Rather than using the roof overhang for solar shading, a structural extrior shading which lifts the eelgrass away from the opening is added towards south. The structure provides shade and contrasts the mass of the roof.
The roof ridge tilts slithtly towards north, due to the rotation of the roof surafces. In the roof ridge a skywindow is installed. Apart from lighting the exhibition, the skywindow also allows for natural ventilation by the stack effect.
The central block of practical functions dividing the exhibition from the hall is preserved in the third design proposal.

Illu. 105. Plan layout of the third design proposal.

Evaluation

The constrast of the heavy eelgrass roof and the structural shading is satifying. However, the eelgrass is once again placed too high up, to allow for the tactile experience of the material, as it is supposed to provide. The next iteration should therefore investigate how to make the roof material reachable.

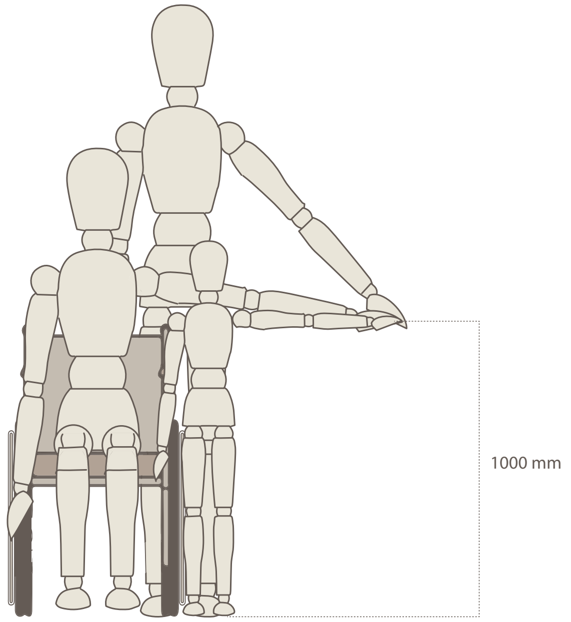


Illu. 106. Perspective drawing of the third design proposal.

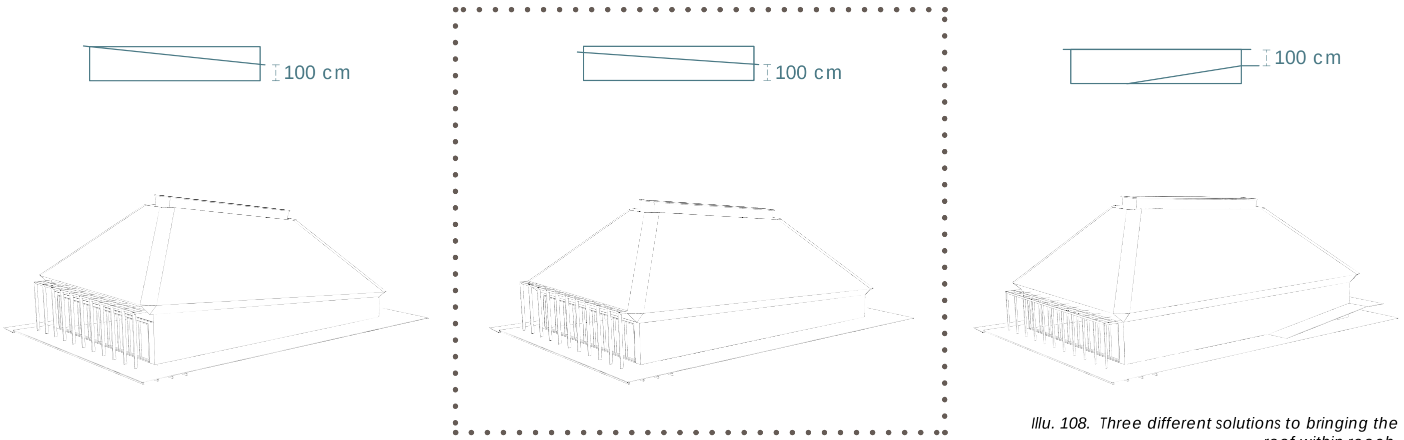
Accessability

Inspired by the Wadden Sea Center, the roof material of the exhibition building is supposed to be within reach for most, to provide a new tactile exprience.

First, a simple study investigating the lowest and highest reachable height for people of varying size is performed, to detemine the optimal height of the roof (Appendix 05).
The reachable height was determined by the study to be between 80 cm and 100 cm, and the roof should therefore partially be no higher than 100 cm.



Illu. 107. Illustration of reachable height for most.



Illu. 108. Three different solutions to bringing the roof within reach.

To bring the roof material down to a height where most can reach, different solutions are investigated.

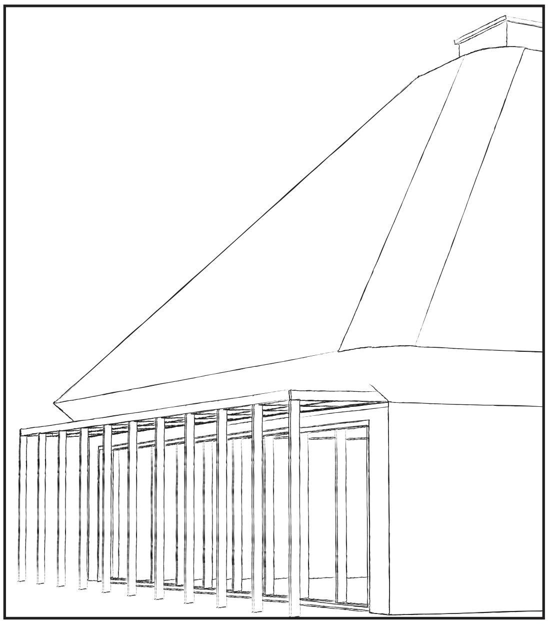
The first solution tilts the roof so that the lowest end is 1200 mm above ground and the higher end is 2500 mm above ground. The roof is 1200 mm above ground, as it is expected that the eelgrass will hang down from this height.
In the second solution all of the roof is lowered with 500 mm, and then tilted so that the lowest end is again 1200 mm above ground, but the higher end is only 2000 mm above ground.
In the third solution the roof stays in its position and instead the plateau around the building rises in the closed end to bring the visitor up to the roof.

Evaluation
In the first solution the tilt of the roof turns the skylight further towards north, which is an advantage. However, the tilt of the roof overpowers the slopes of the roof surfaces.
In the second solution the tilt is less overpowering, while the skylight is still tilted slightly towards north. With the eelgrass roof lower in the open end, the suspense bestween the roof and the structure increases.
In the third solution the raised plateau seems superimposed, as the balcony in the initial design proposal. Additionally, the slope of the plateau creates an obstacle for walking-impaired.

For these reasons the second solution is chosen for further development of the design.

Illu. 109. Photography of detail at opening on original eelgrass house. Photography provided by Læsø Museum.

Illu. 110. Photography of detail on BioSack. Photography by Anne-Mette Rosenkilde.



Illu. 111. Perspective drawing of the structural shading.

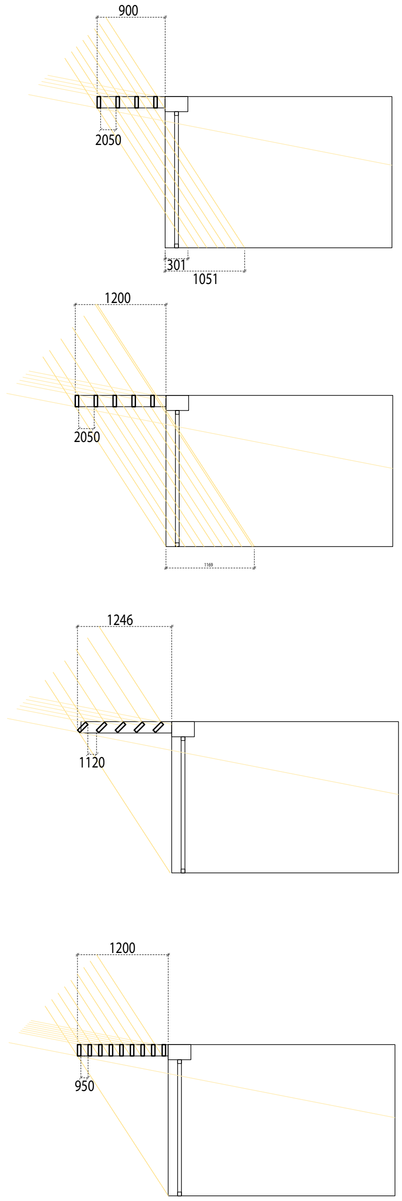
Overhang

The overhang is inspired by the wooden structures found on the eelgrass houses of Læsø. These structures are placed on the facades where openings occur, presumably to keep the eelgrass from covering the openings.
Using a lighter wooden structure to keep away the eelgrass from the openings combined two of the strategies for the design, using history and opposites.

As the largest opening is placed towards south, the opening should have solar shading, to avoid overheating and direct sunlight in the exhibition. The idea is that using the structure horizontically can also provide this solar shading.
In the second photography, the open horizontal structure of BioSack holds up the eelgrass while allowing it to hang down in sections. Walking beneath this structure provides a special tactile and spacious experience. Therefore, this will be the idea foundation for the overhang.

To determine the necesarry depth of the overhang and the distance between the lamellas, a small solar shading study is performed. The initial overhang was 900 mm, but as the illustration shows, this wasn't enough to keep out the summer sunlight. The depth of the overhang is therefore increased to 1200 mm. However, the lamallas are too far apart, and sunlight can penetrate in between. To hinder this, is experimented with two solutions. In one solution the lamellas are rotated 45 degrees. In the other solution the distance between the lamellas is decreased.

The solution with the lamellas closer together is the best solution, as the BioSack inspired effect can still be achieved.



Illu. 112. Solar shading study of the structural overhang.

Skylight

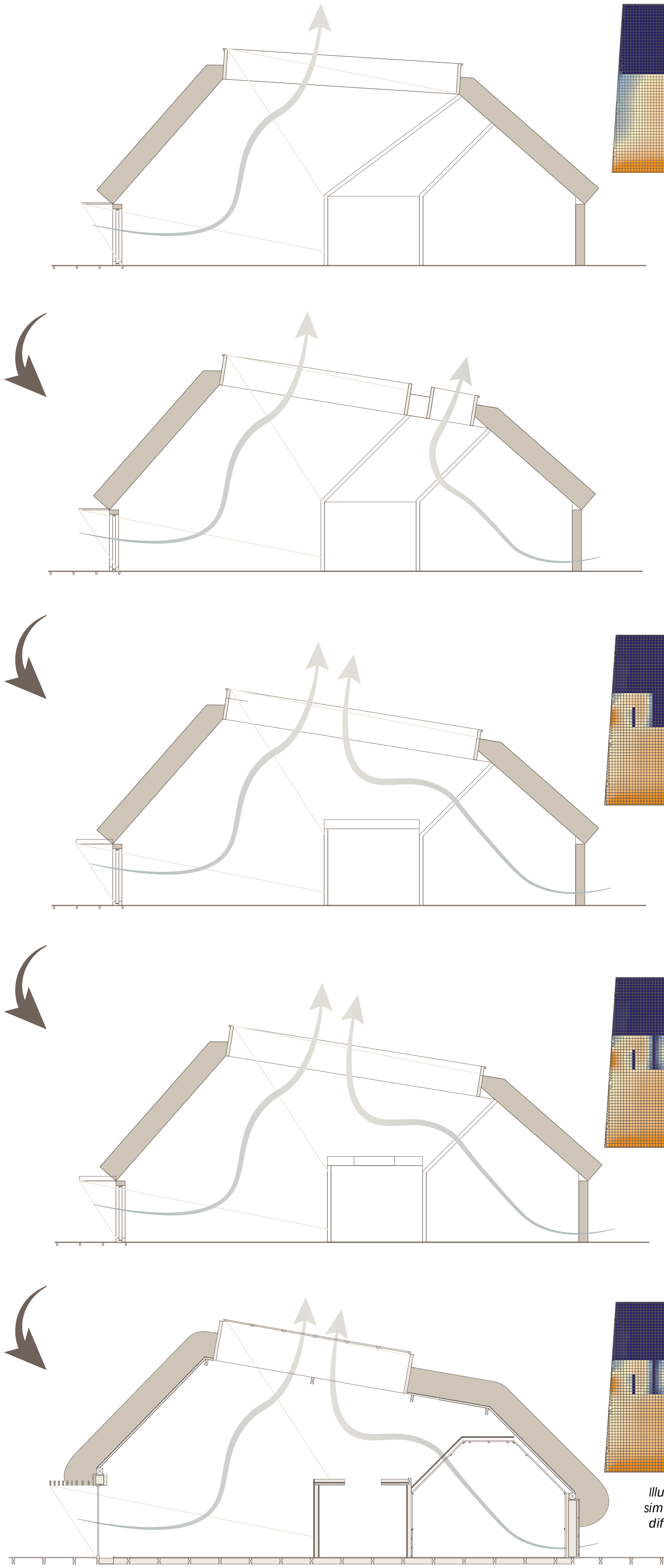
It was a wish that the exhibition avoided direct sunlight and instead were lighted by diffuse light from north. For this purpose, the skylight was implemented. Besides from lighting the exhibition, the skylight could also provide natural ventilation by the stack effect.

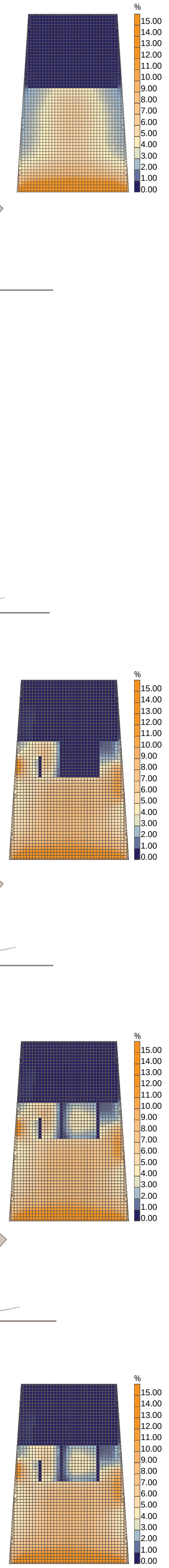
In the first iteration there is a huge waste of space above the closed end. Lowering the height of the roof in one end decreases the waste space, while additionally tilting the skylight further towards north. The skylight is divided into two seperate windows, to allow for diffuse light in the storage room and provide opportunity for natural ventilation of the hall.

In the third iteration the sloping ceiling of the storage room is removed and a flat ceiling is added to make the smaller functions, rooms in the room. As the partioning ceiling is removed, the skylight is again joined into one large opening.

In the fourth iteration a window is installed in the storage ceiling, to utilize the natural light from the skylight. Looking at daylight simulations, the effect is clear.

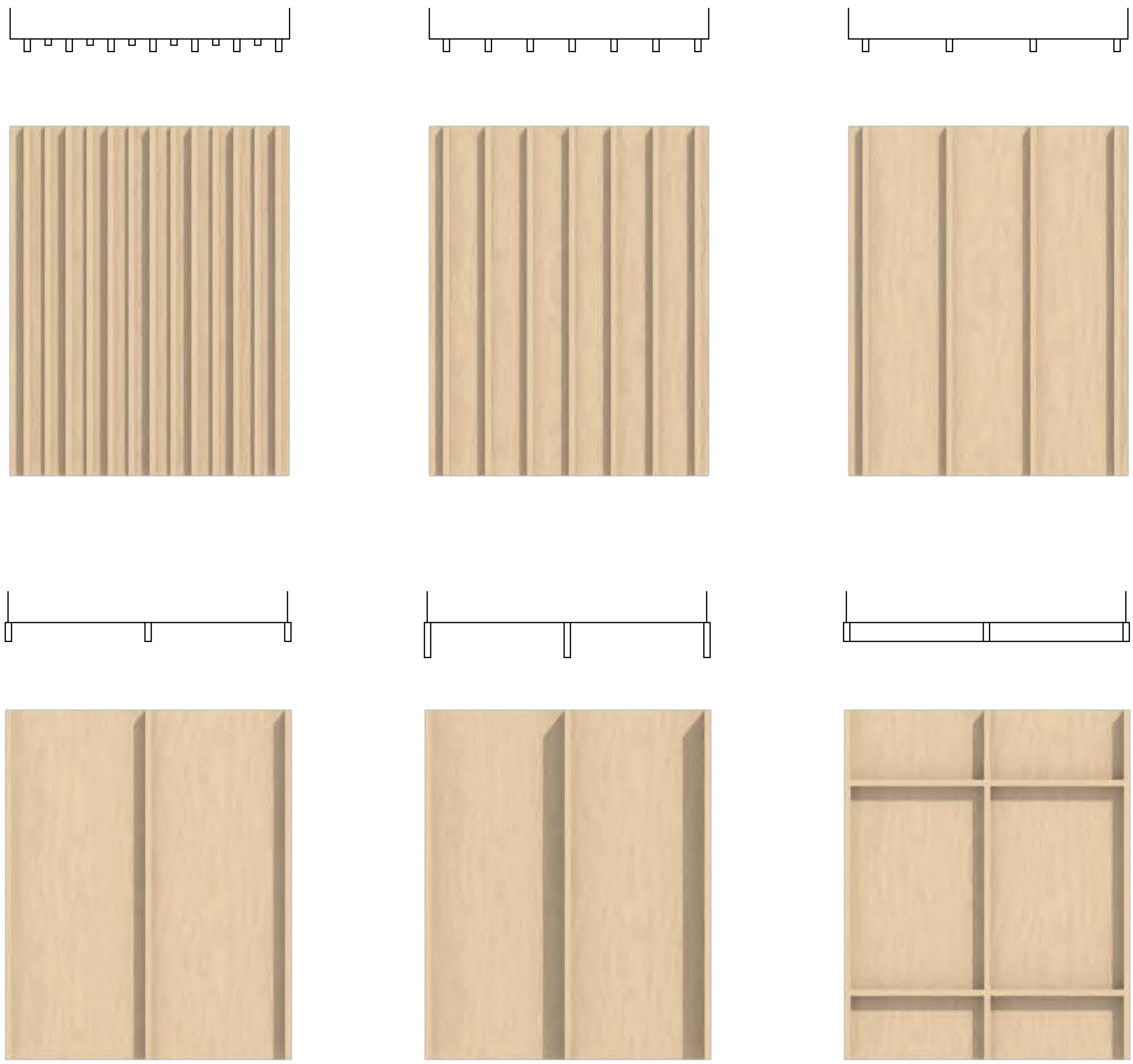
In the final iteration the size of the skylight is minimized, to lower the heat loss. As there is no reason to light up closed off ceilings. And as seen the decrease of the skylight area, doesn't effect the light in the exhibition space. Only the cloakroom is a little less lighted.





Illu. 114. Daylight simulations for the differnt iterations.

Illu. 113. Iterations of the roof and skylgiht.



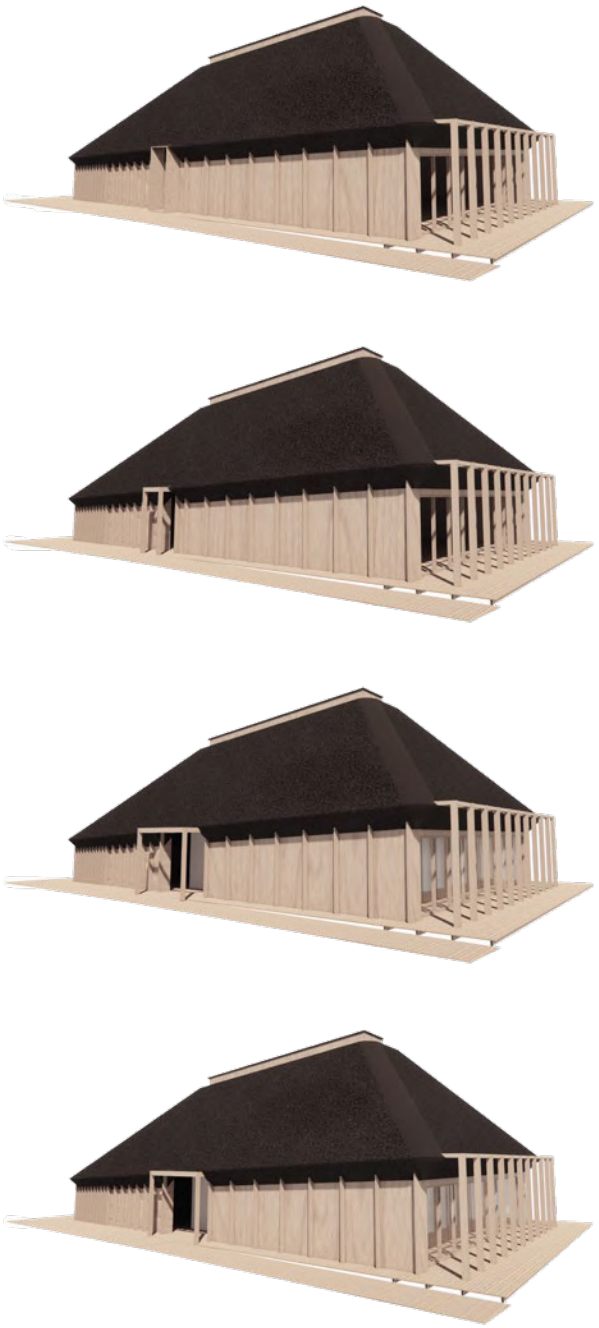
Illu. 115. Appearance of the cladding options, along with the planar section of the claddings.

Cladding

As the exhibition building should promote the use of biobased materials, wooden cladding is used on the facades. As it was formerly determined that eelgrass is better used on the interior side, it is not used as cladding.
A light wood is chosen to contrast the darker eelgrass roof and enhance the appearance of light and heavy. However, in time both wood and eelgrass will turn more silverish, blurring out the contrasts of the materials.
As the bottom of the exterior is supposed to appear light and structural, as opposed to the heavy mass on top, adding differnt structures to the facades have been investigated.
The structures are added vertically, to make them seem lighter.
It was found through the study that the more distance of the rafters, the lighter the surface seems. The denser the rafters, the heavier the surface appears.
This can be used to create a horizontal more-or-less contrast along the façade, by playing with the distance between the facade structures. It is decided that the elements should have the same depth all over the facade, but that the distance between should decrease from the open end towards the closed end, to make the closed end appear heavier and more closed.

Entrance

As the roof is lowered to provide the tactile experience of the eelgrass roofing, it is necessary to make an opening for the entrance, not only in the façade but also in the bottom of the roof.
A natural solution is to reuse the idea of the structure lifting the eelgrass in the open gable. Various editions of this solution are evaluated, together with an additional solution where the opening is cut out by a solid wood frame, sticking out from the façade and roof.
The variations of the solution in the open gable includes a proposal where the structure fits in between two rafters of the façade, equal to 1000 mm. Additionally, two solutions fit in between the width of three rafters, equal to 2000 mm is tested. There are two variations of this solution, since the first one, with the same distance from the building as the grid in the gable, seemed too detached from the façade. Moving the opening structure closer to the façade, matching the dimensions of the width to the depth of the front structure resulted in greater harmony.



Illu. 116. Iterations of the entrance.

EXHIBITION DESIGN

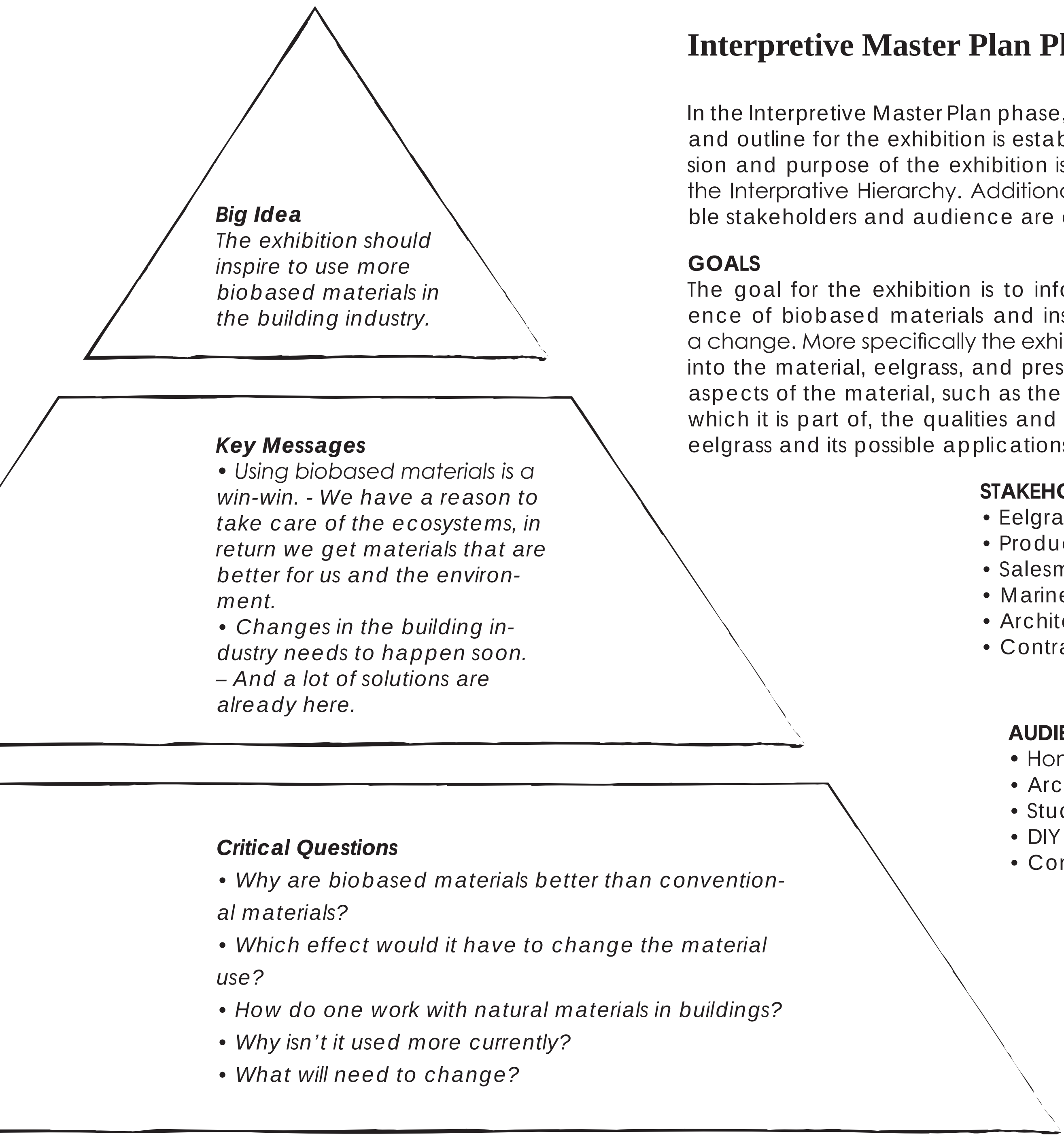
Interpretive Master Plan Phase

In the Interpretive Master Plan phase, the key goals and outline for the exhibition is established. The vision and purpose of the exhibition is presented in the Interprative Hierarchy. Additionally, the possible stakeholders and audience are established.

GOALS
The goal for the exhibition is to inform the audience of biobased materials and inspire to make a change. More specifically the exhibition will dive into the material, eelgrass, and present important aspects of the material, such as the ecosystem of which it is part of, the qualities and challenges of eelgrass and its possible applications.

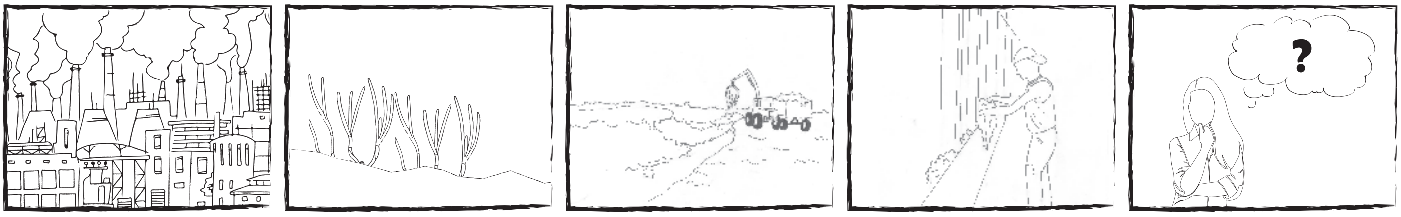
STAKEHOLDERS
- Eelgrass farmers
- Producers
- Salesmen
- Marine biologists
- Architects
- Contractors

AUDIENCE
- Homeowners
- Architects
- Students
- DIY builders
- Contractors



Illu. 117. Interpretive Hierarchy in use.

Illu. 118. Illustration of possible elements for the exhibition.



BUILDING INDUSTRY	ECOSYSTEM	PROCESSING	CONSTRUCTION	FUTURE
• Emissions	• Eelgrass	• Harvest	• History	• Materials
• Requirements	• Occurence	• Process	• Renovation	• Ecosystems
• Sustainability	• Ecosystem	• Raw material	• New build	•
• Need for change	• Oxygen depletion	• Building materials	• Thermal insulation	•
	• CO_2 storage	• Properties	• Acoustic insulation	•
Content	Content	Content	Content	Content
• Text	• Text	• Text	• Text	• Text
• Images	• Images	• Images	• Images	• Images
• Digital media	• Digital media	• Digital media	• Models	• Digital media
		• Tactile elements	• Tactile elements	•

Illu. 119. Illustration of the narrative of the exhibiton, along with the topics, subtopics and possible media to display the content.

Concept Design Phase and Design Development Phase

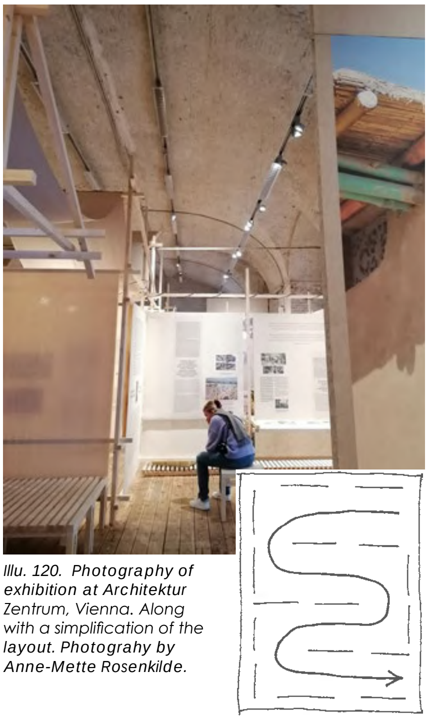
On this page the Concept Design phase and the Design Development is presented together. The Schematic Design phase is skipped, since there are no actual elements to present at the exhibition. Instead ideas for possible elements are presented as part of the Concept Design phase and a narrative for the exhibition is presented as part of the Design Development phase.

The exhibition should be presented in chronological order, and follow the idea of 'Fra Jord til Bord' [From Ground to Table], but instead follow the eelgrass on its journey from the seabed to the building.
The storyline of the exhibition will resemble that of a superhero movie. As a beginning of the narrative, the villain should be presented, the great emissions from the building industry, as this topic concerns all of us. The audience could be presented with a dystopic feeling and the content could be presented with text, images and media elements.
Thereafter, the hero, in form of eelgrass, should be presented. We will slowly see the eelgrass grow from a small green plant under water, to material with great potential to overcome the villain.
The exhibition will end up with the eelgrass overcoming multiple scenarios and present the prospects of the future.

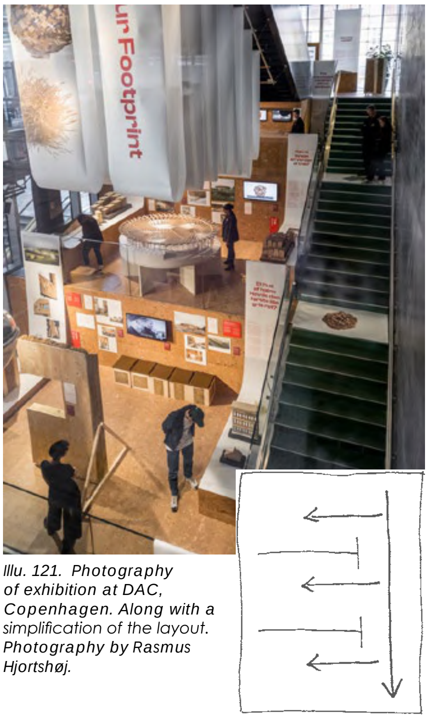
Final Design Phase

EXHIBITION LAYOUT

To determine the desired flow for the exhibition, three different exhibition layouts are evaluated. The evaluation of the layouts are based on personal visits and experience of the flows effect on the experience of the exhibition.



Illu. 120. Photography of exhibition at Architektur Zentrum, Vienna. Along with a simplification of the layout. Photograhy by Anne-Mette Rosenkilde.



Illu. 121. Photography of exhibition at DAC, Copenhagen. Along with a simplification of the layout. Photography by Rasmus Hjortshøj.

Illu. 122. Photography of exhibition at Utzon Center, Aalborg. Along with a simplification of the layout. Photography by Anne-Mette Rosenkilde.

Controlled
ARCHITEKTUR ZENTRUM
-Vienna

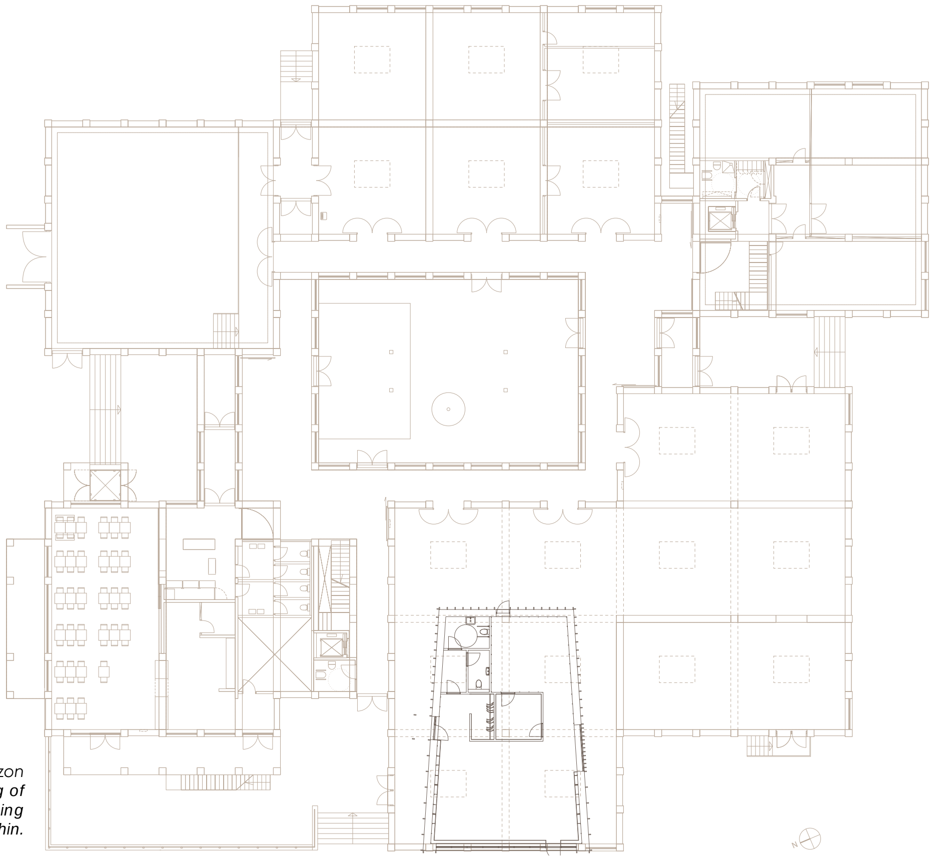
With the controlled layout of the exhibition the intended narrative of the exhibition is closely followed by the audience and ensured that all of the exhibition was visited. The fixed direction of movement created a stressless experience as there was no awkward meetings between visitors. However, towards the end the concentration is low and there is a risk that the last messages are lost.

Directional
DANSK ARKITEKTUR CENTER
-Copenhagen

The directional layout divides the exhibition into themes and gives out a direction. It is then up to the audience to form their own experience. If some themes don't interest the visitor, they can simply be skipped. At the beginning of the directional layout was an introduction, to ensure that the audience knew the key messages.

Free
UTZON CENTRE
-Aalborg

With the free layout, the elements are placed without a visible connection. The free layout lets the visitor determine the experience and often the most exciting piece will draw attention first. The risk of a free layout is that the audience will miss parts of the exhibition. By involving the user by talkbacks in different locations, the risk can be limited.



Illu. 123. Plan drawing of Utzon Center with the plan drawing of the eelgrass exhibition building within.

INVESTIGATION OF UTZON CENTERS EXHIBITION

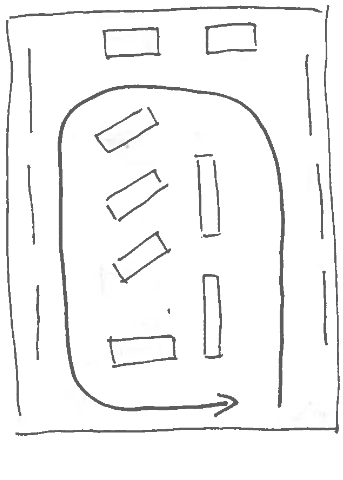
As a case study in layout and engaging visitors in an exhibition, a trip was made to Utzon Center, to observe the layout and the artifacts of the exhibition, and to observe how the visitors acted in the exhibition.
As described on the previous page the layout of the Utzon Center is free, and not determining a path for the visitor. However, it was observed that all visitors started their exploring of the exhibition by following the wall to the right of the entrance, but at the end of the wall the path varied a lot.
For the exhibition several talkback points were installed, for the visitor to interact with the exhibition. The observed visitors used these talkbacks and the talkbacks sparked a conversation between the visitors. (Appendix 06)

The exhibition of Utzon Center is much bigger than the exhibition space of the design proposal. As seen on illustration 123, the exhibition of Utzon Center could fit in all of the exhibition building. The exhibition of Utzon Center is 432 m^2 and 46 artifacts were counted in the exhibition, leaving out text and photos on walls. Meaning that there is approximately one artifact per every 9 m^2. A distance of two meters was measured between the artifacts for passing by.

With the 64 m^2 of exhibition space in the design proposal, the exhibition could contain approximately seven artifacts, to allow for the same space.

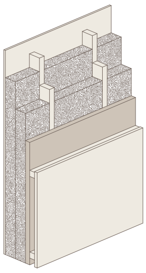
Sub Conclusion

In conclusion, the layout of the exhibition should be free to allow the visitors to skip sections, as the visitors might not have the same interests. Additionally, the layout should be free to avoid room dividers, to keep the space open and light and to allow for an easy overview of the exhibition. The audience should however be nudge in the direction of the intended narrative. The audience will be nudged by the placement of exhibition elements and by references in the graphical material. The exhibition should provide enough space for movement and engage the visitor to interact with the exhibition.

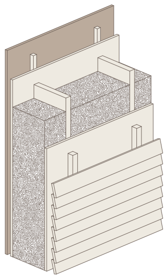


Illu. 124. Drawing of the expected flow of the exhibition.

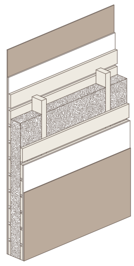
MAPPING OF CONSTRUCTIONS



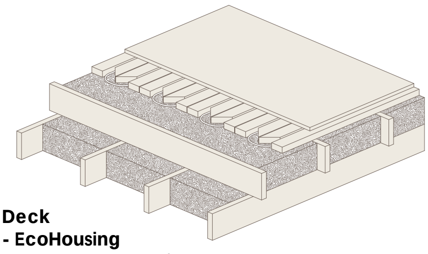
Exterior wall
- EcoHousing
U-value: 0,17 W/m^{2}K
Thickness: 310 mm
GWP: -39 kg CO_2 eq./m^2
Layers:
1. 20 mm Douglas siding
2. 45 mm Installation layer
3. 40 mm Biobased windbarrier
4. 95 mm Eelgrass batts
5. 95 mm Eelgrass batts
6. 15 mm Plywood



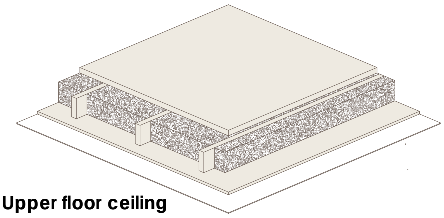
Exterior wall
- Seegrashandel
U-value: 0,22 W/m^{2}K
Thickness: 380 mm
GWP: -66 kg CO_2 eq./m^2
Condensation: 0,91 kg/m^2
Layers:
1. Wooden siding
2. 45 mm Ventilation layer
3. 15 mm Fiberboard
4. 200 mm Eelgrass loosefill
5. 11 mm Wooden board
6. 45 mm Installation layer
7. 20 mm Clay board



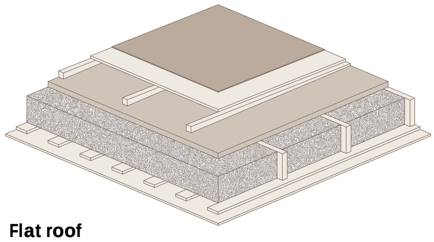
Interior wall
- Seegrashandel
Thickness: 181 mm
GWP: -31 kg CO_2 eq./m^2
Layers:
1. 3 mm Clay plaster
2. 20 mm Reed mat
3. 20 mm Economy boards
4. 95 mm Eelgrass loosefill
5. 20 mm Economy laths
6. 20 mm Reed mat
7. 3 mm Clay plaster



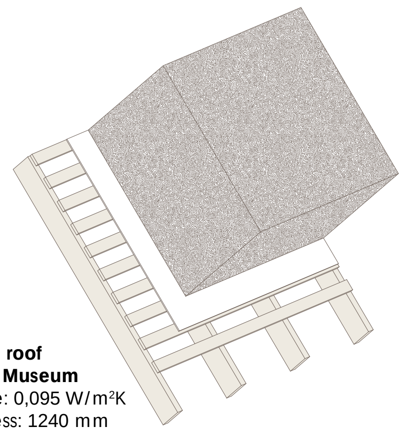
Deck
- EcoHousing
U-value: 0,12 W/m^{2}K
Thickness: 438,5 mm
GWP: -58 kg CO_2 eq./m^2
Layers:
1. 25 mm Douglas flooring
2. Laths and underfloor heating
3. 195 mm Eelgrass batts
4. 195 mm Eelgrass batts



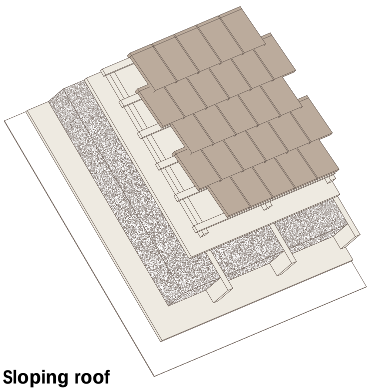
Upper floor ceiling
- Seegrashandel
U-value: 0,28 W/m^{2}K
Thickness: 188 mm
GWP: -33 kg CO_2 eq./m^2
Condensation: 0,88 kg/m^2
Layers:
1. 20 mm Fiberboard
2. 150 mm Eelgrass loosefill
3. 15 mm Wooden board
4. 3 Plaster



Flat roof
- EcoHousing
U-value: 0,16 W/m^{2}K
Thickness: 337,4 mm
GWP: -40 kg CO_2 eq./m^2
Condensation: 0,97 kg/m^2
Layers:
1. Roofing felt
2. 18 mm Plywood
3. Construction wood
4. 40 mm Biobased windbarrier
5. 195 mm Eelgrass batts
6. 20 mm Laths
7. 15 mm Plywood

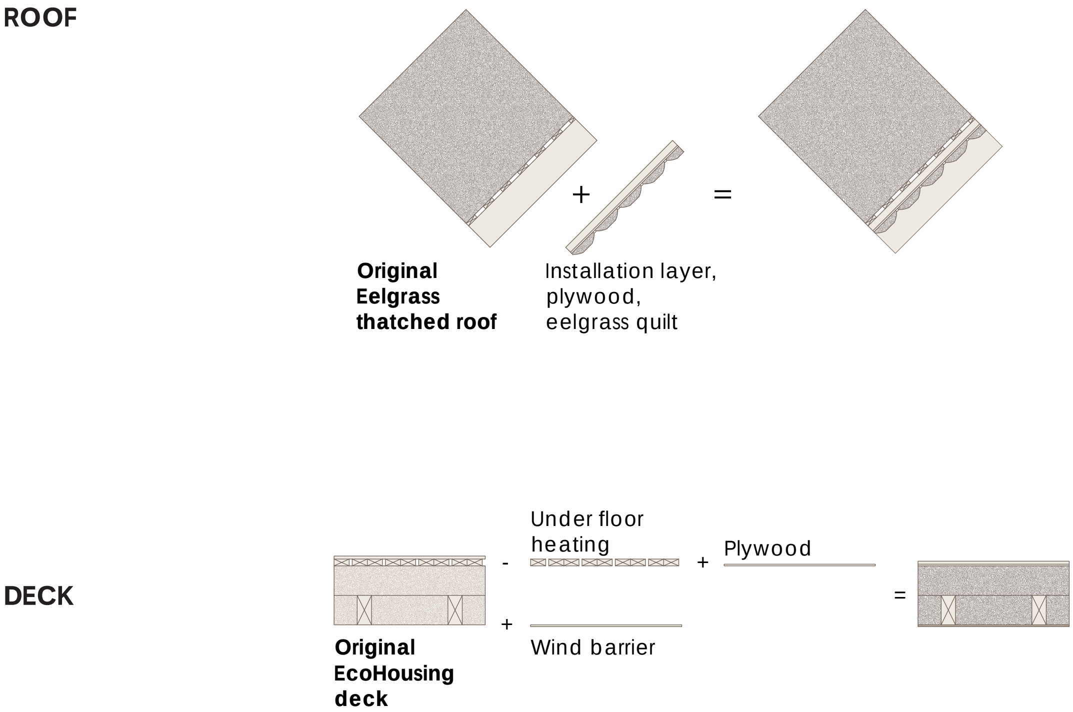


Sloping roof
- Læsø Museum
U-value: 0,095 W/m^{2}K
Thickness: 1240 mm
GWP: -87 kg CO_2 eq./m^2
Layers:
1. 1000 mm Eelgrass
2. 10 mm Birch twigs
3. 20 mm Economy laths
4. 200 mm Rafters



Sloping roof
- Seegrashandel
U-value: 0,19 W/m^{2}K
Thickness: 376 mm
GWP: -5,5 kg CO_2 eq./m^2
Condensation: 0,48 kg/m^2
Layers:
1. Roofing material
2. 45 mm Ventilation layer
3. 20 mm Fiberboard
4. 200 mm Eelgrass loosefill
5. 20 mm Economy laths or board
6. 3 mm Plaster

Illu. 125. Three dimensional illustrations of the known constructions with eelgrass.



Illu. 126. Alterations to the known constructions. Scale, 1:50

CONSTRUCTIONS

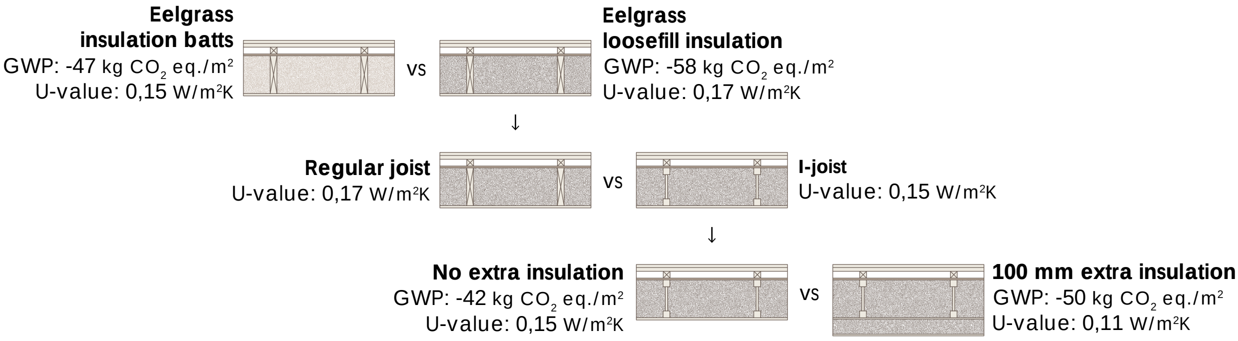
Roof Construction

The roof construction is inspired by the original eelgrass thatched roofs of Læsø. However, a few changes have been made. To seperate the exterior eelgrass from the interior, a plywood board has been installed in between. To be able to still wrap the vaskere around the laths an installtion layer has been added on top of the plywood. On the interior side an eelgrass quilt, inspired by The Modern Seagrass House and Cabots Quilt, has been applied to ensure good acoustics of the large open exhibition space.

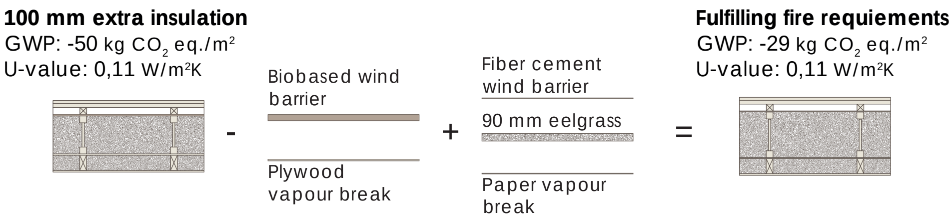
Deck Construction

The construction of the deck is inspired by the deck of EcoHousing as this deck is also raised on a screw foundation. The thicknes of the insualtion layers are preserved, and result in a u-value of 0,12 W/m^{2}K, which is acceptable. A few changes have been made for the construction. The underfloor heating has been removed, as it isn't optimal for this building typology. Instead of the underfloor heating, a plywood board has been installed beneath the flooring, to make the construction air tight and to serve as fire protection of the insulation. Beneath the insualtion, a wind barrier is installed. The functions of the wind barrier is to break the wind and to keep pests out of the construction.

OUTER WALL



Illu. 127. Multiple outer wall iterations for determining the best solution. Scale, 1:50.



Illu. 128. Iteration for fulfilling the fire regulations. Scale, 1:50.

Outer Wall Construction

The outer wall construction takes its point of deapture from the wall construction of EcoHousing, with an added ventilation layer. To determine whether the wall should be insualted with loosefill eelgrass or eelgrass insulation batts, the GWP and U-value of these are compared, based on Ubakus calculations. The insulation batts has a lower U-value, but a higher GWP than the loosefill eelgrass insualtion. It is decided to move on with the low GWP of the eelgrass and then improving the U-value of the construction. The choice of loosefill eelgrass is additionally based on its better fire properties.

It was then investigated if the U-value could be decreased, by exchanging the regular wooden joists with I-joists. Using I-joists did reduce the U-value, however it was still higher than recommended. Therefore, the next iteration explored the effect of adding an extra 100 mm of insulation. This resulted in a U-value of 0,11 W/m²K and additionally the GWP was improved, as loosefill eelgrass has a negative GWP. However, after these iterations it was discovered that the construction culdn't fulfil the fire requirements, when using a biobased wind barrier. A wind barrier of fiber cement had to be installed, as it proved to be the only wind barrier fulfilling the requirements. With the new wind barrier, the plywood no longer functioned as a vapour dampener, as the sd-value of the fiber cement barrier was higher than that of the biobased wind barrier. Instead a vapour break of paper with a sd-value of 6,45 m was installed. Along with these changes an additional 50 mm of insualtion was applied, as the change of wind barrier increased the U-value of the construction. As seen in illustration 128, the application of the mineral wind barrier heavily affects the GWP of the construction, negatively.

Exhibiting Constructions

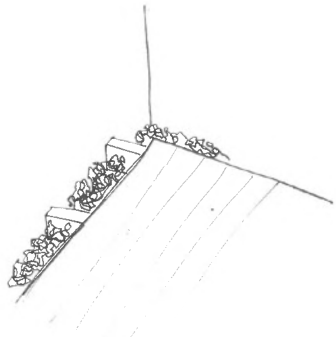
As the exhibition building should be part of the exhibition itself, different solutions for showcasing the constructions have been explored.
The aim is that the showcasing of constructions are subtle and become part of the design, rather than a sudden hole in the wall or so.
Additionally, the opening should not only be a visual opening, but provide a multi sensory experience of the material.

Different solutions were explored. For example it was an idea to retract the interior floor surface to reveal the flooring construction. In illustration 130 it was tested if the construction known from the Renovation section could be used without the finishing layer of reed and clay plaster.
An other idea, as seen illustration 131, was to open up the construction and utilize part of it for a function, for example sitting.
It was also thought to be interesting to let the underside of the eelgrass roof stay open, to showcase the unique construction of this. Lastly, it was explored if the floor could open up into a pit filled with the eelgrass of the floor.

The sitting solutions, weren't as subtle as it was the aim and they stole a lot of space and attention from the exhibiton.

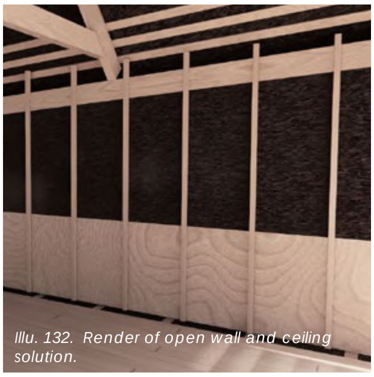
Furthermore, opening the construction is challening as the building must comply with fire regualtions. As the building is less than 150 squaremeters, only has one floor and is not designed with sleeping accomonadtions, the fire regulations of this type of building is slightly loser than those of buildings with more stories.

Working with eelgrass loosefill in the building, it is acceptable to clad the interior surfaces with a $K_1$10/D-s2,d2 cladding, which could for example be 9 mm plywood with a minimum denssity of 500 kg/m^3 or 9 mm woodfiber boards with a minimum density of at least 600 kg/m^3.
For the flooring there are no requirements when using the loosefill eelgrass in a building with these properties.


Illu. 129. Drawing of opening floor.


Illu. 130. Render of open wall appearance.


Illu. 131. Render of using the opening for a function.

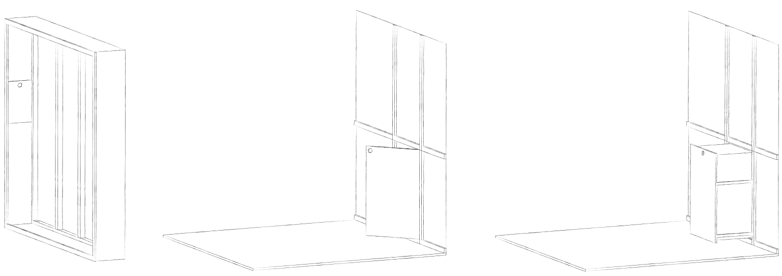

Illu. 132. Render of open wall and ceiling solution.


Illu. 133. Render of open pit in the floor.

Easter Eggs

As opening up the construction is challenged by the fire regulations, it was thought to implement the so called easter eggs.
The easter eggs would be parts of the construction, which the visitor can open and explore. By letting the visitor open the construction, it will mainly be closed of with the required materials. The idea of the easter eggs is to engage the visitor to inspect the building in order to locate the easter eggs, and then to interact with the building and have a multi sensory experience.

Multiple design ideas for the easter eggs were created in order to determine how the construction could be opened up. Openings in the window frames was one idea. Another idea was to open the constrctions like a cupboard. This idea led to the final idea of pulling the construction out like a drawer filled with materials.


Illu. 134. Easter egg iterations.

Illu. 135. Visualisation of the final design proposal, from the front.

DESIGN PRESENTATION

The Design presentation will present the final design proposal for the eelgrass exhibition building. The final design proposal will be presented through plan drawings, sections, elevations and visualisations.

Illu. 136. Visualisation of the final design proposal. Background photography provided by the Facebook group: Hønsinge Lyng strand uden tang.

The design process has resulted in a design proposal which draws associations back to the eelgrass houses of Læsø, by working with the similar dimensions of the building and preserving the roof material and inclination of the original houses. Additionally, the original eelgrass houses have influenced details of the openings.

The design is based on the theory of contradistinctions, and contradistinctions are to be found all around the building. The first contradistinction is found in the façade where the light wooden structures contrast the heavy mass of eelgrass. Inside the building, the contradistinctions are to be found in the atmospheres, as well as in the appearance.

The purpose of the design is to exhibit eelgrass as a building material and thereby raise awareness of the conditions of the marine environment and the use of biobased building materials. The exhibition is designed to be a multi-sensory experience, and contains elements for touching, smelling, listening, and viewing. The exhibition showcases eelgrass constructions, simultaneously the building itself is part of the exhibition. To engage the visitor easter eggs for exploring the construction of the building has been implemented.

As the building seeks to raise awareness of biobased materials, and eelgrass in particular, the building has to as high a degree as possible been constructed of biobased materials.

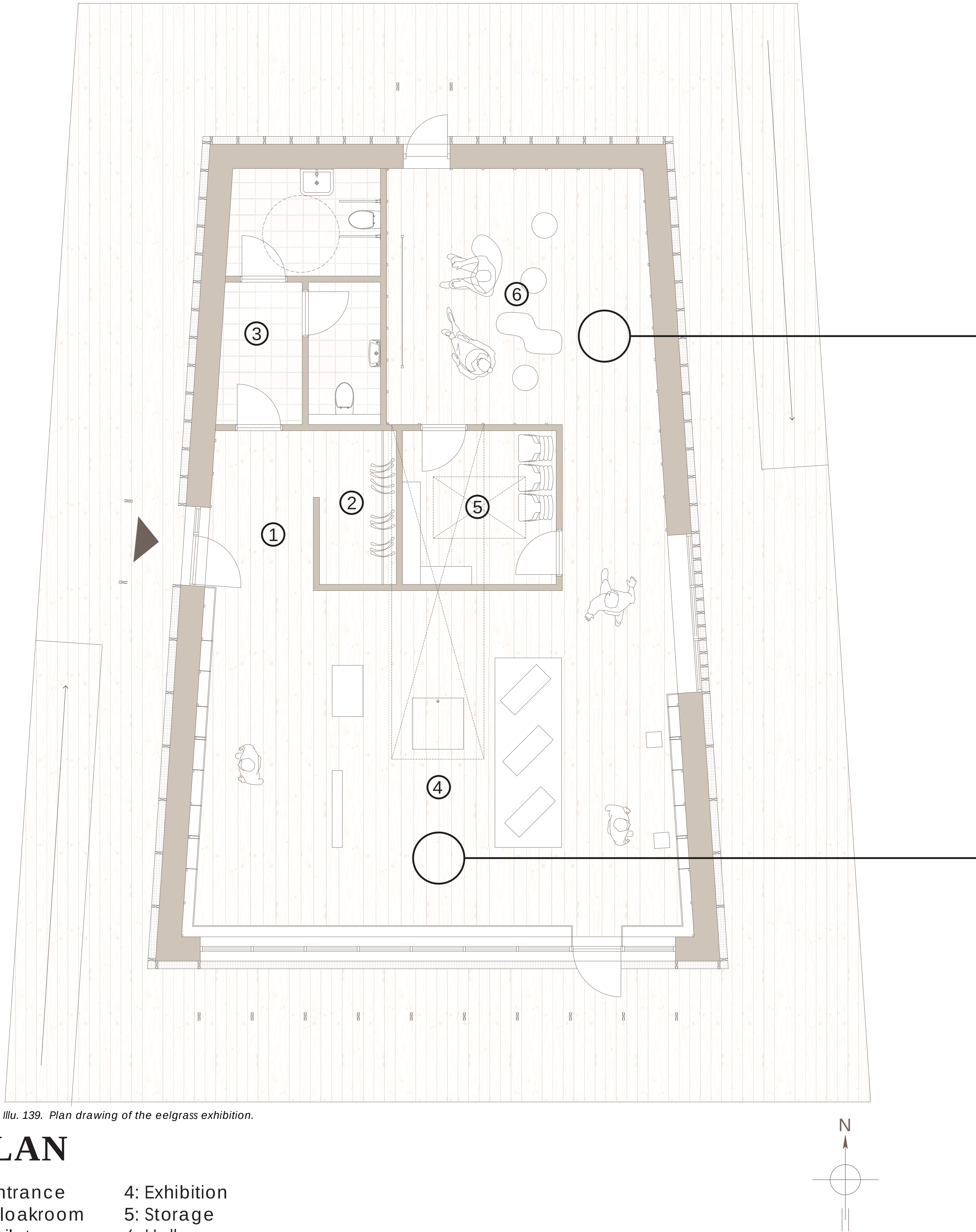
Illu. 137. Situation plan, showing the possible location of the eelgrass exhibition.

1:500

Illu. 138. Map of possible locations.

LOCATION

The exhibition is designed without a defined site. However, the building is designed with a defined orientation and a possible location in mind. The exhibition building is designed for a location on the southern coast of the Danish island Møn, as this, together with Bogø, is the main location for sourcing eelgrass currently and historically. However, it is possible to place the building in other locations. Other possible locations could be Køge, a city close to the capital of Denmark, which suffers from great amounts seaweed washing up at the beaches. Køge is a city undergoing a rapid development, especially along the southern part of the coast. The design could also be placed near Limfjorden or on Als, as these are also areas with great eelgrass occurrence. Additionally, Als is close to Germany, which is very keen on using eelgrass in their buildings.



Illu. 139. Plan drawing of the eelgrass exhibition.

PLAN

1: Entrance
2: Cloakroom
3: Toilets
4: Exhibition
5: Storage
6: Hall

ATMOSPHERES

The building design builds on the theory of working with contradistinctions in order to enhance the effect of the separate elements. Inside the exhibition building the contradistinctions are found in the atmospheres of the two main spaces, the Hall and the Exhibition. Between the two spaces is a transition in form of the hall way, which narrows in and the height of the beams decreases, from the Exhibition towards the Hall.

Illu. 140. Visualisation of the Hall.

Hall

The Hall is a 25 squaremeter enclosed room. The space has no windows and the ceiling is sloping, in order to create a dark and enclosed space. The walls and ceiling are covered with Søuld acosutic panels to provide a quite space, offering a calm atmosphere. The space is meant for presenting digital medie, whcich can be a challenge in the light open Exhibition.

Illu. 141. Visualisation of the Exhibition.

Exhibition

The Exhibition is a large open space with high ceiling and a northern bound skylight and a large window panel in the southern facade. The large space and the openings, create an open and inviting space. The floor and wall surfaces are covered with light wood and along the wall the floor opens up, to reveal the construction.

Illu. 142. Southern Facade *1:100*

FACADES

In the facades of the exhibition building, the contradistinctions are again utilised. For the facades, the contradistintions are found in the appearance of shapes and materials, rather than atmospheres.
The initial idea of the design was to contrast the heavy appearance of the original eelgrass roofs, to enhance the experience of the material.

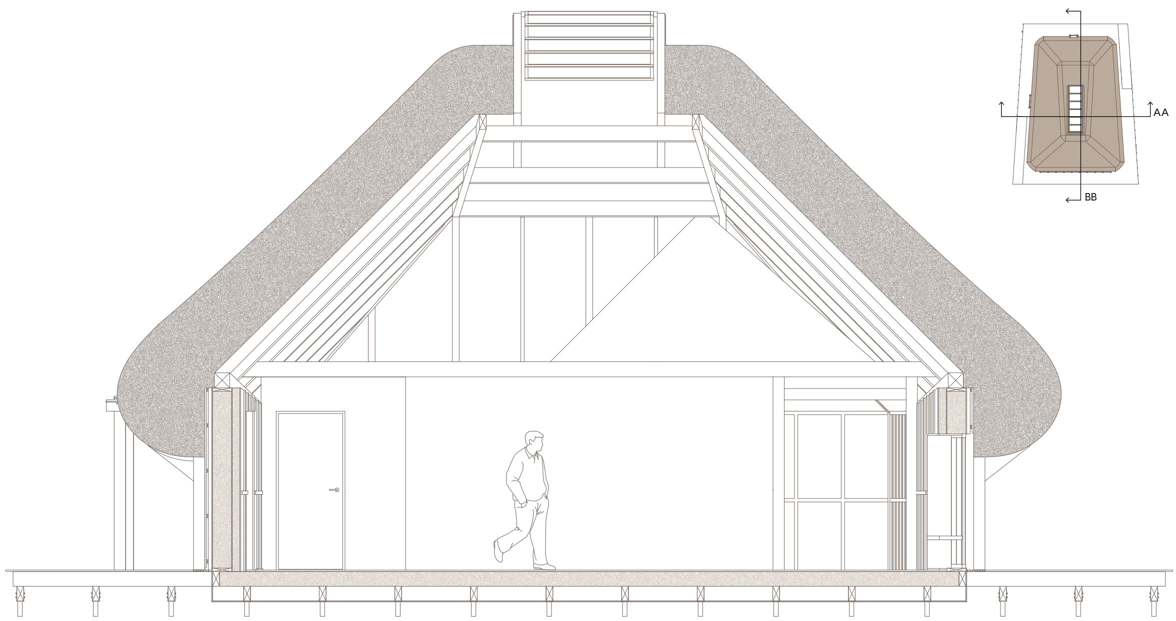
The heavy mass of the eelgrass roof is contasted by a light wooden structure which keeps the eelgrass from blocking openings, just as in the original eelgrass thatched houses of Læsø. This structure is applied to all openings which can be exited. On the western facade the structure isn't applied, and the eelgrass hangs down, covering the window, to allow the visitor to experience the eelgrass roofing from the inside through the window.

In the facade the vertical contadistinctions are either-or, as explained in the theory chapter of contradistinctions, whereas the horizontal contradistinctions are more-or-less. The distance between the horizontal elements in the facade decreases from the open to the closed end, to make the closed end appear denser.

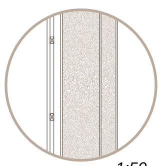
Illu. 143. Northern Facade 1:100

Illu. 144. Western Facade 1:200

Illu. 145. Eastern Facade 1:200



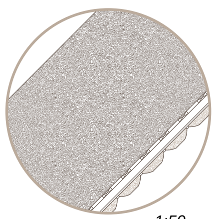
Illu. 146. Section AA. 1:100



1:50

Outer wall

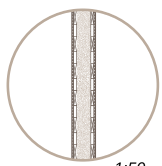
U-value: 0,11 W/m²K
Thickness: 506 mm
Area: 81 m²
Layers:
1. 20 mm wooden siding
2. 25 mm installation layer
3. 45 mm ventilated gap
4. 4,5 mm fiber cement windbarrier
5. 300 mm eelgrass
6. 0,25 mm paper vapour break
7. 100 mm eelgrass
8. 11 mm plywood



1:50

Roof

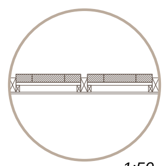
U-value: 0,10 W/m²K
Thickness: 1026 mm
Area: 182,5 m²
Layers:
1. 900 mm eelgrass
2. 20 mm installation layer
3. 45 mm ventilated gap
4. 11 mm ply-wood
5. 50 mm eelgrass upholstery



1:50

Storage wall

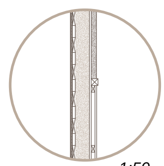
Thickness: 161 mm
Area: 30 m²
Layers:
1. 3 mm clay plaster
2. 10 mm reed mat
3. 20 mm laths
4. 95 mm eelgrass batt
5. 20 mm laths
6. 10 mm reed mat
7. 3 mm clay plaster



1:50

Storage ceiling

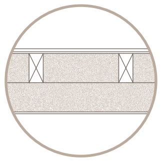
Thickness: 130 mm
Area: 6,8 m²
Heat capacity: 29 Wh/(Km2)
Layers:
1. 54 mm reused brick
2. 20 mm board
3. 45 mm installation layer
4. 11 mm ply-wood



1:50

Hall wall

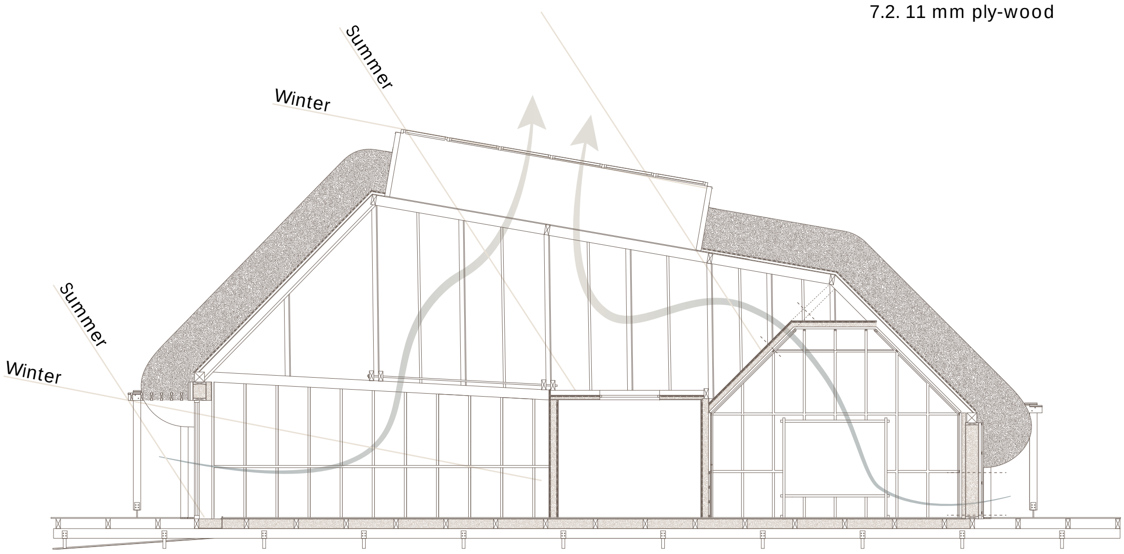
Thickness: 174 mm
Area: 18 m²
Layers:
1. 3 mm clay plaster
2. 10 mm reed mat
3. 20 mm laths
4. 95 mm eelgrass batt
5. 11 mm plywood
6.1. 35 mm Søuld
6.2. 25 mm installation layer
7.2. 11 mm ply-wood



1:50

Floor

U-value: 0,12 W/m²K
Thickness: 433 mm
Area: 125 m²
Layers:
1. 20 mm wooden flooring
2. 11 mm plywood
3. 195 mm eelgrass
4. 195 mm eelgrass
5. 12 mm wind barrier



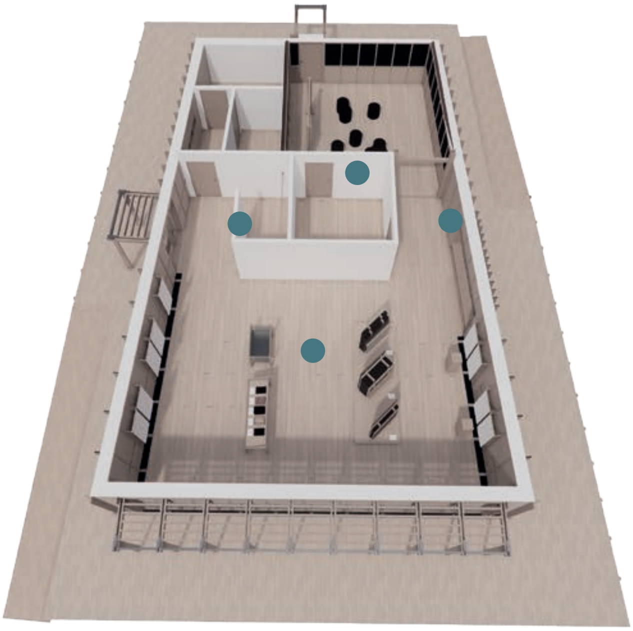
Illu. 147. Section BB. 1:150

SECTIONS

As seen in the detail drawings of the constructions on the previous page, a layer of plywood is applied to most constructions. This is due to the fire classification of plywood, which is viewed as a $K_1$10/D-s2,d2 cladding, the required classification for use on top of eelgrass loose fill. A gypsum board could have been used as a fire-resistant cladding as well. However, the plywood is chosen in order to emphasize the biobased material approach.
As seen in the sections the large skylight tilting towards north lets in diffuse light to the exhibition space, while simultaneously preventing the sun light from entering the exhibition space both in winter and summer.
In summer, the sun will however hit the ceiling of the storage and the hall. In attempt to decrease overheating in summer, the heat capacity of these surfaces has been increased. Especially the ceiling of the storage has a high heat capacity, as the upper surface is made up of reused bricks. However, the small surface with high heat capacity doesn't improve the total heat capacity and with a heat capacity of 14 Wh/(Km^2) the building is classified as an extra light construction. (Appendix 07)
The skylight additionally allows for natural ventilation by utilisation of the buoyancy driving force. For the hall to be ventilated by natural ventilation, an opening besides the escape door and one in the ceiling of the hall has been implemented. These are however not visible at the section, but their height is indicated with dashed line.

EASTER EGGS

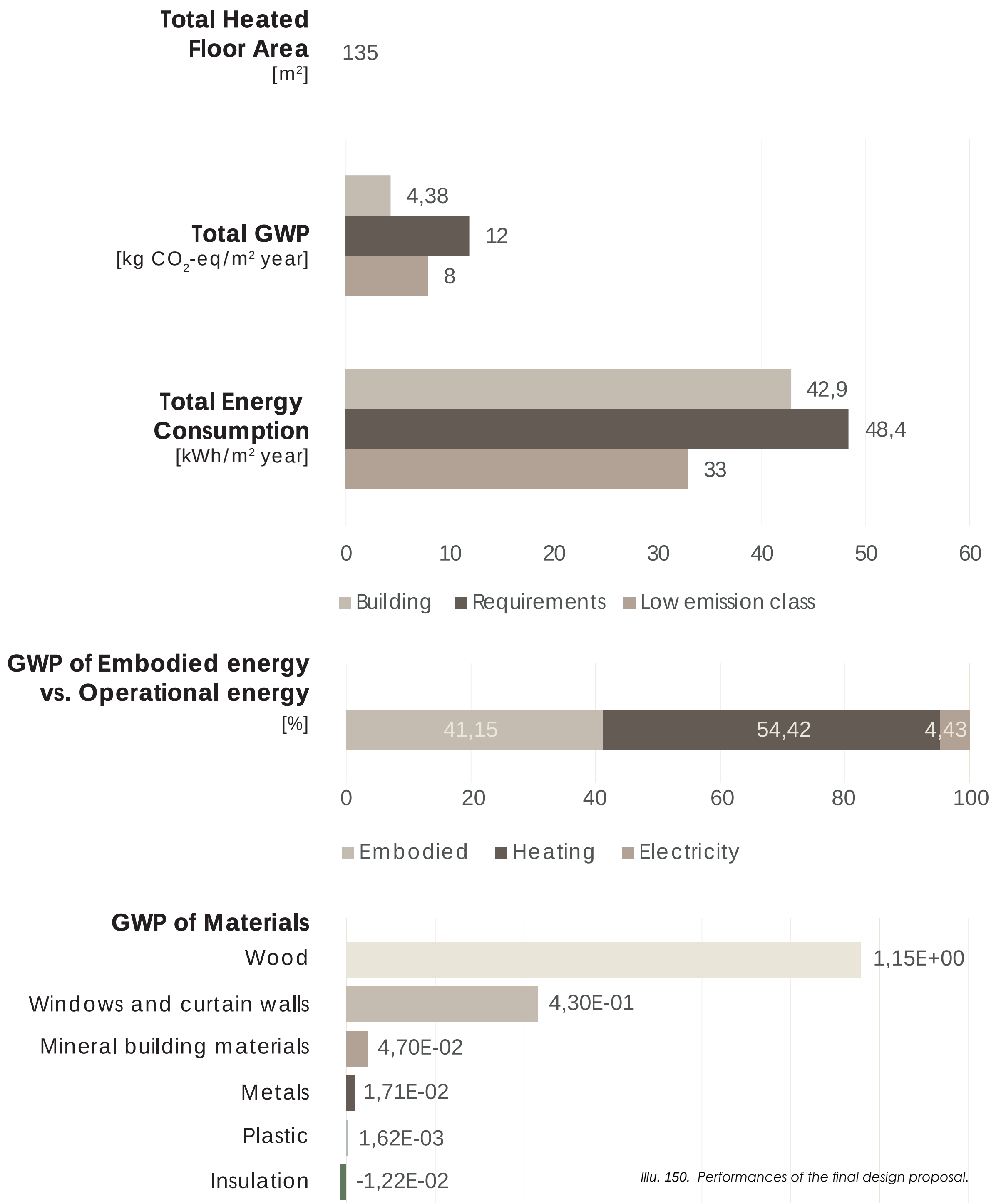
To make the building a part of the exhibition, easter eggs of constructions have been implemented in the building. Illustration 148 displays where these easter eggs are placed. An easter egg in this case is a part of the interior surfaces which opens and allows the visitor to experience to otherwise hidden construction. An example of the easter eggs is shown in illustration 149 where a panel of the wall opens as a drawer filled with the layers of the outer wall. The purpose of the easter eggs is to engage the visitor to interact with the exhibition and to provide a multi-sensory experience.



Illu. 148. Placement of easter eggs, showcased in three dimensional plan.

Illu. 149. Visualisation of easter egg.

PERFORMANCE



Illu. 150. Performances of the final design proposal.

Above the performance of the final design proposal is presented. The graphs show that eventhough the building only just fulfil the requirements of the Energy Frame of the Danish Building Regulations, the Global Warming Potential is lower than the voluntary Low Emission class of 2023.

The bottom table shows the relation of the GWP of the different material groups. The table showcases that the wooden materials have the greatest impact on the GWP of the building, this is due to the great amounts of wood in the building. However, the mineral building material proves to have the third greatest impact on the building, even though the use of mineral materials is very limited. Lastly, it must be noticed that the eelgrass insulation has a negative effect, affecting the GWP positively.

Illu. 151. Visualisation of the final design proposal.
Background photography provided by the Facebook group: Hønsinge Lyng strand uden tang.

EPILOGUE

In the epilogue the conclusion and reflections on the project is presented. Furthermore, the epilogue contains literature and illustration lists.

CONCLUSION

Based on the thesis it can be concluded that eelgrass has qualities which make it as useful in the building industry as other biobased materials.
Eelgrass is a good thermal insulator in its natural form, with a thermal conductivity of approximately 0,045 W/mK, and even more efficient when transformed into insulation batts, with a thermal conductivity of 0,037 W/mK, which is on height with conventional insulation materials.
However, there are downsides to transforming the eelgrass into insulation batts, as among others, the binders added in the production decreases the natural fire resistance of the eelgrass. The natural fire retardant in the eelgrass, caused by the high salinity of the plant, is one of the qualities, which put eelgrass in front of other biobased insulation materials. Naturally the dried loose fill eelgrass has a fire classification equivalent to a class D. With the decreased fire resistance, the eelgrass insulation batts still reach a fire classification E without additives, which is achieved in other biobased materials by adding salts.
Even though the natural fire resistance of eelgrass is considered to be one of advantages of eelgrass and the fire classification is on height with other biobased materials, designing with eelgrass in building require extra thought on the procurement of fire safety.
Another advantage of using eelgrass as a building material is the low Global Warming Potential. Loose fill eelgrass has a negative Global Warming Potential, as it stores more CO_2, than what is emitted during manufacturing. However, in the eelgrass insulation batts, this advantage is decreased, as the production requires more steps and there is added oil-based binders.
A disadvantage of eelgrass is that it is a time-consuming process to install the loose fill eelgrass. However, with prefabrication a technology, this is a challenge which can be concurred.
The greatest challenge of using eelgrass in the building industry is the lack of resources, as the Danish eelgrass meadows are challenged by the state of the Danish waters. Eelgrass is an important contributor to the ecosystem of the Danish waters and scientist are trying to restore the eelgrass meadows; however it is a slow process, which is reliant on the improvement of our waters.
For the building industry to improve by using eelgrass, raising awareness of the state of the eelgrass meadows, and improving these is an important step. This could for example be done by exhibiting the eelgrass and its possibilities to a wider audience.
As eelgrass is currently a sparse resource it is important to apply where it has the greatest effect. This has proved to be on the interior side of the building, as it last longer and provide great thermal- and acoustic insulation, and additionally can balance the humidity of the building.

REFLECTION

From working with the implementation of eelgrass in the building industry throughout this thesis, it has become clear that eelgrass and biobased materials can be part of the solution to bring down the environmental impact of the building industry. However, the implementation of new biobased materials has proven to be challenging due to the lack of information and the challenges of regulations and procedures.

First, it has been a challenge to compare the Global Warming Potential of eelgrass materials to conventional materials, as the predetermined assumptions for determining an LCA for a biobased material brings unrealistic drawbacks to the calculation. For example, at the End-of-life stage for biobased materials, these are as a standard considered to be incinerated. (Kauschen, 2015) For some biobased materials the incineration is the right choice, as it can replace the incineration of non-renewable materials. However, for eelgrass the incineration at the End-of-life stage isn't optimal for the material, as one of the qualities of eelgrass as a building material is its poor ability to burn. (Kauschen, 2015) When comparing the GWP of eelgrass insulation batts to Steico wood fibre batts, the product stage and the C2, transport to processing plant, are very similar. However, the release of CO_2 during incineration in stage C3 is much higher for eelgrass than wood fibre, while the gain from replacing incineration of non-renewable energy sources is only half the amount of the gain for wood fibre.

In the LCA report for the Modern Seagrass House, an alternative End-of-life is proposed. As an alternative the report propose an End-of-life stage where the eelgrass is used as fertilizer on a nearby field. In this scenario it is assumed that 50 percent of the CO_2 stored in the eelgrass will be released to the atmosphere, while 50 percent of the CO_2 is bound in the soil during the decomposition of the eelgrass. (Kauschen, 2015)

This scenario is only possible for the loose fill eelgrass, as the added oil-based binders in the eelgrass insulation batts hinder this approach. However, an alternative to incineration in the End-of-life stage could also be applied to the LCA of the eelgrass insulation batts. As the report for the eelgrass insulation batts states that the eelgrass of the batts could be reused in the production of new batts at the End-of-life (Pallesen, 2018), it would be sensible to assume a scenario where the eelgrass batts are recycled rather than incinerated.

Additionally, the standard lifespan of insulation materials is considered to be 30 years. However, intact constructions insulated with the eelgrass insulation mats Cabots Quilt are still discovered in USA till this day. (Kauschen, 2015) As the mats from Cabots Quilt were patented in 1891 and abandoned the production in 1942, the eelgrass mats must be at least 82 years old, proving a much longer possible lifespan than anticipated by the standards (Archipedia New England, 2020). The lifespan of eelgrass insulation should therefore be tested and reevaluated for future LCA calculations.

Furthermore, proving the positive effect of the high sorption dynamics of eelgrass in constructions, haven't been possible by the use of Ubakus as the calculation tool. Both eelgrass insulation batts, and in particular loose fill eelgrass has proven to have high water vapor sorption dynamics compared to mineral insulation materials. However, the calculations of condensation in Ubakus only consider the sd-value of the materials and not the sorption dynamics. This could be the reason why quite a few of the known constructions with eelgrass, according to Ubakus seems to have issues with condensation.

However, the implementation of eelgrass in the building industry is challenged by other factors than standards and regulations. The lack of eelgrass resources has proven to be one of the biggest challenges of upscaling the use of eelgrass in the building industry. Therefore, it should naturally be considered whether the use of other biobased materials would be more optimal. Straw for example, is also a waste resource which can also be installed directly into the building, however the thermal conductivity of straw is much higher than that of eelgrass and is the GWP, as the use of fertilizer and pesticides used for farming is included in the product stage (The International EPD® System, 2021). Additionally, most biobased materials, as for example wood fibre insulation, will need additional salts in the product to reach the same fire a classification as natural eelgrass (Institut Bauen und Umwelt, 2020).

The current cost of the eelgrass is another challenge for the implementation of eelgrass in the building industry. As seen in the Benchmark the cost of eelgrass products compared to well established products is at least double the cost. To make eelgrass a choice not only for special funded test buildings, but for private developers as well, the cost of eelgrass must get closer to the cost of other materials. However, in the report 'Bæredygtige Tangisoleringsmåtter fra ålegræs', it is anticipated that it will be possible to lower the price of the eelgrass insulation batts, when the demand increases and the production can be greater (Pallesen, 2018). It must be noted that this was the anticipation in 2018, and till this day the cost hasn't decreased. In fact, the cost of loose fill eelgrass seems to have increased since 2018, when comparing the prices from the report, which is 7 kr. pr. kg (Pallesen, 2018), with the price stated at the visit at Møn Tang, which was 15 kr. pr. kg (Appendix 01).

As a LCC hasn't been conducted for the renovations, it must, based on the high cost, be questioned if the economical benefits of renovating compared to building new is still valid when renovating with eelgrass. Before initiating a renovation with eelgrass, calculations of the cost and possible savings are therefore recommendable.

Another challenge of using the eelgrass in buildings, is that it is a time-consuming process insulating with loose fill eelgrass. When insulating with loose fill eelgrass the eelgrass is manually applied to the construction in small sections. Two possible solutions to this issue have throughout this report been presented. The first solution is the eelgrass insulation batts, which apart from being a bit more difficult to cut (Appendix 02), results in the same installation process as that of mineral wool batts. The advantage of the installation process of eelgrass batts, compared to mineral wool, is that it doesn't itch (Appendix 02) and that there is not the same dust nuisance (Appendix 04). However, there are downsides to the eelgrass insulation batts caused by the transformation from eelgrass to batt. For the batts BICO-fibers consisting of polyethylene/polypropylene are added as binders (Pallesen, 2018). The addition of the binders results in a higher GWP than that of loose fill eelgrass and simultaneously eliminates the possibility of reusing the eelgrass as fertilizer and the like. Another solution for decreasing the time consumption of installation without non-renewable additives, is the prefabricated panels of the Modern Seagrass House. The prefabricated panels optimize the time consumption and improves the quality of the insulation (Kauschen, 2015). Using the prefabricated eelgrass panels, could therefore be considered to be the best current solution, to decrease time consumption when insulating with eelgrass.

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ILLUSTRATION LIST

APPENDIX

APPENDIX 01

Visit at Møn Tang

On the 6th February 2024 a visit was made at Møn Tang to interview Kurt Schierup.
The interview was performed in Danish.
The interview had a loose structure, but the following questions were prepared:
Hvordan indsamler I tangen?
- Hvad er processen til færdigt produkt?
- Kunne det gøres mere bæredygtigt?
Er der nogen steder hvor der forekommer mere tang end andre?
Hvor meget tang ville man kunne samle?
Hvad er fordelene og ulemperne ved tang som materiale?
Hvordan tror du at fremtiden ser ud for tang?
Hvordan bliver det brugt i bygninger nu?
- Renovering?
- Ny byg?
Mærker I at man hører at der er forsvundet tang?
Kender du nogen der har gang i nogle spændende projekter?

The answers to the questions and import points of the conversation were manually noted in a block. The following is what was noted during the visit.

- Samlede 81 tons tang I 1958
- Der er intet tang tilbage på det Moderne Tanghus
  - o Pga. hul i undertaget
- Mere tang end de plejer i år
  - o Hænger sammen med regnfuldt og stormfuldt år
- For lidt kvælstof i vandet
- Havmiljøet er blevet dårligere siden 1986
  - o Prøvet at forbedre med lovgivning
- Hvis der er iltsvind, skal der være stormvejr for at få rusket op i bunden
- Udplantning af ålegræs kommer fra ålegræs plantager
- Møn Tang leverer til Søuld
  - o Hovedparten af tang kommer fra Bogø
    - Søuld har indgået aftale med amerikansk firma
- Der er andre opsamlere ved Gjøl og Spødstrup
- Det er en fordel at fjerne tang fra stranden
  - o Tangen indeholder kvælstof
- Coastgrass er et firma der laver bioplast af ålegræs.
- Rabatpillen, ålegræs til el og biogas
- SDU har prøvet at spore ålegræs med droner
- Kathryn Larsen laver alt muligt med tang
- Ålegræs isolering droppet fordi det er for dyrt
  - o Svært at konkurrere med Rockwool
- Samler ålegræs med maskiner
  - o Tørres på marken
- Ålegræs granulat til at blæse ind bliver tungt
  - o Dermed for dyrt, da man betaler pr kg.
- Har maximalt samlet 150 tons ålegræs på et år
- Samler gennemsnitligt 90 tons ålegræs om året pr opsamlingssted
- Ålegræs har været brugt siden bronzealderen
- Har været en salgsvare siden 1914
- Samlede 8 mio. tons ålegræs i 1914
- Ålegræs koster 9 kr. pr kg
- Brugte tang på Læsø fordi de ikke havde andet
- Ålegræsset bliver brugt til renoveringer
  - o Undgår at installere dampspærre
  - o Rester sælges til jordforbedring
- Største problem er at skaffe mere ålegræs
- Bruger 55 kg pr m3
- Pris: 15 kr x 55 kg= 1 m3
- Ålegræsset bruges mest som løsfyld
- Bruges til tangtage og Søuld
- 1 m2 ålegræs binder samme mængde CO_2 som 1 m2 regnskov
- Har lavet isoleringsmåtter
- Ålegræs har været brugt som oliespærre
- Samarbejder med Dansk Tang
  - o Kig Odsherred
- Rabatpillen.dk
- Tangdiger i Ebeltoft
- Kalhave Tangexport
- Tiny House på Friluftsmuseet
- Carlo Volf, vindues ventilation med ålegræs
- Laver piller til bioplast

ENGLISH TRANSLATION OF THE QUESTIONS BY GOOGLE TRANSLATE

How do you collect seaweed?
- What is the process for the finished product?
- Could it be made more sustainable?

Are there any places where more seaweed occurs than others?

How much seaweed would you be able to collect?

What are the advantages and disadvantages of seaweed as a material?

What do you think the future looks like for seaweed?

How is it being used in buildings now?
- Renovation?
- New build?

Do you notice that you hear that seaweed has disappeared?

Do you know someone who has some exciting projects going on?

ENGLISH TRANSLATION OF THE NOTES BY GOOGLE TRANSLATE

- A total of 81 tonnes of seaweed in 1958
- There is no seaweed left at the Modern Tanghus
o Due to hole in the roof
- More seaweed than usual this year
o Associated with rainy and stormy years
- Too little nitrogen in the water
- The marine environment has deteriorated since 1986
o Tried to improve with legislation
- If there is oxygen loss, there must be stormy weather to get the dust up at the bottom
- Planting of eelgrass comes from eelgrass plantations
- Møn Tang delivers to Søuld
o The majority of seaweed comes from Bogø
 Søuld has entered into an agreement with an American company
- There are other collectors at Gjøl and Spødstrup
- It is an advantage to remove seaweed from the beach
o The seaweed contains nitrogen
- Coastgrass is a company that makes bioplastic from eelgrass.
- Rabatpillen, eel grass for electricity and biogas
- SDU has tried to track eelgrass with drones
- Kathryn Larsen makes everything possible with pliers
- Eel grass insulation dropped because it is too expensive
o Difficult to compete with Rockwool
- Collects eel grass with machines
o Dry on the field
- Eel grass granules to blow in become heavy
o Thus too expensive, as you pay per kg.
- Has collected a maximum of 150 tonnes of eel grass in one year
- Collects an average of 90 tonnes of eelgrass per year per collection point
- Eelgrass has been used since the Bronze Age
- Has been a sales item since 1914
- A total of 8 million tons of eelgrass in 1914
- Eel grass costs DKK 9 per kg
- Used seaweed on Læsø because they had nothing else
- The eel grass is used for renovations
o Avoids installing a vapor barrier
o Residues are sold for soil improvement
- The biggest problem is getting more eel grass
- Uses 55 kg per m3
- Price: DKK 15 x 55 kg = 1 m3
- The eel grass is mostly used as loose fill
- Used for seaweed roofs and sea wool
- 1 m2 of eel grass binds the same amount of CO_2 as 1 m2 of rainforest
- Made insulation mats
- Eelgrass has been used as an oil barrier
- Collaborates with Dansk Tang
o Look Odsherred
- Rabatpillen.dk
- Tang dikes in Ebeltoft
- Kalhave Tangexport
- Tiny House at the Open Air Museum
- Carlo Volf, window ventilation with eel grass
- Makes pellets for bioplastic

PICTURES FROM THE VISIT AT MØN TANG

Illu. 157. Eelgrass roof construction for tiny house

Illu. 158. Knitting mill from the Modern Seagrass House

Illu. 159. Eelgrass bales

Illu. 156. Eelgrass fine strands

Illu. 155. Eelgrass long strands

Illu. 154. Eelgrass pellets

Illu. 153. Sorting device

Illu. 152. Sorting device

APPENDIX 02

Interview with architect Carlo Volf

The interview with Carlo Volf was performed in Danish and by phone. The interview had a loose interview form, but questions were prepared in advance. During the interview the important points were noted by hand, while all of the interview was transcribed by Word. The transcription will be placed after the presentation of questions and keypoints in both Danish and English. The transcription is only presented in Danish and has errors to it as it is transcribed by Word. The worst errors have been fixed.

THE QUESTIONS IN DANISH:
- Hvordan blev ålegræsset brugt i sommerhuset?
- Hvilket firma har produceret de batts der er brugt?
- Hvordan var det at arbejde med?
  - Hvilke fordele og ulemper er der ved materialet?
- Er der nogle særlige aspekter man skal være opmærksom på?
- Har man kunne mærke at brugen af ålegræs har haft en betydning for indeklimaet?
- Hvordan tror du at fremtiden ser ud for ålegræs som et byggemateriale?
  - Er du involveret i nogle nye spændende projekter?
- Er det muligt at man kan se de beregninger og tegninger du har udført i arbejdet med sommerhuset?

KEYPOINTS IN DANISH

- Lokalt materiale
- Djursland kendt for ålegræs
- Notech I sommerhuset
- Tungt materiale
- Gradueret tæthed
- Ingen dampspærre
- Damptryk suget ud hurtigere end det kommer ind
- Selvventilerende facade
  - o Skiftede farve i løbet af en dag
  - o Ventilerer både ålegræsset og sig selv
  - o Ingen råd i facaden
- Ålegræs dobbelt så tungt
  - o Isolerer mod varme
  - o Forsinker overtemperaturer
- Bygningsreglementet
  - o Ingen varmegenvinding
  - o Feldballe skole, lavenergi
  - o Reglementet er ikke godt nok
  - o Bygge uden for mange dimse dutter
- Batts er fra teknologisk institur
  - o Ikke standard produkt
- Har målt på fugt
- Sommerhuset er et udviklingsprojekt
- Der er ikke nok ålegræs til isolering
- Ventilation kan sagtens lade sig gøre
- Ikke muligt at få nok ålegræs
  - o Ødelagt af landbruget
  - o 30-40 år før det kan bruges som isolering
- Mennesker skal have vinding for at passe på miljøet
- Vandmiljøplan 1986
- Godt indeklima og redde klimaet
  - o Ålegræs= bedre indeklima og bedre klima
- Nemmere at arbejde med i vægge og gulve, sværere i loftet end mineraluld.
  - o Skal skæres på en anden måde
  - o Stikker ikke efter installation
  - o Mineraluld dårligt for arbejdsmiljøet
  - o Svenskere og nordmænd bruger ikke mineraluld
- Forskel på indeklimaet med og uden dampspærre
  - o Sanser det indirekte
  - o Dampspærre kan ikke ånde
  - o Kan ikke køle
- Skal have luftskifte
  - o Kan lige så godt få det gennem væggene i stedet for rør
- Drift og materiale slået sammen i LCA i BR18
  - o Naturlig ventilation giver øget energiforbrug i Be18
- Sommerhuset optimerer drift og materiale
  - o Pakker ikke noget ind
- Materiale har altid to funktioner
  - o EcoHousing: 2-3 grunde til at vælge materiale
- Ålegræs har god termisk masse
- Om 30 år er der ikke mere beton
  - o Måske ikke engagn i fundamentet
- Dyrke det biologiske
  - o Tager fra fremtidens generationer
- Bygningsreglementet spænder ben
  - o Norge, Sverige og Schweiz er bedre på bygningsfysik, Bevaret tradition
  - o Biobaserede materialer kan ikke normeres
  - o Revolution af systemet
  - o Ungdommen burde stille spørgsmål
- 4 til 1 planet, 25 cases, side 60 EcoHousing
- Tolagsruder
- EcoHousing: holde 200 år ca
  - o Facaden vil blive slidt
  - o Min. Holde 100 år
- LCA for 50 år pga. arbejdspladser
  - o Lavet for alle tre bæredygtighedsprincipper

QUESTIONS IN ENGLISH TRANSLATED BY GOOGLE TRANSLATE

- How was the eel grass used in the summer house?
- Which company produced the batts used?
- What was it like to work with?
  - What are the advantages and disadvantages of the material?
- Are there any special aspects to be aware of?
- Has it been noticed that the use of eelgrass has had an impact on the indoor climate?
- What do you think the future looks like for eel-grass as a building material?
  - Are you involved in any new exciting projects?
- Is it possible to see the calculations and drawings you have carried out in the work on the summer house?

KEY POINTS IN ENGLISH TRANSLATED BY GOOGLE TRANSLATE

- Local material
- Djursland known for eel grass
- Notech In the summer house
- Heavy material
- Graduated density
- No vapor barrier
- Vapor pressure sucked out faster than it comes in
- Self-ventilating facade
o Changed color during a day
o Ventilates both the eel grass and itself
o No advice in the facade
- Eel grass twice as heavy
o Insulates against heat
o Delays overheating
- The building regulations
o No heat recovery
o Feldballe school, low energy
o The regulations are not good enough
o Build without too many gimmicks
- Batts is from the Institute of Technology
o Not standard product
- Measured moisture
- The summer house is a development project
- There is not enough eelgrass for insulation
- Ventilation can easily be done
- Not possible to get enough eel grass
o Destroyed by agriculture
o 30-40 years before it can be used as insulation
- People must have profit to take care of the environment
- Water environment plan 1986
- Good indoor climate and save the climate
o Eel grass = better indoor climate and better climate
- Easier to work with in walls and floors, more difficult in the ceiling than mineral wool.
o Must be cut in a different way
o Does not stick after installation
o Mineral wool bad for the working environment
o Swedes and Norwegians do not use mineral wool
- Difference in indoor climate with and without vapor barrier
o Sense it indirectly
o Vapor barrier cannot breathe
o Cannot cool
- Must have air exchange
o Might as well get it through the walls instead of pipes
- Operation and material combined in LCA in BR18
o Natural ventilation increases energy consumption in Be18
- The summerhouse optimizes operation and material
o Does not wrap anything
- Material always has two functions
o EcoHousing: 2-3 reasons for choosing material
- Eel grass has good thermal mass
- In 30 years there will be no more concrete
o Perhaps not committed to the foundation
- Grow the biological
o Taking from future generations
- The building regulations are troubling
o Norway, Sweden and Switzerland are better at building physics, Preserved tradition
o Bio-based materials cannot be standardized
o Revolution of the system
o The youth should ask questions
- 4 to 1 planet, 25 cases, page 60 EcoHousing
- Double glazing
- EcoHousing: last 200 years approx
o The facade will be worn
o Min. Last 100 years
- LCA for 50 years due to workplaces
o Made for all three sustainability principles

APPENDIX 03

Calculations for Benchmark

EELGRASS THATCH GWP

To determine the GWP for an eelgrass thatched roof, the values of the LCA of the Modern Seagrass House have been modified. First the area of the roof of the Modern Seagrass House was determined. Then the GWP for the roof per m^2. Next, the factor between the weight of the modern eelgrass rrof and the original thatched was determined. This factor was used to determine the GWP for the eelgrass for the roof. This GWP was added to the GWP of the construction.

The modern seagrass house	Floor area	Width	Length	Height	Height till roof
	90	4,8	16,8	5,6	2

Height of roof [m]	Total height-height till roof	3,6
Width of one roof surface [m]	Width of roof/2	2,4
Leght of sloping edge of roof [m]	√height of roof^2+half width of building	4,326662
Area of one roof surface [m2]	Length*sloping length	72,68791
Total area of roof [m2]	Area*2	145,3758
Total GWP for roof [kg CO2-eq]		-1295,54
GWP pr m2 [kg CO2-eq/kg]	Total GWP/Roof area	-8,91166
Weight of eelgrass [kg]		4987,59
Total GWP for eelgrass		283,66
Weight pr m2 [kg/m2]	Roof area/eelgrass weight	34,30825
Weight of eelgrass thatch [kg/m2]		160
Factor	weight eelgrass thatch/weight eelgrass modern	4,663602
GWP for eelgrass thatch pr m2 [kg CO2-eq/m2]	GWP eelgrass modern*factor	1322,877
Total GWP for thatch construction [kg CO2-eq]	Orig. GWP-eelgrass GWP+thatch GWP-roofing felt GWP	-1826,32
Total GWP for thatch construction pr m2 [kg CO2-	Total GWP/roof area	-12,5628

COST OF EELGRASS THATCH

As mentioned, the cost of the eelgrass thatched roof is solely based on the cost of eelgrass and doesn't include cost of roof construction or labor. The calculation of the cost for an eelgrass thatched roof is based on the cost per kilogram as stated in Appendix 01 by Kurt Schierup. He explained that eelgrass is paid per kilogram and the price is 15 kr per kilogram. The weight of one square meter of eelgrass roof is 160 kg as described in the presentation of the original eelgrass houses of Læsø on page 32.
The cost thereby becomes:

$$Cost\ per\ m^2 = 15\frac{kr}{kg} \cdot 160\ kg = 2400\ kr$$

FIRE CLASSIFICATION FOR LOOSE FILL EELGRASS

On the website Seegrashandel.de they state that the fire classification is B2 according to the German standard DIN 4102-1 (Seegrashandel.de, 2018). This classification has been converted to the European standards by the following table:

DIN 4102-1 comprises 5 construction material classes, from A1 through B3 (see Fig. 7.5.2 Table 1, Line 2). The new European standardisation will comprise 7 construction material tests A1 - F (see Fig. 7.5.2 Table 1, Line 3).

Building supervision delineation	Construction material class as per DIN 4102-1	Euro class	Level of standards	Fire stage	
Non-flammable	A1	A1	No contribution to fire	Fully developed room fire	Approx. 60 kW/m²
	A2	A2	Negligible contribution to fire		
Minimally flammable	B1	B	Very minimal contribution to fire	Single burning object	Approx. 40 kW/m²
		C	Minimal contribution to fire		
Normally flammable	B2	D	Acceptable contribution to fire		
		E	Acceptable flammability	Small flame	20 mm flame
Minimally flammable	B3	F	No standards		

Source for the table: Mahmood, A., n.d.. https://www.scribd.com. [Online]
Available at: https://www.scribd.com/document/147546178/DIN-4102
[Senest hentet eller vist den 20 May 2024].

I am currently awaiting the certificate of the fire test of the eelgrass.

COST OF EELGRASS LOOSE FILL

The cost of eelgrass loose fill is based on the cost per kilogram as stated in Appendix 01 by Kurt Schierup. He explained that eelgrass is paid per kilogram and the price is 15 kr per kilogram.
The cost of one square meter of eelgrass loose fill is determined by the thickness necessary to reach a U-value of 0,12 W/m2K and the density of the material. According to Appendix 01 the eelgrass loose fill should have a density of 55 kg/m3 when applied.
The thickness to reach a u-value of 0,12 W/m2k:

$$d = \frac{1}{U} \cdot \lambda = \frac{1}{0{,}12\frac{W}{m^2K}} \cdot 0{,}045\frac{W}{mK} = 0{,}375\ m$$

The thickness is multiplied with the density of one cubic meter of eelgrass and the cost of one cubic meter of eelgrass.

$$Cost = 0{,}375\ m \cdot 55\frac{kg}{m^3} \cdot 15\frac{kr}{kg} = 309{,}375\ kr/m^2$$

GWP FOR EELGRASS BATTS

As mentioned, the GWP for the eelgrass insulation batts is based on the GWP of the Søuld acoustic mats, as the process and the content are the same.

The GWP for the different phases of the Søuld mats are seen in the table below.

Product 2: Søuld Acoustic Mats – Non-Flameretardant

ENVIRONMENTAL IMPACTS PER 1 KG SØULD ACOUSTIC MATS							
Parameter	Unit	A1-A3	C1	C2	C3	C4	D
GWP-total	[kg CO_2 eq.]	-7.47E-01	0.00E+00	2.30E-03	1.57E+00	0.00E+00	-3.52E-01
GWP-fossil	[kg CO_2 eq.]	4.25E-01	0.00E+00	2.26E-03	4.15E-01	0.00E+00	-3.54E-01
GWP-biogenic	[kg CO_2 eq.]	-1.17E+00	0.00E+00	2.46E-05	1.15E+00	0.00E+00	2.63E-03

(Sørensen, 2022)

To determine the GWP for the eelgrass insulation batt the necessary thickness to reach a u-value of 0,12 W/m2K has been determined.

$$d = \frac{1}{U} \cdot \lambda = \frac{1}{0{,}12 \frac{W}{m^2 K}} \cdot 0{,}037 \frac{W}{mK} = 0{,}308\ m$$

The thickness is then multiplied with the density of the product and the total GWP in kg CO2-eq /kg.

$$GWP_{m^2} = 70 \frac{kg}{m^3} \cdot 0{,}308\ m \cdot 0{,}473\ kg\ CO_2 - eq\ per\ kg = 10{,}22\ kg\ CO_2 - eq\ per\ m^2$$

To create GWPs which can be resembled. All GWPs of insulation materials have been converted to refer to one square meter of material with a u-value of 0,12 W/m2K.

The conversion can be found in the table below.

Eelgrass loosefill	A1-A3	C2	C3	C4	D	Total
GWP pr kg [kg CO2-eq /kg]	-0,349					**-0,349**
Thermal conductivity [W/mK]	0,045					
Thickness [m]	0,375					
Density [kg/m3]	55					
GWP pr m2 [kg CO2-eq /m2]	**-7,198125**					

Eelgrass batts	A1-A3	C2	C3	C4	D	Total
GWP pr kg [kg CO2-eq /kg]	-7,47E-01	2,30E-03	1,57E+00		-3,52E-01	**4,73E-01**
Thermal conductivity [W/mK]	0,037					
Thickness [m]	0,308333333					
Density [kg/m3]	70					
GWP pr m2 [kg CO2-eq /m2]	**10,21539167**					

Steico batts	A1-A3	C2	C3	C4	D	Total
GWP pr kg [kg CO2-eq /m3]	-2,83E+01	1,45E-01	7,83E+01		-4,01E+01	**1,01E+01**
GWP pr kg [kg CO2-eq /kg]						1,68E-01
Thermal conductivity [W/mK]	0,036					
Thickness [m]	0,3					
Density [kg/m3]	60					
GWP pr m2 [kg CO2-eq /m2]	**3,02E+00**					

Rockwool	A1-A3	C2	C3	C4	D	Total
GWP pr kg [kg CO2-eq /m2]	4,24E-01	4,35E-03	0,00E+00	1,64E-01	-2,81E-02	**5,64E-01**
GWP pr kg [kg CO2-eq /kg]						**4,70E-01**
Thermal conductivity [W/mK]	0,037					
Thickness [m]	0,308333333					
Density [kg/m3]	33					
GWP pr m2 [kg CO2-eq /m2]	**4,78E+00**					

APPENDIX 04

Interview with Tømrermester Søren H. Rasmussen

The interview with Tømrermester Søren H. Rasmussen was performed by mail correspondence only. As for the two other interviews predefined questions were mailed in advance offering an interview by phone but stating that any reply would be useful.

THE QUESTIONS IN DANISH SEND TO TØMRERMESTER SØREN H. RASMUSSEN WAS:
- Hvor i konstruktionen har I tidligere brugt ålegræs?
  - Har det været i nybyg eller renovering?
  - Har det været løsfyld, granulat eller batts i har brugt?
- Hvordan var det at arbejde med?
  - Hvilke fordele og ulemper er der ved materialet?
- Er der nogle særlige aspekter man skal være opmærksom på?
- Er det noget I har brugt mere siden?
- Hvordan tror I at fremtiden ser ud for ålegræs som et byggemateriale?

THE REPLY IN DANISH WAS:
Hvor i konstruktionen har I tidligere brugt ålegræs? I vægge og tagkonstruktioner.
  - Har det været i nybyg eller renovering? Det har været ved renoveringsarbejde.
  - Har det været løsfyld, granulat eller batts i har brugt? Løsfyld. Vi har eksperimenteret med at lave granulat, men det er ikke lykkedes.
- Hvordan var det at arbejde med? Det var fint at arbejde med, men forholdsvist tidskrævende.
  - Hvilke fordele og ulemper er der ved materialet? Det er en ulempe, at materialet leveres i big-baller, da det er svært at håndtere. Det er en fordel, at det er behageligt at arbejde med – ingen støvgener som ved traditionel isolering.
- Er der nogle særlige aspekter man skal være opmærksom på? Kvaliteten som er afhængig af oprensningen.
- Er det noget I har brugt mere siden? Ja, nogle gange.
- Hvordan tror I at fremtiden ser ud for ålegræs som et byggemateriale? Begrænset pga. manglende leverenser.

THE QUESTIONS TRANSLATED TO ENGLISH BY GOOGLE TRANSLATE:
- Where in the construction have you previously used eelgrass?
  - Has it been in new construction or renovation?
  - Have you used loose fill, granules or batts?
- What was it like to work with?
  - What are the advantages and disadvantages of the material?
- Are there any special aspects to be aware of?
- Is it something you have used more since?
- What do you think the future looks like for eel grass as a building material?

THE REPLY TRANSLATED TO ENGLISH BY GOOGLE TRANSLATE
-Where in the construction have you previously used eel grass? In walls and roof structures.
  - Has it been in new construction or renovation? It has been during renovation work.
  - Have you used loose fill, granules or batts? Loose fill. We have experimented with making granules, but it has not been successful.
- What was it like to work with? It was nice to work with, but relatively time consuming.
  - What are the advantages and disadvantages of the material? It is a disadvantage that the material is delivered in big bales, as it is difficult to handle. It is an advantage that it is pleasant to work with – no dust nuisance as with traditional insulation.
- Are there any special aspects to be aware of? The quality depends on the purification.
- Is it something you have used more since? Yes, sometimes.
- What do you think the future looks like for eel grass as a building material? Limited due to lack of deliveries.

Tømrermester Søren H. Rasmusses was later asked for pictures of the installation of eelgrass, which they kindly provided.

APPENDIX 05

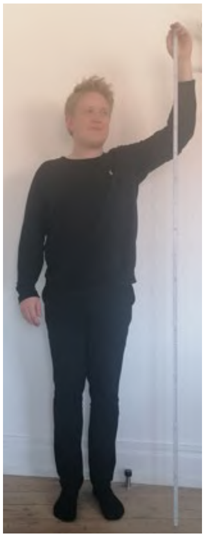
Study of including reachable heights

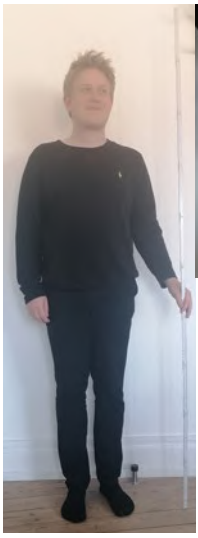
EELGRASS THATCH GWP

To determine in which height the roof should be to be reachable for all, a small study of reachable heights was performed. The study measured the upper and lower reachable heights for a man of average height and for a person in wheelchair, in this case just chair.

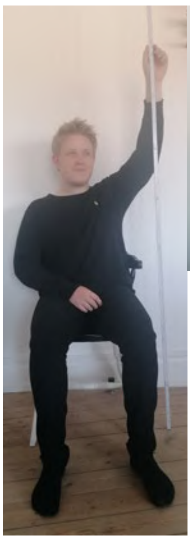
The reachable height for a four-year-old child was observed to be 100 cm.

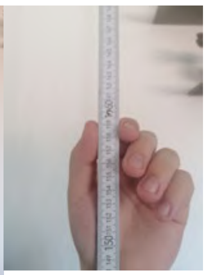
The including reachable height was by the study concluded to be between 80 cm and 100 cm.





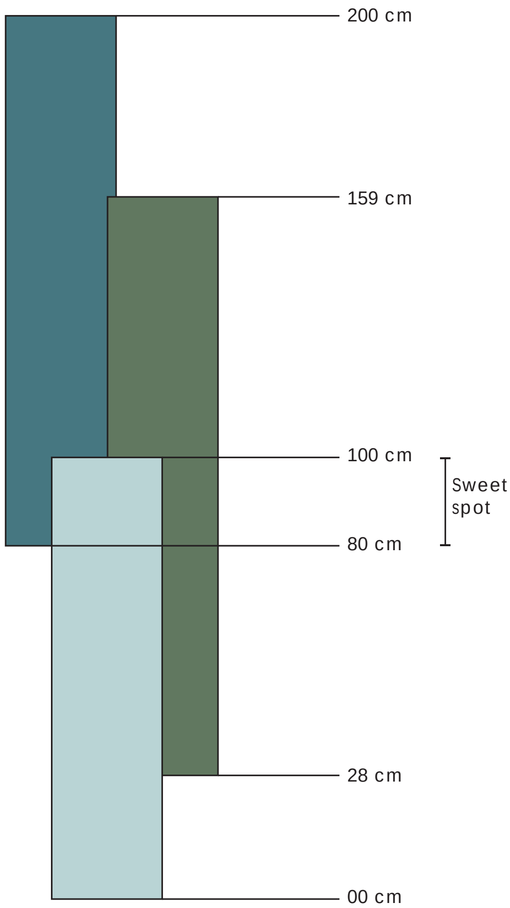
80 cm





159 cm

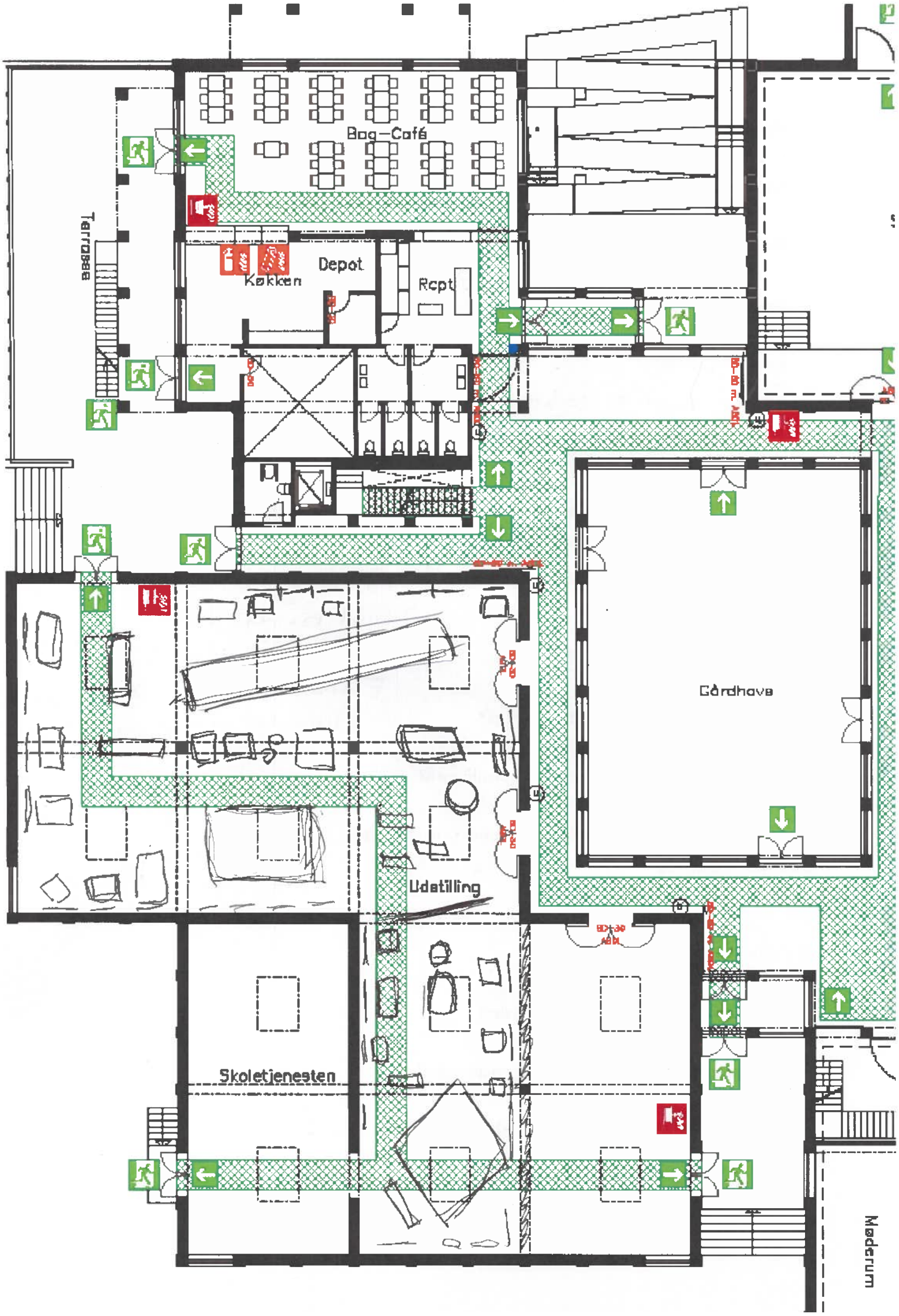
28 cm



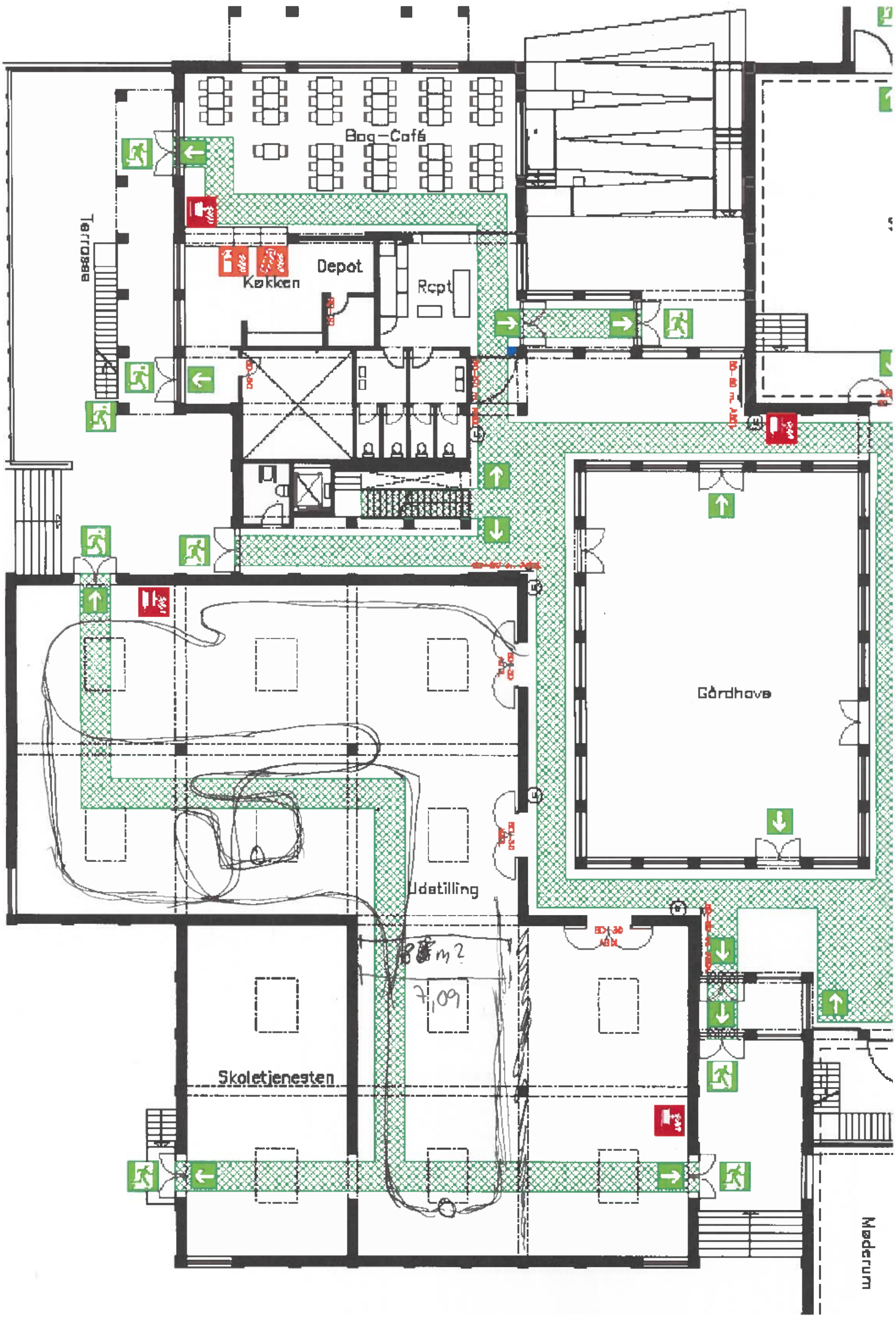
APPENDIX 06

Observations at Utzon Center

When visiting Utzon Center the amount of artifacts and the layout and content of the exihibiton was observed.



Additionally, the movement and interaction with the exhibition of the audience was observed.



APPENDIX 07

Heat Capacity

Determination of effective capacity of a room

Template

Net floor area	125 m2	c	r	d_T	C	$A_{buildingelement}$	C_m
	layer from inside	J/(kg K)	kg/m³	m	Wh/(K m²)	m²	Wh/K
External wall A_{EW}	Plywood	1600	700	0,011	3,42		
	Eelgrass	2100	55	0	0,00		
					3,42	81,00	277
Internal wall A_{IW}	Clay plaster	1000	1700	0,003	1,42		
	Reed mat	1200	155	0	0,00		
	Boards	1600	225	0	0,00		
					1,42	30,00	43
Ceiling A_{Ce}	Eelgrass	2100	55	0	0,00		
	Plywood	1600	700	0	0,00		
					0,00	180,00	0
Floor A_F	Woood flooring	1700	690	0,02	6,52		
	Plywood	1600	700	0,011	3,42		
					9,94	125,00	1242
Storage ceiling	Bricks	1000	1500	0,054	22,50		
	Plywood	1600	700	0,02	6,22		
					28,72	7,00	201

Fill in yellow areas
Read results in grey areas
Read intermediate results

You may add more layers.

C_m	Wh/K	1763
Net floor area room	m²	125,0
C_m/ $A_{netroom}$	**Wh/m²K**	**14**
Classification		**extra light**

APPENDIX 08

Natural ventilation

Hall

The hall is the most critical space regarding ventilation as it is a small, confined space.

First the necessary air flow rate for the room is determined by:

$q_{tot} = n \cdot q_p + A \cdot q_b$

Where:

$n = number\ of\ occupants$

$q_p = outdoor\ air\ supplied\ per\ person\ [\frac{l}{s}]$

$A = floor\ area\ [m^2]$

$q_b = outdoor\ air\ supplied\ to\ consider\ emission\ from\ building\ and\ furnishing\ [\frac{l}{s}\ per\ m^2]$

The room is 25 m2 and with 2 m2 for one person, that makes room for 12 people in the hall.

$Number\ of\ occupants: n = \frac{25m^2}{2\ m^2} = 12{,}5 \sim 12$

ISO 15251

		Airflow for building emissions pollutions (l/s/m²)		
Category	Airflow per person l/s/pers	Very low polluting building	Low polluting building	Non low polluting building
I	10	0,5	1	2
II	7	0,35	0,7	1,4
III	4	0,2	0,4	0,8

$q_p\ is\ a\ table\ value = 7\frac{l}{s}/pers$

$Floor\ area: A = 25\ m^2$

$q_b\ is\ also\ a\ table\ value = 0{,}35\frac{l}{s}/m^2$

Then the air flow rate can be determined

$q_{tot} = 12\ pers \cdot 7\frac{l}{s}\ per\ pers + 25m^2 \cdot 0{,}35\frac{l}{s}\ /m^2 = 92{,}75\ l/s$

This equals to an Air change rate of

The air change rate is determined by:

$$ACH = \frac{Volume\ flow\ \left[\frac{m^3}{h}\right]}{Room\ volume\ [m^3]}$$

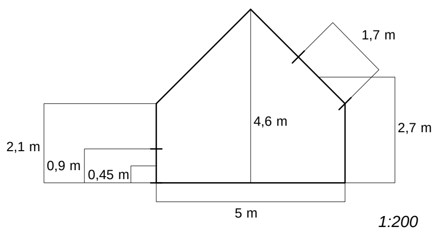
The room volume of the hall is:

$$V_{hall} = 5m \cdot 5m \cdot 2{,}1m + \frac{5m \cdot 5m \cdot 2{,}5m}{3} = 73{,}3\ m^3$$

The air flow rate is converted from l/s to m3/h

$$q_{tot} = 92{,}75\frac{l}{s} = 333{,}9\ m^3/h$$

$$ACH = \frac{333{,}9\ m^3/h}{73{,}3\ m^3} = 4{,}55\ h^{-1}$$



Pressure Coefficient		**Windfactor**	0,57	**Pwind**
Windward	-0,5	**Vmeteo**	6 m/s	**Pmin**
Leeward	-0,5	**Vref**	3,42 m/s	**Pmax**
roof	-0,1			

Location of neutral plan, Ho	2,6 m	**Buildingvol.**
Outdoor temperature	18 C	**Volume**
Zone temperature	20 C	
Discharge coefficient	0,7	**Internal pressure,** pa
Air density	1,25 kg/m3	

	Area m2	Eff. Area m2	Height m	Thermal Buoyancy pa	AFR (thermal) m3/s	Pres Coefficient	Wind pressure pa
1. floor	0,25	0,175	0,45	0,179	0,09	0,06	2,999
1. floor	0	0,000	2,6	-0,001	0,00	-0,38	-0,218
2. floor	0	0,000	5,8	-0,269	0,00	0,06	2,999
2.floor	0	0,000	5,8	-0,269	0,00	-0,38	-0,218
Roof	1,08	0,756	2,7	-0,010	-0,09	-0,38	-0,218
				Massebalance	0,00		Massebalance

Neutral plane A1 H1 A2 H2

0,250 0,45 1,08 2,7 2,59

Volume flow	0,09	m^3/s
Volume flow	337,09	m^3/h
Volume	73,3	m^3
Luftskifte	4,598807666	h^-1
Nødvendigt luftskifte	4,55	h^-1

Exhibition

The same approach is applied for the exhibition space.

15 occupants are expected in the exhibition space.

$n = 15$

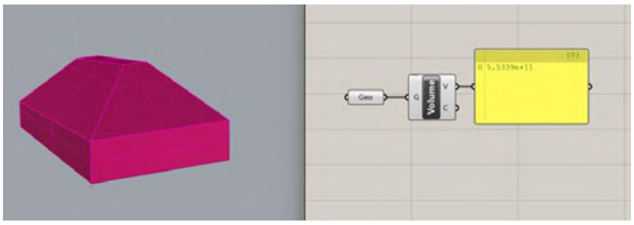
$q_p = 7\frac{l}{s}\ /pers$

$A = 64\ m^2$

$q_b = 0{,}35\frac{l}{s}\ /m^2$

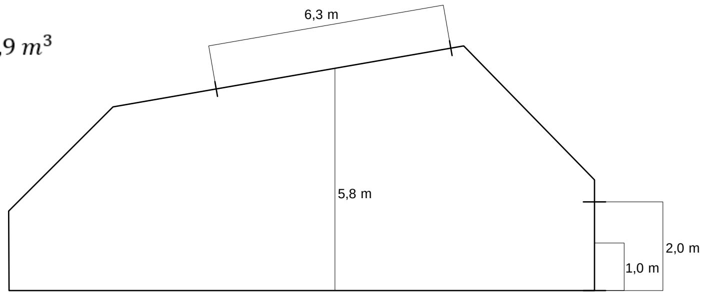
$q_{tot} = 15\ pers \cdot 7\frac{l}{s}\ pr\ pers + 64\ m^2 \cdot 0{,}35\frac{l}{s}\ pr\ m^2 = 127{,}4\ l/s$

The volume of the space is determined in grasshopper, as the geometry is quite complex.



$$V = 553\ m^3 - 70\ m^3 - 3m \cdot 3m \cdot 2{,}5m - 3m \cdot 4m \cdot 2{,}3m = 432{,}9\ m^3$$

$$ACH = \frac{458{,}64\ m^3/h}{432{,}9\ m^3} = 1{,}059\ h^{-1}$$



1:200

Pressure Coefficient			**Windfactor**	0,57	**Pwind**
Windward	-0,5		**Vmeteo**	6 m/s	**Pmin**
Leeward	-0,5		**Vref**	3,42 m/s	**Pmax**
roof	-0,1				
Location of neutral plan,		5,6 m			**Buildingvol.**
Outdoor temperature		18,5 C			**Volume**
Zone temperature		20 C			
Discharge coefficient		0,7			**Internal** pa
Air density		1,25 kg/m3			

	Area m2	Eff. Area m2	Height m	Thermal pa	AFR (thermal) m3/s	Pres Co	Wind pr pa
1. floor	2	1,400	1	0,292	0,96	0,06	2,999
1. floor	0	0,000	2,6	0,191	0,00	-0,38	-0,218
2. floor	0	0,000	5,8	-0,010	0,00	0,06	2,999
2.floor	0	0,000	5,8	-0,010	0,00	-0,38	-0,218
Roof	11	7,700	5,8	-0,010	-0,96	-0,38	-0,218
				Massebalar	0,00		assebalar

Neutral plane	A1	H1	A2	H2		
	2,000	1	11	5,8		5,65

Volume flow	0,96	m^3/s
Volume flow	3444,859	m^3/h
Volume	181	m^3/h
Luftskifte	19,03237	h^-1
Nødvendigt luftskifte	1,059	h^-1

APPENDIX 08

Be18

Bygning

Navn: Zostera Marina

Andet — Fritliggende bolig (fritliggende enfamiliehus)
Sammenbyggede boliger (fx dobbel-, række- og kædehuse)
Etagebolig, Lager mv eller Andet (ikke bolig)

1	Antal boligenheder	0	Rotation, °
135	Opvarmet etageareal, m²	135	Bruttoareal, m²
0	Opvarmet kælder, m²	0	Andet, m²
158	Bebygget areal, m²		
14	Varmekapacitet, Wh/K m²	Start, kl.	Slut, kl.
56	Normal brugstid, timer/uge	10	18

Beregningsbetingelser

BR: Aktuelle f — Se beregnings-vejledningen

Tillæg til energirammen for særlige betingelser, kWh/m² år: 0

Kun mulig for andre bygninger end boliger og beregningsbetingelser: BR: Aktuelle forhold.

OBS: Ny reference for belysning i BR15: 300 lux.

Varmeforsyning

Fjernvarr — Basis: Kedel, Fjernvarme, Blokvarme eller El

☐ Varmefordelingsanlæg (hvis elvarme)

Bidrag fra (i prioritets-orden)

☐ 1. Elradiatorer ☐ 2. Brændeovne, gasstrålevarmere og lign.
☐ 3. Solvarme ☑ 4. Varmepumpe ☐ 5. Solceller ☐ 6. Vindmøller

Mekanisk køling

0 — Andel af etageareal, -

Beskrivelse

Kommentarer

Samlet varmetab

Transmissionstab 2,8 kW 20,8 W/m²
Ventilationstab uden vgv 1,0 kW 7,7 W/m² (om vinteren)
I alt 3,8 kW 28,4 W/m²
Ventilationstab med vgv 1,0 kW 7,7 W/m² (om vinteren)
I alt 3,8 kW 28,4 W/m²

Transmissionstabsramme

Almindelig 21,2 W/m²
Lavenergi 20,2 W/m²

	Ydervægge, tage og gulve	Areal (m²)	U (W/m²K)	b	Ht (W/K)	Dim.Inde (C)	Dim.Ude (C)	Tab (W)
		390,5		CtrlClick	43,185			1381,92
1	Ydervæg	81	0,111	1,00	8,991	20	-12	287,712
2	Tag	184,5	0,102	1,00	18,819	20	-12	602,208
3	Gulv	125	0,123	1,00	15,375	20	-12	492

	Vinduer og yderdøre	Antal	Orient	Hældn.	Areal (m²)	U (W/m²K)	b	Ht (W/K)	Ff (-)	g (-)	Skygger	Fc (-)	Dim.Inde	Dim.Ude (	Tab (W)	Ot
		9			44,45		CtrlClick	44,45			CtrlClick				1422,4	0/1
1	Stort vindue exhib	1	180	90	21	1	1,00	21	0,8	0,63	Med afska	1	20	-12	672	0
2	Dør	1	270	90	3	1	1,00	3	0,8	0,63	Udhæng c	1	20	-12	96	0
3	3 Vinduer	3	90	90	3	1	1,00	9	0,8	0,63	Udhæng c	1	20	-12	288	0
4	Toilet	3	270	90	0,15	1	1,00	0,45	0,8	0,63	Udhæng c	1	20	-12	14,4	0
5	Loft	1	0	10	11	1	1,00	11	0,8	0,63	ovenlys	1	20	-12	352	0

	Skygger	Horisont (°)	Udhæng (°)	Venstre (°)	Højre (°)	Vindueshul (%)
1	Med afskærmning	0	46	1	1	4,3
2	Udhæng dør	0	42	5	5	6,66
3	ovenlys	22	22	55	55	5,5

	MWh	Januar	Februar	Marts	April	Maj	Juni	Juli	August	September	Oktober	November	December	I alt
	Varmebehov													
+1	Trans.- og vent.tab	1,42	1,29	1,52	0,91	0,62	0,41	0,16	0,16	0,39	0,75	1,18	1,42	10,22
2	Vent. VF (total)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	Vent. VGV nedreg.	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	Varmetab	1,42	1,29	1,52	0,91	0,62	0,41	0,16	0,16	0,39	0,75	1,18	1,42	10,22
5	Solindfald	0,28	0,48	0,89	1,06	1,15	1,05	1,13	1,11	0,99	0,76	0,35	0,22	9,48
6	Internt tilskud	0,34	0,30	0,32	0,31	0,32	0,31	0,32	0,32	0,31	0,33	0,33	0,34	3,84
7	Fra rør og VVB konst.	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
8	Samlet tilskud	0,62	0,78	1,21	1,37	1,47	1,36	1,45	1,42	1,30	1,09	0,67	0,57	13,32
9	Rel. tilskud, -	0,44	0,60	0,80	1,50	2,35	3,33	8,94	9,18	3,36	1,45	0,57	0,40	
10	Del af rumopv.	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,75	1,00	1,00	
11	Variabl. varmetilsk.	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	Tot. tilskud	0,62	0,78	1,21	1,37	1,47	1,36	1,45	1,42	1,30	1,09	0,67	0,57	13,32
13	Rel. tilskud, -	0,44	0,60	0,80	1,50	2,35	3,33	8,94	9,18	3,36	1,45	0,57	0,40	
14	Udnyt. faktor	0,72	0,65	0,58	0,41	0,31	0,24	0,10	0,10	0,24	0,42	0,66	0,74	
15	Varmebehov	0,97	0,79	0,82	0,35	0,00	0,00	0,00	0,00	0,00	0,22	0,73	1,00	4,88
16	Vent. VF (centralvarme)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17	I alt	0,97	0,79	0,82	0,35	0,00	0,00	0,00	0,00	0,00	0,22	0,73	1,00	4,88

Nøgletal, kWh/m² år

Renoveringsklasse 2

Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme
111,3	0,0	111,3
Samlet energibehov		42,9

Renoveringsklasse 1

Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme
83,5	0,0	83,5
Samlet energibehov		42,9

Energiramme BR 2018

Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme
48,4	0,0	48,4
Samlet energibehov		42,9

Energiramme lavenergi

Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme
33,0	0,0	33,0
Samlet energibehov		42,9

Bidrag til energibehovet

Varme	36,1
El til bygningsdrift	4,2
Overtemp. i rum	4,3

Netto behov

Rumopvarmning	36,1
Varmt brugsvand	0,0
Køling	0,0

Udvalgte elbehov

Belysning	3,9
Opvarmning af rum	0,0
Opvarmning af vbv	0,0
Varmepumpe	0,0
Ventilatorer	0,0
Pumper	0,0
Køling	0,0
Totalt elforbrug	9,9

Varmetab fra installationer

Rumopvarmning	0,0
Varmt brugsvand	0,0

Ydelse fra særlige kilder

Solvarme	0,0
Varmepumpe	0,0
Solceller	0,0
Vindmøller	0,0

APPENDIX 10

LCA of final design proposal

Indhold

1 Oversigt

Her vises både informative oplysninger om projektet og nogle overordnede beregningsforudsætninger. Bygningens arealer, betragtningsperiode og start år som beregningsforudsætning i hele livscyklussen. Klimapåvirkningen (GWP) for den aktuelle bygning samt iht. bygningsreglementet er desuden vist i denne oversigt. Resultater for øvrige miljøpåvirkningskategorier iht. EN15978:2012 fremgår dog også af rapporten i kommende afsnit.

Projekt	
Projekttitel:	ZosteraMarina
Adresse:	
Bygherre:	
Bygningstype:	Andet
Projekttype:	Bygningsreglement
Dato for rapport:	24-05-2024
Ansvarlig for livscyklusvurdering:	

Nøgletal		
År for ibrugtagning:	2024	-
Betragtningsperiode:	50	år
Version af bygningsreglement:	BR18	-
Gældende grænseværdikrav jf. §298, stk. 1:	12,0	$kg\ CO_2$-$ækv/m^2/år$
Gældende lavemissionsklasse jf. §297, stk. 9:	8,0	$kg\ CO_2$-$ækv/m^2/år$
Samlet klimapåvirkning:	4,4	$kg\ CO_2$-$ækv/m^2/år$
Øget klimapåvirkning jf.§298, stk. 3-4:	0,0	$kg\ CO_2$-$ækv/m^2/år$
Samlet klimapåvirkning jf. §298, stk. 1 ekskl. øget klimapåvirkning:	4,4	$kg\ CO_2$-$ækv/m^2/år$

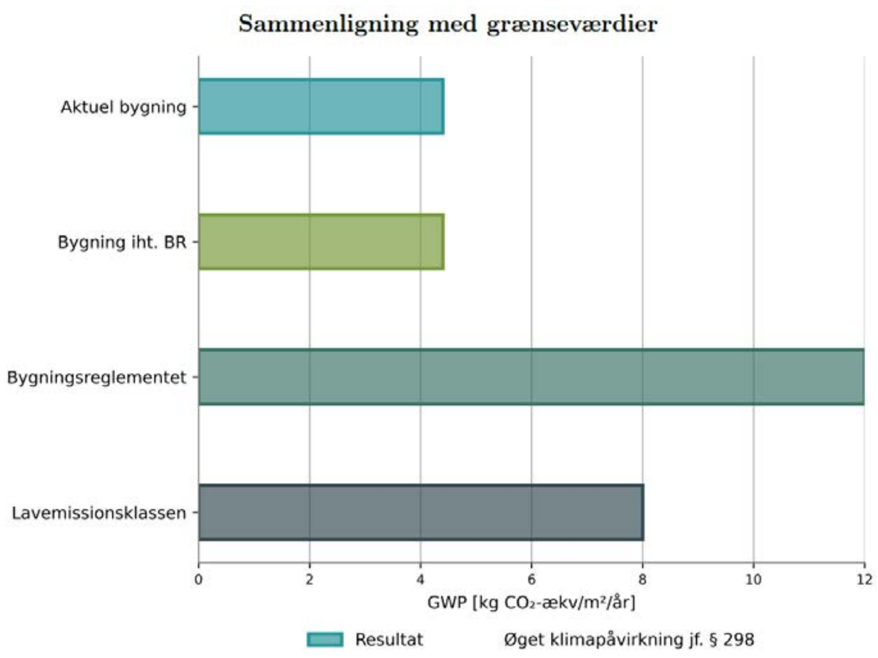
Arealer		
Etageareal :	158,00	m^2
Opvarmet areal:	135,00	m^2
Yderligere areal jf. §297, stk. 3 (50% medregnes i referenceareal):	0,00	m^2
Integrerede garager jf. §297, stk. 3 (25% medregnes i referenceareal):	0,00	m^2
Referenceareal:	158,00	m^2

Bygningsdrift og energiforsyning		
Driftforbrug, varme (uden tillæg):	36,10	$kWh/m^2/år$
Driftforbrug, el (uden tillæg):	4,20	$kWh/m^2/år$
Varme tillæg:	0,00	$kWh/m^2/år$
El tillæg:	0,00	$kWh/m^2/år$
Eksporteret el:	0,00	$kWh/m^2/år$
Varmeforsyning:	Fjernvarme - Fremskrivning	-
Elforsyning:	El - Fremskrivning	-

Særlige forhold

Resultater for moduler		
Produkt (A1-3):	-8,6	$kg\ CO_2$-$ækv/m^2/år$
Udskiftning (B4):	0,0	$kg\ CO_2$-$ækv/m^2/år$
Energiforbrug til drift (B6):	2,7	$kg\ CO_2$-$ækv/m^2/år$
Forbehandling af affald (C3):	10,0	$kg\ CO_2$-$ækv/m^2/år$
Bortskaffelse (C4):	0,0	$kg\ CO_2$-$ækv/m^2/år$
Udenfor system (D):	-4,9	$kg\ CO_2$-$ækv/m^2/år$

Fil	
GUI version:	3.1.0 (BR18, 2023)
Engine version:	6.2.0 (BR18, 2023)
Database version:	1.0.0 (GenDK, 2023)



2 Miljøindikatorer

I tabellen nedenfor angives bygningens samlede miljøpåvirkninger iht. EN15978:2012 opgjort i de respektive miljøindikatorer.

Beskrivelse	Moduler	GWP [kg CO_2 -ækv]	ODP [kg R11 -ækv]	POCP [kg C_2H_4 -ækv]	AP [kg SO_2 -ækv]	EP [kg PO_4 -ækv]	ADPE [kg Sb -ækv]	ADPF [MJ]	PEtot [kWh]
Sum projekt	A1-3, B4, B6, C3-4	3,143e+04	8,800e-04	1,842e+01	1,549e+02	3,815e+01	2,885e-01	3,131e+05	2,070e+06
Sum materialer	A1-3, B4, C3-4	1,193e+04	8,800e-04	6,329e+00	3,440e+01	1,231e+01	2,786e-01	1,411e+05	7,845e+05
Produkt	A1-3	-6,776e+04	8,797e-04	5,654e+00	2,406e+01	8,583e+00	2,783e-01	1,238e+05	1,453e+06
Udskiftning	B4	3,908e+02	2,963e-07	5,341e-02	8,548e-01	1,814e-01	1,077e-04	2,383e+03	5,025e+03
Energiforbrug til drift	B6	1,850e+04	2,689e-08	1,208e+01	1,203e+02	2,558e+01	9,954e-03	1,718e+05	1,295e+06
El til drift		1,394e+03	1,068e-09	8,498e-01	8,278e+00	1,854e+00	3,756e-03	1,412e+04	1,803e+05
Varme til drift		1,710e+04	2,582e-08	1,123e+01	1,120e+02	2,372e+01	6,198e-03	1,576e+05	1,115e+06
Affaldsbehandling	C3	7,915e+04	1,400e-11	6,090e-01	9,325e+00	3,522e+00	1,689e-04	1,458e+04	-6,741e+05
Bortskaffelse	C4	1,447e+02	1,654e-13	1,269e-02	1,674e-01	1,999e-02	2,813e-06	3,724e+02	4,369e+02
Udenfor system	D	-3,845e+04	1,937e-07	-3,149e+00	-2,680e+01	-5,191e+00	-6,653e-03	-5,996e+05	-8,474e+04

3 Detaljerede resultater

3.1 Materialer

3.1.1 Grupper, bygningsdele, konstruktioner (A1-3, B4, C3-4)

Tabel med alle grupper og tilhørende bygningsdele, konstruktioner og byggevarer i projektet. Der oplyses de indtastede mængder i bygningsmodellen og de tilsvarende beregnede mængder.

Navn	Indtastet mængde	Beregnet mængde	Vægt [kg]	Levetid [år]	UUID	Kilde
			Fundamenter			
Pælefundering	-	-	120,00	-	9e424a8b-3286-4fa2-bf09-7f78bb38e272	-
Skrufundament	-	-	120,00	-	50c1e96e-2f2f-4be1-a435-e99f16ce0cdc	User
Skruet stålpæl	1,00 stk.	-	120,00	-	733707c4-b6a0-4380-ad73-0ecf41ea8930	GenDK
Stål, valsede profiler og plader	120,00 kg/stk.	120,00 kg	120,00	120	0e71210a-af89-447b-92e8-b00054fb6b95	GenDK
			Indervægge			
Ikke-bærende indervægge	-	-	1472,98	-	b85597a5-9e19-4328-9895-df0f4bd35820	-
Indervægge	-	-	1472,98	-	d2f015c3-5e74-4314-b3ff-6806dd765438	User
Indervæg, Søuld	30,00 m²	-	745,01	-	1beea21c-9274-475b-9ba3-9fe9366c14fb	User
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,01 m³/m²	0,26 m³	116,96	100	4f17c440-ba5f-4f9f-ae49-bbee5a547bae	EPDDanmark
Krydsfiner, ubehandlet (Forbrænding EoL)	0,02 m³/m²	0,49 m³	237,60	100	f5cf18c0-19b3-475b-a587-d2a6a8399c97	EPDDanmark
Lerpuds	0,00 m³/m²	0,09 m³	81,00	100	e5599536-5925-4d1b-8ac0-8ca515f28e07	GenDK
Søuld FR	0,02 m³/m²	0,60 m³	82,20	50	e7fb7ab4-df72-47b4-b361-0db8110ea2ec	User
Træbrædder, bøg (12% fugtighed / 10,7% H2O) (Klon)	0,01 m³/m²	0,30 m³	221,76	100	eff256b1-929c-4a81-a79e-7cdb928a0a48	User

Ålegræs løsfyld	0,10 m^3/m^2	0,10 m	5,49	50	bb9b2873-d8cd-4760-9006-95263783f54e	User
Indervæg, lerpuds	30,00 m^2	-	727,97	-	a0a014fa-39e2-4407-bccf-6ac0e3a3fa39	User
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,01 m^3/m^2	0,26 m^3	116,96	100	6d10aece-3e6b-470e-8dcc-8612c958ffae	EPDDanmark
Lerpuds	0,01 m^3/m^2	0,18 m^3	162,00	100	129fa188-f331-44a8-b8a2-a1b019ea0b75	GenDK
Træbrædder, bøg (12% fugtighed / 10,7% H2O) (Klon)	0,02 m^3/m^2	0,60 m^3	443,52	100	91a2a28f-f92f-4efb-aa5b-d45ddbc8ef26	User
Ålegræs løsfyld	0,10 m^3/m^2	0,10 m	5,49	50	4a9deb25-7138-41d2-8570-e5d3e5b5d62e	User
			Søjler og bjælker			
Andet (søjler og bjælker)	-	-	3648,00	-	55b5d465-dfd0-4976-ba52-11981f5487ef	-
Loft kons.	-	-	3648,00	-	f08b1347-ec7a-427c-ad45-c00a7ef532b3	User
Bjælker, konstruktionstræ 100/200	400,00 m	-	3648,00	-	35a67dfc-e52e-4f6c-81ce-77d9cb9edf96	GenDK
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,02 m^3/m	8,00 m^3	3648,00	120	34c0aa9e-8105-438d-914e-6a9fc19d49c5	EPDDanmark
			Tage			
Loft	-	-	564,09	-	eae155a5-c683-4c11-93c6-4dbe23a8cd6c	-
Loft hall	-	-	447,01	-	92bcdba4-519a-4639-a8db-8a342b4906d4	User
Indervæg, Søuld	18,00 m^2	-	447,01	-	740495cf-0ae6-405c-9965-0c0477f2eb83	User
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,01 m^3/m^2	0,15 m^3	70,18	100	e0c4c67d-9c2c-411d-9e2b-8528e3208a62	EPDDanmark
Krydsfiner, ubehandlet (Forbrænding EoL)	0,02 m^3/m^2	0,30 m^3	142,56	100	eb4baab4-d998-4a37-9fe9-03c7e1f4526a	EPDDanmark
Lerpuds	0,00 m^3/m^2	0,05 m^3	48,60	100	7f9a4800-4ec9-4cd7-b53b-9962ff2679d6	GenDK
Søuld FR	0,02 m^3/m^2	0,36 m^3	49,32	50	35333238-cc5c-4626-8545-dd57af9fb1b3	User
Træbrædder, bøg (12% fugtighed / 10,7% H2O) (Klon)	0,01 m^3/m^2	0,18 m^3	133,06	100	f98e49bf-d7ca-45c9-b24b-fefc9d10a58c	User
Ålegræs løsfyld	0,10 m^3/m^2	0,06 m	3,29	50	984a2f66-7998-4568-90e6-a6277d355d42	User
Loft storage	-	-	117,09	-	abd966ac-f3df-41c3-9c6e-61c92b0f0c03	User
Loft storage	7,00 m^2	-	117,09	-	9e6fdf8d-682f-4c17-915a-a9291c53c112	User
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL) (Klon)	0,00 m^3/m^2	0,03 m^3	12,93	100	af746cee-4909-49e5-b9a5-b86a4cc7b476	User
Krydsfiner, ubehandlet (Forbrænding EoL)	0,01 m^3/m^2	0,08 m^3	36,96	100	53717f51-164b-4479-ac0e-c667c2fa8aa4	EPDDanmark
Krydsfiner, ubehandlet (Forbrænding EoL) (Klon)	0,02 m^3/m^2	0,14 m^3	67,20	100	f9218d8c-f444-43bf-95d6-0db726f40c21	User
Tage	-	-	2663,95	-	6ae2d88d-00d4-444e-82b2-436384184268	-
Tag	-	-	2663,95	-	5a9f2265-f0d0-4771-8e5c-7405b22a33ec	User
Saddeltag, træspær m. hanebånd 45°, 400 mm isolering (Klon)	182,50 m^2	-	2663,95	-	c14cea9b-24dc-4645-9369-0ed942e2f6e4	User
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,00 m^3/m^2	0,64 m^3	0,00	120	d857b3c3-b657-4729-8e53-c7d801e97845	EPDDanmark
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,00 m^3/m^2	0,74 m^3	0,00	120	d658f92b-d553-4358-ba1b-417e827f8d31	EPDDanmark

Krydsfiner, ubehandlet (Forbrænding EoL)	0,01 m^3/m^2	2,01 m^3	963,60	100	388e0b2e-3aef-4f01-aad8-bdea4d4c61e1	EPDDanmark
Træbrædder, bøg (12% fugtighed / 10,7% H2O)	0,01 m^3/m^2	1,82 m^3	1349,04	50	cd07628b-0347-4876-98a2-ed64bd0c53e3	GenDK
Ålegræs løsfyld	1,00 m^3/m^2	6,39 m	351,31	100	5db3ad87-3e9a-4087-95a6-3f6fba498409	User
■ Terrændæk						
Terrændæk	-	-	2684,17	-	c916bd8e-b493-43b7-9f80-909cb809b7aa	-
Terrændæk	-	-	2684,17	-	04916991-ab01-4f8e-a61a-bddfc43a830a	User
Gulv, trægulv på strøer (Klon)	135,00 m^2	-	2684,17	-	1328938b-3835-4c55-b4dd-e5cef31d44dd	User
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,00 m^3/m^2	0,53 m^3	240,08	80	f2ce44d8-c5b6-47cc-8e1f-6b186c009bd3	EPDDanmark
Krydsfiner, ubehandlet (Forbrænding EoL)	0,01 m^3/m^2	1,48 m^3	712,80	50	32a85e70-f15d-4990-9ec3-82f8c2293547	EPDDanmark
Træ, fyrretræ (12% fugt / 10,7% H2O)	0,02 m^3/m^2	2,97 m^3	1629,94	60	02cc09bd-7a4c-4460-bcad-acb7674f753b	GenDK
Ålegræs løsfyld	0,39 m^3/m^2	1,84 m	101,35	100	50f33475-971e-471d-b057-b9d68e5964a8	User
■ Udendørs areal						
Udendørs inventar	-	-	1385,20	-	822f86b2-cb72-4454-97f9-f49d867457b9	-
Plateau	-	-	1385,20	-	66fc177c-e84c-49cd-9b22-9b1ae72f6499	User
Gulv, trægulv på strøer (Klon)	100,00 m^2	-	1385,20	-	c550ba51-4c8a-4233-b9ed-91d00e93cb11	User
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,00 m^3/m^2	0,39 m^3	177,84	80	fb5dacf1-b55a-4bc6-b1ef-7a72d8d1ffeb	EPDDanmark
Træ, fyrretræ (12% fugt / 10,7% H2O)	0,02 m^3/m^2	2,20 m^3	1207,36	60	701788fc-d04f-432a-a521-b7769db40540	GenDK
■ Vinduer, døre, glasfacader						
Glasfacader	-	-	1487,78	-	9662d9c4-7b4f-4513-90cd-0349db628ad7	-
Vinduer	-	-	1487,78	-	68db6821-e623-4313-8305-e83b082190e4	User
3 vinduer øst	6,00 m^2	-	224,63	-	52ed45aa-2fb8-4d53-a2aa-a75e211dc1b2	User
EPDM-tætning til aluminiumsprofil	5,78 m/m^2	34,65 m	6,24	50	9620acc5-c931-4d3c-b36e-58a5c7619327	GenDK
Rude, 3-lags	0,80 m^2/m^2	4,80 m^2	144,00	50	6c05ae18-2b5e-4015-85b8-e7c7b3921221	GenDK
Vinduesbeslag, aluminium	0,52 kg/m^2	3,08 stk.	3,12	50	9141fd3b-6a41-4b3c-be81-b3326b01ad3b	GenDK
Vindueskarm, træ	2,87 m/m^2	17,22 m	36,33	50	78b72c00-9221-4b69-8004-979a22e2a4b4	GenDK
Vinduesramme, træ	2,76 m/m^2	16,56 m	34,94	50	606e0853-c0b9-4b6a-85da-9650bb1f0347	GenDK
Dør, indvendig glas dør, træ (Klon)	2,00 stk.	-	108,92	-	28a1b3b4-5ab2-46df-8939-eae1e394dfb1	User
Rude, 3-lags	1,11 m^2/stk.	2,22 m^2	66,60	40	101c2d25-c98e-4126-97d3-4fd1d6350814	GenDK
Spånplade	11,16 kg/stk.	0,03 m^3	22,32	40	86862ba2-eb8f-4f88-8444-97f67f1b7b7a	GenDK
Træ, fyrretræ (12% fugt / 10,7% H2O)	10,00 kg/stk.	0,04 m^3	20,00	40	7d804814-238b-4d0d-b136-9a45b9bdfa46	GenDK
Ex. Indvendig dør, træ	5,00 m^2	-	0,00	-	5caa6599-045b-4e8c-ba51-3e9424d3ebf6	GenDK
Grå støbejern	0,05 kg/m^2	0,25 kg	0,00	60	2db62f4b-5db6-4522-b464-49d08ff43ebd	GenDK
Træ, egetræ (12% fugt / 10,7% H2O)	1,71 kg/m^2	0,01 m^3	0,00	60	c2510caa-0fd4-495e-98ad-710cf3f3e567	GenDK
Træ, fyrretræ (12% fugt / 10,7% H2O)	14,71 kg/m^2	0,13 m^3	0,00	40	cf474116-3f0a-4619-8811-fb7dbd18c1ea	GenDK
Ex. Udvendig dør, træ	1,00 m^2	-	0,00	-	b4d0023d-0280-48c0-8415-b5981d91a081	GenDK
Grå støbejern	0,05 kg/m^2	0,05 kg	0,00	60	e8190920-4526-4d78-ba8d-83db3c7daa30	GenDK
Træ, egetræ (12% fugt / 10,7% H2O)	1,63 kg/m^2	0,00 m^3	0,00	60	e7751ed5-3dc2-4025-b447-8e551fbe5a8e	GenDK
Træ, fyrretræ (12% fugt / 10,7% H2O)	22,53 kg/m^2	0,04 m^3	0,00	40	9fa690ed-4047-4bb9-aa9b-198a2236950f	GenDK

Ovenlys	11,34 m²	-	424,56	-	04e347bc-a80a-4493-9a55-775efbdf413d	User
EPDM-tætning til aluminiumsprofil	5,78 m/m²	65,49 m	11,79	50	66ff35c8-edee-4f04-94f3-a2aba9061e15	GenDK
Rude, 3-lags	0,80 m²/m²	9,07 m²	272,16	50	5fa85e97-ec28-475c-bfd9-49019c13a111	GenDK
Vinduesbeslag, aluminium	0,52 kg/m²	5,82 stk.	5,90	50	efcb3cdf-f8a5-4d93-b938-9d568ce948d5	GenDK
Vindueskarm, træ	2,87 m/m²	32,55 m	68,67	50	91e925bb-ee7c-4ac5-85ea-9a221728e7aa	GenDK
Vinduesramme, træ	2,76 m/m²	31,30 m	66,04	50	13fdd66e-167e-44d5-bfd5-d85f0f209751	GenDK
Syd vindue	19,00 m²	-	711,34	-	7c09727c-324e-47d7-987f-99bfdb3ba76e	User
EPDM-tætning til aluminiumsprofil	5,78 m/m²	109,73 m	19,75	50	240a6e16-a69d-4a5b-b94b-0056fc56c7bd	GenDK
Rude, 3-lags	0,80 m²/m²	15,20 m²	456,00	50	6f8e2489-3531-4695-a1a0-deabd130040a	GenDK
Vinduesbeslag, aluminium	0,52 kg/m²	9,74 stk.	9,88	50	e27942e3-3b93-49c6-9a54-02ef4b84ef56	GenDK
Vindueskarm, træ	2,87 m/m²	54,53 m	115,06	50	105971bb-4241-4a63-bb8a-0386585db154	GenDK
Vinduesramme, træ	2,76 m/m²	52,44 m	110,65	50	beeb4e16-1428-421b-9ea0-c16ea4ec41fb	GenDK
Toilet	0,45 m²	-	18,33	-	57c43149-0f7d-4cc9-a019-4e5b0b883177	User
Beslag til dreje-kip vinduer (aluminium)	2,00 stk./m²	0,90 stk.	1,48	50	e987785e-5e29-4583-b4fc-bf9b7fb2cbd5	GenDK
EPDM-tætning til aluminiumsprofil	5,78 m/m²	2,60 m	0,47	50	5ebfb785-942f-4142-8638-eac58e79fcf5	GenDK
Rude, 3-lags	0,80 m²/m²	0,36 m²	10,80	50	acf1d100-3712-4a51-9e1f-28800efda6a2	GenDK
Vinduesbeslag, aluminium	0,52 kg/m²	0,23 stk.	0,23	50	5d3d6a68-9d27-4bc9-8284-d72b10734029	GenDK
Vindueskarm, træ	2,87 m/m²	1,29 m	2,73	50	fd4e40c6-1076-449d-833c-dba044059bab	GenDK
Vinduesramme, træ	2,76 m/m²	1,24 m	2,62	50	a7d42fa0-42b6-4a2a-85bd-a9f7e3153270	GenDK
Ydervægge						

Ydervægge	-	-	37435,75	-	00339237-3b4a-4a19-9fd5-2366c79a55ba	-
Ydervæg	-	-	37435,75	-	f28e0c9f-af93-4a16-9ab8-961a5befd179	User
Ydervæg	81,00 m²	-	37435,75	-	8af7124c-24e2-47af-864c-8eedec780b74	User
Byggepap	0,17 kg/m²	177,19 m²	14,18	50	74bb063a-1748-4ac3-aff6-0ef18fad7ebd	GenDK
Fibercementplade	7,60 kg/m²	47,35 m²	615,60	100	ec4d6dcd-6a79-4765-9999-bb71ec15ec9d	GenDK
Konstruktionstræ af fyr og gran, Høvlet (Forbrænding EoL)	0,94 m³/m²	75,82 m³	34572,10	100	1a2781ac-70d1-4c90-9bba-621fb8959039	EPDDanmark
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)	0,00 m³/m²	0,33 m³	149,59	100	3acba778-e959-4b93-8d89-d5c5e4f8c000	EPDDanmark
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL) (Klon)	0,00 m³/m²	0,18 m³	83,11	100	ff8a9eff-f618-4413-8132-4c2181db2f1e	User
Konstruktionstræ af nåletræ, Høvlet (Forbrænding EoL)	0,01 m³/m²	1,09 m³	586,12	30	3956c575-de19-4e1b-8a10-4e98e850294b	EPDDanmark
Krydsfiner, ubehandlet (Forbrænding EoL)	0,01 m³/m²	0,89 m³	427,68	50	4b6dd3d3-d310-43b5-aead-1b2910764a8e	EPDDanmark
Træ, ceder	0,02 m³/m²	1,62 m³	925,02	50	c82c1d52-0075-4d8c-972e-70c5d2188acf	GenDK
Ålegræs løsfyld	0,40 m³/m²	1,13 m	62,37	50	5decf647-33c8-41eb-af55-24d00b475a1f	User

3.1.2 Brugeroprettede byggevarer og anvendte EPD'er, faser (A1-3, B4, C3-4, D)

Oversigt over de anvendte EPD'er og brugeroprettede byggevarer. I tabellen vises hvilke faser (A1-3, C3-C4 og D) der er anvend i livscyklusvurderingen for de pågældende materialer.

Fase	Link	Kilde	Udløbsdato	Ekstern ID	Standard
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL)					
A1to3	link	EPD Danmark	2025-04-22	MD-20002-EN	EN15804+A1
C3	link	EPD Danmark	2025-04-22	MD-20002-EN	EN15804+A1
C4	link	EPD Danmark	2025-04-22	MD-20002-EN	EN15804+A1
D	link	EPD Danmark	2025-04-22	MD-20002-EN	EN15804+A1
Ålegræs løsfyld					
A1to3	link		2026-08-02		EN15804+A1
Krydsfiner, ubehandlet (Forbrænding EoL)					
A1to3	link	EPD Danmark	2025-04-22	MD-20008-EN-rev2	EN15804+A1
C3	link	EPD Danmark	2025-04-22	MD-20008-EN-rev2	EN15804+A1
C4	link	EPD Danmark	2025-04-22	MD-20008-EN-rev2	EN15804+A1
D	link	EPD Danmark	2025-04-22	MD-20008-EN-rev2	EN15804+A1
Konstruktionstræ af fyr og gran, Høvlet (Forbrænding EoL)					
A1to3	link	EPD Danmark	2025-04-22	MD-20004-EN-rev1	EN15804+A1
C3	link	EPD Danmark	2025-04-22	MD-20004-EN-rev1	EN15804+A1
C4	link	EPD Danmark	2025-04-22	MD-20004-EN-rev1	EN15804+A1
D	link	EPD Danmark	2025-04-22	MD-20004-EN-rev1	EN15804+A1
Konstruktionstræ af fyr og gran, Savede og tørrede (Forbrænding EoL) (Klon)					
A1to3	link	EPD Danmark	2025-04-22	MD-20002-EN	EN15804+A1
C3	link	EPD Danmark	2025-04-22	MD-20002-EN	EN15804+A1
C4	link	EPD Danmark	2025-04-22	MD-20002-EN	EN15804+A1
D	link	EPD Danmark	2025-04-22	MD-20002-EN	EN15804+A1
Konstruktionstræ af nåletræ, Høvlet (Forbrænding EoL)					
A1to3	link	EPD Danmark	2025-11-30	MD-20003-EN	EN15804+A1
C3	link	EPD Danmark	2025-11-30	MD-20003-EN	EN15804+A1
C4	link	EPD Danmark	2025-11-30	MD-20003-EN	EN15804+A1
D	link	EPD Danmark	2025-11-30	MD-20003-EN	EN15804+A1
Træbrædder, bøg (12% fugtighed / 10,7% H2O) (Klon)					
Søuld FR					
A1to3	link		2026-08-02		EN15804+A1
C3	link		2026-08-02		EN15804+A1
D	link		2026-08-02		EN15804+A1
Krydsfiner, ubehandlet (Forbrænding EoL) (Klon)					
A1to3	link	EPD Danmark	2025-04-22	MD-20008-EN-rev2	EN15804+A1
C3	link	EPD Danmark	2025-04-22	MD-20008-EN-rev2	EN15804+A1
C4	link	EPD Danmark	2025-04-22	MD-20008-EN-rev2	EN15804+A1
D	link	EPD Danmark	2025-04-22	MD-20008-EN-rev2	EN15804+A1

3.2 Resultater for alle indikatorer

3.2.1 Grupper (alle indikatorer)

Tabellen viser resultater for alle hovedgrupper med alle indikatorer. Resultatet er summen for den gruppe i projektet set iht. den valgte betragtningsperiode.

Gruppe	GWP [kg CO_2 -ækv]	ODP [kg R11 -ækv]	POCP [kg C_2H_4 -ækv]	AP [kg SO_2 -ækv]	EP [kg PO_4 -ækv]	ADPE [kg Sb -ækv]	ADPF [MJ]	PEtot [kWh]
Afløb	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
Altaner og altangange	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
Andet	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
Dæk	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
El- og mekaniske anlæg	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
Fundamenter	1,352e+02	2,358e-10	4,826e-02	2,604e-01	2,636e-02	5,917e-05	1,226e+03	1,563e+03
Indervægge	3,313e+02	7,351e-06	6,298e-01	9,899e-01	2,476e-01	3,085e-04	3,168e+03	2,521e+04
Søjler og bjælker	3,840e+02	7,224e-05	2,074e-01	2,736e+00	1,987e+00	8,700e-04	5,576e+03	4,124e+04
Tage	1,787e+03	1,566e-05	1,568e+00	3,109e+00	1,207e-02	1,192e-03	9,003e+03	6,166e+04
Terrændæk	8,204e+02	1,295e-05	2,185e-01	2,770e+00	3,924e-01	7,939e-04	7,745e+03	6,372e+04
Trapper og ramper	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
Udendørs areal	4,629e+02	3,522e-06	2,221e-02	1,142e+00	3,365e-01	1,119e-04	3,468e+03	3,156e+04
Vand	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
Varme	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
Ventilation og køl	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00	0,000e+00
Vinduer, døre, glasfacader	3,628e+03	4,529e-11	1,080e+00	1,077e+01	1,996e+00	3,123e-02	3,976e+04	6,687e+04
Ydervægge	5,385e+03	7,683e-04	2,563e+00	1,276e+01	7,571e+00	2,440e-01	7,136e+04	4,836e+05

As the climate changes continuously become more evident, it is clear that action is necessary. With the building industry being a big contributor to the energy use and CO_2 emissions, this industry is an important piece in the global reduction of energy use and CO_2 emissions.
This thesis therefore investigates the use of eelgrass a biobased building material. The report determines advantages and disadvantages of eelgrass as a material based on analysis of historic use and properties of the material, and by comparing the existing eelgrass products with similar products.
The possible utilisations of eelgrass as a building material are showcased by presenting examples of the possible utilisation in renovation as well as in new build. For the new build example, a small exhibition building showcasing and raising awareness of eelgrass is designed.
Through the works of the thesis, it is established that eelgrass products have properties similar to existing biobased materials, and sometimes even better, and on some parameters similar to those of conventional building materials. The eelgrass performs well on parameters such as thermal- and noise insulation, and has low Global Warming Potential.
The biggest challenge of upscaling the use of eelgrass in the building industry is the lack of resource, due partly to the oxygen depletion of the Danish waters.