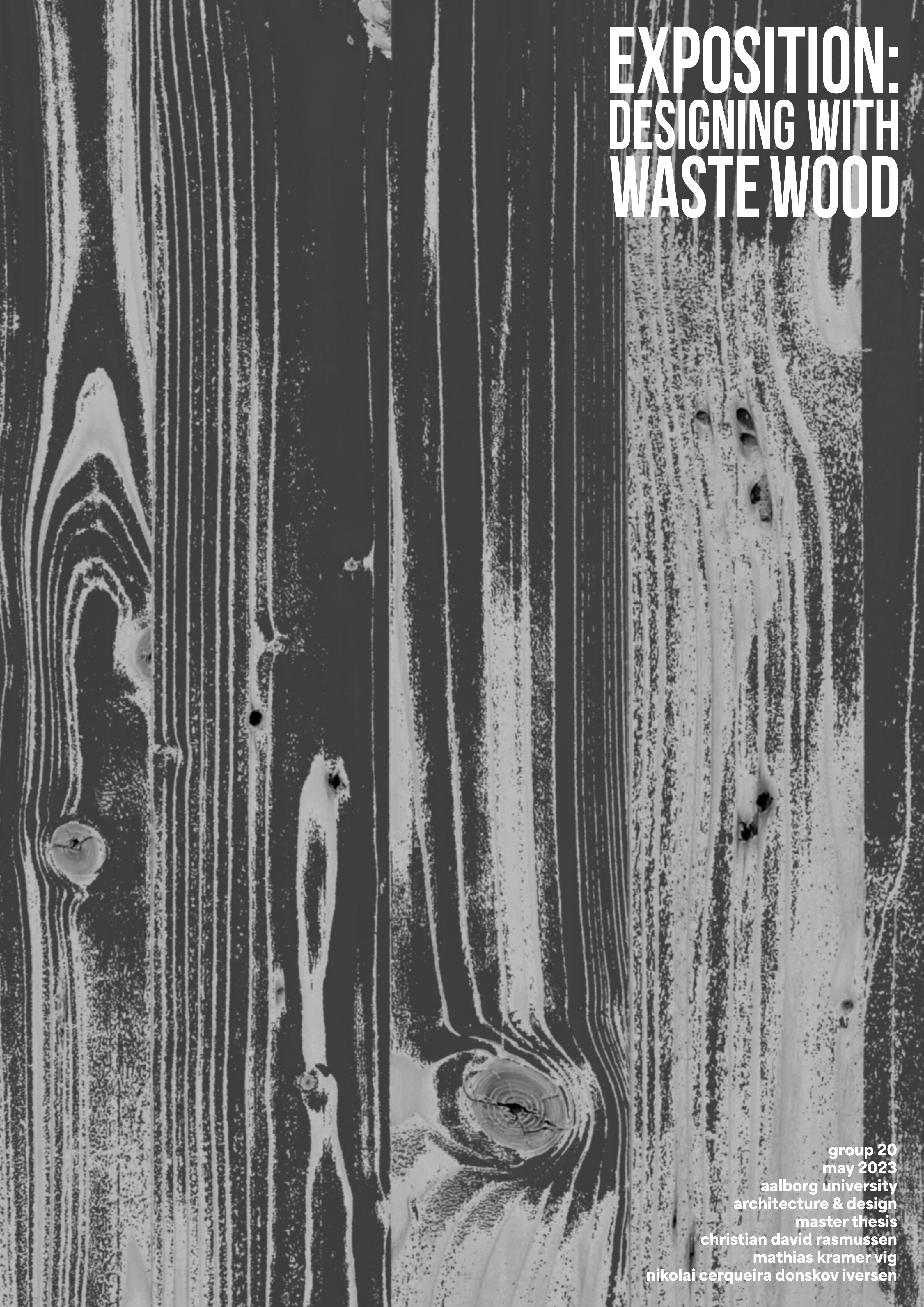

EXPOSITION: DESIGNING WITH WASTE WOOD

group 20
may 2023
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master thesis
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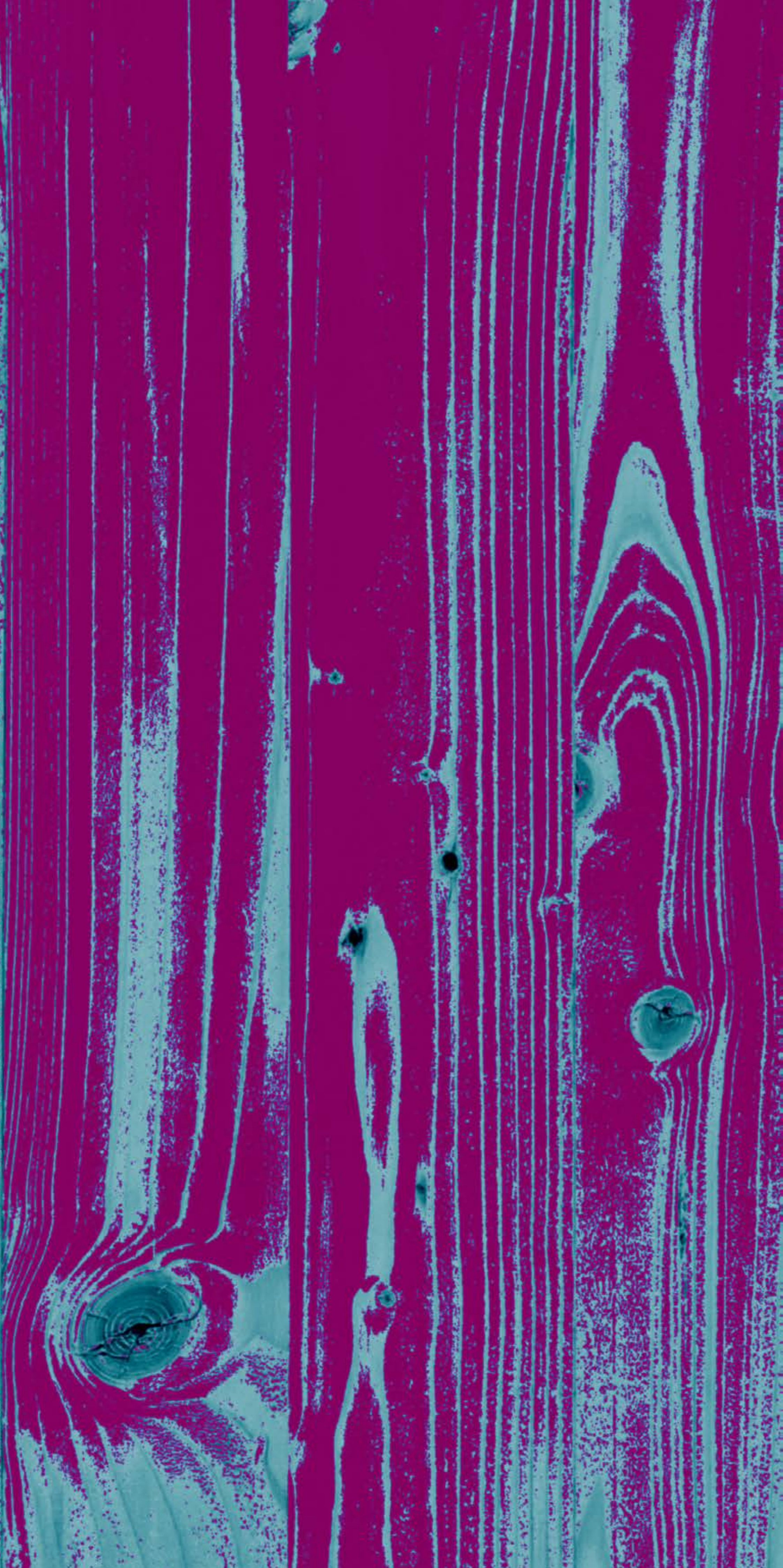
"It is a question of surrendering to the wood, then following where it leads by connecting operations to a materiality, instead of imposing a form upon a matter: what one addresses is less a matter submitted to laws than a materiality possessing a nomos. One adresses less a form capable of imposing properties upon a matter than material traits of expression constituting affects."

Deleuze, G. & Guattari, F. (1987). A Thousand Plateaus: Capitalism and Schizophrenia, Minneapolis, MN: University of Minnesota Press



We want to dedicate this page to the people who have helped and supported us to make this thesis.
Major thanks to:
Our supervisor Mads Brath Jensen for making us trust the process.
Thomas Vang Lindberg for continuous technical support.
Anneberg Limtræ for letting us make use of their production facilities and giving us insight into the fabrication process.
Bjarke Midtiby for providing us with all the wood we could need from the mink farms.
Big thanks to all the people who have shown interest in our project and taken the time to listen to us, share their knowledge, and guide us in the right direction.

Project: **Exposition: Designing With Waste Wood**
Department: **Department of Architecture, Design and Media Technology**
Semester: **MSc04, Architecture, Aalborg University**
Module: **Master Thesis**
ECTS: **30**
Project period: **1/2/2023 - 26/6/2023**
Group: **20**
Supervisor: **Mads Brath Jensen**
Technical supervisor: **Thomas Vang Lindberg**
Pages: **160**

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Extinction - ozone depletion - global warming - ecological disaster.

abstract

Humans' effects on the earth are rarely positive and with resources becoming ever more scarce this master thesis takes a critical look at the direction that society has been advancing and by extension the established building industry. By using the demarcation of the Danish mink industry as a case for how to employ waste wood the hypothesis is developed; "Wood from the mink farms that otherwise would end up being recycled, recovered, or becoming waste has the potential to be reclaimed as timber for use in the design of new buildings." It seeks to compose a process of how it can be done while complying with current regulations. Through mapping of available material from mink barns and current procedures for testing, verifying, documenting, and grading materials for construction we are demonstrating how reclaimed timber can be used and what steps are necessary to integrate it in the established practice. By employing computational design thinking and the advantage of computational design a structure emerges to demonstrate the potential in reshaping the traditional design process. Advocating for a material-oriented design process that exploits material as a method for sustainable design, where characteristics and properties, structure, and atmosphere are allowed to develop while optimizing material use in architecture.

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INTRODUCTION

It is a matter of acknowledging the world around us. Architecture doesn't exist in a vacuum where its relationship with its loci is non-existent.

The choices we make as architects have a profound impact on the world, and how we choose to enact our profession dictates the world of tomorrow. This master builds on this notion by demonstrating how architecture can serve to alleviate challenges in wider society.
Through material-oriented design, we are utilizing waste materials in all aspects of our design. Demonstrating how a design that takes its departure from the material, allows it to dictate the design process, where defects and flaws are not seen as a problem, but as a potential. Why emancipating wood is necessary to develop a design process suited for this heterogeneous material that doesn't want to conform to form, where the designer instead conforms to matter.
This is not the first project or research that has looked at how the industry can reduce its environmental impact through the use of undesirable wood and the potential in offering an alternative, an extra resource alongside new virgin wood, that also includes a different aesthetic value(Menges et al., 2016). Either with the idea to extend the material's life cycle in solid form before it is turned into particle board or recycled, (Rose et al., 2018)(Browne et al., 2022)(Nordjyske.dk) or by utilizing information technology to include wood that is uneven, curved, twisted, cupped, etc (Wójcik, 2015). Besides arguing for the environmental potential, they advocate for the latent architectural qualities that can be attained in the waste wood if properly used (Groba, 2022). The challenges that are repeated in most of the literature on this topic are the lack of a framework, that the building code does not facilitate the use of reclaimed timber, the need for scaling and developing a fabrication process, and the importance of proper data management, developing a database for the properties of the materials to make the most of the inherent value in the material.
The inception of this master thesis is the demarcation of the mink industry that led to an immense stock of building mass waiting to be demolished and presumably ending the life cycle of the wood sequestered in its building mass. With the mink farms as a case for the feedstock in industrializing the process from waste material to reclaimed timber, and from reclaimed timber to built structure, we are demonstrating how a material agency can be the catalyst in the fabrication of the building material, the design of a structure and in the manufacturing of the architectural element.

/delimitation

This master thesis confines itself within the challenges that it sees as relevant to answer the hypothesis that it poses.
The resulting design is a result of the material properties and its needs. It does not contemplate a specific function, demographic, or social responsibility. It does not relate to a specific context, site, environment, or orientation. Furthermore, the design is limited to utilizing the wood that we acquired from one of the investigated mink farms. This is because we wanted to work within the boundaries of the material that we could observe and measure, and its resulting properties.

/limitation

The master thesis considered both destructive and non-destructive tests on a theoretical level to evaluate the material properties of the available wood. Facilities accommodating material tests are difficult to access as they are either expensive to get times for, used for other purposes, specified for other dimensions, or exclusive for special users. As a result, only a limited number of tests were conducted on some of our fabricated elements, which then became the foundation of our material properties.

Ill. 1. unfinished mink barn

PREF

Framing the thesis, this section sets its base focus on pollution and waste and the potential in rethinking the way we treat materials - taking a point of departure from the demolition of mink barns in Denmark. Starting an architectural design process with a single material departs from the industry standard. As such, alternative methods and methodologies are explored, redefining the project structure to showcase research and investigations in a research pavilion.

situation:

/The building industry

The United Nations estimated in 2007 for the first time in history, more than half of the world's population was living in cities and that by 2050 two thirds of the population will live in cities(Ritchie & Roser, 2018). As more people move to the city, and old buildings are decaying, the demand for urban development is increasing, and with it, the building sector expands.
The building sector today is a large contributor to pollution and land use, as a consequence, it is a considerable contributor to the stress the environment is facing today. According to the "2022 Global Status Report for Buildings and Construction" published by the United Nations Environment Programme (Environment), the building sector consumes an estimated 30% of global energy through operation, which in turn is responsible for 27% of CO_2 emissions. When including CO_2 emissions from material production, the building sector as a whole is responsible for an estimated 37% of global CO_2 emissions.
With the goal of reaching net zero carbon emissions by 2050, the industry needs to reduce its emissions by over 98% from 2020 levels. With the combined knowledge that the demand for more buildings is increasing and with the goal of reducing emissions by 98%, it is therefore paramount that the building industry moves towards a more sustainable practice.

/Potential

As the attention on sustainable practices increases and we move towards greener solutions, wood, and timber is a good choice as it is carbon neutral and function as a carbon sink as long as it is in use, storing CO_2 within the buildings. But with such monumental demands and ambitious goals, we need to reconsider our approach to how we can build in the future. Even by moving towards more sustainable materials, if we limit ourselves to using only new materials, the environmental impact will still be substantial. Considering the amount of waste

FACE

produced during the lifetime of a building, from the production of the building materials to its demolition, there are many ways of expanding the lifetime of what might otherwise be considered waste. In this project we want to expand the building materials' lifetime by initially closing the material loop, increasing its lifetime through reuse, recycling, and upcycling; narrowing the material use through computer-assisted design to simulate the structural system, optimizing material use; slowing down the flow of resources by the design of a long-lasting building; and arguing for the qualitative dimensions of materiality and the potential present in the narrative of recycled materials, to bring forward affordances and atmospheres(Jørgensen et al., 2018).

/Demolition of mink barns

On the 15th of June 2020, the first case of Covid-19 was reported on a Danish mink farm. In the following months, more and more cases of Covid-19 were confirmed across the country. Fear of a mutation from the interspecies contamination between humans and mink would lead to a new variant that would be resistant to the, at the time, current vaccines being developed. As a result, the Danish government on the 4th of November 2020 decided to cull the entire population of mink. On the 25th of January the following year a coalition between the Danish government and several other parties agreed upon a compensation deal of upwards of 19 billion DKK intended to cover for the mink farmers and their loss.
As a consequence of the expropriation of the mink industry is a project 240 times larger than the previous biggest demolition project in Danish history. 8.000.000 m^2 of building mass. 1264 mink farms. The process is projected to last until at least 2028, demolishing 250 farms a year, costing 3.5 billion DKK in demolition costs. Every weekday for the next five years one farm will be demolished(Christensen, 2022).

/Timing and scale

As the situation stands today there are some actors in the industry that are working for a more circular economy; some larger demolition firms re-sell used material when there are an economic profit, smaller businesses that upcycle waste to a new product, and initiatives by larger funds that are working towards establishing a national material bank and how material properties of waste material can be tested, verified and documented. But these approaches are either in the developing phases, small scale, or driven by profit. To establish good practice today the question of timing and scale is crucial as an incentive to develop a framework for how a circular economy can be implemented. Without it, the challenges overcome the future benefits as long as there is no legislation or building code that facilitates the use of recycled material on a large scale.
The timing and scale of the demolition of the Danish mink farms offer an opportunity to develop a suggestion as to how the expropriation of the mink industry can be seen as an opportunity for how a circular economy can be implemented. The mink barns are uniform in their construction, most of them constructed of timber with standard dimensions. With potentially close to 100.000 tons of wood alone. Some of the farms are not older than 3 years. This represents a huge potential in keeping the wood embedded in buildings instead of being burnt and releasing the CO2 back into the atmosphere. (Appendix A)

There are many ways in which the industry can extend the life cycle of wood and in turn, keep the CO2 sequestered in buildings a while longer. In research about this topic, this is referenced in many different terms that need to be specified. ➡

The advantage of how we can approach used materials in the building industry in this thesis project when compared to "real life" is that we are not dependent on profit or to uphold current building codes, standards, or laws. We seek to discover the challenges, find the limits, and explore the possibility of using reclaimed timber from the mink farms both on a theoretical and practical level. Today there aren't many opportunities to use reclaimed timber for structural purposes. There isn't any framework for how to test, verify or document the properties of the reclaimed timber and the methods that are used on new timber are either not suitable or possible for application on reclaimed timber.

Some of the challenges pertaining to the use of reclaimed timber have already been solved, whilst others are currently being worked on. The first challenge is the documentation of wood species and growth area, this has an influence on the growth rate of the tree and its characteristic strengths. In most cases, this data is not available for timber in older buildings, but a solution to this could be the use of material passports. With the use of BIM in the industry, the data is available and it is just a question of implementation. The effect of the microclimate inside buildings and its effect on the properties of the materials is another. Therefore the structural properties of used timber cant be verified and standardized as easily. Established testing methods are destructive and aren't suitable for reclaimed wood because of the necessity for testing multiple elements from each building. The necessary testing will by current methods destroy the limited supply of material. Research on the non-destructive test and characteristic values are being done but is still in its infancy. This project will not meet the requirements necessary to grade timber. But we will propose a way to how reclaimed timber could be approached, and how it as a material could be tested, documented, and verified. This will be supplemented with the current methods of how new materials are tested and verify it as described in relevant Danish standards, document deviations and conduct machine grading on a limited sample of select elements, not to verify it, but to show the possibility in reclaimed timber as a building material that might not be able to perform as new, but as something that can be used. This thesis will be an example of how it could be done, an argument for why standards and methods need to be developed for reclaimed timber, and an example of what it can be used for.

REUSED/

Using something for the same purpose again.

RECOVERED/

Converting what would otherwise become waste into either energy or nutrition.

RECLAIMED/

A used product that has been regenerated to a usable state

UPCYCLED/

Converting what would otherwise become waste into either energy or nutrition.

RECYCLED/

A process where the product is broken down and transformed to make either the same product or another product

WOOD/

Wood is used when referencing the material itself or products made out of wood, such as doors, windows, frames, furniture, packaging, etc.

TIMBER/

Timber is used when referencing sawn, milled and dimensional wood used for structural purposes that have been strength-graded.

HYPOTHESIS:

“Wood from the mink farms that otherwise would end up being recycled, recovered, or becoming waste has the potential to be reclaimed as timber for use in the design of new buildings.”

From the problems and challenges mentioned in the preface, it is clear that the industry needs to rethink how to approach its resource use. With a point of departure from the Danish mink barns, an initial hypothesis is developed as a way to conserve our resources:

This hypothesis will be the foundation for several questions that will be examined in this project. These questions will be answered chronologically and will shape the answer to the initial hypothesis. A proposal for a design based on the available wood from the mink farms with a focus on how to design with wood for longevity will act as a demonstrator, a structure that showcases the results from the investigations, the material properties of the wood available from the mink barns, and solutions for the challenges present in designing with reclaimed timber. The first investigation seeks to discover the amount available, the dimension, and the condition of the wood,

“What wood is available from the mink farms and what is its condition?”

Subsequently, the previous phase will inform the direction of the following phases where the next step is to analyze the wood and find out what possibilities there are in using it as a structural element:

“What structural building elements can be made from the available wood and what are their properties?”

These building elements can then be defined and tested. The results of these investigations will inform the design of a research pavilion, looking at reclaimed timber in use and the structural system:

“What structural systems are feasible to construct out of reclaimed timber from the mink farms?”

Being conscious about the entire life cycle of the structure, where the first investigations have been focused on taking something that would otherwise become waste and turning it into reclaimed timber, the research pavilion draws attention to the longevity of the built structure.

“What does longevity look like and how is it created?”

With a structure made out of timber, special considerations are necessary to be able to withstand the elements over time:

“How can wood be utilized as a facade material to ensure longevity for the structure?”

As a research pavilion, the goal of the structure is to demonstrate the possibilities in reclaimed timber, present the results of the findings, and communicate them through its design.

“How can the structure be experienced and convey the results of the investigations?”

METHODS & METHODOLOGY

/introduction

When deciding what methods and methodology to apply to the project it is important to be aware of what knowledge it is we are trying to find. Research is defined as:

"the systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions"
(Research, 2015)

This thesis lies in the cross-section between research and design, where we are alternating between them and letting the previous activity inform the next step. It is crucial to be conscious of the knowledge we are after when structuring the process to ensure that the investigation leads toward answering the hypothesis. When doing research there is always an aspect of demarcation present. For the creation of new knowledge, it is necessary to reduce the observed phenomena and experiences into fragmented pieces of information in order to categorize and communicate the results (Groat and Wang, 2013).
The first step is to distinguish between what fields of science and the different methods that are applied. In this thesis, we are working across multiple fields, and as such incorporates epistemologies from quantitative and qualitative sciences. A positivistic approach, an objective reality where everything can be measured, is used when conducting empirical experiments on wood to find its material properties or how to construct structural systems. On the other hand, when searching for value in architecture, the creation of different atmospheres that the architecture should inhabit, we might apply a social constructivism or phenomenological approach, where the reality is based on subjective human experiences and consciousness. Where the knowledge emerges as designs are tested and evaluated. The experiments and analysis used in this project are established on the parallel processes of both qualitative and quantitative methods in order to solve design problems (Groat and Wang, 2013).
The more common processes of problem-solving or inference are deduction, induction, and abduction. The article "The core of 'design thinking' and its application" by Kees Dorst describes these approaches with an equation:
Where depending on the known and unknown the different processes can be attributed.

Here deduction allows us to predict the outcome. As an example, we know that there are 1246 Danish mink farms waiting to be demolished, and we are aware of their structural systems and we can then predict the amount and dimension of available wood. Induction would be that we know that we have a piece of wood, and based on the results of a compression test, we can induce its material properties. Abduction-1 is more relatable to the traditional process of architects and engineers. Here the end is not a fact (result), but the attainment of a certain value. The design describes the value and working principles, but the design process seeks to discover the thing that fulfills these conditions. Abduction-2 can be said to be the overarching process we are seeking to find a solution. We, based on our hypothesis, see a value in "...reclaimed as timber for the use in the design of new buildings."(Dorst, 2011). But we are not yet aware of the 'what' or the 'how' that is necessary to achieve this value.

equation

what	+	**how**	=	**result**
(thing)		*(working principle)*		*(observed)*

deduction

what	+	**how**	=	**?**
(thing)		*(working principle)*		*(observed)*

induction

what	+	**?**	=	**result**
(thing)		*(working principle)*		*(observed)*

abduction 1

?	+	**how**	=	**value**
(thing)		*(working principle)*		*(observed)*

abduction 2

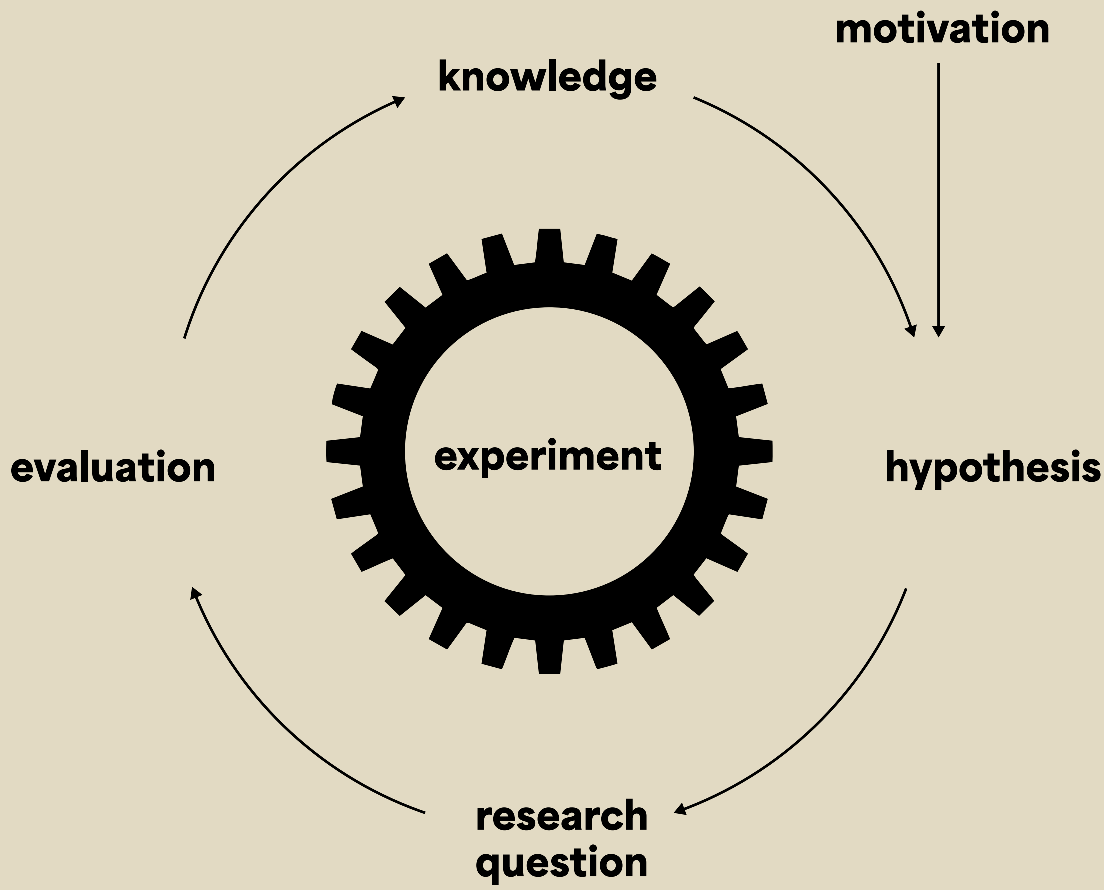
?	+	**?**	=	**value**
(thing)		*(working principle)*		*(observed)*

thesis process

The traditional phases of the architectural design process are often divided into three distinct phases: pre-design, schematic, and design development. Where the first phase includes interactions with the client to establish needs and desires, familiarization with the site and its context, and the attached zoning laws and land-use restrictions. The next phase interprets this knowledge into a design concept through sketches and models, explorations of plans and elevations, and a final form starts to emerge. The final phase incorporates relevant engineers to meet codes and the final design is detailed and materials are decided (The 7 phases of the Architectural Design Process - 2023).

In order to address the limitations that exist within the heterogeneous material that wood is, even more so when it is re-used, it is necessary to challenge this established process. Hence the need for a material-oriented design process. Material agency is an extension of the Actor-Network-Theory that proposed science, technology, and society as areas of human and nonhuman agency in an equal rather than hierarchical fashion. Giving the material agency emancipates the material, gives it control over the process, and lets it dictate the direction of the project, the authorship is shared between material and designer. This approach has the capacity to embrace the unknown arising from the material side by the process of cooperation. The material is to act as a counterpart to form, where the form is not something that is decided, but rather something that is discovered; letting the material self-organize on the path to the design. In that sense, the initial sketching phase is seen as an inadequate work method, as the material might not conform to the proposed form.

Ill. 2. louis kahn doesnt know what timber wants - comic



constructive design research

An essential method for this project is Research-through-Design (RtD) or Constructive Design Research (CDR). More specifically it is based on the model developed by Bang et al. in their article “The Role of Hypothesis in Constructive Design Research”. RtD has become a recognized method for designers to create knowledge established by the skills and capacities of designers. They take the definition of CDR from Koskinen et al. who defined it as: “Design research in which construction - be it product, system, space or media - takes center place and becomes the key means in constructing knowledge”(Koskinen et al.).

The criticism it sometimes gets is that it is not rooted in scientific methods and results can be hard to replicate. But designers are in need of methodological and theoretical flexibility in order to preserve artistic values as well. They describe CDR as being shaped in three different contexts: the lab, the field, and the showroom. Where the research culture differs in the different contexts.

This is where Bang et al. are trying to bridge the gap between the academic discourse and the activity of artists and designers. They propose a model where motivation is a key aspect of the process that shapes the initial hypothesis, which again defines research questions. They emphasize that the process isn’t necessarily that linear, but that the hypothesis-making process is necessary to understand the correlation between the steps and that it is an ongoing process. In their model, the experiments are placed in the center, where the experiments and motivation should have a clear relevance.

The experiments lie at the center, as they constantly inform the different steps, while the steps themselves are a cyclical process, where evaluation leads to knowledge that then again can inform a new hypothesis (Bang et al.).

computational design

"Computational design is a way of working that seeks to use a combination of algorithms and parameters to solve design problems by means of utilizing advanced computer processing. "

(Menges, A., Ahlquist, S. 2011)

This way of designing and utilizing computer-assisted design systems as a tool is built around the human problem solver and the proposed solution is always limited to the humans' capability to solve and grasp the problems at hand. In his 1987 book Design Thinking, Peter G. Rowe argues that human problem solvers rarely are in a position to identify all possible solutions to a given problem, ultimately settling for a choice that seems to satisfy the required solution properties for a problem, as they see them at the time. (Rowe, P.G., 1987).

/computational design thinking

Computational design thinking (CDT) refers to the methodology by which architects and designers can achieve success with computational design. Are the capabilities of computational design to be taken advantage of, computational design thinking is needed. The primary design generator becomes the computer and the architects become the authors of the code, specifying what is asked and wanted from the computer.

"(...) computers must be acknowledged not only as machines for imitating what is understood but also as vehicles for exploring what is not understood."

(Terzidis. K, 2006)

"(...) the capacities of computational design are only fully unfolded at the convergence of exercising both computational thinking and practice"

(Menges, A., Ahlquist, S. 2011)

Computational design has enabled architects and designers to communicate through ideas in a more visual and understanding way. Presenting 2D as well as 3D drawings and models as easily understood conceptual designs and getting instant feedback

/design thinking vs. cdt

Computational design thinking differentiates itself from design thinking in that it is not tied to the human's limited ability to identify solutions. Computational design thinking strides towards formulating hypotheses and questions for the computer to work with and ultimately solve. The problem at hand should, if this methodology is used, be worked into code and scripts for the computer to then generate results and possibilities. Practicing computational design thinking is crucial for computational design to be a success and the architect should by this continuously formulate questions and problems for the computer to solve, moving the project forward based on unknown findings.

Computers should in regard to computational design be seen as tools for exploring the unknown and unpredictable. We should on this note be prepared for unexpected results and furthermore be willing to develop these findings, striding towards a design. Well-defined problems, code, and scripts for investigating are to be used exploring the limits and possibilities of both material, structural and architectural solutions.

Peter G. Rowe addressed this improved way of design thinking in his 2017 book, Design Thinking in the Digital Age. He explains how the digital age has changed the way we perceive problem-solving in the field of architecture alongside four points of design thinking that have been brought on by the digital age.

1/ improved representation and modeling techniques

The available software enables architects and designers to achieve a higher degree of precision and detailing as a result of modern modeling tools. This leads to a more precise graphical representation of a project and furthermore focuses attention on incompleteness, setting the tone for further work.

2/ improved iterative and generative powers

Through computational techniques, architects and designers are able to generate numerous design proposals. The wide range of geometries enables the observer to access different options and by this achieve more satisfaction with the final proposal. More complex geometries are also made possible by this generative process.

3/ improved test procedures for generated designs

The methods for testing design options have improved significantly. The means of evaluating and simulating various areas of performance in regards to a building is often incorporated into different software, making it easily accessible and very usable. A building's performance in regard to structure, materials, and environment are among others some of the testing methods used by modern software.

4/ increased access to varying domains of knowledge

Acquiring knowledge has become easier in the digital age making it more accessible to use and draw inspiration from. The increased sharing of information has made knowledge within and beyond the field of architecture more common, heightening the capabilities with for example structural and environmental design.

/our approach

Computational design is to a large extent already utilized by architects and designers as a modeling tool, extending their capabilities into the digital realm. Alongside utilizing the rather common CAD tools that is Rhino will this project stride to use both computational design and computational design thinking as a way to develop a design solution that is both feasible and durable based on the available materials. In the process generate suitable solutions that are based on the identified material properties of reclaimed timber and the element's dimensions. Computational design is to be used as a generative tool shaping different design options and furthermore, as a performance-based evaluation tool used to address different designs' structural performance based on the material usage and structural properties.

WOOD FROM MINK BARNS

RESEARCH QUESTION:

“What wood is available from the mink farms and what is its condition?”

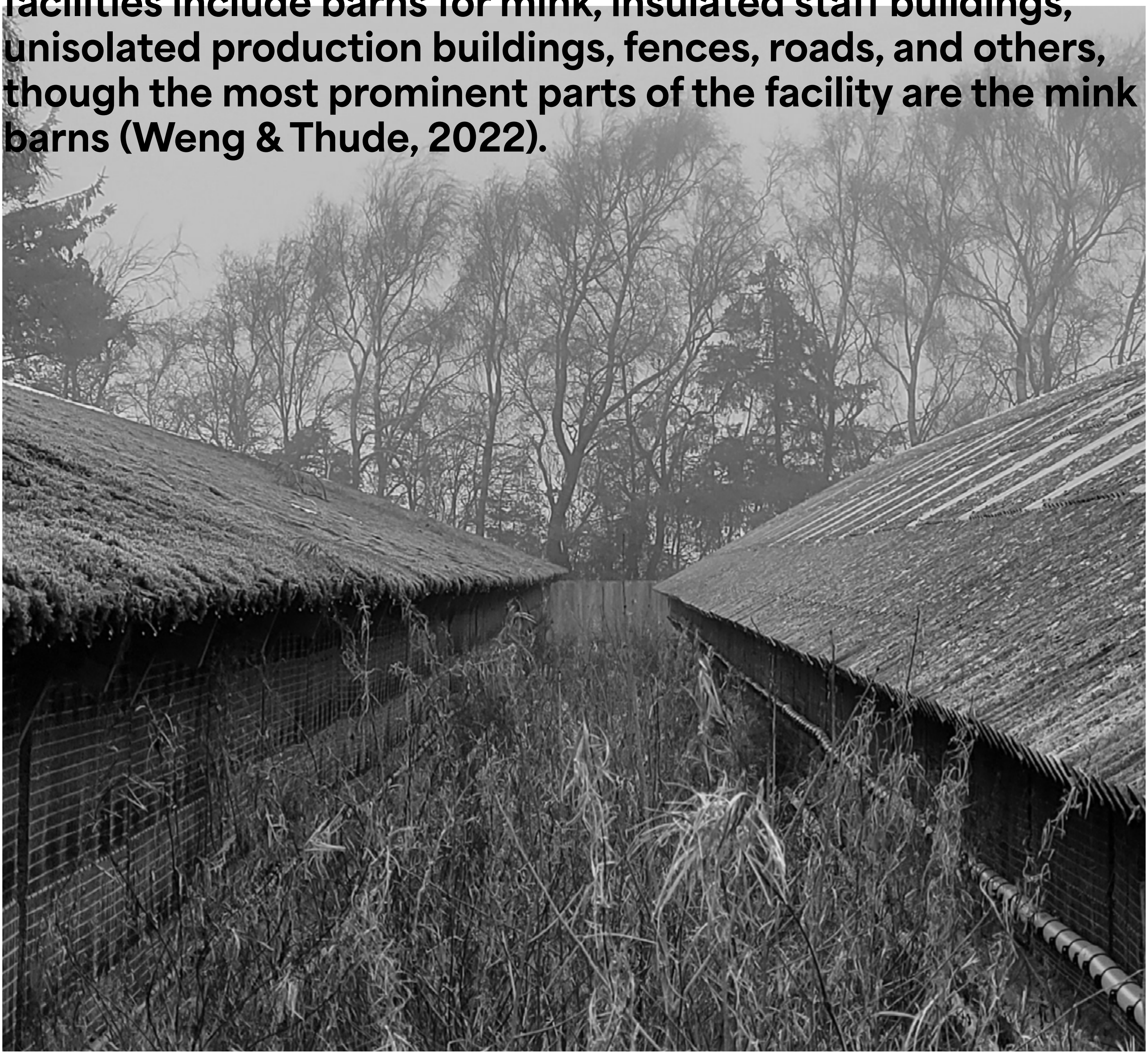
This is an analytical phase focused on investigating the mink farms, their barns, the use of wood, and their state. Viewed as a relevant case, the mink barns will act as a base for investigating wood that will become waste. The goal of phase one is to extract information on the structural wood, its condition, typical lengths, and dimensions, and to create an overview of what is available and the potential of reclaiming the timber from the mink farms.

mink farms in denmark

≈ **1246** mink farms
≈ **8.000.000+ m²** building mass
≈ **100.000t** timber

Ill. 4. Mink barns in Northern Jutland

There are 1246 production facilities for mink (mink farms) in Denmark, mainly focused in Jutland in the west to the north in Vendsyssel. The facilities vary greatly in size from hobby production to mass-production facilities. Production facilities include barns for mink, insulated staff buildings, unisolated production buildings, fences, roads, and others, though the most prominent parts of the facility are the mink barns (Weng & Thude, 2022).



Ill. 5. map of mink barns in Denmark

mink farm observation

To get an understanding of the available materials, conditions, and structural systems, visits to different mink farms were arranged. Two different mink farms were visited with a wide array of different barn types and sizes. The mink barns registered will function as a basis for the investigations in the rest of the chapter.

Kaj Beilegaard, Gjøl, 9400 Aabybro
Located in Gjøl, an area with a lot of mink farms. Kaj´s farm has been expanded several times through the years. The farm consisted of one 2-row and three 4-row barns with a collective capacity of around 3500 mink. The different barns were all built at different times and therefore all had different structural systems.

The barns were all built in timber with mostly nail plates used as joints. The oldest barn is from 1985 and the timber structure is still in very good shape, as was the timber from the newer barns built in 2006, 2013, and 2014, where the newest barn visually had the best-looking timber. (Appendix B)

Bjarke Midtiby, Finderup, 6900 Skjern
Large mink farms are few and far between, hence most barns are 2-or 4-rows. Bjarkes farm is on the larger side. The farm consists of 15 2-row barns with 47 frames each and four connected 12-row barns, two in wood and two in steel, with 47 frames each. The wooden 12-row barns are especially interesting as they show the size and material used. Bjarkes barns are newer compared to some of Kaj´s farms and a further expansion of the farm was in process when the mink industry was shut down.
Consisting of four large barns and 15 small ones, the two wooden barns each spanning 28m wide were from an architectural perspective interesting. Despite the size, the barns are constructed of the same size timber joined with nail plates as in smaller barns but with an added amount, estimating nearly 1m³ of wood pr. frame. The large steel barns used large wooden laths on the roof structure. The 15 small barns were under construction revealing the timber structure, also using nail plates for joints. (Appendix B)
The visit provided us with an insight into the durability and condition of the material over time. Neither of the mink barns showed any significant damage caused by time, weather, or insects. The free airflow and open sides of the barns is the main contributor to this enabling the timber to freely dry whilst being protected from rain and other elements.

2- & 4-row open wooden barns

The most common barn types are the 2- or 4-row open timber barns. Their structure has almost been unchanged over time. The basic structure consists of a frame system constructed in untreated timber that functions as the load-bearing base for roofing, sidings, cages, manure ducts, and others. The width of the barns is almost the same whereas the length of the barn can vary. Most mink barns are constructed in the frame system, though all barns vary slightly from each other in structure and joints. The 2- and 4-row open timber barns have been constructed since the 1930s and can vary greatly in quality.

6-16-row closed wooden barns

Closed timber barns with more than 2-4 rows are also common. They can vary from 4-16 rows and are built on the same timber frame principle as the 2-row barns. The sizes of the barns need larger, more complex, frames. Closed barns have sidings and timber structures surrounding the main frame structure. As 2-row barns, the barns have relative standard widths but can vary in length, and all vary slightly in their structure.

<16-row closed steel barns

Closed steel barns have become more prominent in the last years and can include up to 16 rows. Constructed in a typical steel-arch structure, the room is open and does not include timber other than the construction around the rows of mink cages and the laths. Closed steel barns can vary in length and are built according to new Danish standards BR18.

2- & 4-ROW OPEN WOODEN BARNS

<100KG

TIMBER PR. FRAME

Ill. 6. 2-row mink barn

6-16-ROW CLOSED WOODEN BARNS

<460KG

TIMBER PR. FRAME

Ill. 7. 12-row mink barn

<16-ROW CLOSED STEEL BARNS

<230KG

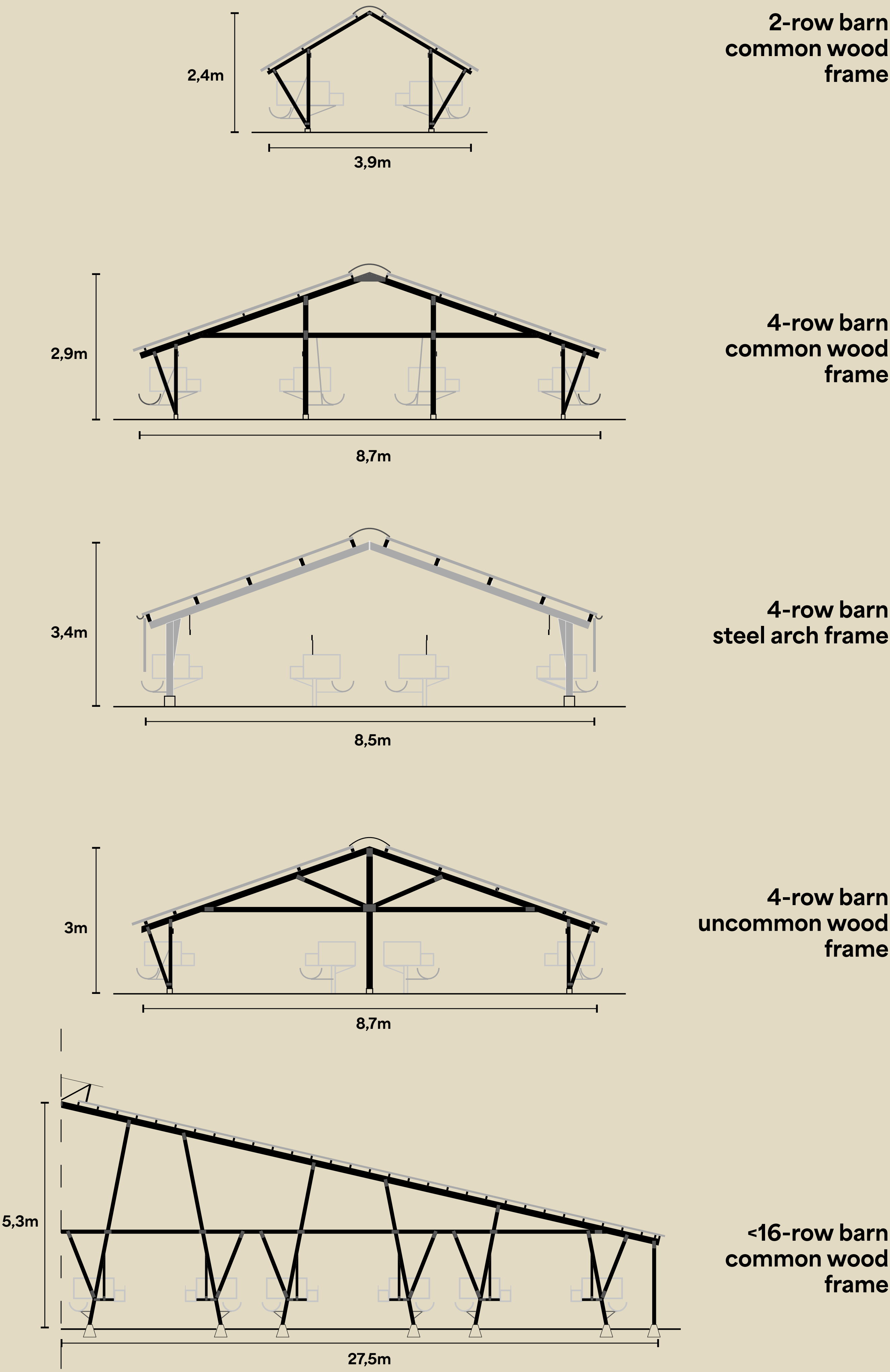
TIMBER PR. FRAME

Ill. 8. 12-row mink barn w. steel structure

FRAMES AND STRUCTURE

Typical structures relying on wood and used as mink barns have been identified. Most mink barns are made as 2- or 4-row barns constructed with timber frames. The basis for the frames is to allow access between the cages to create long hallways giving access to the cage and the manure drains, therefore having columns aligned to the cage systems and attaching the cage elements and manure system directly to the timber frame.

Some uncommon structures for 2- & 4-row barns are steel structures that create one large open space (usually used for up to 16-row barns). Here you have to build a substructure, usually of timber, for the cage systems. Some mink barns are constructed in untraditional ways where you have to change the placement of the manure drain to have access to it.
In later years larger timber barns have been constructed with the same principles of access, resulting in some semi-complex frames that act as a structural element for the building but also for the cage and manure systems. (Appendix F)



Ill. 9. sections of types of mink barns

identified materials

Ill. 10. 2-row minkbarn

/materials

Mink barns are mainly built in timber frames. The timber used is untreated standard construction timber (pine) in standard sizes and strengths (older facilities can have varying non-standard element sizes). The timber frames are usually built in 1 dimension, connected by metal nail plates, whereas older structures can use metal plates, screws, and bolts. The timber serves different purposes other than being the building's structure; it is used for mounting cage systems, upholding manure systems, inserting cardholders, and other elements, meaning the timber can contain many different parts in itself.
Other than the structure itself, the barns contain metal bracing for stability, metal cages, PVC plastics for manure drain, metal sidings, and usually asbestos roofing (newer barns have metal roofing).

Ill. 11. collage of materials in mink barns

WOOD

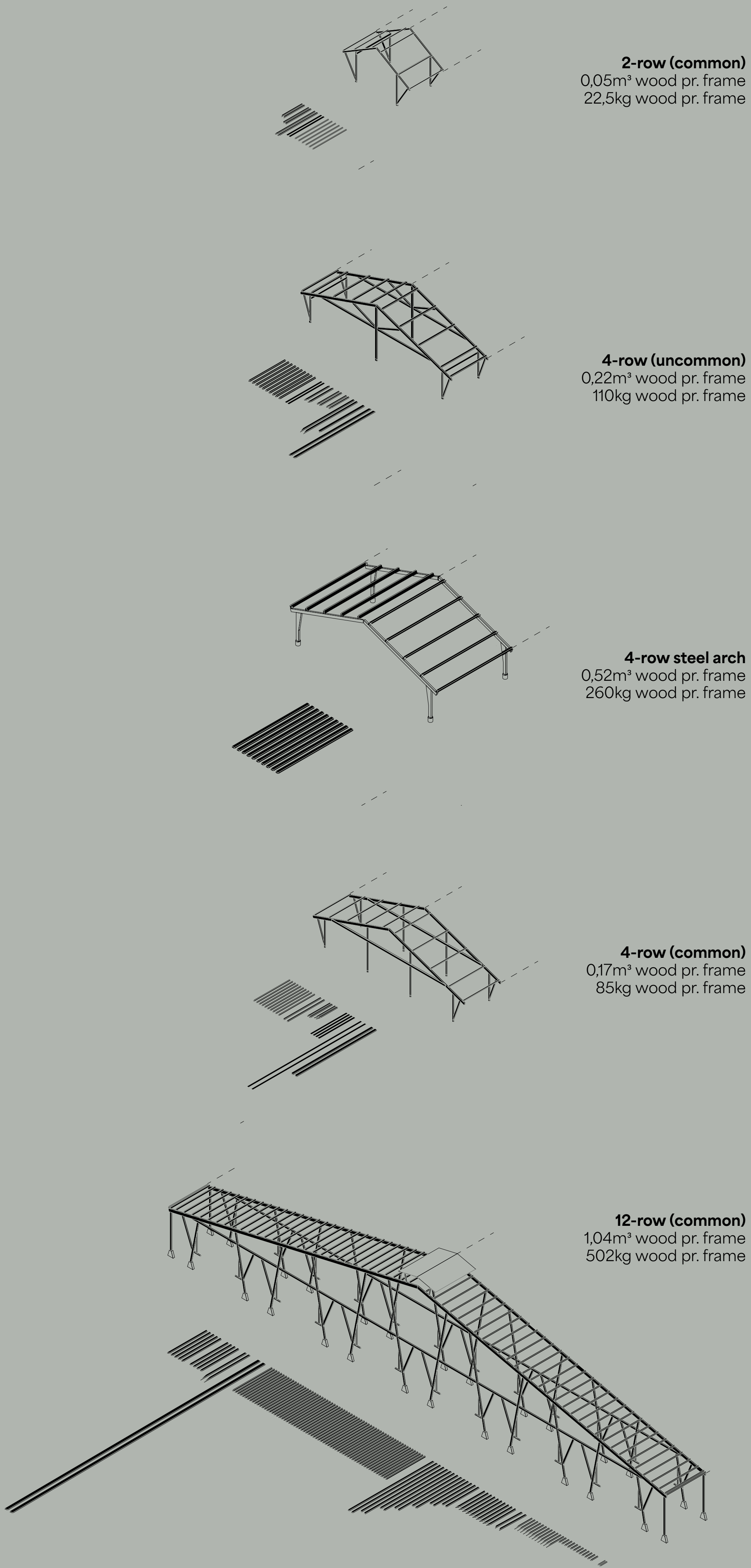
standard timber elements (pine)
C18/C24

NAIL PLATES

standard nail plate sizes

OBJECTS IN WOOD

plastics, nails, screws, other

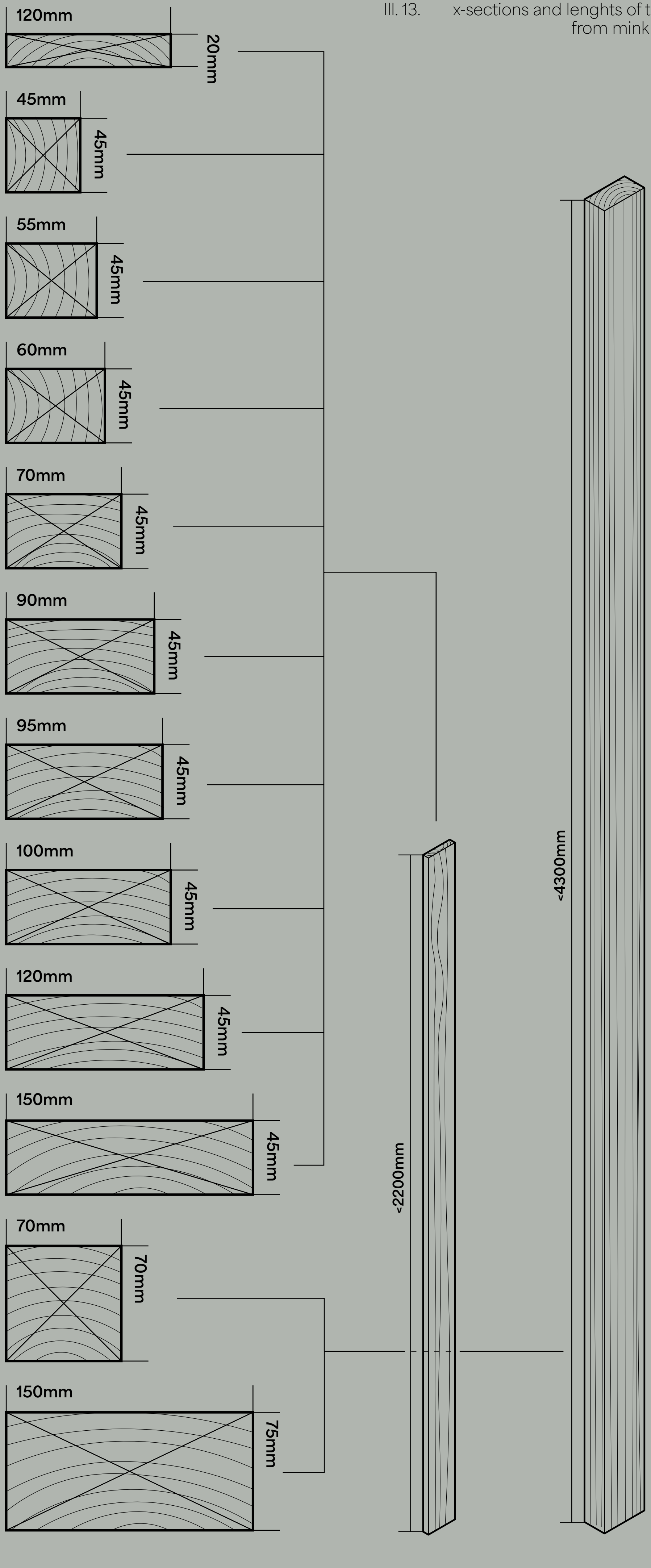


elements

The mink barns are constructed in timber frames, usually in smaller pieces of construction timber in standard dimensions with a strength grading of either C18 or C24. Almost all barns are a variety of the same timber frame, which means that the frame elements will vary slightly from each barn as well. The 2- & 4-row open timber barns contain smaller and shorter pieces of structural timber than for example the 12-row closed timber barn. The steel arch barns also contain timber laths as well, usually also having larger and longer pieces.
The amount and sizes of structural materials, as well as the amount and sizes of timber, vary greatly. For a common 4-row barn the average volume of timber per frame can be set to 0,17m³ (approx.: 85kg wood), whereas the 4-row steel barn has an average volume of timber pr. frame at 0,52m³ (approx.: 260kg timber), even though its main structure is steel. 2-row barns typically have 0,05m³ timber pr. frame and 12-row timber barns typically have 1,04m³ timber per frame.
Considering a 12-row barn typically consists of 50 frames it will include a little over 50m³ of timber which is equivalent to around 25 tons of timber.

Ill. 12. isometric of mink barns

Ill. 13. x-sections and lenghts of timber from mink banrs



dimensions

Looking at the different barns, typical pieces of structural timber have been identified. The largest pieces are found in the steel arch barns (used as laths), which have a rather large cross-section of 75x150mm and are typically around 4m long. Besides that, the pieces are relatively similar (all used for columns, beams, and laths in timber barns).

Most barns are constructed in standard construction timber from pine in standard sizes. Almost all timber elements have a cross-section of 45mm x(45, 55, 60, 70, 90, 95, 100, 120, and 150mm). These are used to create the frames for the barns in one dimension, meaning all pieces will be flush with each other while being able to maintain different structural purposes by varying heights of the timber elements. This also meant that the frames, or part of the frames, could be pre-manufactured at the factory with only shipping left.

The typical width of the 'hallways', the distance between the frame columns, is around 2,3m. Since the frames are constructed differently, the lengths of timber elements vary. By identifying the timber elements at different mink farms we can predict that the majority of the elements' lengths can be anything up to 2200mm. Typically the large pieces of 75x150mm are up to 4300 mm long.

Ill. 14. collage of photos of quality of timber from mink barns

WOOD

The timber in the mink barns is generally in good condition due to the shielding of weather, but also from the natural ventilation of the barns. The outermost layer of the timber can have some smaller damages, but nothing that affects the functionality of the wood.

NAIL PLATES

Many barns are constructed by creating frames in 1 dimension joining the elements with nail plates that are inserted into the timber. The nail plates have barbs rendering them almost impossible to remove. Some, usually older, barns are constructed the same way but with bolt plates instead that are easily removed.

OBJECTS IN WOOD

Since the timber structure is used for hanging or placing stuff on, (usually the timber nearest the cages) many foreign elements such as nails, screws, plastics, and other unknown elements might be embedded in the wood. How this affects the functionality of the wood differs, it might have a negative impact on the material properties.

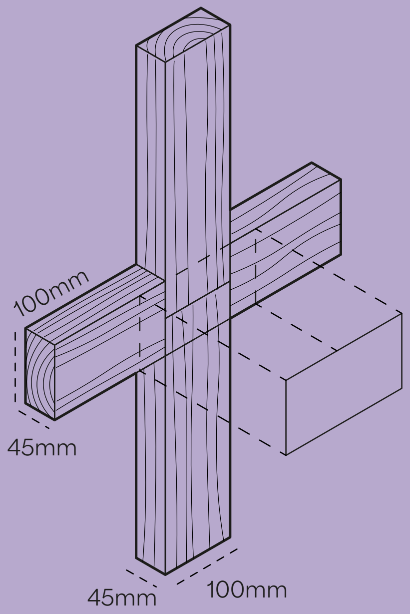
UNUSABLE WOOD

Mink farms generally have problems with bacon beetles, a beetle that eats and resides in the timber. The beetle digs tunnels into the timber weakening its properties. Some farms are so infested that most of the timber is unusable, whilst some farms don't suffer from the beetle.

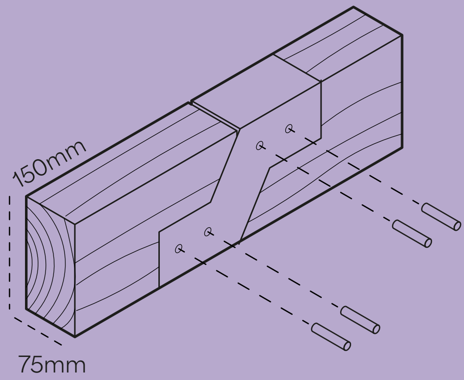
joints

For joining wood elements into frames, nail plates are typically used.
Regardless of whether it is for a center column joint or for a ridge joint, the nail plates are versatile and strong and will thus join the pieces together very robustly. For creating an extension of a beam, nail plates are used with the addition of screws.
If nail plates are not used then bolt plates typically will be the substitute, while some barns are built by exclusively using nails and screws.
The way joints are made has a huge impact on how easy they are to disassemble. Nail plates are nearly impossible to remove and can only be done by using a crowbar, thereby potentially damaging the wood. Nails and screws are usually easy to disassemble if they have not rusted - in such cases, you would either let them stay in the timber or poke them out using a nail punch.

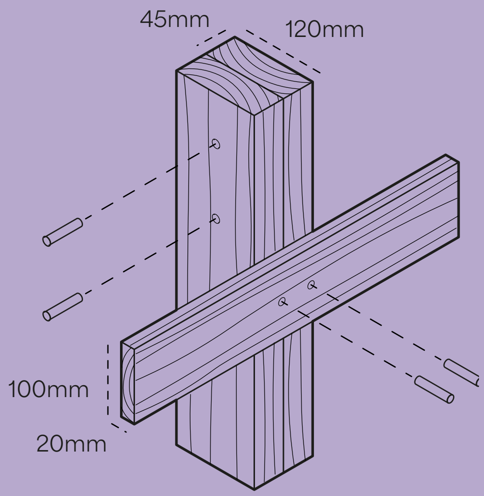
Ill. 15. joints identified in mink barns



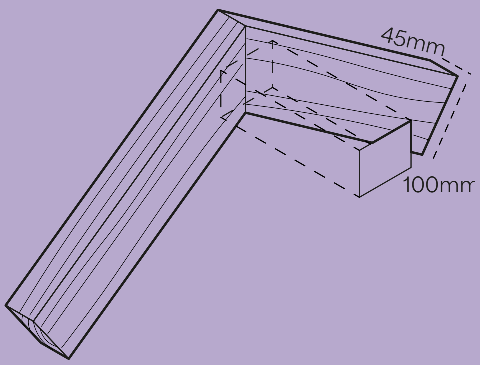
center-column joint



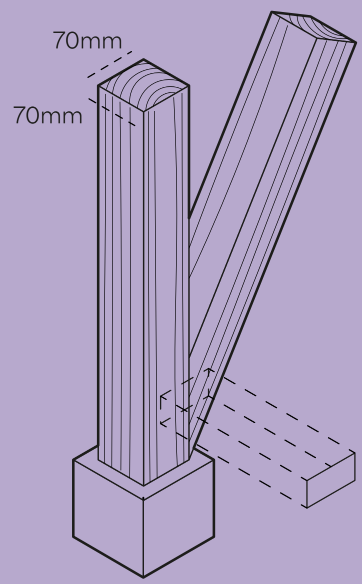
beam/lath joint



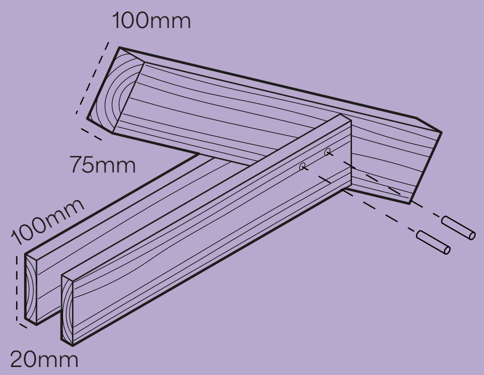
column joint w. beam



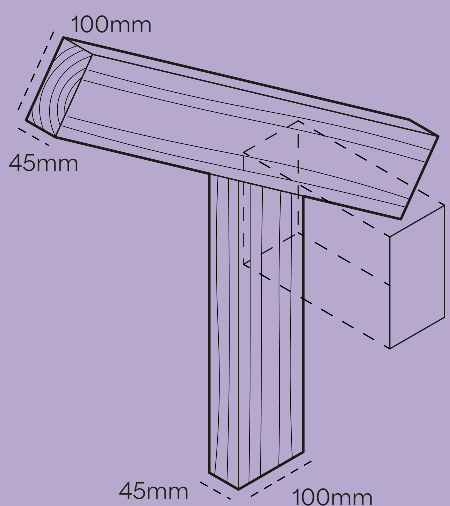
ridge joint



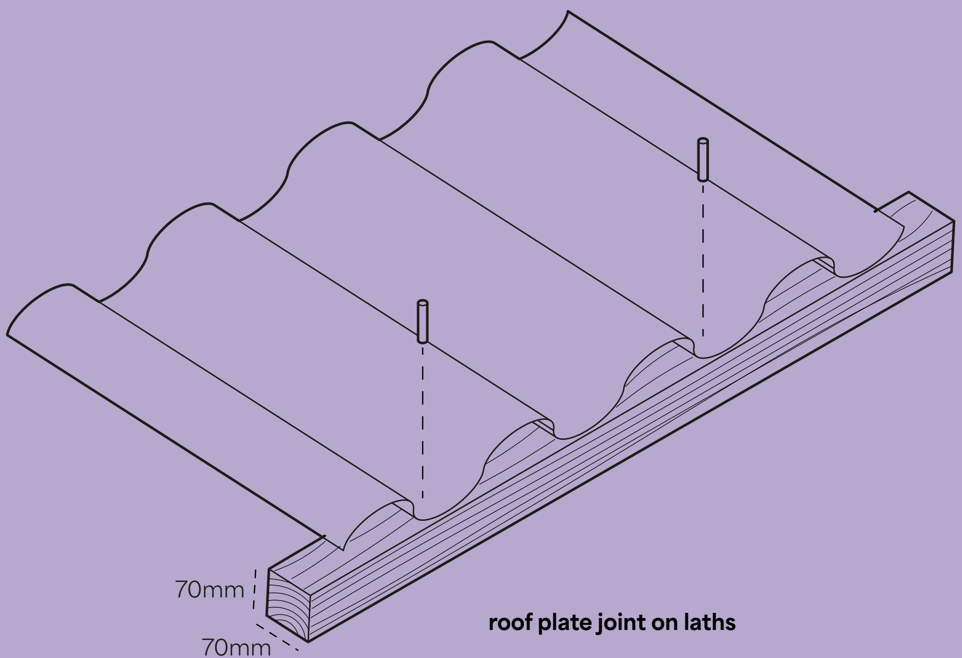
foundation joint with column



bracing

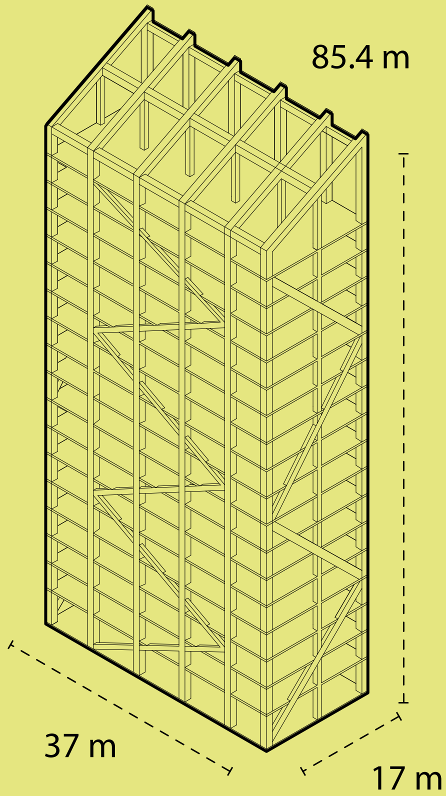


side-column joint



roof plate joint on laths

mjøs tårnet



Ill. 16. diagram of mjøs tårnet

potentials for reclaiming timber

If the wood available in the mink farms is successfully reclaimed and utilized a range of additional qualities can be achieved. Both reclaimed and newly produced timber have potential in the building industry.

Reclaimed timber differentiates itself from new timber in its previous use, in this case as part of the mink barns. Nature, loads, and interactions affect the quality of the timber and bring forth a different expression compared to new timber. Holes, imperfections, and different kinds of insects alter the aesthetic appearance and visualize the timbers' former usage. Two of the most important qualitative dimensions are achieved by atmosphere and narrative. The atmospheric quality of timber raises awareness of tactility and beauty. The narrative quality seeks to communicate with the user, explaining the material and its presence. (U. Groba, 2020)
Timber undoubtedly has qualities in the field of architecture and reclaimed timber arguably has even greater potential in terms of increased tactile qualities and a strong narrative.

Reclaiming timber extends the life cycle and thereby keeps the CO2 in the timber sequestered longer. The CO2-saving aspect is a core argument for utilizing reclaimed timber as opposed to newly produced timber. Not all timber from the mink barns is expected to be reclaimed but each time an element is reclaimed CO2 is saved. If the timber is recovered and burned for heating as supposed by Bygningsstyrelsen, all the stored CO2 in the timber, collected during the growing period, would be released (Dovetail Partners Inc., 2013). The CO2 stored in the timber will inevitably seep back into the atmosphere when the timber either decays or is burned but prolonging this process is in the best interest of both the environment and future generations.

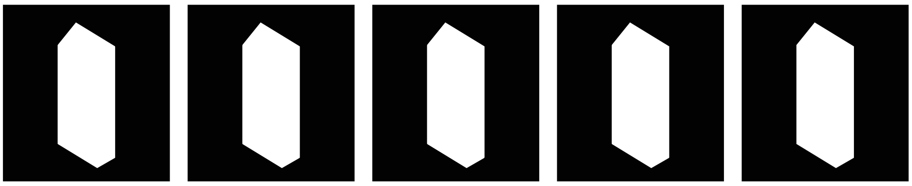
/co2

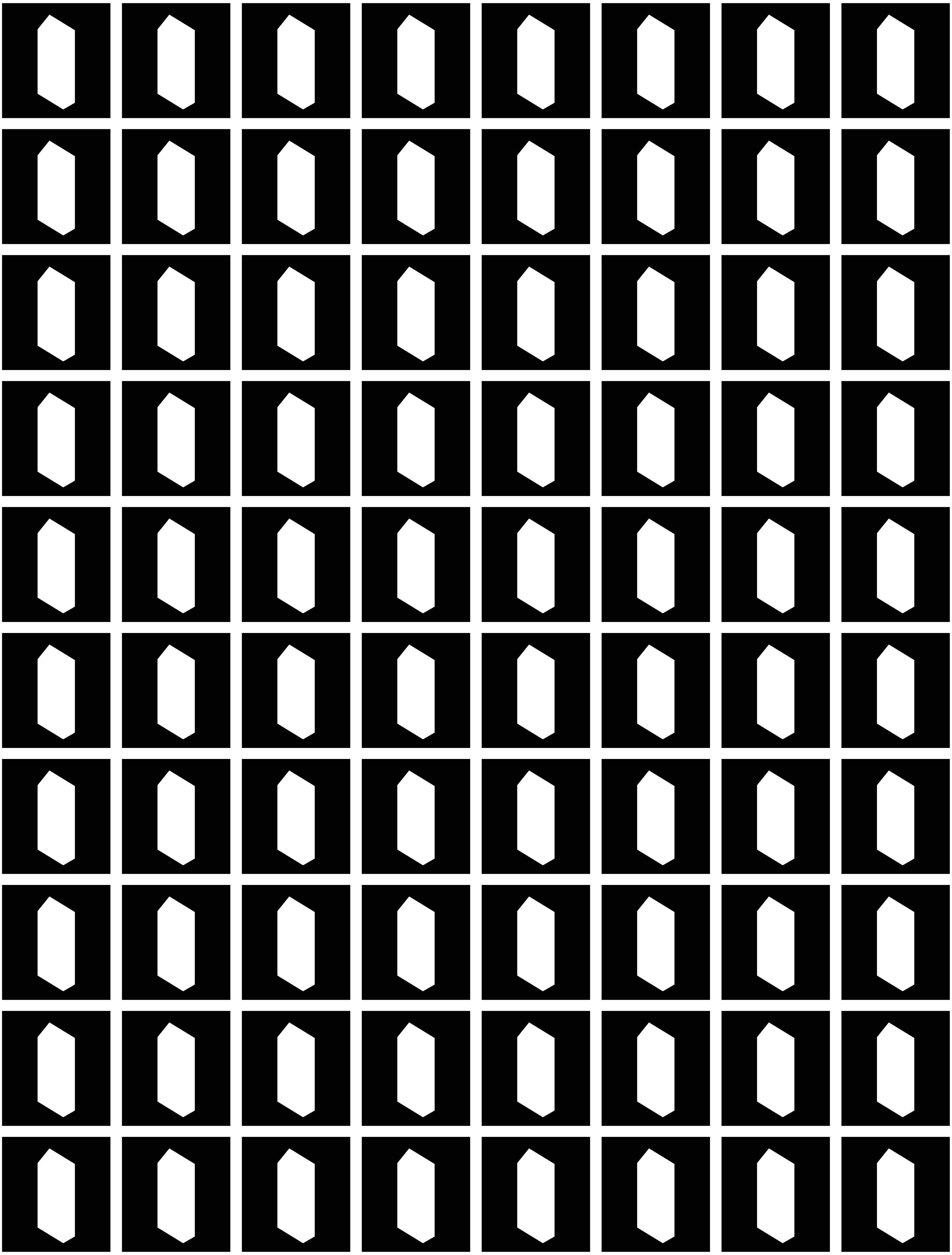
Trees obtain CO2 as part of photosynthesis and bind it to the trees' branches, leaves, and trunk. The amount of CO2 obtained varies from species to species. Pine and spruce obtain 232,1 tons of CO2 per hectare. Bygningsstyrelsen estimates all Danish mink barns collectively are made up of around 100.000 tons of timber which corresponds to 460 hectares of forest. Properly reclaiming all this timber would prolong the emission of 165.000 tons of CO2. This corresponds to a year's emission of 14.000 average Danes with a yearly emission of 7,5 tons of CO2 equivalent or 12.000 flights around the earth (Danmarks Statistik, nd.)(Thomas, 2018).

/material mass

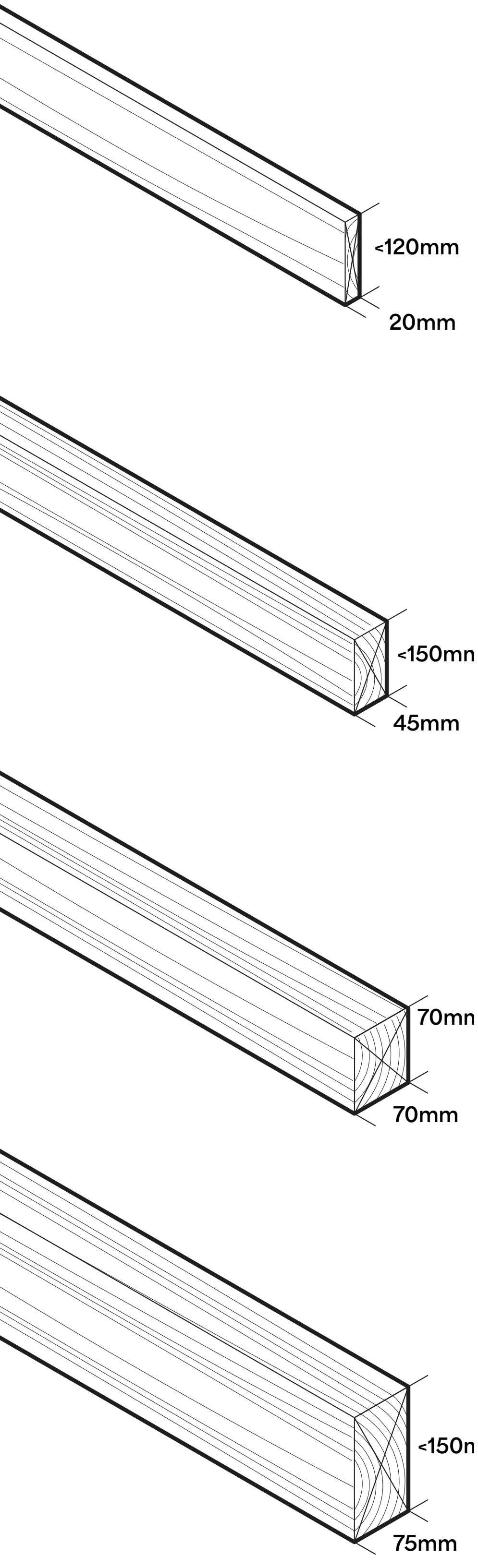
There is an estimated 100.000 tons of timber within the mink barns which corresponds to around 222.000 m³ of C18 pine (Weng & Thude, 2022). That amount of material is large and difficult to compare. The tallest timber building in Scandinavia is the Mjøs Tower in Norway: 81 meters in height, 18 floors, and glulam beams as big as 1485x625 mm. The wooden structure is made of around 2300 m³ of timber. If all timber is reclaimed from the mink barns one would have enough material to build 85 similar structures. It's unrealistic that all the reclaimed timber is possible to use again, but the sheer amount of material makes it highly relevant to consider reclaiming (Heunicke et al., 2021).

X85





summary



Ill. 17. identified wood elements

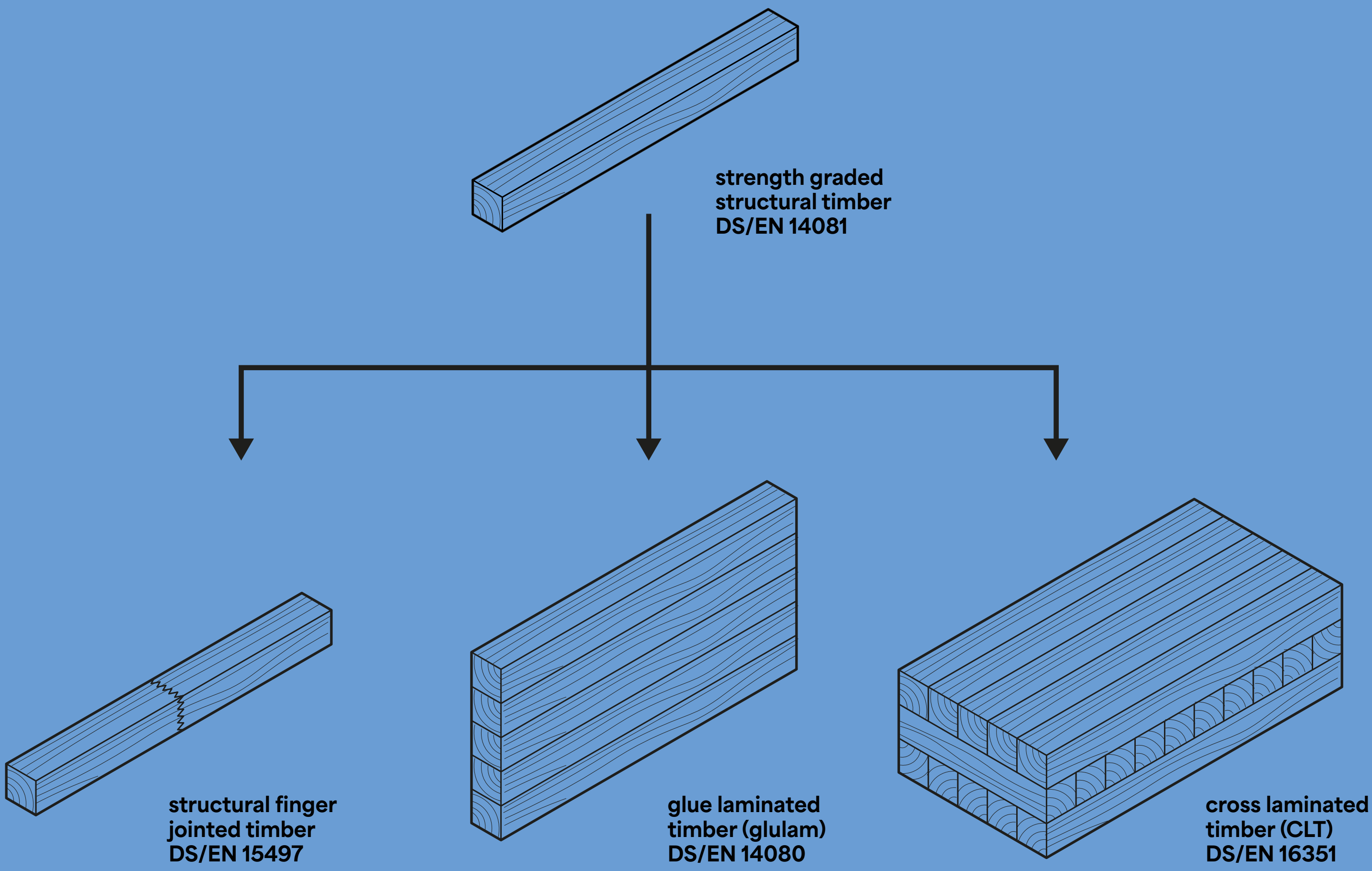
A massive stock of wood has become available in the form of mink barns. The potentials for reclaiming the timber are many.

A massive stock of wood has become available in the form of mink barns. The potentials for reclaiming the timber are many.
From visits to mink farms, it has become evident that not one barn is entirely identical, but are all built on the exact same principle of using structural frames, mainly of timber (Weng & Thude, 2022). The wood is in fairly good condition due to its favorable circumstances in the mink barns, while the timber elements are found in a wide variety of lengths and heights but are almost all based on the same standard thickness and strength. Joining the elements into a frame, nail plates are usually used, while alternatives such as bolt plates or nails/screws are used less.
The frames can be easy or difficult to disassemble, where screws and nails are easily removed, the nail plates are nearly impossible, and the timber piece containing it will need to be cut off, leaving the timber element reduced in size.
From the identified barn types and their structure, the typical wood element sizes can be concluded into four categories: 20mm width, 45mm width, 70mm width, and 75mm width, whereas all categories include varying heights and lengths (with the exception of 70mm width), were of quality C18/24, and of pine. The project takes a point of departure within the available wood retrieved: 20x120mm and 70x70mm.
There is an estimated 100.000 tons of wood in the 1246 mink farms in Denmark (Weng & Thude, 2022).
Disassembling the barns' wood structure to gain single elements will leave a huge stock of a variety of wood elements, and if these (even just half of them) can be used or utilized in some way, would it be possible to build many structures of the reclaimed timber. The woods' lifespan will be prolonged, extending the release of around 200.000 tons of CO_2.

Ill. 19. 70x70mm & 20x120mm wood from mink barns

Ill. 18 three identified cross sections

Ill. 20. timber options diagram



DESIGN WITH TIMBER

Knowing the qualities and weaknesses of the wood from mink barns, the next step is to understand the Danish regulations on wood and timber in the building industry, the grading of timber, and how to conduct the grading of timber. Therefore it is also important to understand timber as a material, its joinery, and its potential and possibilities.

regulations

The building industry is strongly regulated and the requirements for construction materials are extensive. The hypothesis in this project is based on the assumption that reclaimed timber from the mink farms has the material properties necessary, but this does not account for the regulations and standards that need to be upheld. Here we will present the main purpose of the different regulations that apply to construction wood.

The Danish building regulation §340- 357 states the requirements for the construction of a building and refers to what standards need to be fulfilled. For information on DS (Danish Standard), see Appendix C.

§340 describes the main purpose of the building regulation, to ensure that the project planning, execution, operation, and maintenance of structures and building elements don't injure or cause harm to persons' health or adjacent buildings.

§344 rrequires the building to withstand static and dynamic loads depending on its use and placement as described by a number of international standards concerning consequence class, loads, application category, etc.

§348 references Eurocode 5 and DS/EN 1995 and how to calculate wooden structure, partial coefficients, modification factors, etc

These paragraphs and the standards the reference are written with new timber in mind, this makes it time-consuming and difficult to withhold when using reclaimed timber, as there isn't a basis for what factors to use for reclaimed timber.

§352 & §356 suggest that deviation from the aforementioned paragraphs can be acceptable as long as the security requirements can otherwise be achieved and documented. (BR18 nd.)

In the European Union producers and suppliers of building materials are required to CE certificate their products according to the international standard or an ETA (European Technical Assessment). If there aren't any existing standards that apply to the material or if there haven't been issued an ETA, it is not possible to get a CE certification. One of the reasons is that the origin of the material is a requirement. Materials reclaimed from older buildings can't document the origin of the materials. As it stands it is therefore not possible to use reclaimed timber according to European and Danish regulations. For new buildings, it is possible to implement material passports so that the origin in the future can be established. There is however a number of research being conducted on different kinds of recycled and reclaimed materials. In Denmark, Structural Reuse, a consortium of actors in the industry and researchers are working on preliminary standards that can be submitted to Dansk Standard and the EU. They were approached to learn of the current state of the development of new standards for reclaimed materials. This will be covered in a later section.

Questions regarding how and where reclaimed materials would fit into the established regulations began to arise and a meeting with Alexander Mollan, a consultant from Danish Standard, partly working in the Danish standardization committee for timber constructions.
The interview made it clear that reclaimed timber is yet to be fully understood in regards to structural properties and that reclaimed timber is difficult to certify partly because there is limited documentation in regards to where the timber originally was produced and what its initial strength capabilities were and what capabilities are left. It's furthermore important that reclaimed timber won't be categorized as a second alternative to new timber but should be comparable to acknowledged standards found in for example DS/EN 14080 in the case of reclaimed timber used for glulam production. The reclaimed timber should therefore be investigated on the same terms as new timber to obtain a comparable grade. Utilizing reclaimed timber for large structures seems far off by initial tests, and experiments are according to Alexander crucial for initiating future processes as regulations formulated by Danish Standard often build on scientific research and results.

grading

In the case of new timber, intended for construction whether as construction wood or for mass timber products, it is appearance graded based on visual defects. A timber element is typically visually graded at the sawmill in the case of new timber. The grading is determined by a wide array of potential defects seen in timber, all of which have an impact on the element's mechanical properties and potential usage. The grading procedure and measurements follow DS/EN 1611-1.

DS/EN 1611-1 is based on visually grading coniferous timber with a grading system ranging from G4 - 0 to G4 - 4. The grading system sorts 0 as the highest grade and 4 as the lowest. Gx (2 or 4) indicates the number of sides that's been graded, which most of the time is all four sides.
Defects like knots, resin pockets, and insect attacks are all part of the visual grading. The size, amount, and area of implication are what place the individual element sides into grading categories. Timber in each category is used and applied differently ranging from construction timber to formwork boards.

g4 - 0 - construction timber
Is the best assigned visual grade. The timber of this grade is primarily used for construction timber.

g4 - 1 - construction timber
This grade allows for slightly more defects than the previous grade. Timber in this category is mainly used for construction or for mass timber production.

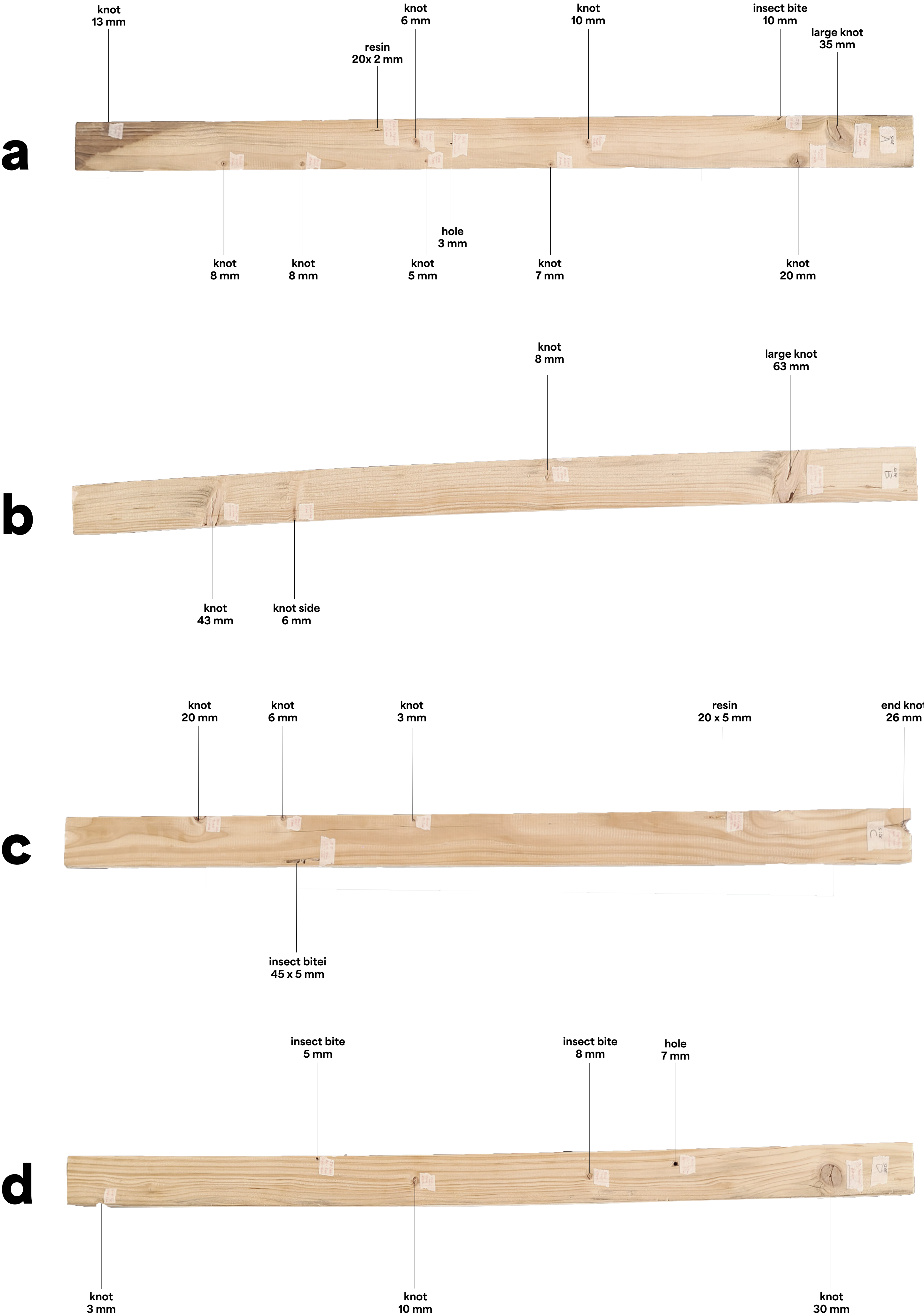
g4 - 2 - planed timber
Used for high-quality facade cladding or high-quality floor decks and sheathing. The timber of this grade is partially used in construction but mainly in load-bearing parts like wall studs.

g4 - 3 - planed timber
Is primarily in similar applications like the G4 - 2 timber but in a lower quality result. It furthermore applies timber for packaging and good quality formwork boards.

g4 - 4 - packaging/formwork
The worst visually graded timber, used primarily for formwork when casting concrete and timber packaging.

piece of reclaimed timber was selected for grading to get a better understanding of the process and the expected grade of the material. The piece chosen was a roof lath from a 2-row mink barn. The element was considered to be one of the worst-appearing reclaimed elements and was therefore chosen for visual grading. The element had before grading been planned and trimmed to a length of 105 cm with a cross section of 63 x 63 mm.
Each side of the timber was then graded and defects were measured.
Sides A, C, and D were all graded G4 - 3, whilst side B would be G4 - 4 due to a large partially ingrown knot. DS/EN 1611-1 states that if one side in a G4 grading is lower than the other three the piece of timber is collectively graded one grade above the lowest. The graded piece of timber would therefore collectively get a G4 - 3 grading.

The primary factor resulting in the assigned grading can be attributed to the insect bites registered on three of the element's four sides. Insect bites of any size relative to the surface area result in a grade of G4 - 3 or lower, even if the defects are smaller than 1% of the sides' surface area. The existing regulations that determine the grading point leave very little room for timber with insect bites to achieve a good grade. The reason for this is based on how difficult it is to assess how much internal damage insects have done to a piece of timber.
The grading system referenced in DS/EN 1611-1 does not consider holes or dents caused by nails, screws, or bolts because the grading regulations are made for new timber without holes.



Ill. 21. visual grading of an element on side a, b, c, and d

Ill. 22. collective visual grading of all four sides table

/collective visual grading of all four sides

defects		number	G4 - 0	G4 - 1	G4 - 2	G4 - 3	G4 - 4
small knot			10% of width +10 mm (16.3 mm)	10% of width +20 mm (26.3 mm)	10% of width +35 mm (41.3 mm)	10% of width +40 mm (41.3 mm)	remaining knots
<10 mm diameter	*sound ingrown*	12	12	-	-	-	-
large knot			10% of width +10 mm (16.3 mm)	10% of width +20 mm (26.3 mm)	10% of width +35 mm (41.3 mm)	10% of width +40 mm (41.3 mm)	remaining knots
	sound ingrown	8	3	1	1	-	1
			10% of width <6.3 mm	20% of width + 10 mm (<16.3 mm)	10% of width + 20 mm (<26.3 mm)	10% of width + 50 mm (<56.3 mm)	remaining knots
>10 mm diameter	*partially ingrown*	1	-	-	-	-	
			not permitted	not permitted	10% of width + 15 mm (<21.3 mm)	10% of width + 40 mm (<46.3 mm)	remaining knots
	unsound or loose	1	-	1	-	-	-
resin pocket			allowed number pr worst meter (2)	allowed number pr worst meter (4)	allowed number pr worst meter (4)	allowed number pr worst meter (4)	allowed number pr worst meter (unlimited)
	number pr worst meter	2	2	-	-	-	-
			allowed colective length (75 mm)	allowed colective length (100mm)	allowed colective length (200 mm)	allowed colective length (300 mm)	unlimited
	total length (mm)		40	-	-	-	-
insect bite			% of surface area (not permited)	% of surface area (not permited)	% of surface area (not permited)	% of surface area (15%)	% of surface area (unlimted)
	surface stain % of surface	3	-	-	-	1.06%	-

/strength grading

Comparing reclaimed timber to acknowledged standards like the C-class (C16, C18, C24...) mentioned in DS/EN 338, is difficult as not much is usually known about reclaimed timber. New timber from a known forestry is often assigned a strength grade based on their product's usual strength and only a limited sample is actually tested. Comparing features of C-class timber with reclaimed material is to some extent possible to get an idea of the reclaimed timber element´s structural capabilities. This is however done with great uncertainty as each piece of reclaimed timber varies. C-class timber is generally graded based on annual rings, knot sizes, and density. DS/INSTA 142 details how these parameters are measured. (Appendix C)

The comparative test indicates that the reclaimed timber has properties that span from better than C24 to worse than C14. The deviating results are a testament to how difficult it is to categorize reclaimed materials. The piece of reclaimed timber is categorized as C14 or C16, based on this visual grading. But its high density could indicate a higher strength.

Visual grading is a comprehensive term that covers a range of different aspects and defects found in timber. The grading of a timber element determines its usage based on its visual conditions and the strength grade it gets as a result. It is important but difficult to grade reclaimed timber as the conditions vary and the materials can´t be collectively graded like new timber. Comparing reclaimed timber to values found for C-class timber indicates its mechanical properties even though further destructive strength test is needed.

Ill. 23. reclaimed timber compared to regular c-class elements

strength	density kg/m3	ring distance	knot size width	knot distance thickness
C14	350	-	1/2 width	1/2 thickness
C16	370	5	-	-
C18	380	3.1	2/5 width	4/5 thickness
C20	400	-	-	-
C24	420	0.9	1/4 width	1/3 thickness
reclaimed timber	444	5	1/2 width	1/1 thickness

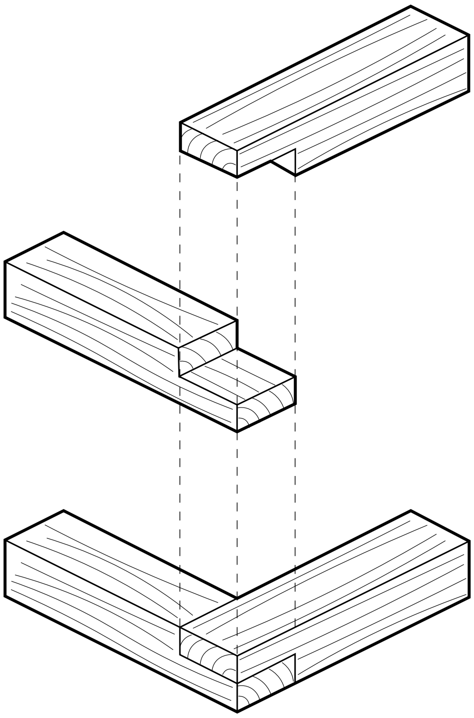
bolts and joints

"A structure is a constructed assembly of joints separated by members"
(McLain, 1998)

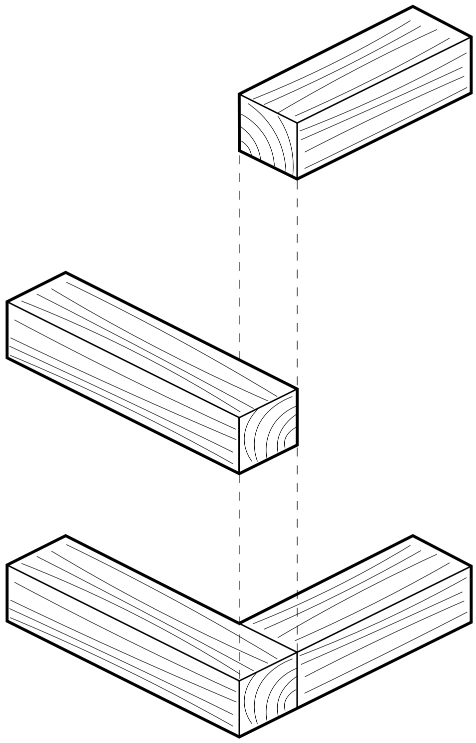
n timber engineering the joint is a critical factor in the design of the structure. The joint will generally dictate the strength of the structure where its stiffness will influence its behavior. Member sizes and strengths and joints and their stiffness co-influence each other. The structures' inner forces caused by external actions are transferred from one member to another at a node point, where the transfer of forces is via a joint. Disregarding the strength of a joint, but focusing on its properties, there are mainly three types: a pinned joint (no moment), a semi-rigid joint, and a rigid joint (moment).
Timber joints are typically made of lap joints (ex. finger joint or tongue and groove joint) or butt joints (ex. basic- or mitered butt joints). Lap joints are connected by adhesive (glues) or by laterally loaded dowel-type fasteners (nails, bolts, screws, dowels, or connectors as nail plates) whereas butt joints only are connected by the latter. Depending on the structure, timber joints are typically rigid.
Lap joints are typically related to traditional joinery and handcraft, which makes the joints aesthetically pleasing, but advanced and time-consuming to create. Butt joints are rooted in simplicity and function, where connectors can be utilized in different ways to create a rigid joint.

Focusing on butt joints, steel connectors are typically used either by nail plates or steel plates fastened with nails, screws, or bolts. The steel connectors can either be placed on the sides of the joint onto the members or inside the member. Using steel connectors with bolts allows for a joint to be taken apart without further damaging the timber, as it will with nail plates. A disadvantage of using steel connectors is the weakening by rain, where the metal can oxidize and affect the integrity of the timber. (Livingstone, 2015)(Timber frame joinery nd.)
When using steel plates and bolts, the bolt's size, amount, and placement influence the shear strength of a bolted joint, as well as geometrical factors. Being subject to potential bearing, splitting, shear-out, block shear, or net tension failure, the placement, size, and amount are important to consider. Taking the timber members' width, the apparent internal load, rigidness, and bolt load capabilities into consideration, it is possible to utilize recommendations for bolt placement and the amount needed defined by the diameter of the bolt. Loads parallel or perpendicular to the grain define bolt placements in a square grid, whereas other load directions define shifted bolt placements. (Prasad, 2023)(Timber Joint Design - 3 nd.)(Sawata, 2015)

There are a plethora of timber joints. The specification of a joint will depend on a range of factors: the nature of the forces applied in relation to the structure type, the practicality and manufacturability, the aesthetics, environmental conditions, and cost. Specifying a connection should consider how the whole system is to function.

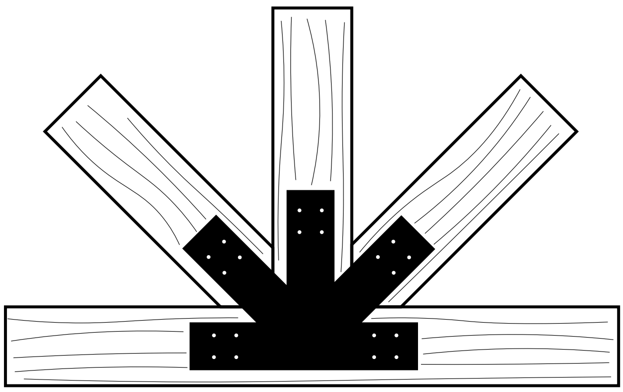


simple lap joint

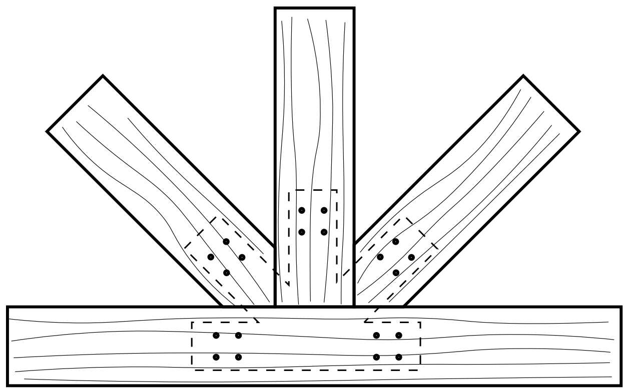


simple butt joint

Ill. 24. lap- and butt joint diagram

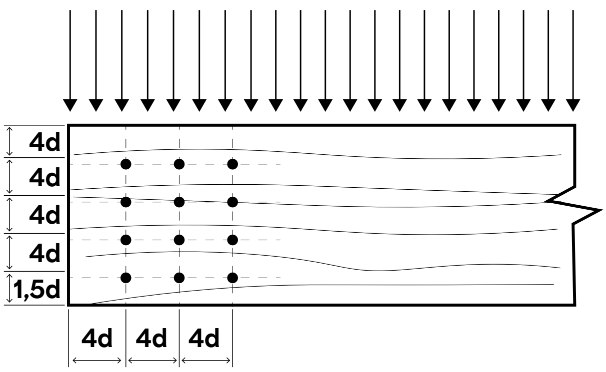


steel connector on joint frame

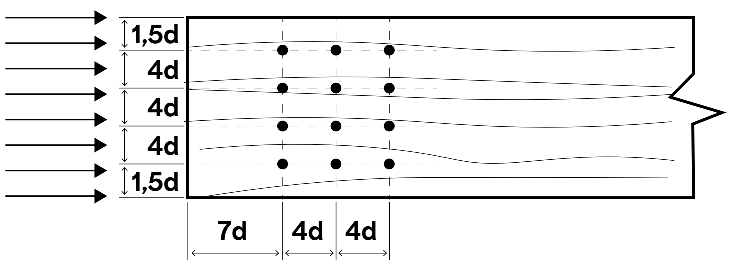


steel connector in joint frame

Ill. 25. steel connector diagrams



bolt placement with loads perpendicular to wood grain



bolt placement with loads parallel to wood grain

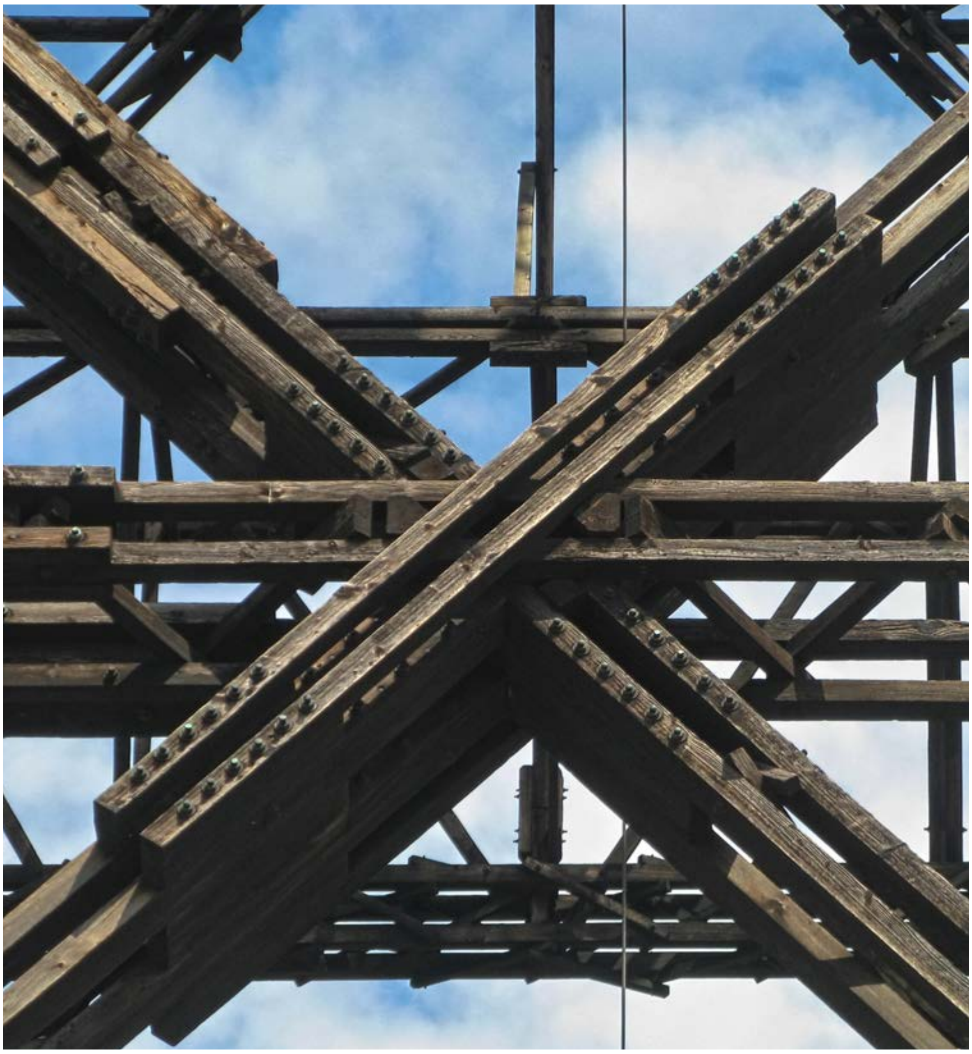
Ill. 26. bolt placement recommendations

designing with timber case: gliwice radio tower

architect: lorenz (company) construction: 1935 structural system: impregnated larch wood

Ill. 27. gliwice radio tower joints 2018 © Adrian Grycuk

Ill. 28. gliwice, radiostacja 04 © Gabriel Wilk

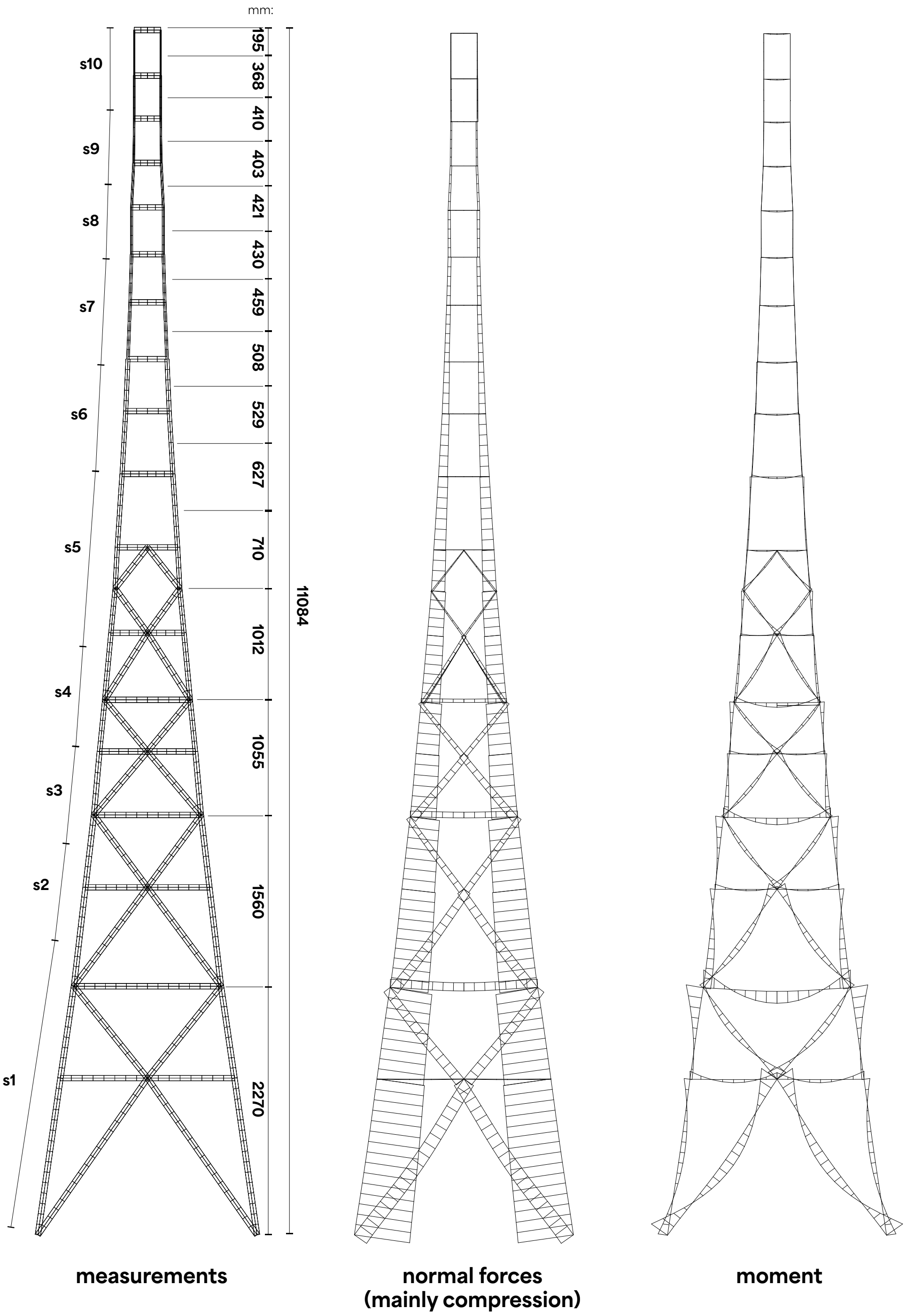


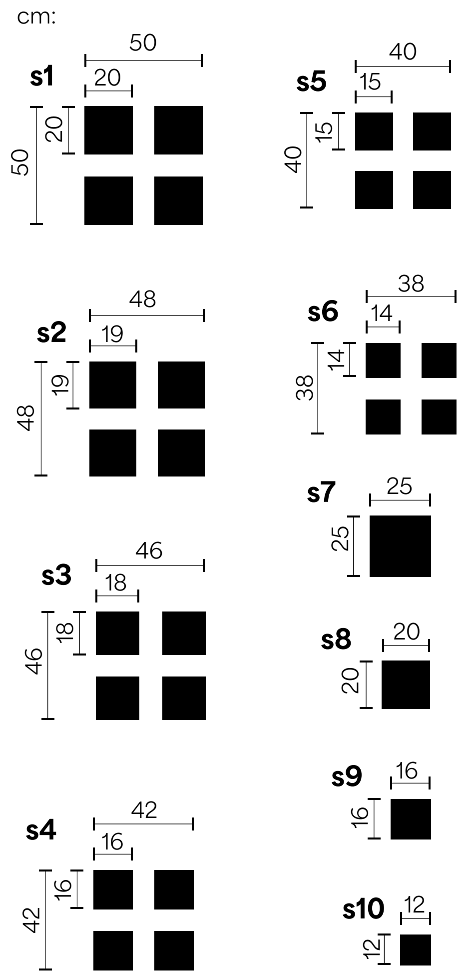
The Gliwice Radio Tower is a transmission tower in the Szobiszowice district of Gliwice, Upper Silesia. The radio tower is the highest wooden construction in Europe, with a height of 110 meters. It was built in 1935 by the German company Lorenz, from impregnated larch wood that is especially resistant to pests and weather conditions (Gliwice radio tower - its Poland nd.).

The wooden tower has a spatial lattice structure with variable cross-sections. The axial spacing of columns at the base is 19,8m. The tower consists of four lattice trusses that form a parabolic spatial structure with four platforms throughout the structure. The four columns are connected by load-bearing and stabilizing crosses. They are further divided by horizontal braces for stability and to prevent buckling on the longer elements. At the intersection point of the columns and crosses horizontal beams span the distance between the columns and support the platforms and.

The simple principles on such

Ill. 29. axial forces on gliwice radio tower





Ill. 30. sections of gliwice radio tower structure

a large scale create complexity in joints and cross-sections of the members. The columns are made through a substructure consisting of a four-branch cross-section composed of 200x200mm elements with a 100mm spacing - the cross-section is reduced according to the height of the structure gradually, eliminating unnecessary self-load. The columns are connected through caps and inserts (rings, screws, brass bolts), making the structure possible to be disassembled and taken down. The height of the structure requires that the timber columns are connected and joined together (to elongate the column) through large joints. The lattice structure follows the same principles as the columns.

The tower was constructed before the current grading of the C-classes, so the classification of the wood is uncertain, but recent samples of the wood that have been tested have shown material properties equal to the C40 classification. (Wojaczek et al., 2018)

The case study demonstrates that a timber structure can reach an impressive height with careful considerations towards varying cross sections and proper load distribution if it is well designed. The column elements' cross-section increases towards the ground, gradually increasing strength, corresponding to the increased load from the structure above.

This principle is observed from the normal- and moment forces. Cross bracing is also important in the case of tall structures, whether they are made of wood or not, cross bracing provides stability and therefore has less to no load-bearing properties compared to the columns. The only loads applied to the structure are the self-weight of the timber, hence the structure is not exposed to live load while snow and wind loads are limited because there are no walls for the wind to push against or surfaces where snow can gather. (Wojaczek et al., 2018)

RECLA

Manifesting the potential and possibilities of reclaiming wood from mink barns, timber as a structural material, and the regulations following, proof that the wood can be reclaimed to timber is needed. The proces of creating reclaimed timber is tested from disassembly to the production of glulam, identifying the possibility of grading individual pieces of timber. Proposing the handling of producing reclaimed timber and the data following each piece towards a relevant and streamlined proces.

RESEARCH QUESTION:

“What structural building elements can be made from the available wood and what are their properties?”

AIMING TIMBER

disassembly/ reclamation

Ill. 31. unfinished mink barn

The task of taking down all the mink barns is huge and the task cant be handled by a single firm. The Danish mink farms have by Bygningsstyrelsen been divided into two regions, east, and west. 6 contractors are set to manage the demolition of region west and 3 will manage region east (Weng & Thude, 2022).
Until the demolition firms have been chosen to lead the demolition of the mink farms, the mink barns are standing empty. It is unknown what will happen to the wood structures, though there is a Danish demolition sector agreement NMK96 (demolition sectors control-order) which is to ensure environmentally friendly demolition of high quality, based on good demolition customs. It ensures equal and simplified handling of the building industry's waste through cooperation for environmentally friendly sorting and control.

In NMK96 §2, it is understood that building materials are to be sorted into material fractions of the necessary quality of cleanliness, before being removed from the site, to enable the possibility of a high degree of recycling (Nedbrydningsbranchens MiljøKontrolordning 1996 1996).
It is known that the wooden structures of the mink barns will be sorted into their own timber fraction, meaning the timber would be sorted already on-site, enabling an easier process for utilizing the timber for recycling. The timber will though still include foreign elements such as nails, screws, plastics, etc., whereas it is presumed the easiest solution for recycling the timber on an industrial scale today is to grind it into wood chips thus being able to sort wood and metal. (Appendix D)

The disassembly process for the timber requires removing/ cutting off unusable parts of the wood either due to rot, moist, chemicals, or where there have been used nail plates (due to the inability to remove them from the timber), leaving a plethora of varying lengths and sizes of timber. Being able to reclaim the timber, another strategy than recycling it into wood chips is required.
Presuming the timber is reusable when the foreign elements have been removed, the process of removing this by hand is tested using screwdrivers, crowbars, hammers, and dowels.

Timber from mink farms includes a relatively large amount of screws and nails (between 5-15 per element), and it is a cumbersome process to remove them by hand, though it is easily possible to do. Industrializing this process would be beneficial. This can be achieved by utilizing carbide tools with a slower feed rate when planing the wood as this would also be able to plane metal. It is found that cleaning the timber with steel brushes is effective in removing dirt, etc., and discovering unusable weak points, like rot.

From the already sorted timber elements from the mink farms by the demolition company, it is possible to remove foreign elements, clean them, and sort them into functional timber elements.

reclaimed timber today

When considering the possibilities of reclaimed and reused timber, taking a look at the current practice is a valuable and necessary activity to establish a foundation of the components that dictate the current use of reclaimed and reused timber.

As previously mentioned the lack of a framework in current regulations is hindering initiatives that could develop the practice of reclaimed timber. As it stands today the process is slow and troublesome. They need dispensations to be built by the municipality that is given on a case-to-case basis where the deciding factor is often the municipality clerk assigned to the case.

The cases where reclaimed materials are often found today are on finishing surfaces that don't have structural properties. This is due to the fire and safety classes where the uncertainty of the material properties of reclaimed materials can't guarantee that they can hold. Recently some cases of smaller structures under 50 square meters have been developed as they don't adhere to those requirements.

As with all businesses, architectural firms are driven by capitalistic forces in order to produce a profit. Most budgets don't have a lot of room for innovative and experimental practices, since these activities are often expensive, complicated, and unsure investments.

Reclaimed materials often come with a lot of hidden expenses in the form of extra time spent on the gentle demolition process necessary, transport and storage of materials, and the process of removing nails, screws, and other unwanted objects or finishes.

This combination of the cost, the limited and fluctuating supply chain, and the uncertainty associated with reclaimed material is driving the bigger actors that could evolve the knowledge base of reclaimed materials.

/upcycling orangeri

Upcycling Orangery is an exception where some businesses have gone together to develop a structure based on reclaimed materials. Titan Nedbrydning A/S, Frandsen & søndergaard, and Arkitektfirmaet NORD have gone together to create an orangery where concrete elements are laid as foundations, double-glazed windows are framed by a timber structure and brick gables to create an outhouse that can be the setting for activities even in the winter. (Nordjyske.dk)

The project could be realized since the orangery is less than 50 m², since that is under the building regulations requirements for safety requirements on buildings. The structural properties of the timber were evaluated on the basis of visual grading (growth rings, knots, dimensions, etc), and were evaluated to be equivalent to C24, to get a building permit from the municipality. (Appendix D)

Ill. 32. upcycling orangery

treatment

The timber reclaimed from the mink barns has varying qualities regarding, condition, strength, weight, and dimensions. It's therefore important to investigate and consider what potential treatment and usage the timber would benefit from. The reclaimed timber can be processed in four different ways towards being used again.
The processing time increases as the reclaimed timber undergoes more processes. But the processes also enable the reclaimed timber to make up different parts of a building. Using the reclaimed wood as it is would be suitable for outdoor construction, planed timber would be suitable for indoor parts that don't require a high degree of structural strength, and finally, mass timber products made from reclaimed elements would be suitable for structural elements such as columns, beams, and load bearing walls. To find out whether any of this is possible, strength tests need to be conducted as a starting point for figuring out the possibilities and limitations of the reclaimed timber.

Ill. 33. images of reclaimed timber as is, planed and as mass timber

/as is

Visible foreign objects like dirt, nails, and screws are removed. If the reclaimed timber element is just cleared of foreign objects could it be used for minor outdoor purposes like sheds and so on? The reclaimed timber would not be suited for indoor usage and the timber would still appear dirty and used.

/planed timber

Visible foreign objects like dirt, nails, and screws are removed and the elements are planed to remove the outer timber, affected by algae and external damage. Reclaimed timber which has been planed on all four sides would to a large extent appear new at least by the look. The structural properties would not have improved but the wood would be suitable for indoor usage as partition walls, interior elements and so. The questionable and limited strength would not enable the wood to make up structural elements. (DS/EN 14081)

/mass timber

Visible foreign objects like dirt, nails, and screws are removed and the elements are planed to remove the outer timber, affected by algae and external damage. These elements can be used in the production of mass timber either as glulam or cross-laminated timber (CLT). Mass timber products seek to combine the strength of different elements to produce structurally durable elements. (DS/EN 14080) (DS/EN 16351)

To ensure that it is possible to achieve reclaimed timber from wood from mink barns, the process was tested. From retrieving used wood to producing glulam at a factory, it proved viable.

/1 - disassembly

To start the process of, all the mink farms in Denmark were mapped. A mink farmer who had wood from mink barns laying around allowed us to retrieve it.

After finding a material source for wood, the barn needs to be disassembled. The mink farmer was building a barn from old mink barn frames when the corona-crisis came, which meant that he had already-disassembled wood that could be retrieved.

/2 - shipment

The wood was moved to a garage where further work could be done.

/3 - drying

After talking with the glulam production, they said it is important that the wood has a moisture level of around 12%. The wood retrieved was laying outside, so it was moved to an indoor barn with a heater blowing on it for 2 weeks.

/4 - removal of foreign elements

The wood had many foreign elements inserted in it which were removed. This process was very time-consuming and it is probably the most difficult task in reusing wood from mink barns - it would need to have a solution that can work on an industrial scale.

The elements that couldn't be removed from the wood needed to be cut off, due to the machines at the glulam factory were not made to cut in metal. It is possible to have planers that can cut through metals. After the off-cutting, there were pieces of wood in varying sizes.

/5 - cleaning

The wood pieces were dirty from standing in a mink farm for many years. On the surface were algae, fur, leftover food, and excrement. A steel brush was used to take the worst of the dirt away. It is unsure if this process is needed since the wood would later go through a planer and remove the outer layer completely.

/6 - sorted/dried

This is where the process starts at the glulam factory, by receiving planks that have been drying from Sweden. Th wood was transported to the factory and it proved to be dry enough to their standard.

(fingermilling, applying glue, compression)

The first thing that happens in the factory is to turn the wood planks into 25m planks. This is done by finger milling (milling a finger joint connection between all planks), applying glue to the joints, and pressing the joint together. This is repeated until the plank is long enough.
The goal was to produce smaller pieces, the process was skipped.

/7 - planing

Usually, the 25m long planks are planed in a large planing machine.
In this process, since there were smaller pieces of wood, a smaller 4-sided planer was used. The planer removed the outer layer leaving the wood looking new

/8 - prepared timber

The timber elements have now been disassembled, cleaned, and planed to become timber elements suited for gluing.

/9 - applying glue

For normal production a large machine rolls all the planks through and applies glue - it automatically stacks the glued planks, so they are ready to be hoisted to the tension machine.
In this process there were smaller wood pieces that used a smaller tension machine, making the process easier if glue was applied by hand and stacking the wood pieces manually.

/10 - tension

The tension machine holds everything in place. A metal bar is moved down on top of the stacked wood, hereafter a long air-pillow is placed at 8 bar pressing the wood from the bottom upwards keeping the stack in tension for 2 hours whilst the glue is drying.

/11 - planing

The piece is planed again to remove glue and make an even surface.

/12 - finishing touches

The piece is planed again to remove glue and make an even surface.

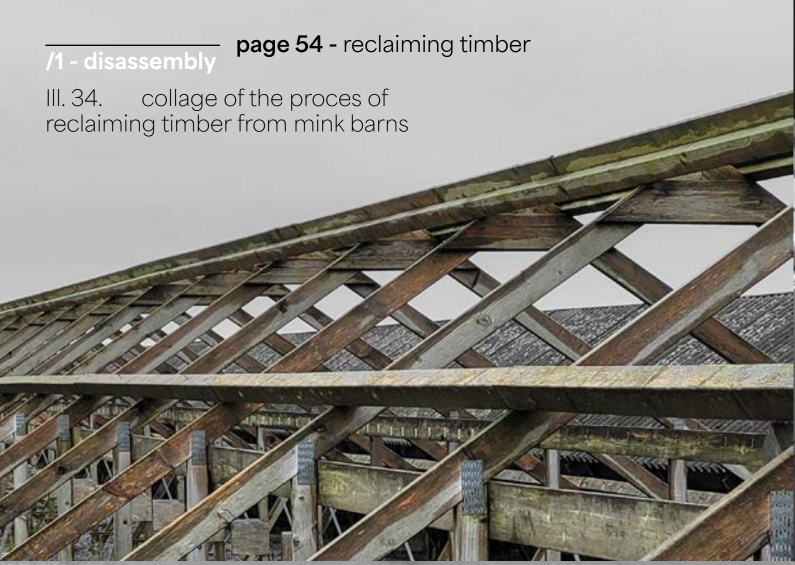
/13 - shipment

The finished glulam product can now be shipped.

page 54 - reclaiming timber

Ill. 34. collage of the proces of reclaiming timber from mink barns

/1 - disassembly



/2 - shipment

/5 - cleaning

/6 - sorted/dried

/9 - applying glue

/11 - planing


/3 - drying


/4 - removal of foreign elements


/7 - planing


/8 - prepared timber


/10 - tension

/12 - finishing touches


/13 - shipment

TESTING

/destructive strength test

Ill. 35. images of destructive test on reclaimed timber

A piece of reclaimed timber has been tested in a destructive compression test. The element tested was before testing subject to a visual grading giving it an estimated strength of C16. The tested element was 1 meter long with a cross-section of 63x63 mm. Foreign objects had been removed and the elements were planned before the destruction was conducted.

The reclaimed timber element withstood 963 kg of pressure before breaking. If converted to MPa the results show a load-bearing capacity in bending orthogonal to the grain direction of 16,6 MPa. Which makes the element comparable to C16. The test showed slightly more strength than what was expected from the visual grading.

With the known strength of a single element, investigating the possibility of using the reclaimed timber as feedstock for glulam production is relevant as it would enable greater strength capabilities of elements when glued together. One of the main advantages of glulam and mass timber products revolves around the spreading of weaknesses. Minor defects like dents and holes caused by nails and insect bites become less relevant in mass timber products because no single element carries the entire load. The elements in mass timber products like glulam and CLT can, if properly arranged, cover each other's weaknesses resulting in no defects that penetrate the entire element.

/delamination test

Ill. 36. images of a delamination test on reclaimed timber

As stated in DS/EN 14080 any manufacturers of glulam products should test the product in regard to delamination. Delamination is the result of inadequate glue bonds between laminated elements which can result in the element splitting apart. The delamination test is conducted on planed and trimmed glulam elements with a length of 75 mm. The test element is placed in hot water and put under 10 bar pressure for 60 minutes. The element is then placed in a drying cabinet for 22 hours, at 60-70 degrees with an airflow of 2-3 m/s. The delamination is measured in both mm and percent of the entire glue bond. (Appendix C)

The delamination test was conducted twice on glue-laminated products made from reclaimed timber from mink barns and showed less than 10% delamination of the 63 mm glue bond. The results indicate no issues with the reclaimed materials' capabilities to form and maintain a strong glue bond and are comparable to normal glulam. (Appendix E)


963 kg
breaking point:
963kg/16,6MPa


<10% delamination

A study from 2018 investigated the possibilities of using secondary (reclaimed) timber to produce Cross Laminated Secondary Timber (CLST). The research was based on testing the mechanical properties of CLST and CLT, comparing them, and concluding on the result and possibility for use. The timber used for CLST production was gathered from a London-based reuse enterprise that sells reclaimed material from demolition sites. (Rose, C. M, 2018)

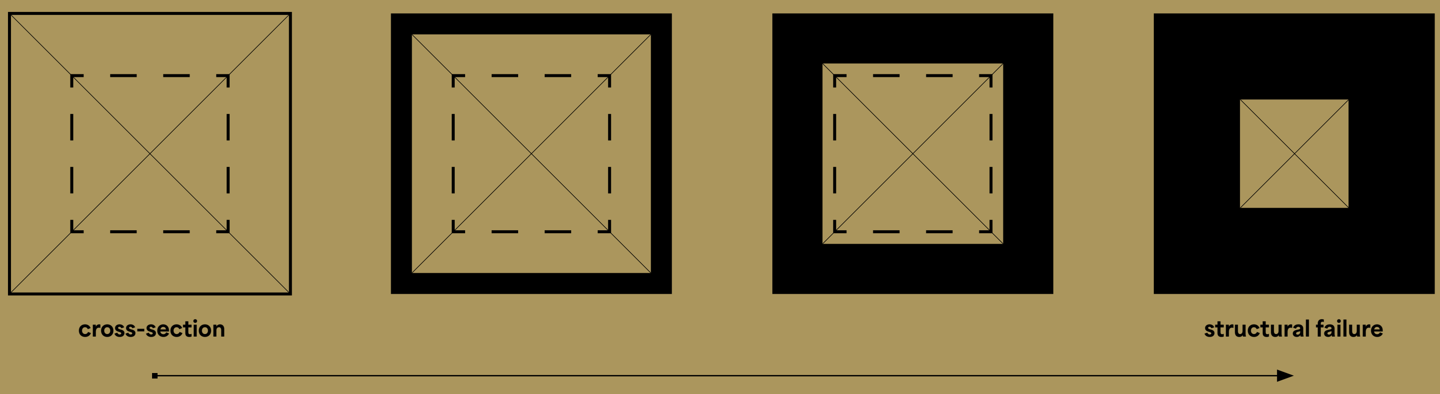
reclaimed timber tomorrow: clst

Before producing and testing CLST, different considerations regarding damage, aging, and load history were addressed. The researchers argue that timber used in structural systems largely is protected from biological degradation as the moisture level should be below 20%. If timber is well-ventilated, sheltered from the weather, and able to get rid of moisture, only a slight reduction in mechanical properties is expected over time. They even mention that timber might benefit from the increased cellulose crystallization taking place as the timber ages naturally, possibly contributing to increased density, hardness, stability, tensile strength, and modulus of elasticity. This is however uncertain and results on the subject differ. The duration of load applied to timber elements causes them to deform slightly. While overloaded parts can cause degradation of the timbers, testing indicates that bending of strength and modulus of elasticity appears to be unaffected by aging and previous load history.
(Rose, C. M, 2018)

The first step of their process for making CLST revolved around visual grading, mapping defects such as knots and holes made by nails, screws, or bolts. The defects affected the timber's mechanical properties based on the size and placement of the timber element. Their results showed that small defects like nails and screw holes would degrade the modulus of elasticity of CLST in either compression or bending by 6% compared to a configuration without flaws. The results furthermore showed 21% degradation caused by large defects which concludes that a single large defect like a bolt hole would have a greater impact than many small holes and defects. (Rose, C. M, 2018)

The laboratory test conducted at University College London showed no significant differences in compression strength between CLST and CLT. The finite element modeling (FEM) test suggested that minor defects in the reclaimed timber only have a small effect on the CLST panels' stiffness in compression and bending. Utilizing both new and reclaimed timber to produce CLT was found to be a valid possibility as it would reduce the amount of used new material only showing minor effects in regard to compression strength. The research is regarded as a pilot investigation into utilizing reclaimed timber to produce mass timber products. More testing is needed to achieve a greater understanding of the characteristic properties of both reclaimed elements and CLST.
(Rose, C. M, 2018)

This research concluded by stating the possibilities of using reclaimed wood for mass timber production even though their sample size was limited. The research results show an overall minor decrease in mechanical properties especially in bending. The research also documented the alterations to the timber elements' mechanical properties considering timber durability, the aging process, and defects. Utilizing reclaimed timber for mass timber products seems promising as it would not only cover for some of the individual defects observed in the reclaimed timber but also enable larger structures as mass timber elements are stronger and considered to be one element when joined by lamination.



Ill. 37. diagram of cross-section reduction by burning over time

fire

Fire resistance is important in all aspects of the built environment and it's especially important when dimensioning and designing timber structures. The structural system of any building is expected to maintain its load-bearing capabilities for a certain amount of time, depending on the building's height and application category. A structure is supposed to maintain its load-bearing capabilities long enough for the building to be evacuated. The estimated burn rate of glulam is 0,7mm/min (Jensen, B.C, 2022) The burn of a glulam element is relatively safe and predictable which is seen as an advantage.

Whilst a lot is known about burn rates, smoke emissions, and general safety measures when designing buildings with new timber. A lot of uncertainty is tied into the fire resistance of reclaimed timber, as it has not been put to the test yet. A recent and yet unpublished study worked on by UPCYCLING ORANGERI, DBI (Dansk Brand- og Sikringsteknisk Institut), AAU (Aalborg Universitet), and DTU (Danmarks Tekniske Universitet) have recently conducted a fire exposure test on reclaimed timber elements over a hundred years old.

Based on this a structure designed with reclaimed timber would have a comparable fire resistance to a structure made of new timber. We can because of this assume a similar burn rate for both reclaimed timber and glulam elements made of reclaimed timber.

"The test results show a comparable burn rate for reclaimed timber, compared to values from EuroCode used to dimension load-bearing timber constructions. The tests point to the fact that it is possible to use reclaimed timber in projects with requirements to the structural fire resistance." - DTU (Red.)

indutrializing the process

When the disassembly process has been concluded and materials suited for reclamation have been separated, all elements are to be thoroughly analyzed before application in a new structure or project. This process should result in a strength grading comparable to the C strength class. All timber products used in construction have a strength grade based on the timber's capabilities. A central issue that faces and complicates the usage of reclaimed timber is based on the uncertainty associated with its strength and condition. Internal damage caused by insect bites and rot can be hard to detect from a visual external grading whilst it could have a crucial impact on an element deeming it unfit for reclamation. As no structural capabilities can be guaranteed all elements should undergo analysis.

Timber grading has in recent years seen graduate industrialization, especially in regard to large-scale mass timber manufacturers and sawmills. Grading machines used in industrial settings have the capability to analyze several meters of timber every minute with incredible precision. The equipment used for analysis is seen as a way of achieving an in-depth impression of the reclaimed timber´s structural capabilities externally and internally without destroying or damaging the elements.

The GoldenEye series produced by MicroTec is an example of analytical equipment utilized in timber production. The multi-sensor quality scanners are designed to evaluate and analyze timber elements with the usage of lasers, x-ray, computed tomography, and cameras (MiroTec). The machines are able to distinguish and locate knots, rot, insect bites, holes, and other defects and conclusively map said defects alongside element weight and annual rings. It's not unlikely that deviating structural capabilities and strength are observed through the length of the element and that elements consist of strong and weak parts.

The results gathered by the non-destructive timber grading raise the question of how the reclaimed timber elements should be processed moving forward. There are a range of different ways to address the individual element based on the results. (Goldeneye, 2023)

/the lowest strength

The collective strength of an element is reduced to the lowest observed grade. Even though a majority of the element might be stronger. This option is considered to be the safe option and it's also the option that's used today in the timber industry when grading timber elements and boards. This approach is a quite simple way of guaranteeing an element's strength without additional processing, cutting, or finger jointing necessary.

/divide parts and finger joining

If the analysis shows varying areas with different strength grades the element can be cut into smaller parts and joined together with finger joints. Whilst this additional process will produce the best possible element made up of equally strong parts it also prolongs the processing time and requires precise cuts and a good jointing technique.

/removing the weakest part

If an element is analyzed to have a weak part or area, said part can optionally be cut out and the element can then be finger-joined back together. This method would increase the overall strength of the element whilst shortening the length. This approach will in turn also require extra processing time but comparably less than if the element is divided more times.

The different options require either more or less additional processing of the analyzed elements. The approach used moving forward is "the lowest strength option" as it requires the least amount of additional processes. By always labeling the elements based on their weakest point is a certain strength guaranteed.

The analysis process concludes with a strength grade assigned to each element based on the lowest strength identified. The correlation between these parameters is to be based on and compared with the acknowledged grades assigned to new timber. The results determine each element's capabilities and streamline the sorting process separating the analyzed elements into three categories.

/timber

Elements in the timber category have structural capabilities suitable for application in load-bearing structures either on their own or as feedstock for glulam productions. Elements categorized as timber have little to no visual damage and no internal defects. Elements in this category have a strength grade based on analysis of above C16 and a visual grading of G4 - 1 or better.

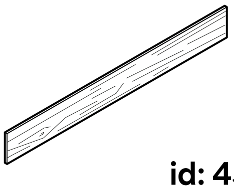
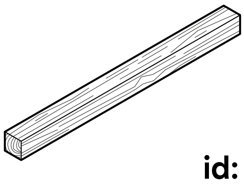
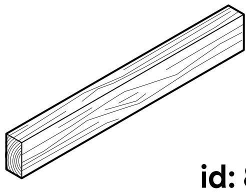
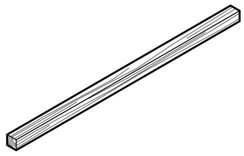
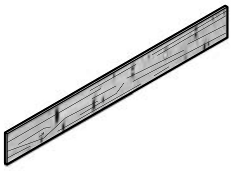
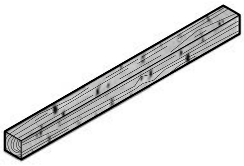
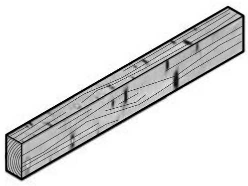
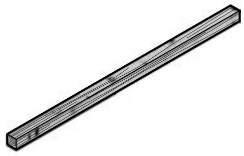
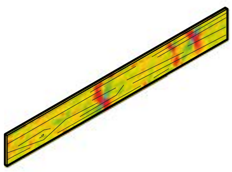
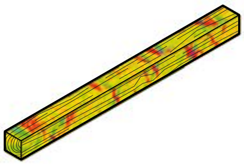
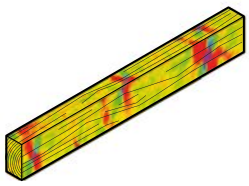
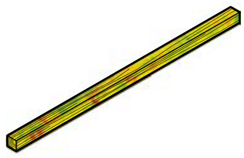
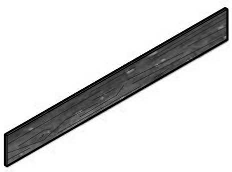
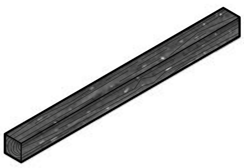
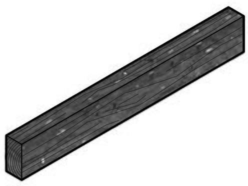
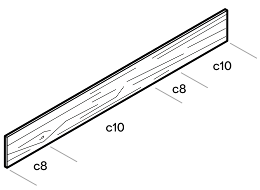
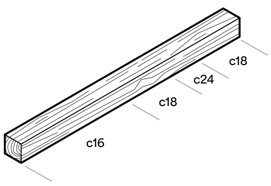
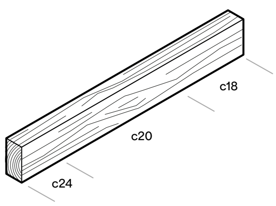
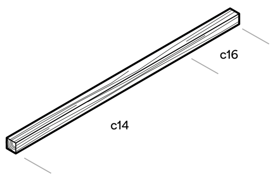
/wood

Elements in the category are labeled as wood if they have no reliable structural capabilities but are still applicable in non-load-bearing parts of construction, for example as a facade material. Elements in this category have a strength grade below C16 and a visual grade G4 - 2 and G4 - 3

/waste

Elements in this category are initially considered unsuited for any structural or non-load-bearing usage. Elements that through analysis indicate a high degree of either internal or external damage are considered waste and should be discarded properly. Elements in this category have no relevant or reliable strength grading and a visual grade of G4 - 4.

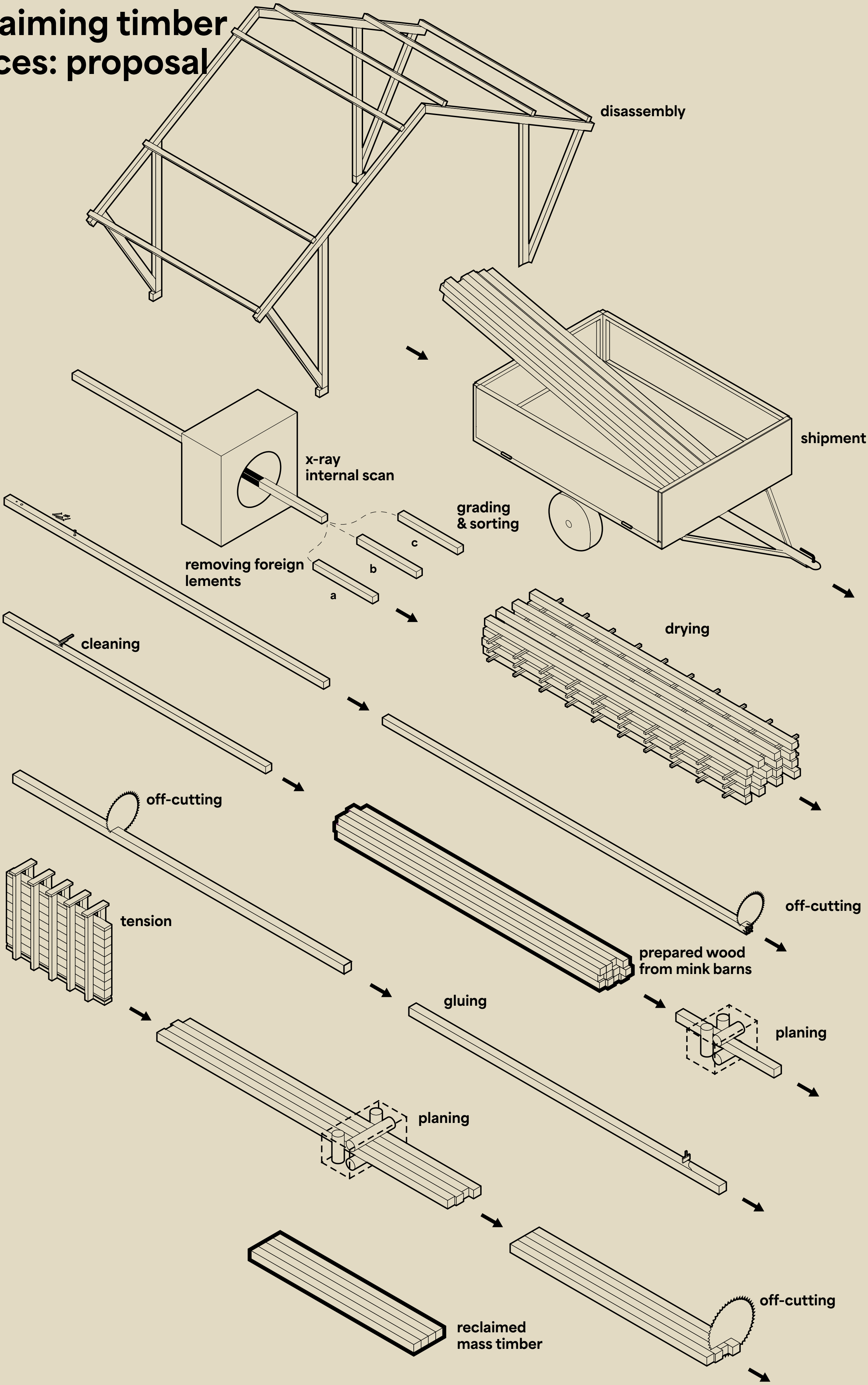
Ill. 38. table of data management of reclaimed timber

element	 id: 45	 id: 71	 id: 84	 id: 25
cross-section	20 x 120 mm	70 x 70 mm	75 x 150 mm	45 x 45 mm
length	2500 mm	4000 mm	3000 mm	2000 mm
weight	240 kg/m3	453 kg/m3	423 kg/m3	402 kg/m3
moisture	29 %	13 %	17 %	19 %
knot - placement				
3d-scan analysis				
defects (resin pockets, insect bites)				
estimated strength graded				
visual grade	g4 - 4	g4 - 1	g4 - 1	g4 - 3
strength	c8	c16	c18	c14
category	waste	timber	timber	wood

reclaiming timber process

The proposed process for producing glue laminated timber with reclaimed material as feedstock adds additional phases. The proposed process starts with disassembling a mink barn and in the process gathering the timber. The elements are then passed through analytical equipment which locates and registers defects like knots, resin pockets, holes, insect bites, and most importantly the timber's internal condition. The analytical results form the basis for sorting the elements into three categories. A and B-rated elements are based on their visually assigned strength grade. A-rated elements are to be used in glulam production and B-rated elements are set aside for usage as facade material or applications requiring lower load-bearing capabilities. In the process, C-rated elements are discarded due to weakness and significant defects that deem them unviable for structural and non-loadbearing use. The timber is then dried and sheltered for a certain amount of time to reduce the timber's moisture contents to around 12% and bring the timber closer to room temperature. Both the moisture level and surface temperature of the timber have an impact on the strength of the glue bond formed when laminated. Identified foreign objects like nails and clips are removed before the elements are trimmed into a desired length based on which glulam element is to be produced. The last step in the additional process is cleaning, the elements are brushed with a stiff metal brush to remove the outer layer of algae and dirt and potentially reveal rotten/dead parts of the elements. The product is reclaimed timber with an assigned strength grade prepared for being processed into structural glulam elements. The remaining process has been described in detail earlier and consists of first planing the timber, trimming the elements, applying adhesive material, pressing the laminated elements, trimming the ends, and a last round of planing. The finished product is a glulam element produced with reclaimed material.

reclaiming timber proces: proposal



Ill. 39. diagram of a proposal for reclaiming timber process

DESIGN WITH RECLAIMED TIMBER

The design process was initiated with the reclaimed timber at its center. Knowledge gathered from previous studies of the material impacted the design process to a great extent dictating the possibilities leading toward the final design. The first part of the process is built on testing the material in a structural setting, applying loads, and working with different structural principles. The process prioritizes material properties, shape, size, and structural properties above imposing form. The reclaimed timber is in the driver seat and the design is a result of material possibilities.

/computational design setup

The analytical phase of the design process was centered around utilizing the capabilities of computational design as a way of obtaining results and generating potential structures that would accommodate the reclaimed timber and its potential.

The setup used is grounded in the computer-assisted design (CAD) tool Rhino. Besides the fundamental modeling components, it also has a visual programming component incorporated called Grasshopper. Grasshopper as a programming tool has the ability to create and manipulate objects in Rhino based on a wide range of components. Designing a project by coding won't necessarily result in a single design but may produce a wide array of potential designs as the parameters for the code consist of changeable values.

In addition to utilizing Rhino and Grasshopper, two components are introduced in the coding procedure: Karamba and Galapagos. Karamba is a parametric engineering tool based on Finite Element Analysis (FEA). Axial forces, displacement, and utilization factors are calculated and shown based on the material properties, cross sections, and the loads applied to a design. Karamba is a plug-in for Grasshopper and is used to cover the engineering and structural part of design proposals.

The last component utilized is a single objective evolutionary solver called Galapagos. This component is an underlying component found in Grasshopper. Galapagos searches for local optimums in either maximizing or minimizing a user-defined "fitness" by changing a select number of parametric changeable values. It can for example be used to minimize displacement in a structure by giving it an array of sliders to choose "solutions" from continuously changing values and evaluating the results to find design options with gradually less displacement.

Working with a computational design setup brings additional challenges in that a new language is introduced in the form of visual coding but the objective of the process remains, to search for a good solution based on structural and architectural qualities.

RESEARCH QUESTION:

"What structural systems are feasible to construct out of reclaimed timber from the mink farms?"

structural investigations

The reclaimed timber is expected to be more unreliable in regard to strength. The structural aspect of the project should therefore seek to correspond with the timbers' strongest sides.

Timber, whether reclaimed or not, is an anisotropic material meaning its strength varies depending on the direction of the load applied. (Sandaker, 2011) Contrary to anisotropic materials, isotropic materials like metal have the same properties for every load direction. The direction used in regard to timber is either perpendicular or orthogonal to the grain. Timber is always the strongest parallel to the grain direction.

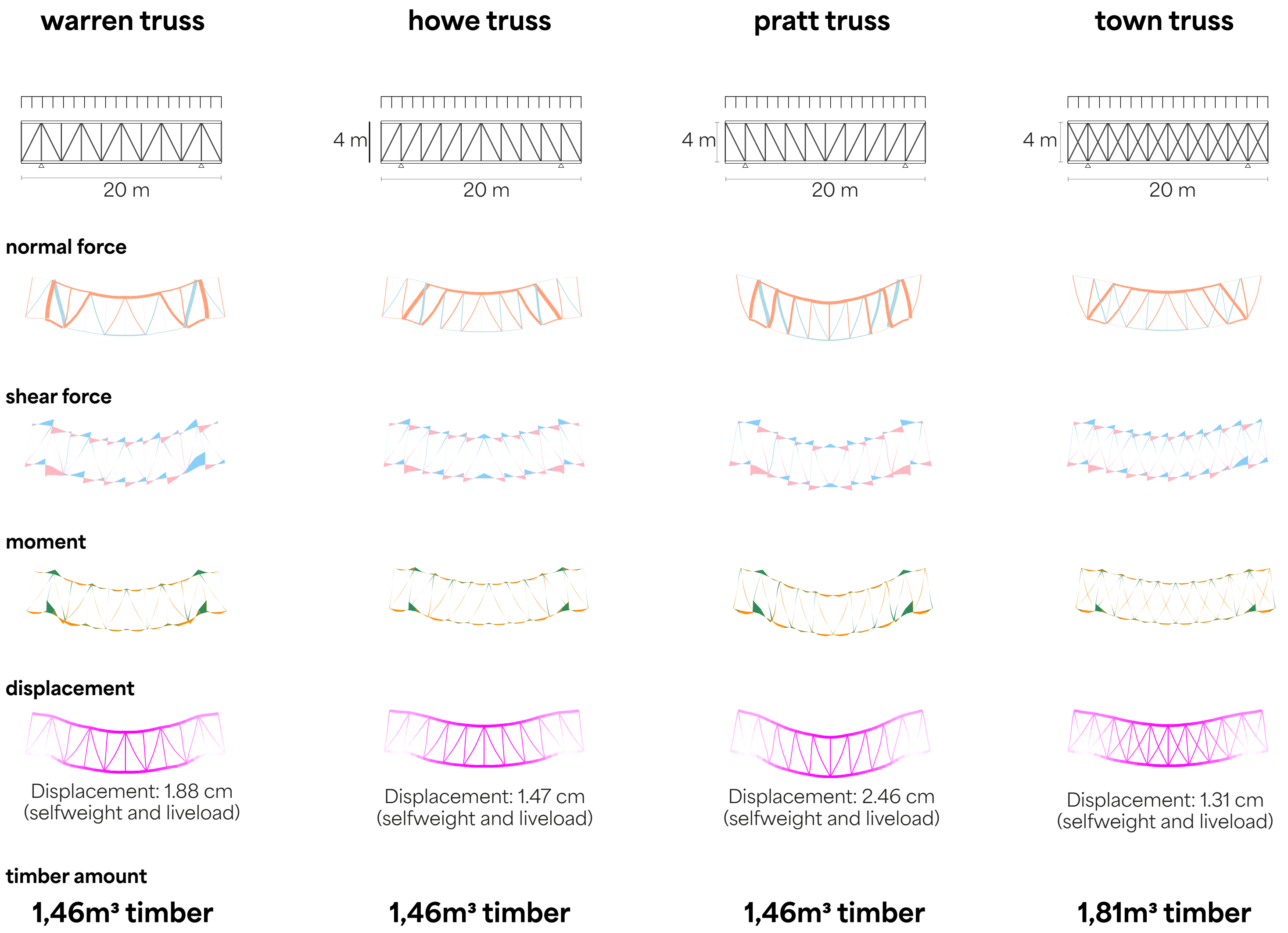
One of the main issues found in regards to utilizing timber in general is centered around loads applied orthogonal to the grain as in the case of beams for floor constructions or flat roofs. A possible way of working around this is by utilizing a truss. A truss is defined as a structure that's made of linear elements arranged to form triangles. The triangular shapes effectively resist overall deformations and loads are distributed between the elements residing in the truss structure. The elements in a truss structure either experience compression or tension. (Sandaker, 2011)

To investigate how different configurations of trusses react to loads, deform and distribute loads, four acknowledged truss designs were modeled and tested in Karamba. The trusses were dimensioned to span 20 meters with a height of 4 meters and a fixed joint at each end.

The normal forces depicted across the four different trusses are displayed in orange for elements in compression and blue

flat truss designs:

Ill. 40. table of flat truss design structural investigations



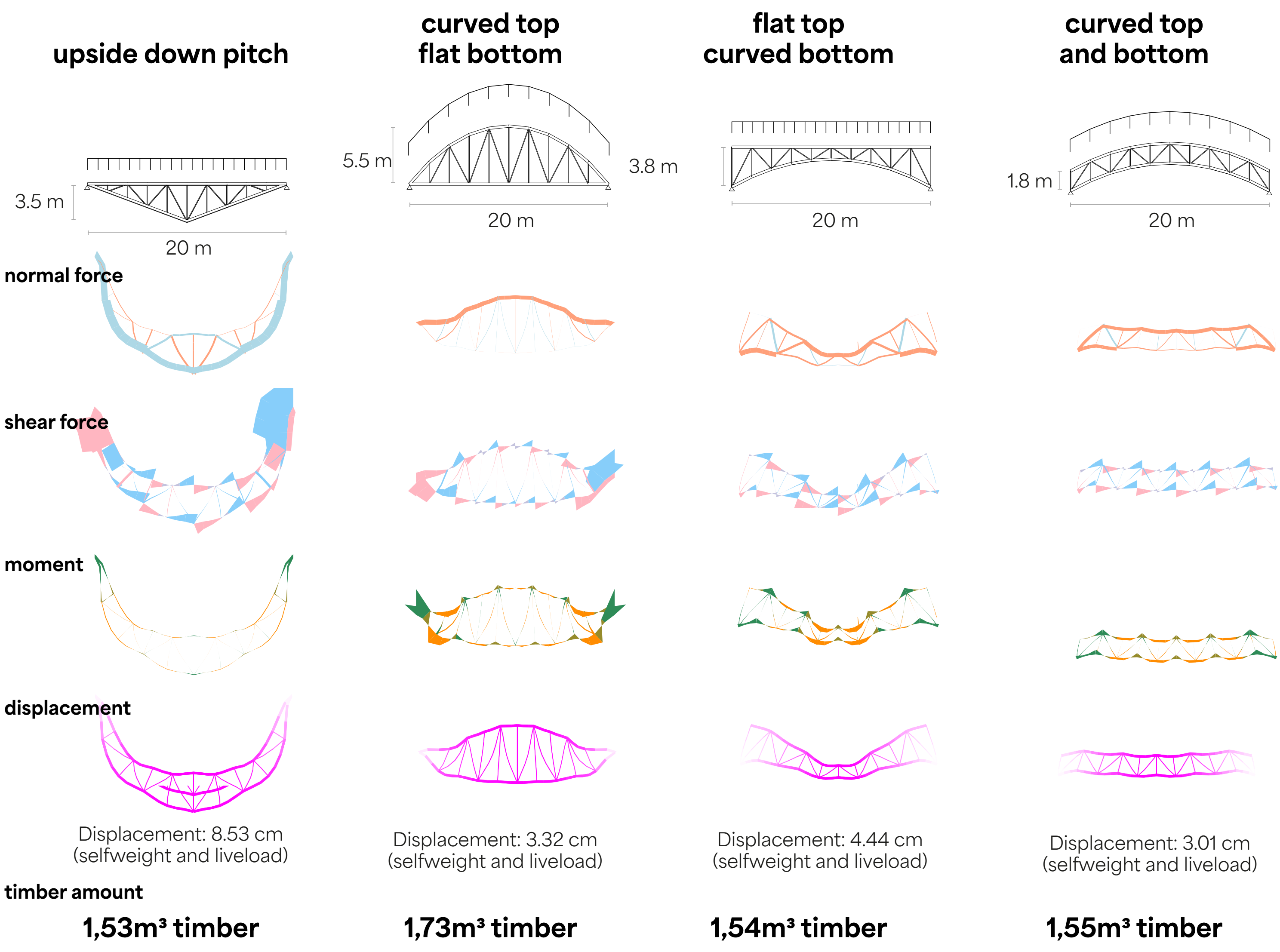
for elements in tension. Having more elements as in the case of the Town Truss reduces the overall force experienced by the individual element.
In regards to displacement, the Howe- and Town Truss showed the least. The reason for this is either the extensive use of the material in the case of the Town Truss or the orientation of the center truss elements, facing towards the points of support.
The truss configuration is by no means without effect on the performance of the truss. It's however difficult from this study to conclude which truss is "the best" as it's affected by other aspects like the overall shape, support points, and dimensions.

The structural principle of a truss is not limited to a single shape. The structural properties of a truss are present as long as the fundamental principles of linear elements and triangles are present. This investigation was aimed at addressing different truss shapes and comparing their performance in regard to loads and displacement. The four trusses designed for this investigation were identical in regard to cross-section and material. The only deviating factor was the overall shape.

The results showed a clear benefit from curving both the bottom and top elements. The results furthermore indicated that the amount of material used is of less importance compared to having a "better" shape as more material is not necessarily an advantage. The truss with both a curved top and bottom was shaped based on a catenary curve which should expose a majority of the elements to compression. The results confirmed this as a majority of the elements shown are orange. The study concluded in moving forward with a curved truss design preferably curved similar to a catenary curve or an arch to have a majority of elements in compression and loads directed parallel to the grain direction.

alternative truss designs:

Ill. 41. table of alternative truss designs structural investigations



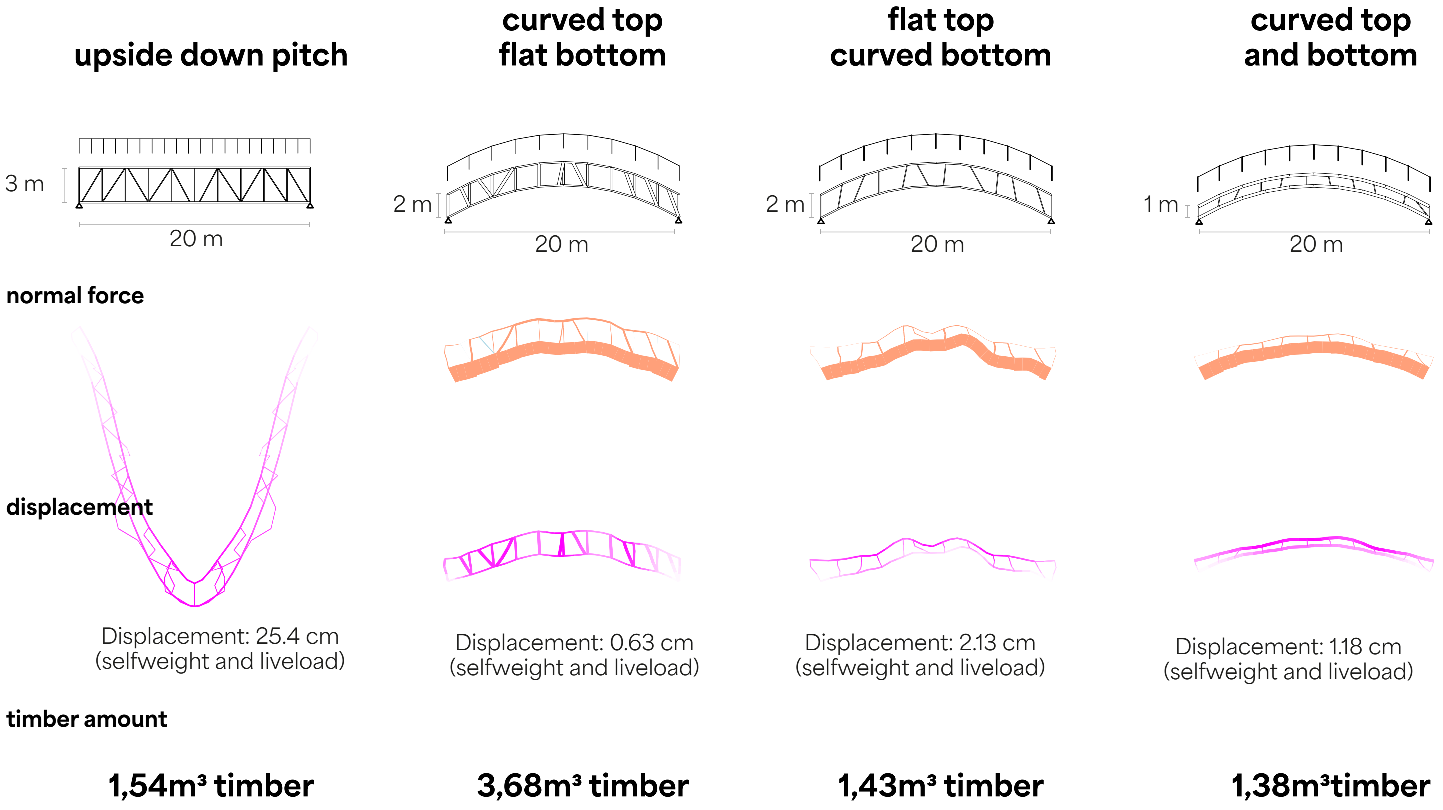
The trusses investigated up until this point have been based on acknowledged trusses designed in the mid-nineteen hundreds. The next investigation was conducted utilizing the evolutionary solver Galapagos. A component that can optimize one objective based on a select number of parameters. The investigation was centered around the placement of the middle elements in the truss, their angle, and orientation. Galapagos was tasked with minimizing the deformation based on moving the end points of each middle element.

To illustrate the effectiveness of curving both the top and bottom elements, a straight truss was included in this study. The results depicted the straight truss as the worst having much higher displacement than the three curved trusses. The curved trusses showed less displacement if more material is added and if the length of the middle elements was reduced. The Galapagos study did not result in any big findings in regards to the placement of the middle elements as their results were based on the amount of material used and height.
The curved shape had by this point been established as a good option for having a structure based on compression. The next investigation sought to define whether the entire structure should be curved or whether there would be a structural benefit in having straight columns towards the ground. The frames were models with similar cross-sections and materials. The loads applied to the structures are the same but are distributed differently.
The results indicated a comparatively large displacement and normal force in the square frame and less in the two with a curved top. The frame with a curved top and straight columns at the bottom showed a large moment where the curved and straight parts were joined, indicating a difficult load transfer. The preferable option of the three is the full curved frame which has a low moment and displacement whilst having a uniform load distribution.

Two points are concluded on behalf of the structural investigation. One is that the structural principle behind a truss is interesting in its way of configuring relatively short linear elements in a triangular shape to divide loads and having elements in either tension or compression. This is seen as an advantage as the reclaimed timber elements are relatively short.
Another point that stems from the structural investigation is centered around curves and curvature. Curving the truss with inspiration from catenary curves and arches was found to be an advantage in that more elements experience compression. The curvature furthermore directs the compression loads towards the supports. Lastly, the structure's curvature should not be interrupted by adding vertical columns as this results in a difficult load transfer adding unwanted moments to the construction.

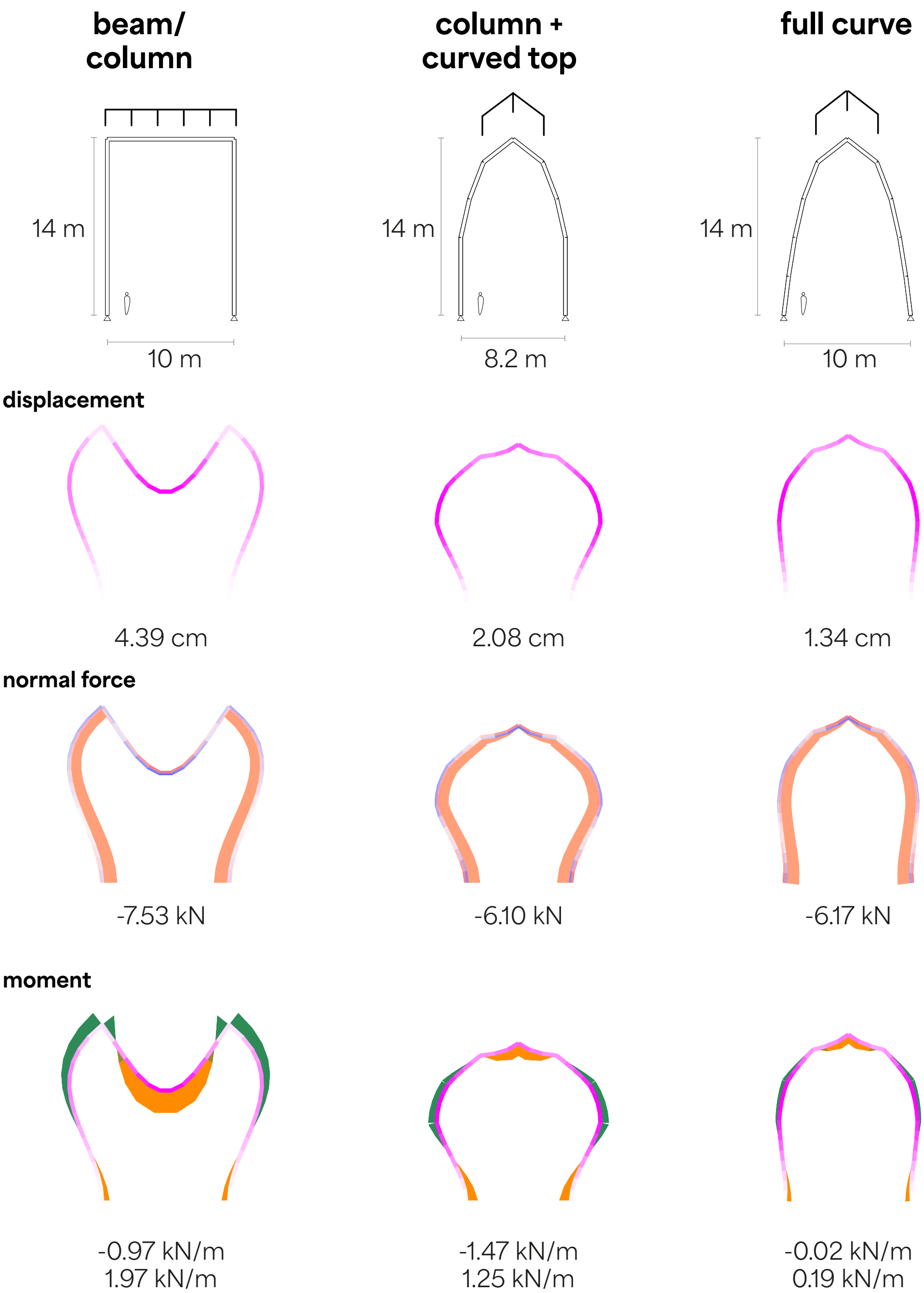
Ill. 42. table of an evolutionary study of minimizing displacement

minimize displacement: evolutionary study (galapagos)



frame shape and forces

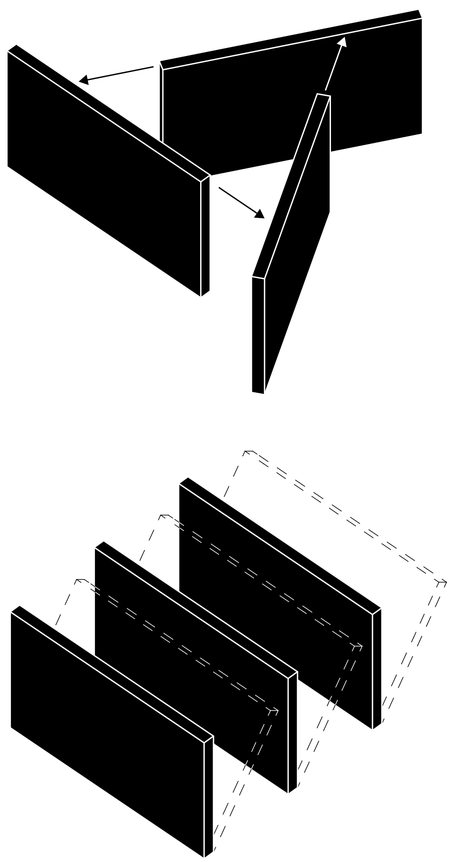
Ill. 43. table of frame shapes and their forces



/stability

Having only investigated structural principles on a two-dimensional frame, stability is yet to be considered. Stability is or rather can be created when the structure is dimensioned in three dimensions. A simple way of creating stability is by positioning the frames so that they are placed at an angle in relation to each other. The resulting shape is simple but strong as it only relies on the frame and no additional objects are necessary. If needed, elements connecting the frames can be added for additional stability and facade material. Stability is achieved when a structure has sufficient reactions to external loads like wind, snow, and so on. A common denominator of these loads is their effects in the three dimensions.

Ill. 44. stability diagrams



FACADE

ensuring longevity

This project where reclaiming timbers is seen as a solution to keep CO2 sequestered in the buildings longer and to supplement the current timber industry in order to meet tomorrow's need for material consumption, slowing, narrowing, and closing material flows are key elements.

By analyzing and reusing the building material from the mink farms the material flow has been closed. We will slow down the material flow with life-prolonging design solutions (Usto et al., 2022). Considerations towards moisture control and water protection are essential to ensure the longevity of the wooden structure. With an open structure, the airflow will naturally regulate the humidity of the wood, as long as water can be led away from the structure. The development of a weather barrier based on utilizing the non-structural stock of wood from the mink farms that is durable and long-lasting can be a challenge considering woods' tendency to decay and rot when the moisture content becomes too high.

shingles case: little shelter

architect: department of architecture
construction: 2019
structural system: concrete
facade: wood & polycarbonate shingles

Ill. 45. little shetler hotel facade
© Little Shelter Hotel

Little Shelter Hotel is located in Chiang Mai, Thailand, where the old cityscape is defined by vernacular architecture. Characterized by wooden structures with shingle-pitched roofs, the building builds upon the same principles. A gradient from polycarbonate shingles to wooden shingles through the facade and wooden shingles on the roof, the specific shingle principle roots in a centuries-old building tradition where small units of wood shingles are laid out like fish scales to become a watertight plane.
The shingles are placed in shifted overlapping rows, connected only by plastic nails to thin laths of translucent carbonate. The overlapping and gradually changing material of shingles create a watertight layer while utilizing the translucent properties where necessary. (Caballero, 2019)(Angelopoulou, 2019)

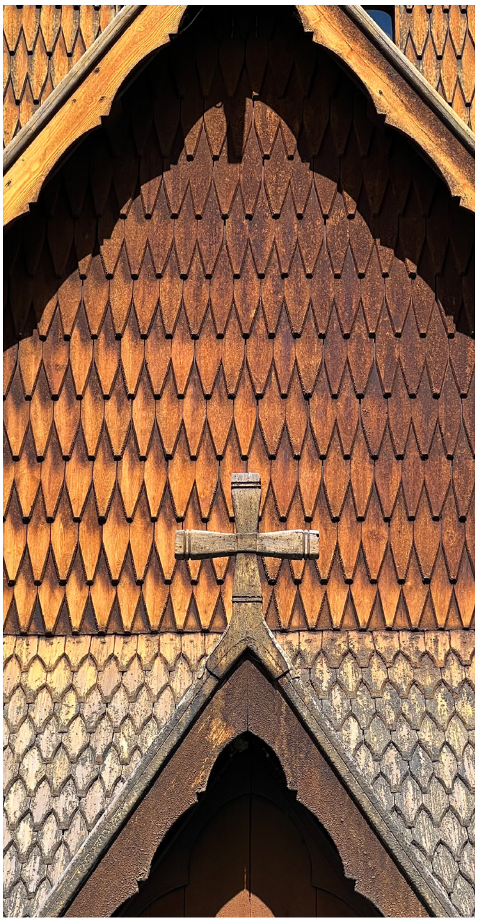
Ill. 46. little shetler hotel interior
© Little Shelter Hotel

shingles
case:
heddal stavkirke

architect: unknown
construction: <1200
structural system: stave timber
facade: timber and wooden shingles

Ill. 47. heddal stavkirke zoom
Ill. 48. heddal stavkirke
Ill. 49. heddal stavkirke shingles

Heddal Stavkirke is the largest stave church in Norway and is thought to be built in the 12th century. It is constructed in the method of timber staves, where load-bearing wooden poles sit on a foundation of stone, with wooden shingles as roofing - all are painted with char to protect the timber and wood, leaving it standing for almost 900 years.
Wooden shingle roofing is based on the principle of shifting rows of overlapping shingles attached to wooden laths. The shingles are treated with char to withstand rainwater and prevent the wood from deteriorating. The shingles have a pointed end to direct the water downwards and let it fall onto the underlying shingle. (Skrudland, 2021)
Understanding the principle of laying wooden shingles, it is important to treat the wood to withstand rain and prevent rot.



materials from minkbarns

As the facade is non-load bearing the material properties differ from the needs of the load-bearing frames. Off-cuts, smaller sizes, and structurally compromised materials can be used. The requirements are that with the right treatment, it can withstand exposure to the elements and that its durability can be compared to alternative roofing solutions.
Identifying the potential for utilizing wood as a facade material, and that shingles create a watertight layer through the use of many smaller objects, opens the possibility for using wood from mink barns that otherwise could not be used structurally. In mink barns wooden planks are used above the cages for having notes on - the planks measure 20x120mm, which are favorable measurements for converting them into shingles.

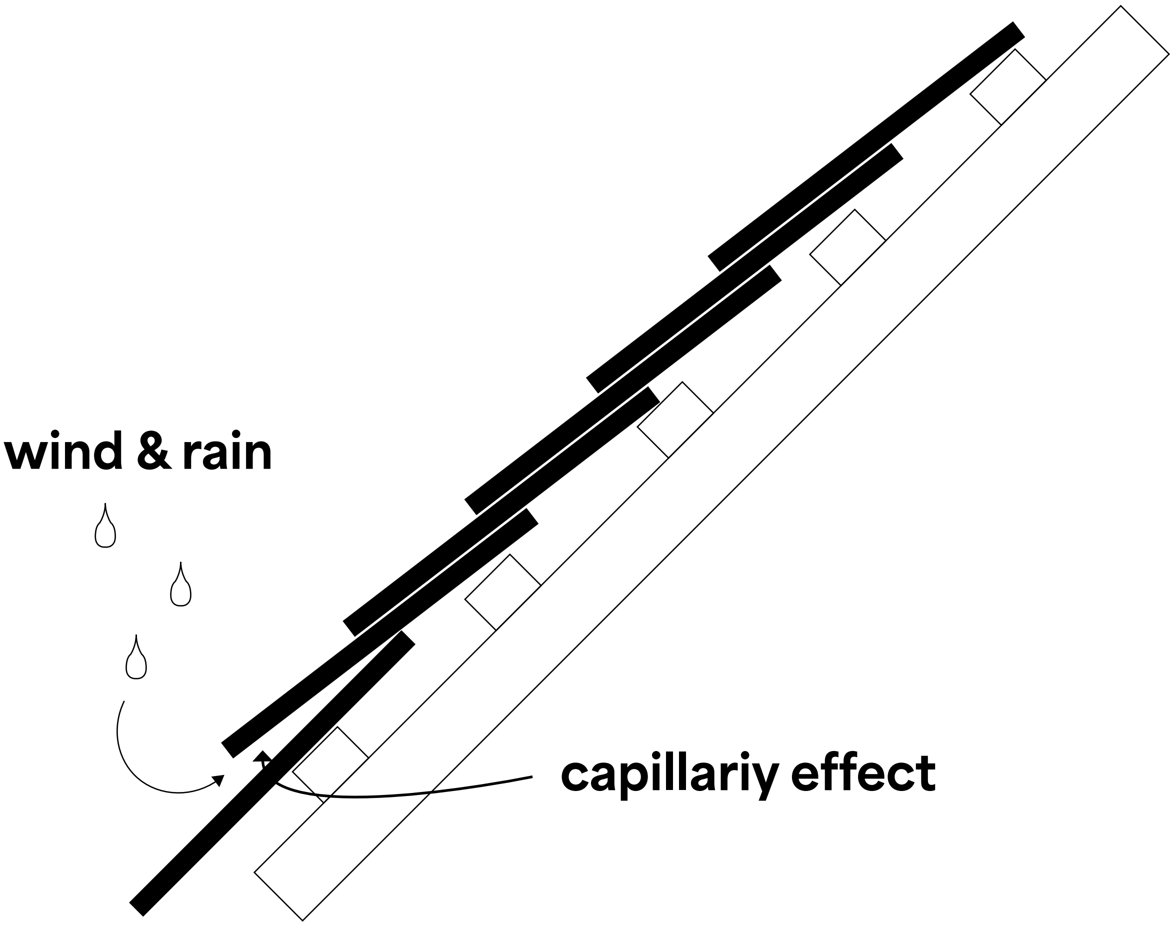
Ill. 50. note-planks in mink barn
Ill. 51. stack of note-planks

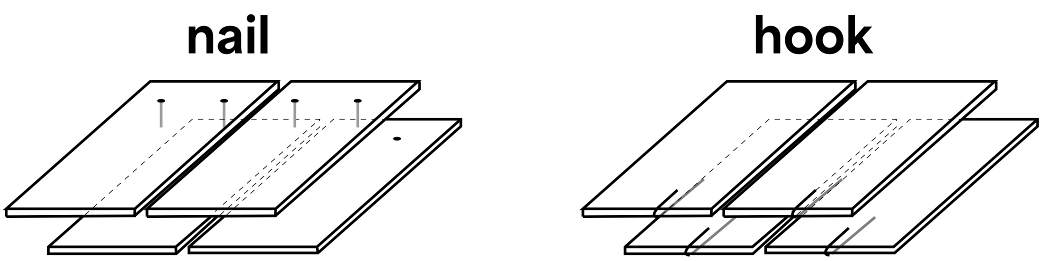
shingles

Wood shingles are one of the oldest known natural roof coverings used on homes and churches. Shingles are thin, profiled slats made of coniferous and deciduous wood types and can have varying shapes and sizes, though usually rectangular or trapezoid-shaped. Shingles are laid in shifted overlapping rows on a simple supporting bed (typically a timber structure) that creates a watertight surface.
Shingles must ensure waterproofing, a quality that depends on the wood type, the quality of it, and installation parameters such as the pitch, orientation, roughness, and the overlap of the tiles in order to avoid capillarity. Traditionally, the minimum slope for shingle roofing is 2:12, or 9,46 degrees, whereas for wooden shingles the minimum roof pitch is 1:6, or 45 degrees (Inc., 2021). The roughness of the shingle impacts capillarity, where the rougher it is, the higher the risk of capillarity. Attachment methods are typically by nails or hooks, where the effect of capillarity differs and influences the 'safety zone', or the headlap in shingle placement. The exposed part of the shingle is to be no more than a third of the length of it, where nails always must be covered. Knowing the attachment method, pitch, and the material and its roughness and quality, it is possible to define a shingle pattern. (Friedman, nd.)(Cardenes et al., 2020)
When using wood shingles it is key to protect the surface of the wood, since rotting can significantly increase the failure of watertightness by capillarity. Treatments include using oil, paint, or tar, as seen on the Norwegian stave churches, whereas techniques such as shou-sugi-ban (the charring of the surface of the wood) also provide a protective layer. Wooden shingle roofing can last for more than 30 years, but with proper maintenance, it is able to last much longer. (Cappellazzi, 2020)

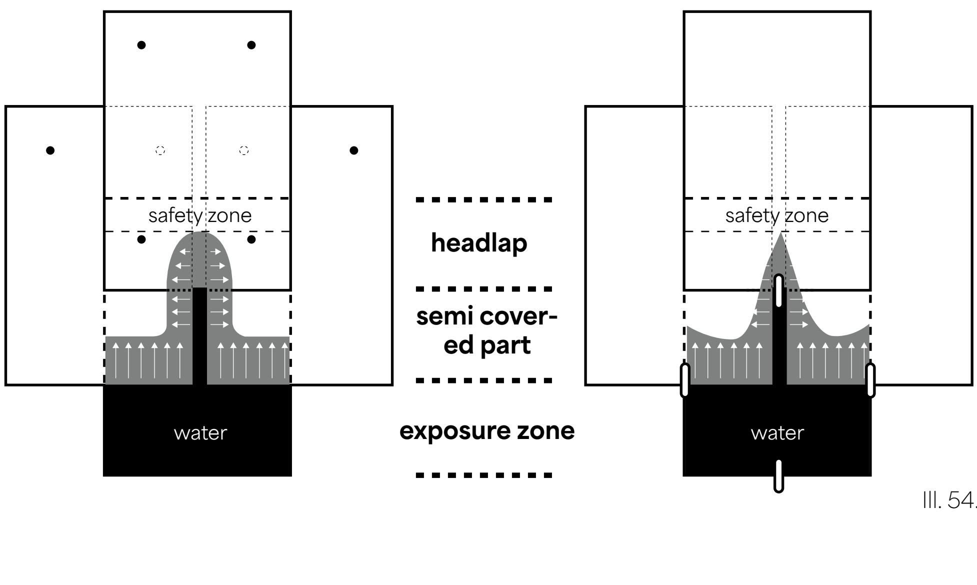
Wooden shingles prove to be a durable and long-lasting roofing and facade solution. It is important to recognize its qualities and disadvantages. Being a natural material that can provide water tightness, it cannot be used at a lower pitch than 45 degrees due to its roughness and susceptibility to absorbance.

Ill. 52. capillary effect diagram



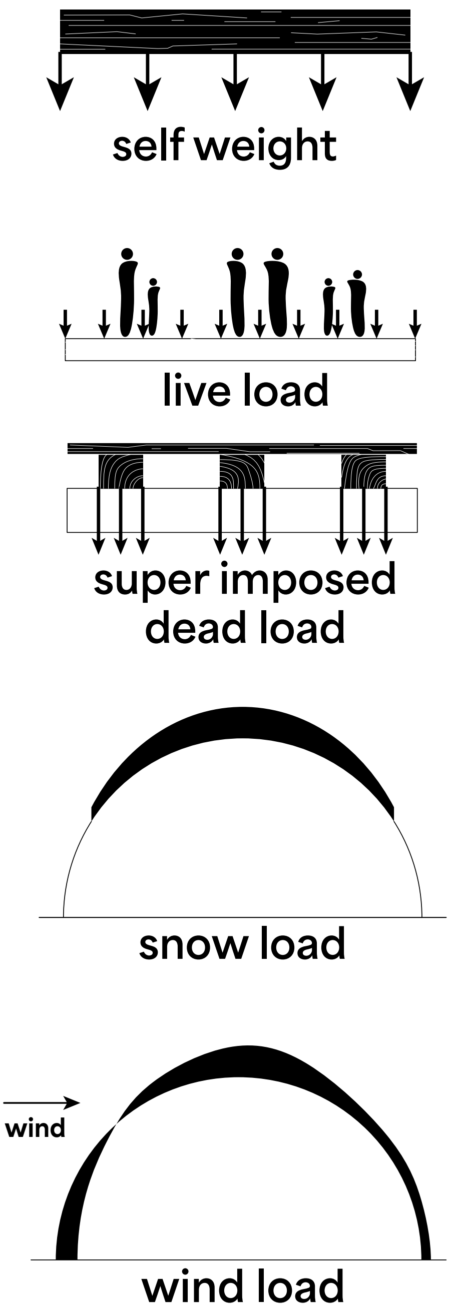


Ill. 53. nail and hook placement



Ill. 54. capillary effect by nail and hook placement

DETAILING OF RECLAIMED TIMBER



Ill. 55. load diagrams

The self-weight of the structure is determined by the weight of the material and the amount of material used. The building utilizes reclaimed timber, a material whose weight deviates from standard timber oftentimes either increased by cellulose crystallization or decreased by insect bites, holes, or rot. The weight used for calculations is 400 kg/m³, corresponding to the mass of regular C16 timber.

Live load is applied when the weight applied varies in time. The calculated load is 2 kN/m² representing people standing next to each other.

The facade applies another load to the structure, what's known as a superimposed dead load. The facade has no structural application but protects the load-bearing construction from natural deterioration caused by wind and rain. The facade from reclaimed timber has been estimated to weigh 30 kg/m². The facade is around 1400 m² in total adding up to 42.000 kg of facade material in total.

The roof/facade angle determines the potential snow load. The snow load is largest towards the top of the structure where the roof angles the smallest at 14 degrees. The calculated snow load is set to 0.8 kN/m² at the top part of the roof until the angle hits 30 degrees, gradually lowering the snow load to where the roof angle is 60 degrees where the snow load no longer is relevant. The building's shape prevents snow from gathering somewhere on the structure asserting more load on an area. (Danske Normregler for SNELAST nd.)

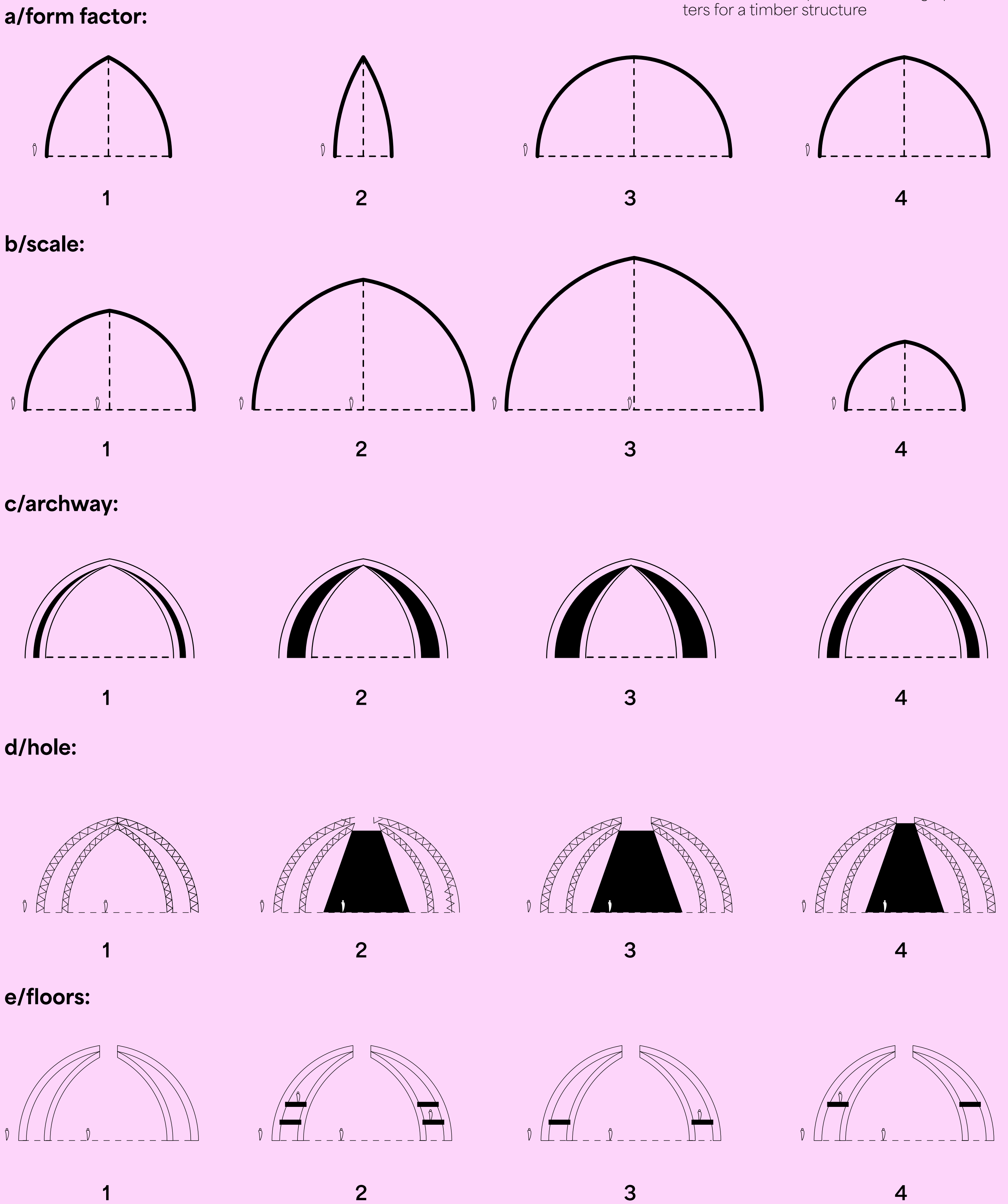
A dome shape has an unusual effect on the wind's behavior around the building and the load caused by it. The area directly hit by the wind experiences pressure whilst the wind is accelerated moving around a dome and inflicting tension of varying degrees on the remaining structure. The areas that experience either pressure or tension are based on wind direction meaning all areas of the facade should be capable of withstanding both pressure and even larger tension. The calculated loads caused by the wind are calculated on the structure being situated in an open landscape with wind speeds reaching 26 m/s.

RESEARCH QUESTIONS:

“What does longevity look like and how is it created?”

“How can wood be utilized as a facade material to ensure longevity for the structure?”

Ill. 56. table of parametric design parameters for a timber structure



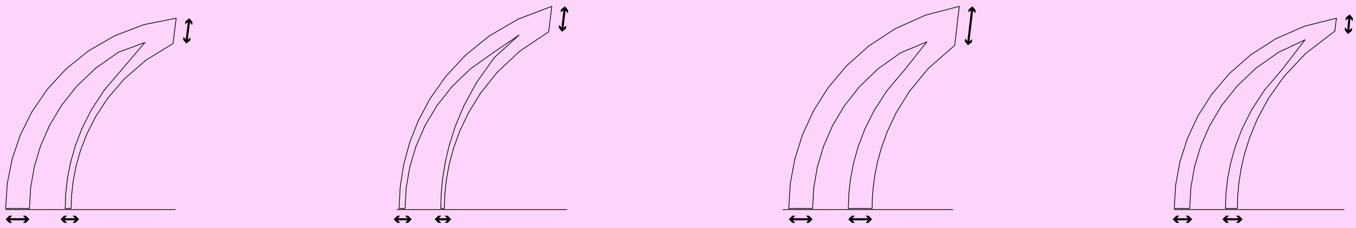
timber structure

The process that constitutes the foundation for the frame design is based on parametric changes made possible by designing a script capable of changing individual aspects of the structure such as shape, truss angle, and the number of elements. The design process that cleared the way for the frame design was based on understanding the impact of alternative options aiming at a design proposal with both architectural and structural qualities. The illustration displaying different options for each parameter is simplified to only four values, the design is based on having several additional values, and the form factor parameter for example contains 12 potential values all resulting in slightly different designs. Design proposals are given an ID (#xxxxxxxxxxx). Each x represents the option chosen from each parameter.

f/beams:

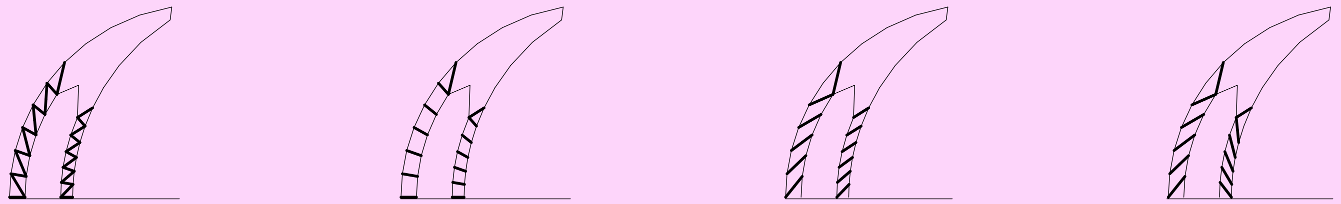
1 2 3 4

g/truss width:



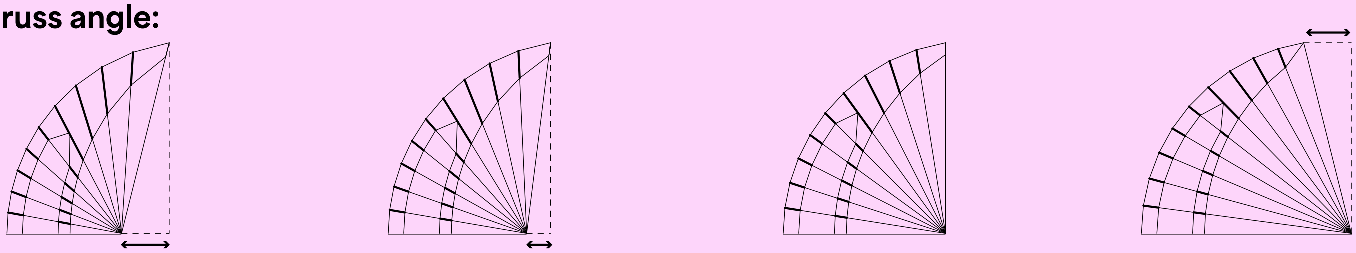
1 2 3 4

h/truss type:



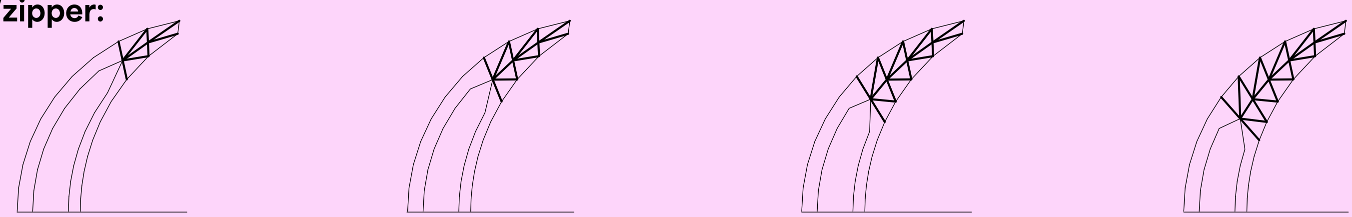
1 2 3 4

i/truss angle:



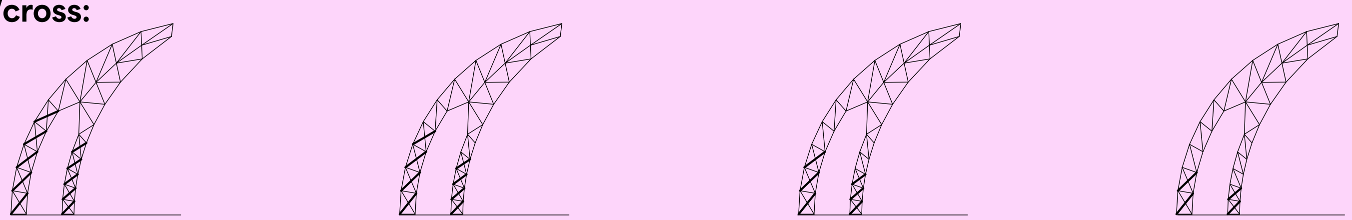
1 2 3 4

j/zipper:



1 2 3 4

k/cross:



1 2 3 4

form factor | archway | floors | truss width | truss angle | cross

#41223341231

scale | hole | beams | truss type | zipper

The first five parameters are based on architectural qualities in regard to shape, space, and scale. Whilst these parameters were mainly aimed at creating a structure with architectural qualities they also impacted the design's structural performance to a large extent, especially the parameter dealing with the structure's shape.

a/form factor

The shape is made from two overlapping circles to ensure curvature. The form factor changes the size and "roundness" of the two circles. A large form factor results in two large circles and an almost perfect half-circle. A pointed arch with similar curvature to a catenary is the result of a small form factor.

b/scale

The scale corresponds to the structure's top point. This parameter is used for a better understanding of the human scale and how the structure would be perceived from a scale-wise point of view.

c/archway

Introducing an inner truss improved the overall structural performance and made way for movement and passage through the archway. This parameter determines how far the inner truss is moved from the outer, resulting in a varying size of an archway. The inner truss is shaped similarly to the outer truss drawing inspiration from a catenary curve.

d/hole

Splitting and moving the frame apart result in some structural complications but make it possible to open the construction up and introduces daylight into the center of the structure. This parameter determines the distance between the split frames.

e/floors

If the archway is large enough, can platforms be introduced making it possible for visitors to explore the structure vertically. This parameter determines based on the archway whether there are introduced platforms to the structure.

The next six parameters are specifically aimed at the inner and outer trusses and their structural build-up. The parameters collectively form all aspects of the truss with reference to the architectural parameters. Whilst the structural parameters are centered around the structural performance they still influence the architectural expression.

f/beams This parameter determines the number of beams in both the outer and inner shell and subsequently determines the number of notes in the trusses. The number of beams and notes is very important for the truss as they impact the element's length and also the truss element's angle. For a truss to be effective it should create triangular shapes that are neither too big as the elements would be stretched and potentially break in columns buckling or too short and the structure would become too dense increasing the weight of the structure.

g/truss width The truss width is defined by three parameters, each parameter can be adjusted individually independent of each other. Two of them determine the width of the inner and outer trusses and the last one determines the width of the top part of the truss. Altering the width of the trusses either increases or lowers the material density. This typically increases or lowers the strength of an area, as areas with a lot of material are stronger but also have a greater self-weight.

h/truss type The truss type refers to the direction of the truss elements. The direction of the middle truss elements can be changed for both the outer and inner truss individually. They can either point towards the center of the structure, point outwards, or be removed. Potential crosses are added later. The direction of the middle elements, the load distribution, and the way loads are transferred through the structure. It furthermore influences the loads that are directed towards the inner or outer shell depending on their direction.

i/truss angle Each truss is made of two long curved lines consisting of the same number of beams and therefore the same number of notes. Corresponding notes are joined with an element, the angle of this element is determined by a moveable point. Changing this parameter moves the point back and forth. The angle is increasingly faced downwards as the point moves towards the truss and becomes more linear as they move away from the trusses.

j/zipper To avoid tough and suboptimal joints towards the top the two trusses merged into one towards the top. This "zipper" principle made the two trusses become one and therefore maintained the structural benefits of the truss. The truss elements in the zipper are though longer and therefore more susceptible to column buckling. The zipper always starts at the top and this parameter determines how many joints it consists of.

k/cross Additional crosses can be added based on this parameter, determining if any, how many crosses to add to existing truss elements. The crosses have the same cross-section as the existing truss elements and serve to add material and therefore strength to the structure by dividing two triangles into four when a cross element is added.

The design process can be by having the ability to control and manage a wide array of sliders shaping the frame. This way of designing accommodates the overlapping discipline that is architectural- and structural design as each parameter's influence on the design proposal can be observed and tested moving towards a desirable design. The number of parameters and their individual changes to the design results in an enormous amount of possible designs. If only the previous 11 sliders with all four options constitute 4.1 million potential designs. While some of them are unrealistic and unrealizable with reclaimed timber they are no matter the fewer options that could be explored. It would be a huge task to sort through all the different possibilities but by utilizing evolutionary solvers and multi-objective solvers could the best designs be selected for further investigation. This process could constitute the basis of a master thesis in and of itself and has not been further investigated in this project. But by analyzing and changing different parameters a range of design possibilities has been selected for evaluation in regards to architectural and structural qualities.

The curved shape and structural principle are constituted core values for designing the frame. Computational design and the ability to alter design solutions based on numeric slider values became important tools in generating different design options for further structural and architectural evaluation. The four designs illustrated have similar structural properties in regard to cross sections and loads. The loads applied to the structures are self-weight and 200kN divided by the number of notes in the outer shell.

#34131234121

This design had a lot of beams in the outer and inner shell, resulting in a dense structure with high timber usage considering its dimensions. The truss density made it almost similar to solid glulam elements. The amount of timber used added unnecessary weight and significantly increased both displacement, axial forces, and bending moment in the construction.

#41223341231

This design proposal increased space in the archway to the point where platforms could be added for additional exploration of the building. The inner and outer truss merges to form a large truss top lowering the deformation significantly. An adequate dimensioned truss ensures low moment and the curved shape distributes the applied loads in almost exclusively compression. This design was based on these findings and chosen to set the direction for further work.

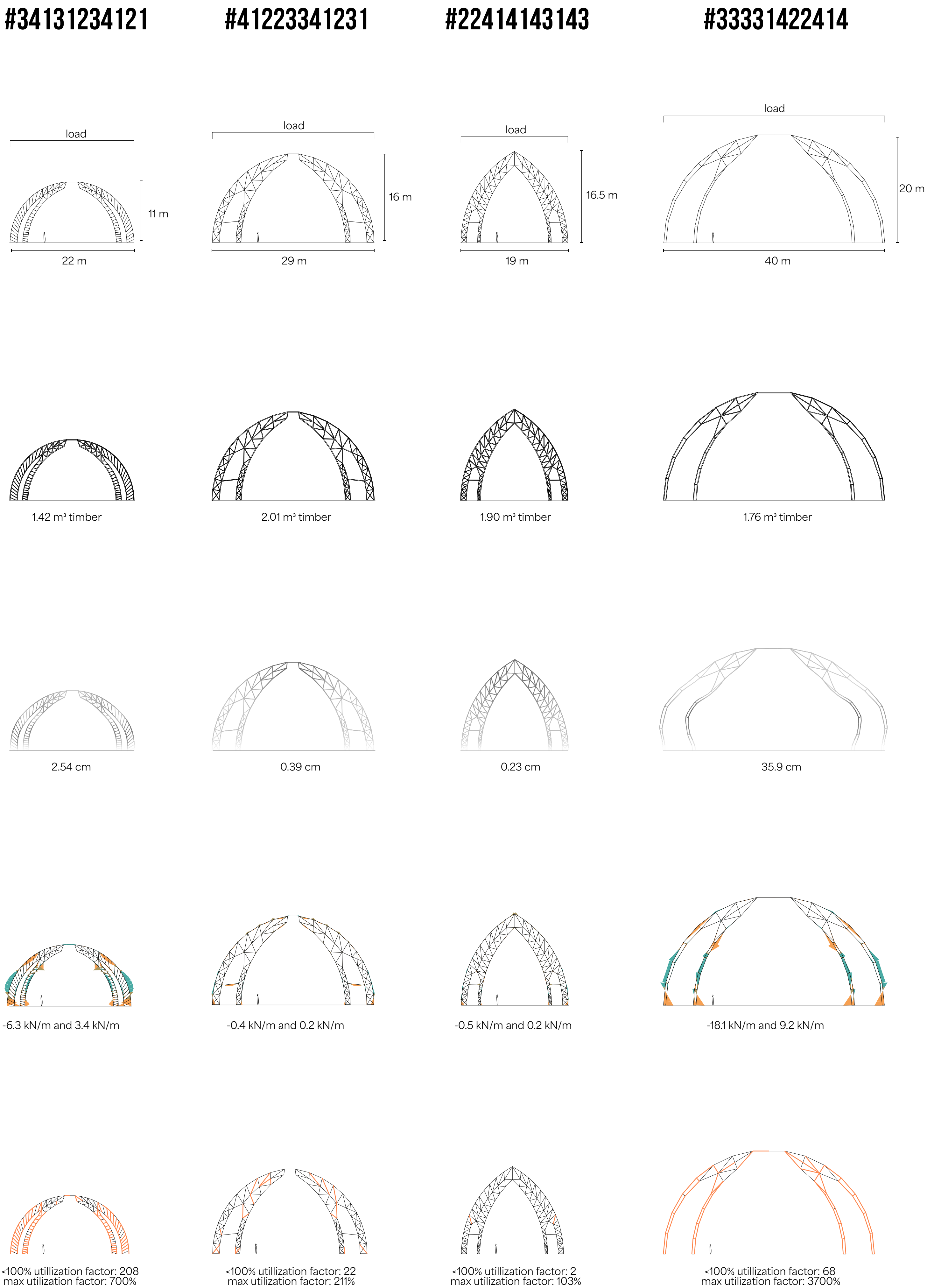
#22414143143

This design's shape resembles that of a catenary curve making it one of the best options in regards to reducing the number of elements in tension and increasing the number of elements in compression. The design reduces the available space due to its dimensions and shape, this is seen as a disadvantage as it also limits potential functions and usage.

#33331422414

This design had a span-to-material usage ratio making it both slender, slim, and large at the same time. The lack of material and small dimensions increased the displacement, axial force, and bending moment. To sustain a structure of this scale would mean an increase in material and an alternative truss design.

Ill. 57. table of highlighted possible solutions by parametric parameters



creating longevity

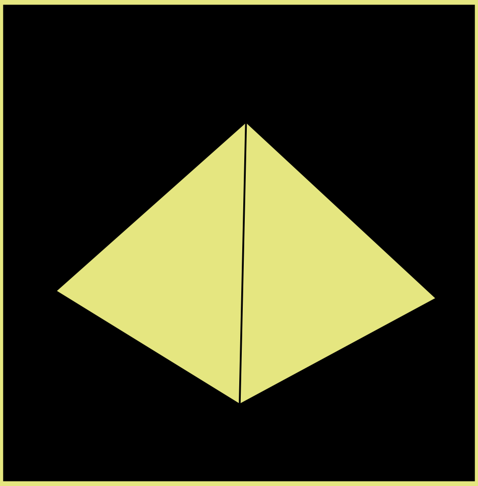
Taking sustainability into account on all levels implies not only looking at a structure’s material use but also how the material is used. A structure that is not only allowed to stand through time but taken care of and used is reducing its environmental impact for every year it is allowed to stand. How the immaterial values of the past engage the public in the building. How it can be enhanced by the principle that is shaped by the reclaimed timber. How the gesture that emerges can further encourage the care of the building and the slowing of the material flow. Designing a building for longevity, a building that signifies its own importance is by itself sustainable. What is architecture if not representations of its own time, its hope, values, or dreams? (Usto et al., 2022)

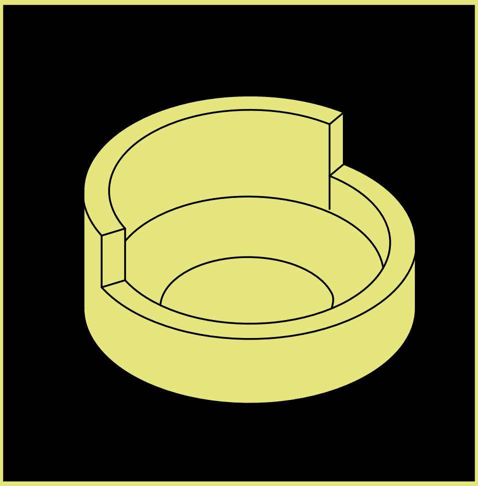
“Monuments are defined by Rossi as primary elements in the city which are persistent and characteristic urban artifacts. They are distinguished from housing, the other primary element in the city, by their nature as a place of symbolic function, and thus a function related to time, as opposed to a place of conventional function, which is only related to use.”

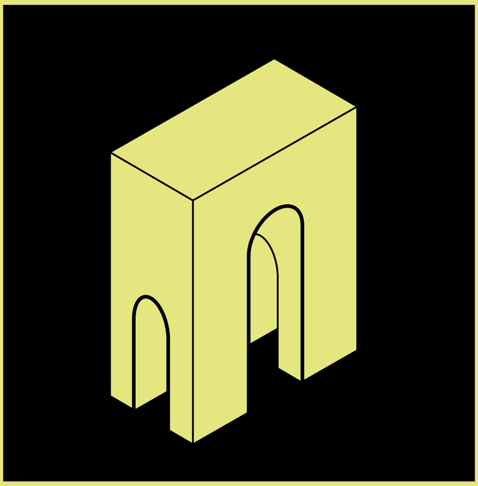
Aldo Rossi The architecture and the city p.6

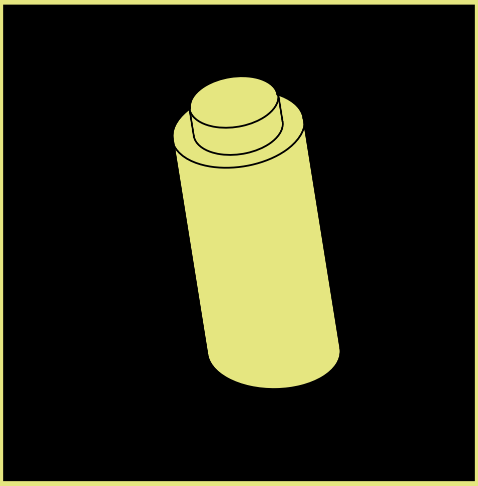
Ill. 58. pictograms of famous monuments: pyramids, colosseum, arc de triomphe, leaning tower of pisa

monuments/simplicity







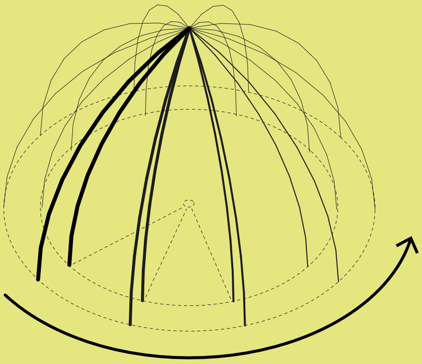


The Danish mink farms can in many ways be described as one of the largest and most general topics in recent years. If it was consensual or coerced, the "elite" against the "common" or if it was exclusive to only a few are irrelevant, but these are some of the characteristics that are shared between the mink farms and the monumental building that often defines them.
Besides their scale and public nature, an often shared feature of monumental architecture is their simple geometry. The geometric shape of architectural monuments often becomes synonymous with the structure. A possible reason for why monuments tend to utilize the simple geometries might be a result of their scale and the construction methods available at the time. Constructing large-scale projects based on simple well understood structural principles. The argument is that if one has knowledge of the structural principles of for example arches or catenaries, it would be possible to scale said principle to monumental size without compromising the structural benefits.

Monuments in architecture tend to be stunning large objects with an underlying simplicity making them truly remarkable to observe and interact with. Leaning towards simplicity when addressing the design geometry is advantageous as it makes the structure easier to understand and comprehend. These monumental and simplistic principles are present in the projects as the overall shape is easily understood even though the structure itself is of a larger scale. (Hirst, 2019)

The circular three-dimensional shape is a consistently strong shape and the evenly distributed frame makes the shape uniform and equally strong all the way around.

Ill. 59. a three-dimensional shape from timber frames



cross-section

Having achieved stability through rotating the designed frames around a center point where the experienced and calculated loads are applied to the structure. The wind load was especially important as it exposes the structure to both push and pull due to the building's circular dome shape. Designing and dimensioning the cross sections used is structured around the changing cross sections dimensions based on utilization factor and material factor.

The cross sections are dimensioned based on utilization factors calculated based on elements experiencing compression and bending from self-weight, superimposed dead load, live load from platforms, and wind load. The structural system is to be made from reclaimed timber elements having a squared cross-section of 63 x 63 mm. This standard cross-section is the foundation of all elements and the smallest cross-section available. The cross sections can be increased by glulam and block-laminated glulam elements. If a larger cross-section is needed elements are as a minimum increased with half a 63 x 63 element. Besides providing a range of closely related cross-sections all glulam elements can be made from the same reclaimed timber elements.

Ill. 60. study and process of dimensioning the cross section of the building

/general dimensioning of cross-section

The first investigation dimensions all elements equally regardless of placement, length, and expected load. This investigation acts as a foundation for further studies. It is observed how a graduate increase in cross-section increases the structure's strength, lowering the number of elements that break. For each increase is more material however added contributing to an increase in self-weight. This increased weight does not result in additional elements breaking.

If all elements are assigned a 157.5 x 157.5 cross-section none of the elements break, the collective usage of reclaimed material is however 130 m³, and with a maximum utilization factor of 70% the proposal is deemed over-dimensioned with a lot of unnecessary material.

/dimensioning of the truss cross-section

Based on the over-dimensioned 157.5 x 157.5 cross-section, it investigated whether the truss elements can be reduced to minimize material usage and maintain a feasible structure that won't exceed 100% utilization factor. The results showed that reducing the truss element too much would induce breaking. By analyzing the element's utilization factor the truss elements subdivided and dimensioned differently based on which element faced breaking. This method was performed repeatedly and the truss was eventually structurally sound with a reduced cross-section. The material used was by this process reduced from 130 m³ to 73.6 m³ without compromising the structure causing elements to break when the loads are applied.

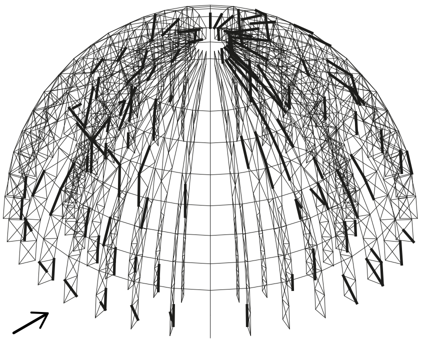
/last adjustments to cross-sections

The cross sections went through an extensive process with the aim of reducing the amount of material used. This resulted in individual elements of the truss being exposed to an increased load, causing them to break. The last adjustments consisted of slightly increasing the cross sections of a select number of elements, in the process providing them with more strength and making them easier to join with the outer shell. The result was a structure without any breaking elements collectively weighing in at 24.8 tons using 62 m³ of reclaimed material consisting of 32 identical frames.

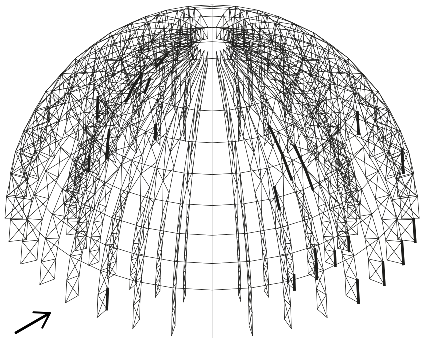
summary

One could in theory simply just increase all cross sections until the structure was not showing any breaking and move on. But being aware of the material used and its application gives the structure a collectively higher utilization factor with significantly fewer materials used. The result is a lighter construction that is shaped by the strength and limitations of the reclaimed material with a maximum utilization factor registered in combined bending and compression at 0.92 or 92%. The structure was also checked in regards to failures caused by tension, column buckling, and pure compression which did not result in any changes to the cross sections as no elements indicated breaking.

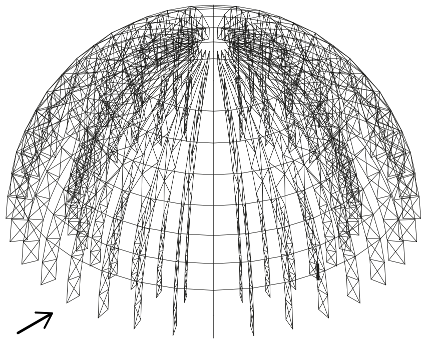
general dimensioning of cross-section



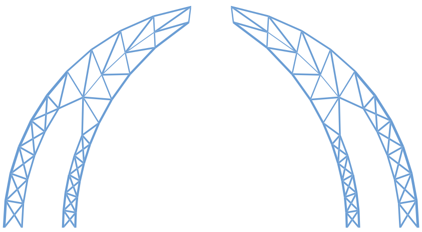
max util. factor: 512%
element above 100%: 315
timber amount: 22 m³



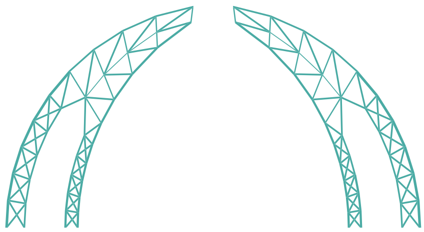
max util. factor: 183%
element above 100%: 44
timber amount: 48.4 m³



max util. factor: 105%
element above 100%: 1
timber amount: 77.5 m³



cross-section 63 x 63



cross-section 94.5 x 94.5

cross-section 126 x 126

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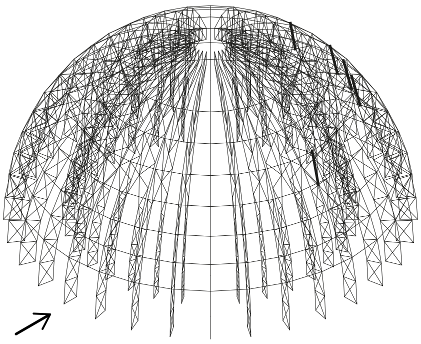
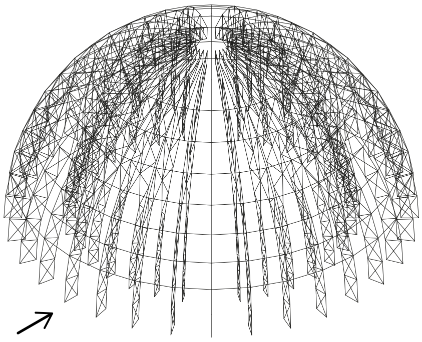
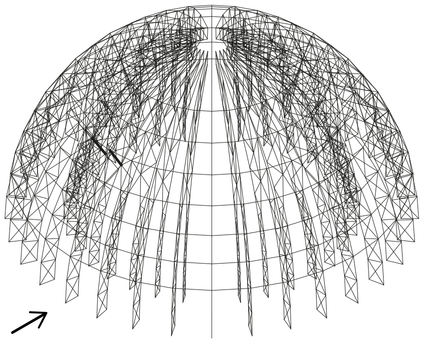
dimensioning of the truss cross-section



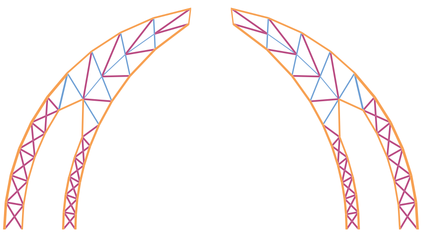
max util. factor: 126 %
element above 100%: 7
timber amount: 73.3 m³



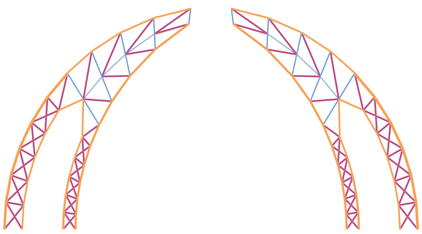
max util. factor: 98 %
element above 100%: 0
timber amount: 73.6 m³



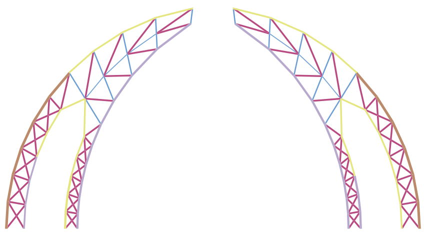
max util. factor: 103 %
element above 100%: 3
timber amount: 62 m³



a select number of top truss elements are increased to avoid beaking



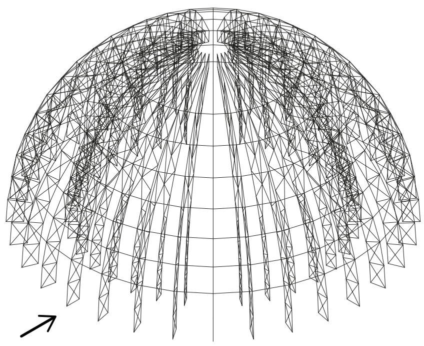
two top truss element get an increase in cross section as the break due to wind loads



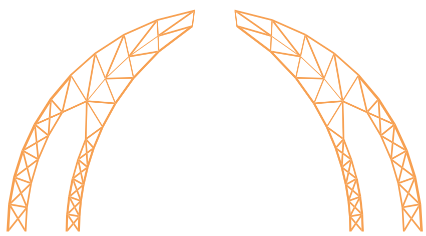
deviating cross sections generally large towards the bottom and smaller

Ill. 61. cross section investigation diagrams

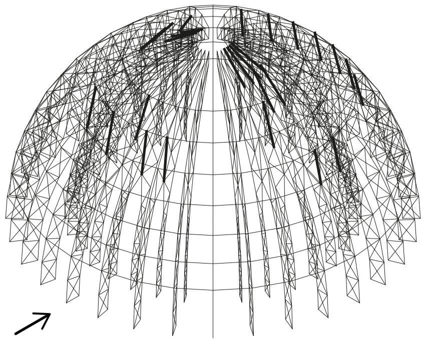
last adjustments to cross-section



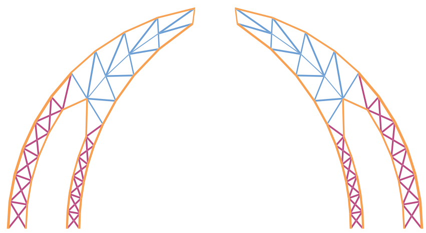
max util. factor: 71%
element above 100%: 0
timber amount: 130.8 m³



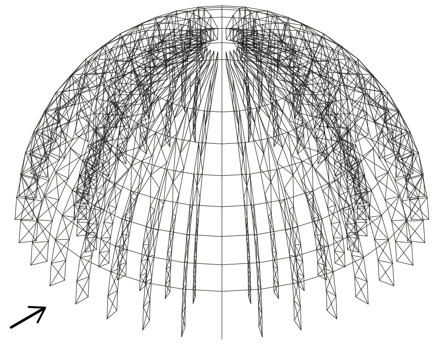
cross-section 157.5 x 157.5



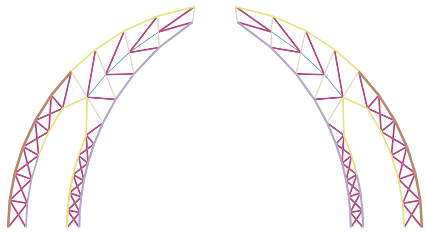
max util. factor: 176 %
element above 100%: 40
timber amount: 70.4 m³



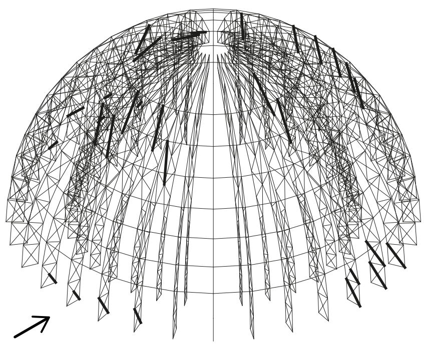
different truss cross sections small in the top, larger at the bottom



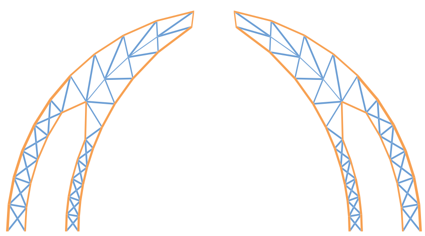
max util. factor: 94 %
element above 100%: 0
timber amount: 62.9 m³



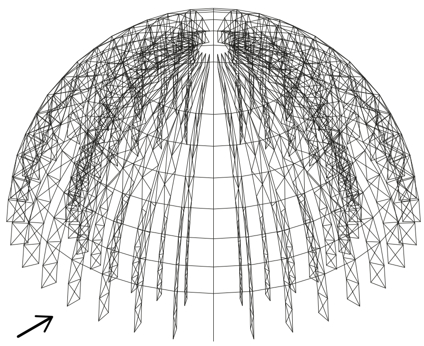
18 elements get a larger cross section to reduce the number of elements that



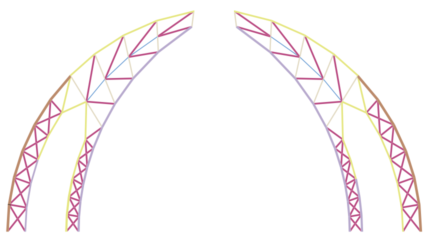
max util. factor: 186 %
element above 100%: 77
timber amount: 63.6 m³



all truss elements have the same cross section



max util. factor: 0.92 %
element above 100%: 0
timber amount: 63.6 m³



two cross sections are increased to enable a easier joint assembly with the outer shell

63x63mm

63x94,5mm

63x126mm

94,5x94,5mm

126x126mm

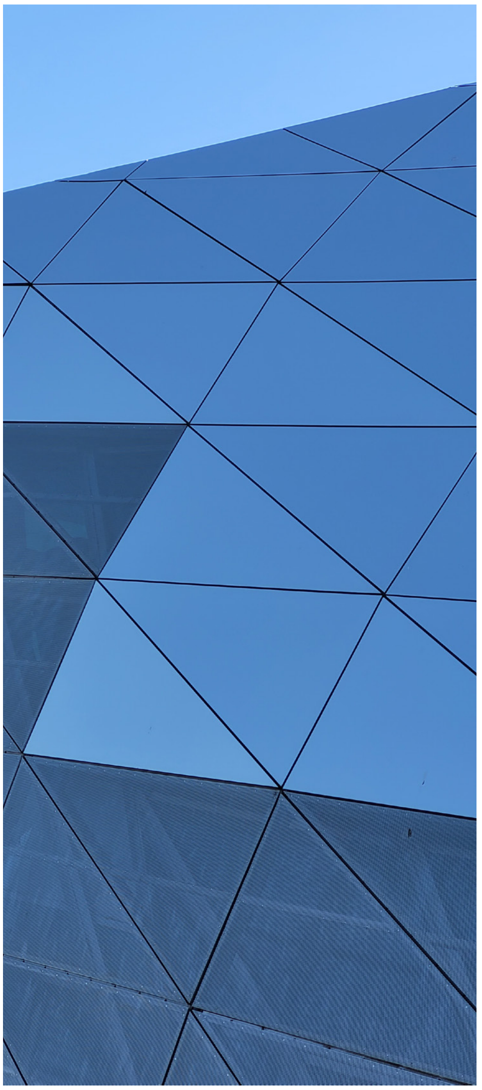
126x157,5mm

126x189mm

157,5x157,5mm

>1 utilization factor

Ill. 62. facade of musikkens hus



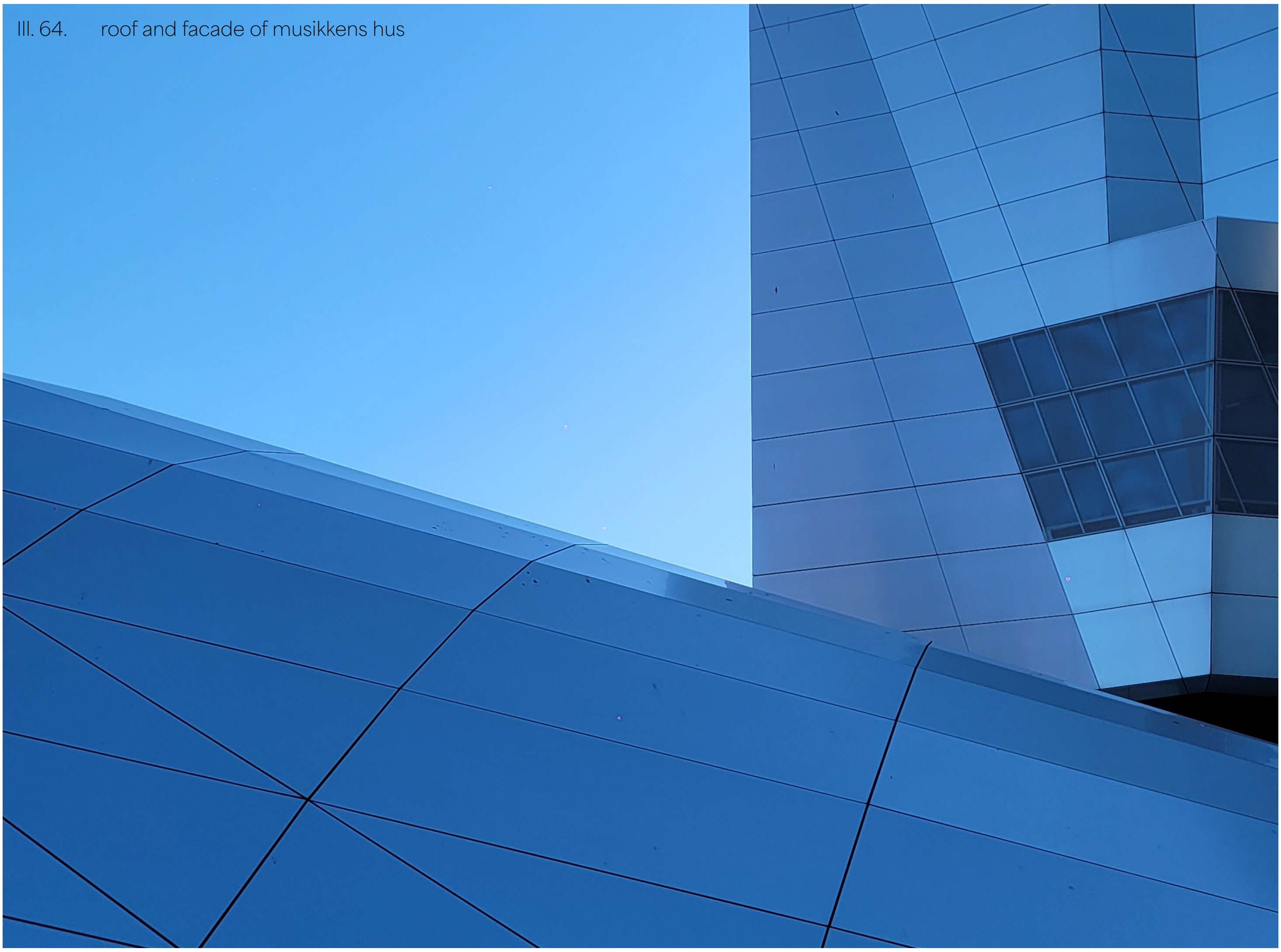
achieving double-curvature case: musikkens hus

architect: coop himmel(b)lau
construction: 2010-2013
structural system: concrete
facade: metal and glass

The House of Music (Musikkens Hus) in Aalborg is a local landmark in a deconstructivist style especially visible from the outside as its exterior is made up of a range of different geometric shapes. The shape that surrounds the entrance and adjacent restaurant is erected on a structure, composed of metal plates that collectively give the appearance of a double-curved building. The external metal plates have a minor gap resulting in intruding water. To prevent the water from seeping into the underlying construction the metal frame fills the gap between the external metal plates and lets the water run away. The facade panels were attached to the structure in the later stages of construction and have no structural application. The panels and construction method give the facade a simplistic and clean look as no joints, frames or downpipes are visible from the outside. The House of Music has achieved its iconic doubled curved entrance by utilizing the principles of tessellating a curved shape and dividing it into polygons. The frames and external metal plates are repetitions of the same shape where the angle between them is what lets the tessellation be formed to fit that exact placement. Making it a fairly labor-intensive process to produce and assemble.

The project's desire to utilize and experiment with reclaimed timber limits the usage of bendable metal to construct facade frames. Inspiration found in the facade principle using underlying joints and potentially in the water management is however relevant regardless of material choice. Depending on the facade, it would be possible to prefabricate the facade panels and mount them on-site during construction due to them being non-load elements and their underlying joints.

Ill. 63. joint in facade



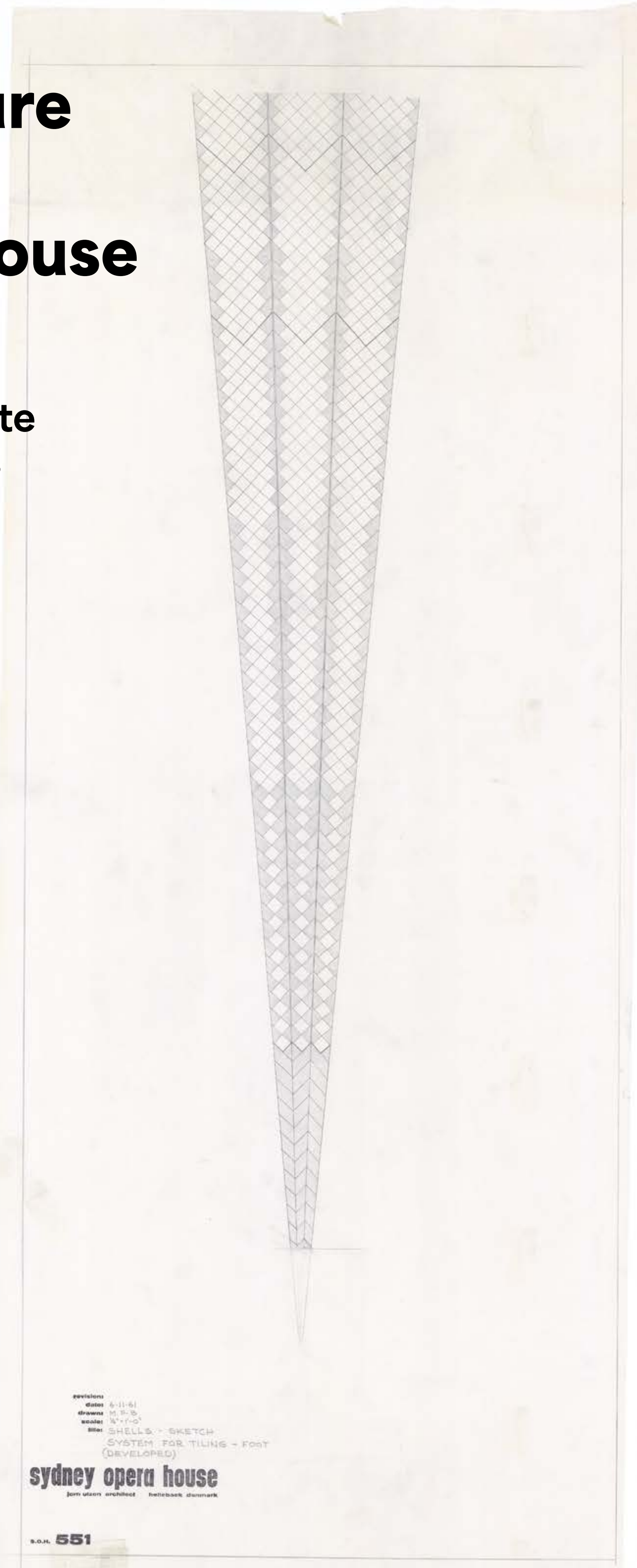
Ill. 64. roof and facade of musikkens hus

Ill. 65. overview of double-curved facade on musikkens hus

achieving double-curvature case: sydney opera house

architect: jørn utzon
construction: 1959-1973
structural system: concrete
facade: concrete and tiles

The Sydney Opera House is a true architectural marble located in Australia. The shell structure covering the concrete plateau was and still is an impressive feat of engineering, built upon persistence from the architect and principles drawn from a simple circle. The shell design and construction presented themselves as a problem both in regard to shape and strength. The finished shape of the shells is all drawn from the same circle and could as a result be cast from the same mold. The concrete pointed arches are covered with 4000 slightly curved prefabricated panels made of concrete that are covered with over a million glazed tiles. The facade panels were curved to properly cover the double curved surface of the structural concrete. The curvature of the shells was engineered in such a way that the panels could be placed and arranged in a way that required a limited number of unique tiles, where all the panels could be poured into the same mold. This led to a great reduction in production cost, where the project might not even have been realized without this solution. The Sydney Opera is a great example of how knowledge of structural principles and geometry and how to utilize them can act as the foundation for an impressive and renowned structure. (Syd-



Ill. 66. SOH ORIGINALER_L_2-2_551_005

ney Opera House 2023)
The pointed arch and curvature in general are advantageous as it transfers loads in primarily compression. It does however require that the materials used are strong in compression and that the dimensioning of elements accommodates the possibility of column buckling, especially if the elements intended for usage are long and slender.
Working with curvature in facades and roofs does however in some cases introduce issues in regard to double-curved surfaces. As is the case with the Sydney Opera. The issue, in that case, lay in properly conversing the double curved surface with a linear facade material. Jørn Utzon and the design team's solution was to create prefabricated curved panels made up of identical glazed tiles for a majority of the roof exterior and during construction place unique glazed tiles in the gaps between the panels. Resulting in a visually pleasing smooth double curved facade. Utilizing smaller linear elements to cover a larger curved area is advantageous as the gaps visually become smaller and less noticeable compared to using larger elements.

Ill. 67. SOH_L_3-5_583_003
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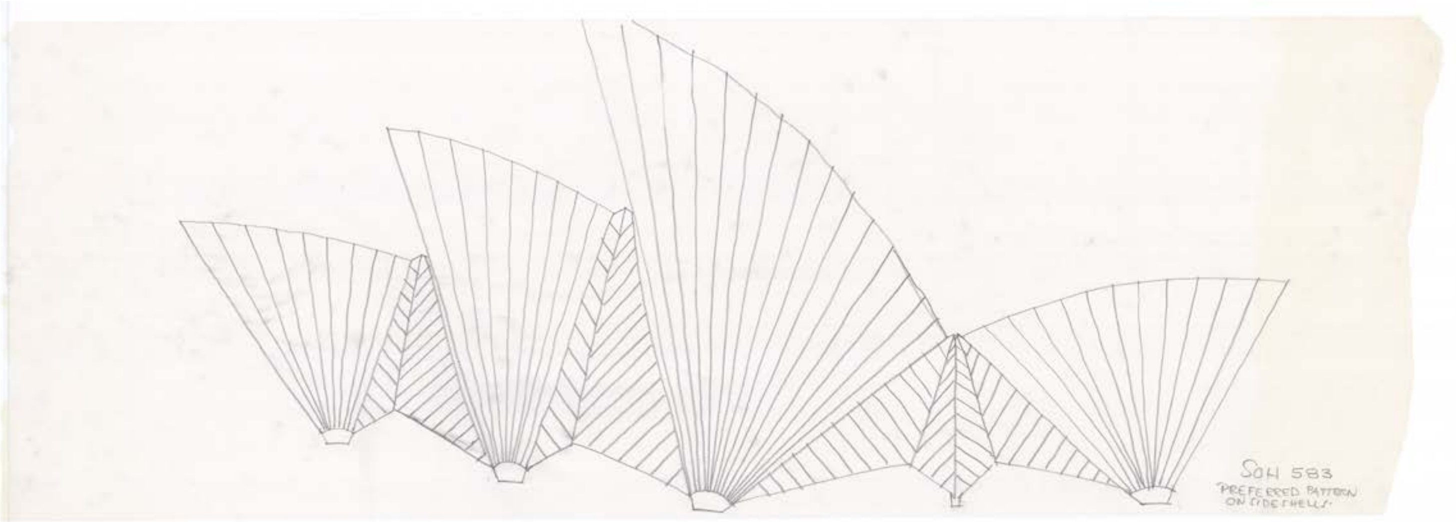
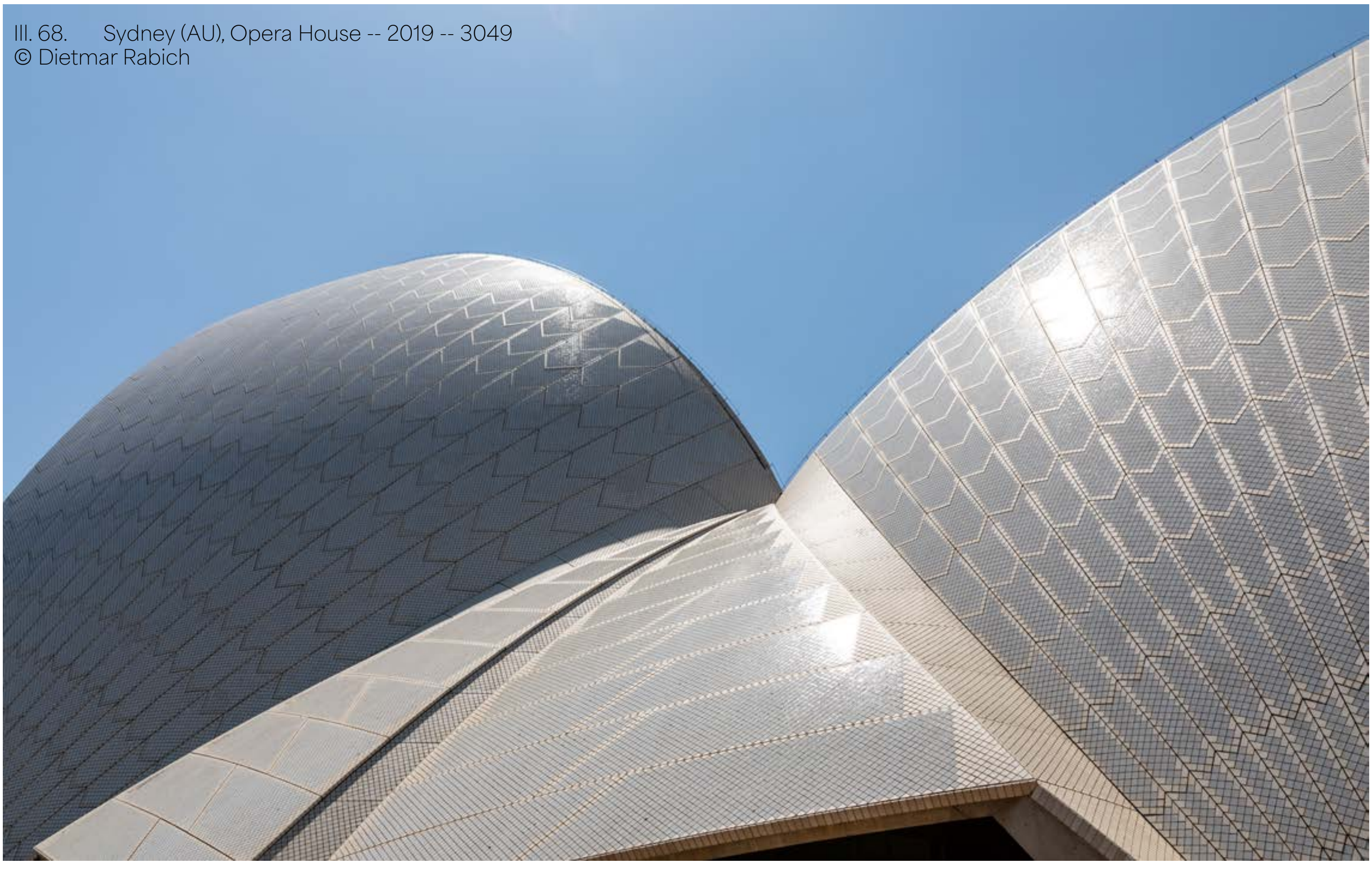


Ill. 68. Sydney (AU), Opera House -- 2019 -- 3049
© Dietmar Rabich



DETAILING THE FACADE

facade and structure

The theoretical foundation and inspiration from the stave church and little shelter on how to construct a weatherproof roof out of wooden shingles and utilizing the same principles of how to construct a double curved facade as Utzon and Coop himmelb(l)au is the starting point on the design process for the facade.

Given the final design's double curvature, and the challenges of creating a design that can both ensure the necessary weather barrier, whilst also being attentive to the construction perspective of the structure, a requirement was that the final design should consist of as few custom elements as possible. This poses two different challenges, the first is the tessellation pattern of the facade that would define the panel shapes, and the second is the shape and pattern of the shingles. As the tiles would need to be specified to the panels, the panels were defined first.

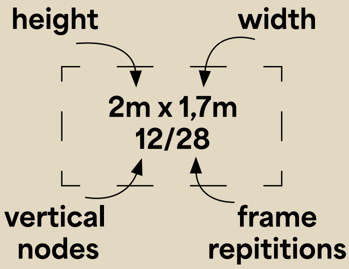
The initial thought was that we wanted the resolution of the tessellation to be high in order for the final structure to have a more defined curved shape. The result was dividing the spherical structure into longitudinal sections, and connected by triangular panels. This was initially seen as an advantage as it would create a more dynamic expression, where the diagonal lines created between the panel in combination with diamond-shaped tiles would create a uniform expression. Combined with the knowledge obtained from Utzon's experience at the Sydney Opera House the prospect was that we could organize the shingle pattern in such a manner that it would reduce the number of special tiles. When in reality the overlap required to create a watertight facade in combination with the triangular panels proved to not be a reasonable solution as the introduction of diagonal lines in the panel that wasn't conjoined with the shape of the shingles would require too much labor time and the top layers of shingles on every panel to be in cumbersome shapes. Also, with the introduction of shingles on the facade in a gradient pattern, the need for the panels to create an expression disappeared.
The dynamic expression would also come through the addition of the poly-carbonate tiles that in addition represent the material properties of the wooden shingles and their relative expected lifetime.

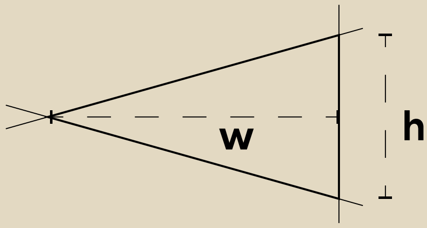
The panels following a grid proved to be a better solution in combination with the rectangular shingles as it, in theory, doesn't require any special shingles as they can just be cut to dimension with a jigsaw after they have been attached to the panel before the panel is assembled to the structure.
The rectangular shingles also required less material compared to the diamond-shaped shingles in order to get the required overlap in order to ensure the facade was waterproof.

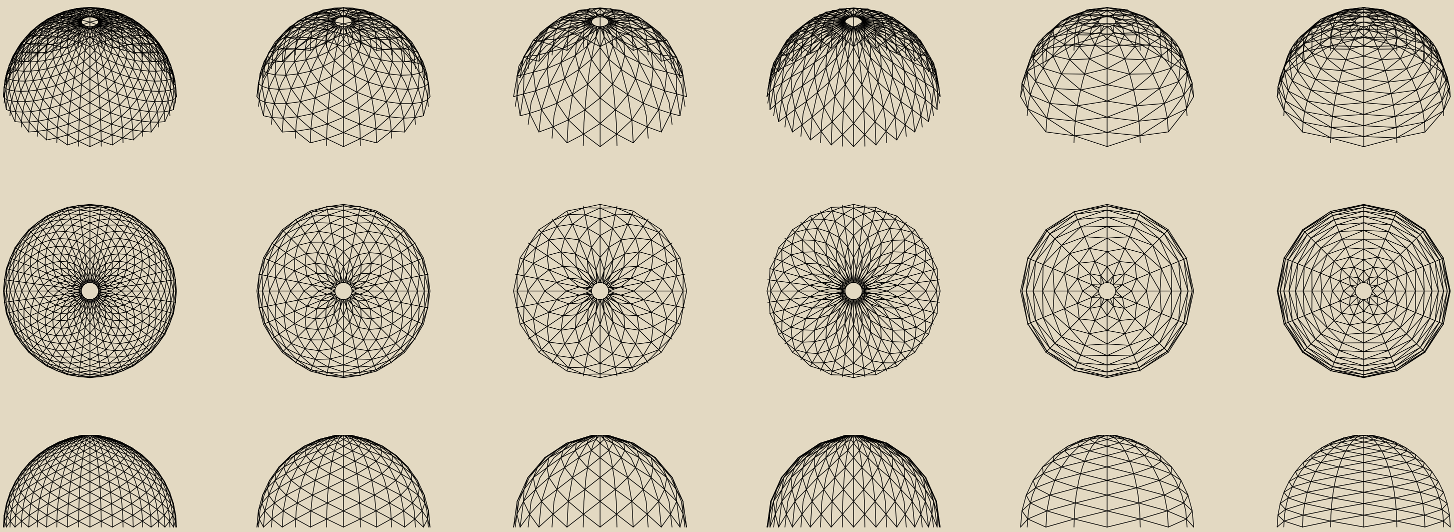
The disadvantage of the grid-organized panels is the lack of horizontal overlap of shingles between the panels. This required the addition of hip/ridge shingles or something similar, this was done with the addition of the available plastic from the mink farms to ensure the necessary barrier against rainwater.

Ill. 69. diagrams of the dispositions of the dome

triangular panels investigation

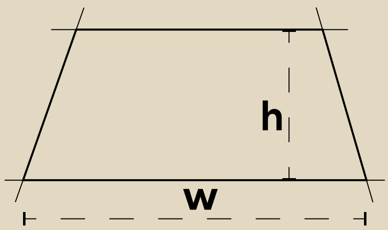


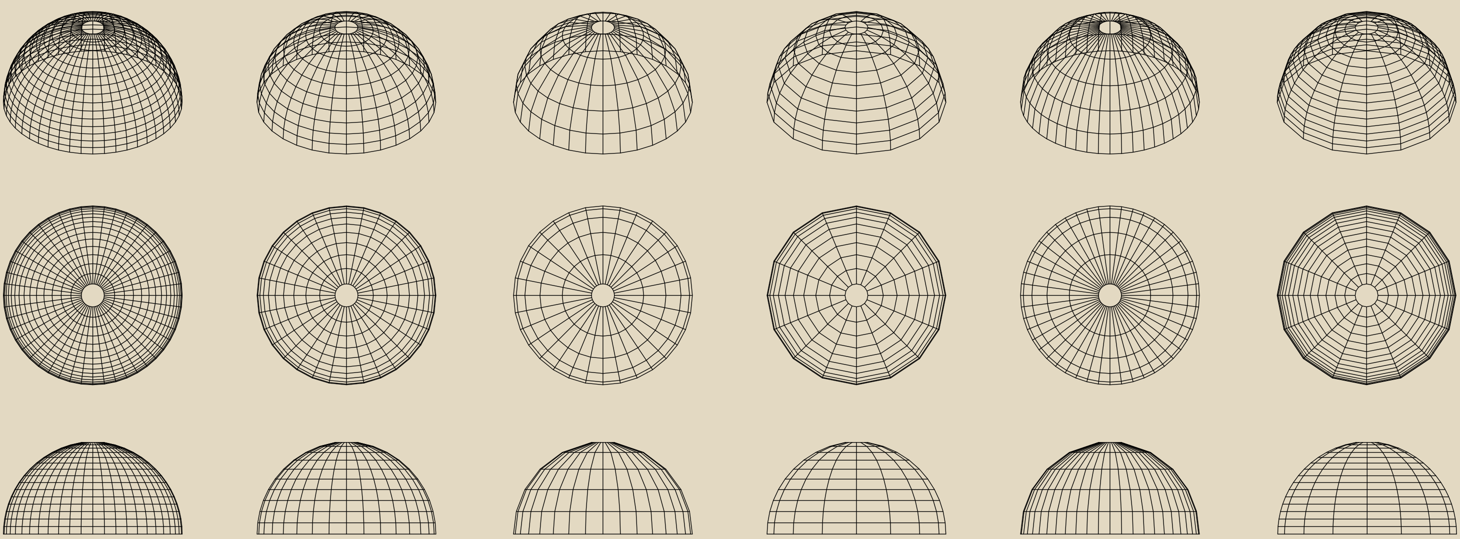




2m x 1,7m 12/28 | 4,5m x 2,5m 6/32 | 2,5m x 2,5m 9/32 | 4,5m x 1,7m 6/48 | 2,8m x 5,3m 9/16 | 2m x 5,3m 12/16

trapezoid panels investigation

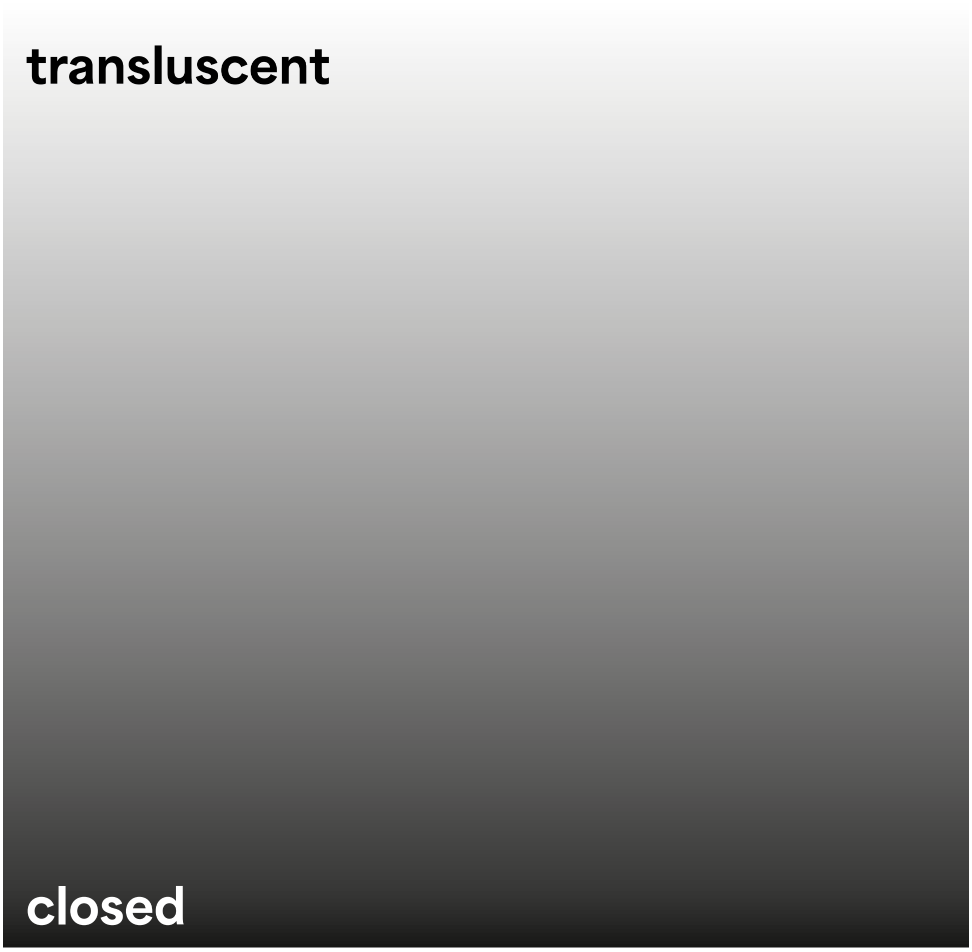




2,5m x 1,5m 15/48 | 2m x 2m 10/32 | 2,5m x 4,5m 5/32 | 5m x 2m 10/16 | 1,5m x 4,5m 5/48 | 1,5m x 5m 15/16

shingle pattern

The graduating pattern of wood and poly-carbonate shingles are based on the material properties of the wood. On the lowest panels with an almost vertical facade, the wood will have an almost indefinite lifetime with adequate care. On the two highest panels the inclination is too low to justify the use of wooden shingles as the rate of water runoff is too low and in windy conditions there might be a risk of water being pushed up between the shingles with the help of the capillary effect that is present in textured and absorbing materials. The graduation between these two areas is then meant to narrate the wood's durability, with decreasing life expectancy the higher up the shingles are. With the final pattern of the shingles, the worst-performing shingles are expected to have the same maintenance requirements as normal roofs.



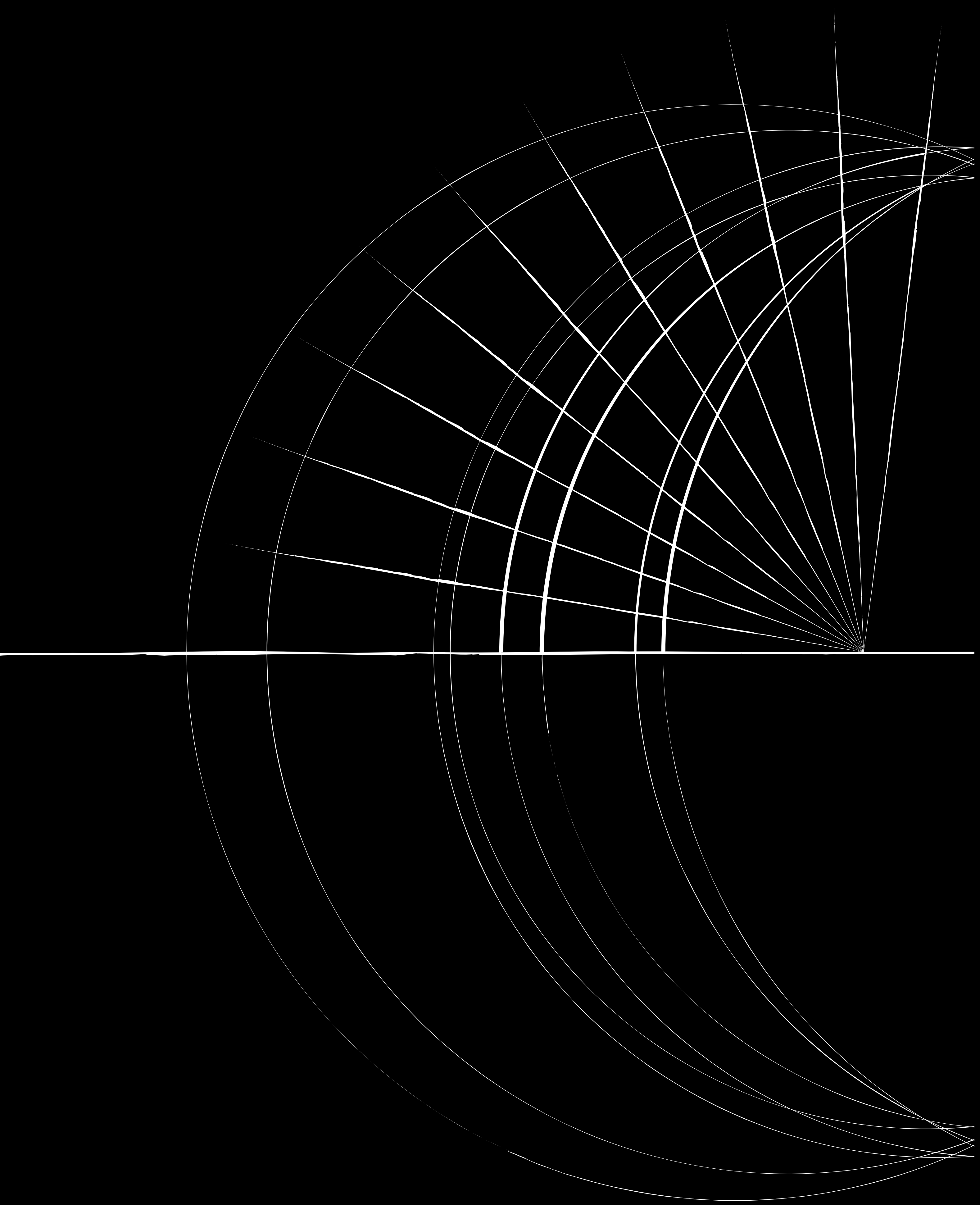
Ill. 70. tests of treatments on timber from mink barns

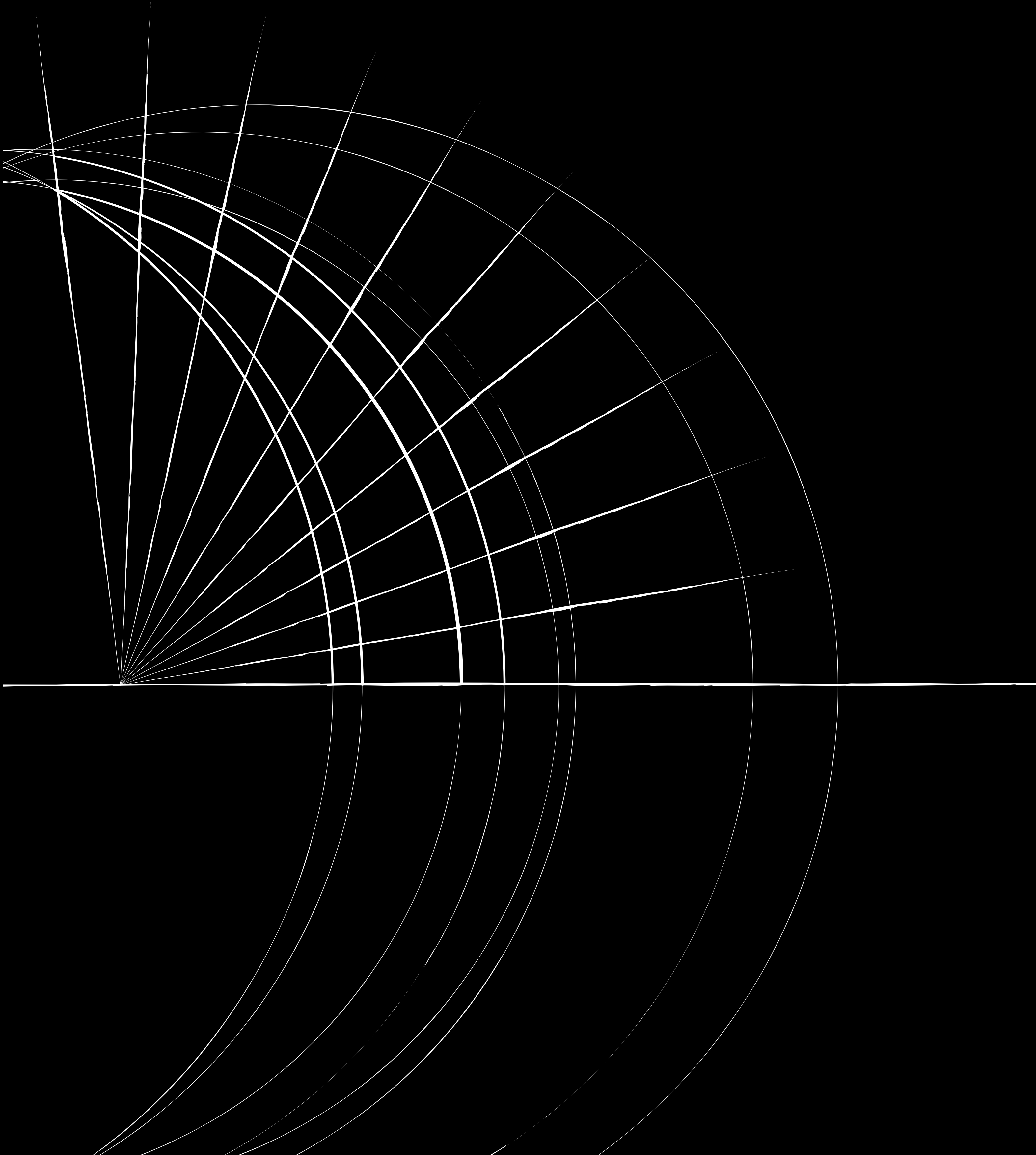
shingle material

tests of treatments on timber from mink barns

Treatments can be done by applying tar as in the stave church in order to protect the wood from humidity, rot, and insects. Modern surface treatments of wood such as oils and paints can be found in all kinds of different expressions to achieve the protection needed in the facade. Burning the outer layer of the wood with the Japanese technique of shou-sugi-ban is another well-proven technique that can be applied to wood to protect long-lasting structures. A study on different surface finishes was conducted to inform the decision. (Frøslev Flamewood nd.)

The wood can be planned down to remove the existing patina to make the wood accept all the different surface finishes, an advantage was seen in using the shou-sugi-ban technique as this step could be omitted and we could burn the wood without any processing of the wood.





“How can the structure be experienced and convey the results of the investigations?”

PRESENTATION

research pavilion

The research pavilion is an architectural proof, an embodiment of research. The building is a place for mediation, learning, and understanding. Being nothing else than a structure made of reclaimed timber, and deliberately focusing on only being that, to show what it has to offer, the research pavilion is context-less and function-less.
Constructed of 32 radial wooden frames, the dome-like structure stands on its own protected by wooden and translucent polycarbonate shingles.
The building allows for insight, for inspections to happen, to understand and see what reclaimed timber can do structurally, but also as a protective material - it is to set a focus on the future and what potential lies there.

Ill. 71. research pavillon in marsh

building contents

Built from almost exclusively reclaimed timber from the demolished mink farms, the research pavilion is a proof of concept, idealizing the potential of reclaimed timber. The research pavilion repurposes 117.3 m3 of timber that otherwise would have been discarded. The material list is exclusively made up of reclaimed timber and materials to augment the timber. All joints are made from bolted steel plates inserted in the wood, creating the wooden frames. The research pavilion's facade is made of either wooden or polycarbonate shingles. Reclaimed wood shingles where the angle is favorable.
An array of different timber elements consisting of different cross sections are used, that are either kept as is, or glue-laminated.

frames
63,6m³ timber (23.532kg)

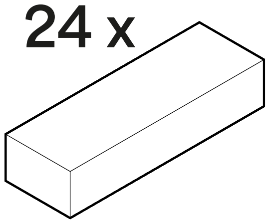
facade shingles (timber)
46,3m³ timber (17.148kg)

platform (timber)
7,5m³ timber (2.775kg)

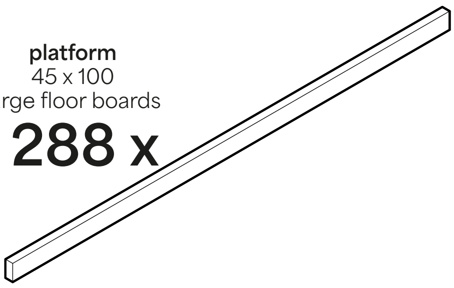
collective timber usage
117,4m³ timber (43.455kg)

corresponding to:
95 frames from a 16-row mink barn

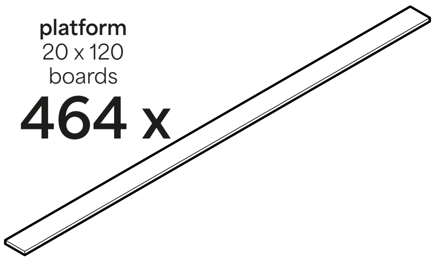
platform
250 x 330 x 2100
step boxes
24 x



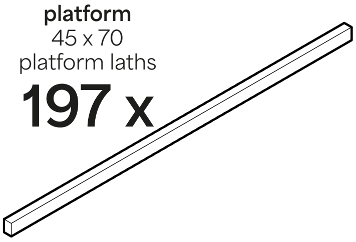
platform
45 x 100
large floor boards
288 x



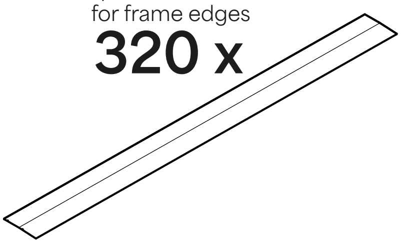
platform
20 x 120
boards
464 x



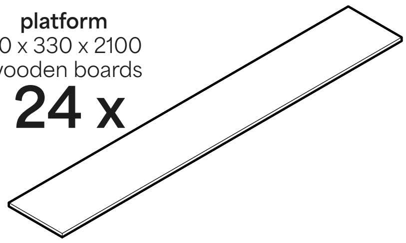
platform
45 x 70
platform laths
197 x



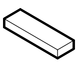
facade
5 x 200
plastic sheets
for frame edges
320 x



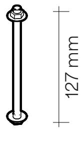
platform
20 x 330 x 2100
wooden boards
24 x



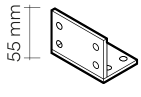
platform
45 x 100 x 330
timber supports
66 x



platform
metal bolts
for assembly
1736 x

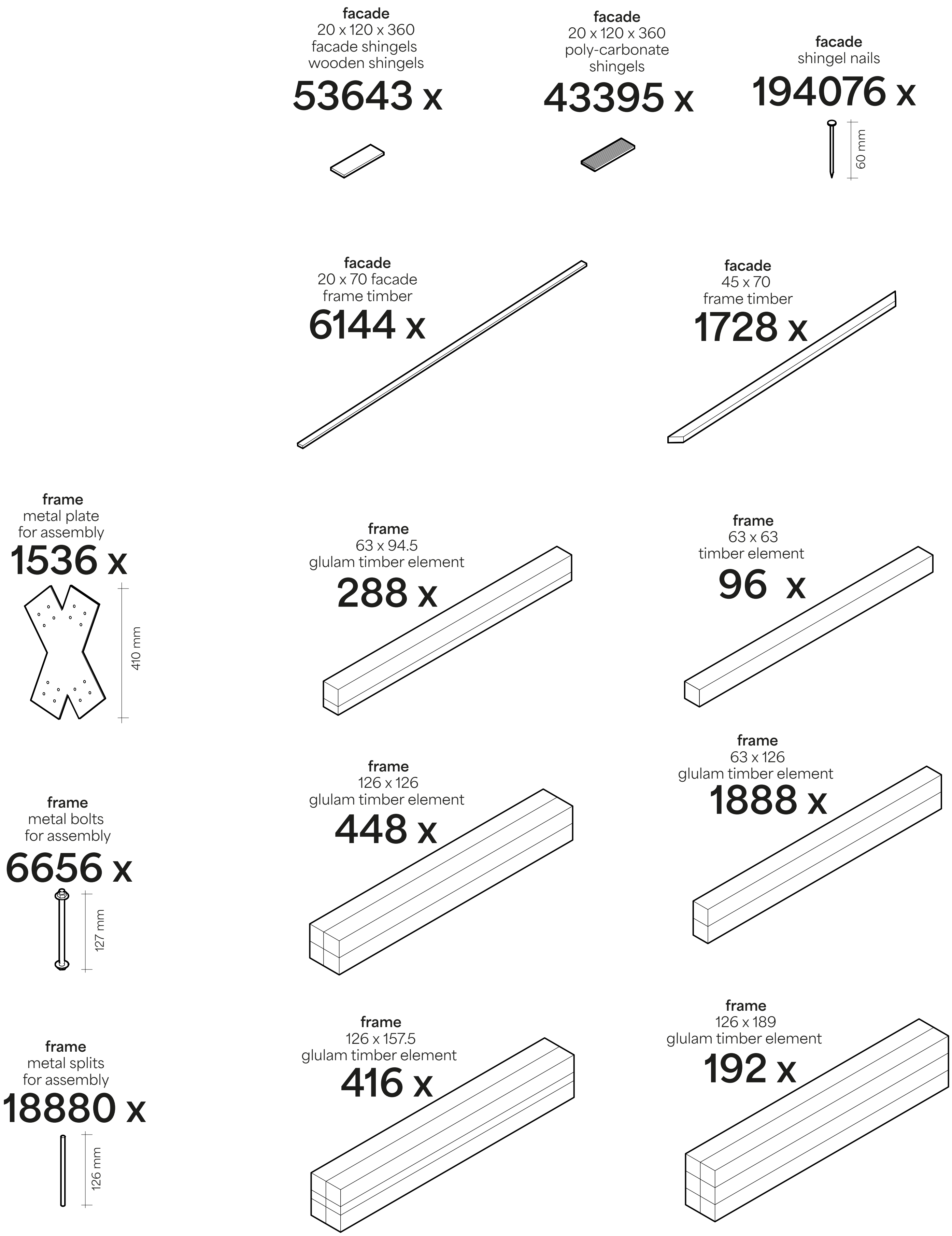


platform
metal fittings
for platforms
217 x



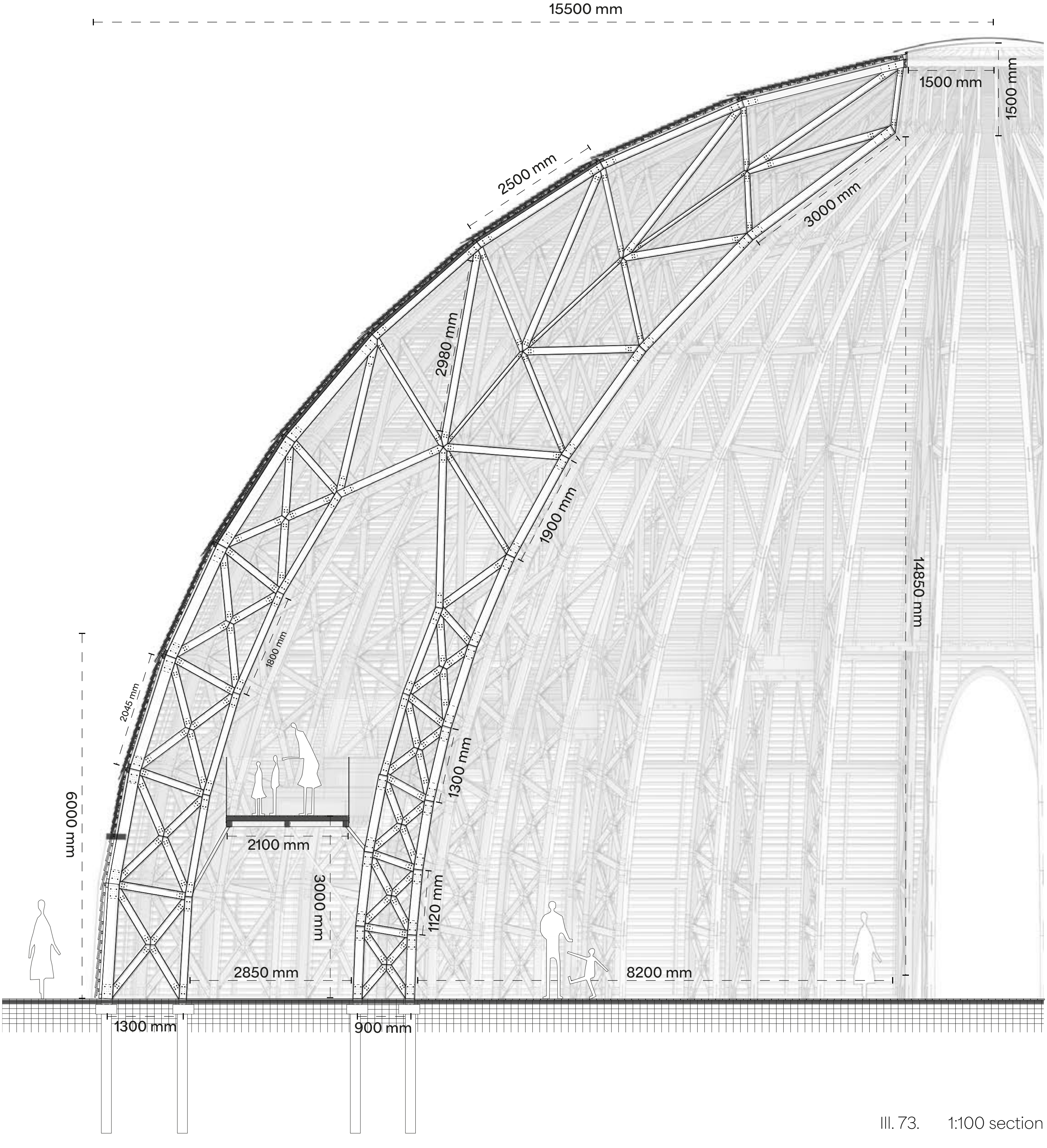
platform
40 x 50
metal pipe for
platform support
78 x

Ill. 72. building content



frame
1:100

The research pavilion is made up of 32 identical frames rotated around a central axis shaping the space within. A sheltered and open space with atmospheric presence facilitating unlimited possibilities. The frames are built upon the structural principle of the truss, utilizing short available elements reclaimed from the mink barns. Each frame consists of two trusses forming an archway before merging and becoming, narrowing towards the top reaching for a dome-shaped skylight providing atmospheric light emphasizing the structure's scale.



Ill. 73. 1:100 section

Ill. 74. interior view of research pavilion

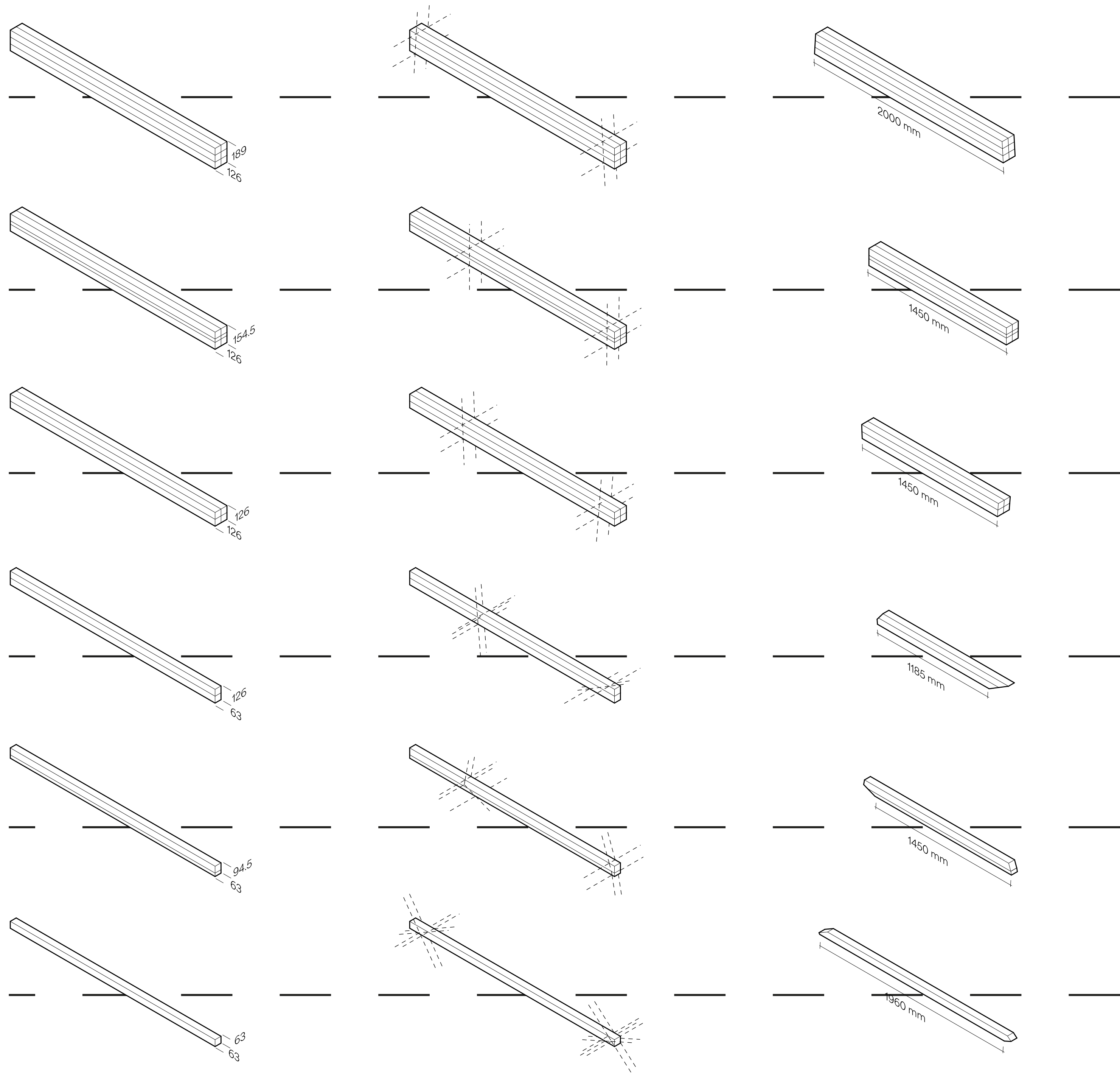
timber treatment

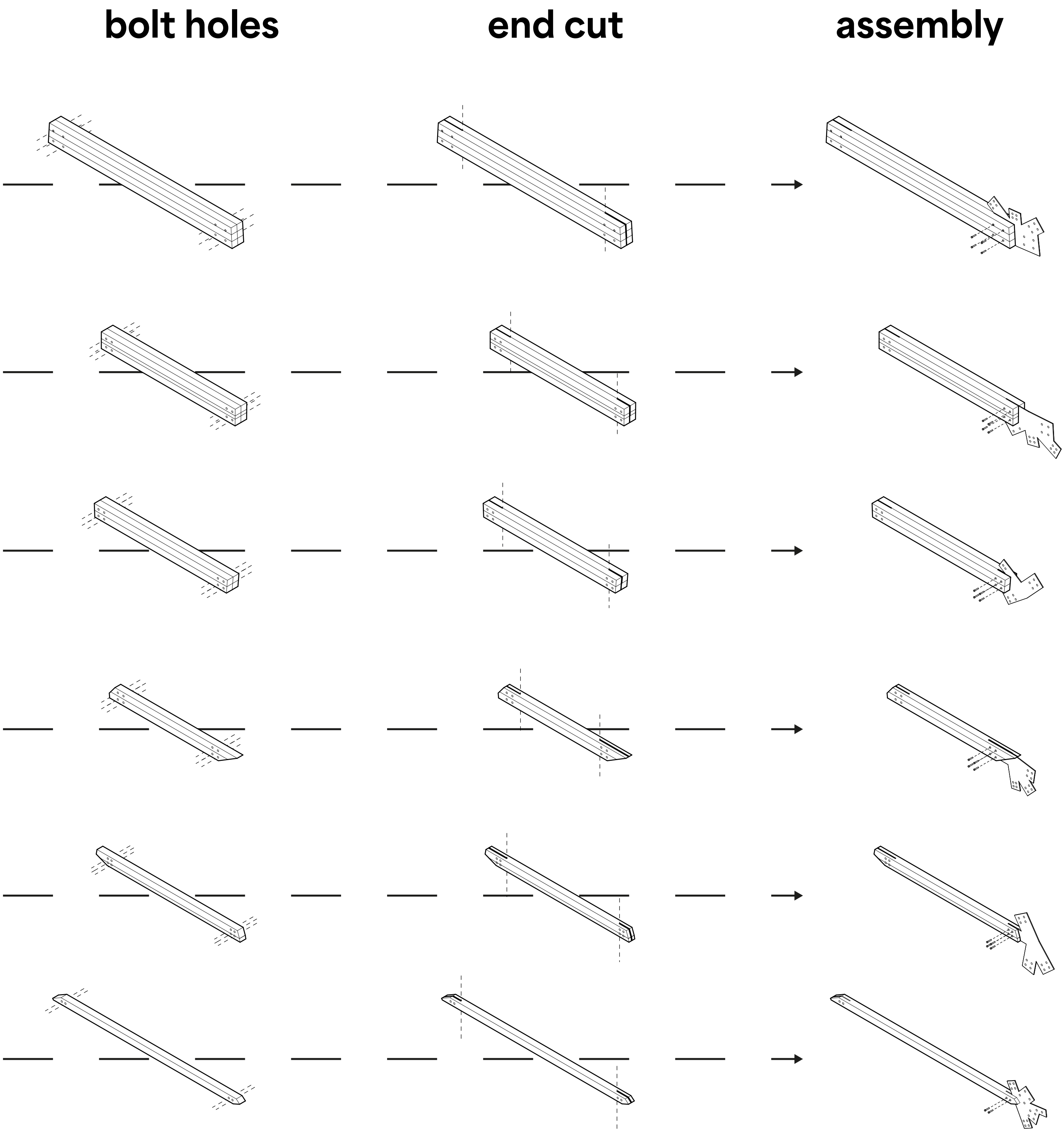
The majority of the structural elements used in the load-bearing frame are made from glue-laminated reclaimed timber. The process from glulam elements to frame consists of six steps among others, drilling bolt holes and cutting end slots enabling the glue-laminated elements to be assembled into the finished frame.

glulam element

cut pattern

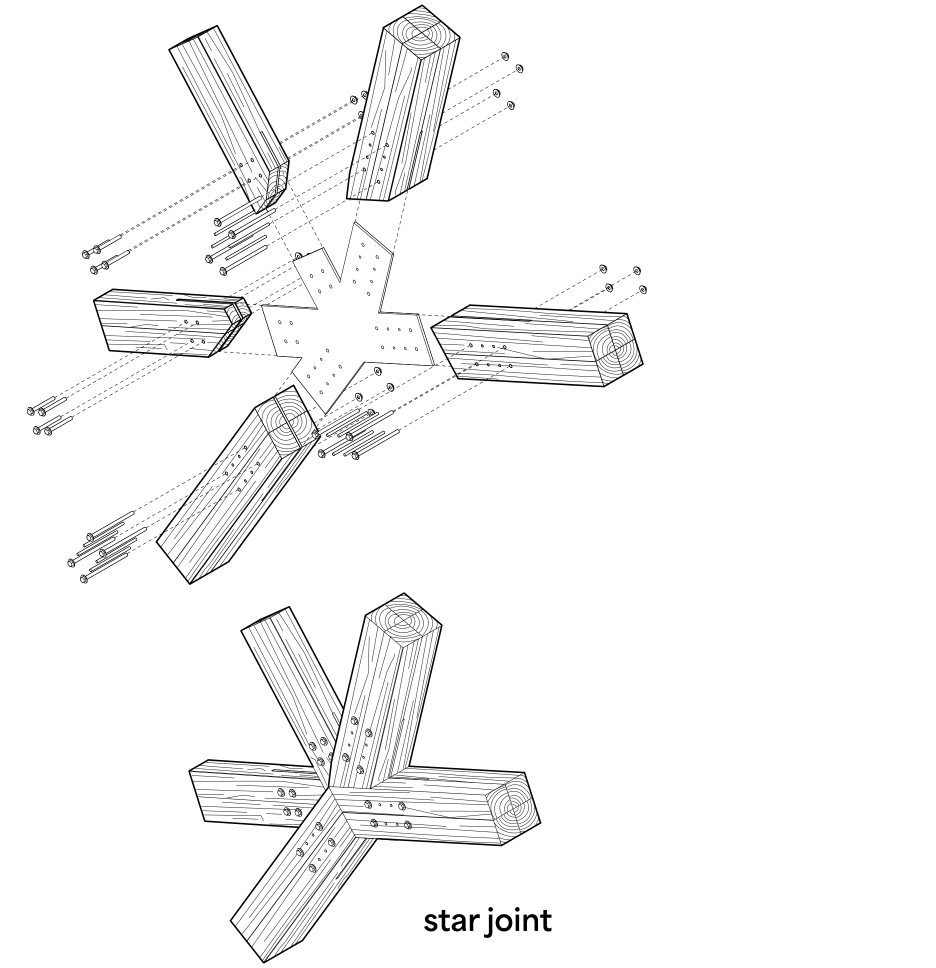
trimmed element



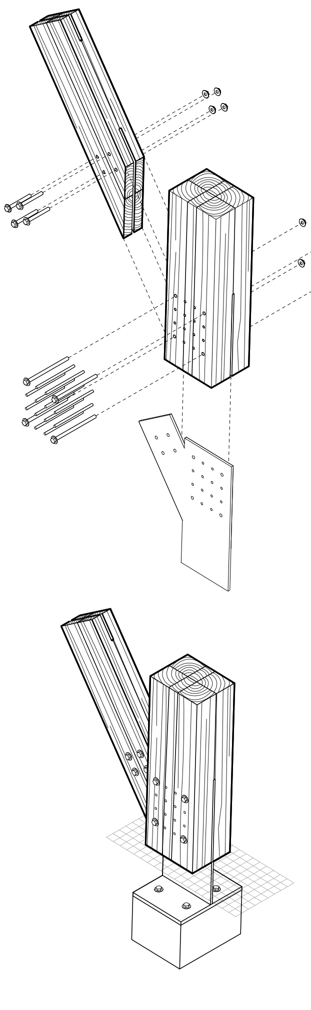


Ill. 75. timber treatment

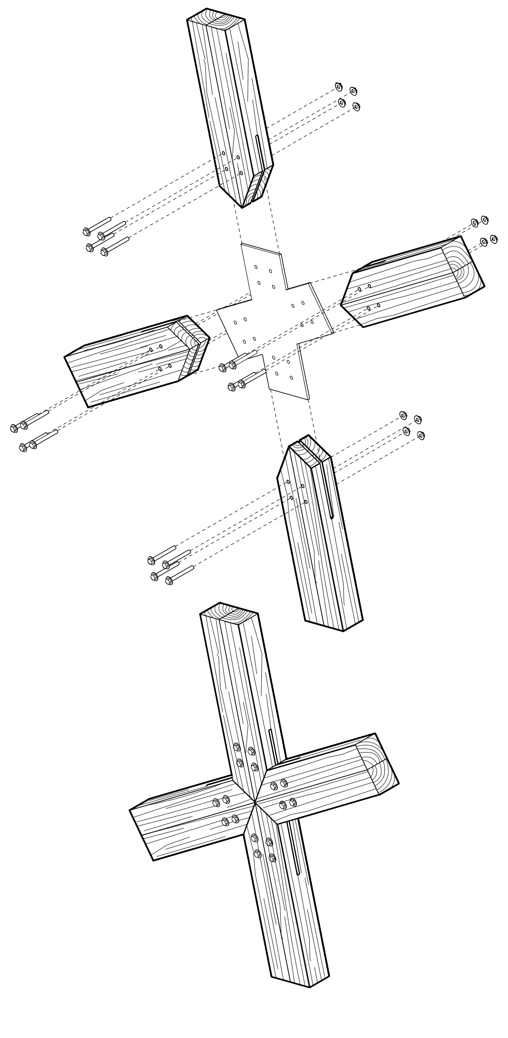
The metal plates are crucial for assembling the elements. The joints are fastened with bolts and additional metal plates in the case of larger elements. The bolts are 8 mm in diameter. The dimensioning of the metal plates is based on the elements it connects to, this allows for a large effective area in each joint, no matter the width. The elements are assembled so the metal plate fully pierces the timber, in order to reduce torsion in the metal plates



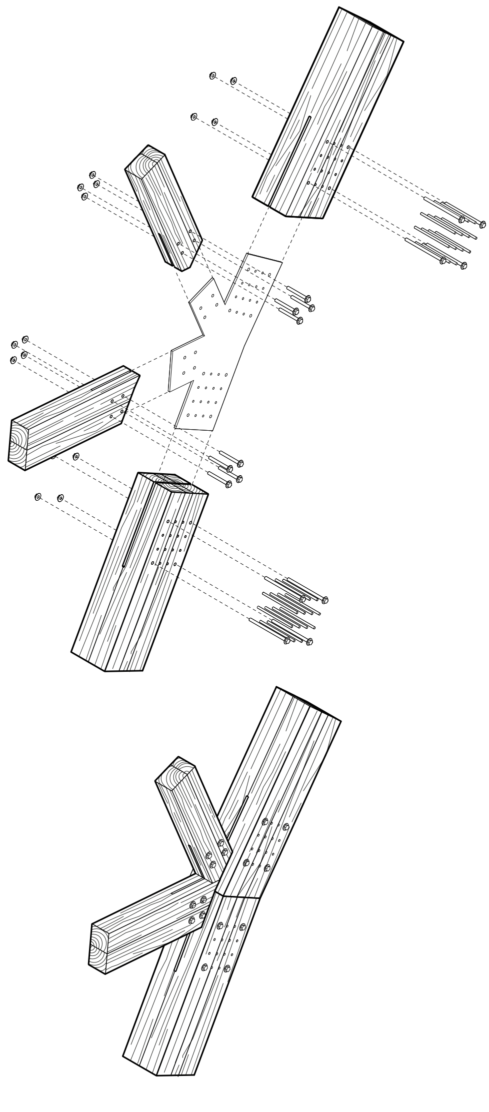
star joint



bottom joint



cross joint



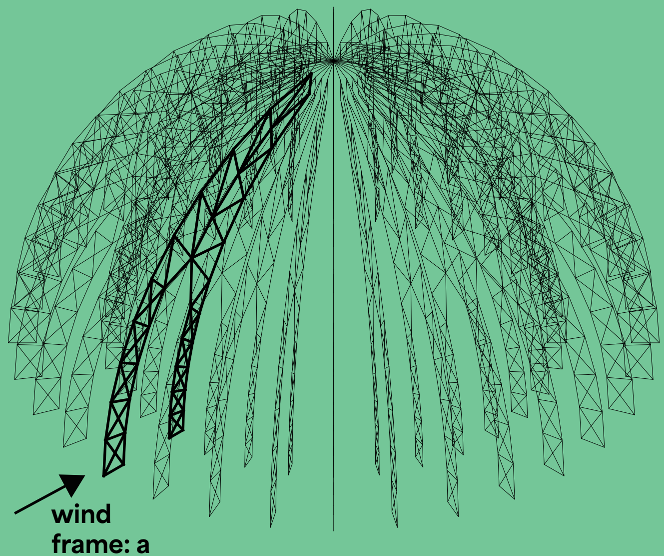
inner truss joint

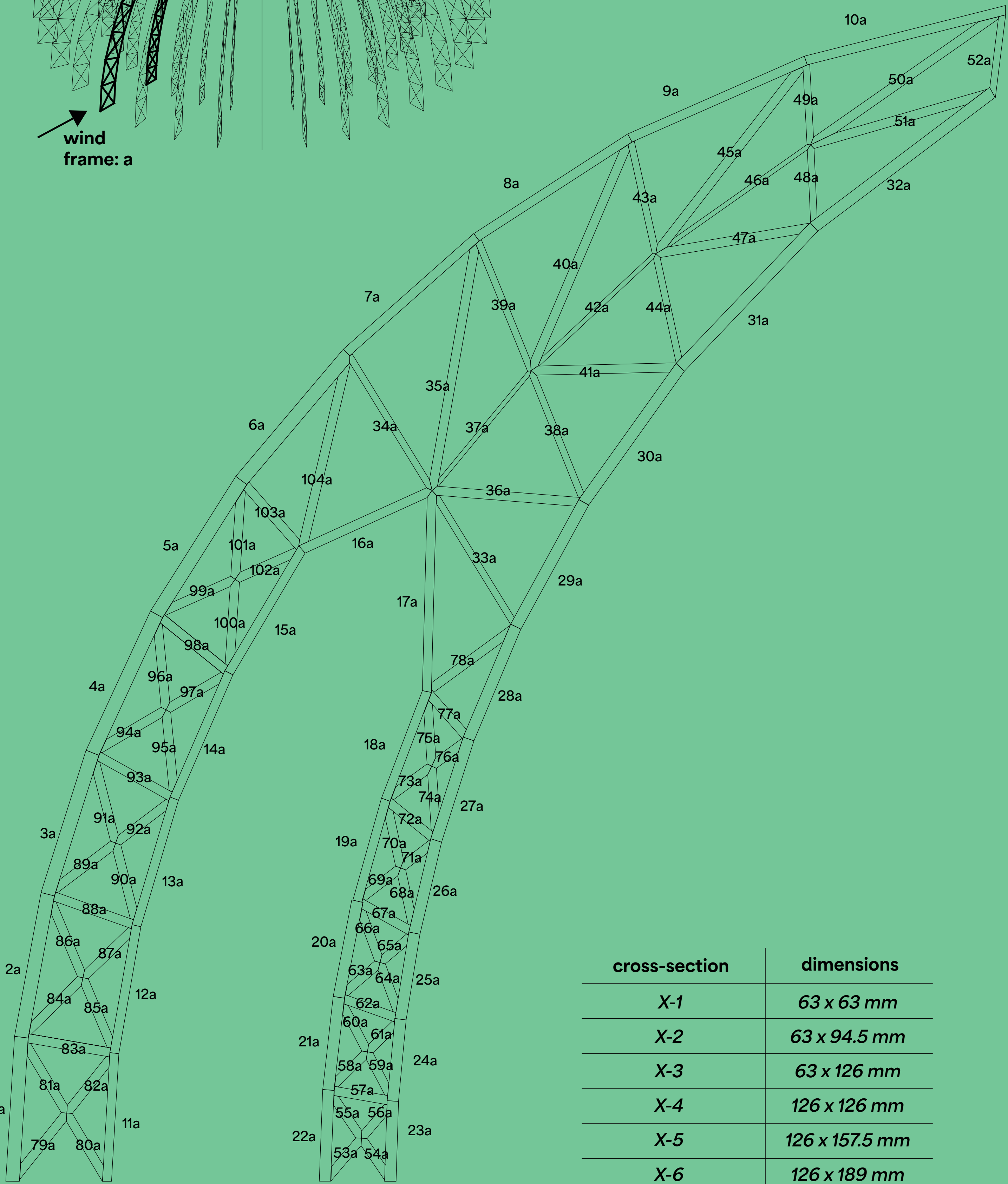
Ill. 76. joints in research pavillon

Ill. 77. frame of research pavillon

Ill. 78. dimensions on frame a

frame: a





cross-section	dimensions
X-1	*63 x 63 mm*
X-2	*63 x 94.5 mm*
X-3	*63 x 126 mm*
X-4	*126 x 126 mm*
X-5	*126 x 157.5 mm*
X-6	*126 x 189 mm*

For calculations, see appendix H

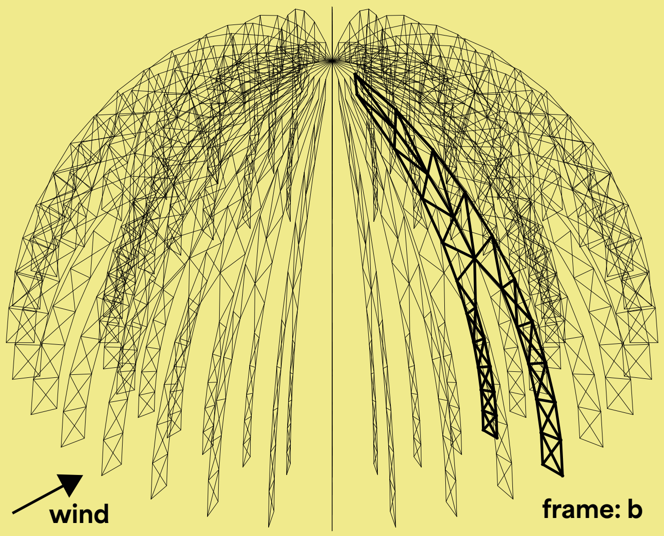
material: C16 reclaimed timber

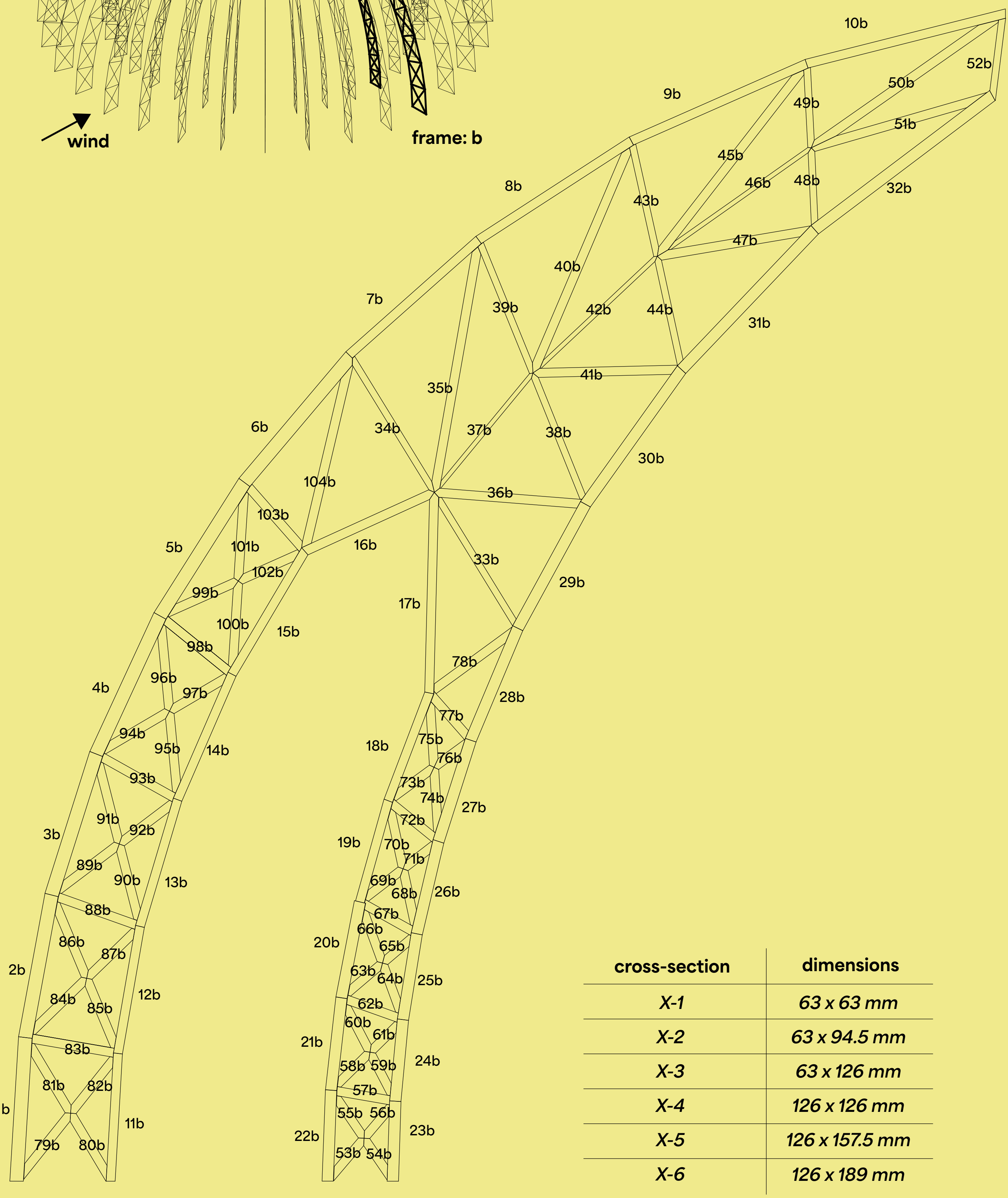
id	cross-section	length	util. combined compression and bending (y)	util. factor tension
1a	X-6	1.97 m	0.13	0.14
2a	X-6	1.99 m	0.02	0.03
3a	X-6	2.03 m	0.14	0
4a	X-6	2.09 m	0.19	0
5a	X-6	2.17 m	0.13	0
6a	X-6	2.27 m	0.09	0
7a	X-4	2.38 m	0.04	0.03
8a	X-4	2.50 m	0.04	0.01
9a	X-4	2.64 m	0.06	0
10a	X-4	2.77 m	0.09	0
11a	X-4	1.75 m	0.78	0
12a	X-4	1.77 m	0.28	0
13a	X-4	1.81 m	0.02	0.03
14a	X-4	1.88 m	0.01	0.09
15a	X-4	1.96 m	0.01	0.08
16a	X-4	1.96 m	0.15	0
17a	X-4	2.75 m	0.35	0
18a	X-4	1.58 m	0.13	0
19a	X-4	1.44 m	0.02	0.01
20a	X-5	1.34 m	0.02	0.05
21a	X-5	1.27 m	0.03	0.04
22a	X-5	1.24 m	0.02	0.03
23a	X-5	1.09 m	0.39	0
24a	X-5	1.12 m	0.34	0
25a	X-5	1.19 m	0.29	0
26a	X-5	1.30 m	0.22	0
27a	X-5	1.46 m	0.1	0
28a	X-5	1.67 m	0.02	0
29a	X-5	1.94 m	0.02	0.01
30a	X-5	2.27 m	0.04	0
31a	X-5	2.66 m	0.05	0
32a	X-5	3.07 m	0.05	0
33a	X-2	2.19 m	0.07	0
34a	X-2	2.19 m	0.72	0
35a	X-3	3.50 m	0.88	0
36a	X-3	2.09 m	0.27	0
37a	X-1	2.13 m	0.68	0
38a	X-2	1.94 m	0.02	0.08
39a	X-2	1.94 m	0.04	0.1
40a	X-3	3.44 m	0.54	0
41a	X-3	2.05 m	0.03	0
42a	X-1	2.35 m	0.32	0
43a	X-2	1.59 m	0.03	0.03
44a	X-2	1.59 m	0.01	0.01
45a	X-3	3.34 m	0.32	0
46a	X-1	2.59 m	0.18	0
47a	X-3	2.21 m	0.03	0.01
48a	X-2	1.12 m	0.06	0
49a	X-2	1.12 m	0.03	0
50a	X-3	3.19 m	0.22	0
51a	X-3	2.60 m	0.02	0.01
52a	X-2	1.09 m	0.03	0.1

id	cross-section	length	util. combined compression and bending (y)	util. factor tension
53a	X-3	0.76 m	0.07	0
54a	X-3	0.70 m	0.16	0
55a	X-3	0.80 m	0.12	0
56a	X-3	0.66 m	0.11	0
57a	X-3	0.90 m	0.02	0
58a	X-3	0.74 m	0.04	0
59a	X-3	0.76 m	0.19	0
60a	X-3	0.84 m	0.16	0
61a	X-3	0.64 m	0.05	0
62a	X-3	0.90 m	0.12	0.02
63a	X-3	0.73 m	0.16	0.02
64a	X-3	0.82 m	0.18	0
65a	X-3	0.62 m	0.05	0.02
66a	X-3	0.89 m	0.15	0
67a	X-3	0.90 m	0.04	0
68a	X-3	0.91 m	0.19	0
69a	X-3	0.74 m	0.01	0.05
70a	X-3	0.95 m	0.17	0
71a	X-3	0.62 m	0.07	0.05
72a	X-3	0.89 m	0.07	0
73a	X-3	0.78 m	0.02	0.08
74a	X-3	1.02 m	0.24	0
75a	X-3	1.02 m	0.23	0
76a	X-3	0.63 m	0.01	0.08
77a	X-3	0.86 m	0.17	0
78a	X-3	1.51 m	0.01	0.01
79a	X-3	1.19 m	0.05	0.17
80a	X-3	1.08 m	0.74	0
81a	X-3	1.21 m	0.72	0
82a	X-3	1.05 m	0.07	0.17
83a	X-3	1.29 m	0.19	0
84a	X-3	1.17 m	0.04	0.19
85a	X-3	1.12 m	0.6	0
86a	X-3	1.24 m	0.75	0
87a	X-3	1.02 m	0.04	0.19
88a	X-3	1.29 m	0.21	0
89a	X-3	1.16 m	0.02	0.1
90a	X-3	1.16 m	0.27	0
91a	X-3	1.27 m	0.26	0
92a	X-3	1.01 m	0	0.1
93a	X-3	1.29 m	0.09	0
94a	X-3	1.16 m	0.02	0.03
95a	X-3	1.22 m	0.09	0
96a	X-3	1.31 m	0.04	0
97a	X-3	1.00 m	0.02	0.2
98a	X-3	1.27 m	0.01	0
99a	X-3	1.18 m	0.13	0
100a	X-3	1.28 m	0.02	0.04
101a	X-3	1.35 m	0.11	0.05
102a	X-3	1.01 m	0.15	0
103a	X-3	1.26 m	0.19	0
104a	X-3	2.75 m	0.01	0

Ill. 79. dimensions on frame b

frame: b





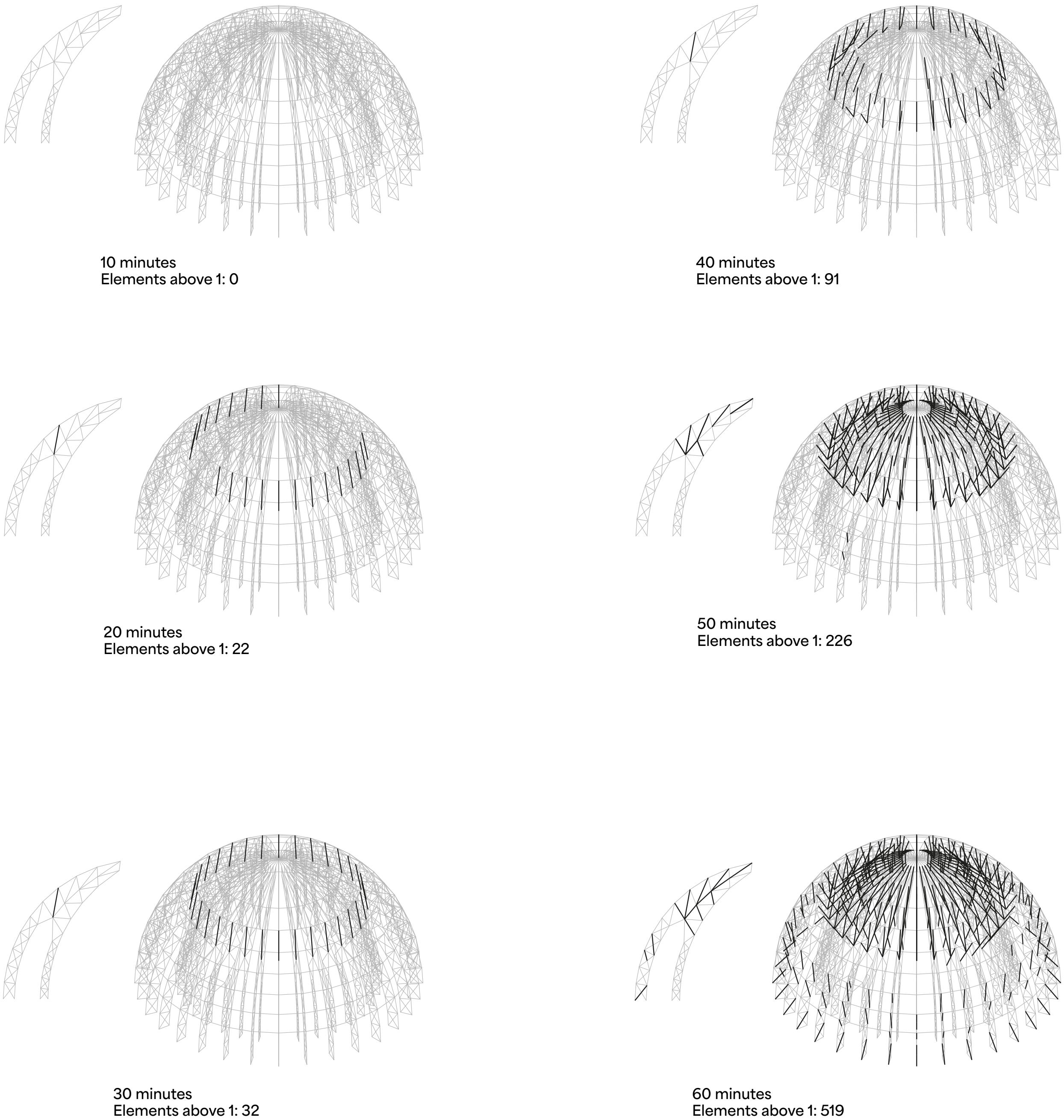
cross-section	dimensions
X-1	*63 x 63 mm*
X-2	*63 x 94.5 mm*
X-3	*63 x 126 mm*
X-4	*126 x 126 mm*
X-5	*126 x 157.5 mm*
X-6	*126 x 189 mm*

For calculations, see appendix H

material: C16 reclaimed timber

id	cross-section	length	util. combined compression and bending (y)	util. factor tension
1b	X-6	1.97 m	0.71	0
2b	X-6	1.99 m	0.14	0
3b	X-6	2.03 m	0.05	0.11
4b	X-6	2.09 m	0.04	0.2
5b	X-6	2.17 m	0.06	0.23
6b	X-6	2.27 m	0.08	0.22
7b	X-4	2.38 m	0.03	0.28
8b	X-4	2.50 m	0.04	0.31
9b	X-4	2.64 m	0.05	0.29
10b	X-4	2.77 m	0.22	0.24
11b	X-4	1.75 m	0.15	0.46
12b	X-4	1.77 m	0.04	0.21
13b	X-4	1.81 m	0.04	0.01
14b	X-4	1.88 m	0.28	0
15b	X-4	1.96 m	0.4	0
16b	X-4	1.96 m	0.11	0.01
17b	X-4	2.75 m	0.07	0.17
18b	X-4	1.58 m	0.08	0.1
19b	X-4	1.44 m	0.1	0
20b	X-5	1.34 m	0.34	0
21b	X-5	1.27 m	0.6	0
22b	X-5	1.24 m	0.86	0
23b	X-5	1.09 m	0.15	0.25
24b	X-5	1.12 m	0.06	0.14
25b	X-5	1.19 m	0.04	0.03
26b	X-5	1.30 m	0.16	0
27b	X-5	1.46 m	0.47	0
28b	X-5	1.67 m	0.66	0
29b	X-5	1.94 m	0.61	0.01
30b	X-5	2.27 m	0.52	0
31b	X-5	2.66 m	0.37	0
32b	X-5	3.07 m	0.23	0
33b	X-2	2.19 m	0.46	0
34b	X-2	2.19 m	0.04	0.21
35b	X-3	3.50 m	0.02	0.08
36b	X-3	2.09 m	0.08	0.06
37b	X-1	2.13 m	0.03	0.24
38b	X-2	1.94 m	0.66	0
39b	X-2	1.94 m	0.2	0
40b	X-3	3.44 m	0.57	0
41b	X-3	2.05 m	0.06	0.09
42b	X-1	2.35 m	0.05	0.14
43b	X-2	1.59 m	0.31	0
44b	X-2	1.59 m	0.59	0
45b	X-3	3.34 m	0.87	0
46b	X-1	2.59 m	0.05	0.07
47b	X-3	2.21 m	0.04	0.11
48b	X-2	1.12 m	0.44	0
49b	X-2	1.12 m	0.45	0
50b	X-3	3.19 m	0.92	0
51b	X-3	2.60 m	0.04	0.12
52b	X-2	1.09 m	0.44	0

id	cross-section	length	util. combined compression and bending (y)	util. factor tension
53b	X-3	0.76 m	0.55	0
54b	X-3	0.70 m	0.09	0.15
55b	X-3	0.80 m	0.11	0.14
56b	X-3	0.66 m	0.5	0
57b	X-3	0.90 m	0.11	0.08
58b	X-3	0.74 m	0.53	0
59b	X-3	0.76 m	0.04	0.14
60b	X-3	0.84 m	0.08	0.13
61b	X-3	0.64 m	0.47	0
62b	X-3	0.90 m	0.08	0.08
63b	X-3	0.73 m	0.48	0
64b	X-3	0.82 m	0.01	0.11
65b	X-3	0.62 m	0.43	0
66b	X-3	0.89 m	0.05	0.11
67b	X-3	0.90 m	0.07	0
68b	X-3	0.91 m	0.03	0.08
69b	X-3	0.74 m	0.47	0.09
70b	X-3	0.95 m	0	0
71b	X-3	0.62 m	0.48	0.09
72b	X-3	0.89 m	0.9	0
73b	X-3	0.78 m	0.53	0.07
74b	X-3	1.02 m	0.07	0
75b	X-3	1.02 m	0.04	0.08
76b	X-3	0.63 m	0.55	0.06
77b	X-3	0.86 m	0.04	0
78b	X-3	1.51 m	0.07	0.08
79b	X-3	1.19 m	0.65	0
80b	X-3	1.08 m	0.09	0
81b	X-3	1.21 m	0.06	0.4
82b	X-3	1.05 m	0.66	0.4
83b	X-3	1.29 m	0.17	0
84b	X-3	1.17 m	0.64	0.04
85b	X-3	1.12 m	0.05	0
86b	X-3	1.24 m	0.03	0.34
87b	X-3	1.02 m	0.61	0.34
88b	X-3	1.29 m	0.11	0
89b	X-3	1.16 m	0.39	0.06
90b	X-3	1.16 m	0.01	0
91b	X-3	1.27 m	0.02	0.22
92b	X-3	1.01 m	0.38	0.22
93b	X-3	1.29 m	0.06	0
94b	X-3	1.16 m	0.22	0.03
95b	X-3	1.22 m	0.05	0
96b	X-3	1.31 m	0.06	0.11
97b	X-3	1.00 m	0.12	0.06
98b	X-3	1.27 m	0.13	0
99b	X-3	1.18 m	0.12	0
100b	X-3	1.28 m	0.06	0.07
101b	X-3	1.35 m	0.21	0
102b	X-3	1.01 m	0.09	0.13
103b	X-3	1.26 m	0.11	0
104b	X-3	2.75 m	0.27	0



Ill. 80. burning of timber elements

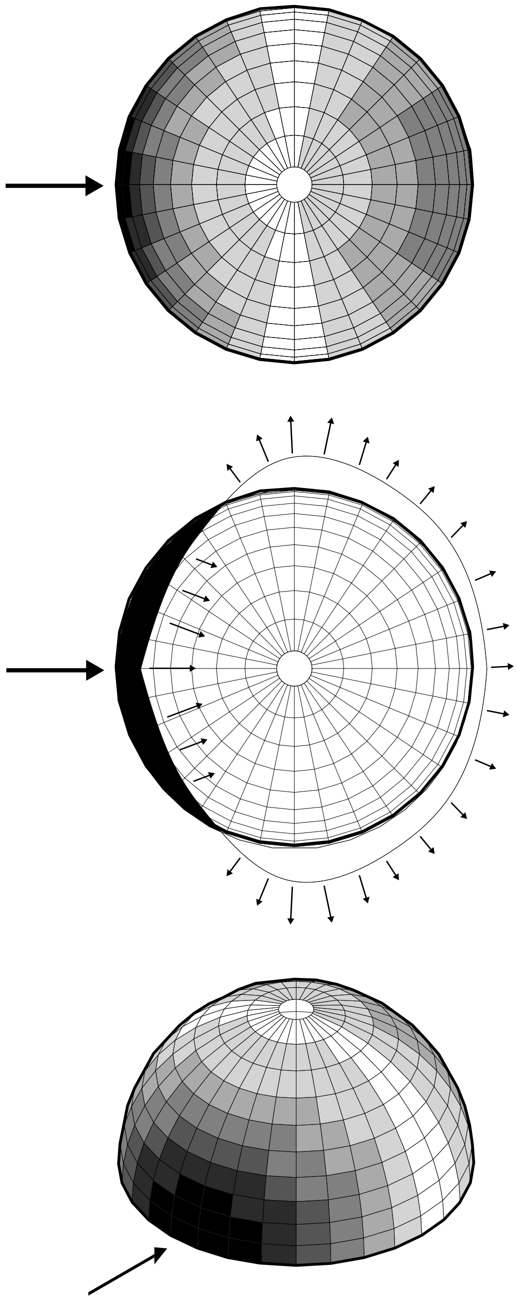
fire

The structural system was tested in a digital fire test which sought to gradually reduce the timber elements cross-section comparably to the burn rate of 0.7 mm/min and evaluate the results. Relevant regulations state that structural elements in a one-story building should be able to maintain their structural capabilities for a burn time of 30 minutes. (Brand (§ 82 - § 158)) The fire is simulated by parametrically reducing all structural elements cross section by 0.7 mm/min. 30 minutes of burn time would reduce the cross sections by 21 mm on all four sides.

The structure shows no breakage in the first 10 minutes of burning. After 20 minutes 22 elements registered having a utilization factor above 1 resulting in breaking. At the 30-minute mark were 32 elements expected to break. The elements expected to break were then removed due to their lack of structural integrity. The removed elements did not significantly affect the remaining structure and 30 minutes of fire won't cause the structure to collapse. As the fire continues, elements gradually break due to their reduced cross-section. The roof covering the center is expected to collapse first which makes the platforms located in the archway between the inner and outer truss relatively safe to move through in the case of an emergency.

loads

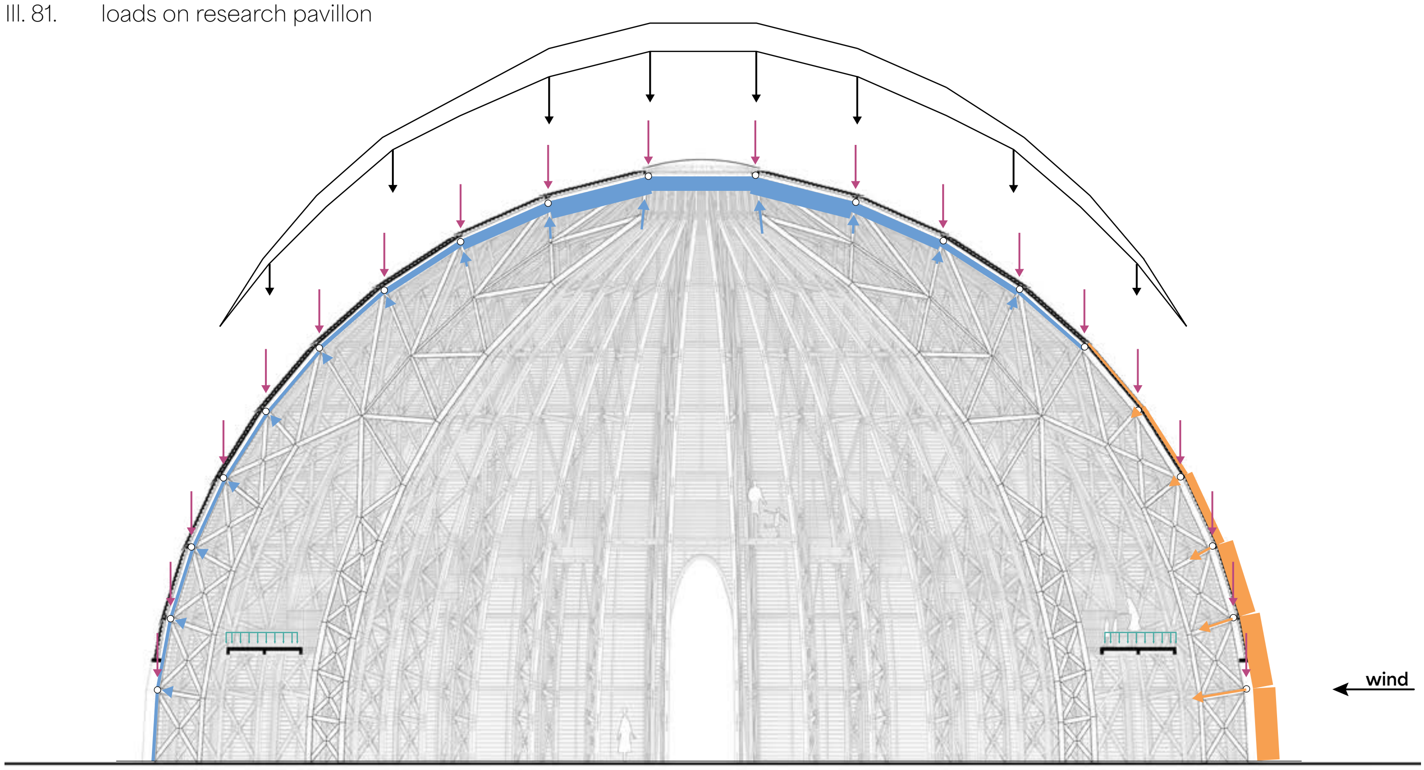
The wind's movement around the dome-shaped structure causes pressure on the panels directly facing the wind direction and an even stronger pulling force on the sides perpendicular to the wind direction. The wind direction dictates which areas that are exposed to either push or pull forces. The calculated wind loads applied to the structure are based on a wind speed of 27 m/s comparable with that of a strong storm. For calculations, see Appendix G.



load-type	amount	display
self-weight	400 kg/m³	—
live load	2 kN/m	→ (teal)
wind load	0,9 kN/m² / -1,4 kN/m²	(blue) (orange)
facade load	30 kg/m²	→ (magenta)
snow load	1 kN/m²	→ (black)

Ill. 82. wind load on research pavillon

Ill. 81. loads on research pavillon



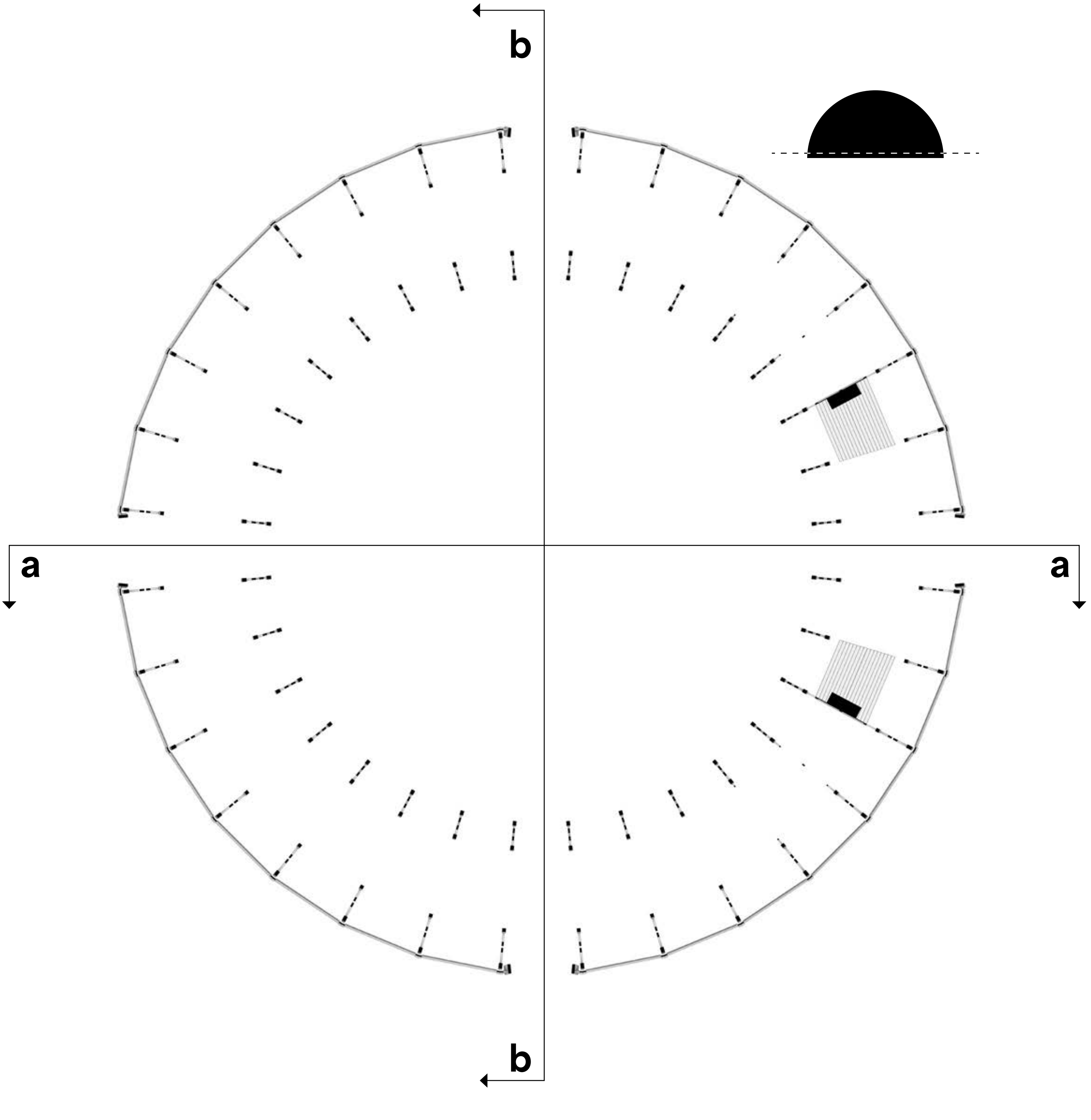
appearence

The facade displays the capabilities and limitations of the wooden shingles. Towards the top is gradually more polycarbonate shingles, accommodating the decreasing angle. Wooden shingles are not a viable solution when the angle is reduced towards the horizontal plane hence the timber would decay within years and not favor the longevity aspect of the structure. The translucent polycarbonate furthermore introduces natural diffuse light in the building opening up and drawing visitors' attention to the structural aspect and span of the structure. Additional polycarbonate shingles replace the wooden shingles along the stair enabling more light.

Ill. 83. research pavillon on coast

plan 1
1:200

The spacious layout of the project is divided into two, the frame forms a 300 m2 inner space and a passable archway. Their structure has four access points, one of which is located at the bottom of the platforms and the remaining three passing under the elevated platforms. All of the entrance points have direct access to the central room. The ground floor has no predetermined flooring to build upon as the structure should reflect its surroundings and build upon its environment.

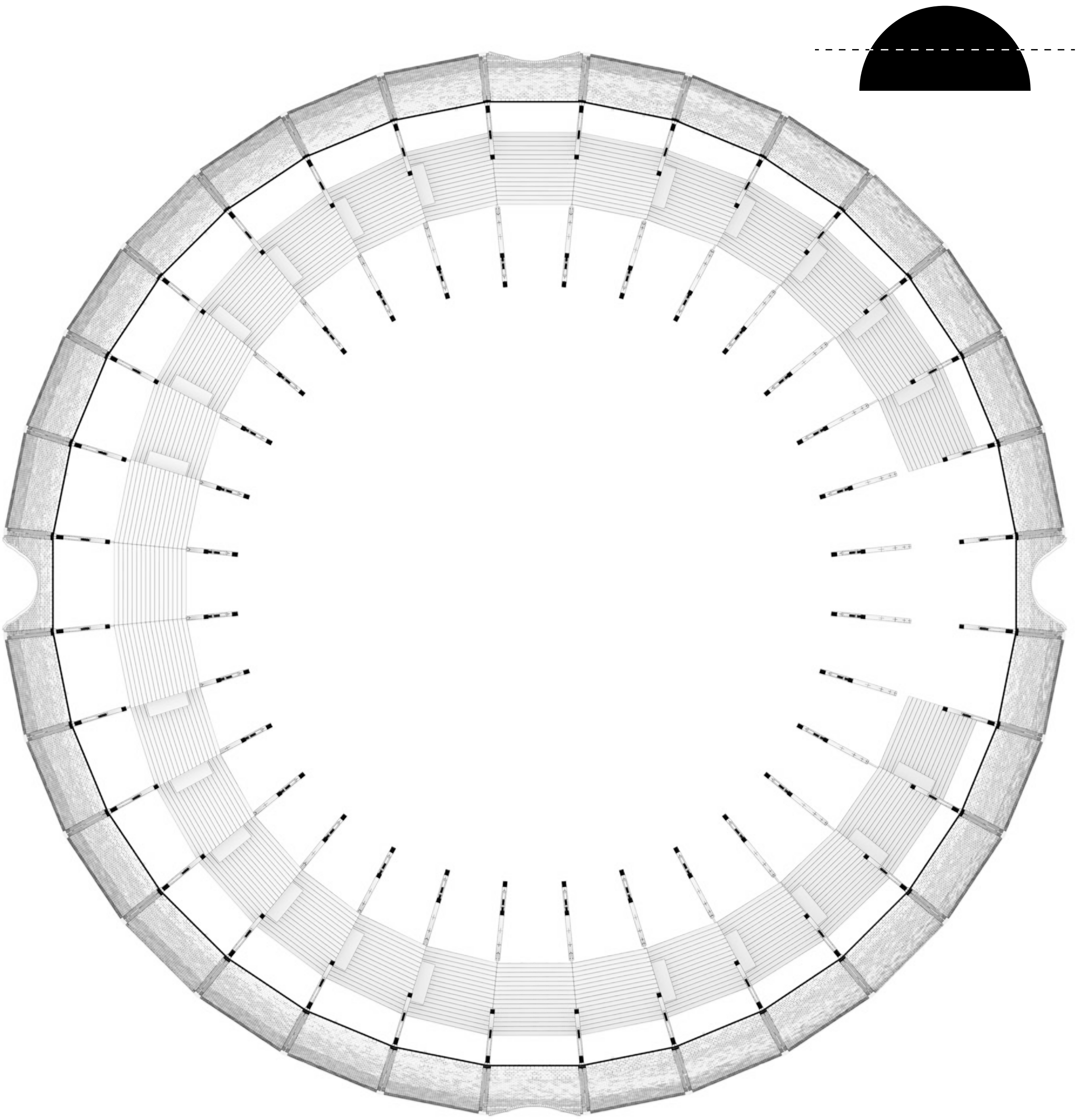


Ill. 84. plan of research pavillon at 0,8m

plan 2

1:200

A total of 29 platforms are situated in the archway shaped by the inner and outer structure, giving shape to a stair along the perimeter. The platform design invites the visitor to step onto the reclaimed material and experience the structure in a more vertical direction, in turn being drawn towards the translucent structural top. Different elements show themselves as they enter the visitor's field of view. The highest elevated platform is located 6 meters above the ground giving the visitor an elevated experience of the structure and central space.

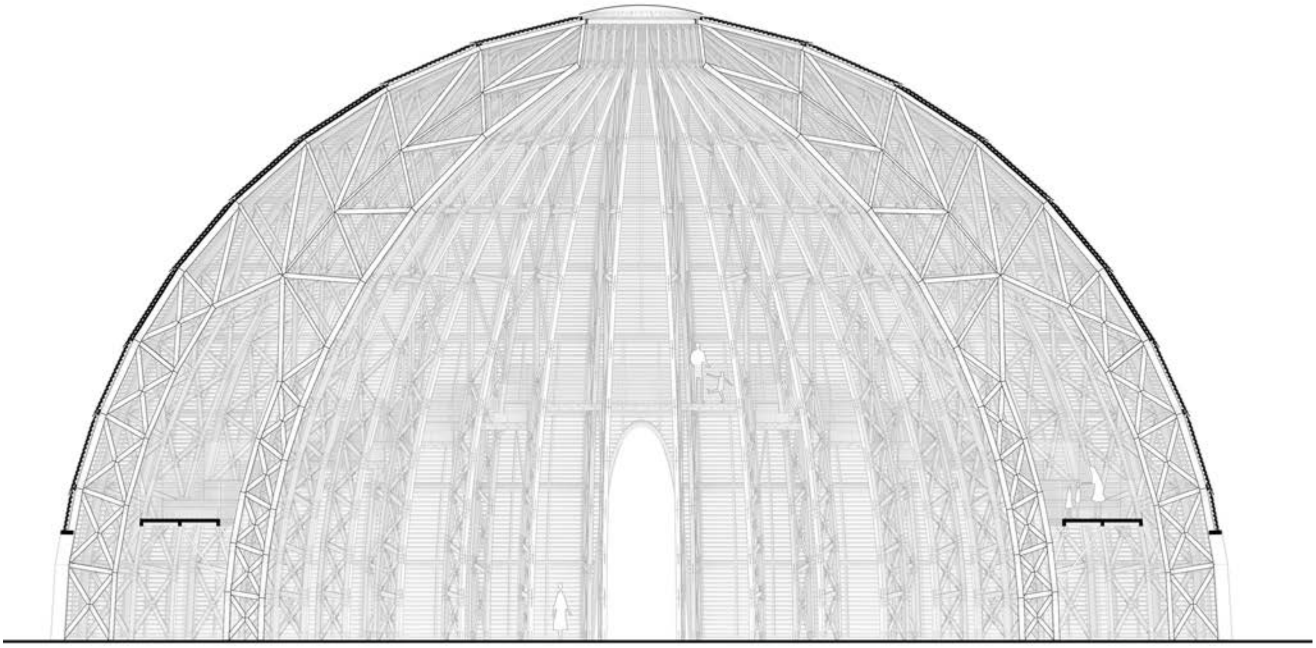


Ill. 85. plan of research pavillon at 7m

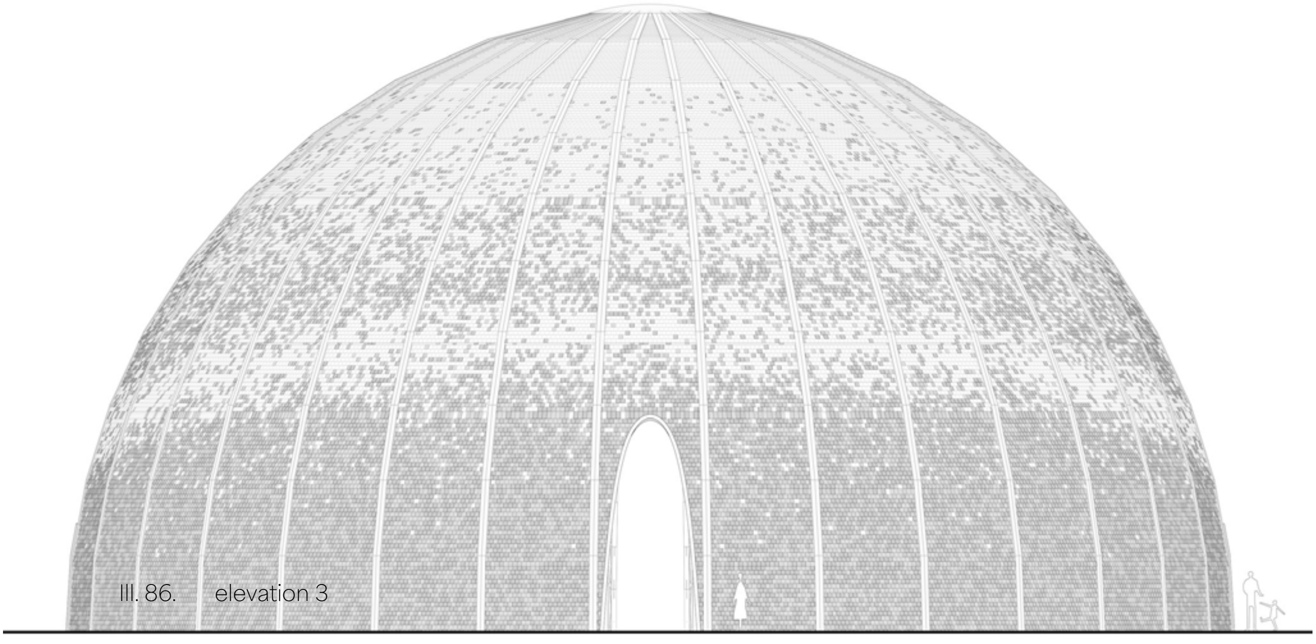
interior

b-b - 1:100

The open interior enables both permanent and temporary functions. The platforms are positioned within the archways and won't limit the possibilities in the center space witch due to its spatial dimensions have a spatial configuration that opens for functional interpretation shaped by the environment and who uses it.



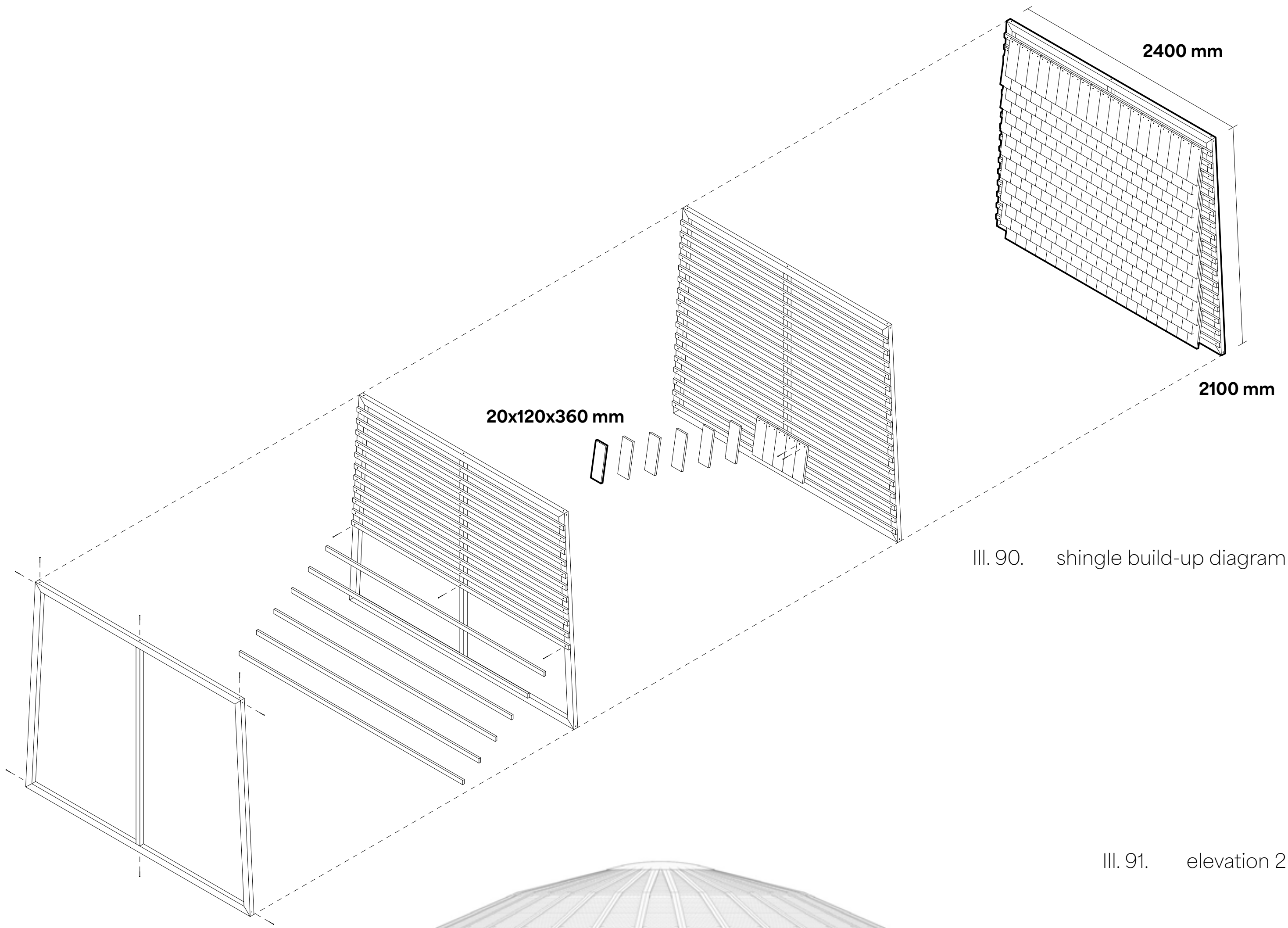
Ill. 87. section 1



Ill. 86. elevation 3

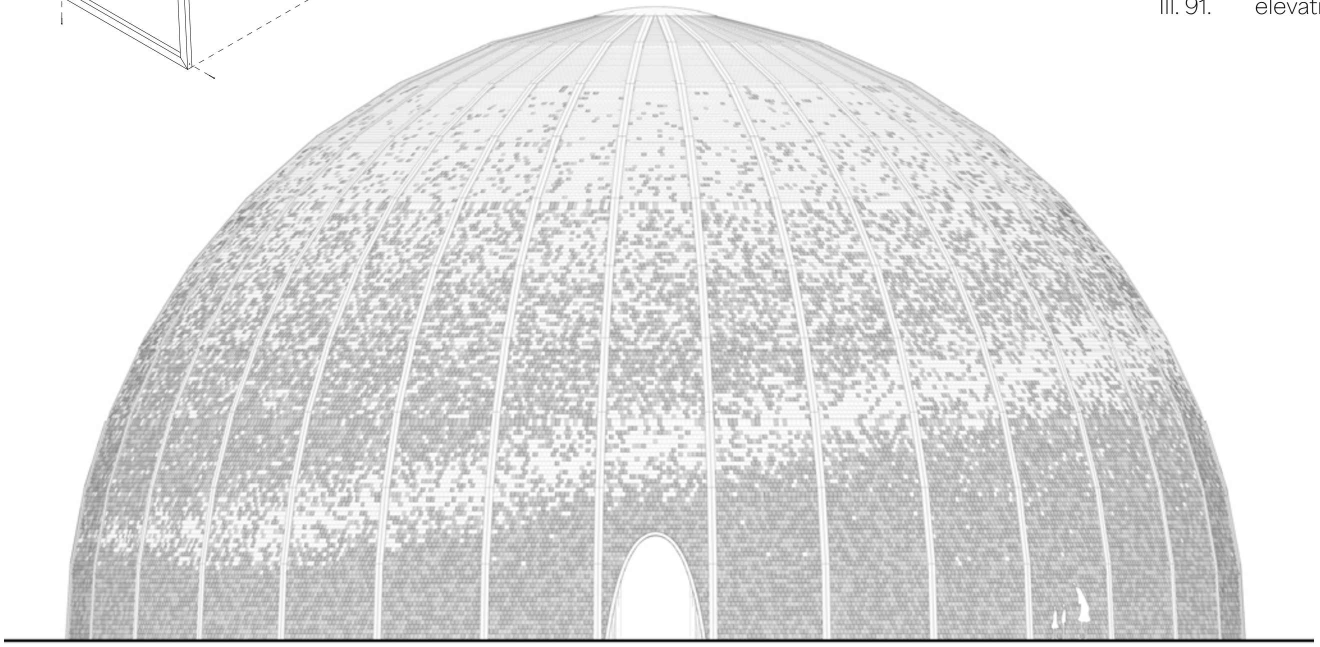
Ill. 88. inside research pavillon looking out

Ill. 89. looking through research pavillon



Ill. 90. shingle build-up diagram

Ill. 91. elevation 2



facade

1:200

Approaching the research pavilion the pattern reveals itself. Indicating the movement within, rising upwards. Moving closer the gradient pattern becomes clear, with the wood growing out of the ground before dissolving in thin air. An analogy of the wood, its life, and its demise. All things must end.

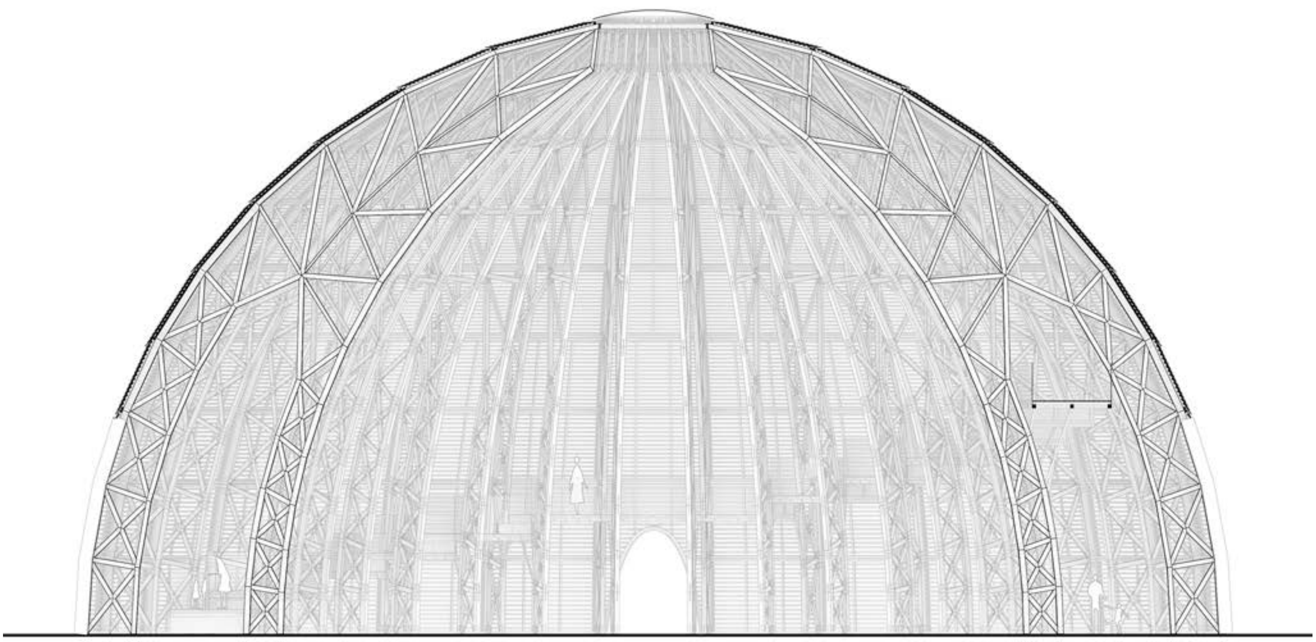
Next to the pavilion, you can see each individual shingle, and how they cracked differently under the extreme heat of the shou-sugi-ban. Raising your hand and feeling the velvety char turning your fingers black as you walk towards the entrance.

The panels are constructed as modules that can be independently manufactured and assembled. With the possibility to replace a single shingle or an entire panel in minutes. making maintenance easy and accessible to ensure longevity.

experience

a-a - 1:200

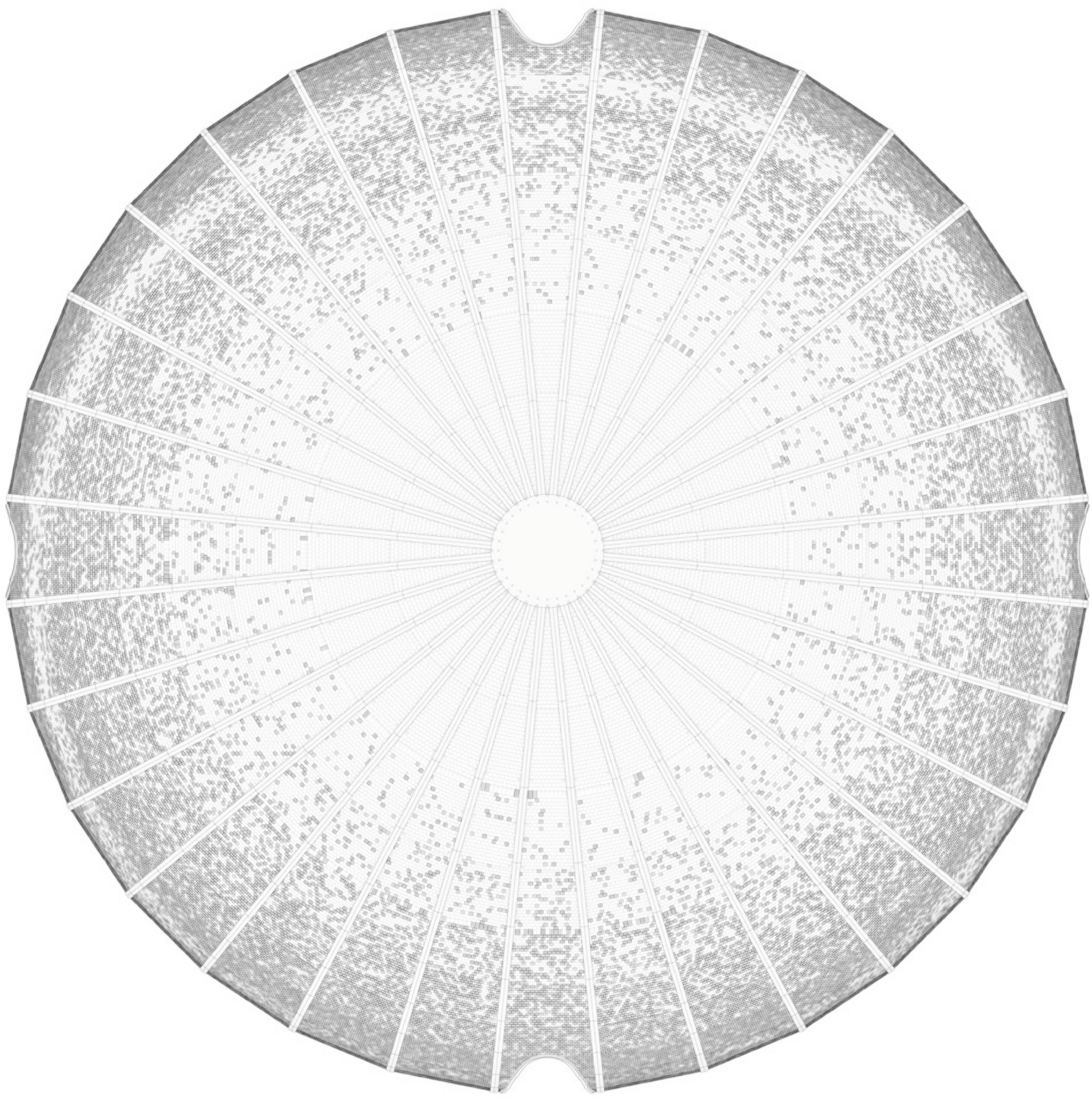
The learning experience gathered from visiting the research pavilion is centered around the reclaimed timber. The structure's monumental scale and simple geometry display the potential of the reclaimed timber. The structure presents the timber's visual qualities as well as its tactile as the entire structure can be seen and touched.



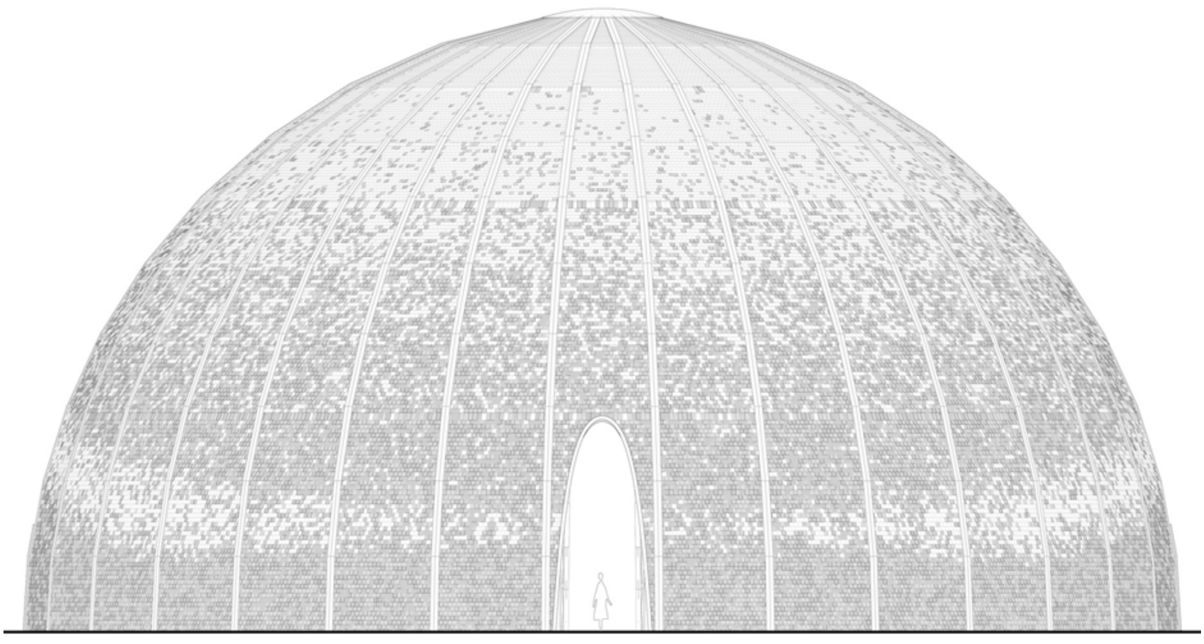
Ill. 92. section 2

Ill. 93. on platforms in research pavillon

Ill. 94. research pavillon in østre havn, aalborg



Ill. 96. top view



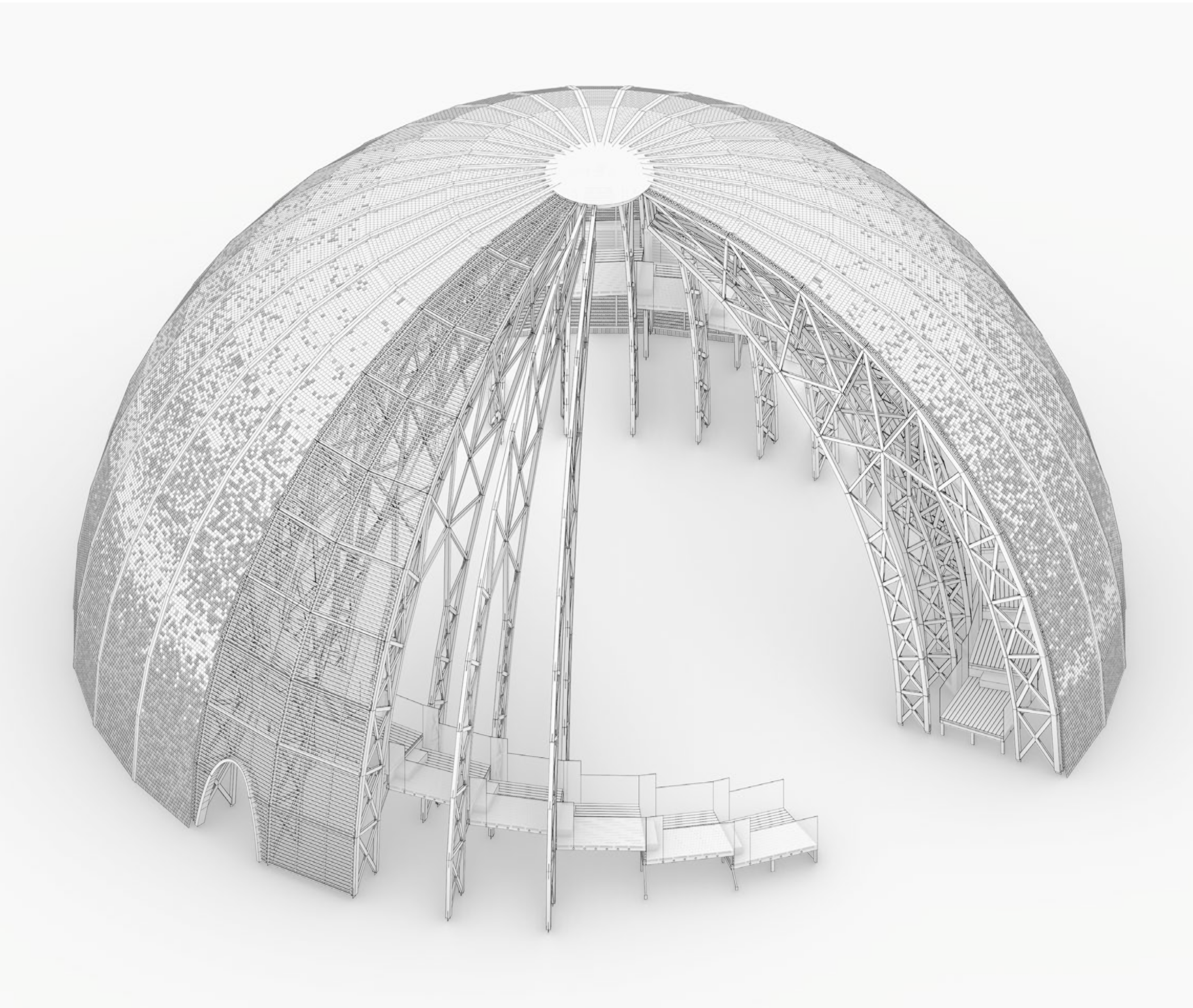
Ill. 95. elevation 1

Ill. 97. research pavillon on beach

"A creator is someone who creates their own impossibilities, and thereby creates possibilities."

Gilles Deleuze

Ill. 98. isometric of research pavilion



OUTRO

CONCLUSION

The project is a proof of concept based on demonstrating the potential of reclaimed timber. The design stride to act on the consciousness of the pavilion's visitors, creating awareness and through this awareness educating the wider society. Pushing for a more sustainable building sector the research pavilion should be considered as an example of how waste materials can be implemented into the circular economy, the potential present in reclaimed timber, and how its material properties come to be reflected in a design solution that distinguishes itself from what is seen today and interprets what is possible in the near future. The values of the design are expected to remain relevant for the foreseeable future, ensuring the structure's longevity. When working with longevity in timber structures a key aspect is keeping water away from the structural elements. By utilizing waste materials as the facade cladding we are taking a product that would otherwise be discarded, a material whose material properties don't allow for structural use, but still have the necessary integrity to deflect water. In doing so replacing new timber to expand upon the available materials in the building industry. The difference between designing a building that can last and a building that will last is the reception by its constituents and if it is allowed to last. It necessitates a strong connection between building and man, where a unique narrative can be told through the building. A building that is explicit in its design, allowed to adapt to the time it is in, while still possessing the values of its own time. Predicting the functional needs of the future is difficult. To therefore discard the established notion of how we can build opens for a plethora of interpretations that can accommodate tomorrow's needs as well as today's. The challenge lies in providing incontestable and compelling proof that will compel the wider society to rethink how we build. When looking at cities and developments as not only what facilitate human life, but as what could provide the supply for further development has the potential of revealing an eldorado of resources. Discarded structures that have outlived their use contain an abundance of resources, like the mink farms, where the wood has been sheltered from the rain and subjected to plenty of airflow the wood still has a lot of potential for reuse and to be reclaimed as timber.

Wood from the mink farms that otherwise would end up being recycled, recovered, or becoming waste has the potential to be reclaimed as timber for use in the design of new buildings.

A functionless building that exists in its isolation, sees time pass by while facilitating all who come by. A building that asks for nothing while accepting everything. A monument that conforms to its surroundings while it reminds us all, to think of those that come after.

REFLECTION

a range of reflections through the process presented themselves and raised questions aimed at our process, future work, and alternative angles of entry. The following reflections are based on said emerging questions encountered along the unknown paths we followed as we sparred with the material.

/turning the process up-side-down

We have through our education worked extensively with the traditional phases in the field of architectural design, generally made up of; pre-design, schematic, and design development framed by the integrated design process. The three phases are a conclusive encompassing trinity that covers a wide array of projects faced generally in architecture and also during our education. This structured way of addressing architecture and design was discarded in favor of the unknown. The unknown is the reclaimed material and underlying qualities, capabilities, and potentials. Fully surrendering to the material and breaking ties to a well-known method like the integrated design process is a terrifying prospect but nevertheless necessary if new and experimental knowledge is to be created. Through the process of designing and working with the material the focus shifted from being centered around developing a more or less predetermined typology, towards accepting and working with the limitations of the reclaimed timber, not seeing the design as the end goal but more as a result of an experimental process.

/the process of creating new knowledge

A majority of regulations found in for example Danish Standard is built up around scientific results and empirical results. The process of creating new data is a difficult process based on the extensive amounts of testing that are required to achieve statistical significance, to enable replication, and guarantee the results. Having a limited number of tests makes the individual test results unreliable as there is no way of knowing where the results are placed on the distribution that it is part of. The project and our acquired material knowledge is based on research done on the potential for reclaimed timber, waste, or undesirable wood, supplemented with our own tests. Often they are only concepts, sometimes proof of concept but rarely developed and proven theories. The notion that timber structures have the capability to stand for centuries if maintained and the design considers the environment it is situated in makes it fairly easy to induce that wood should have the potential to be used for more than 50 years, but the nuances of its life story make it challenging to categorize and designate it to categorize.
Comprehensively testing the potentials and material properties of reclaimed timber is a research project in and of itself, that will far surpass the time and resource requirements available for this thesis. As such simplifications and assumptions have been made but the thesis sought to be a part of the foundation on which the future of reclaimed timber stands, by stating identified potentials in utilizing relevant technology to estimate materials properties and design a feasible structure.

/technological aspect and the construction methodology used today

The elements are to be thoroughly analyzed for defects and internal damage if they are to be applied to a structure. One of the primary testing methods used today to determine the properties of a material relies on destructive tests. This method is not suitable for reclaimed timber that is sourced from a limited stock of each individual context, where “all” elements have to be tested and therefore destroyed. The potential for establishing a reliable non-destructive test was investigated and the results were promising. The adaptation of technologies from the medical industry in the form of analytical equipment with the capability of determining the structural properties have been developed for wood and are in use at industrial-scale timber manufacturers and sawmills. Using this technology to not produce new timber but to analyze reclaimed timber would be a step in the right direction the technology exists and the knowledge foundation is exciting, it just needs to be prompted or incentivized for someone to further adapt this technology to another part of the industry. We were however not able to analyze the reclaimed material in such a machine and the project is therefore built upon the idea that it would be possible to analyze reclaimed material and obtain reliable results and strength grades in the process.

/computational design

Today most architects and designers take advantage of computational design and computer-assisted design tools. This project is no exception when trying to investigate and unlock the reclaimed materials’ structural properties. The process of doing so relied on us being able to both understand and develop strings of code in Grasshopper usable for different studies. This way of work made us more authors of code than sketching architects and resulted in hours and hours in front of the computer. The process of using computational design seemed slow and uneventful up until the script was nearing completion. We suddenly had literally millions of potential designs just waiting to be explored and evaluated in regard to structural and architectural qualities. Investing time into coding paid off partly due to the structural calculations that with Karamba could be finished in a matter of seconds.

The design process was reliant on computational capabilities and differentiated itself from a more traditional design process in that its focus points were not centered around shaping a specified space for a predetermined function at a predetermined site but rather sought to enable the reclaimed material to show its capabilities and form the project on behalf of the material. Another aspect of computational design opposite to us where we used it to evaluate thousands of solutions based on a few inputs, is its capability to also take databases with thousands of options as inputs. Here lies a huge potential in combining computational design with 3D scanners and other tools that can evaluate materials on millimeter precision in all dimensions at the same time. Using the results from scanners as inputs to choose, shape, cut, and place material to utilize the material to its full extent.

/the construction methodologies of today and tomorrow

With the processing powers of computers today the limitations of what is possible is the human imagination and what they can do. The focus of this project was rooted in trying to alleviate today’s problem and as such was looking for solutions that could be implemented today and not the potential of tomorrow. New ways of construction are emerging with robotic technologies at its center. These modern technologies enable unprecedented precision and efficiency and the potential of combining computational design with robotics would enable the utopia of material-oriented design where every element could be utilized to its limit.

This project is however shaped for the construction methodologies available today in that it is based on processes utilizing technologies already available alongside consideration of how the construction site operates today. The project and the design outcome had been completely different if centered around robotic construction and the advantages that reside in that field. Utilizing robotic technologies to achieve maximum strength by trimming, cutting, and reducing defects to produce timber elements with the highest possible strength and not settle on the lowest grade observed in each individual element could customize each frame based on different elements with different properties.

/rules and regulations

To provide the project with relevant ties to the applicable rule and regulations a majority of building codes, standards, and Eurocode relating to wood and timber constructions was looked through. In an interview with a consultant from Danish Standard, it became apparent that testing, analyzing, and building with reclaimed timber would be more realistic if the grading methodology, properties, and construction methods of reclaimed timber could be used with the use of current standards. This constituted a framework for the project, conforming to relevant rules and regulations for timber construction.

The number of rules and documents detailing what seems to be every aspect of timber construction can be overwhelming and with the project's experimental nature, it is simply impossible to comply with all regulations. Timber elements with visible insect attacks cant for example constitute structural elements as their internal condition cant be guaranteed. Technology using 3D-scan can provide an in-depth understanding of the internal condition of an element. This would arguably be enough proof to determine whether an element is suited for structural application. If a project of this character were to be established some standards would need to change or at least be compensated by a set of specific regulations applied to structures utilizing reclaimed timber to make it an economical alternative. Current research, with the assistance of modern technology, goes a long way to enable the use of reclaimed timber if relating to the building regulation that allows the use of alternative materials, it is just an expensive affair that makes it infeasible. Another aspect is that this "exemption" in the regulation still has to be approved by a case worker at the relevant municipality. Here there is a question of this worker's subjective decision as they are putting their name on an untested project. So it becomes a cycle of not getting it approved since it hasn't been done before and but you can't realize it before it gets approved. This was the case for the 'Upcycling orangeri' which was first rejected in Aalborg, but after it had been realized in Frederikshavn it was accepted in Aalborg.

/research pavillon

When working with the 'research pavilion' the goal is to present and convey the results and potentials of the research. It seems fairly simple to do, however, it is not easy to argue for subjective opinions and choices in architecture, even when based on empirical data and research. The research pavilion is a dome made of timber frames covered in wooden and translucent polycarbonate shingles - but why is this exactly? The reclaimed timber was to dictate choices, giving the material agency, but where lies the border of what the material wants, and what the material has been manipulated to want? Arguing that timber wants 90-degree angles and squares is a reasonable point of departure, but it originated as a cylinder - it has already been manipulated into a building material favoring the grid. So the next point of departure is the grid, but we made a circular-based frame. Already there the wood is presumed to have been augmented to create the large span and height. The timber is cut in angles to create the curve, and even further cut into to give space for a steel plate to connect the wood in joints. It seems that the wood is being neglected, that its agency is taken away. Recognizing the original, cylindrical piece of wood, it would never in its state alone become anything than logs. Instead of using the word manipulating, we will use the word helping. Treating the wood and using steel plates and bolts for joints is helping the wood, boosting its potential, and helping it to become something more. The addition of metal in the joints and the augmentation of the timber elements are recognizing what wood can, and what it can't. Wood can sustain compression, but it cannot join 6 timber members together to form a rigid joint.
The dome shape is an odd result for a project working with timber, recognizing that wood is a rectangular building material.
Maybe we do not show what wood wants, but what it can.

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APPENDIX

appendix: a
Arbejdsbeskrivelse miljøsanering og nedrivning

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Kajs & Bjarkes minkfarms

appendix: c
relevant Danish Standards

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titan nedbrydning notes

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Arbejdsbeskrivelse miljøsanering og nedrivning

Bygningsstyrelsen (no date) Arbejdsbeskrivelse miljøsanering og nedrivning. Bygningsstyrelsen.

BYGNINGSSTYRELSEN

1 Indledning

Denne arbejdsbeskrivelse vedrører miljøsanering og nedrivningsarbejde i henhold til rammeaftale om nedrivning af minkerhvervets produktionsanlæg.

Bygningsstyrelsen står foran eksekvering af nedrivning og bortskaffelse af 1.246 minkfarme.

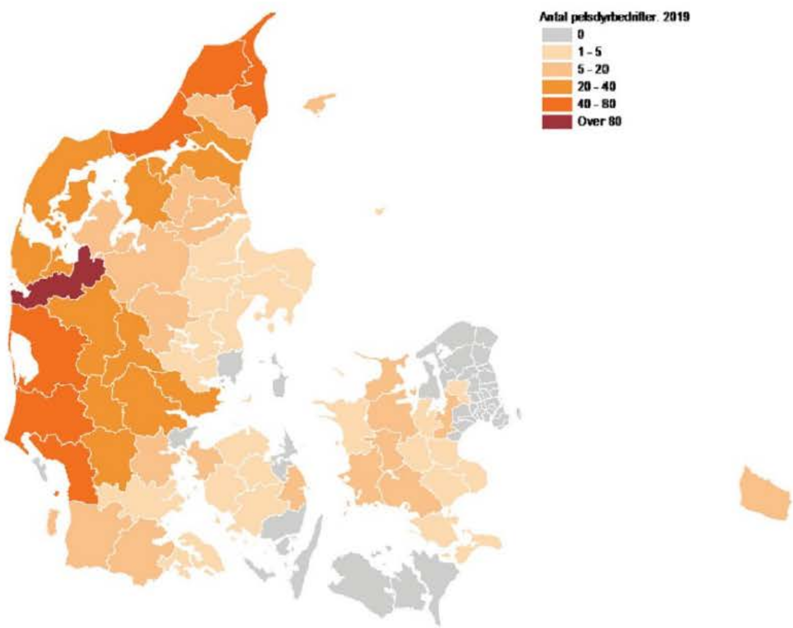
Krav til gennemførelse af nedrivningsopgaverne skal som minimum overholde NMK96 og øvrige regler og retningslinjer for nedrivning af bygninger samt håndtering af affald.

Omfanget af nedrivningsopgaven er samlet estimeret til at omfatte:

- 8 mio. kvm. bygningsmasse
- 10,9 mio. minkbure svarende til ca. 40.000 ton. metalskrot
- 10,9 mio. redekasser og tilhørende legerør i plast
- Mere end 3.000 km gyllerender
- 1.000 stk. gylletanke

På ejendommene er det anslået at der forefindes ca. 1.500 fodersiloer og kilometervis af beton/asbesthegn, dertil kommer maskinhuse, pelserier og mandskabsfaciliteter på mange af minkfarmene.

Nedenstående kort viser fordeling af minkfarme i 2019:

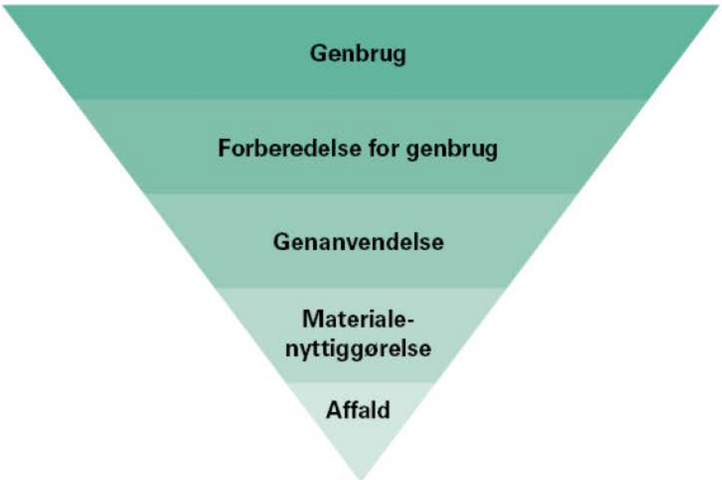


The two pages are relevant examples from the tender from Bygningsstyrelsen about demolition of mink barns. The full document can be retrieved by contacting Bygningsstyrelsen at:

www.bygst.dk
+45 4170 1000
bygst@bygst.dk

BYGNINGSSTYRELSEN

5.2.1 Genbrug, genanvendelse og bortskaffelse af bygge- og anlægsaffald



Genbrug - Genanvendelse

Affald i forbindelse med nedrivning af bygninger og konstruktioner skal bortskaffes til genanvendelse, forbrænding eller deponering og skal opdeles som minimum i følgende fraktioner:

- Natursten, f.eks. granit sten
- Uglaseret tegl (mur- og tagsten) som ikke genbruges
- Beton
- Jern og metal
- Gips
- Stenuld (Nyere end fra 1998)
- Asfalt (fra veje mv.)
- Blandinger af beton og asfalt
- Asbestholdige materialer (inkl. jord med asbest)
- Træ og træbaserede plader
- Glas
- Pap/pap og beton, hvis pappet ikke kan skilles fra
- Elkabler
- Plast i minimum 3 rene fraktioner (PP. PE. PVC)
- Termoruder
- Olie i pumper og maskiner
- Ren jord
- Let forurenet jord
- Forurenet jord

Entreprenøren skal sikre at termoruder, som ikke kan dateres produceret efter 1977, udsorteres som farligt affald til destruktion, da disse med stor sandsynlighed indeholder PCB i kantforseglingen i høj koncentration.

appendix: b

Kajs & Bjarkes minkfarms

Kajs mink barns

1985:
The oldest still-standing barn is from 1985. It is a traditional and highly used 2-row, 47-frame wooden construction, with room for 287 mink. The joint and assembly method is made with small metal plates and nails. The condition of the wood is quite good considering it had been standing for almost 40 years.

2006:
A somewhat homemade 4-row 47-frame wood construction. Hence the barn is twice as big as the one from 1985 it consists of more wood and bracing. This barn has room for 1128 mink. The joint and assembly method used in this barn varies and reflects the barn being made by himself and not prefabricated. Small metal plates, nails, and nail boards are used depending on the forces present in the different assembly points. The timber used for this construction is partially reused from a barn that was torn down.

2013:
A 4-row 23-frame construction made of steel frames, metal bracing, and wooden roof laths. The barn has room for 1104 mink. The metal frames enable large spans and visually more open construction. The joint and assembly method is made of bolts and metal plates welded to the structural I-beams.

2014:
A commonly used prefabricated wood construction consisting of 4 rows and 47 frames. The barn size and capacity are similar to the 2006 barn and have room for 1128 mink. The wooden structure is joined exclusively by nail boards. The timber used for this barn has the visually best condition of the barns at Kaj´s farm.

Bjarkes mink barns

2016:
Two connected 12-row, 47-frame barns made of timber. This structure is considered Denmark's largest timber barn spanning 28m in width and consisting of approximately 1 m³ of wood per frame. The barns were partly prefabricated and assembled into completed frames at the site, then joined together before bracing, laths, and roofing were added. The joints are primarily made of nail plates with additional screws and bolts added during assembly. Despite the size of the 12-row farms, timber was still the material of choice, and to our surprise, the timber elements were not considerably bigger than what was used at a 4-row barn, there were just more elements.The sheer amount of timber elements visible made the visit interesting from an architectural standpoint. The timber doesn't show any visible damage and the wood seems to be in good condition due to free airflow through the mesh sides.

2018:
Two 12-row, 47-frame barns made of large metal frames spanning 28m. One barn has a capacity of 3300 cages. The laths in these barns are the only elements made of timber. The joint and assembly method is made of bolts and metal plates welded to the structural I-beams. Metal plates are also used to extend the timber laths thereby enabling greater spans.

2020:
The farm was in the process of expanding its capacity when the mink industry was shut down. The intended expansion was made up of 15 2-row, 47-frame barns. The barns had previously been situated at another location but were overtaken by Bjarke who intended to set them up at his farm. The timber´s condition is good considering its previous use. The joints and assembly method of these barns is nail plates and would collectively have had a capacity of 4000 mink. The expansion was halted and not completed due to the industry closing.

appendix: c

relevant Danish Standards

Regulations set by Danish Standard (DS) are subdivided with additional regulations for mass timber products and structural finger joints. The standards DS/EN 15497, DS/EN 14080, and DS/EN 16351 are seen as an addition to DS/EN 14081 which constitute the foundations for further processed timber products.

DS/EN 338

- Structural timber and strength classes

This document contains characteristic strength values for both softwood and hardwood. The tables are divided into C- and T-classes. This regulations act as the foundation for the dimensioning of any timber constructions using both solid timber and mass timber products. The tables contain contain the following values

- Characteristic bending strength
- Characteristic tension strength (parallel and perpendicular)

DS/EN 14081

- Strength graded structural timber with a rectangular cross-section

This document contains different rules and regulations regarding the properties of structural wood. These regulations are to be upheld if said wood is to be used either on its own or in the production of mass timber products (glulam or CLT).

- Requirements for structural timber
- Fire resistance
- Structural timber with and without preservative treatments
- Factory production control (FPC)
- Marking regulations

DS/EN 15497

- Structural finger joints

This document contains information regarding standards for dimensioning finger-jointed elements and characteristic properties regarding strength.

- Dimensioning of finger joints
- Structural properties (compression, tension, and bending)
- Adhesive material
- Resistance and reaction to fire

DS/EN 14080

- Glued laminated timber and glued solid timber

This document contains all worth knowing about the production, strength, rules and values of laminated timber (glulam and CLT).

- Strength and stiffness of used boards
- Strength and zone differences in glulam products
- Strength and stiffness of finished glulam products (combined and homogeneous)
- Finger joint requirements, strength, and tests
- Adhesive material requirements, strength, and tests
- Moisture measurements
- Minimum production requirements

DS/EN 16351

- Cross laminated timber

This document contains information about the properties, production, strength, and verification of cross-laminated timber (CLT).

- Board build-up, sizes, and placement
- Strength, stiffness, and bending tests
- Adhesive materials, regulations, and tests
- Finger joint test
- Finger joint production
- Moisture content

DS/INSTA 142

- Nordic visual strength grading rules for timber

This document explains how to measure and visually grade timber elements alongside images showing different defects found in timber elements. This document is a central part of the visual grading process. Some of the measuring methodologies include

- Annual ring width
- Knots measurements
- Grade slope
- Distorsion

appendix: d

titan nedbrydning notes

The task of taking down all the mink barns is huge and the task cant be handled by a single firm. The Danish mink farms have by Bygningsstyrelsen been divided into two regions, east, and west. 6 entrepreneurs are set to manage the demolition of region west and 5 entrepreneurs will manage region east. The demolition of each region will consist of a range of bids to subcontractors who then will demolish specific farms when the time comes.

To get a better understanding of the demolition process we reached out to one of the entrepreneurs applying for region west.

We met with Hans Ulrik Møller who is marked-chief at Titan Nedbrydning to discuss their demolishing process and the potentials in reclaimed materials. Titan Nedbrydning A/S is a demolition firm with around 130 employees handling the task of demolishing buildings and structures all over Denmark. They are currently in the process of applying for a task to demolish a range of mink farms around Jutland. In addition to demolishing buildings they also practice selective demolition and repurpose the reclaimed material for new projects.

They have recently finished a project named “Upcycling Orangeri” which primarily consists of reused materials such as concrete slabs, repurposed windows and reclaimed wood from a roof renovation. All the material gathered has been used to shape a new 50m² orangery, the project is a result of a collaboration with local architects and engineers and Titan Nedbrydning providing reclaimed materials.

The demolition process is complicated and involves a lot of safety measures, environmental considerations and documentation. The from bid to demolition typically involve the following steps:

Tender material

The task is assessed by the entrepreneur and an estimated price alongside environmental and safety precautions is noted. A bid for the task is sent back.

Client dialog regarding the bid

Discussing relevant topics regarding the task with the client and possible alterations to the bid is adjusted and agreed on.

Approval or rejection of bid

The bid is either approved or rejected by the client. If the bid is approved is the task handed over to the entrepreneur and further detailing the specific tasks and precautions regarding safety and environment.

Environmental documentation and reclamation of materials

The step contains a lot of documentation. All elements should be documented and environmental risks should be informed to the authorities before being properly disposed of. It's important that no materials and elements are forgotten hence the entire demolition process should be explainable if need be.

Initiating the demolition

When all documentation is in order can the demolition commence. At site a staff meeting is held informing about safety, environmental issues and possible reclamation of certain materials.

During the demolition

Whilst the demolition is ongoing, employees should take notes and pictures regarding material conditions, amount, possibility for reclamation and potential environmental issues.

The removal of hazardous material

Materials with environmental and safety precautions have a different process. The older mink barns would for example be expected to contain asbestos within the roofing. Broken roofing plates containing asbestos contaminate the surrounding area with asbestos-dust. The employees are therefore adequately equipped with protection before bagging the elements in two different plastic bags and then vacuuming the surrounding area and getting rid of accumulated dust. Materials in close proximity to broken asbestos containing roofing plates is not safe to reclaim and should therefore be properly disposed of.

Reclaimed materials

Materials labeled suitable for reclamation can be sold to either private or public customers. Materials containing unwanted nails, screws and other foreign objects are removed by employees at Titan Nedbrydning´s storage facility. Reclaimed materials are usually not more affordable than newly produced material due to the processing time of gathering and cleaning reclaimed materials.

Using reclaimed materials is contrary to the general idea of reuse quite expensive and usually has an increased cost compared to new materials. The expenses tied up with reclamation lies within the processing, gathering and cleaning of materials. The incentive for utilizing reclaimed materials is therefore focused on CO2 savings, aesthetic- and narrative qualities. It is generally speaking possible to reclaim and reuse around 50% of the material demolished, the loss is contributed to destroyed, damaged and environmentally dangerous elements. The potential for reclamations also relies on a careful disassembly process hence this would lead to fewer materials being destroyed during demolition.

appendix: e

delamination test results on wood from mink barns - anneberg limtræ

Workers at Anneberg Limtræ explained that these results are comparable to regular glulam products.

Summary Report

Serial Number 064030406
Logger Name Anneberg Log

First Reading	12:02:06 06-03-2023
Last Reading	13:35:36 08-03-2023
Elapsed Time	2d, 1h, 33m, 30s
Total Readings	5948
Alarm	*Triggered*
Logging Rate	30 Seconds

Celsius

Minimum
24,5°C 13:32:06 08-03-2023

Maximum
75,5°C 11:55:36 07-03-2023

Average Reading
64,09°C

Mean Kinetic Temperature
63,92°C (ΔH83,14472)

Standard Deviation
7,47°C

	Low Alarm 20,0°C	High Alarm 70,0°C
Alarm Occurrences	0	23
Total time in alarm	N/A	7h, 53m, 0s
First Alarm Triggered	N/A	01:52:36 07-03-2023
Longest Alarm	N/A	2h, 36m, 0s

Humidity

Minimum
2,5%rh 12:01:06 07-03-2023

Maximum
36,0%rh 12:06:36 06-03-2023

Average Reading
9,27%rh

Standard Deviation
6,52%rh

	Low Alarm 10,0%rh	High Alarm 50,0%rh
Alarm Occurrences	20	0
Total time in alarm	1d, 10h, 28m, 0s	N/A
First Alarm Triggered	17:49:36 06-03-2023	N/A
Longest Alarm	18h, 2m, 30s	N/A

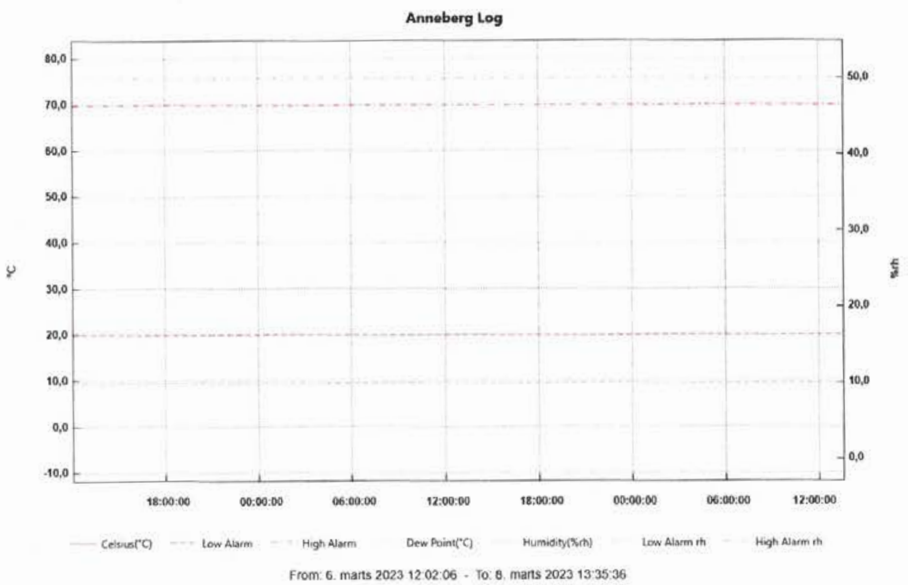
Dew Point

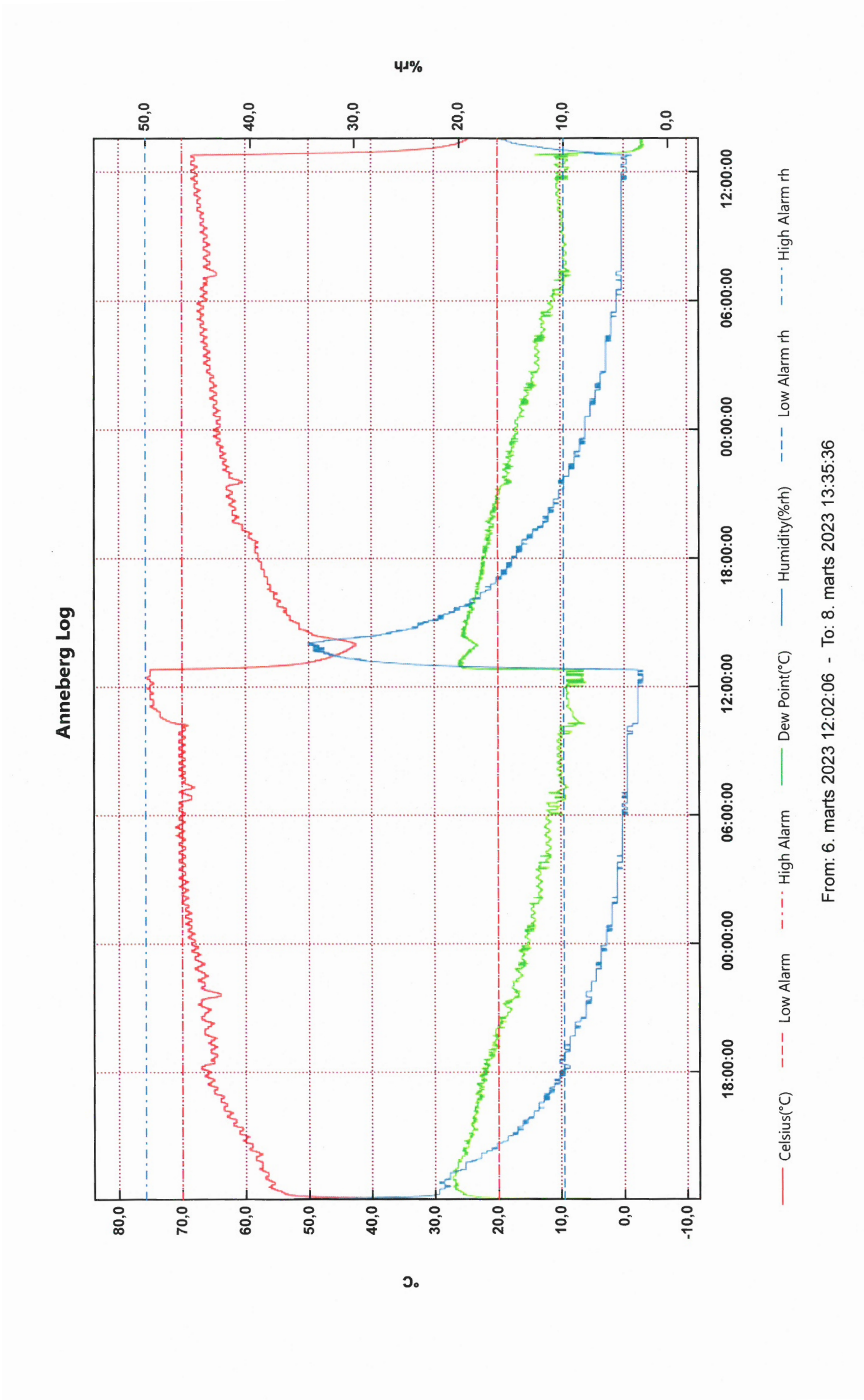
Minimum
-3,2°C 13:14:36 08-03-2023

Maximum
27,3°C 13:23:36 06-03-2023

Average Reading
16,09°C

Standard Deviation
6,12°C




Anneberg Log
°C
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
-10,0
%rh
50,0
40,0
30,0
20,0
10,0
0,0
18:00:00
00:00:00
06:00:00
12:00:00
18:00:00
00:00:00
06:00:00
12:00:00
Celsius(°C)
Low Alarm
High Alarm
Dew Point(°C)
Humidity(%rh)
Low Alarm rh
High Alarm rh
From: 6. marts 2023 12:02:06 - To: 8. marts 2023 13:35:36

appendix: f

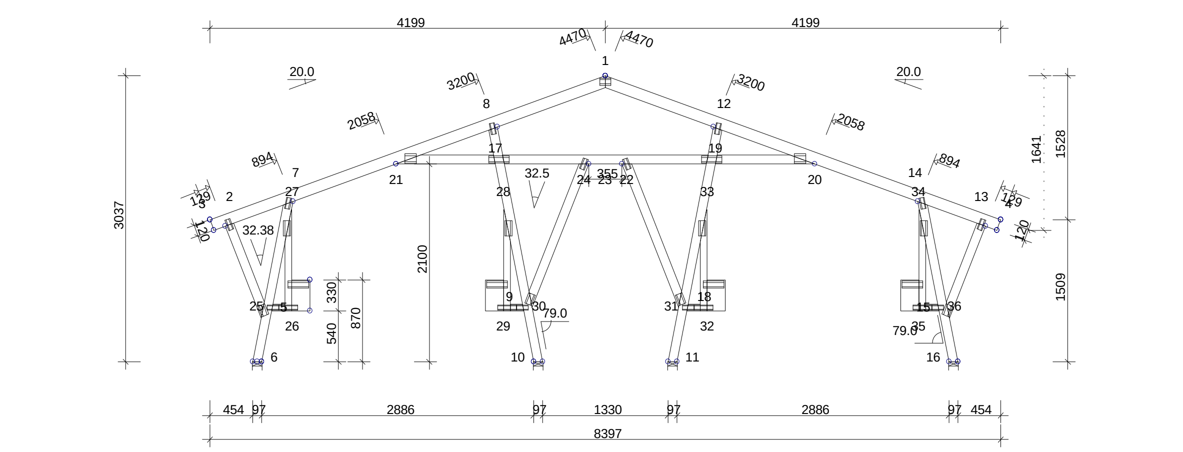
minkbarn dimensions and technical drawings

4 row - mink barn
section provided by TrussCon

S1 - 31 stk.

Vægt: 71 kg/stk

MARKERER AFSTIVET DIAGONAL.



TRÆ:	TYKKELSE 45 mm			
TRÆ-DEL	HØJDE mm	KVAL.	AFSTIVN. mm	LAST N/m²
3-1	120	C24	400	220
6-7	95	C24	Nej	
1-4	120	C24	400	220
25-26	70	C18	600	250
29-30	70	C18	600	250
31-32	70	C18	600	250
35-36	70	C18	600	250
14-16	95	C24	Nej	
8-10	95	C24	Nej	
11-12	95	C24	Nej	
17-21	95	C24	< 4292	
17-19	95	C24	< 4292	
19-20	95	C24	< 4292	
26-27	70	C18	Nej	
32-33	70	C18	Nej	
28-29	70	C18	Nej	
34-35	70	C18	Nej	
9-24	95	C24	Nej	
18-22	95	C24	Nej	
2-5	95	C24	Nej	
13-15	95	C24	Nej	
27-26	195	C24		
34-35	195	C24		
28-29	195	C24		
33-32	195	C24		

BEREGNINGSFORUDSÆTNINGER:

TRÆTYKKELSER: (mm) 45
SPÆRAFSTAND c/c (mm): 1000
ANVENDELSESKLASSE (1=I, 2=IU, 3=U): 2
SIKKERHEDSKLASSE (1=LAV, 2=NORM, 3=HØJ): 2
BRAND - KLASSE: D-s2, d0 (Ikke brandimprægneret)
SPÆRFABRIKKEN OVERVÅGES AF DS CERTIFICERING A/S
PRODUKTCERTIFIKAT 0527-CPD-2217

BELASTNINGER (N/m²):

SNELAST (GRUNDVÆRDI): 1200
VINDLAST (GRUNDVÆRDI): 540

EGENLASTE: SE TRÆTABEL.
ØVRIGE LASTE: SE BEREGNINGSUDSKRIFT.

GENERELLE OPLYSNINGER

SPÆRET ER KONSTRUERET OG BEREGNET MED EDB-PROGRAMMET "TRUSSCON". LIC.NR: 8232
SNITKRÆFTER ER BEREGNET SVARENDE TIL 1.ORDENS DEFORMATIONSTEORI.
TRÆNORM : EN 1995-1-1 + DS-NA + DS/INF 175:2009
BEREGNINGSMETODE 2 iht. EN14250 pkt. 5.1
TANDPLADER: EN-GODKENDELSE

VERSION: 2014 SR3b
TID: 12.58

TEGNET KONSTR.AF | GODK. | ORDRE NR. 42382

, den 18.03.2015

Jens Hansen

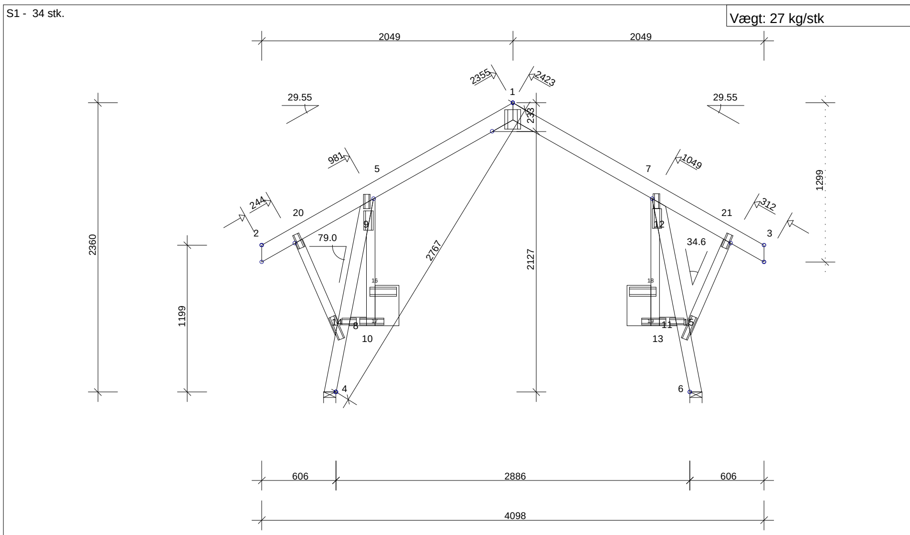
Projektleder: kaj
Kontrol. af:

TYPE S1 | TEGNINGS NR. | REG.

2 row - mink barn
section provided by TrussCon

S1 - 34 stk.

Vægt: 27 kg/stk



GENERELLE OPLYSNINGER

SPÆRET ER KONSTRUERET OG BEREGNET MED EDB-PROGRAMMET "TRUSSCON". LIC.NR: 8232
SNITKRÆFTER ER BEREGNET SVARENDE TIL 1.ORDENS DEFORMATIONSTEORI.
TRÆNORM : EN 1995-1-1 + DS-NA + DS/INF 175:2009
BEREGNINGSMETODE 2 iht. EN14250 pkt. 5.1
TANDPLADER: EN-GODKENDELSE

MAX. LÆGTEAFSTAND 400 mm.

BEREGNINGSFORUDSÆTNINGER:

TRÆTYKKELSER: (mm) 45
SPÆRAFSTAND c/c (mm): 2060
ANVENDELSESKLASSE (1=I, 2=IU, 3=U): 2
SIKKERHEDSKLASSE (1=LAV, 2=NORM, 3=HØJ): 1
BRAND - KLASSE: D-s2, d0 (Ikke brandimprægneret)
SPÆRFABRIKKEN OVERVÅGES AF DS CERTIFICERING A/S
PRODUKTCERTIFIKAT 0527-CPD-2217

BELASTNINGER (N/m²):

SNELAST (GRUNDVÆRDI): 900
VINDLAST (GRUNDVÆRDI): 540
NYTTE LAST: NR

EGENLASTE: SE TRÆTABEL.
ØVRIGE LASTE: SE BEREGNINGSUDSKRIFT.

VEDERLAGSREAKTIONER BRUDGR. (N):

NR	RETN.	LK P MAX	LK M MAX	LK K MAX	LK Ø MAX	LK Ø MIN	V-BR MM
4	Horiz	-231	-193	-1040	-2311	1001	
4	Vert	1247	1039	5142	2221	-426	10
6	Horiz	231	193	1040	2312	-1002	
6	Vert	1247	1039	5142	2221	-426	10

MAX DEFORMATION FOR KARR. LAST (mm):

KNUDE NR	VERT.	HORIZ.	LK NR.
2	-3.7	10.4	18
3	-3.7	-10.4	19
1-5	-3.1	-14.8	19

FOR DEFORMATION I FLERE PUNKTER: SE BER.UDSKRIFT

TOLERANCE FOR FORBINDELSEMIDLET: 10 mm

TRÆ:	TYKKELSE 45 mm				
TRÆ-DEL	HØJDE mm	KVAL.	AFSTIVN. mm	LAST N/m²	UDN. %
1-2	120	C24	400	210	83
1-3	120	C24	400	210	81
10-14	70	C18	600		9
13-15	70	C18	600		9
6-7	95	C24	Nej		60
4-5	95	C24	Nej		60
9-10	70	C18	Nej		14
12-13	70	C18	Nej		16
8-20	70	C18	Nej		30
11-21	70	C18	Nej		31
Kile 1	95	C24			8
16-17	195	C18			
18-19	195	C18			

TANDPLADER: EXCL. STØDSAMLING

KNUDE NR	PLADE-TYPE	BREDDE mm	LÆNGDE mm	UDN. %
1	GNT100S	130	159	49
5	GNT100S	55	119	77
7	GNT100S	55	119	75
8	GNT100S	55	198	41
9	GNT100S	76	159	31
10	GNT100S	55	198	39
11	GNT100S	55	198	42
12	GNT100S	76	159	31
13	GNT100S	55	198	39
14	GNT100S	55	119	39
15	GNT100S	55	119	39
20	GNT100S	55	119	57
21	GNT100S	55	119	54
16	GNT100S	76	218	
18	GNT100S	76	218	

TANDPLADER - STØDSAMLING:

KNUDE NR	PLADE-TYPE	BREDDE mm	LÆNGDE mm	UDN. %

VERSION: 2014 SR3b
TID: 07.17

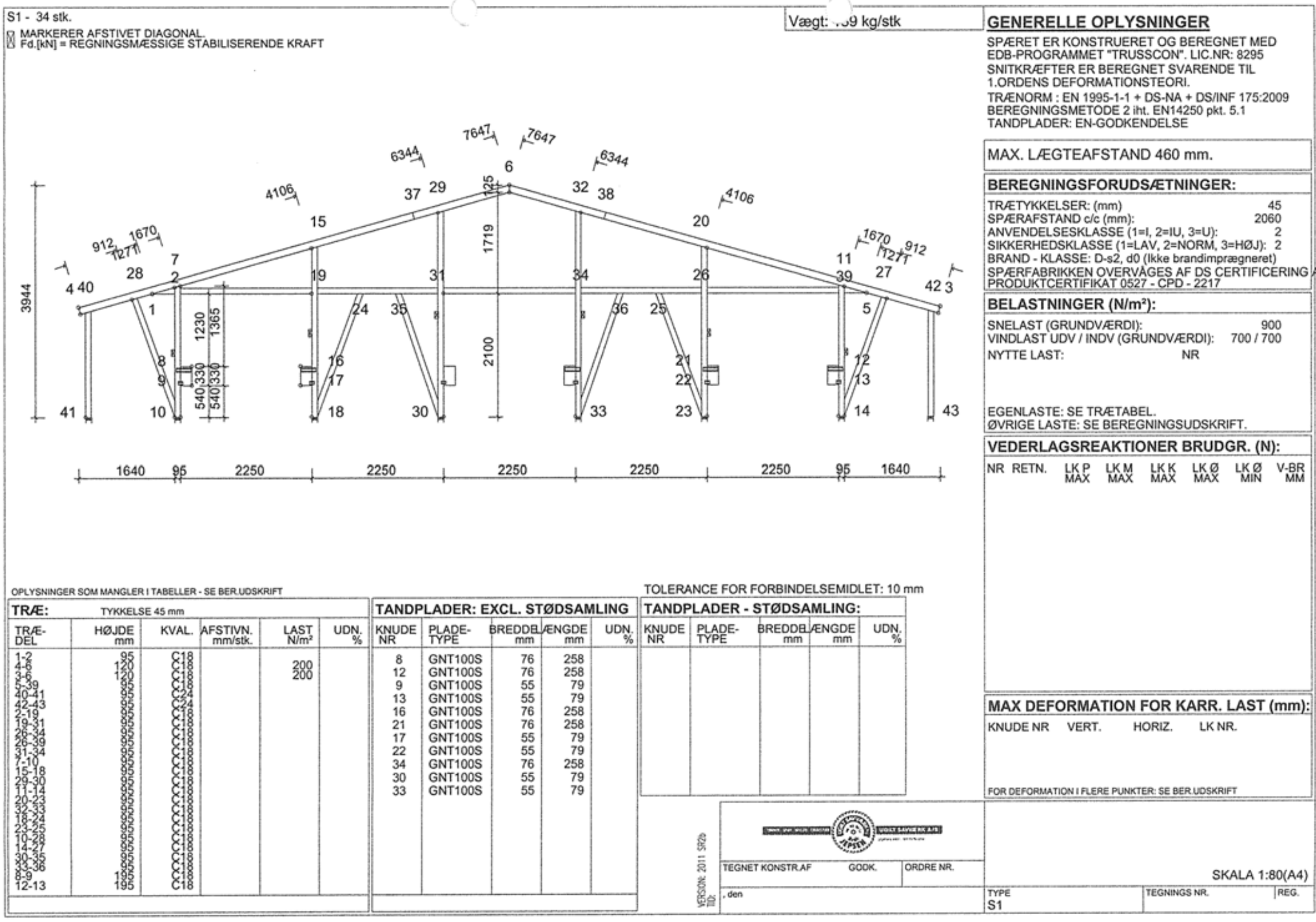
TEGNET KONSTR.AF | GODK. | ORDRE NR. 42565

, den 13.04.2015

Projektleder: kaj
Kontrol. af: kj

TYPE S1 | TEGNINGS NR. | REG.

6 row - mink barn
section provided by Thyrrestrup Mink



TRÆ: TYKKELSE 45 mm

TRÆ-DEL	HØJDE mm	KVAL.	AFSTIVN. mm/stk.	LAST N/m²	UDN. %
1-2	95	C18			
4-6	120	C18		200	
3-6	120	C18		200	
5-39	95	C18			
40-41	95	C24			
42-43	95	C24			
2-19	95	C18			
19-31	95	C18			
26-34	95	C18			
26-39	95	C18			
31-34	95	C18			
7-10	95	C18			
15-18	95	C18			
29-30	95	C18			
11-14	95	C18			
20-23	95	C18			
32-33	95	C18			
18-24	95	C18			
23-25	95	C18			
10-28	95	C18			
14-27	95	C18			
30-35	95	C18			
33-36	95	C18			
8-9	195	C18			
12-13	195	C18			

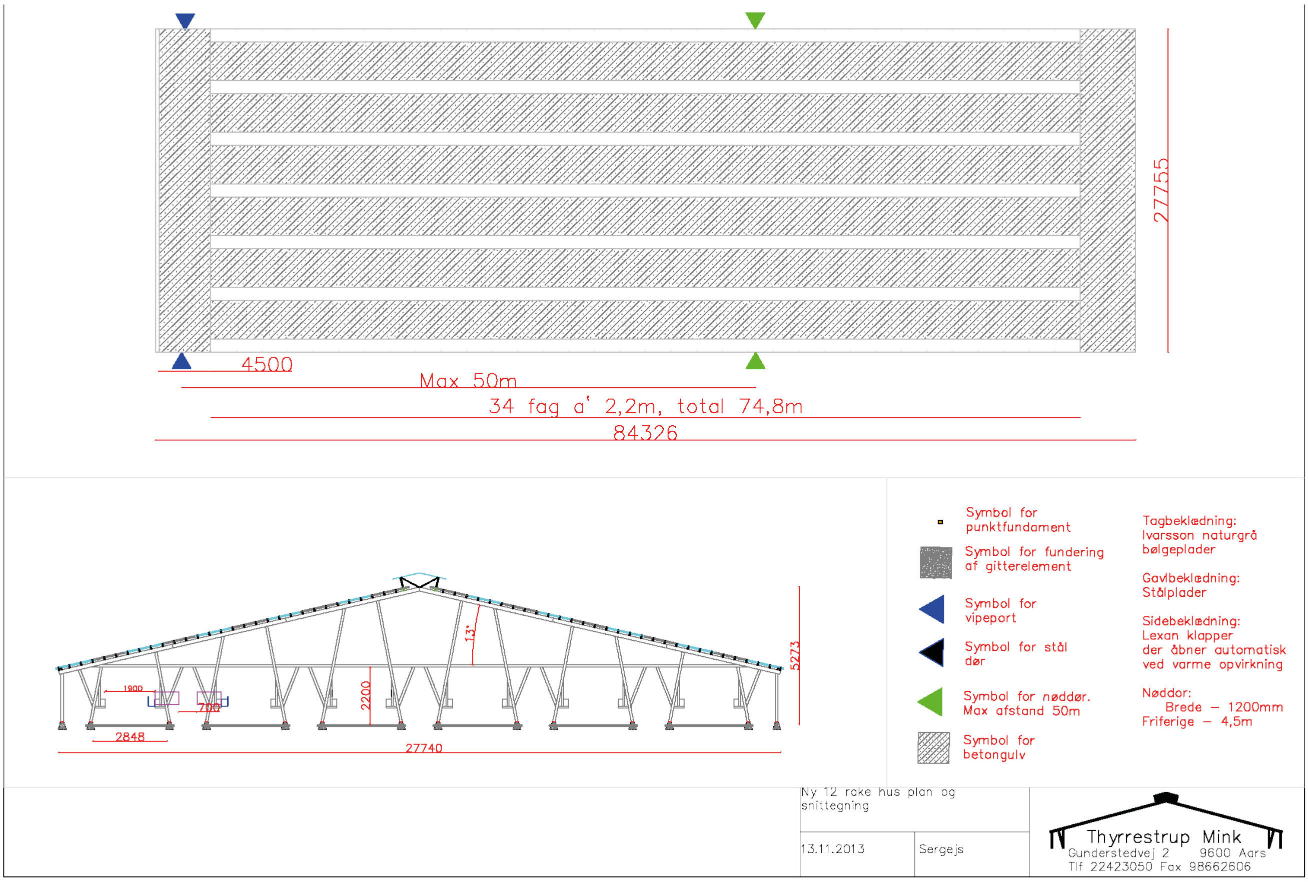
TANDPLADER: EXCL. STØDSAMLING

KNUDE NR	PLADE-TYPE	BREDDE mm	LÆNGDE mm	UDN. %
8	GNT100S	76	258	
12	GNT100S	76	258	
9	GNT100S	55	79	
13	GNT100S	55	79	
16	GNT100S	76	258	
21	GNT100S	76	258	
17	GNT100S	55	79	
22	GNT100S	55	79	
34	GNT100S	76	258	
30	GNT100S	55	79	
33	GNT100S	55	79	

TANDPLADER - STØDSAMLING:

KNUDE NR	PLADE-TYPE	BREDDE mm	LÆNGDE mm	UDN. %

12 row - mink barn
section and plan provided by Thyrrestrup Mink



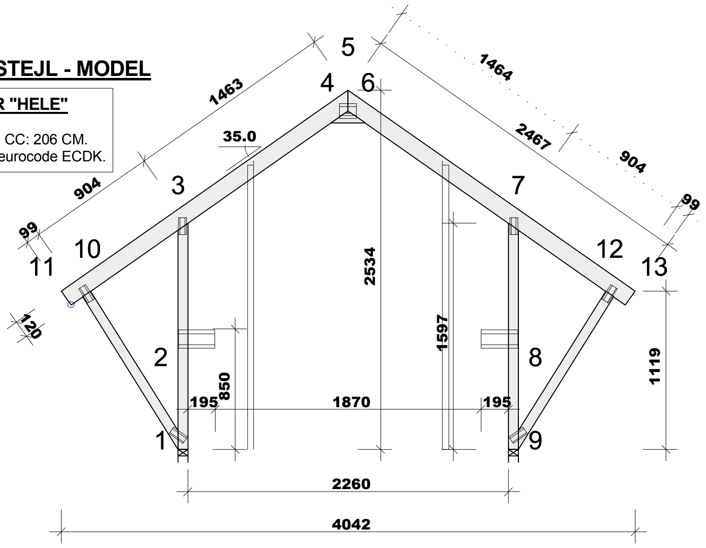
2 row - mink barn
section provided by Palsgaard Spær

R2-5 - 1 stk.

Vægt: 23 kg/stk

STEJL - MODEL

STK MINKRAMMER "HELE"
LET TAG.
MAX SPÆRAFSTAND, CC: 206 CM.
Statisk beregning efter eurocode ECDK.



GENERELLE OPLYSNINGER
SPÆRET ER KONSTRUERET OG BEREGNET MED EDB-PROGRAMMET "TRUSSCON". LIC.NR: 6419
SNITKRÆFTER ER BEREGNET SVARENDE TIL 1.ORDENS DEFORMATIONSTEORI.
TRÆNORM : EN 1995-1-1 + DS-NA + DS/INF 175:2009
BEREGNINGSMETODE 2 iht. EN14250 pkt. 5.1
TANDPLADER: EN-GODKENDELSE

MAX. LÆGTEAFSTAND 550 mm.

BEREGNINGSFORUDSÆTNINGER:

TRÆTYKKELSER: (mm)	45
SPÆRAFSTAND c/c (mm):	2500
ANVENDELSESKLASSE (1=I, 2=IU, 3=U):	2
KONSEKVENSKLASSE (1=CC1, 2=CC2, 3=CC3):	2

BRAND - KLASSE: D-s2, d0 (Ikke brandimprægneret)
SPÆRFABRIKKEN OVERVÅGES AF DS CERTIFICERING A/S PRODUKTCERTIFIKAT 0527-CPD-2215

BELASTNINGER (N/m²):

SNELAST (GRUNDVÆRDI):	900
VINDLAST UDV / INDV (GRUNDVÆRDI):	900 / 900
NYTTE LAST:	NR

EGENLASTE: SE TRÆTABEL.
ØVRIGE LASTE: SE BEREGNINGSUDSKRIFT.

VEDERLAGSREAKTIONER BRUDGR. (kN):

NR	RETN.	LK P MAX	LK M MAX	LK K MAX	LK Ø MAX	LK Ø MIN	V-BR MM
1	Horiz	-0.04	-0.03	-0.34	1.22	-0.03	
1	Vert	1.62	1.35	5.90	5.48	-3.06	9
9	Horiz	0.04	0.03	0.34	-1.22	0.03	
9	Vert	1.62	1.35	5.90	5.48	-3.06	9

TOLERANCE FOR FORBINDELSEMIDLET: 10 mm

TRÆ: TYKKELSE 45 mm

TRÆ-DEL	HØJDE mm	KVAL.	AFSTIVN. mm	LAST N/m²	UDN. %
1-3	70	C24	Nej		66
5-11	120	C24	550	200	97
5-13	120	C24	550	200	97
7-9	70	C24	Nej		66
1-10	70	C24	Nej		13
9-12	70	C24	Nej		13
4-6	70	C24	Nej		18
Kile 2	195	C24			0
Kile 8	195	C24			0

TANDPLADER: EXCL. STØDSAMLING

KNUDE NR	PLADE-TYPE	BREDDE mm	LÆNGDE mm	UDN. %
1	GNT100S	55	119	40
2	GNT100S	130	258	11
3	GNT100S	55	119	85
5	GNT100S	103	119	75
7	GNT100S	55	119	85
8	GNT100S	130	258	11
9	GNT100S	55	119	40
10	GNT100S	55	119	38
12	GNT100S	55	119	38

TANDPLADER - STØDSAMLING:

KNUDE NR	PLADE-TYPE	BREDDE mm	LÆNGDE mm	UDN. %

MAX DEFORMATION FOR KARR. LAST (mm):

KNUDE NR	VERT.	HORIZ.	LK NR.
11	-15.4	18.7	37
13	-15.4	-18.7	38
3-4	2.3	31.1	37

FOR DEFORMATION I FLERE PUNKTER: SE BER.UDSKRIFT

VERSION: 2019d TID: 08.39

Palsgaard Spær

TEGNET	KONSTR.AF	GODK.	ORDRE NR.
FA			746737

Palsgaardtræ afd. Nord- Vodskov, den 26.03.2019

PALSGAARD SPÆR
MINKSPÆR
EUROCODE
Sagsbeh.

TYPE	TEGNINGS NR.	REG.
R2-5	R2-5	

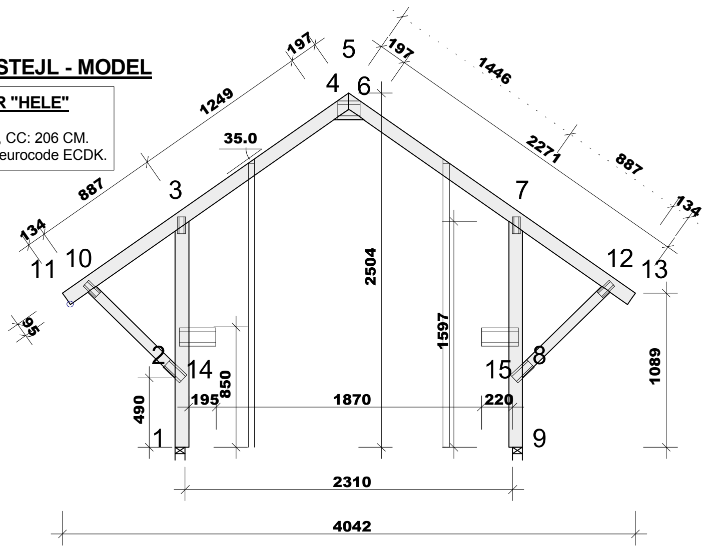
2 row - mink barn
section provided by Palsgaard Spær

R02 - 1 stk.

Vægt: 21 kg/stk

STEJL - MODEL

STK MINKRAMMER "HELE"
LET TAG.
MAX SPÆRAFSTAND, CC: 206 CM.
Statisk beregning efter eurocode ECDK.



GENERELLE OPLYSNINGER
SPÆRET ER KONSTRUERET OG BEREGNET MED EDB-PROGRAMMET "TRUSSCON". LIC.NR: 6419
SNITKRÆFTER ER BEREGNET SVARENDE TIL 1.ORDENS DEFORMATIONSTEORI.
TRÆNORM : EN 1995-1-1 + DS-NA + DS/INF 175:2009
BEREGNINGSMETODE 2 iht. EN14250 pkt. 5.1
TANDPLADER: EN-GODKENDELSE

MAX. LÆGTEAFSTAND 550 mm.

BEREGNINGSFORUDSÆTNINGER:

TRÆTYKKELSER: (mm)	45
SPÆRAFSTAND c/c (mm):	2060
ANVENDELSESKLASSE (1=I, 2=IU, 3=U):	2
KONSEKVENSKLASSE (1=CC1, 2=CC2, 3=CC3):	2

BRAND - KLASSE: D-s2, d0 (Ikke brandimprægneret)
SPÆRFABRIKKEN OVERVÅGES AF DS CERTIFICERING A/S PRODUKTCERTIFIKAT 0527-CPD-2215

BELASTNINGER (N/m²):

SNELAST (GRUNDVÆRDI):	1000
VINDLAST UDV / INDV (GRUNDVÆRDI):	600 / 900
NYTTE LAST:	NR

EGENLASTE: SE TRÆTABEL.
ØVRIGE LASTE: SE BEREGNINGSUDSKRIFT.

VEDERLAGSREAKTIONER BRUDGR. (kN):

NR	RETN.	LK P MAX	LK M MAX	LK K MAX	LK Ø MAX	LK Ø MIN	V-BR MM
1	Horiz	-0.04	-0.03	-0.31	0.68	-0.03	
1	Vert	1.35	1.12	5.29	4.80	-1.39	8
9	Horiz	0.04	0.03	0.31	-0.68	0.03	
9	Vert	1.35	1.12	5.29	4.80	-1.39	8

TOLERANCE FOR FORBINDELSEMIDLET: 10 mm

TRÆ: TYKKELSE 45 mm

TRÆ-DEL	HØJDE mm	KVAL.	AFSTIVN. mm	LAST N/m²	UDN. %
3-1	95	C24	Nej		44
5-11	95	C24	550	200	87
5-13	95	C24	550	200	87
7-9	95	C24	Nej		44
10-14	70	C24	Nej		10
12-15	70	C24	Nej		10
4-6	70	C24	Nej		18
Kile 2	195	C24			1
Kile 8	195	C24			1

TANDPLADER: EXCL. STØDSAMLING

KNUDE NR	PLADE-TYPE	BREDDE mm	LÆNGDE mm	UDN. %
2	GNT100S	130	258	11
3	GNT100S	55	119	77
5	GNT100S	130	159	91
7	GNT100S	55	119	77
8	GNT100S	130	258	11
10	GNT100S	55	119	33
12	GNT100S	55	119	33
14	GNT100S	76	159	23
15	GNT100S	76	159	23

TANDPLADER - STØDSAMLING:

KNUDE NR	PLADE-TYPE	BREDDE mm	LÆNGDE mm	UDN. %

MAX DEFORMATION FOR KARR. LAST (mm):

KNUDE NR	VERT.	HORIZ.	LK NR.
13	-15.5	-20.4	38
11	-15.5	20.4	37
6-7	2.8	-33.2	38

FOR DEFORMATION I FLERE PUNKTER: SE BER.UDSKRIFT

ERSION: 2019d ID: 13.20

Palsgaard Spær

TEGNET	KONSTR.AF	GODK.	ORDRE NR.
FA			746737

Palsgaardtræ afd. Nord- Vodskov, den 13.03.2018

PALSGAARD SPÆR
MINKSPÆR
EUROCODE
Sagsbeh.

TYPE	TEGNINGS NR.	REG.

appendix: g

calculating wind loads

Difining wind loads

Basis wind speed: $V_{(b)} = C_{(dir)} * C_{(season)} * V_{(b,0)}$

Mean wind speed: $V_{(m,z)} = Cr_{(z)} * Co_{(z)} * V_{(b)}$

Terrain factor: $Kr = 0.19 * \left(\frac{Zo}{Zo,II}\right)^{0,07}$

Terrain roughness: $Cr_{(z)} = Kr * \ln\left(\frac{Z}{Zo}\right)$ if $z_{(min)} < z < z_{(max)}$

$Cr_{(z)} = Cr * z_{(min)}$ if $z_{(min)} < z < z_{(max)}$

Turbulence intesity: $I_{(v)} = \left(\frac{\text{sigma (v)}}{\text{vm(z)}}\right) = \frac{Ki}{Co_{(z)} * \ln(z/z_o)}$

Peak intesity: $q_{p(z)} = [1+7*I_{v(z)}] * 0.5 * p * v^2_{m(z)}$

Pressure on exterior surface: $w_e = q_{p(ze)} * C_{pe}$

Storm: 24,5 - 28,4 m/s (DMI)
C(dir) = primary wind direction
C(season) = Season
V(b,0) = Fundemental wind speed

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
NOTE: The terrain categories are illustrated in A.1.			

Co(z) = orografic factor (set to 1)
Zo = roughness length
zo,II = Terrain category
z(min) = minimum height
z(max) = 200 meters
Ki = turbulens factor (1)
p = air density (1,25 kg/m³)

Calculated wind loads

Used wind seed for wind load calculation: 27 m/s

Basis wind speed: $V_{(b)} = 1 * 1 * 27 \text{ m/s} = 27 \text{ m/s}$

Terrain factor: $Kr = 0.19 * \left(\frac{0,03}{0,01}\right)^{0,07} = 0,174$

Terrain roughness: $Cr_{(z)} = 0,174 * \ln\left(\frac{15 \text{ m}}{0,03}\right) = 1,481$

Mean wind speed: $V_{(m,z)} = 1,481 * 1 * 27 \text{ m/s} = 39,9 \text{ m/s}$

Turbulence intesity: $I_{(v)} = \left(\frac{\text{sigma (v)}}{\text{vm(z)}}\right) = \frac{1}{1 * \ln(15 \text{ m}/0,03)} = 0,1174$

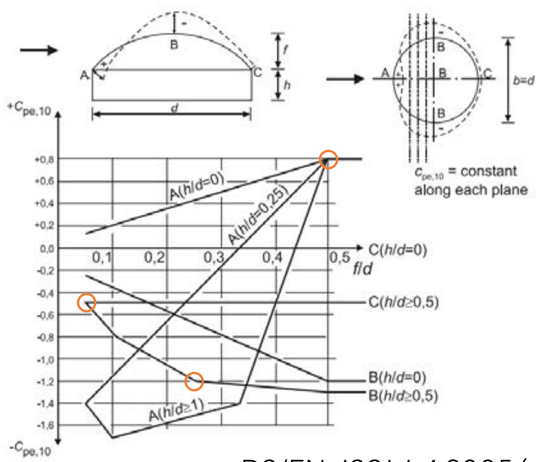
Peak intesity: $q_{p(z)} = [1+7*0,1174] * 0.5 * 1,25 * 39,9^2 = 1812,7 \text{ N/m}^2 \longrightarrow 1,81 \text{ kN/m2}$

Pressure on exterior surface: $w_e = 1812,7 * C_{pe}$

$w_{e(A)} = 1812,7 * 0,8 = 1,45$ kN (pressure)

$w_{e(B)} = 1812,7 * -1,2 = -2.17$ kN (pull)

$w_{e(B)} = 1812,7 * -0,5 = -0,9$ kN (pull)



DS/EN: 1991-1-4:2005 (pp 51)

appendix: h

calculating frames

Design of members in bending

Bending arround one axis

$$\frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \leq 1$$

k_m = 0,7 rectagular cross section
k_m = 1 for other cross sections

Bending arround two axis

$$\frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

$$\frac{\sigma_{m,z,d}}{f_{m,z,d}} + k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} \leq 1$$

$\sigma_{m,y,d}$ = design moment stress (y-axis)
$\sigma_{m,z,d}$ = design moment stress (z-axis)
$f_{m,y,d}$ = design moment strength (y-axis)
$f_{m,z,d}$ = design moment strength (z-axis)

Design of members in shear

$$\frac{t_d}{f_{v,d}} \leq 1$$

$$t_{max} = \frac{3}{2}\frac{V}{A}$$

t_d = design shear stress
$f_{v,d}$ = design shear strength
t_{max} = maximum shear stress (rectagular cross sections)

Design of members in tension (parallel to grain)

Design requirement

$$\frac{\sigma_{t,d}}{f_{t,o,d}} \leq 1$$

Tension stress parallel to grain

$$\sigma_{t,d} = \frac{F_{t,d}}{A_{ef}}$$

$\sigma_{t,d}$ = design tension stress
$f_{t,o,d}$ = design tension strength parallel to grain
$F_{t,d}$ = tension force
A_{ef} = cross section area

Design of members in compression

Design requirement (pure compression)

$$\frac{\sigma_{c,d}}{f_{c,o,d}} \leq 1 \qquad \text{if } y_{rel} \leq 0.3$$

Compression stress paralell to grain

$$\sigma_{c,d} = \frac{F_{c,d}}{A_{ef}}$$

Design requirement (column buckling)

$$\frac{\sigma_{c,d}}{k_c \cdot f_{c,o,d}} \leq 1 \qquad \text{if } y_{rel} > 0.3$$

Slenderness ratio (y and z-axis)

$$\lambda_y = \frac{l_s}{i_y} = \frac{l_s}{h} \cdot \sqrt{12}$$

$$\lambda_z = \frac{l_s}{i_z} = \frac{l_s}{h} \cdot \sqrt{12}$$

$\sigma_{c,d}$= design compression stress
$f_{c,o,d}$ = design compression strength
y/z_{rel} = relative slenderness
$F_{c,d}$ = compression force
A_{ef} = cross section area
l_s = element length
$i_{y/z}$ = inertia radius

Buckling strength reduction factor

$$k_{c,y} = \frac{1}{k_y + \sqrt{k_y^2 - \lambda_{rel,y}^2}}$$

$$k_y = 0{,}5(1+\beta_c\,(\lambda_{rel,y} - 0{,}3) + \lambda_{rel,y}^2$$

$\lambda_{y/z}$ = slenderness ratio
k_c = buckling strength reduction factor
β_c = imperfections (0,2 solid timber, 0,1 glulan

Relative slenderness ratio

$$\lambda_{rel,y} = \frac{\lambda_y}{Pi}\sqrt{\frac{f_{c,o,k}}{E_{0,05}}}$$

Column buckling

Eulers formula for column buckling

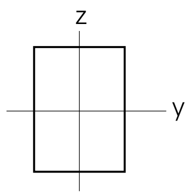
$$P_{cr} = \frac{Pi^2\,EI}{L_{cr}^2}$$

P_{cr} = the critical load a collumn can widthstand
I = moment of inertia
E = modulus of elasticity
L = collumn length

Slenderness ratio (y and z-axis)

$$\lambda_y = \frac{l_s}{i_y} = \frac{l_s}{h}\cdot\sqrt{12}$$

$$\lambda_z = \frac{l_s}{i_z} = \frac{l_s}{h}\cdot\sqrt{12}$$



Design of members in combined bending and column buckling

$$\frac{\sigma_{c,d}}{f_{c,o,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m\,\frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

Design of members in combined bending and axial compression (one axis)

$$\left(\frac{\sigma_{c,d}}{f_{c,o,d}}\right)^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m$$

$k_{c,90}$

Design of members subjected to compression perpendicular to grain direction

$$\frac{\sigma_{c,90,d}}{k_{c,90}\;f_{c,90,d}} \leq 1$$

$\sigma_{c,90,d}$ = design compression stress perpindicular to grain direction
$f_{c,90,d}$ = design compression strength perpindicular to grain direction
$k_{c,90}$ = factor based on how loads i applied

(Jensen, B. C. & Mohr, G. (2022) Teknisk ståbi. 27. udgave. Kbh: Akademisk Forlag.)

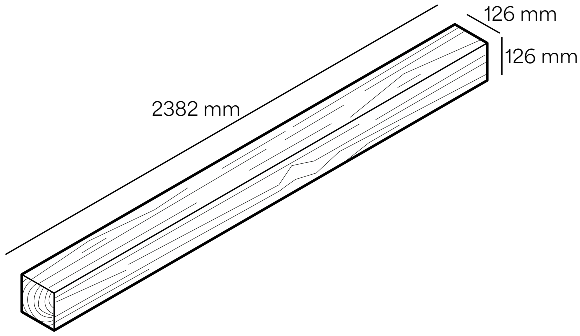
Karamba calculations

The calculations executed by Karmaba is based on the following structural formulas.
values for characteristic bending strength, characteristic compression strength
and characteristic tension strength is based on the values given to C16 timber (DS/EN 338)
The formulas used for calculations found in Teknisk Ståbi (Jensen, B.C & Mohr, G. (2022))

Design bending strength y-axis and z-axis

$$f_{myd} = \frac{f_k \cdot k_{mod}}{\gamma_M} \longrightarrow \frac{16\text{ mPa} \cdot 0.37}{1.35} = 4.3\text{ mPa}$$

$$f_{mzd} = \frac{f_k \cdot k_{mod}}{\gamma_M} \longrightarrow \frac{16\text{ mPa} \cdot 0.37}{1.35} = 4.3\text{ mPa}$$



Design bending stress y-axis and z-axis (values from Karamba)

$$\sigma_{myd} = \frac{M}{W} \longrightarrow \frac{0.0606\text{ kNm} \cdot 10^6}{333396\text{mm}^3} = 0.18\text{mPa}$$

$$\sigma_{mzd} = \frac{M}{W} \longrightarrow \frac{0.0431\text{ kNm} \cdot 10^6}{333396\text{mm}^3} = 0.12\text{mPa}$$

Utilization factor bending y-axis and z-axis

$$\frac{\sigma_{myd}}{f_{myd}} \leq 1 \longrightarrow \frac{0.18\text{ mPa}}{4.3\text{ mPa}} = 0.04\ (4\%) \longrightarrow \leq 1 \checkmark$$

$$\frac{\sigma_{mzd}}{f_{mzd}} \leq 1 \longrightarrow \frac{0.12\text{ mPa}}{4.3\text{ mPa}} = 0.02\ (0.2\%) \longrightarrow \leq 1 \checkmark$$

Bending around both y-axis and z-axis

$$\frac{\sigma_{myd}}{f_{myd}} + k_m \cdot \frac{\sigma_{mzd}}{f_{mzd}} \leq 1 \longrightarrow \frac{0.18\text{ mPa}}{4.3\text{ mPa}} + 0.7 \cdot \frac{0.12\text{ mPa}}{4.3\text{ mPa}} = 0.06\ (6\%) \longrightarrow \leq 1 \checkmark$$

$$k_m \cdot \frac{\sigma_{myd}}{f_{myd}} + \frac{\sigma_{mzd}}{f_{mzd}} \leq 1 \longrightarrow 0.7 \cdot \frac{0.18\text{ mPa}}{4.3\text{ mPa}} + \frac{0.12\text{ mPa}}{4.3\text{ mPa}} = 0.05\ (0.5\%) \longrightarrow \leq 1 \checkmark$$

f_d = design bending strength
f_k = chareteristic bending strength
k_{mod} = modification factor
γ_M = partial factor
1.30 for solid timber
1.35 for glulam
σ_m = design bending stress
M = bending moment
W = moment of resistance

Design tension strength

$$f_{t0d} = \frac{f_{t0k} \cdot k_{mod}}{\gamma_M} \longrightarrow \frac{8.5\text{ mPa} \cdot 0.37}{1.35} = 2.32\text{ mPa}$$

Design tension stress (values from Karamba)

$$\sigma_{td} = \frac{F_{td}}{A_{ef}} \longrightarrow \frac{0.656\text{ kN} \cdot 10^3}{15876\text{ mm}^2} = 0.041\text{mPa}$$

Utilization factor tension

$$\frac{\sigma_{td}}{f_{t0d}} \leq 1 \longrightarrow \frac{0.041\text{ mPa}}{2.32\text{ mPa}} = 0.017\ (0.17\%) \longrightarrow \leq 1 \checkmark$$

$\sigma_{t,d}$ = design tension stress
f_{t0k} = chareteristic tensile strength
$f_{t,o,d}$ = design tension strength parallel to grain
$F_{t,d}$ = tension force
A_{ef} = cross section area
$F_{c,d}$ = compression force

Design compression strength parallel to grain

$$f_{c0d} = \frac{f_{c0k} \cdot k_{mod}}{\gamma_M} \longrightarrow \frac{17\text{ mPa} \cdot 0.37}{1.35} = 4.6\text{ mPa}$$

Design compression stress (values from Karamba)

$$\sigma_{cod} = \frac{F_{cd}}{A_{ef}} \longrightarrow \frac{20.65\text{ kN} \cdot 10^3}{15876\text{mm}^2} = 1.30\text{mPa}$$

Utilization factor compression

$$\frac{\sigma_{cod}}{f_{c0d}} \leq 1 \longrightarrow \frac{1.30\text{ mPa}}{4.6\text{ mPa}} = 0.28\ (28\%) \longrightarrow \leq 1 \checkmark$$

Design column buckling

Design compression stress (values from Karamba)

$$\sigma_{cod} = \frac{F_{cd}}{A_{ef}} \longrightarrow \frac{20.65\ kN \cdot 10^3}{15876mm^2} = 1.30mPa$$

Element length = 2382 mm
Column factor 1

Radius of gyration

$$\sqrt{\frac{I}{A_{ef}}} \longrightarrow \sqrt{\frac{21004 \cdot 10^{11}}{15876}} = 36.37\ mm$$

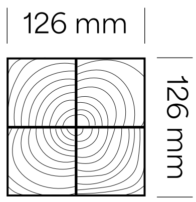
Critical length of element (lc)

Element length · column factor ⟶ 2382 mm · 1 = 2382 mm

Slenderness ratio (y and z-axis)

$$\lambda = \frac{l_c}{i} \longrightarrow \frac{2382\ mm}{36.37\ mm} = 65{,}4\ mm$$

I = moment of intertia
A_{ef} = effective area
k_{mod} = modification factor
γ_M = partial factor
1.30 for solid timber
1.35 for glulam
σ_m = design bending stress
M = bending moment
W = moment of resistance



Relative slenderness ratio

$$\lambda_{rel} = \frac{\lambda_y}{Pi} \cdot \sqrt{\frac{f_{c,o,k}}{E_{0,05}}} \longrightarrow \frac{65.4}{Pi} \cdot \sqrt{\frac{17\ mPa}{8000\ kN/mm}} = 0.67$$

$\sigma_{c,d}$= design compression stress
$f_{c,o,d}$ = design compression strength
y/z_{rel} = relative slenderness
k_c = buckling strength reduction factor
β_c = imperfections
0,2 solid timber, 0,1 glulam

Buckling strength reduction factor

$$k = 0{,}5(1+\beta_c\,(\lambda_{rel} - 0{,}3) + \lambda_{rel}^2 \longrightarrow 0{,}5(1+0{,}1\,(0.67 - 0{,}3) + 0.67^2 = 0.74$$

$$k_c = \frac{1}{k + \sqrt{k^2 - \lambda_{rel}^2}} \longrightarrow \frac{1}{0.74+\sqrt{0.74^2 - 0.67^2}} = 0.93$$

Design requirement (column buckling)

$$\frac{\sigma_{c,d}}{k_c \cdot f_{c,o,d}} \leq 1 \longrightarrow \frac{1.30\ mPa}{0.93 \cdot 4.6\ mPa} = 0.3\ (30\%) \longrightarrow \leq 1$$ ✓

Design requirement combined bending and axial compression

Bending around one axis (y-axis)

$$\frac{\sigma_{c,d}}{k_c \cdot f_{c,o,d}} + \frac{\sigma_{myd}}{f_{myd}} \leq 1 \longrightarrow \frac{1.30\ mPa}{0.93 \cdot 4.6\ mPa} + \frac{0.18\ mPa}{4.3\ mPa} = 0.34\ (34\%) \longrightarrow \leq 1$$ ✓

Design requirement combined bending and axial compression

$$\left(\frac{\sigma_{c,d}}{f_{c,o,d}}\right)^2 + \frac{\sigma_{myd}}{f_{myd}} \leq 1 \longrightarrow \left(\frac{1.30\ mPa}{4.6\ mPa}\right)^2 + \frac{0.18\ mPa}{4.3\ mPa} = 0.12\ (12\%) \longrightarrow \leq 1$$ ✓

$$\frac{\sigma_{c,d}}{k_c \cdot f_{c,o,d}} + \frac{\sigma_{myd}}{f_{myd}} + k_m \cdot \frac{\sigma_{mzd}}{f_{mzd}} \leq 1 \longrightarrow \frac{1.30\ mPa}{0.93 \cdot 4.6\ mPa} + \frac{0.18\ mPa}{4.3\ mPa} + 0.7 \cdot \frac{0.12\ mPa}{4.3\ mPa} = 0.36\ (36\%) \rightarrow \leq 1$$ ✓

$$\frac{\sigma_{c,d}}{k_c \cdot f_{c,o,d}} + k_m \cdot \frac{\sigma_{myd}}{f_{myd}} + \frac{\sigma_{mzd}}{f_{mzd}} \leq 1 \longrightarrow \frac{1.30\ mPa}{0.93 \cdot 4.6\ mPa} + 0.7 \cdot \frac{0.18\ mPa}{4.3\ mPa} + \frac{0.12\ mPa}{4.3\ mPa} = 0.36\ (36\%) \rightarrow \leq 1$$ ✓

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EXPOSITION: DESIGNING WITH WASTE WOOD

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