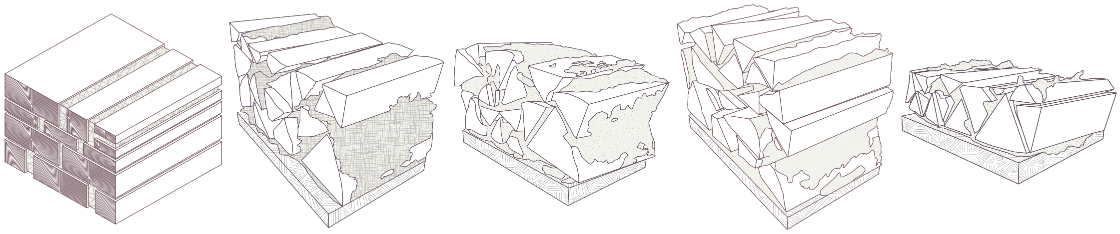
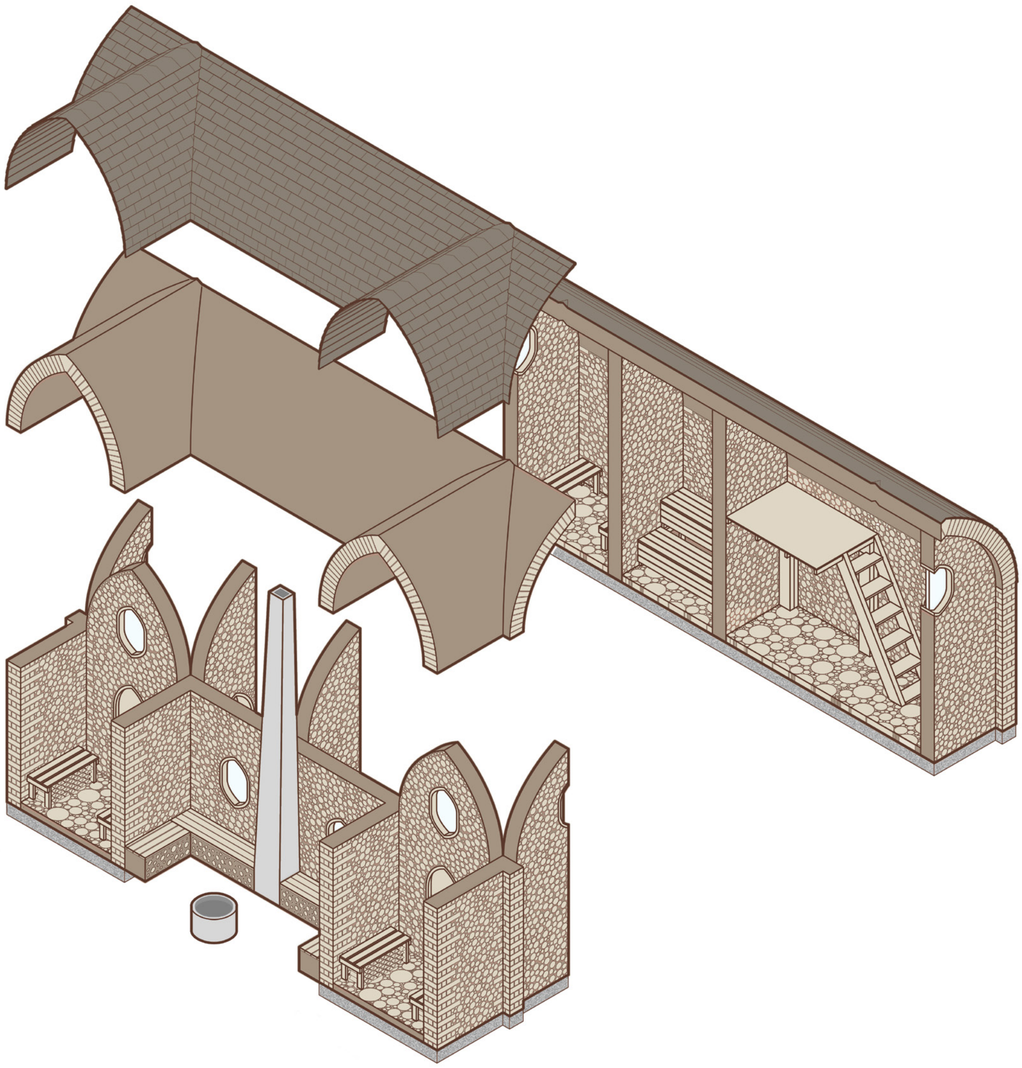
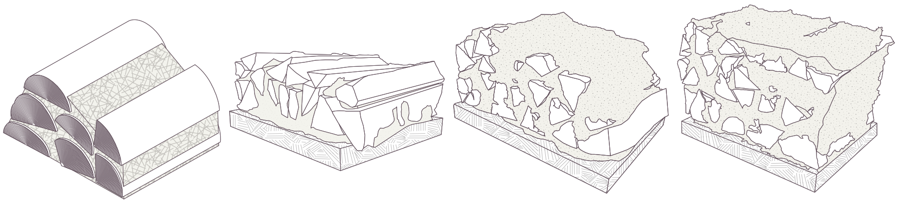
Globwood

Cellulose-Glue binder for cordwood masonry







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2025
Supervisor: Mimmi Amini
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Abstract

Wood masonry is a building technique category that has existed in Europe and North America since the 1800s (Hagman, 2014); there are multiple names including cordwood masonry, stovewood masonry, and plank masonry that all describe similar and overlapping techniques. Cutoffs from the timber industry, stovewood, and reused materials can be used with a binder, primarily clay in Europe, or cement or lime mortars in North America to form walls. The walls can be load-bearing or be used as an infill in a load-bearing frame.

This thesis investigates alternative wood-based binders made from rest products from the wood industry to use in contemporary wood masonry construction with particular focus on hiking shelters along trails in Haninge through model making and testing of different recipes. The binders are tested for density, shrinking, and environmental stability.

A woodbased binder could have better insulating properties than clay, cement, or lime mortars allowing for buildings with better thermal properties while having a lower carbon footprint than existing binders.

This thesis finds that a binder using papier mache mixed with sawdust and lignin provides a good mix of strength and low shrinking. Experiments showcase that binders with a higher lignin content are more resistant to environmental effects. The density of the binder mixtures suggest that binders with higher lignin content are stronger but have worse insulating properties than binders with correspondingly higher sawdust content.

The material is applied in the proposal of a hiking shelter and sauna, where the building technique is used in both traditional and novel ways..

Keywords: cordwood masonry; stovewood; vernacular; sustainable structures; hiking shelters

Thank you!

I want to start by thanking the people I got the opportunity to interview for this thesis: to Olle for providing the inspiration for this thesis and for believing in my potential to further develop cordwood masonry, to Anna for telling me of her experience with material and to Ulf for allowing me to participate in a clay workshop and answering my questions about clay and natural building materials.

I want to continue by thanking the teachers and Chalmers staff that helped me: to Mimmi and Jonas for their feedback and tutoring during the project, to Diana and Manuela for providing me with lignin dregs

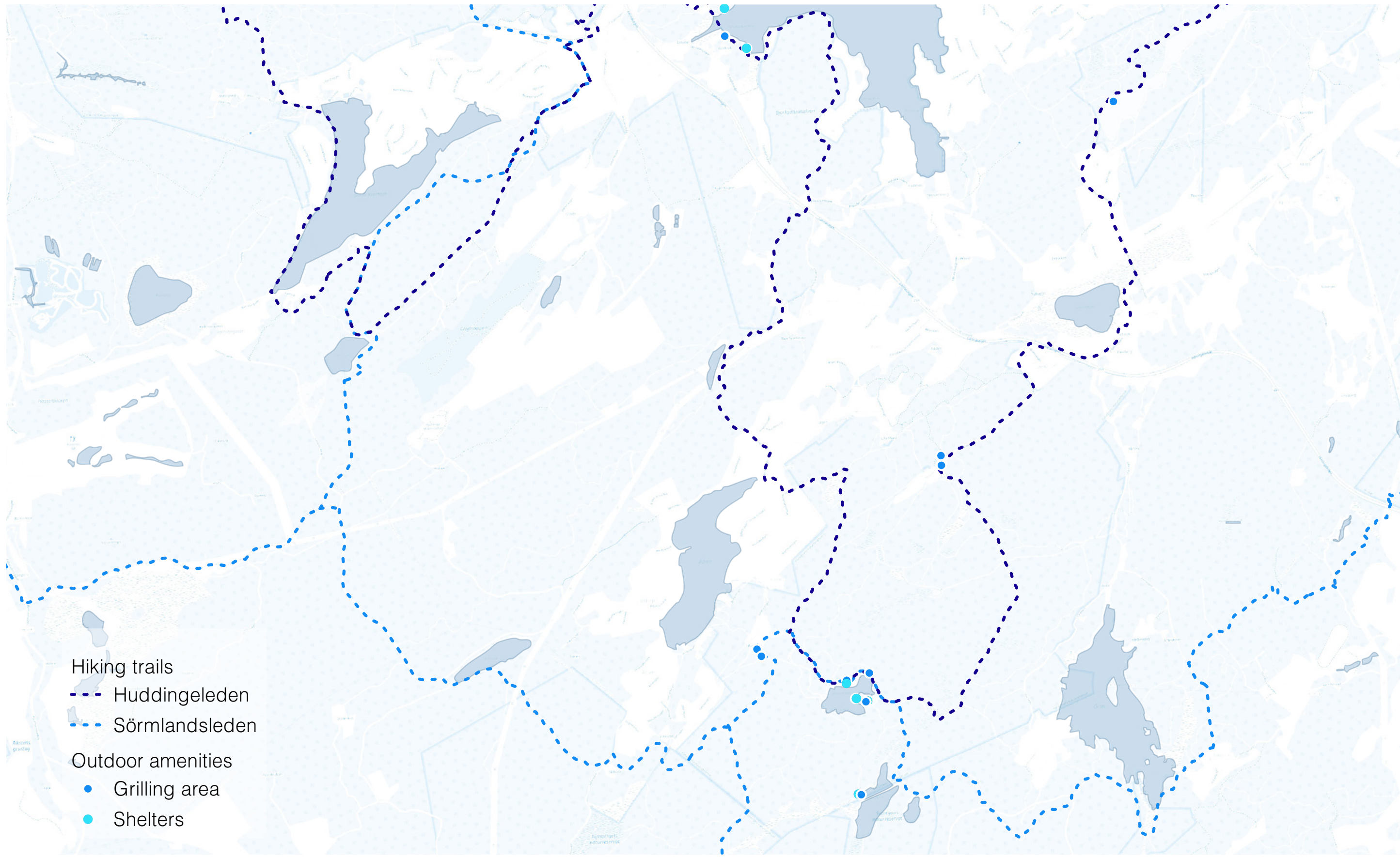
I also want to thank my grandfather Ingmar and my girlfriend Naomi for reading and providing feedback on the text.

Lastly I want to thank Niklas, Carl, Axel and Elias and the many others who have supported me during the thesis writing process, providing both feedback and company.

TABLE of CONTENTS

1	Introduction	3
1.1	Purpose	4
1.2	Thesis questions and objectives	5
1.3	Background	6
1.3.1	Reference Projects	8
1.4	Theory	10
1.4.1	Building Technique	10
1.4.2	Material	12
1.4.3	Impacts for sustainability	14
1.5	Delimitations	15
1.6	Method	16
1.6.1	Interviews	17
1.6.2	Workshops	18
1.6.3	3D scanning of existing buildings	19
1.6.4	Full scale modeling	20
1.6.5	Small scale modeling	21
1.6.6	Dimensional Stability	22
1.6.7	Environmental stability	23
1.6.8	Modeling of masonry elements	24
2	Experimental results	26
2.1	Qualitative findings from small scale modeling	27
2.2	Quantative findings from dimensional stability	28
2.3	Environmental stability	29
2.4	Model photos and material gallery	30
2.4.1	Sawdust	30
2.4.2	Lignin	32
2.4.3	Sawdust-Lignin A	34
2.4.4	Sawdust-Lignin B	36
2.4.5	Vault models	38
3	Design: Hiking shelters and cabins along Sörmlandsleden and Huddingeleden	40
3.1	Analysing the trail	42
3.1.1	Hiking cabins	46
3.1.2	Lean-to shelters	48
3.2	Designing Cordwood Cabins and Shelters	50
3.2.1	Hiking cabin	52
4	Discussion	60
5	Bibliography	62
6	Student Background	64

1 Introduction



The forests in Sweden are one of the country's most important resources both from an economic and human standpoint. At the same time Swedish forests are suffering from spruce bark beetle damage. Trees damaged by the beetle are expensive for the forestry industry to take care of with separate sawmills needed and worse lumber being produced .

Allemansrätten ("freedom to roam") provides the Swedish people with opportunities to explore and utilise the vast forests and nature in the country. This has led to hiking trails stretching far and wide across the country. There are more than 400 recognised hiking trails in Sweden. Well maintained hiking trails with shelters play an important role in allowing people of different experiences and equipment to explore.

Building shelters along the trails can be difficult with limited vehicular access so a building with a technique that can use shorter pieces could allow for easier construction.

I have been a Scout for most of my life and the forest and hiking trails mean a lot to me. The outdoors are where I find my peace.

The Scout troop that I have been a part of for the longest is Huddinge Scoutkår and we have one of our cottages in Gladö nature reserve near Kvarnsjön, one of the places where Sörmlandsleden meets Huddingeleden.

I truly enjoy this place and enjoy hiking here, but the route lacks enough shelters for hikers without tents to have somewhere to sleep on popular nights.

1.1 Purpose

This thesis explores the use of cordwood as a building material for hiking shelters focusing on testing and developing a novel binder with a lesser carbon footprint than the cement and lime based mortars used today and better insulating properties than clay binders.

Cordwood is chosen for the building techniques ability to utilise bark beetle damaged timber, ease of construction and small construction unit size making it suitable for use in shelters with limited road access and tool use.

1.2 Thesis questions and objectives

The thesis has two main objectives. It aims to investigate the use of cellulose-glue-based binders in cordwood constructions and how cordwood construction can be used for hiking shelters.

Objective 1:
Can a binder be made using waste material from the wood and paper industry and glue be used for cordwood construction?

i) What would a recipe be? What waste products can be utilized?

ii) What structural properties does it have?

Objective 2:
How can wood masonry techniques best be utilised in the construction of hiking shelters.

i) Can a cordwood hiking shelter be constructed with mostly biodegradable material? What impacts does this have on the design?

1.3 Background

Wood masonry is a set of building techniques that were introduced together with the thin blade saw at the beginning of the 19th century (Hagman, 2014). In Scandinavia mainly two variations of the technique were practiced kubbhus, cordwood houses, and knubbhus, plank masonry houses. The technique may have originated in Norway (Thor, 2024) but houses were built with the same or similar wood masonry techniques in North America and Europe at the same time (Hagman, 2014). Wood masonry can therefore be counted as the traditional or vernacular building techniques of the areas. Vernacular buildings use local materials and are well adapted to their situation (Rudofsky, 1964).

A cordwood wall is made of short logs set into a binder matrix (Roy, 2016). Cordwood can be used as a load-bearing structural element, as an infill in between a post and beam structure, or with built-up corners. The central European wood masonry technique differs a bit from the Scandinavian one, the latter using log-ends set perpendicular to the wall while the former uses log-ends set in diagonally crosswise placed layers (Szewczyk, 2023).

Building using your own labor makes cordwood houses a very cost-effective building method for small scale production and builder-occupier arrangements. The technique can make use of scrap wood from the wood industry; burnt, insect-attacked, or otherwise damaged lumber; or reused material from older timber buildings (Hagman, 2014). The binder was often clay from the farmlands in Europe making both parts of the cordwood wall readily available and cheap. This together with the fact that a cordwood wall doesn't require any heavy lifting made the technique attractive (Hagman, 2014). For similar reasons as why the technique first gained popularity, it has had a resurgence for self-builders since the 1970s mainly in the USA (Roy, 2016). The construction technique was never dominating, except for possibly a short while in Fredrikstad in Norway (Hagman, 2014), and has mostly faded away in favor of less labor-intensive building techniques.

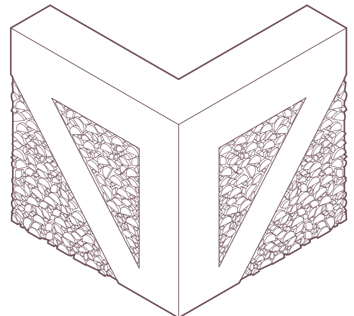
Cordwood walls have a high thermal mass and can be well insulated. The walls have less embodied carbon than traditional brick masonry and many other building techniques (Hu, 2023).

The binder matrix is often made out of cement or lime mortar but can use cob or clay to lower the embodied carbon further (Roy, 2016)

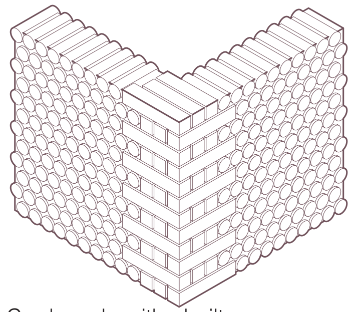
Cordwood building has with the modern resurgence seen some development. The traditional cordwood wall is a single wall made out of a lattice of log-ends and binder. The wall can contain insulation, in that case following the pattern binder - insulation - binder (Roy, 2016). Depending on the climate, modern cordwood walls can make use of a double wall design with two thinner cordwood walls sandwiching an insulation element (Roy, 2016). Olle Hagman has done preliminary tests with prefabricated wall elements without success because of the weight. Hagman has also tried glue-based binders in small-scale, with shrinking being identified as a problem. Developing this binder further would allow for an alternative to cement or clay-based binders that can have a higher insulating effect while keeping a low carbon footprint. Further studies have been done to verify the structural properties of cordwood assemblages (Mouterde, 2010, Brics, et al, 2022) with most research focusing on cement-based binders. Cordwood with a clay binder has been used for fire compartmentalization in a building in Nyköping, Sweden (Hagman, 2014).

Cordwood construction has been used for single-family detached homes in up to two stories and for a few public buildings but the design space for the multi-family houses and buildings of more than two stories is unexplored. Further, the technique could be adapted to reuse construction packaging materials to construct economy buildings with materials already transported to the site. Exploring and testing the properties of different binders with a focus on less carbon intensive alternatives to cement would provide insight for newer constructions with materials. One of the more interesting uses of cordwood is the possibility to use wood attacked by bark-beetles, allowing for use in the construction of the large parts of the Swedish forest that now are only turned into heat and energy following the latest infestation. Today the process of making construction timber from infested wood is expensive and requires a fully segregated pipeline with separate sawmills and even then the timber produced is of worse quality than the normal process.

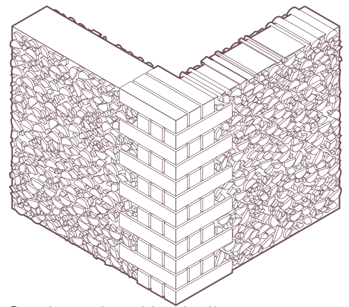
Sweden has more than 400 hiking trails (Hansen, 2019) and the promotion of outdoor activities is mandated by the Swedish government in 10 mål för friluftslivspolitiken ("10 goals for outdoor life politics") (Folkhälsomyndigheten). Outdoor activities are good for public health on both personal and societal levels.Providing access to outdoor activities through shelters along hiking trails is one way of promoting good and equal access in accordance to the goals.



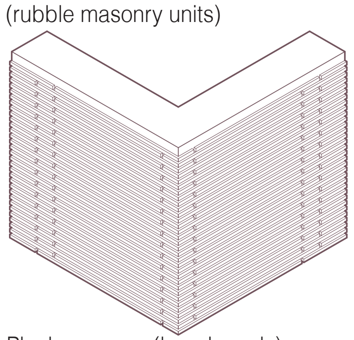
Cordwood as infill within post and beam structure



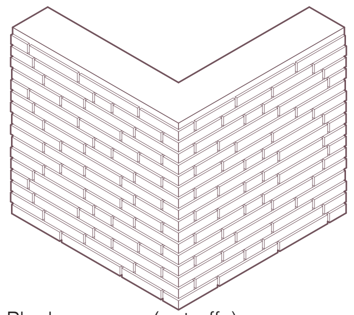
Cordwood with built up corner (similar masonry units)



Cordwood with built up corner (rubble masonry units)



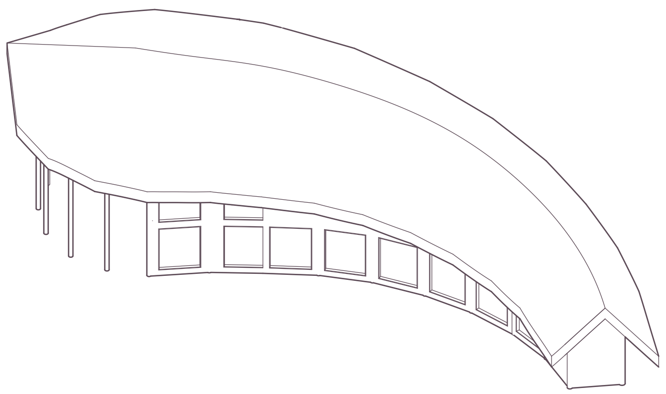
Plank masonry (long boards)



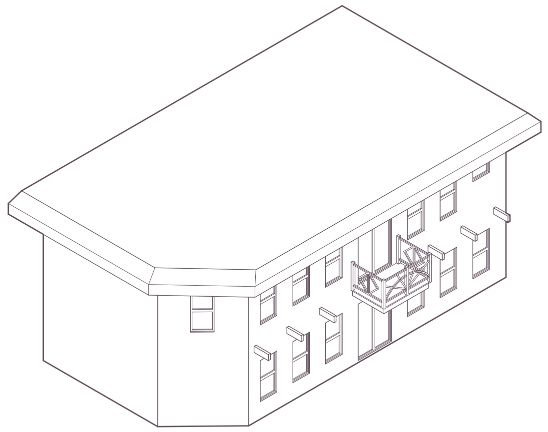
Plank masonry (cut-offs)

1.3.1 Reference Projects

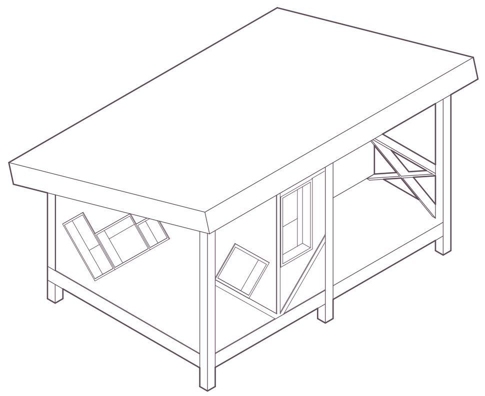
The reference projects are of very different scales and showcase a diversity of use cases and techniques.



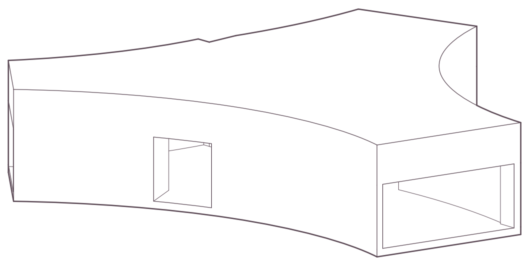
The Quetzal Cordwood Classroom is a complex of two buildings, built between 2012 and 2018 in Guatemala by. Community Cloud Forest Conservation. Together they make the largest cordwood complex. They are built with local material by mostly volunteers in the community. The building is cordwood infilled within a timber structure. The structure is made from an invasive tree species and removing them from the area is a benefit for the building. (Roy, R & Flatau, R. 2015). This project showcases how cordwood can utilise undersirable materials, adding potential benefits to the material outside of the low cost and low carbon footprint.



Ravenwood is the personal house of Bruce Kilgore and Nancy Dow who built it themselves between 2006 to 2010 in the USA. It is considered one of the most beautiful cordwood buildings by many in the self building community. The difference in binder color and wood color creates a big contrast. The building is built with a double wall and cordwood infill within a timber structure. (Roy, R & Flatau, R. 2015). Ravenwood shows how beautiful cordwood masonry can be when built with care.



Eko-Odlarnas shop was built in 2018 as an experimental structure by BI0N in Sweden. The structure uses local material and reused lumber combining both cordwood and plank masonry walls. The whole structure uses a timber frame. (Sundman, A. 2018)



The Arcus Center for Social Justice Leadership is one of the larger cordwood buildings in the world. It was built in 2014 by Studio Gang Architects in the USA. It differs from the other buildings referenced here in that cordwood is only a facade material and the structural materials are concrete and steel, something than can be criticised. The Arcus Center showcases that cordwood can exist in a modern urban context. (Roy, R & Flatau, R. 2015).

None of these examples showcases cordwood as a loadbearing material, while thie thesis projecr do.

1.4 Theory

The theory is divided into three parts: building technique, material, and impacts for sustainability.

1.4.1 Building Technique

A cordwood wall is made of short logs set into a binder matrix (Roy, 2016). Cordwood can be used as a load-bearing structural element, as an infill in between a post and beam structure, or with built-up corners. The central European wood masonry technique differs a bit from the Scandinavian one, the latter using log-ends set perpendicular to the wall while the former uses log-ends set in diagonally crosswise placed layers (Szewczyk, 2023)..

The traditional cordwood wall is a single wall made out of a lattice of log-ends and binder. The wall can contain insulation, in that case following the pattern binder - insulation - binder (Roy, 2016).

Depending on the climate, modern cordwood walls can make use of a double wall design with two thinner cordwood walls sandwiching an insulation element (Roy, 2016).

Olle Hagman has done preliminary tests with prefabricated wall elements without success because of the weight. Hagman (2016

Cordwood mortar is made out of a binding agent, a stabilizing agent, and fibers. Typical binders today include cement, clay, cob and paper enhanced mortar .

Hagman has also tried glue-based binders in small-scale, with shrinking being identified as a problem. This paper continues his research.

Clay and cement have a higher heat conductivity than paper or cellulose. A binder made of glue, wood chips, and paper could possibly work as a replacement for current binders, based on preliminary testing by Olle Hagman (private communication).

Further studies have been done to verify the structural properties of cordwood assemblages (Mouterde, 2010, Brics, et al, 2022) with most research focusing on cement-based binders. Cordwood with a clay binder has been used for fire compartmentalization in a building in Nyköping, Sweden (Hagman, 2014).

Cordwood masonry differs from traditional masonry in some key aspects.

In traditional masonry the header stones are necessary to connect and bind together wythes. The amount of header stones in a load bearing masonry wall is typically 20 % (Granholm, H., 1953). Header bonds are weaker and more prone to diagonal cracks (Kummer, N., 2007). A cordwood wall on the other hand needs header bonds for the logends to be able to breathe and release water since the end grain is more efficient than side grain for this. This means that the amount of headers will be much greater than 20 % with planks sometimes used to stabilise along the direction of the wall.

In a traditional masonry wall the bricks are all uniform while in a cordwood wall the masonry units are irregular. This leads to masonry bonds closer to rubble masonry than brick masonry. A plank masonry wall can have a similar unity in the masonry units as a brick wall.

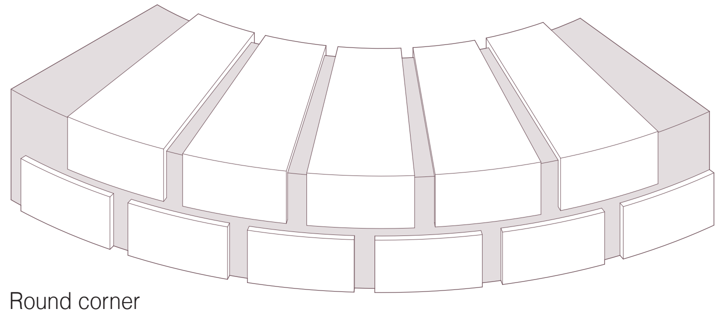
In a cordwood wall the masonry units reach through the thickness of the wall while this is only true for 1-brick walls in traditional masonry. The thickness of the wall determines the length of the cordwood units while the thickness of the wall determines the number of bricks in a traditional wall.

A common building style for many vernacular building techniques is round buildings. Round buildings maximise

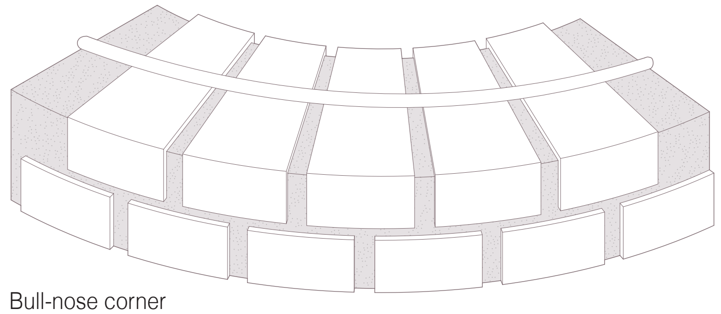
the floor area for a given wall area. Round buildings also avoid corners making load bearing cordwood walls easier.

Bull-nose corners is a form of built up corners where the corners are built along a quarter circle instead of an orthogonal corner. The corners are tied together. (Roy & Flatau, 2015, P. 76-19). Sobeck's bull-nose corners are tied with barbed wire for additional support and grip into the binder but, a different tensile cable made from natural fibers could likely work (hemp rope).

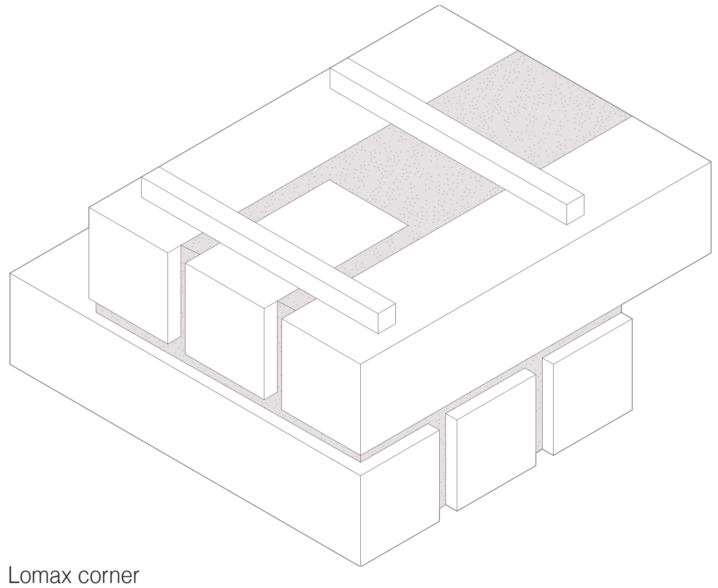
Lomax corners (Roy, R. 2016) are a form of built up corners made from pre-built units made of rectangular quoins tied together with smaller pieces of wood. These corners have the advantages that they are stronger than individual log ends and are easier to keep plumb.



Round corner



Bull-nose corner



Lomax corner

1.4.2 Material

Glue
The glue used for the binder experiments in this report is wall paper glue made from more than 95 % cross linked carboxymethyl ether from corn starch. Similar glues can be produced using less processed means by directly using corn starch or potato starch.

Starch is today investigated as a resource for bioadhesives in the wood industry (Arias, A., et. al., 2021), showcasing a potential to replace petrochemicals but further research on how to improve the process is necessary.

Lignin
Lignin is together with cellulose the main constituent parts of wood.Today lignin is a by-product from the paper and pulp industry that is mostly burned for heat. Research is ongoing on its use for biobased resins and adhesives. (Tribot, et. al, 2019)

Sawdust
Sawdust is a waste product from wood workshops and industries. Sawdust can be used as insulation.

Paper
Newspapers are abundant still even in a more digital age. The wet newspaper works as fibers in the mixture.

Wood cutoffs
Cordwood buildings have been made from reused timber since the inception of the building technique. Logs from log houses were reused to make cordwood buildings with thicker walls and therefore better insulation. Reuse from modern timber buildings makes it easier to utilise parts of damaged timber that can't be directly reused in new construction.

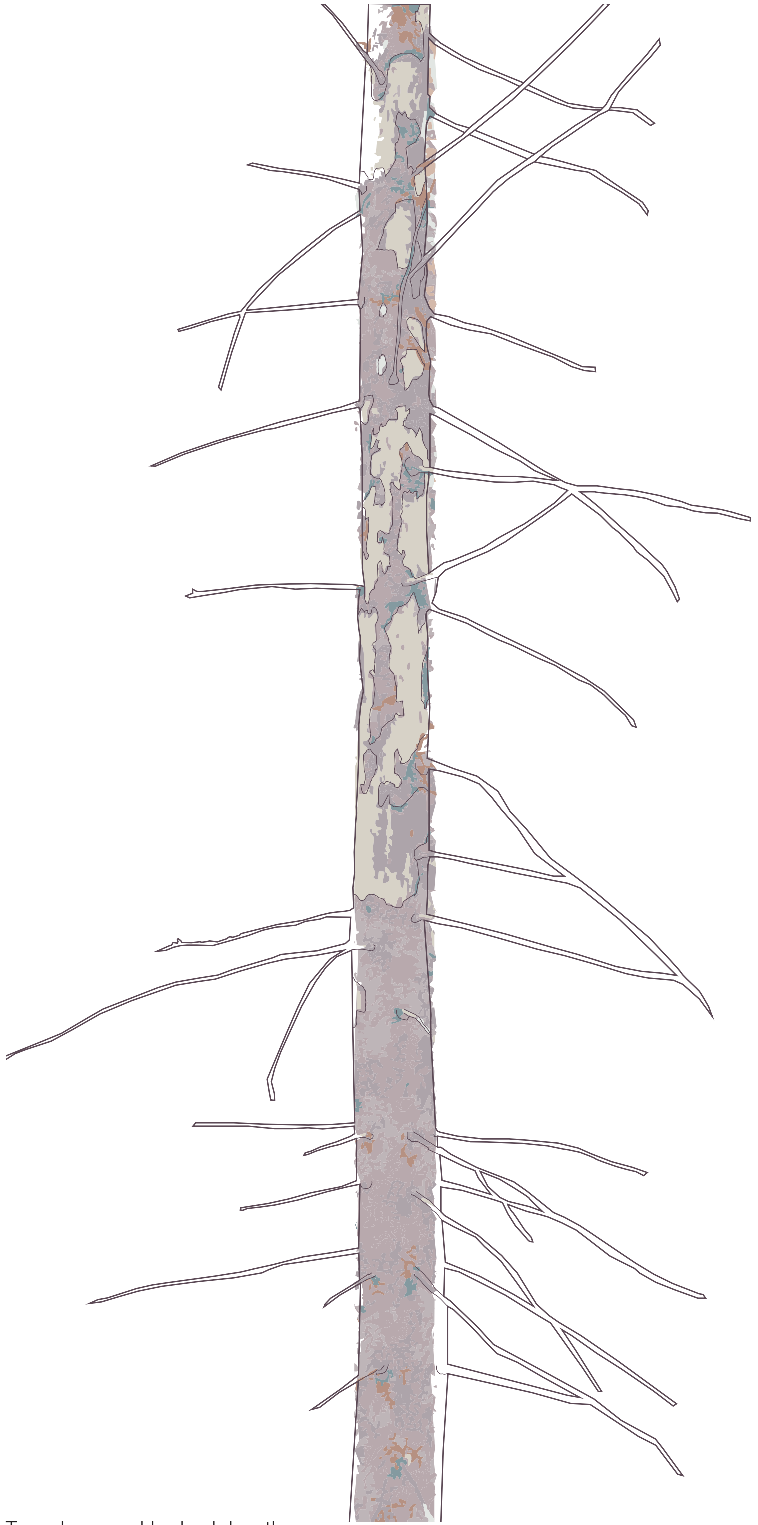
Bark beetles
Bark beetles are a family of insects that can attack trees burrowing into the bark. There are over 90 families of bark beetles in Sweden, 30 of which can attack spruces. The spruce bark beetle is the only one that can damage healthy spruces and it is a problem for the Swedish wood industry. The beetle primarily attacks fallen or stressed spruces, e.g. wind felled or spruces exposed to droughts, but the beetle can attack healthy spruces as well Different bark beetles can attack pine trees. (Om granbarkborre, Skogsstyrelsen. se)

The Swedish Forest Agency provides a map for what areas are most exposed, but the beetle is a widespread problem in large parts of the country..

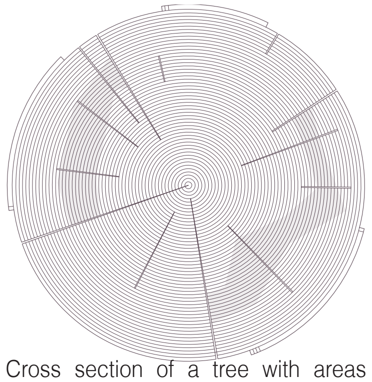
Spruces attacked by bark beetles are less useful for sawn construction timber since the wood product is more expensive to produce and the quality is lower. If the trees are not identified early enough the attack will lead to the trees losing their bark and starting to dry in a way that causes cracks. The beetle also comes with a blue fungus that discolours the wood.

With shorter pieces necessary and a higher flexibility in profile these damaged trees can be used for cordwood buildings. The attacked timber has a higher porosity stemming from the beetle ingress and thereby lower density giving the wood better insulating properties (Hagman, O., 2016). This allows a cordwood building to utilise a resource that today is difficult to use in a way that fully utilises its properties.

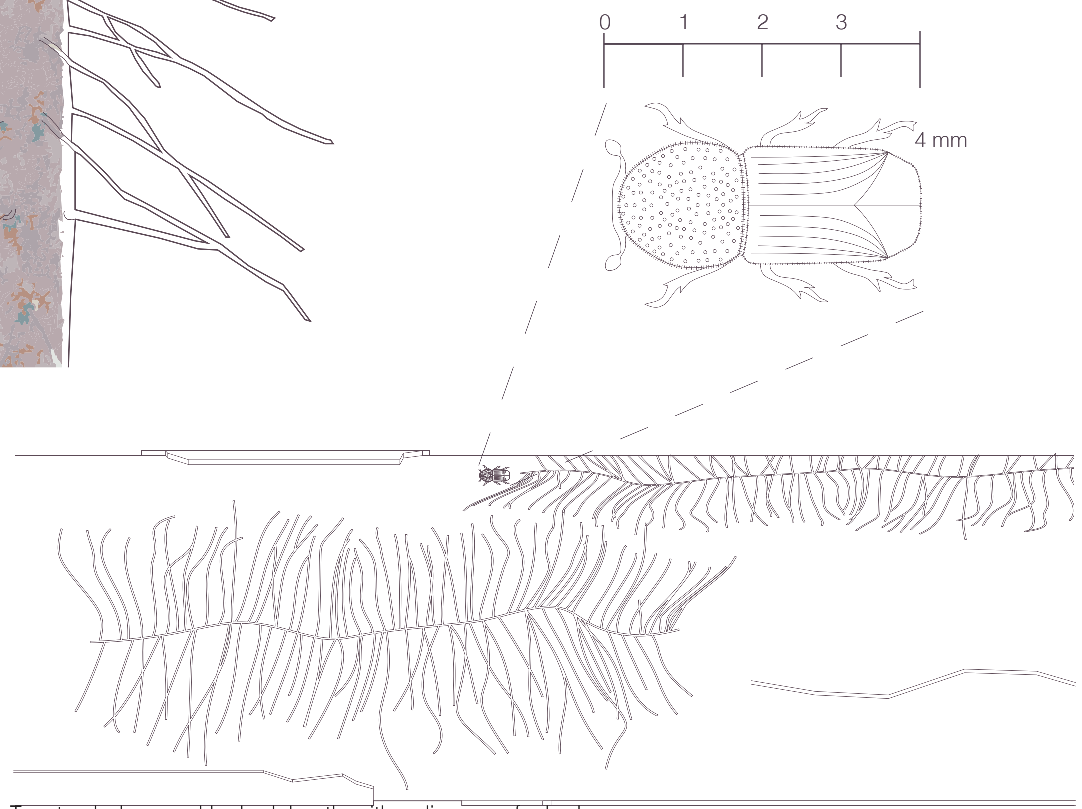
Mold and tar
White mold can develop in the binder since similar problems are common in clay construction. Tar is added as natural biocide to counteract that.



Tree damaged by bark beetles



Cross section of a tree with areas damaged by fungus



Tree trunk damaged by bark beetle with a diagram of a bark beetle.

1.4.3 Impacts for sustainability

The sustainability aspects that the project highlights are both based on cordwood, the binder and the typology.

Building a structure of cordwood allows for the use of timber as the primary building material. Depending on the specifics the walls can provide a well insulated structure with a high thermal mass providing a good indoor climate with low energy needs to heat. Cordwood allows the use of shorter pieces of lumber which in turn gives a longer carbon cycle to wood that otherwise would be turned into heat.

The proposed binder is made from renewable and biodegradable resources and is therefore likely biodegradable even if this should be established experimentally. This differs from more common binders, cement and lime mortar that can at best be ground down to a powder to be used in other mixtures. Clay is similar in that it can go back to nature but differs in that it needs to be separated from the wood while the new binder is made from similar material to the wood itself.

The building provides some aspects of environmental sustainability but its main function is part of the government's goal for social sustainability, providing the possibility for more people to access the outdoors regardless of means. This corresponds to goals 1, 4 and 9 of the 10 government goals for outdoor life politics (Naturvårdsverket, 2025), they are access to nature for everyone, access to nature for outdoor life and outdoor life for public health.

1.5 Delimitations

This thesis is only meant to start the exploration of alternative binders for cordwood structures. The testing of the binders is limited and meant to give an indication of the properties and more rigorous testing is necessary to understand the variation between samples and within samples and to provide more certain data. For most experiments only one sample was tested for each binder mixture.

The testing is limited to only a few of the many important properties that a binder has to have and further testing is necessary to provide more information.

The possibility to use damaged timber is not tested and the sources arguing for the use are third-hand and vague. Therefore the argument in this thesis for the use is based on the ability to work around the damage due to the shorter lengths of cordwood masonry units compared with other manufactured timber products and the ability to use irregular shapes.

The proposed building is developed in parallel with the experiments and seen as an example of a typology that can be built with cordwood assuming that the binder works. If the binders characteristics of the recipe are not strong enough for the use this will be discussed in the end.

1.6 Method

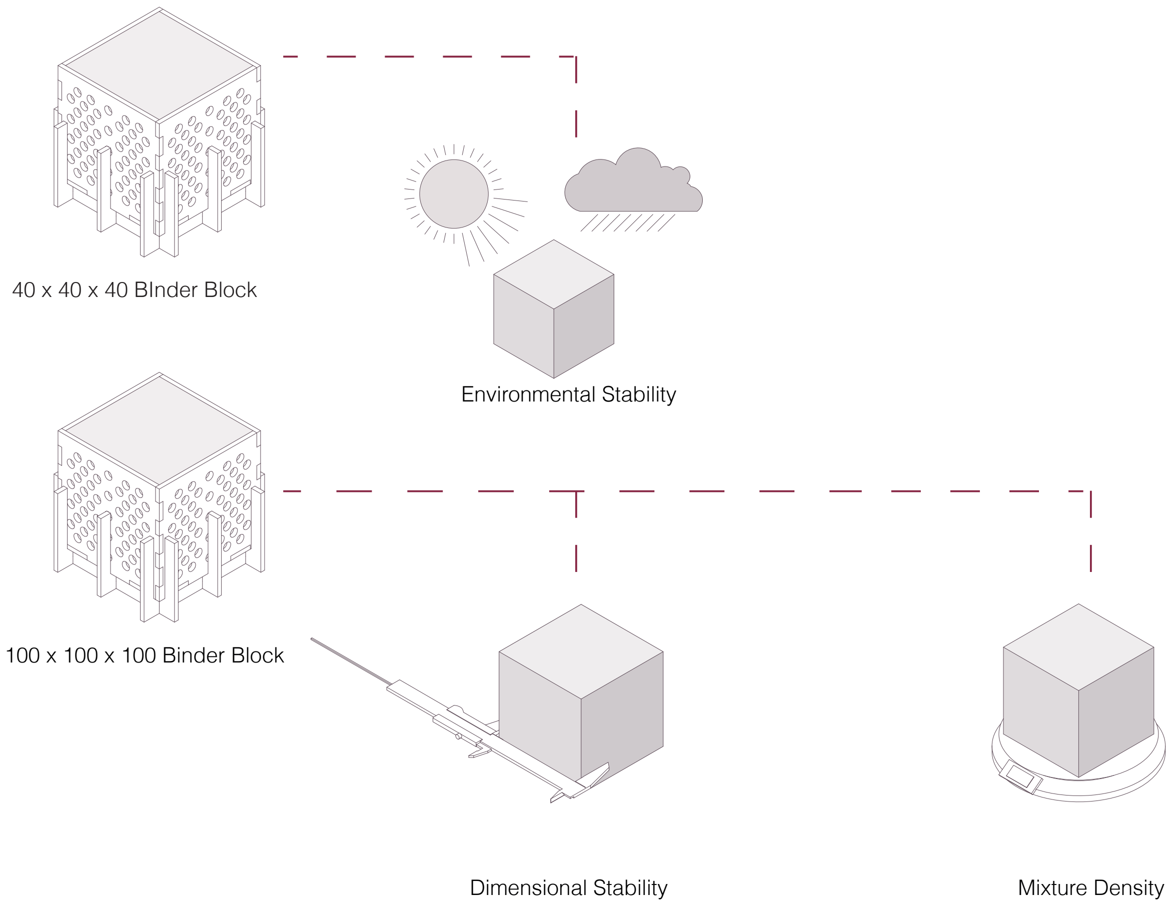
The methods used in the thesis are divided into information gathering and information creation.

The information gathering includes interviews, a workshop, and 3D scanning of an existing building, and references and aims to situate the project in an already existing context and to provide tools and knowledge that can be used as a basis for the experimentation.

The information creating methods starts with the creation of the binder recipies. Based on the informaton gathering methods a recipe made from starch, paper sludge and ballset in the form of sawdust, lignin and green liquor dregs.

The different binder recipes where exoerimented on to establish material parameters and to reduce the number of recipe candidates.

The experiments tested dimensional stability while drying, density and reaction to environmental factors. The experiments also include modeling of masonry sections in different scales.



1.6.1 Interviews

To situate the work in a context three interviews were conducted with people that have worked with cordwood in Sweden. Questions focused on their experience with the material and technique, their thoughts on the possibilities for the future and what knowledge they wished were developed in the field

Olle Hagman is an engineer who have written two books about cordwood construction: Väggar av ved (2013) and Mura med Ved (2017). He has participated in the Continental Cordwood Conferences (CoCoCo) in the USA and contributed with an article to CoCoCo 2015 (Roy & Flatau 2015). He has also contributed to Cordwood Building (Roy 2016). He has hosted workshops teaching the building technique. Hagman provided the starting point for the recipe using sawdust, paper sludge and a starch based glue.

Anna Sundman is an architect who did a project exploring the technique together with Architectural Environmental Strategies. Her work is described in (Sundman & Nyren 2018). Her work is the latest cordwood project I could find in Sweden at the time of writing making her learnings interesting for the thesis.

Ulf Henningson is an engineer and clay builder. He has built a building with cordwood but the discussion with him focused more generally on clay construction. The interview with Ulf was less structured as an interview and more a longer continuous conversation during a weekend workshop. Ulf hosts workshops on clay construction and is one of the experts in the field in Sweden.

Diana Bernin is a professor in Applied Chemistry and Chemical Engineering at Chalmers. She suggested during consultations to add lignin and green liquor dregs as alternative ballasts in the binder mixture.

1.6.2 Workshops

Participation in workshops focusing on natural building methods to further familiarity with the techniques and the setting most common today for their use.

The workshop format is how much of today's natural building techniques are tried, developed, and utilized.

Participating in them provided material familiarity with clay and information on the community aspect also present in much of today's cordwood construction. The workshops did not provide direct experience in wood masonry.

One workshop was conducted focusing on clay plastering giving hands-on experience with the viscosity and mixture properties that are appropriate for a binder and how this could be further implemented in the development.

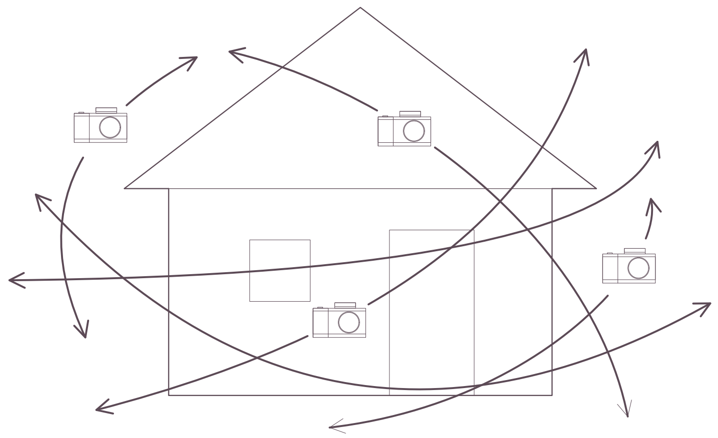
Another workshop focusing on roof shingles disscussed different alternatives, treatments and methods of shingle production. The knowledge from this workshop influneced the decisions in the design

1.6.3 3D scanning of existing buildings

The inspiration for working with the material was a cordwood barn in Hållnäs, east of Uppsala.

The existing building was 3D scanned using Scaniverse to document it. Both mesh models and gaussian splats were generated.

The scans provided an understanding of dimensions that have traditionally been used and gave an insight of some of the building techniques that can be utilised with the material.



Pictogram showing how lidar scanning

Scan of cordwood barn

1.6.4 Full scale modeling

Full-scale blocks of wood masonry were constructed to observe the behavior of the binder and wood material.

The mix used was 1 part wallpaper paste, 1 part soaked newspaper sludge, and 3 parts sawdust.

The sawdust was mixed particle sizes and materials recycled from a wood workshop's vacuum system.

The newspaper had been cut into pieces soaked in water and finally further slurried with a paint mixer.

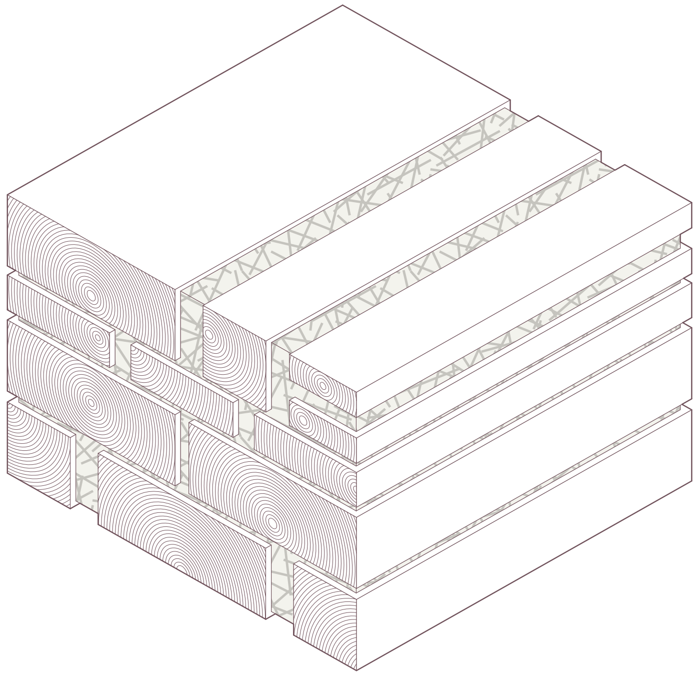
Wood masonry blocks were constructed both with sawn timber and firewood.

The sawn timber pieces were pine and the firewood was debarked birch wood. The firewood pieces were about 28 cm long and the sawn timber pieces were 20 cm long.

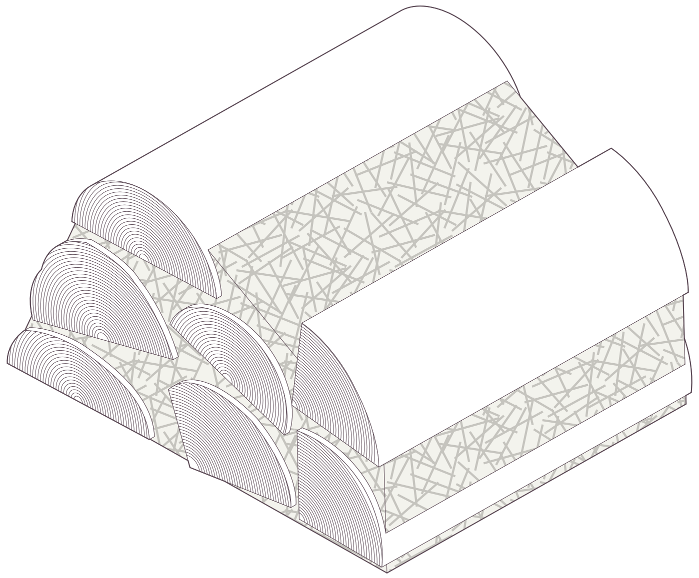
The masonry joints varied in thickness generally between 0.5 cm to 2.5 cm with some of the sawn timber pieces having even thinner and thicker joints stemming from the uniform thickness of the curved wood pieces.

The joints were "pointed" or pushed in around one cm from the ends of the wood ends.

The samples were numbered 1.1 and 1.2 for reference later in result tables.



Fullscale model using plank cutoffs



Fullscale model using split logends

1.6.5 Small scale modeling

Smaller 1/4 scale models were produced to more quickly and less material intensively test different binder mixtures and ballast materials.

Birch firewood pieces were sawn and splintered to imitate 1/4 size logs, 7 cm long, acknowledging that this can affect the grain direction and expansion direction.

Binder mixtures were mixed according to the formula 1 part glue, 1 part paper slurry, 3 parts ballast.

The same sawdust as in the full scale modeling was used as ballast, and compared with lignin and green liquor dredge (GLD).

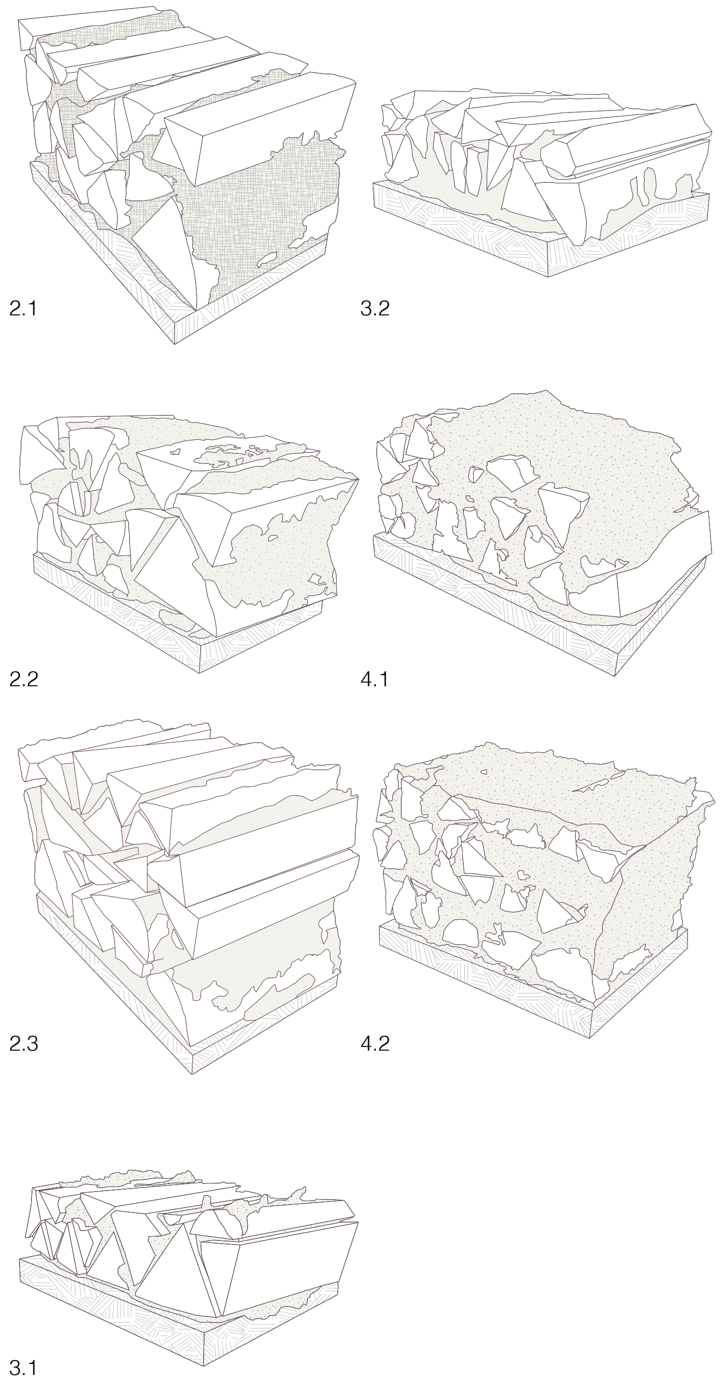
The glue was paper paste prepared to a dry mix water ratio of 100 g to 2.4 l.

The fibers in the paper slurry and sawdust could not be scaled down, limiting the data that can be observed from the experiment, but care was taken to use short particles of paper slurry.

The GLD mixture was less sticky than the two other mixtures and a different ingredient ratio is considered for further tests.

The mortar joints were generally between 1 mm and 5 mm thick, making pointing difficult..

Objects numbered 2.1 - 2.3 are 1/4 scale models from the first batch using only one type of ballast while objects 3.1 and 3.2 use a mix of lignin and sawdust in a ratio of 1:2 and 2:1 respectively. Objects 4.1 and 4.2 test different mixtures based on GLD. Object 4.1 uses a mixture of lignin and GLD as the ballast with a higher ratio of glue and object 4.2 uses sawdust and GLD with the standard ratio of glue.



1:4 scale models using split log ends and different binders

1.6.6 Dimensional stability

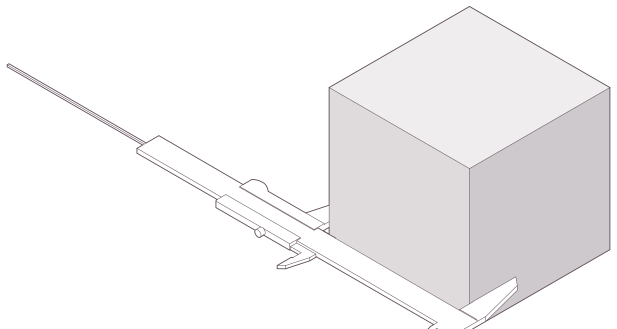
Test cubes with a nominal side length of 100 mm are measured to determine shrinking and density.

The test cubes are made using only binder. The mixture is cast into a formwork made from 4 mm plywood sheets with holes cut to provide additional drying area for the samples. The plywood form is covered with a thin plastic sheet to make removal easier and to provide a flat surface while the forms are filled. The plastic sheet is punctured after the form is filled. After 4-5 days the formwork is removed and the test cubes continue to dry until testing.

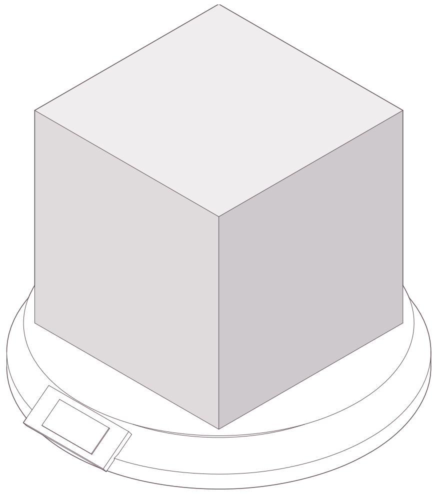
The binders tested all use the recipe ratio of 1 glue, 1 paper sludge, 3 ballast. The ballasts tested are 3 Lignin, 2 Lignin + 1 Saw dust, 1 Lignin + 2 Saw dust, 3 Saw dust.

The cubes are measured with a calliper after drying. The difference between the formwork dimensions are calculated and noted.

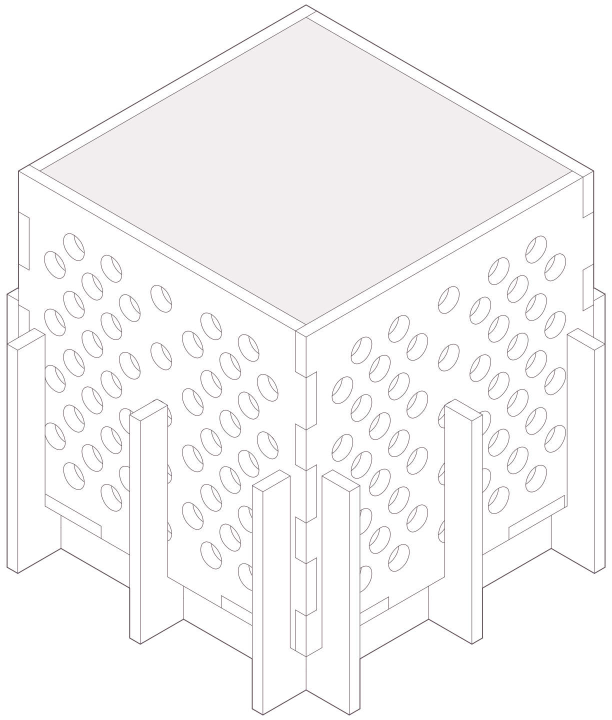
The dried samples are weight and using the dry dimensions the density of the material is calculated.



100 mm * 100 mm * 100 mm Binder cube measured by callipers



100 mm * 100 mm * 100 mm Binder cube on scale

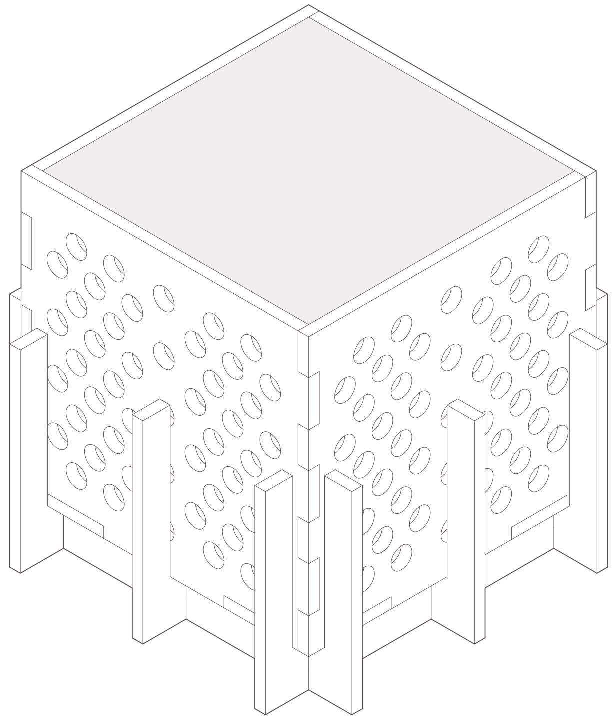


100 mm * 100 mm * 100 mm Binder cube in formwork

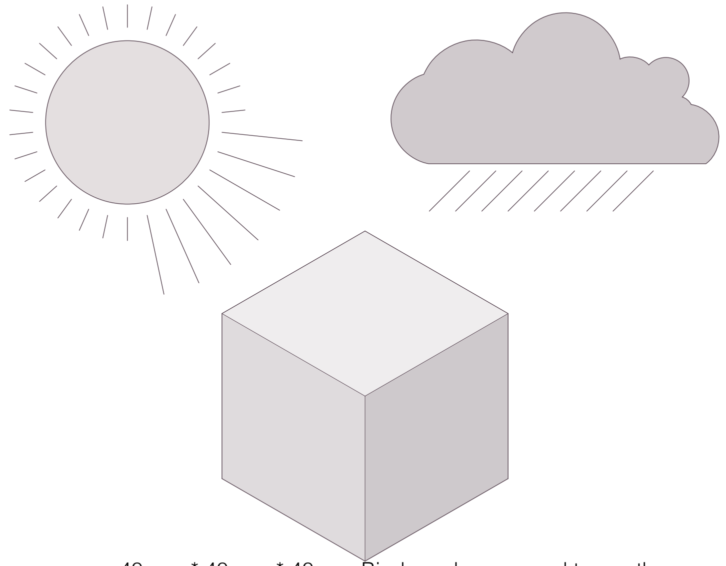
1.6.7 Environmental stability

Test cubes with a side length of 4 cm were filled with binders. The cubes are dried and then placed outside in the forest and observed over time. Photos are taken at each observation and changes are noted.

Binders with a ballast of only lignin, only sawdust and the two mixes of lignin and sawdust were tested.



40 mm * 40 mm * 40 mm Binder cube in formwork

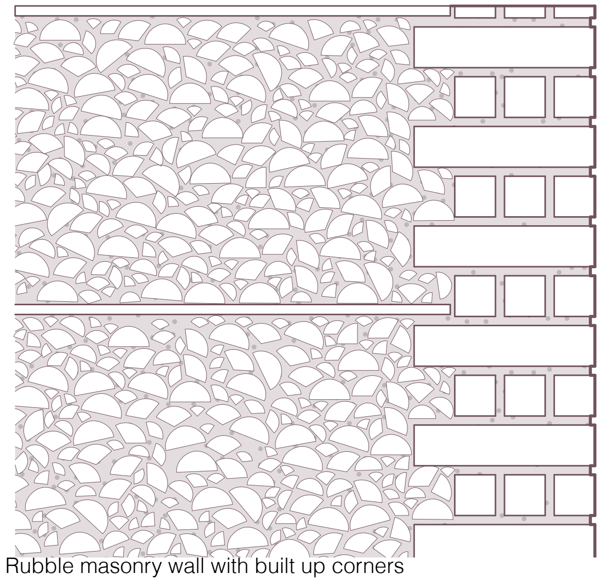


40 mm * 40 mm * 40 mm Binder cube exposed to weather.

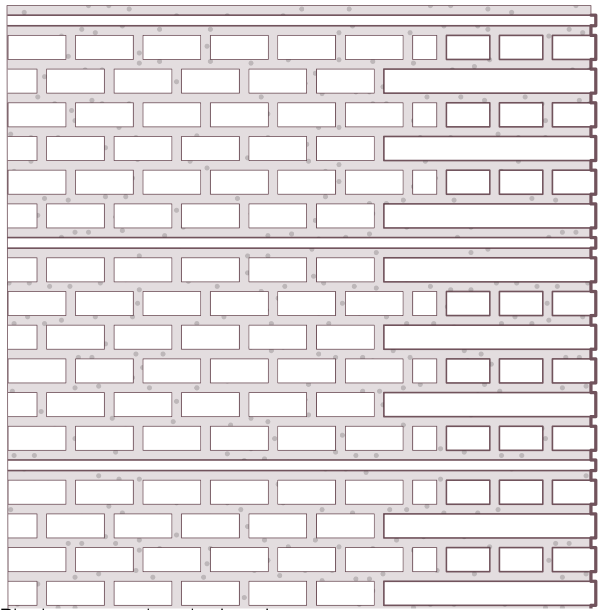
1.6.8 Modeling of masonry elements

Digital modeling of masonry bonds allows planning and exploration of the possibilities. The goal is to create a toolbox that can be used for further design.

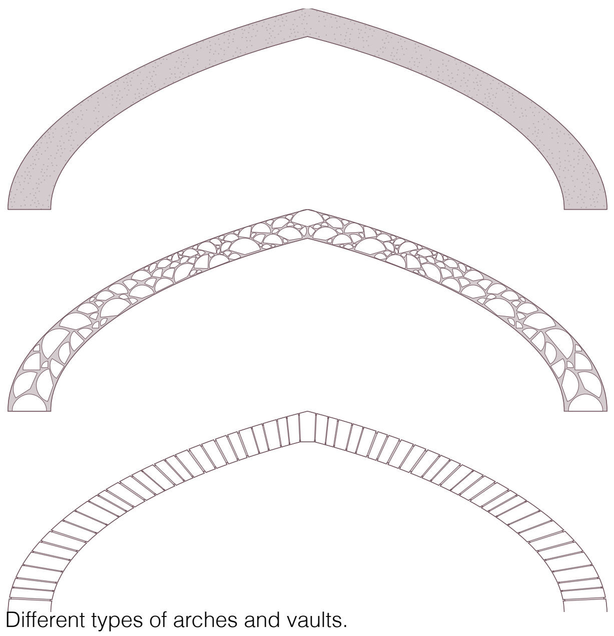
Vaults were explored both in digital models and physical models in small scale to investigate the structural soundness of the ideas.



Rubble masonry wall with built up corners



Plank masonry header bond



Different types of arches and vaults.

2 Experimental results

The experimental results are presented in the forms of tables and discussions followed by model photos and summaries of the shown material's properties.

2.1 Qualitative findings from small scale modeling

Table 1: Small scale experiment

Object	Images	Binder Ratio (G/P/B)	Ballast Parts	Binder Strength	Binder Texture	Binder Color
1.1		1/1/3	Sawdust	3/5	1/5	Beige
1.2		1/1/3	Sawdust	3/5	1/5	Beige
2.1		1/1/3	Sawdust	3/5	1/5	Beige
2.2		1/1/3	Green Liquor dregs	0/5	2/5	Black
2.3		1/1/3	Lignin	4/5	4/5	Brown
3.1		1/1/3	2 Sawdust 1 Lignin	4/5	3/5	Brown
3.2		1/1/3	1 Sawdust 2 Lignin	4/5	3/5	Brown
4.1		1.5/1/3	2 GLD 1 Lignin	2/5	3/5	Black
4.2		1/1/3	2 Sawdust 1 GLD	1/5	2/5	Black

The binder strength is rated on a relative scale with binders with a higher perceived strength receiving a higher score. The binders using lignin mixture as a ballast generally felt stronger than the binder using only sawdust. Green liquor dregs resulted in a binder that didn't work.

2.2 Quantative findings from dimensional stability

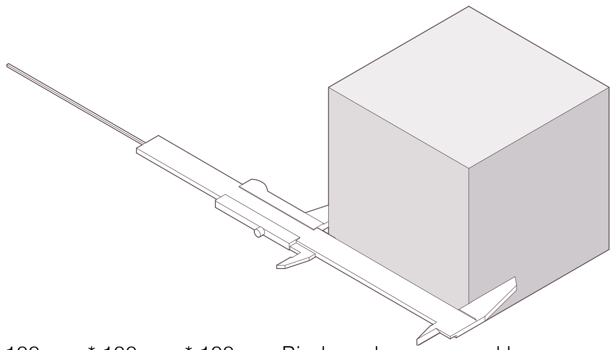
Table 2: DImensional stability

Mixture	W1 (mm)	W2 (mm)	H (mm)	w1 (mm)	w2 (mm)	Avg (mm)	Delta dim (%)	Dry Weight (g)	Dry Density (kg/m3)
Sawdust	97	98	99	97	97	97,6	-2,4	240	255
Lignin-Sawdust A	98	98	95	96	97	96,8	-3,2	303	332
Lignin-Sawdust B	99	98	100	95	96	97,6	-2,4	385	397
Lignin	94	93	94	97	97	95	-5	438	533

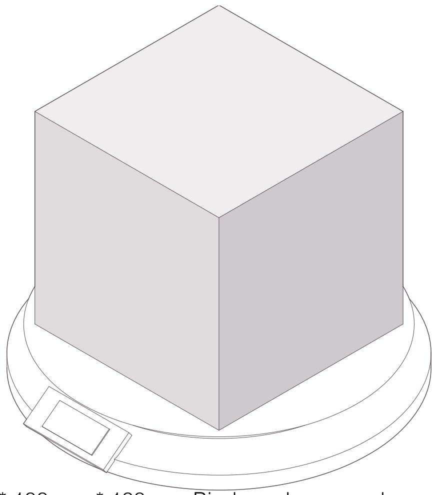
The table showcases the dimensions of the test cubes for compression testing with a nominal dimension of 100 mm in wet state. The measured lengths W1 and W2 correspond to the two side lengths and H the height of the cube. w1 and w2 correspond to the measured length of the test blocks for heat conductivity testing, also with a nominal side length in wet state of 100 mm.

The lignin based mortar mixes hardened faster than the binder only using sawdust. Binders with a higher lignin content also experienced more shrinking but all binder candidates showcased similar shrinking. More testing is necessary.

Sawdust sparsely packed used for insulation usually have an effective density of 80 - 200 kg/m3 and spruce have a dry density of 400 - 600 kg/m3 (traguiden).



100 mm * 100 mm * 100 mm Binder cube measured by callipers



100 mm * 100 mm * 100 mm Binder cube on scale

2.3 Environmental stability

The four samples were placed outside in the forest in an unsheltered environment for two weeks. The weather varied with an approximately equal number of days with rain and sunshine.

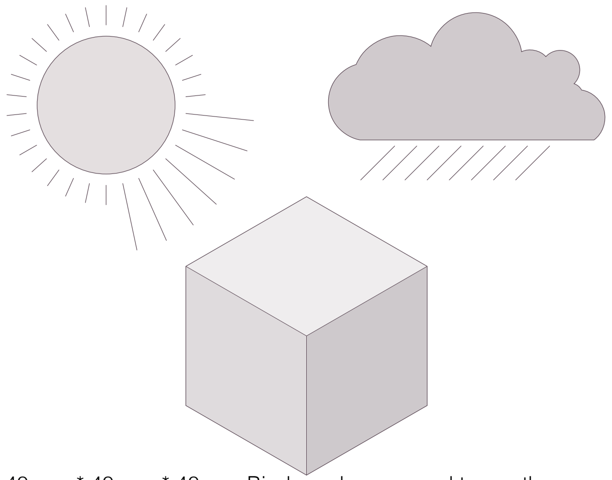
Day 0: All samples are dry and feel strong.

Day 2: After being exposed to rain, the sawdust binder cube has lost most of its strength while the lignin binder cube remains feeling strong.

Day 4: More rain resulted in the sawdust binder starting to break down. No change in the lignin binder. The mixed binders show smaller signs of damage at places with more sawdust.

Day 10: No new changes in any binder except in the sawdust binder that has mostly dissolved.

Day 14: All samples are dry again and have regained any lost strength. In total only small changes to the mixed binders after the initial damage i n areas with high sawdust concentration and no noticeable damage to the lignin binder. The sawdust binder is completely destroyed.



40 mm * 40 mm * 40 mm Binder cube exposed to weather.

Day 0

Day 2

Day 4

Day 10

Day 14

2.4 Model photos and material gallery

2.4.1 Sawdust

Recipe:
1 Glue 1 Paper sludge 3 Sawdust

Qualitative properties:
Strong, light, large fibers, rough texture

Dry density:
255 kg/m3

Dimensional:
2.4 %

Environmental Stability:
Lost strength after one day exposed to rain, crumbled in less than two weeks of outdoor exposure to the weather.

2.4.2 Lignin

Recipe:
1 Glue 1 Paper sludge 3 Lignin

Qualitative properties:
Strong, heavy, small fibers, smooth texture

Dry density:
533 kg/m3

Dimensional:
5 %

Environmental Stability:
Kept strength over the duration of the experiment (2 weeks), even when wet.

2.4.3 Sawdust-Lignin A

Recipe:
1 Glue 1 Paper sludge 1 Lignin 2 Sawdust

Qualitative properties:
Strong, medium light, small fibers, smooth texture

Dry density:
337 kg/m3

Dimensional:
3 %

Environmental Stability:
Kept most of the strength over the duration of the experiment (2 weeks), but showed signs of damage.

2.4.4 Sawdust-Lignin B

Recipe:
1 Glue 1 Paper sludge 2 Lignin 1 Sawdust

Qualitative properties:
Strong, medium heavy, small fibers, smooth texture

Dry density:
397 kg/m3

Dimensional:
2.4 %

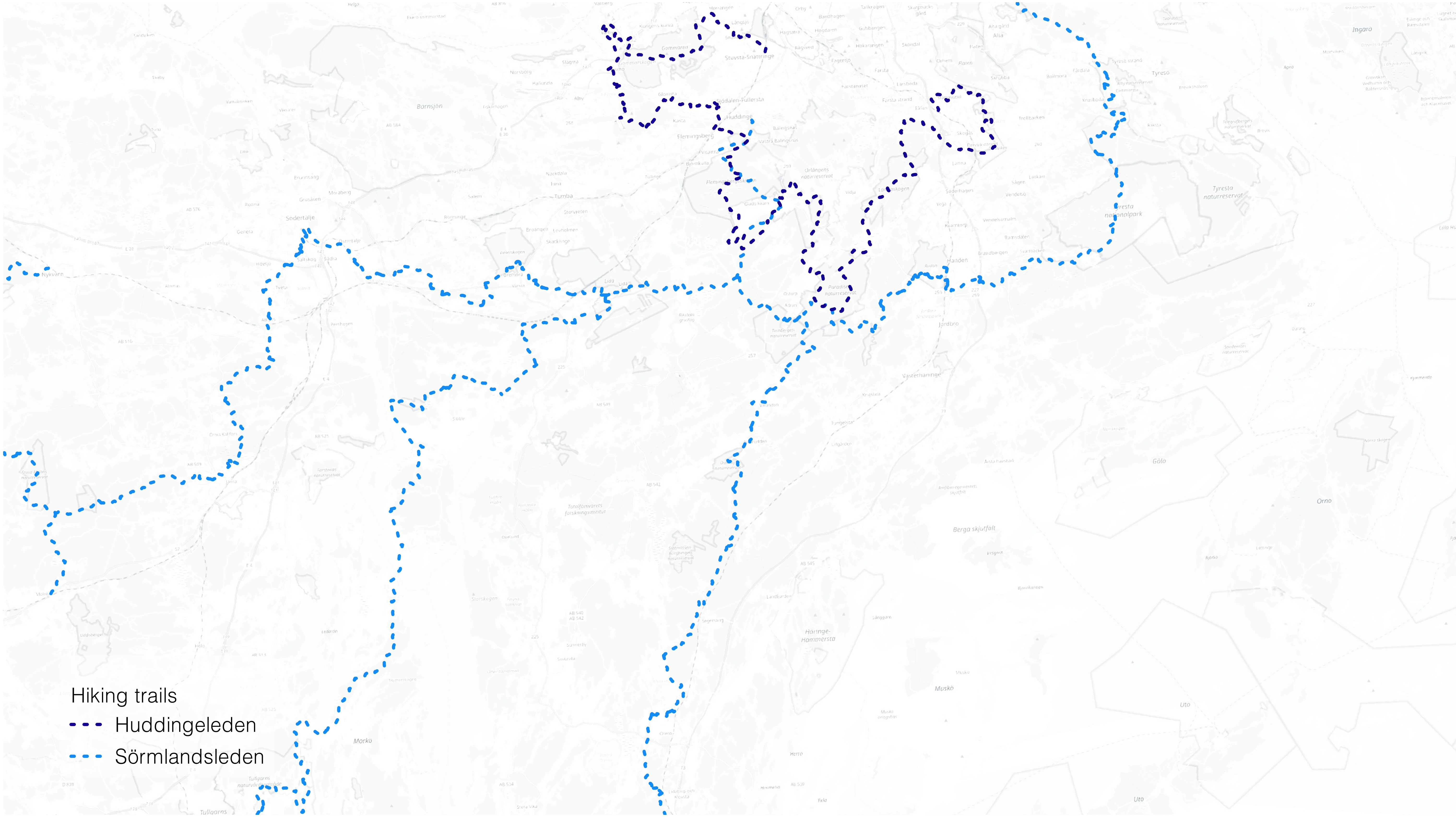
Environmental Stability:
Kept most of the strenght over the duration of the experiment (2 weeks), but showed signs of damage.

2.4.5 Vault models

Binder arch, lacks reinforcement from logends. Built with too steep of an angle and with too little material at the top. The model showcases that an arch built from just the binder is possible.

Header vault. Some layers lack continuity of the binder leading to loss of strength in the vault. The model demonstrates that a cordwood vault is posible.

3 Design: Hiking shelters and cabins along Sörmlandsleden and Huddingeleden



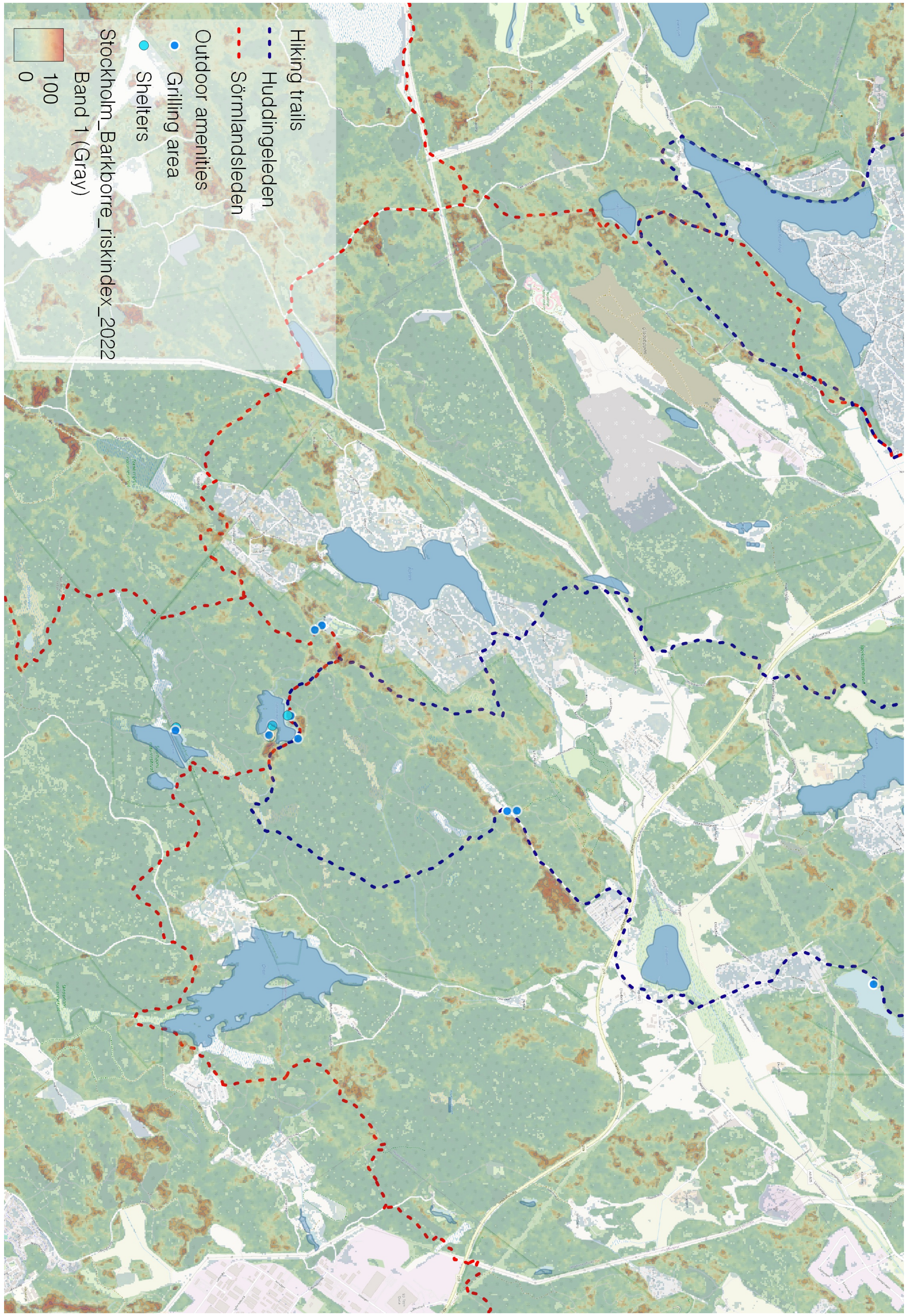
3.1 Analysing the trail

Huddingeleden
Huddingeleden is an 83 km long hiking trail in Huddinge municipality just south of Stockholm. The trail passes through 13 nature preserves and varying environments. The most popular stage passes through Paradiset's nature preserve where you can choose between different routes including the Sami trail. The route passes close to Haninge municipality that borders Paradiset. (Huddinge)

There are already some cabins and shelters on the trail but the popularity of the route necessitates that additional shelters are constructed. Today there are already plans for shelters located at Kärrsjön.

Sörmlandsleden
Sörmlandsleden is a 1000 km long hiking trail in 101 parts (Hansen, 2019). It was the first route established in the Swedish lowlands and is still one of the longest in the country. The parts that pass close to the sites are parts 5 and 6.

Bark beetle exposure
According to Huddinge municipality the bark beetle is today a limited problem with only peripheral forests damaged but large areas of the municipality are exposed to a high risk. The risk index is similar in Haninge and a similar.



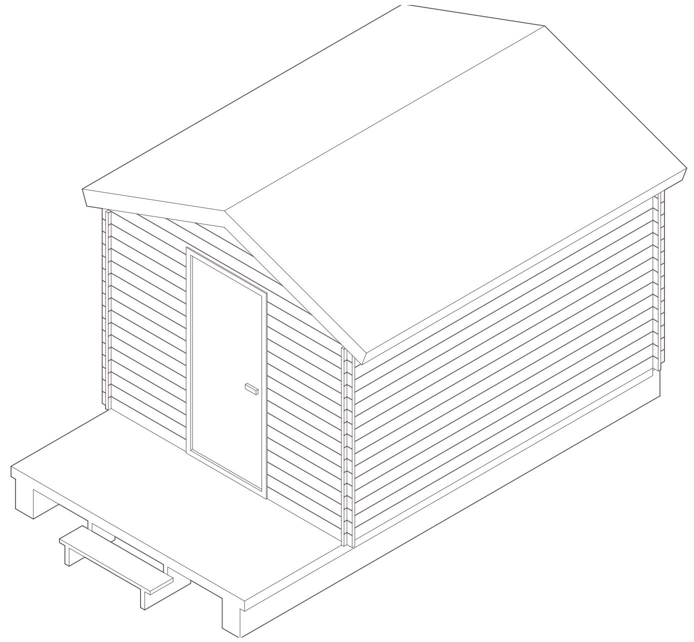
Öran is a lake that straddles the border between Paradiset's and Skeppnan's nature preserves. The lake is both in Huddinge and Haninge. Sörmlandsleden follows the south edge of the lake. There are a couple of campsites with fireplaces but no permanent shelters.

3.1.1 Hiking cabins

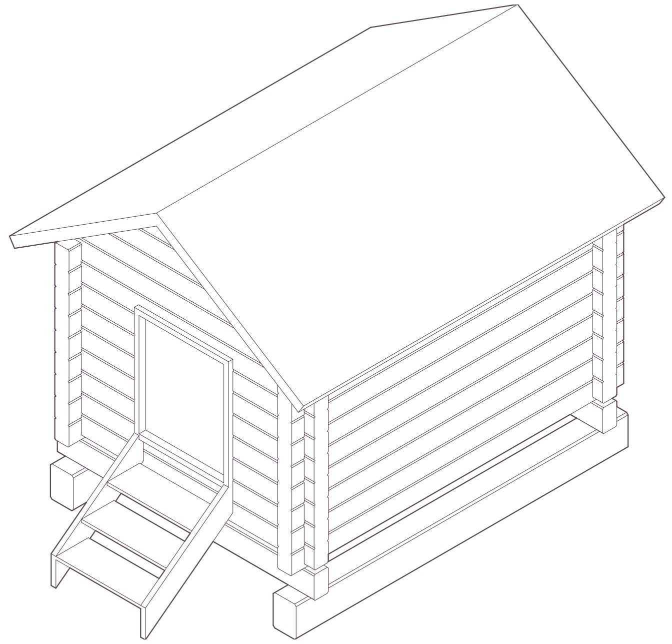
Two hiking cabins that showcase the types in Paradiset nature preserve are ”Raststugan” and ”Ugglekojan”. They are both small rectangular cabins with room for up to 6 people.

Raststugan is built with thin planks while Ugglekojan is built with thicker laying logs. Neither have any large windows.

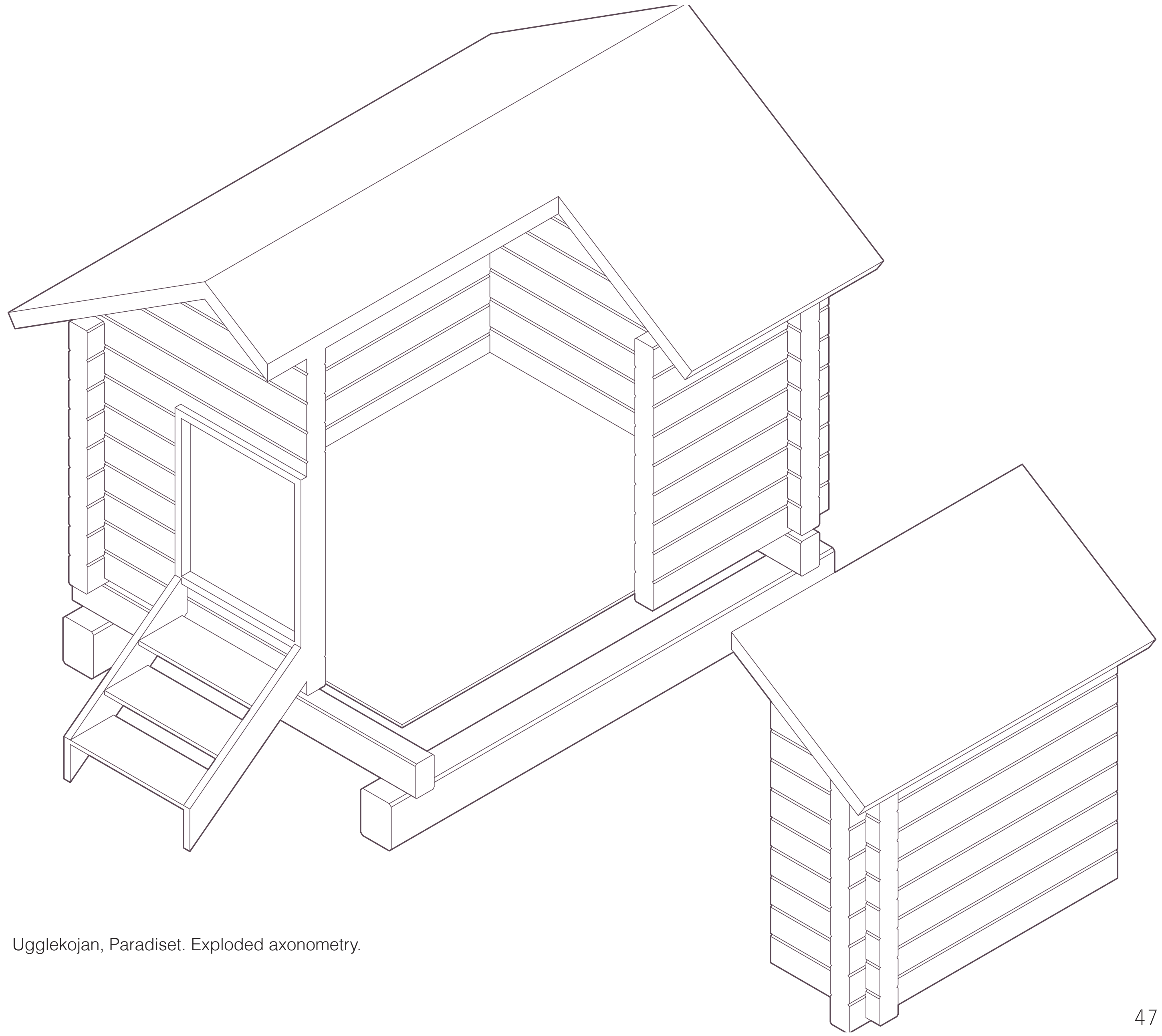
The door to Ugglekojan is a small hatch while Raststugan has a regular door.



Raststugan, Paradiset

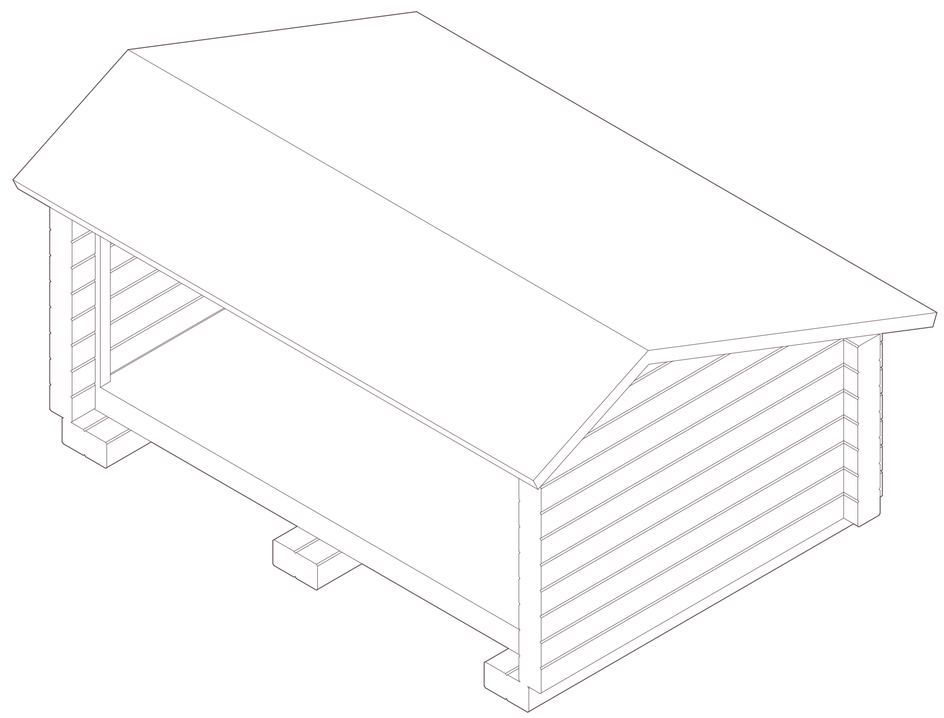


Ugglekojan, Paradiset

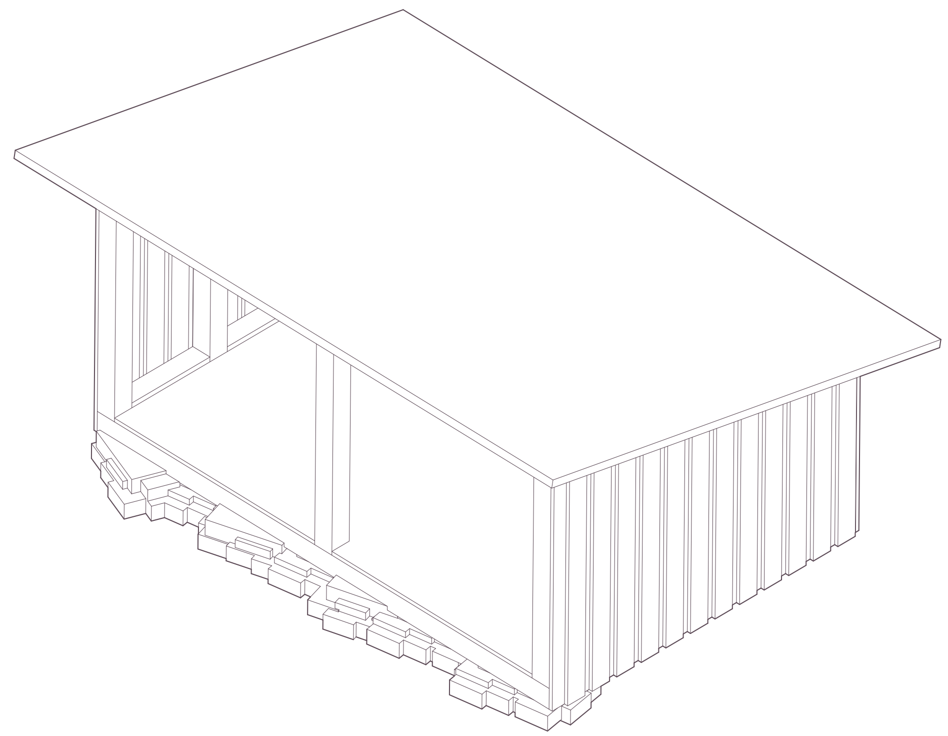


Ugglekojan, Paradiset. Exploded axonometry.

3.1.2 Lean-to shelters



Lean-to made from lying logs, Paradiset



Lean-to with standing panel, Paradiset

The wind shelters in Paradiset are very typical. Either built with lying logs or a timber frame with standing panels. The shelters are equipped with a nearby fireplace and some benches.

3.2 Designing Cordwood Cabins and Shelters

Design principles
The shelters serve the dual purpose to showcase different aspects of wood masonry and to serve hikers.

Hiking cabins main function is to provide shelter but allows for additional amenities compared to wind shelters. Being fully closed the cabins allow the materials insulating properties to be used.

In the simplest terms the shapes that are investigated are buildings using a rectangular plan and buildings using a round plan.

Round shelters provide the largest floor area per wall area and also circumvent one of the more difficult obstacles of cordwood shelters with load bearing walls, the corners.

Round walls introduce a new problem which is doors and windows.

Rectangular shelters with load bearing walls may require built up quoins to support the rubble masonry.

Doors and windows can be installed much simpler than in a round cabin but an arch or beam is necessary to bridge the gap and disperse the load to the rest of the wall.

Roof structures can be made simply using roof trusses or using masonry techniques such as a tunnel vault. Covering the roof with shingles provides a wood based solution for weather protection.

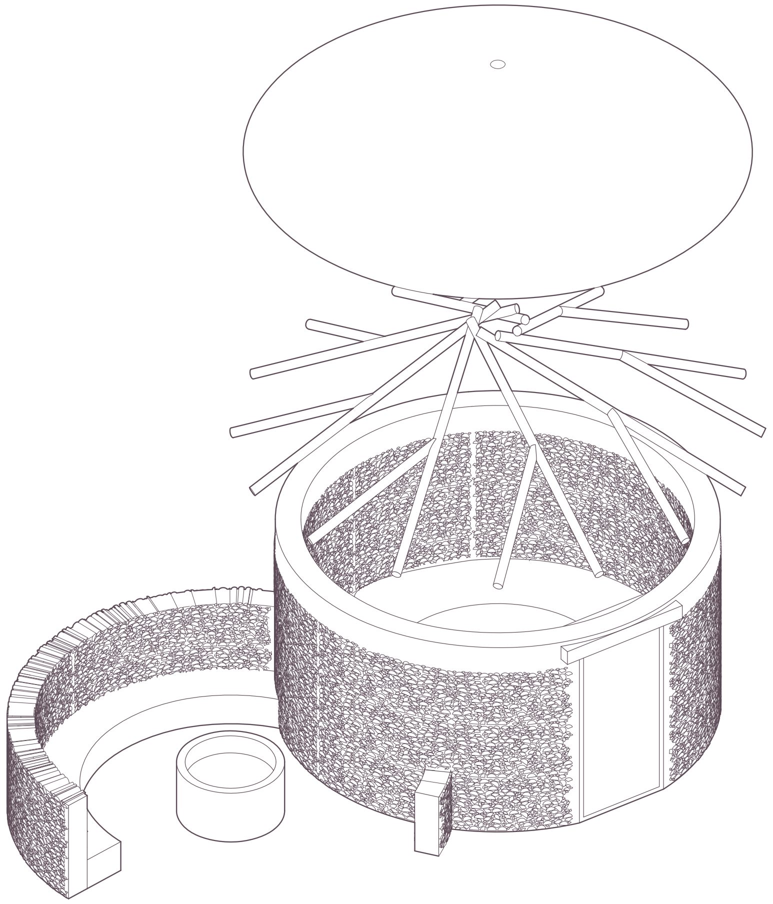
One of the amenities that is most interesting to add to the cabins that are close to a lake is a sauna and that is explored in some of the proposals.

Design process
Different alternatives were explored during the design process.

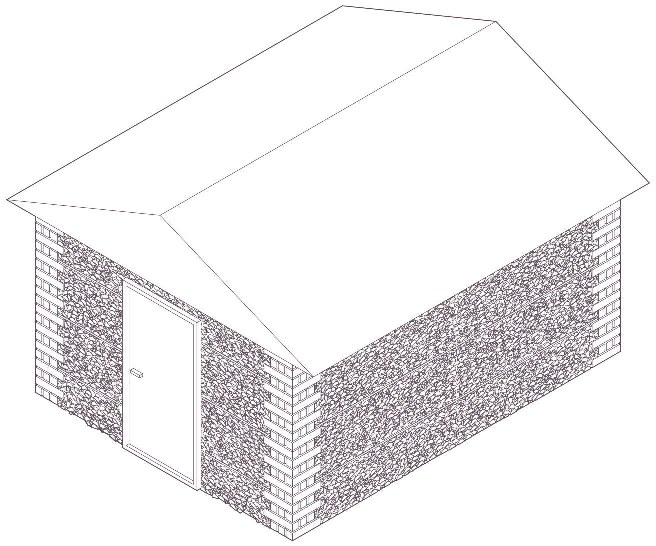
Round shelters were a starting point that was explored but the limited design space in how the space could be utilised led to the concept being abandoned after a few iterations. Round buildings with larger dimensions and less restrictions in wanting to use load bearing cordwood would make it a viable route to explore again.

Rectangular buildings with a separate roof structure was the easiest starting point, but the separation of the roof structure from the main material made the alternative less interesting. A building with built-up corners still provided an interesting way to move forward with.

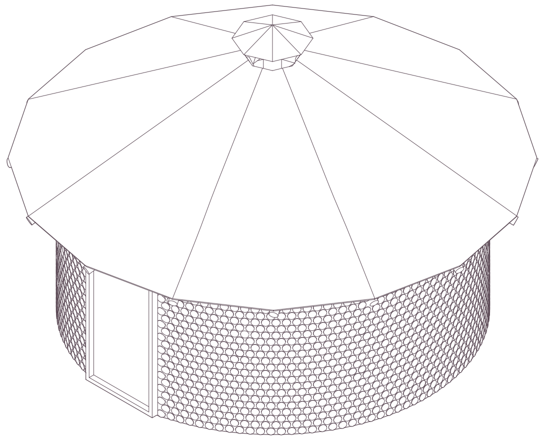
The vaulted ceiling provided a way to make a roof structure from cordwood. Having the walls and roof be a combined unit led to a limited roof height.



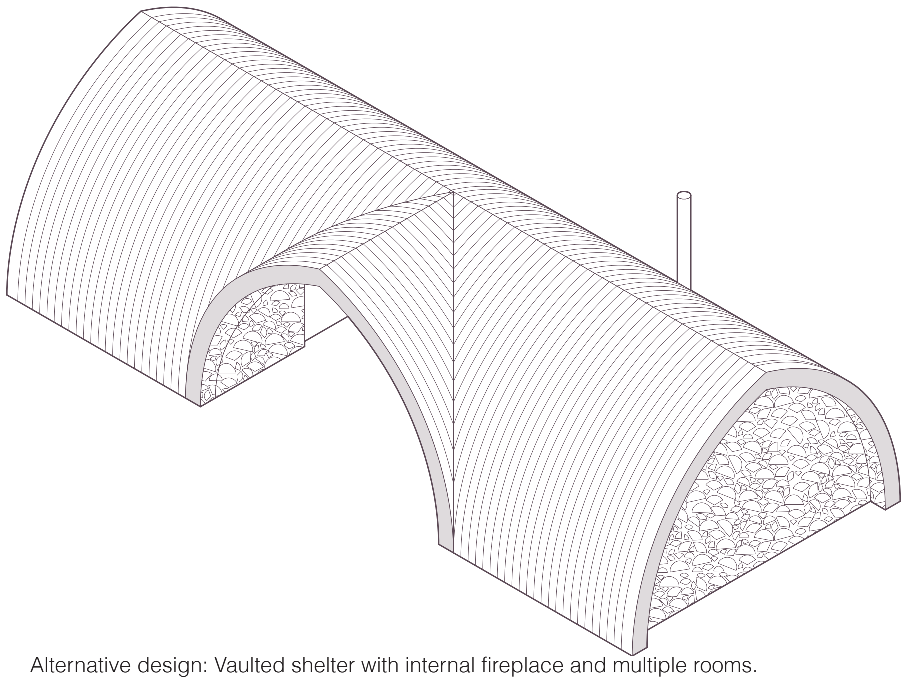
Alternative design: Round shelter alternative with fireplace to the side.



Alternative design: Rectangular building with built up corners.



Alternative design: Round shelter with internal fireplace



Alternative design: Vaulted shelter with internal fireplace and multiple rooms.

3.2.1 Hiking cabin

Hiking and sauna bathing is for many a spiritual experience. Forest bathing, a concept present both in Sweden and Japan, encourages people to relax and absorb nature. Inspired by this spiritual experience and the formfinding excercises based on the material in the earlier chapter led to a building harking back to woodland chapels, crematorium or other similar structures.

The final cabin is built with load bearing cordwood, built-up corners and rubble masonry bonds. The walls support a masonry vault. The vault is covered with shingles to protect the binder from weather exposure.

Shingles can be either thin and untreated and used as a sacrificial layer or thicker and treater with wood tar. For this project the second option is chosen since this means the cabin needs less maintenance and because this is the method used on churches further aligning the visual design of the structure with a spiritual building

The floor structure is made from cordwood set in the binder on top of sand and crushed rocks. The foundation of stone blocks surround the floor structure and support the walls.

Openings in the wall, windows and doors, are covered with vaults spreading the load from the masonry above.

The floorplan is simple, providing three rooms, two covered entrances and a sheltered outside bench and fireplace.

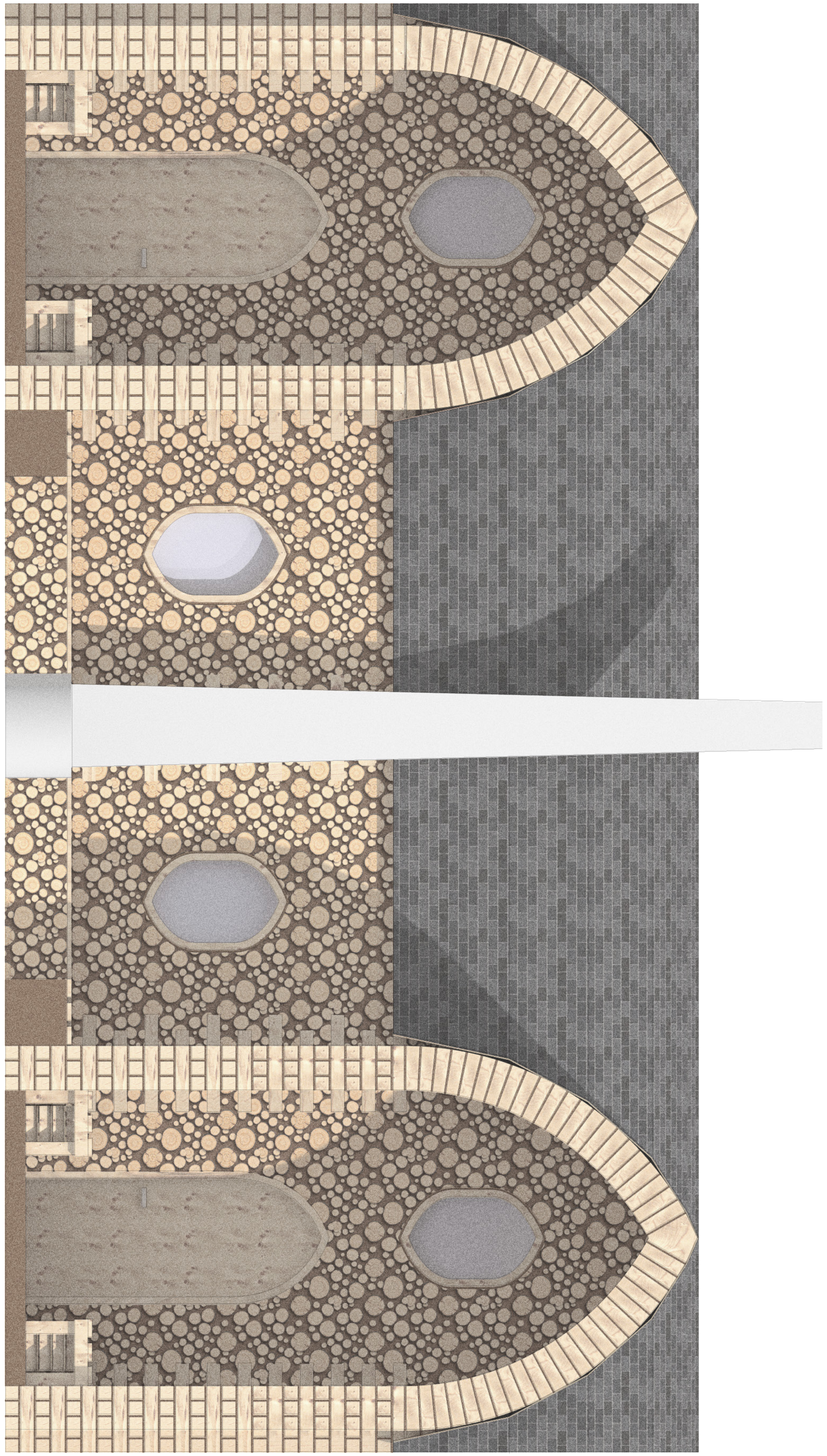
The three rooms are an inner sauna with a view over the water, an antechamber connected to the sauna providing a place to change and as a heat lock to preserve the warmth in the sauna. The last room is the main sleeping room with both space on the floor and on the loft.

The antechamber can serve as an additional sheltered area to sleep in for larger groups.

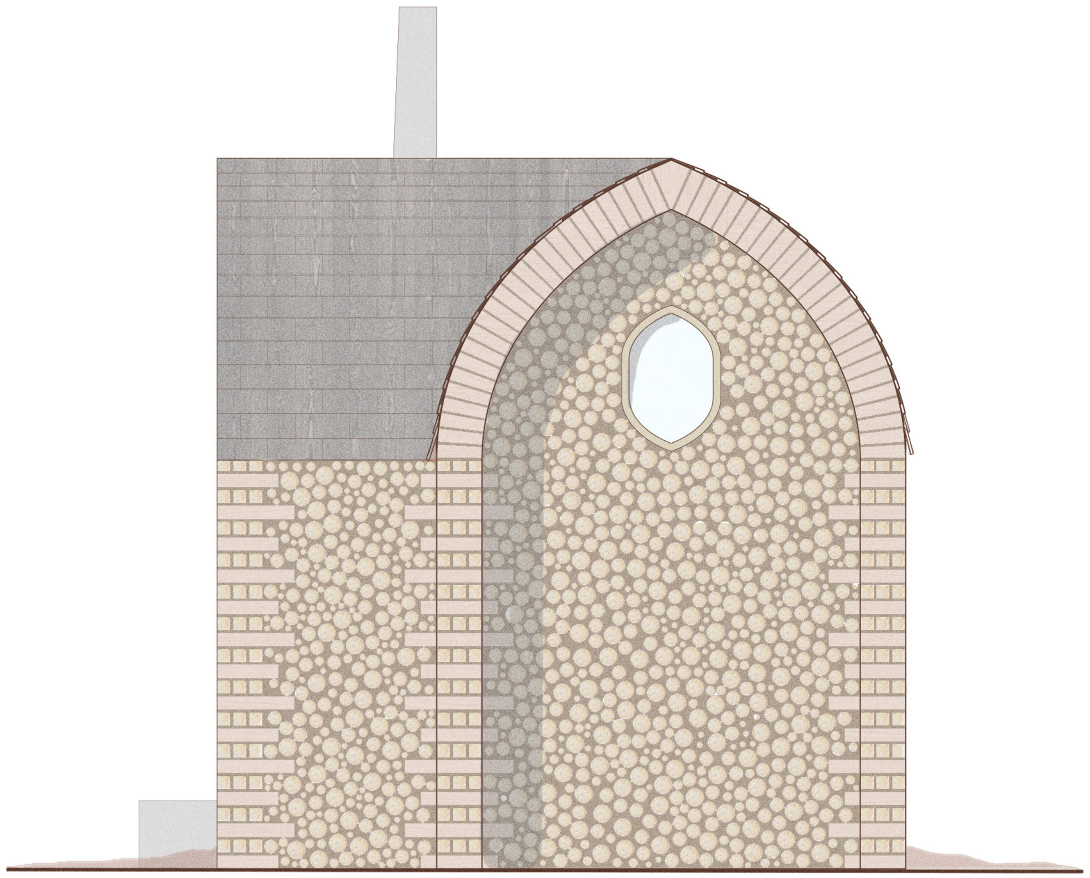
The main materials for the building are the logends of bark beetle damaged spruce for the rubble bonds and the binder of the lignin-sawdust mix B. The built up corners are made from short pieces of square lumber.

In addition glass for the windows, steel for the chimney and the doors are reclaimed from existing building materials but customised to fit the specifics for the project.

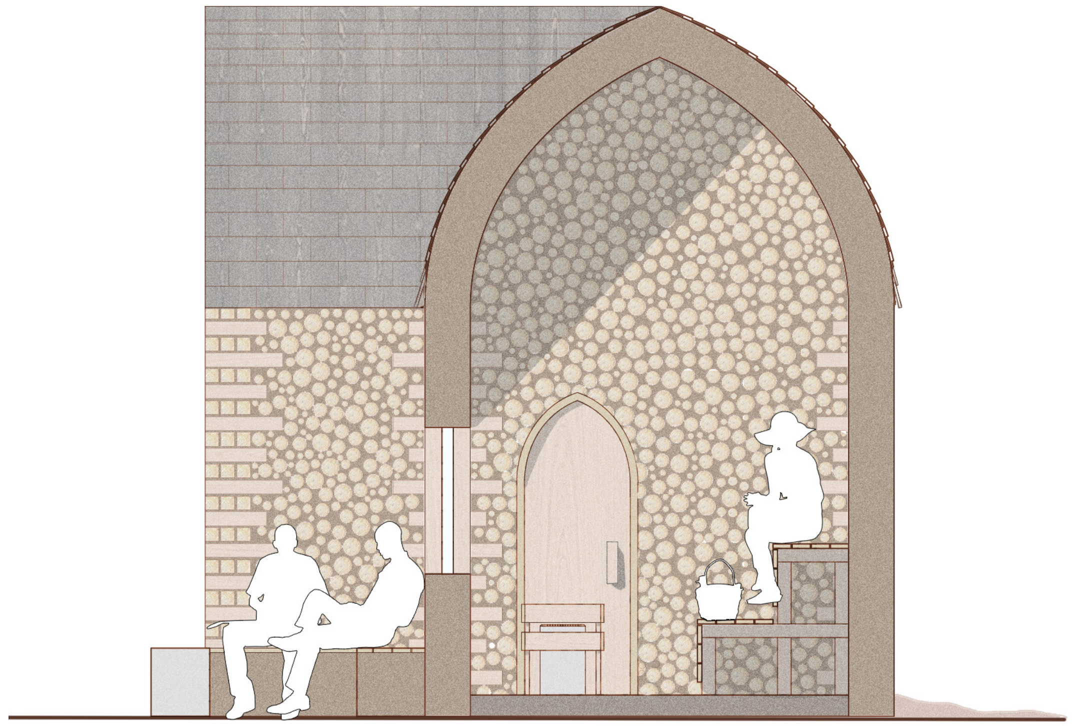
The fireplace is made from a reclaimed concrete drum similar to other fireplaces in the area.



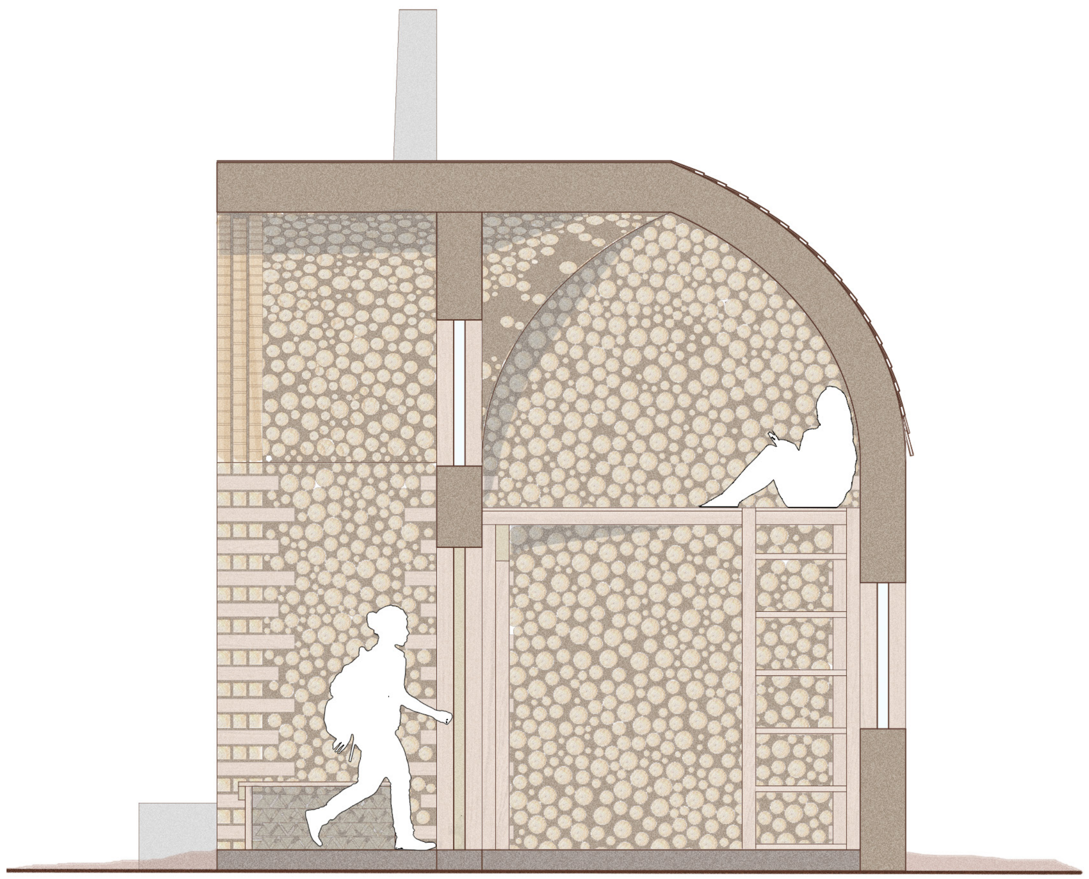
Front elevation



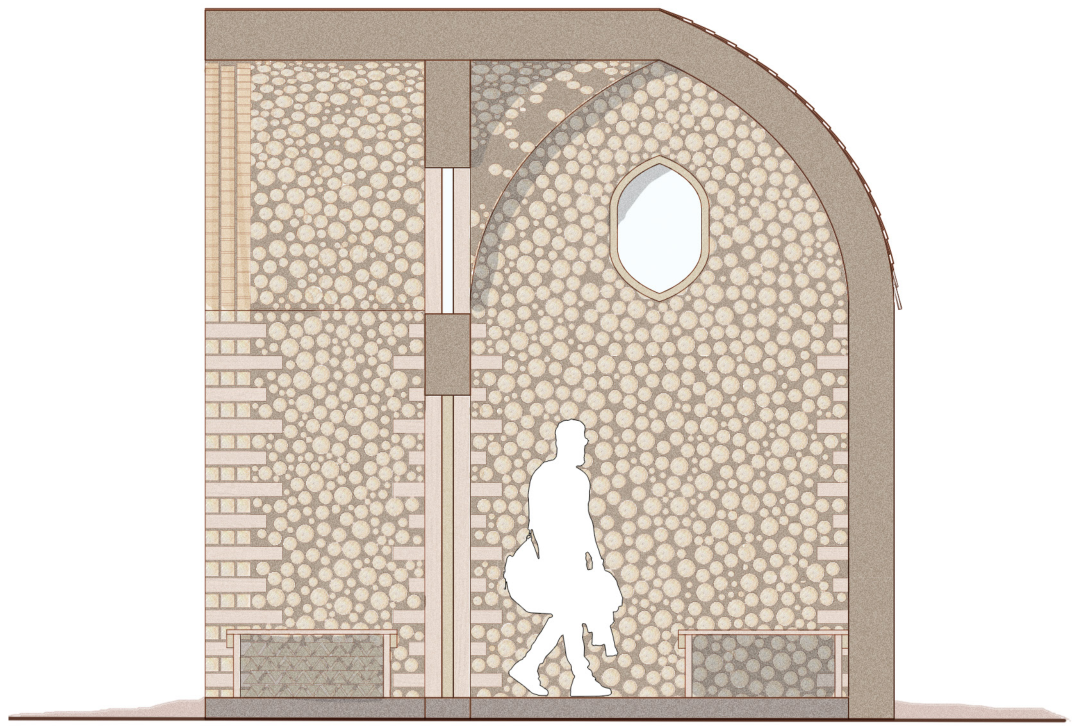
Right elevation 1:100



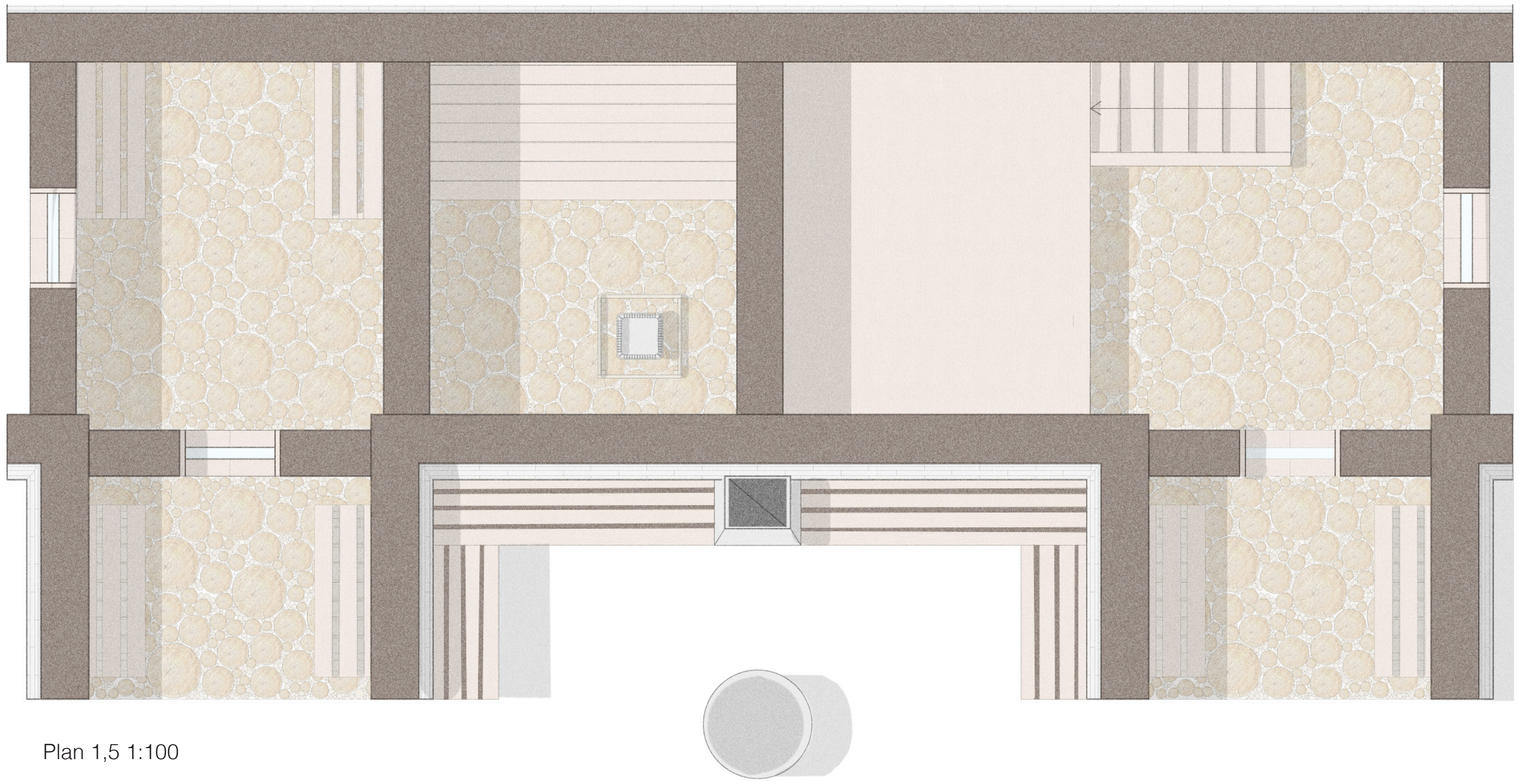
Section B-B 1:100



Section A-A 1:100

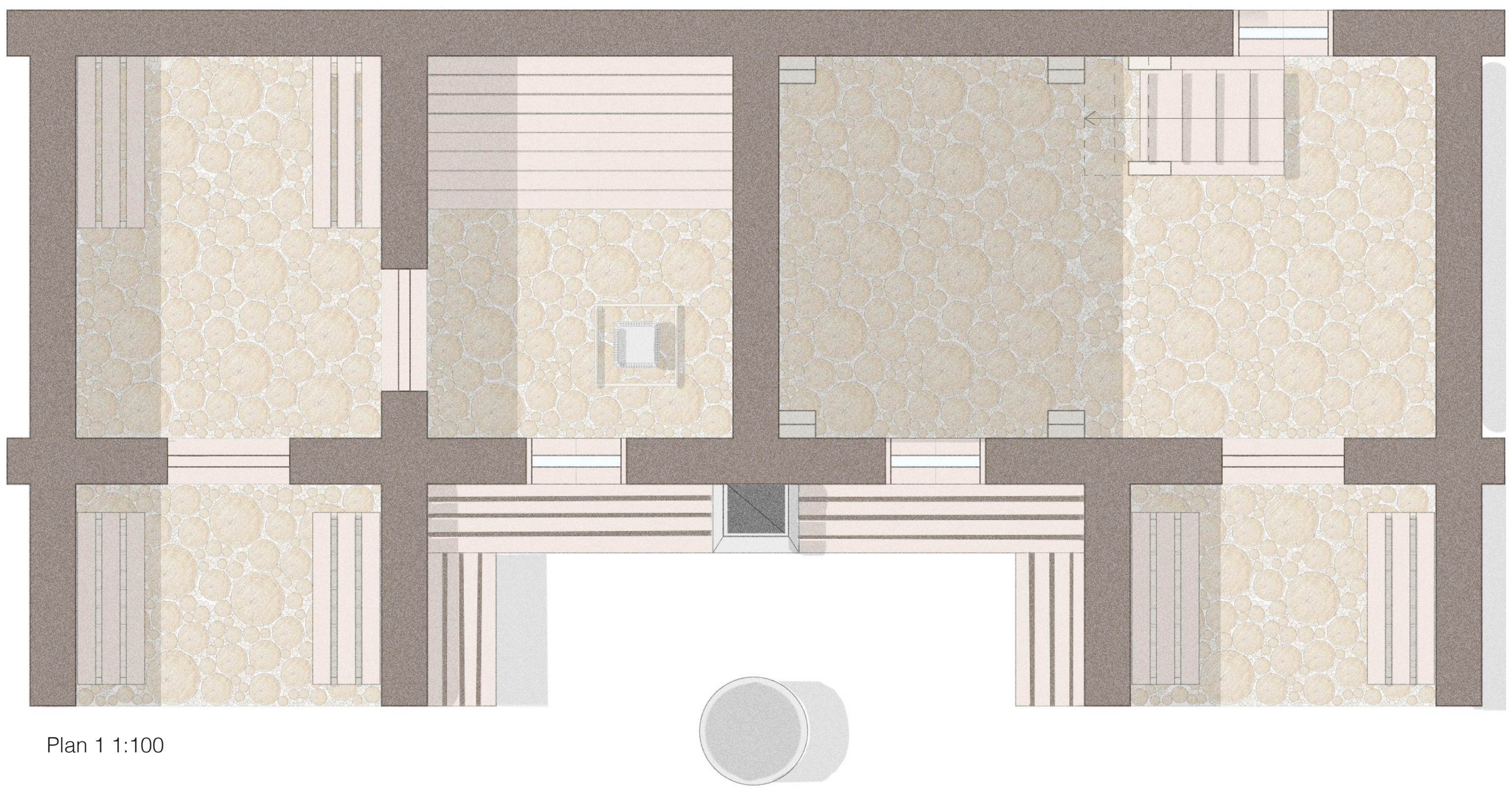


Section C-C 1:100



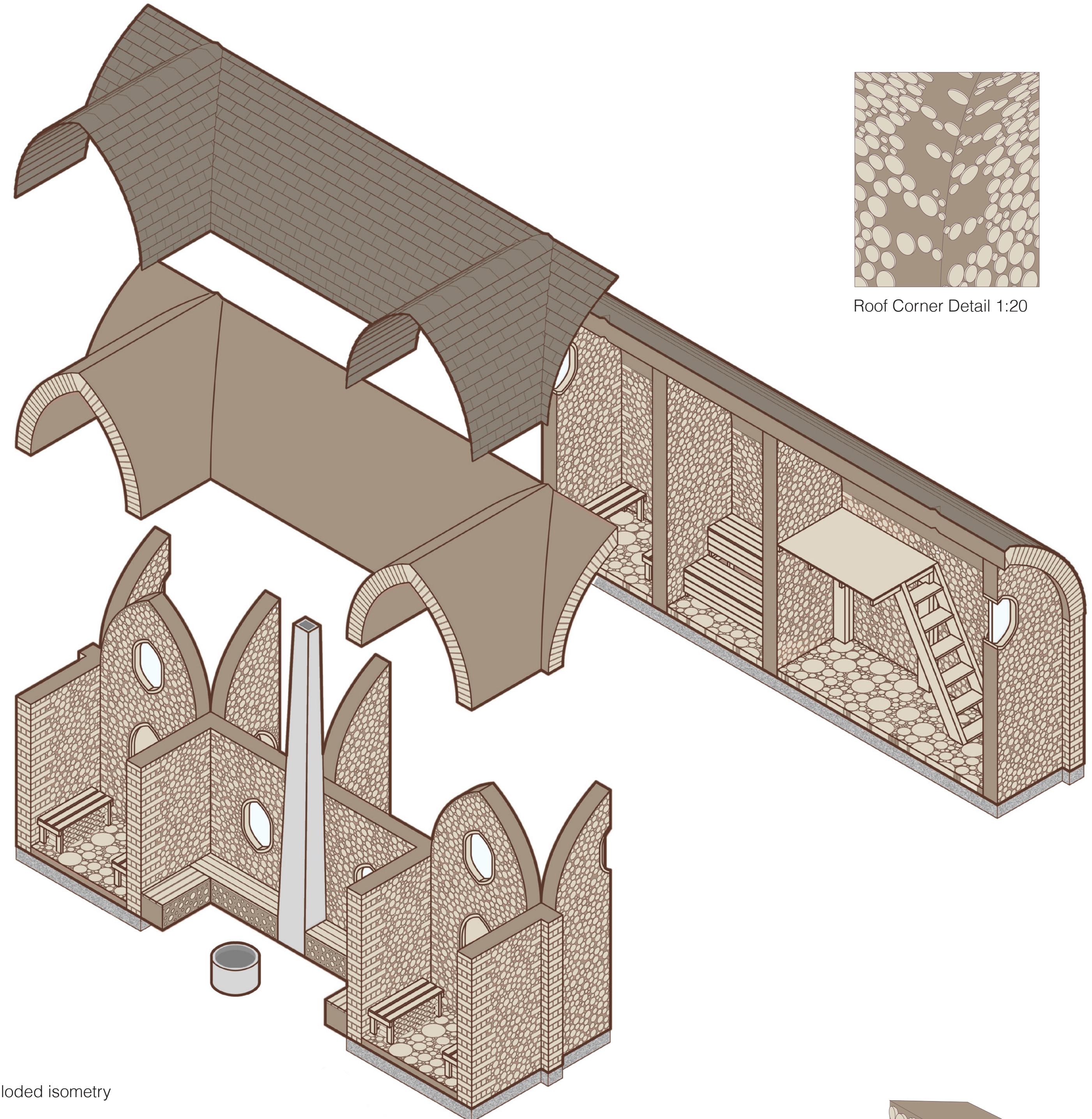
Plan 1,5 1:100

C B A



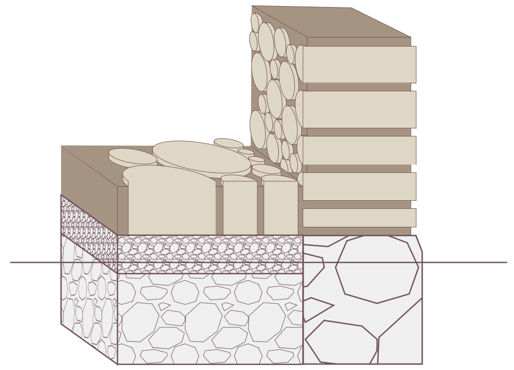
Plan 1 1:100

C B A



Exploded isometry

Roof Corner Detail 1:20



Foundation Detail 1:20

The building in its context

4 Discussion

Binder
The results from the tests and development of the binder suggests that a combination of lignin and sawdust in conjunction with a starch based glue and paper sludge provides adequate structural properties while being lightweight. The density tests suggest that the material is insulating but more tests are necessary.

The strength may not be high enough to work as a load bearing building material outside of the masonry matrix but can definetly used for additional non structural uses outside of cordwood masonry such as decorative elements, space dividing screens, and insulation material.
Further tests are needed to determine if structural use is possible.

In conjunction with cordwood the binder provides an intriguing possibility to increase the reuse of smaller timber elements that are difficult to reuse for other structural purposes in a way that does not need to be separated at end of life since the whole binder-masonry matrix is made from similar materials.

The number of tests done in the thesis does not constitute enough evidence to make solid claims of the material's property but establishes an idea that can be further tested in later studies.

Because of limited human resources the heat transfer experiment and compressive strength experiments were unable to be performed, and needs to be performed in a further study.

The most likely candidtes for further use are the binders with higher lignin content. They showcase better durability and likely have higher strength. Sawdust based binders are still worth further investigations to determine if the lighter material is more insulating.

Cordwood and wood masonry
Wood masonry techniques in general and cordwood in specific is interesting to study further. The claim of being able to use bark beetle infested timber needs to be investigated further in a separate study focusing on the properties and manufacturing of the logends.

The technique is most suited for construction where labour is cheap and where material can be sourced locally. This limits the use in commercial large constructions but makes it interesting for builder-occupier houses and building projects by volunteers for nonprofits.

The ability to reuse materials that otherwise would be turned into fuel also prolongs their carbon cycle and works towards the goal of increased reuse in line with the environmental targets.

Shelters
The shelters explored in this thesis showcases some of the possibilities with the material. In doing so some decisions have been made that limits how practical and efficient the designs are for the use case but they still provide adequate functionality.

To fully equip the hiking routes with enough shelters other designs proposed during the design process could be further explored.

Challenging the limits of the material and building technique opens up the design space and thereby showcases and promotes its use.

The design used mostly biodegradeable material with only a limited number of windows, the sauna heater and the chimney being material that needs to be removed. These elements can in large part be reclaimed both for the construction of the building and after it has served its life.

Further research
Further research into cordwood is necessary to determine the quantative properties. Experimental designs to test compressive strength and heat transfer properties were created but not implemented in time.

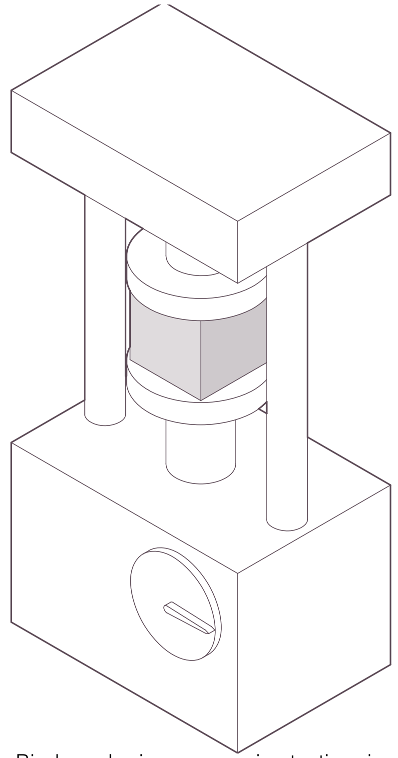
The method to test compressive strength proposed is applying an increasing compressive load to a 100 mm side cube until failure.

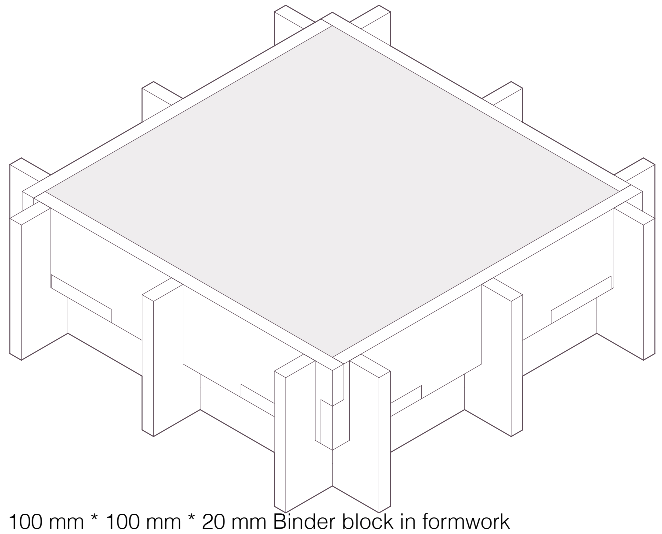
To test heat transfer the guarded hot plate meithod is proposed. Samples are placed between two metal plates. One plate is heated and the rate of the heat flow is measured in the material.

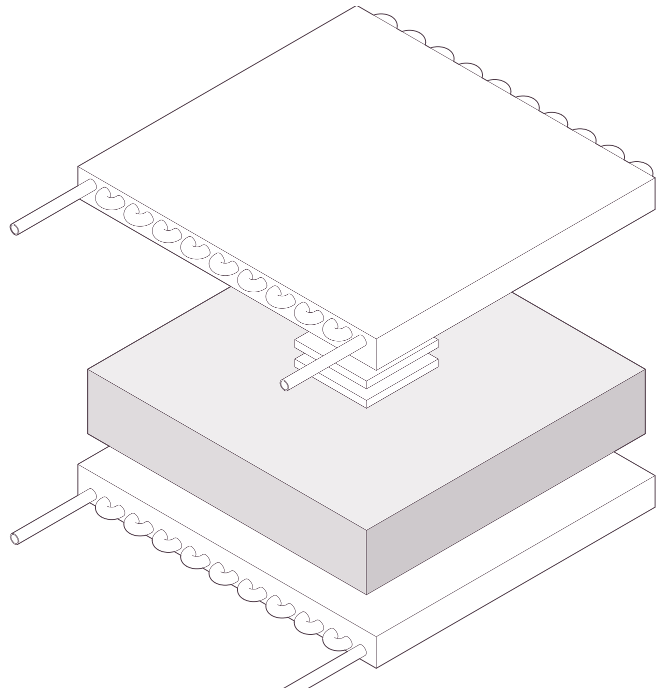
The samples are constructed in a similar way as for the compression test with a height of 20 mm instead of a height of 100 mm.

The equivalent resistance of the assembly can be calculated from the proportion of binder to logends.

In conclusion
Cordwood masonry is a building technique that has promising environmental benefits. Using a novel binder made from lignin and starch, waste products can be utilised. This binder needs more research to quantify the structural properties. Qualitative tests within this thesis have showcased that a binder with higher lignin content has a higher density and is more stable to envirionmental factors than a binder with a larger proportion of sawdust.


100 mm side Binder cube in compression testing rig


100 mm * 100 mm * 20 mm Binder block in formwork


100 mm * 100 mm * 20 mm Binder block iin heat transfer testing rig

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6 Student Background

2023 - 2025 Master's program - Architecture and Urban Design
Chalmers University of Technology
Gothenburg, Sweden

Courses
Mediated material interfaces
Hybrid practice of architecture
Social-ecologcal urbanism
Media and representations
Material and technique
Sustainable development and the design professions
Architecure in the anthropocene

2022 - Master's program - Structural Engineering and Building Technology
Chalmers University of Technology
Gothenburg, Sweden

Courses
Dare to build
Timber engineering
Finite element method - strcutures
Structural concrete
Building performance: Design and assessment
Finite element method - basics
Material performance
Structural systems: Design and assessment

2019 - 2022 Bachelors's program - Architecture and Engineering
Chalmers University of Technology
Gothenburg, Sweden

Self contained courses
Virtual tools in a material culture
Body, space, image