Hemp Matter(s)

Exploring the Architectural Potential of Hemp and Lime Materials in Sweden

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Architecture and Planning Beyond Sustainability (MPDSD)
Profile: Building Design and Transformation for Sustainability

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Abstract

The building industry has a significant and undeniable impact on the environment, characterized by high energy consumption, harmful chemical pollution, and waste generated from non-renewable resources. Hemp Matter(s) focuses on hemp-lime, one of many biomaterials with the potential to provide innovative, durable, and ecological alternatives to conventional building systems, ultimately supporting the development of more resilient architecture. This exploration of hemp-lime's architectural potential in Sweden examines the material's life cycle, using circularity as a guiding principle for creating sustainable built environments.

The research began with the question: How can hemp-based materials help architecture move towards more sustainable and regenerative practices? A literature review helped build foundational knowledge of the constructive properties of hemp-lime while identifying issues and challenges related to its use. A collaboration with the Swedish company EVIA provided experience-based insights and helped bridge the gap between architectural design and construction processes throughout the research. The production of samples was followed by laboratory testing, which yielded data on the material's thermal and mechanical performance. Additional findings highlighted the multiple benefits of hemp as a rotational crop, including improved soil structure and CO^2 sequestration. Hemp's supply chain shows potential for supporting the regional economy by being locally grown, processed, and manufactured. Moreover, the insulation material fosters circularity, as it can be reused, recycled, or biodegraded.

These findings were applied in a design proposal for a showroom located in Lindome, at EVIA's production site. The project explores the architectural expression of hemp-lime, and its modest scale allows for detailed design of construction elements. It presents replicable and adaptable solutions based on prefabricated wall panels.

Hemp Matter(s) aims to shine a light on the re-emergence of hemp as a reliable, sustainable, and beautiful building material, while hopefully contributing one more small step towards a healthier and more resilient society.

Keywords

Bio-materials, Circularity, Indoor comfort, Regenerative, Energy Efficiency

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01
introduction

«The house should not keep us isolated from the outside world. It should select and filter, keeping out and expelling what is bad, and welcoming in and storing what is good. This is possible through the selection of the right *location*, appropriate *materials* and *shape* of construction, and the right technical installations.»

Dr. Anton Schneider - Bau Biologie

hemp-lime samples
01: author

Background

Promoting human and environmental health

The building and construction industry is estimated to contribute 39% of global greenhouse gas emissions, with cement production alone accounting for 7% (Ritchie & Rosado, 2025). Additionally, the sector is responsible for 20% of total plastic consumption in Europe (Earth Action, 2024).These figures highlight the sector's responsibility to move towards more resilient practices and promote regenerative solutions, not only to reduce energy consumption and global pollution, but also to implement circular economy action plans for sustainable growth.

Global emissions of microplastics into the natural environment are estimated to be between 10 and 40 million tonnes per year, contaminating soil, oceans, waterways and the atmosphere, and harming biodiversity and human health (Earth Action, 2024). These plastic particles contain endocrine disrupting chemicals (EDCs), which are responsible for a range of health problems in humans and wildlife (SAICM, 2023). In the construction sector, plastics are found in insulation, window frames, piping and interior fittings (Plastics Europe, n.d.).

Conventional materials also release chemicals called volatile organic compounds (VOCs) into the air, a phenomenon that is exacerbated by fluctuations in humidity and outdoor temperature. A study by YouGov (2018) shows that people in European countries spend 90% of their time indoors, exposed to pollution, damp and mould.

Replacing fossil-based materials with bio-based alternatives that are free of chemicals and plastics can help improve indoor air quality and reduce the amount of microplastics produced by the built environment, thereby improving human health and biodiversity.
Hemp-based materials have great potential as they are hygroscopic and chemical free, providing optimal humidity levels and clean air for a healthy indoor environment.

microplastics are polymers deriving from tyre wear, synthetic textiles and degraded plastic waste. They are smaller than 5mm but accumulate in ecosystems, harming wildlife and entering food chains through inhalation or ingestion.

volatile organic compounds (VOCs) are carbon-based chemicals that evaporate at room temperature and cause air pollution. Coming from paints, solvents, fuels and cleaning products, they are inhaled and cause health problems.

37 %
global emissions

20 %
plastic consumption

90 %
time spent indoor

Bio-based materials

Bio-based materials can be defined as products derived from living organisms such as plants or fungi. Wood, cork, straw and hemp are typical bio-based materials used in construction, they can be by-products or waste from the agricultural industry for example, and at the end of their life they can also be recycled, extending life cycles and reducing waste (Material Cultures, 2021). Depending on the production process, bio-based materials have many applications, including structure (wood), aggregates and insulation (fibres).
Bio-based materials have been used for centuries in vernacular architecture and practices. While their use and knowledge declined with the development of the petrochemical industry (Material Cultures, 2021), we can observe a new growing interest in these materials for their sustainability criteria, versatility and the indoor comfort they can provide in construction. In addition, bio-based materials, combined with contemporary solutions, high-tech and innovative construction methods, can offer a wide range of possibilities to meet today's challenges.

Biodegradability

Bio-based materials are not necessarily biodegradable, as many of them are combined with non-biodegradable binders and glues, compromising the idea of a circular life for the material.

This thesis investigates the biodegradability of hempcrete by studying different types of binders and their composition, some of which contain additives to increase the carbonation of the lime. As the hemp hurds are completely covered by the binder, it is impossible to separate the two compounds, which means that the non-biodegradability of the binder would make the final product non-biodegradable.
If biodegradable, hempcrete could potentially be composted and used as fertiliser. In this case, when the material is sent to landfill, much of the carbon sequestered during growth is released (Material Cultures, 2021).

From craft to prefab

The implementation of biomaterials in buildings on a large scale requires compliance with industry standards and requirements. Prefabrication processes can help scale up the use of biomaterials by providing a more efficient, less risky and systematic method of building construction and renovation through standardisation. The market demand for sustainable building materials is increasing due to new regulations, including requirements for environmental product declarations (Strandberg, 2025). This growing demand must be met with reliable and standardized products.

Circularity in the built environment

A circular material can be defined as a product whose end-of-life phase closes a renewable life cycle loop that supports local resources and economy. Local sourcing reduces transport emissions and keeps the economic value in the region supporting «diverse economic distribution across the supply chain» (Material Cultures, 2021) while creating jobs. Promoting short to medium term renewable resources ensures regenerative systems that can have a positive impact on ecosystems.

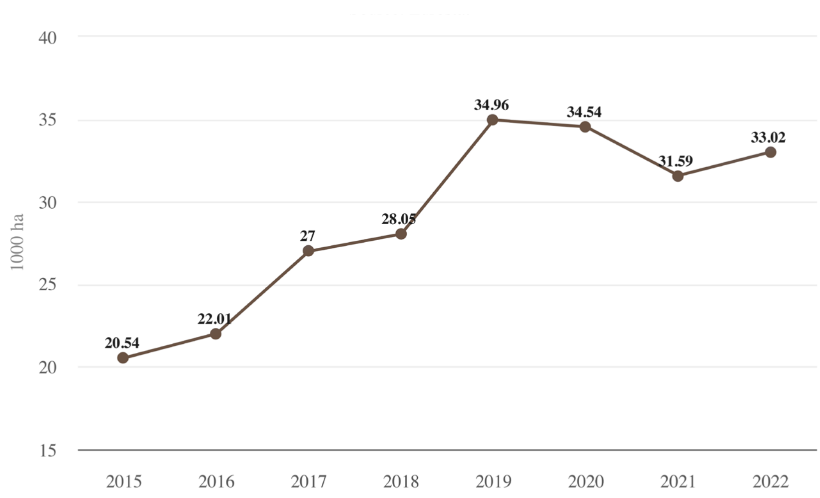
Several projects showcase hemp's use in circular framework. The Flat House project (Practice Architecture, Material Cultures, 2019) included the on-site cultivation of hemp in the Cambridgeshire, followed by its processing and prefabrication into panels and cladding solutions, combining innovation with traditional knowledge. In Hemp as Incubator of a Circular Economy, Tobias Luthe explores the versatility of hemp and its various applications that promote "circular flows of resources, services, and people" in Piedmont, Italy (2019). This theory is applied in the experimental laboratory of the MonViso Institute, where crops are harvested on mountain slopes and processed in workshops that combine science, innovation, craft, and participation to promote systemic regenerative design.

The Doughnut theory

Chemical pollution, excessive fertilizer use, and biodiversity loss are three of the nine planetary boundaries in the ecological ceiling of Kate Raworth's Doughnut theory. This doughnut, designed for humanity to thrive in the 21st century, draws a line of safe and just space bounded by a social fundation and an ecological ceiling. The theory applied to urban development identifies two types of impacts on ecosystems: local impacts, which can be seen on-site, and remote impacts, which occur throughout the global supply chain. Looking at the life of a product through a global lens, including before and after life on site, provides a holistic view of the impacts of urban development and can better support a positive transition at many levels, from the plot to the city scale (Birgisdóttir, H., et al., 2023).

By developing a prefabricated wall system based on hemp-lime, the Hempfab project is contributing to the development of new products on the market that are in line with the Doughnut theory. Through the collaboration of various industries, including EVIA, the project links construction companies, academic research, architects and other stakeholders, creating communication throughout the supply chain of the product, while aiming at the same goals of sustainable development.

'business-as-usual' scenario
inspired from The Doughnut for Urban Development, 2023



EU Land Area Used for Hemp Fibre Cultivation
Fig 01: © Eurostat

«Urban development has a choice to move away from destroying, degrading, polluting, and fragmenting natural habitat and biodiversity, and instead choose to design for clean outdoor air, *regenerate ecosystems* and implement ambitious nature-based solutions.»

Birgisdóttir, H., et al., 2023

Framework

Aim

Biomaterials are playing an increasingly important role in the construction industry and contemporary architecture. However, hemp remains relatively unknown—not only for its construction properties and the interior comfort it provides but also for its potential aesthetic finishes when combined with lime.
The aim of this thesis is to bridge technical knowledge and practical experience in hemp-based materials with their application in building design, highlighting hemp's capacity to drive circularity and encourage the construction industry toward more sustainable and resilient practices. The research will explore the architectonic potential of hemp, encompassing material properties, structure, functionality, aesthetics and spatial atmospheres.
Scaling up the use of hemp-based materials poses the challenge of production efficiency, which this thesis aims to address by investigating prefabrication methods as an innovative way to bring bio-based materials up to industry standards. Integrating practical experimentation in a construction factory into the research process aims to create a tangential link, often overlooked, between architecture and construction.

The design proposal aims to present construction solutions that are sustainable, effective, simple, honest and, above all, replicable.

Research Questions

How can hemp-based materials help architecture move towards more sustainable and resilient practices?

What are the construction possibilities of hemp-lime materials and how do they help provide energy efficiency and indoor comfort?

What are the architectural opportunities and challenges of using prefabricated hemp-lime modules?

Delimitations

This thesis will

Investigate existing knowledge and techniques to assess their potential in design and architecture.

Investigate the construction possibilities and aesthetic potential of prefabricated hemp-based wall panels.

Explore the use of hemp-based materials, including hempcrete, hemp-lime plaster, and hemp fiber for insulation.

Explore the thermal and mechanical properties of hemp-lime through laboratory testing.

Design a small-scale project to showcase the versatility and architectural qualities of hemp and lime materials.

Design construction solutions that are replicable and adaptable.

Design construction details including connections between different elements and materials.

This thesis will not

Consider legal restrictions an obstacle to the development of hemp as a building material.

Create a new hemp-lime mix recipe or explore a new way of using hemp fiber.

Exclusively use hemp in the design proposal. Other materials will be used for the main structure and foundations.

Explore the use of alternative binder such as clay.

Carry out an in-depth site analysis. The site serves as a basis for the design of a showroom related to the construction process.

sprayed hempcrete on
a timber structure

02: author

Methods

Litterature Review
The study of academic and practice-based literature was a first approach to build a solid theoretical framework for the research process of the thesis, while connecting it to a larger scientific context.

The Hempcrete Book (Stanwix & Sparrow, 2014), *Hemp Lime Constructions* (Woolley & Bevan, 2008), and *Hemp Buildings* (Allin, 2021) are some of the main sources that allowed the collection of knowledge and data about hemp-based architecture, covering the historical background of the plant, its cultivation process, the manufacture of the material and its application in design.

The review of academic research reports helped define relevant methodologies and approaches for understanding problems, challenges, and opportunities related to the research questions. The references include *Circular Biobased Construction in the North East and Yorkshire* (Material Cultures, 2021) and *Revival of Industrial Hemp* (Young, 2005)

Case Study
The analysis of built references, such as the *Block House* (Material Cultures, 2021) and *Can Monges* (Ideo Arquitectura, 2022), provided concrete examples of material application in design.
Hemp lime buildings can be found in many countries around the world, with different climates and geographical contexts, showcasing a variety of construction techniques from project scale to detail, adapted to the local context.
The analysis consisted of identifying building structures, wall systems, insulation and finish techniques, as well as material choices and construction processes.

Material Investigation
This part of the process begins with the collection of quantitative data on the physical performance of the materials, focusing on thermal and mechanical properties.

On the other hand, the investigation of the hemp supply chain's environmental impact includes two main sources: a review of a life cycle analysis of hemp by HES (2021) in Sweden, and the report *Hemp as an Incubator of Circularity* (Luthe, 2019), which examines hemp's supply chain impact in a local context and its effect on the economy.

The material investigation process included a field study trip to the 12th International Hemp Building Symposium in Staffanstorp in October 2024. This event was an opportunity to meet many international professionals involved in the development and research of hemp in the building industry and beyond, including the textile and food industries. The symposium provided valuable insights and inspiration, as well as opportunities to estab-

lish contacts within the field. It was fascinating to meet people who have spent decades researching and advancing knowledge and possibilities.
The event, held at the Ekolution factory, showcased their manufacturing process for hemp fiber insulation panels, while a site visit demonstrated the application of hempcrete to a timber structure using a spraying method.

Overall, the material investigation acted as a knowledge base providing benchmarks for material experimentation.

Material Experimentation
Collaboration with the Swedish company EVIA made it possible to carry out material experiments. Touching and feeling the physical aspects of the materials brought the notion of phenomenology into the research. The collaborators reported that people who come to the factory and see the prototypes for the first time really want to touch and feel the hempcrete, it is warm, porous and seems to arouse interest for its qualitative and aesthetic aspect. This phenomenological approach to the material informs the design application in terms of qualitative data.

Being on site and seeing the workshops and manufacturing techniques brought a very practical and detailed understanding of material processing and factory systems. The next step was to experiment with the material. I made samples with the help of EVIA and carried out thermal property tests using the TPS (Transient Plane Source) testing method in the Chalmers Building Materials Laboratory.

Material Application
This final stage of the process translates research and experimentation into a design proposal that presents a panel of design possibilities and details using hemp, lime and other materials. While the design proposal is situated in a specific context, the construction solutions aim to be replicable and adaptable. The aim is to use prefabrication processes as a starting point to design buildings that are connected to and informed by their immediate environment. The prefabricated modules act as dimensional criteria, while the context shapes the overall geometry and design solutions.

The project is a showroom located in Lindome on EVIA's workshops site.
The simplicity of the programme allows for attention to detail, while one of the requirements was a heated space to apply the material's ability to create a qualitative indoor environment.
The design approach is based on an iterative process, informed by the material investigation and experimentation, which optimized the site criteria and helped refine the programme to support an overall focus on materials.

Glossary

Airtightness focuses on building's envelope continuity, eliminating gaps and cracks to avoid energy loss. This helps create energy efficient buildings. When airtightness is not acheived, we talk about air leakage (Crosson, 2017).

Biodegradable materials are characterized by their ability to decompose over time through the action of natural elements and microorganisms. During this process, the materials release gases such as carbon dioxide and hydrogen, but do not leave behind microplastics or toxic chemical residues (Prime Biopol, 2022).

A ***Binder*** is a substance that causes two or more other materials to combine together producing a uniform or consistent appearance (Material Cultures, 2021).

Bio-based materials are, by definition, materials derived from plant or animal biomass (Pichon, 2015).

Effusivity characterizes the radiant temperature of the wall, which contributes to the perceived thermal comfort (Pichon, 2015).

Embodied carbon is the total greenhouse gas emissions generated throughout the life cycle of a final product. It considers emissions caused by extraction, manufacture/processing, transportation, and assembly. Depending on the boundaries of the life cycle assessment, it can also include maintenance and end-of-life energy consumption (Material Cultures, 2021).

Hygroscopicity is the ability of a material to absorb moisture from the air through adsorption and then release it through desorption (Pichon, 2015).

Vapour travels from hot to cold, therefore having more permeable materials in the outer layers and less permeable materials in the inner layer helps vapour move outwards.
The prevailing strategy has been to make buildings as watertight as possible, blocking the exchange of moisture between the outside and inside environment.
Biomaterials are changing this approach by allowing vapour to move within the walls. This provides a building envelope that is resilient to seasonal changes in humidity and temperature. The building is sensitive and responsive, adapting to its natural environment (Bryce & Weismann, 2015). This approach also provides better air quality by improving the indoor environment.

Regenerative design aims to have a positive impact on the environment by fostering resilient systems that are ecologically restorative. Instead of designing for waste, it focuses on circular products and systems that promote "resource efficiency and enhance social well-being". (Hill-Hansen & Guldager Jensen, 2023).

The ***Supply chain*** of a product refers to the network of interconnected stakeholders involved throughout the entire lifecycle of the finished product, from raw material extraction and production to use, reuse, and end-of-life. It encompasses both local and global scales, affecting human and non-human species, and takes into account the social, ecological, and economic impacts associated with each stage of the product's journey (Hill-Hansen & Guldager Jensen, 2023).

A ***Thermal bridge*** is a point or linear zone in the building envelope where there is a variation in thermal resistance. It is a point in the construction where the insulating barrier is interrupted (Pichon, 2015).

Thermal conductivity refers to a material's ability to transfer heat through conduction—that is, the movement of heat through the material's own body. Materials with lower thermal conductivity have better insulating properties.

Thermal mass refers to a material's ability to absorb, store, and release heat. In general, denser materials with higher specific heat capacity and mass, such as concrete, brick, or stone, can store more heat than lighter materials.

Moisture buffering is a material's ability to moderate changes in humidity by absorbing moisture from the air when humidity is high, storing it, and releasing it when the air becomes drier. This phenomenon provides passive indoor humidity regulation.

In hemp fibers, moisture is stored in the form of liquid water within the fiber's central core.

02
materials matter

This chapter introduces hemp and lime as building materials, covering the raw resources, their key characteristics, and the transformation processes involved in creating ready-to-use construction products. It begins with a brief historical background and an overview of the sustainability aspects of their supply chains, followed by an examination of their construction properties. This chapter aims to provide a contextual understanding of the materials that shape architectural form.

Hemp has been cultivated since Neolithic times and has historically played an important role in economic development (Stanwix & Sparrow, 2014). Although its cultivation was restricted for legal reasons in the last century, it was widely used in many countries, particularly for rope in the shipping industry. Its many beneficial properties have been rediscovered and promoted in recent decades. The term 'industrial hemp' refers to the variety *Cannabis sativa*, which contains up to 0.2% THC.

Hemp cultivation has many positive attributes, including improved soil health and structure, significantly reduced water use and no-to-low pesticides inputs, which preserves biodiversity and ecosystems. The multipurpose plant suppresses weeds and allows farmers to grow multiple co-products that can benefit local networks and communities (Marquardt & Savage, 2023).

Resources

The hemp crop

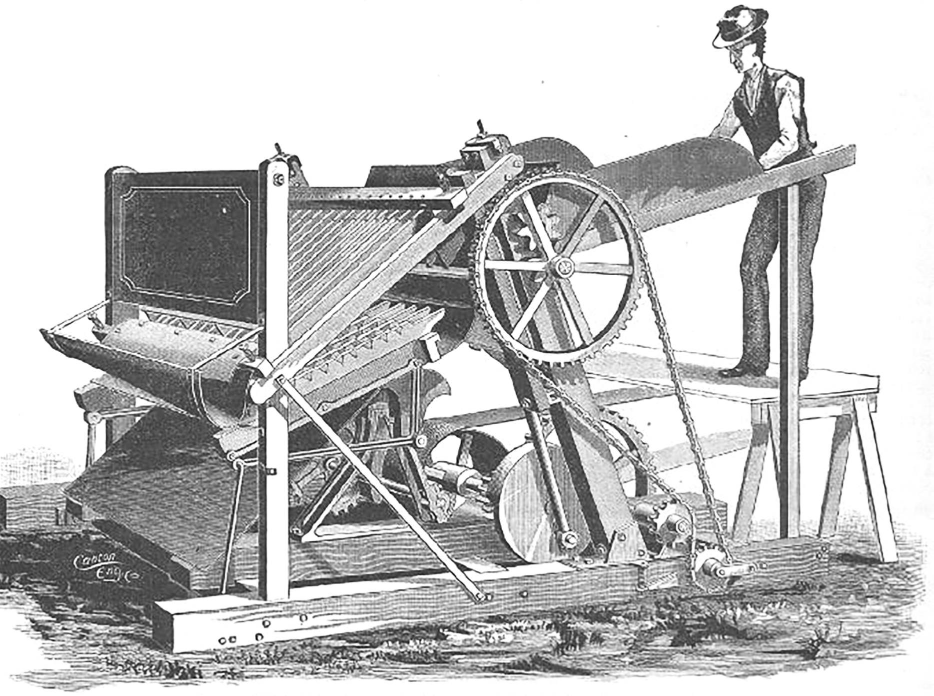
Historical background

Industrial hemp, or Cannabis sativa L. of the Cannabaceae family, is an annual herb that grows in 90 to 110 days, making it a rapidly renewable resource. The plant, which originated in China in 4000 BC, has been cultivated throughout the world for more than six thousand years and plays an important role in world commerce (Roulac, 1997). The wild plant was domesticated into a cultivated crop in the earliest Neolithic period and was grown along with millet, wheat, beans and rice (Clarke, 1995).
Throughout history, the crop has been used to produce many products derived from its fiber and oilseed, including cordage, paper, food, cloth, oil and medicine. Hemp had a high cultural value, it was considered as one of the five major grains in ancient Chinese society and symbolised purity and fertility in many East and Southeast Asian religions, being used in Shinto and Buddhist rituals (Roulac 1997).

In Europe, military power relied upon hemp ropes and sails. The plant was also used in the art of papermaking, and the Renaissance word canvas takes its name from the genus Cannabis. Many villages in England testify to the historical presence of hemp, such as Hempstead, Hempton and Hampshire. The role of hemp-based materials was so important in times of war that the British monarchy made its cultivation compulsory (Roulac 1997).
In the late 19th century, hemp's role in commerce began to decline, as steam and petroleum engines reduced the demand for hemp material, while the cotton industry cut its labour costs, creating competition in the market. In the United States in the 20th century, many inventors tried to come up with new machines to increase the efficiency of the harvesting and manufacturing process, newspapers were printed on hemp paper and the industry continued to grow.
In 1937, the American government passed the Marihuana Tax Act which criminalised marijuana.

Hemp rapidly became associated with its other phenotype, containing higher levels of THC, the plant's psychoactive compound (Young, E. 2005). Growing hemp became so difficult, requiring licences and administrative procedures, that many farmers stopped cultivating it. Hemp cultivation became illegal in many European and colonial countries after World War II (Young, 2005)

Since the 1990s, European countries have gradually lifted the ban on hemp cultivation, making it legal again, although highly regulated. It wasn't until 2018 that hemp cultivation became legal in the United States, and it is still illegal in some countries such as South Africa and Indonesia.



AN IMPROVED HEMP AND FIBER BREAKING MACHINE.

The Shely Fiber Breaker

Fig.02: © Scientific American, 1892

Hemp in Sweden

Industrial hemp was once grown in Sweden, with the largest cultivation on Gotland, where the drained marshes provided ideal soil, as evidenced by the 1,955 hectares harvested in 1955 (B. Nilsson, 2018). The fibre was processed locally in the Visby factory, opened in 1942, and used mainly for clothing. It wasn't until 1965 that the cultivation of hemp in Sweden came to an abrupt end due to global prohibition. It wasn't until 2003 that the ban was lifted in the country, allowing industrial hemp to be grown with a licence from the Swedish Board of Agriculture, with a maximum THC (delta-9-tetrahydrocannabinol) content of 0.2 per cent.

In 1995, when Sweden joined the EU, some farmers from Gotland imported seeds from France, where the cultivation ban had already been lifted, and started growing hemp on the island. However, the ban was still in place in Sweden and the police confiscated the 12 tonnes of hemp harvested, suspecting the farmers of drug possession. Although all farmers were eventually acquitted by the European Court of Justice, hemp cultivation on Gotland slowly declined, possibly due to a lack of demand, processing and manufacturing infrastructure, as well as the competitive development of synthetic fibres in the textile industry (B. Nilsson, 2018).
More recently, the cultivation of industrial hemp has started in Skåne, and the opening of the fibre processing factory Ekolution at the end of 2024 heralded the growing interest of farmers and developers in the crop, especially because of its sustainability criteria and profitability. In 2024, approximately 600 hectares of hemp were cultivated in the region (H. Assarsson, 2024). The factory produces insulation products from the raw material. The investment in large and technologically advanced equipment will enable hemp to be processed and refined on a large scale, with the aim of providing an efficient and reliable bio-based alternative to conventional insulation materials.

Cultivation

Hemp grows easily in most climates and can reach a height of 4 metres in 3 to 4 months. The crop has low susceptibility to pests and doesn't require pesticides. Although hemp is fairly hardy and easy to grow, it requires well-drained soil and is sensitive to compaction, which is why heavy rain in the early spring after sowing can threaten its growth (H. Assarsson, 2024). The crop needs light soil and

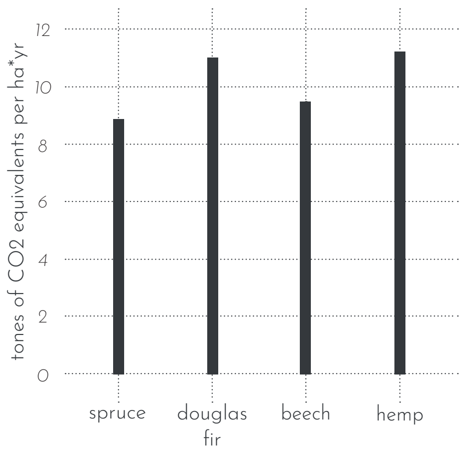
> « It is a crop with the potential to contribute to increased profitability in agriculture, and the establishment of hemp can also contribute to regional development on Gotland. »
>
> Nilsson, B. 2018

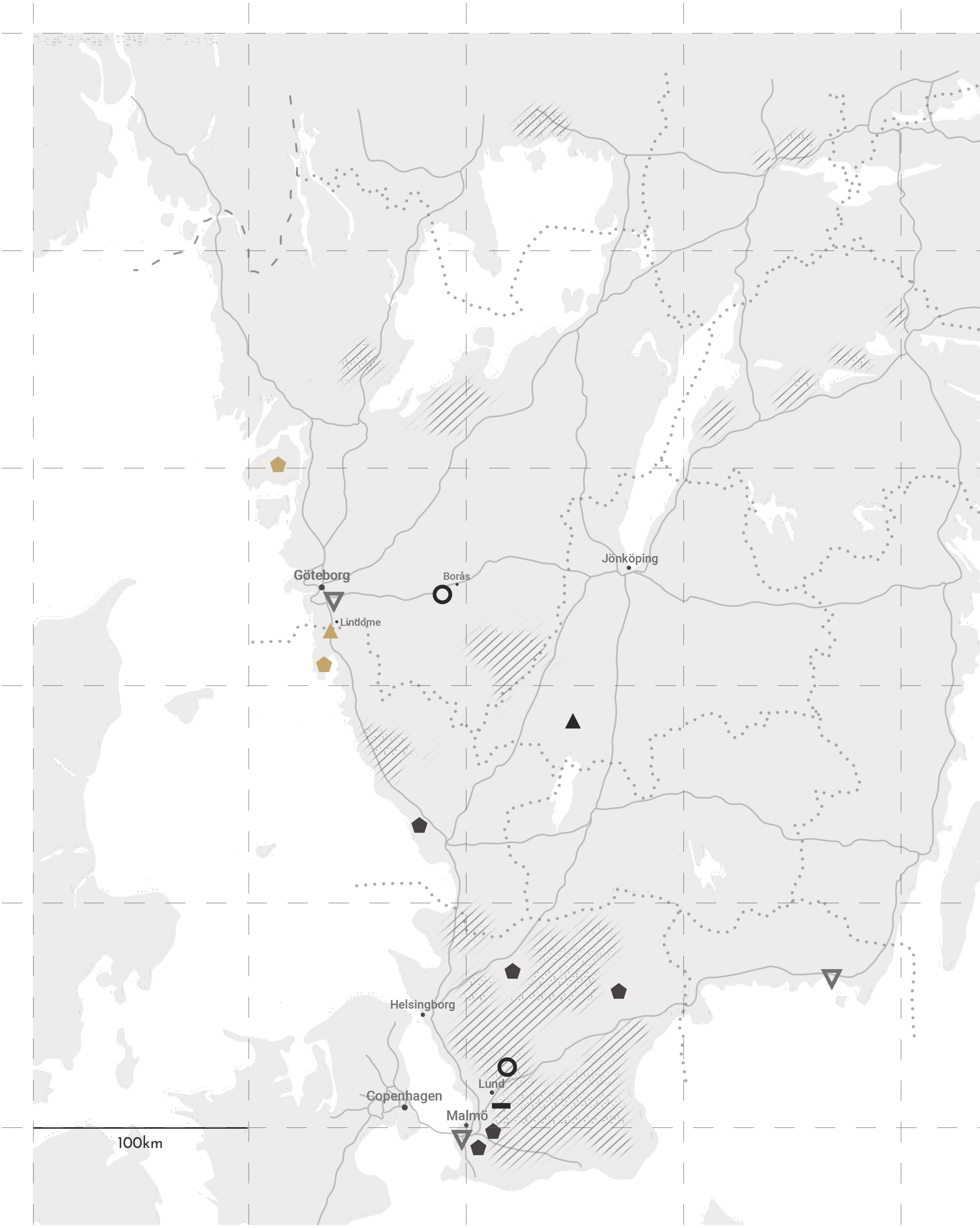
is sown very shallowly (K. Wahlquist, 2024), it thrives in calcareous soils and showed a daily growth of 4 to 7 centimetres in June on Gotland (B. Nilsson, 2018).
Because hemp is fairly drought resistant, farmers in Skåne have noticed that the crop stops growing during a drought, but doesn't wither or lose its green colour. When the rain comes back, the crop starts growing again.
Industrial hemp is a great rotational crop with very deep roots, the fibre used in insulation products comes from waste streams or by-products of the hemp stalk, it is the outer part of the stalk that contains the hemp hurd inside.

Carbon removal

Hemp crops can store an amount of CO2 comparable to that of Douglas firs and birch trees, more precisely, according to a study from nova-Institute, net carbon removal rates range from 5.5 to 11 tons per hectar for both hemp and wood. As it grows, the plant sequesters 1.6 times its weight in CO2, providing about 10 tonnes of sequestered gas for a house. [JustBio-Fibre] Being an annual plant that grows in five months, hemp is an interesting option to adress carbon removal while restoring forests.
A life cycle analysis carried out by the company HES, including cultivation, harvesting, processing, packaging and transport of the raw material in 40ft containers by truck, showed a result of -1.32 tCO2eq/t hemp hurds.

Carbon Removal Gross
Fig. 03: © EIHA, 2023

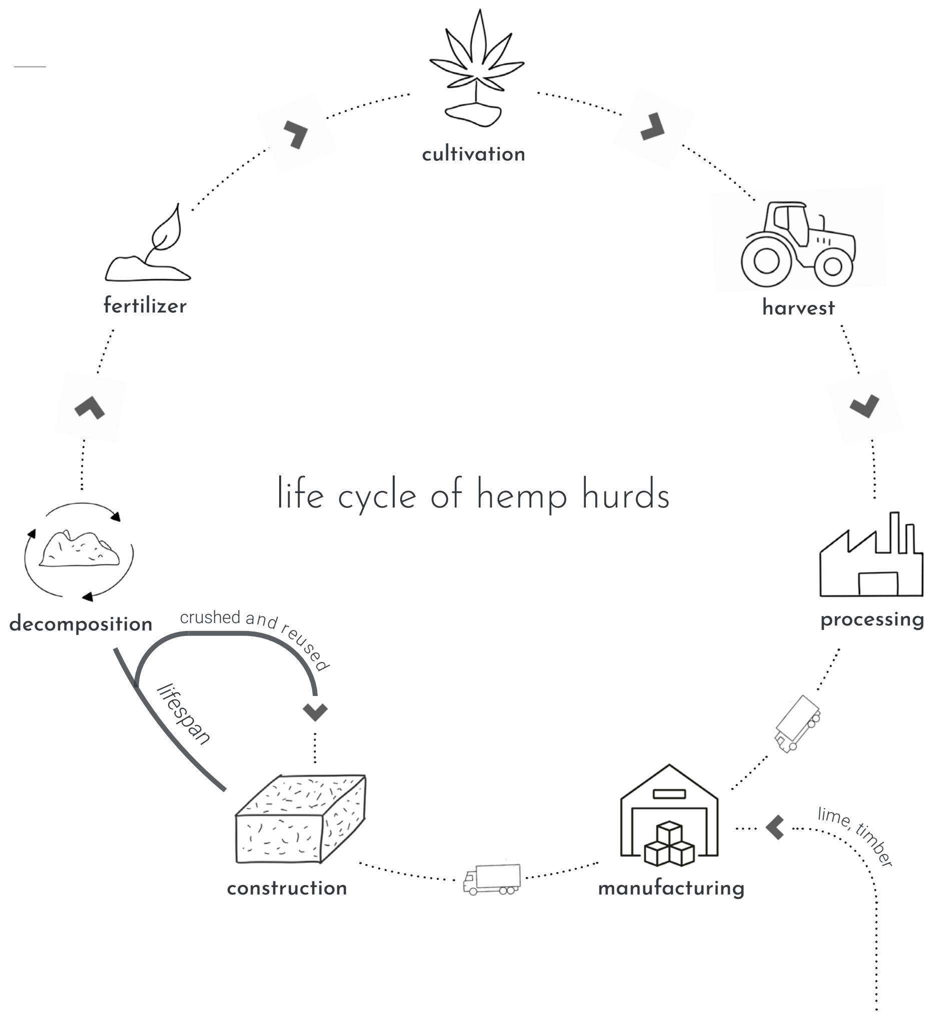



Göteborg
Lindome
Borås
Jönköping
Helsingborg
Copenhagen
Lund
Malmö
100km

South Sweden Hemp-related Stakeholders

non-exhaustive list

- processing factory
- manufacturing companies
- research on hemp
- supporting projects
- hemp-based residential buildings
- hemp-based industrial building
- EVIA factory
- EVIA hemp-lime projects
- hemp crops



Lime

Calcium oxide, also known as quicklime, is obtained by heating sources of calcium carbonate, such as limestone, chalk, and shells, at an average temperature of 900 °C (Bevan & Woolley, 2008). This process releases CO_2 and creates in kilns. Water is then added to the material to form hydrated lime (calcium hydroxide), which later dries and hardens when exposed to air. During this recarbonation process, calcium carbonate is reformed (Sutton & Black, 2011).

Air lime, or hydrated lime, is a high-purity lime produced from pure calcium carbonate sources. In contrast, calcium carbonate sources that contain impurities, which are more common geologically, produce what is known as hydraulic lime. Hydraulicity refers to "the nature of the setting mechanism of lime in a mortar form" (Bevan & Woolley, 2008). Hydraulic lime contains up to 35% more silicates and other impurities than hydrated lime and is commonly used in Portland cement, as its high initial strength makes it suitable for structural applications. Its production is more polluting, as it must be burned at higher temperatures, up to 1400 °C (HES, n.d.).

The high alkalinity of lime imparts antibacterial properties to hemp-lime mixtures, reducing the risk of mould and fungal growth (Sutton & Black, 2011).
It is worth noting that some binders have been specifically developed for use with hemp, as using an inappropriate binder can lead to failure—often due to competition for water between the binder and the hemp. Excess water or an unsuitable binder can result in damp hemp or a dry, powdery mix (Bevan & Woolley, 2005).

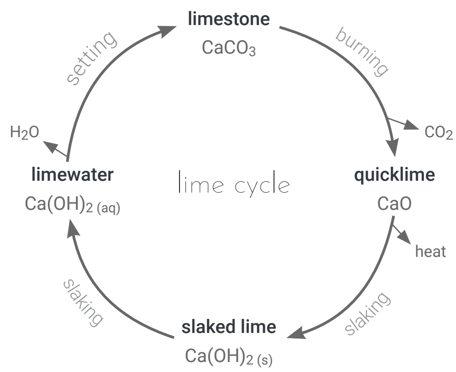
While research has explored improving the load-bearing capacity of hemp-lime by adding cement, sand, or other additives, Bevan and Woolley argue that "there seems little point in this," noting "no significant increase in strength" and a loss of "the beneficial properties of hemp lime," such as thermal insulation and hygroscopicity.
Other types of binders have been explored in combination with hemp to improve both mechanical performance and environmental impact. Clay, for example, offers great sustainability characteristics due to its low embodied carbon, local availability, and biodegradability.

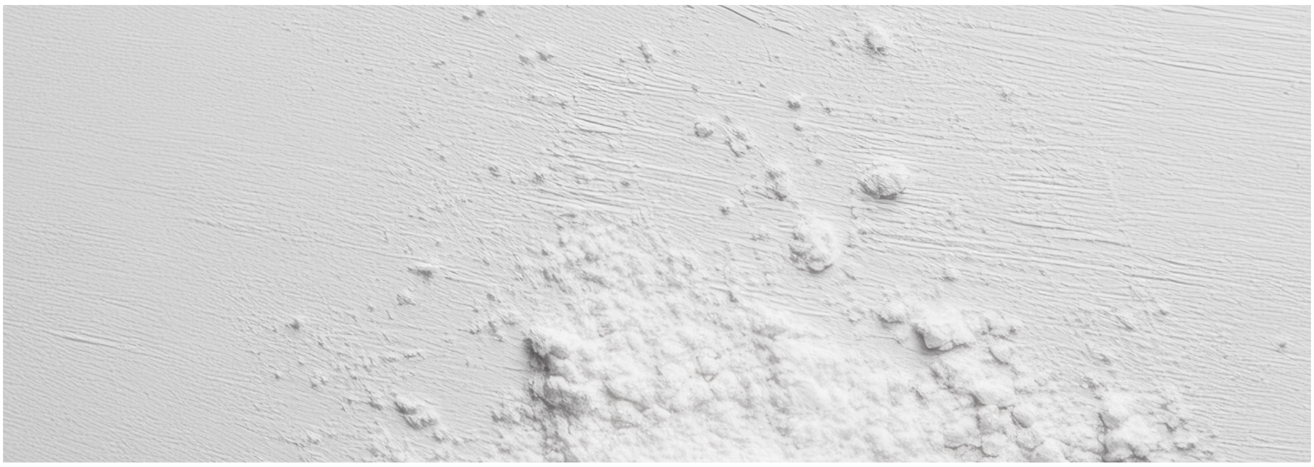
Environmental impact

Lime is relatively energy-intensive in its extraction and production; however, during its curing phase, it undergoes carbonation, absorbing CO_2 and partially offsetting the emissions generated during the firing process. A life cycle analysis of hydrated lime conducted by HES - which includes mining, processing, packaging, transport, and the carbonation phase - reports emissions of 0.646 tCO_2eq per tonne. While the lime life cycle shows a positive emission, when combined with hemp, the final material

can result in net-negative CO_2 emissions. This is due to the carbon sequestration properties of hemp. The more hemp included in the mix (and consequently, the less lime), the lower the environmental impact.
Pure lime is often regarded as more environmentally friendly than cement due to its lower embodied energy. However, Bevan and Woolley (2005) note that “the difference between lime and cement is not as great as often assumed,” especially as cement production increasingly incorporates recycled materials, reducing its environmental impact. When assessing the life cycle of a specific material, factors such as sourcing and recyclability may make lime with cement a more appropriate choice in certain contexts. Therefore, materials should be selected with careful consideration of both environmental and economic factors, prioritizing local and bio-sourced options whenever possible.

Lime in Sweden
Gotland was one of the major lime producers in the Baltic Sea region during the 13th to 15th centuries, and archaeological evidence suggests that lime kilns have been used on the island since the 12th century to produce mortar for stone construction, including churches (Balksten, 2016). The island’s Silurian limestone, a sedimentary rock formed during the Silurian period, provided high-quality lime that was exported (Balksten, 2016). Today, Gotland lime is primarily used in restoration projects, although some companies, such as Målarkalk, offer a wide range of lime-based paints and pastes. While lime is still mainly imported from other European countries, Gotland lime has significant potential. As the demand for hemp-lime materials grows, research and development in this area will likely increase. This would not only reduce transportation emissions but also support the local economy.





hydrated lime binder

03. © Adobe Stock

Building Materials

Hemp-lime

Hemp-lime, also called hempcrete, is a mixture made from hemp hurd, which is high in silica, with water and lime, which is high in magnesium. The latter "activates the carbonation of the material and the hardening of the fibres" (Sutton & Black, 2011). When mixed, the evaporation of the water causes a change of state, with the lime mineralising the vegetable component of the hemp hurd.
The components are combined in specific proportions, typically 1 part hemp to 1.5-2 parts lime (Sutton & Black, 2011).
Once protected by a vapour permeable external finish or rainscreen, the material provides long term performance.
Hempcrete is permeable, therefore it must be protected from rising damp and cannot be used below ground level (Sutton & Black, 2011).

Drying time is important to give hemp lime its final performance, it should be properly protected from the weather and good ventilation should be provided to aid the drying time.
Hemp lime can be dried on site, poured or sprayed. It can also be pre-cast off-site using a prefabrication method, reducing on-site construction time.

Stanwix and Sparrow in The Hempcrete Book (2014) identify three parameters that influence the finished composite material: the individual components and their properties (hemp and lime), the mixing ratio of these components and the amount of water, and finally the construction process including mixing and placing. By manipulating these parameters, a wide range of applications can be achieved, such as roof insulation requiring a low density mix, or floor slabs requiring a higher binder content.

Hygroscopicity

The microscopic structure of hemp hurds contains tiny capillaries that are permeable to water vapour, making the material hygroscopic. The porous structure absorbs, retains and releases moisture with changes in humidity and temperature; the hemp hurds, typically between 5-20mm long and 2-5mm wide, can absorb up to five times their own weight (HES, 2021). In winter, the biocomposite material absorbs moisture from the indoor air, creating a phenomenon called 'capillary condensation', which reduces the humidity level and increases the indoor temperature. In summer, the reaction is reversed (degre.47, 2020). Hemp-lime maintains the overall humidity level between 50-60% (Vieille Matériaux, n.d.).

Vapour barriers have the disadvantage of trapping moisture, which encourages mould growth within the wall. With hemp-lime walls, the vapour barrier is eliminated and the hygroscopicity of the walls prevents the accumulation of moisture.
The binder is a key factor in maintaining good vapour permeability, for example a hydraulic

lime will reduce the hygroscopic behaviour of the wall while a hydrated lime will provide high vapour permeability (Stanwix & Sparrow, 2014).

Thermal performance

Hemp-lime walls provide both thermal mass and insulation, making the internal temperature of the building stable and relatively independent of external temperature variations (HES, 2024).
Heat accumulates in the walls and slowly radiates throughout the day/night. This phenomenon, together with the reduction of thermal bridges due to the continuity and plasticity of the material, drastically reduces energy consumption and losses.
The type of binder, the density of the mixture and the degree of compaction affect the thermal properties of the composite material (Stanwix & Sparrow, 2014). The hygroscopic behaviour of hemp-lime influences its thermal performance, Stanwix and Sparrow (2014) describe how the ability of the hemp hurds to hold liquid water on the inner surface of their pores causes the thermal conductivity of the wall to change during moisture exchanges, as water is more conductive and can store more heat than air. These hygrothermal properties affect the storage and transfer of heat, providing what is known as 'thermal buffering'. Hemp lime is a good option for passive design as it helps to maintain stable indoor temperatures.

Mechanical properties

Hempcrete is a lightweight material with low compressive strength, typically around 0.4 N/mm^2 for hempcrete blocks (Senini, 2022). The material is not able to withstand structural forces on its own, which is why it is often combined with a structural frame such as wood, steel or concrete. The hemp fibres give the material high resistance to dynamic stresses, making it suitable for use in seismic areas (Senini, 2022).

Past and ongoing research has attempted to develop high-density hempcrete with load-bearing capacity by strengthening the material or adding additives to the binder. Higher levels of aggregates and compaction of the mixture improve the mechanical behaviour, but the challenge is to maintain the high insulation properties provided by the hemp shives.

A vaulted prototype of load-bearing cast-in-place hempcrete was tested at Cardiff University in 2009, showing some potential for low rise and small scale projects. Two main factors appear to influence the structural behaviour: material composition mix and geometry optimisation. The hempcrete used in this trial was supplied by Tradical, which is a mixture of air lime and cement.
Although the material showed potential for load bearing, the lack of tensile strength limits the design possibilities, a priori excluding

"cantilevers, corner openings, free plans and separation of structure and envelope" (Harris & Lea, 2010).
According to Coleridge, a lecturer at Cardiff University, this experiment "indicated a fresh architectural expression that directly challenges the high-tech minimal 'eco-technical' logic [...], a new tectonic, that works with the inherent qualities of the material rather than squeezing it to fit a predetermined form" (2014).

As the compressibility of the material depends on the mixture, the properties can vary, making it difficult to achieve a systematic product with calculated performance that meets building regulations. The correlation between material, structure and form is enhanced by the monolithic material, "challenging contemporary prejudices and creating sensitivity to the essential nature of materials" (Bohn & Mazelli & Bocco, 2022).
According to another study on the compression and shear behaviour of hemp-lime concrete, the material is anisotropic (Youssef et al., 2015), meaning that its mechanical properties can vary depending on the fibre orientation. The tests showed a high ductility of the material in shear, allowing it to undergo plastic deformation prior to failure or fracture. This confirms its relevant use in seismic contexts.

Acoustic performance
The micro and macro porosity (capillaries/fibres) give hemp-lime its high acoustic properties. Again, factors such as density, porosity and mixing processes can affect the acoustic performance of the final product. Hempstatic is an R&D start-up that has developed hemp based acoustic panels, their tests show a sound reduction index of 50dB for a 5cm hemp panel combined with gypsum board. Hydraulic and hydrated lime show better performance than cement-based binders (Stanwix & Sparrow, 2014).

Fire resistance
The lime encases the hemp hurds, giving the composite material good resistance to fire. In addition, if a wooden structure is in place in the middle of the wall, the hemp-lime will protect the wood, which will dramatically increase the fire resistance of the wall.
In some tests conducted by JustBioFiber (2019), hemp lime showed 100% structural integrity after 2 hours of fire exposure. Bevan and Woolley (2008) observed that 250mm thick hempcrete blocks remained intact after 1 hour and 40 minutes, with no emission of toxic gases. Other tests conducted by the Bre Group in the UK, French manufacturer Isochanvre and others have concluded that hemp-lime is a non-flammable material (Stanwix & Sparrow, 2014).

Insulation Fiber

Hemp fiber can be processed into insulation panels comparable to those made from wood fiber. These panels offer excellent thermal insulation and can serve as an additional layer on hemp-lime walls to meet insulation requirements in colder climates.

Available in various dimensions and thicknesses, the panels have a thermal conductivity (λ) of 0.04 W/m·K. Their environmental impact is minimal, as they are produced entirely from locally grown hemp fiber. According to Ekolution, the Global Warming Potential (GWP) of these fiber boards is calculated at -6.81 kg CO_2 eq., indicating a net carbon-negative effect.

hemp fiber
04. author

Lime plaster

There is usually a proportion of sand in lime plasters, they can be applied to hemp-lime walls to give a rather smooth finish that maintains the hygroscopicity of the wall. They are often referred to as 'semi-soft skin'. They have strength, durability and vapour permeability properties between those of clay render (soft) and cement render (hard). The quality of the lime affects these properties. Non-hydraulic limes are more vapour permeable and hygroscopic, whereas hydraulic limes and pozzolans are denser and therefore less permeable (Bryce & Weismann, 2015).

Different application techniques result in more or less permeable and durable finishes. Detailed information on the use of these plasters can be found in the book Clay & Lime Renders, Plasters & Paints (Bryce&Weismann, 2015).

tadelakt plaster
05. © DuChanvre

Pozzolan is a siliceous or aluminous material that, when finely ground and mixed with lime and water, reacts chemically, giving cementitious properties to the material. Pozzolan are typically by-products of volcanic ash and clay (Neville, 2011).

Tadelakt is a lime plaster technique from Morocco, the lime finish is polished by hand with a round stone which makes it water resistant. It is a good suitable for bathrooms, saunas and kitchens (Bryce & Weismann, 2015).

Hemp-lime plaster

Hemp-lime plaster acts more as a humidity regulator than an insulating material, as its thickness does not exceed 8 cm and its composition is high in lime. It is used as an interior plaster and can be left visible or covered with a thinner plaster (HES, 2021).
The addition of fibrous material to the lime allows it to follow the changes in humidity

and temperature of the building, expanding and contracting without cracking. This allows moisture to escape like rainproof clothing, ensuring a healthy building and good indoor air quality. An optimal building envelope prevents liquid moisture from entering the body (building) while allowing water vapour to escape, this approach provides equilibrium within the building (Bryce & Weismann, 2015).

The hemp-lime plaster maintains an alkaline environment which inhibits the growth of mould, mildew and bacteria, making it suitable for bathrooms, kitchens and work areas where acoustic and moisture regulation is required. However, it shouldn't be directly exposed to water and can be applied in one or two coats, depending on the mix.

In all areas where movement may occur, the first layer of lime finish should contain a plaster fabric to prevent cracking. It is not advisable to apply the plaster in direct rain or at temperatures below -3°C.

Alternative to lime

Other types of binders can be used as alternatives to lime. Clay is one of them, offering very low embodied carbon, local sourcing, and biodegradability. Clay paints provide high quality and smooth coating that can be colored with natural pigments. The earth material presents higher hygroscopic behavior and vapour buffering performance than lime. However lime presents alkanity, durability and mold resistance. Combining both materials such as applying a clay paint on a hemp-lime wall can combine both material's performances while encouraging local sourcing. The project Villa Lerkil by Wingårdhs architects showcases the use of prefabricated hemp-lime walls, supplied by EVIA, with a clay paint as interior finish;

clay finish - Lerkil Villa
06. © Wingårdhs

Contruction Techniques

Cast in-situ

The traditional way to build with hemp-lime is by casting it in-situ within a timber frame, like post-and-beam or stud construction. When studs are placed at the center of the wall, the hemp-lime provides racking strength and protects the wood from mold and pests (Bevan&Woolley, 2008).

Depending on the structure, hemp-lime can be poured vertically using shuttering or applied with a spray machine. The ingredients; hemp hurds, lime, water, and possible additives, are mixed on-site just before use. Larger batches can be mixed mechanically for better efficiency. With shuttering, the mix is poured, spread, and lightly compacted by hand between the boards, which are gradually raised as the wall grows.
The wall can be formed into any shape and thicknesses, the limits being the timber frame and shuttering method.
The spray method has been used in larger projects, such as the *Anciens Ateliers de Rotation* rehabilitation by ACAU architects (2022), which featured wood panel cladding and lime plaster.

In-situ hemp-lime offers a high-quality, often locally sourced product. But this technique is weather-dependent, construction typically halts in winter, and can't easily compete with conventional construction methods at scale. According to Anthony from DuChanvre, a Canadian practice, hemp-lime is 20–30% more expensive than standard materials (Exploring Alternatives, 2018), this doesn't take into consideration durability or low maintenance needs.

While the in-situ method is appealing for its simplicity, accessibility and flexibility, it remains a challenge to scale or standardize for wider use, while reducing production costs.

Hemp-lime is user-friendly, not only for those living in the house but also for the builders, as it doesn't release any harmful substances. In-situ construction techniques are relatively easy to learn, and several companies across Europe offer workshops and training for construction workers and self-builders.

spraying hemp-lime
07. author

Prefabrication

Hemp has been used in architecture since antiquity, but its role in modern construction is still emerging. Industries are working to adapt biomaterial techniques like hemp-lime to more systematic methods that meet building standards and offer a reliable alternative to conventional materials. Prefabrication helps make the process safer and more consistent, especially for the drying phase, which can be better controlled in a factory setting with regulated temperature and ventilation.
There are two main prefabrication methods: panels and blocks.

Panels production begins with a timber frame that serves as the load-bearing structure, which is then filled with hemp-lime. Studs can be left exposed, fully covered, or designed with varying geometries. Panels can incorporate ventilation and plumbing, and smaller sections can be cast on-site to join walls or close service openings. Additional insulation, such as hemp or wood fiber, can be added to meet energy performance requirements. Panel thickness depends on the building design, additional insulation, and environmental context. Although prefabrication is more systematic, it still allows for adaptable, tailor-made designs.

Formwork geometry and surface treatment are key to achieving a high-quality finish. To prevent sticking and achieve a uniform appearance, lime-based whitewash or vegetable oil can be applied. Plywood is typically used for molds, as it allows moisture to escape, unlike plastic or metal forms, which can trap moisture and lead to discoloration or uneven textures.

Blocks are valued for their efficient manufacturing, ease of use, and light weight. Dimensions and thicknesses vary. On-site, blocks are assembled using hemp shiv and lime mortar, which helps maintain vapor permeability and avoid thermal bridging at joints.
Blocks are particularly useful in renovation projects, where they add insulation to existing brick or stone walls. They're also commonly used for partition walls, offering good acoustic and thermal performance.

Innovative "Lego-style" blocks with an integrated bio-composite resin load-bearing core were used in the Harmless Homein British Columbia (Anderson Greenplan, 2017). According to the manufacturer, these blocks weigh half as much as concrete and offer ten times the insulation value, meeting passive house energy standards (JustBioFiber, 2021). With an estimated lifespan of 100 years, the hemp-lime continues to strengthen over time by absorbing CO_2 and forming a molecular bond with the lime, which helps prevent shrinkage and cracking. These blocks can withstand similar pressure to concrete and are capable of handling shear stress from wind, hurricanes, and earthquakes by redistributing loads horizontally (JustBioFiber, 2021).

In general, hemp-lime blocks have a higher density than panels or cast-in-situ applications, giving them greater compressive strength but lower thermal insulation. The best construction method depends on the context. In a country like Sweden, where timber is locally sourced and high thermal performance is essential, a lower-density hemp-lime system with better insulation may be the more suitable choice.

connection window-wall panel
08. author-study visit

Care & Maintenance

Damaged areas can be repaired by adding new material at any time. During the transportation of prefabricated walls, some damage may occur; this can be fixed on-site by applying fresh material to the already dry surface. A metal or plastic mesh can be added to ensure good adhesion to the original material. Scratched surfaces plastered with lime can also be easily repaired by adding new material, which will dry and merge with the existing layer.
The drying process of hemp-lime can be uneven, resulting in a heterogeneous surface color. Adding new material to visible hemp-lime may accentuate this uneven appearance.

Renovation & Restoration

Improved energy efficiency
Due to its high hygroscopicity and thermal insulation properties, hemp-lime can be used as an additional layer on existing buildings, providing internal or external insulation depending on the context. In this case, both in situ and prefabricated products can be relevant, with the choice of construction technique taking into account the existing materials and context.

Blocks
If the existing support has a regular surface, the blocks can be easily fixed directly to the wall; if the surface is irregular, a cavity filled with granular material between the wall and the new blocks ensures a regular installation. Depending on the desired thickness of the finished wall, some fibre panels with higher insulation capacity can be combined with thinner blocks, providing higher performance with less overall thickness.
In the Can Monges case study (p.44), hemp-lime bocks plastered with lime were used to tackle damp problems in the existing stone house.

Plaster
Another option is to use a thermal plaster, a lime-based mixture that also contains small hemp shivs for thermal performance. This plaster can be applied to existing stone, brick or wooden walls in thicknesses of 3-5 cm (Senini, 2022), creating a continuous building envelope that reduces thermal bridges. The advantage of this technique is its flexibility, as the plaster can fill any gap and follow irregular shapes. The plaster can be left visible or covered with a thinner coating of lime and water only.

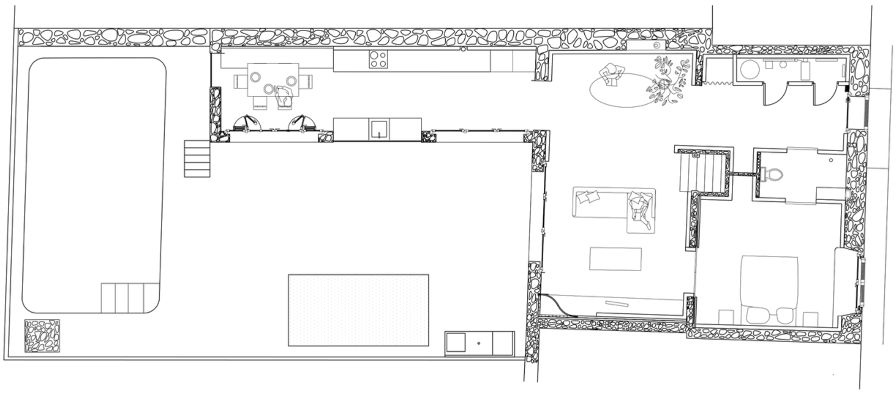
The mixture maintains the hygroscopicity of the wall, which is why it is often used in restoration work where the existing materials need to be protected from possible condensation between the different layers of the wall. This type of plaster has been shown to be effective against rising damp and salt efflorescence (Senini, 2022) and is used in the restoration of historic buildings to sustainably improve their energy performance without losing their cultural heritage values (Strandberg, 2023).

03
case study

Can Monges

architect Virginia del Barco from Ideo Arquitectura
year 2022
location Mallorca, Spain

Can Monges is a renovation project located on the largest of the Balearic Islands. Its Mediterranean climate features relatively wet winters with frequent heavy rains and hot, humid summers. The high humidity levels led to rising damp, posing a threat to the 200-year-old stone house.
The original structure consists of thick, uninsulated stone walls with a non-orthogonal layout and significant irregularities. Hemp was chosen for its hygrothermal regulating properties, aiming to improve indoor comfort and reduce energy consumption. A one-meter-high plinth of hempcrete blocks lines the entire ground floor. As moisture rises through the walls by capillarity, the hemp allows it to be released into the interior air, which is then ventilated through façade openings. Ceramic vents enable passive ventilation even when the house is closed.



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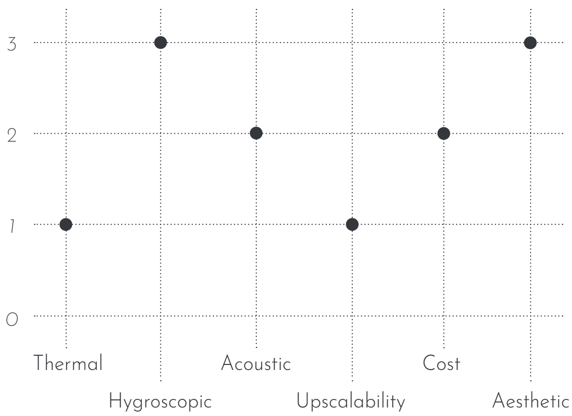

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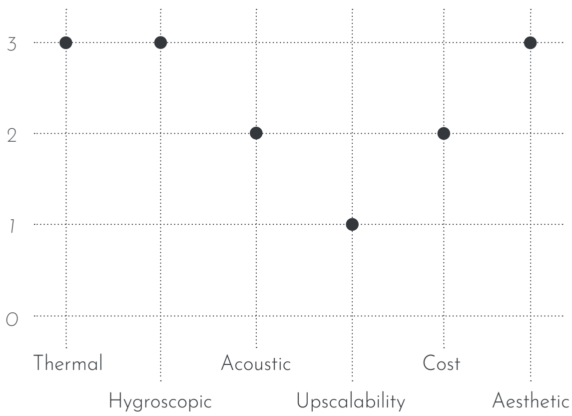
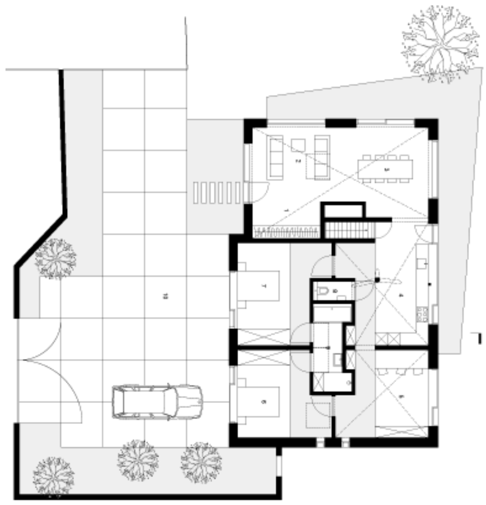
The project follows a philosophy of zero pollution and reliance on local resources, with many materials, such as tiles, doors, and flooring, being reused. Lime work, a traditional local technique, was carried out by island-based companies, supporting the local economy. Other materials like clay, ceramics, and wood were also sourced locally.
Hemp is used in the roof for its high thermal capacity, and its versatility is highlighted by using hemp rope for the stair railings.
The interior lime plaster finish provides a seamless, plastic continuity that creates a soft, aesthetically pleasing atmosphere, giving the house a unified, monolithic character.

Guillemin

architect	Martens Van Caimere
year	2016
location	Gent, Belgium
building type	Housing

This project, situated in a temperate maritime climate with frequent precipitation and high humidity, involves transforming an existing bungalow into a compact family home.
The house is fully self-sufficient in energy, water, and heating requirements, with solar panels providing electricity and a rainwater collection and filtration system supplying drinking water.
The floor plan is arranged so that the four main rooms surround a central technical block. A large finnoven, located in the living room and plastered with lime to create continuity with the interior walls, provides sufficient warmth to heat both the walls and sanitary water. The thermal mass of hemp-lime absorbs the heat from the finnoven and gradually releases it throughout the day.
The thick hemp-lime walls, left exposed on the exterior, recall the appearance of rammed earth, while large wooden block frames create wide openings that cut through the walls and





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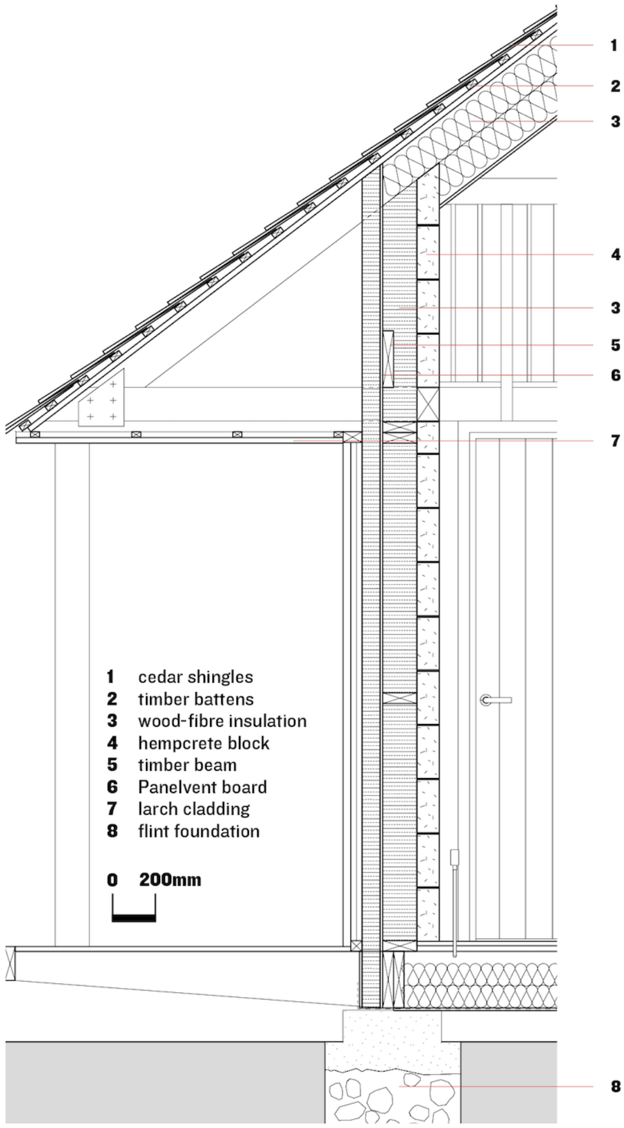
frame the surrounding landscape. Materials from the old bungalow were reused as interior cladding, reducing demolition waste.
A unique feature of this project is that the hemp-lime walls are not protected by the traditional large overhanging roof. Instead, a single wooden board runs along the top of the exterior walls, and the roof is flush with two of the four façades. A stone basement separates the hemp-lime from the ground, preventing moisture from rising through capillary action.

© Cedric Verhelst

Block House

architect Material Cultures, Studio Abroad
year 2021
location Somerset, United Kingdom

The residential project is located in a region of the United Kingdom characterized by a temperate climate particularly wet and mild, with less extreme seasonal temperature variation than in much of the country.
The timber-framed house has a 90 m² floor plan and primarily uses locally sourced, bio-based materials, with the goal of sequestering more carbon than was emitted during its construction. To minimize impact on the ground and existing flora, the house rests on two simple flint trench foundations. Prefabricated timber panels form the core of the structure, surrounded by oak columns that sit on a cantilevered deck and are sheltered by an overhanging roof.
The steep gable roof, clad in cedar shingles and insulated with wood fiber, features deep eaves that protect the façade, which is clad in locally sourced larch painted a soft pink. Hemp blocks are used to fill the prefabricated frame, providing thermal mass to the building. Their light weight makes installation easy. These blocks remain visible on the interior and are softened with a clay-based paint, bringing warmth and texture to the space.



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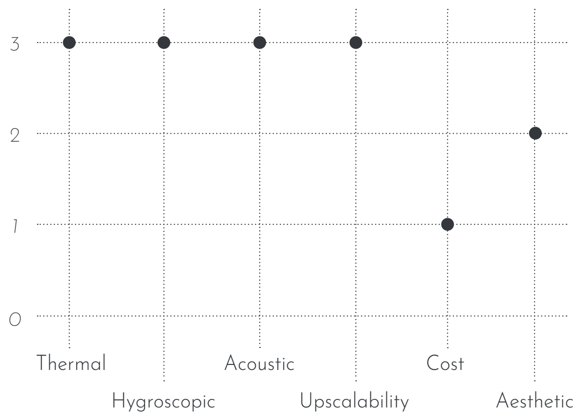

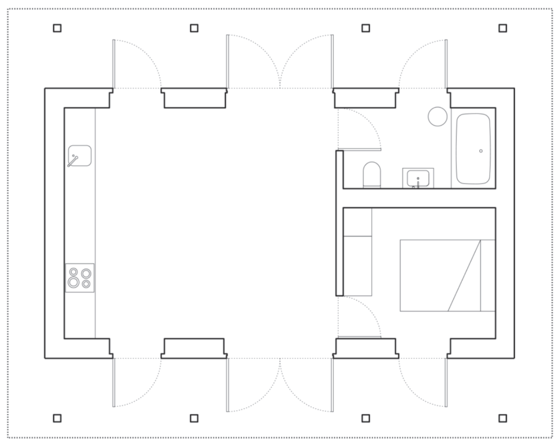

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04
material experimentation
with EVIA

EVIA is a Swedish construction company based in Lindome. They provide a cellular glass-based foundation system called the Koljern, as well as prefabricated hemp-lime wall panels marketed as Biostone.
The company is part of a two-year collaborative project called HempFab, alongside four industry partners: Wingårdh Arkitekter, Göteborgs Stadsfastighetsförvaltning, Lund University, and House of Hemp. The project is co-financed by Vinnova and aims to develop a hemp-based wall system, addressing aspects of architecture, construction, materials, production, and market needs (EVIA, 2024).

The material trials took place at the company's workshops in Lindome, where EVIA kindly provided materials and assistance throughout the research process.

- Test 1 - *Matter of Shape*
- Test 2 - Matter of *Binder*

hempcrete sample
21. author

Shape samples

The shape samples aimed to explore the plasticity of hemp-lime by presenting three relief variants; crenellated, corrugated and curved. This initial trial led to a better understanding of the design possibilities and challenges of the material, the mixing and drying processes and the importance of the formwork in prefabrication techniques.

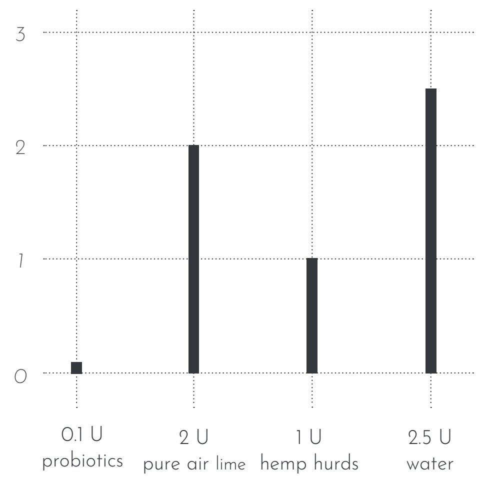
The test can be analysed with qualitative data such as how evenly the material dried, where it stuck to the mould and how the size of the fibres affects the complexity of the shape that can be achieved.

The binder used in this trial was supplied by Italian supplier Senini. It consists of pure air lime from the Dolomites with probiotic additives to enhance the carbonation process. This binder is attractive because there is no cement in the mix, which reduces the environmental impact of the product while potentially increasing the hygroscopic performance of the material.

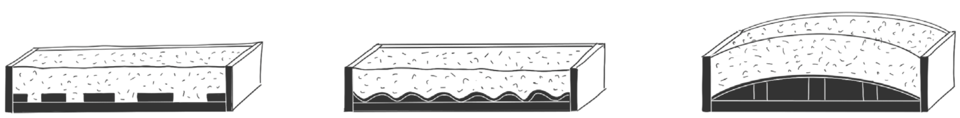
The shape samples were reinforced with metal mesh to prevent breakage due to the reduced thickness. Full-scale hemp-lime walls do not require reinforcement to support themselves as they integrate a timber frame and thicker insulation material.

mix recipe

supplier: Senini
density: 300 [kg/m^3]



Probiotic additives are a blend of micro-organisms that speed up the lime carbonation process, while providing greater short-term mechanical resistance and shorter drying times. The mixture includes lactic acid bacteria, photosynthetic bacteria and yeasts (Senini, 2022).



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crenellated

Wooden slats of decreasing width and 20mm thickness were fixed to the bottom of the formwork and removed one by one after 24 hours. The two thinnest slats - 20mm and 40mm - proved difficult to remove without breaking the slots, but after a further 24 hours they could be removed without tearing the hemp-lime.

The crenellations were well defined despite the size of the fibres. The material disintegrates slightly at the edges and the corners would probably be more precise with smaller fibres.

23

corrugated

The corrugated test was designed to assess the ductility of hemp-lime. Two corrugated tiles were placed at the bottom of the formwork and covered with a geotextile to prevent the hemp-lime from sticking to the tiles, which proved to be very effective. The waves were regular and even and the hemp-lime did not disintegrate. However, the corners and ends could be better defined. The tile method was possible and effective on this scale, but seems difficult to implement on a larger scale. A more effective method of producing a corrugated wall would need to be developed.

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curved

The curved sample was the most challenging in terms of formwork. An MBF panel was bent and framed with plywood to create the appropriate curve. In this first trial, the MBF wasn't treated before casting. It seemed impossible to remove the formwork after 24 hours without tearing the hemp-lime, so it was removed after a week. The sample tore at the corners, leaving moisture stains on the MBF, indicating that the material hadn't been able to dry properly.This trial highlighted the challenge of finding the right drying time before removing the mould, whilst avoiding too much moisture if the form is left too long.

Lab tests

The laboratory tests aimed to measure quantitative data on the thermal and mechanical behaviour of hempcrete, comparing the performance of different binders and different densities. The measurements were carried out at Chalmers' laboratories, providing initial experience with laboratory testing methods.

fail

A batch with a 260 kg/m^3 density was made at EVIA but two of the four binders didn't hold, they were therefore removed from the measurement test due to time constraints. If there had been more time, another batch with a denser recipe would have been needed to test the performance of the four binders.
In this test, we decided to use only one single recipe to limit the parameters; however, the recipe turned out not to be suitable for all the binders.
The cement/lime still gave good results, although it was more brittle than expected, the recipe usually used for making walls is a bit denser, with more water. The pure air lime gave similar results, with a rather dry and brittle material, although the block held together.

Because of these unexpected results, the measurement tests was performed with two binders: cement and lime (Tradical), and pure air lime (Senini).
The first batch made for the shape test was denser and performed much better. A sample from this batch was tested, along with a sample previously made at EVIA and a sample provided by the supplier Senini, which served as a comparative element.

Testing Procedure

1.Sample Preparation

Two different parameters:
Binder
Density

2.Moisture Conditioning

Samples are conditioned at 20°C and 50% RH for at least 3 days before thermal property testing.

3.Performing TPS Tests

Thermal properties are measured using the Transient Plane Source (TPS) method, the data obtained are the following:

- Thermal conductivity (λ) in [W/(m·K)]
- Specific heat capacity (c) in [J/(kg·K)]
- Density (ρ) in [kg/m³]
- Thermal diffusivity (α) in [mm²/s]

4.Data Analysis

$$a = \frac{k}{p c_p}$$

a: thermal diffusivity
k: thermal conductivity W/(mK)
p: density
c_p: specific heat capacity J/(kgK)

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architecture in progress

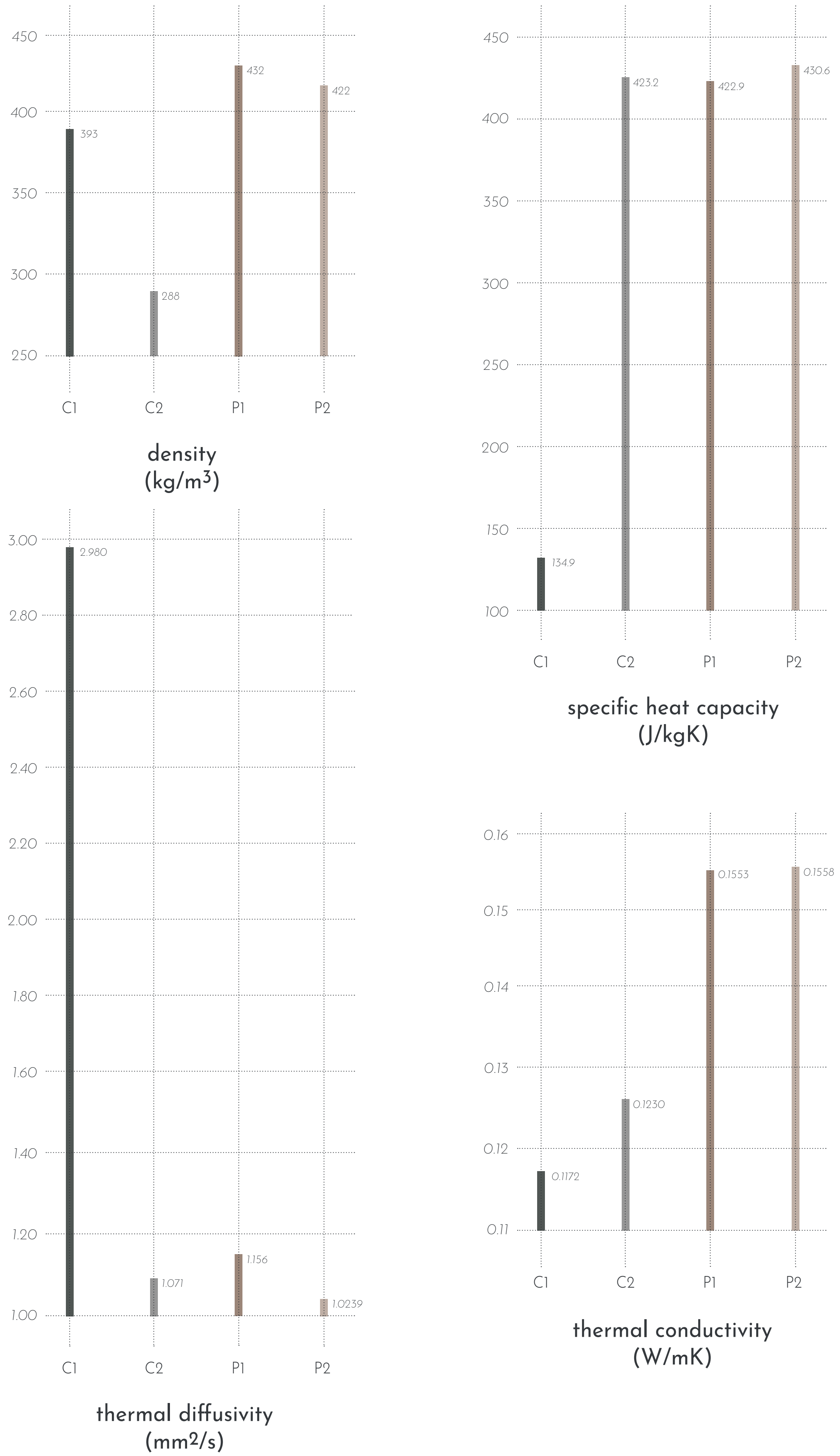


Fig.04 **C1** : cement-lime **C2** : cement-lime **P1** : pure air lime **P2** : pure air lime

Conclusion

The data obtained using the TPS (Transient Plane Source) method with the Hot Disk system showed significant variability when measured at different points on the same sample, highlighting the material's inherent heterogeneity. This variability can be attributed to fluctuations in density caused by the uneven distribution of hemp shiv and binder, as well as the presence of numerous air voids. Additionally, the irregular surface of the material can lead to poor contact with the sensor, further affecting accuracy.

Due to time constraints and issues in the formulation process, the samples tested in the lab were produced using different methods. The sample provided by the lime supplier followed a standardized procedure, while those manufactured at the factory were not. In future research, implementing a more systematic approach, with tight control over mixing ratios, sample dimensions, density, moisture content, and drying processes, would enhance the reliability and interpretation of the thermal property data.

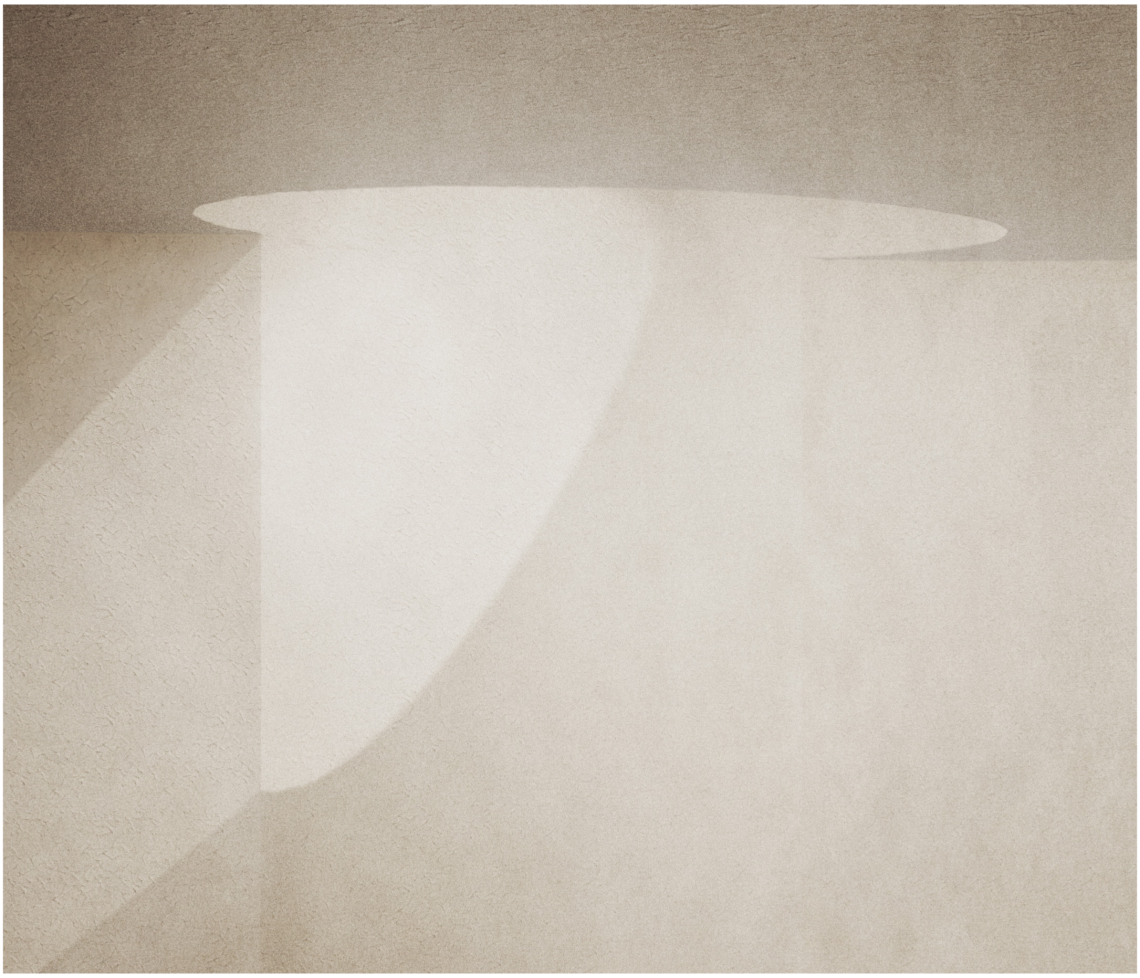
However, the tests concluded that the material is highly anisotropic, meaning that its performance varies with orientation and direction.

The samples performed poorly in compressive strength tests, they didn't fracture like concrete but showed high deformability under stress due to the high fibre content.

Increasing the lime content would increase the compressive strength, and using hydraulic lime might produce a load-bearing material, but the insulating properties would be drastically reduced. This laboratory experience confirms that hemp-lime is very relevant as an insulation material and that the load-bearing function should be ensured by another structure such as wood, especially in Sweden. Further research with long fibres would be interesting as they could give the material strength.

05
material application

Material application demonstrates the use of hemp and lime-based materials in design.
The first design proposal is a prototype of a curved wall panel made in collaboration with EVIA. The prototype combines innovation with a prefabrication process and aims to offer new design possibilities with an up-scalable construction method.
Finally, a design proposal for a showroom on the construction company’s premises aims to highlight the versatility of the materials by showcasing construction solutions and details, energy efficient systems, finishes and furnishings.



Skylight - Design Proposal

Material Palette

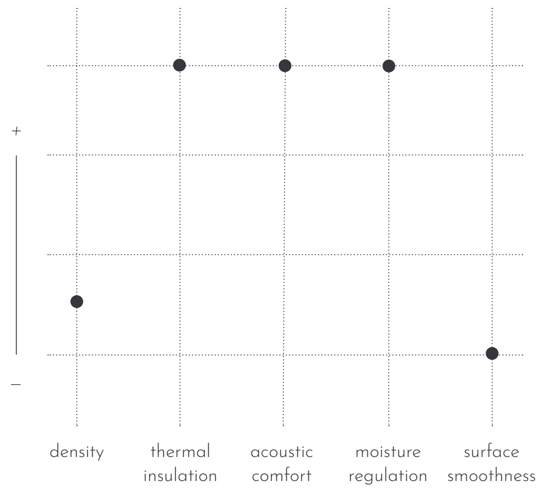
This non-exhaustive list presents hemp and lime-based materials and serves as a material palette for the design proposal.

Panels with timber frame

product description
The panels have a timber frame which ensures the load bearing properties of the wall.

application
- New construction (multi-storey buildings)
- Building extension

properties ***(data depend on material and mix density)***
- Density (ρ) in [kg/m³]: 240-300



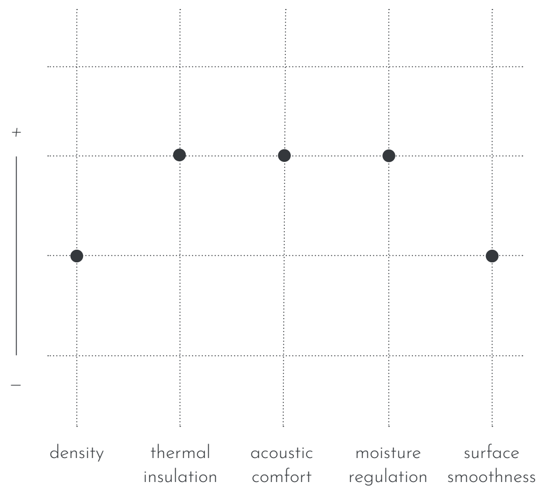
Blocks

product description
The blocks have no reinforcement, although they don't have enough compressive strength to be load-bearing, the shear properties of the material increase the stability of the wall, which can be used as a bracing wall.

application
- New construction
- Internal partition wall
- Retrofit
- Integrated furnitures

properties
- Density (ρ) in [kg/m³]: 310
- Thermal conductivity (λ) in [W/(m·K)]: 0.048
- Specific heat capacity (c) in [J/(kg·K)]: 1280
- Compressive strength [N/mm²]: 0.4

Data from Senini, 2022



Infill

product description
Hemp-lime infill has a low density due to the high hemp shiv content.

application
- Roof, subfloor and wall insulation

properties
- Density (ρ) in [kg/m³]: 175
- Thermal conductivity (λ) in [W/(m·K)]: 0.053
- Specific heat capacity (c) in [J/(kg·K)]: 1480

Data from Senini, 2022

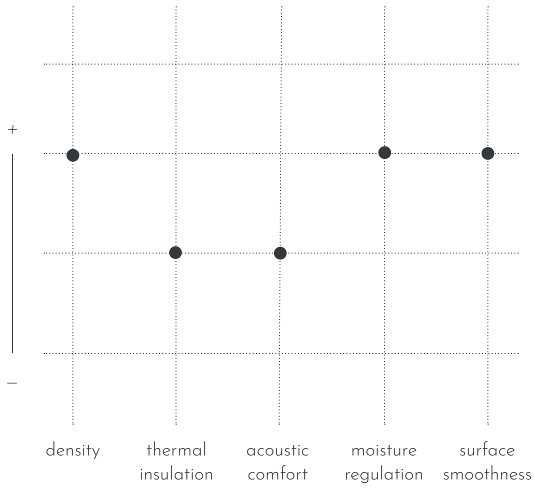
Hemp-lime plaster

product description
The lime-based plaster contains small hemp shives, making it an excellent moisture regulator.

application
• Interior wall finish
• Restoration (rising damp, salt efflorescence)

properties ***(may vary depending on mix density)***
• Thickness [mm]: 30-50
• Density (ρ) [kg/m³]: 500
• Thermal conductivity (λ) [W/(m·K)]: 0.12
• Specific heat capacity (c) [J/(kg·K)]: 1330
• Vapour permeability μ: 4.5

Data from Senini, 2022



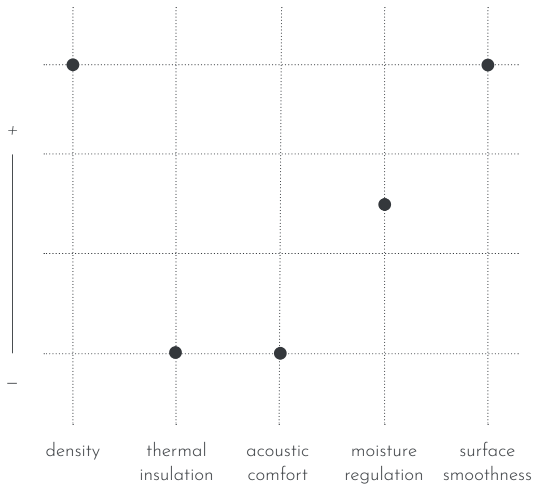
Lime plaster

product description
The plaster contains air lime and sand. It can be used as interior finish on a hemp-lime wall, providing a smooth finish while maintaining vapour permeability.

application
• Interior wall finish
• Wet surfaces (tadelakt)

properties
• Thickness: 5-10 mm
• Density (ρ) in [kg/m³]: 1600-1900

Data from Senini, 2022



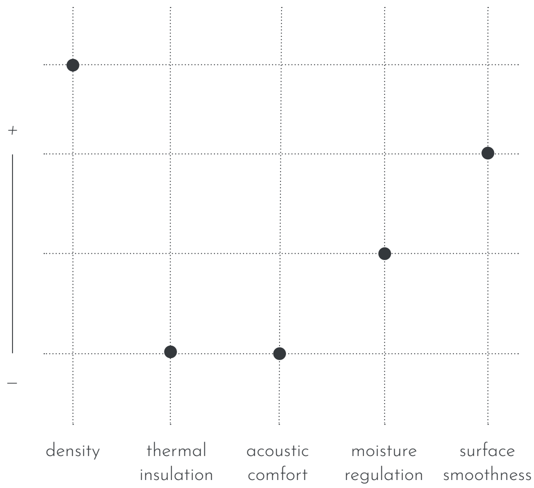
Mineral render

product description
The render is made from hydraulic lime and may contain mineral additives, it provides a durable exterior finish that maintains the hygroscopicity of the wall.

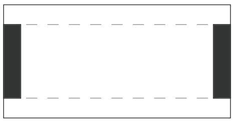
application
• Exterior wall finish

properties
• Thickness: 10-20 mm
• Density (ρ) in [kg/m³]: 1500-1900

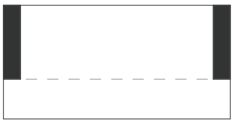
Data from Senini, 2022



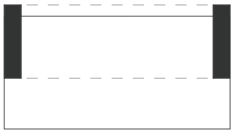
Timber frame
positioning



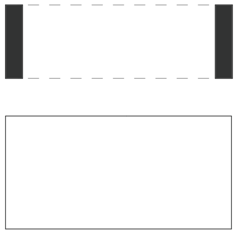
whithin the wall



flush with the wall

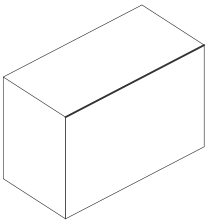


proud of the wall

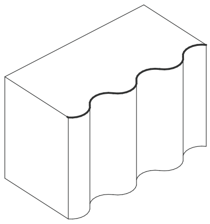


offset from the wall

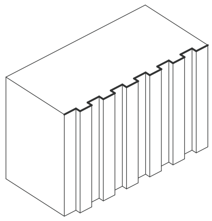
Hemp lime relief
variations



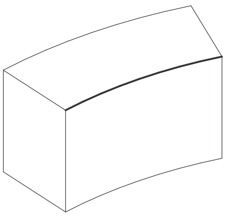
flat



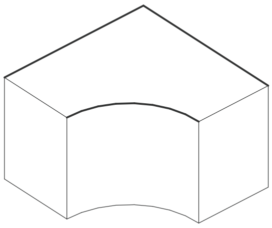
wavy



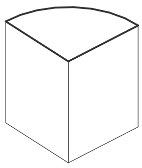
crenellated



curved



rounded inner corner



rounded outer corner

Finish

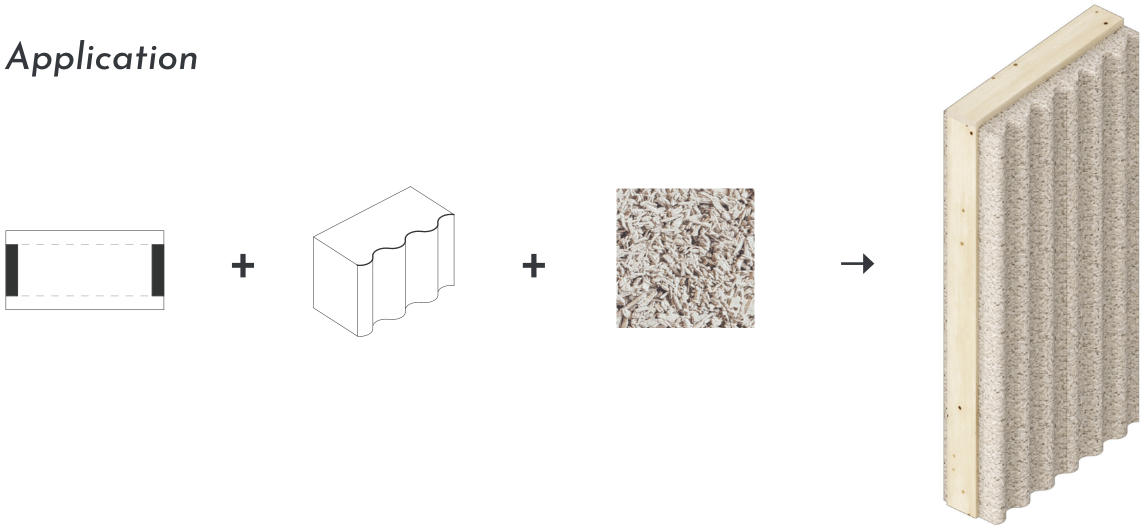
Hemp-lime can be left exposed to provide high acoustic comfort. It can alternatively be plastered with a dense hemp-lime mixture or coated with lime for a very smooth finish. Lime-based plasters ensure the vapour permeability of the wall and can also be used as exterior render.

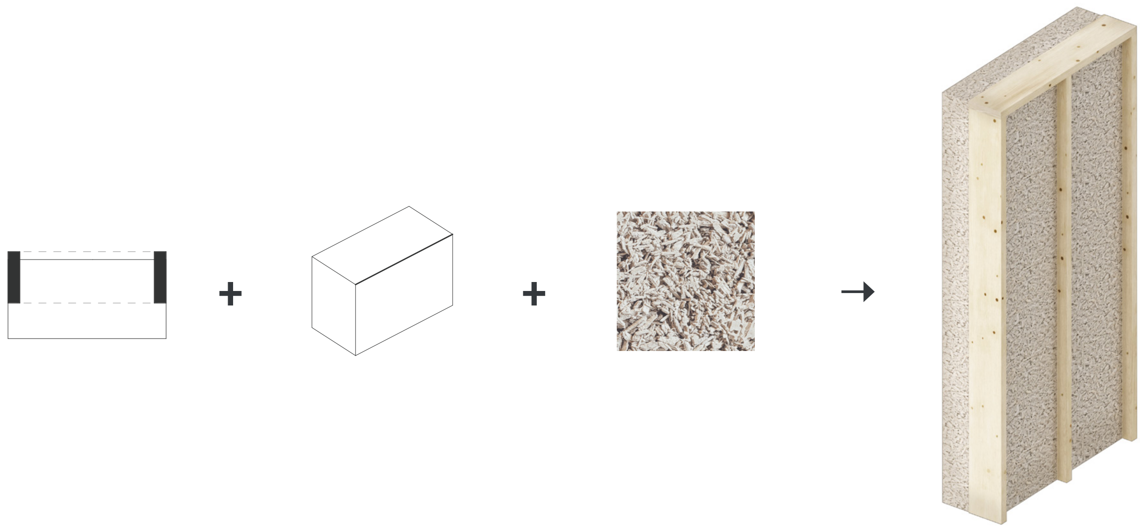
exposed hemp lime

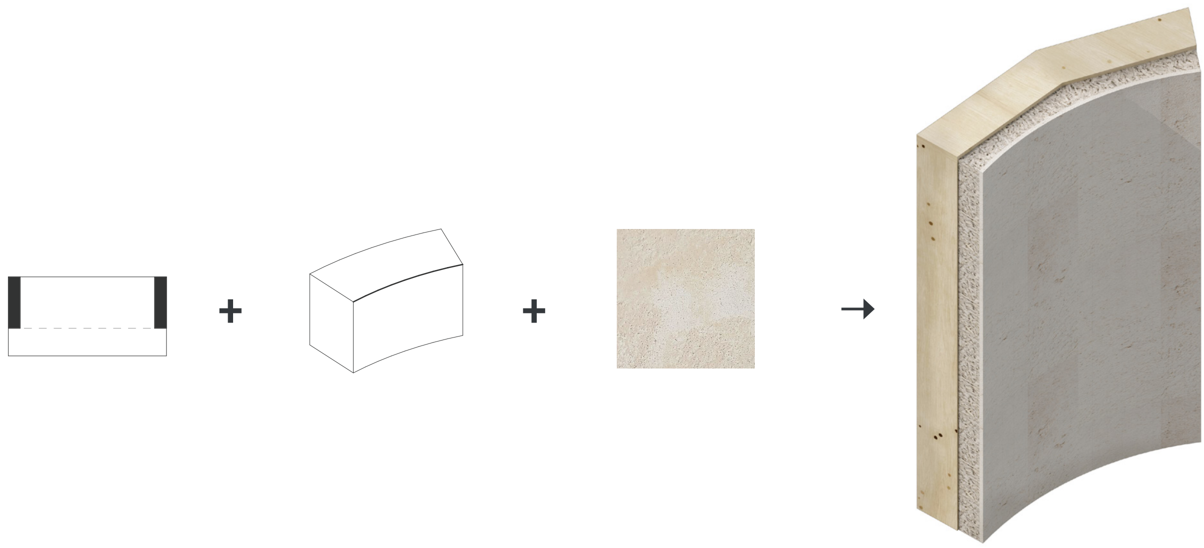
plaster

coating

Application







Prototype

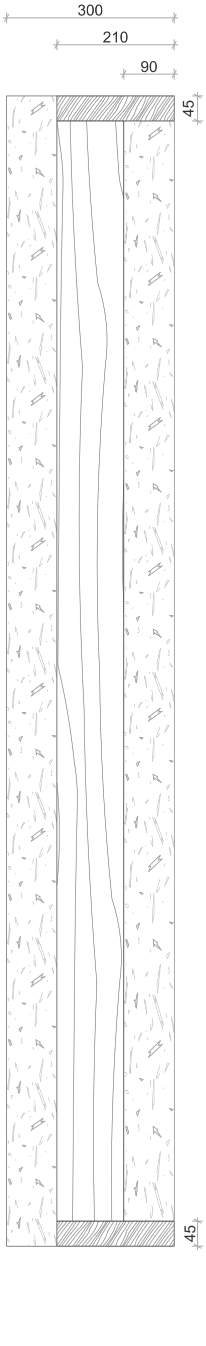
The design of a curved wall prototype followed the Shape Sample experiment. This prototype is a full-scale wall panel that includes a timber structure and a curved plywood frame. It was also an opportunity to test a pure air lime binder.

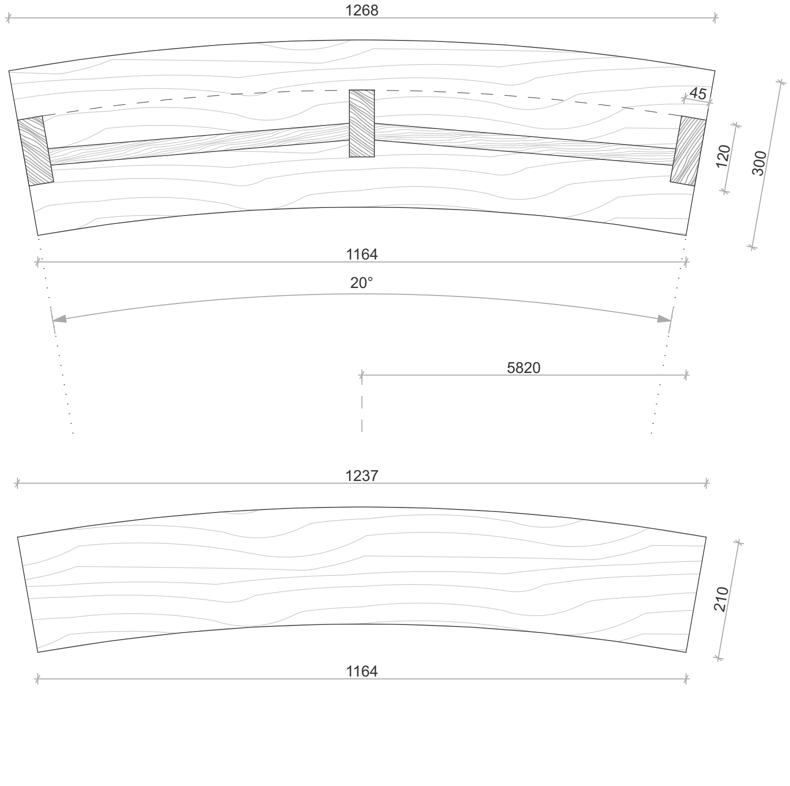
Although the binder showed great results on a small sample scale, the full-scale prototype did not hold when lifted, the hemp-lime separated from the structure and fell apart. Two main factors could be responsible for this: the drying process and the mix recipe.

Pure air lime takes longer to carbonate than hydraulic lime or mixes containing cement. Perhaps the wall should have remained on the ground longer to dry. However, one issue is that hemp-lime needs to be in contact with air to dry properly, which means the formwork should be removed as soon as possible to avoid moisture buildup. One possible solution could be to lift the panel while keeping a frame in place to hold the hemp-lime together for a few more days, allowing more time for the lime to carbonate and solidify.

Another factor is the mix recipe. The ratio of components used for this panel works well for blocks and on-site cast hemp-lime, but prefabricated wall panels follow a different casting and drying process that might require a slightly adjusted formula. More tests are needed to find the right recipe and manufacturing method to use pure air lime effectively.

In the meantime, another panel was made using a binder containing a small percentage of cement.


300
210
90
45
45


1268
45
120
300
1164
20°
5820
1237
210
1164

30

31

Hemp Showroom

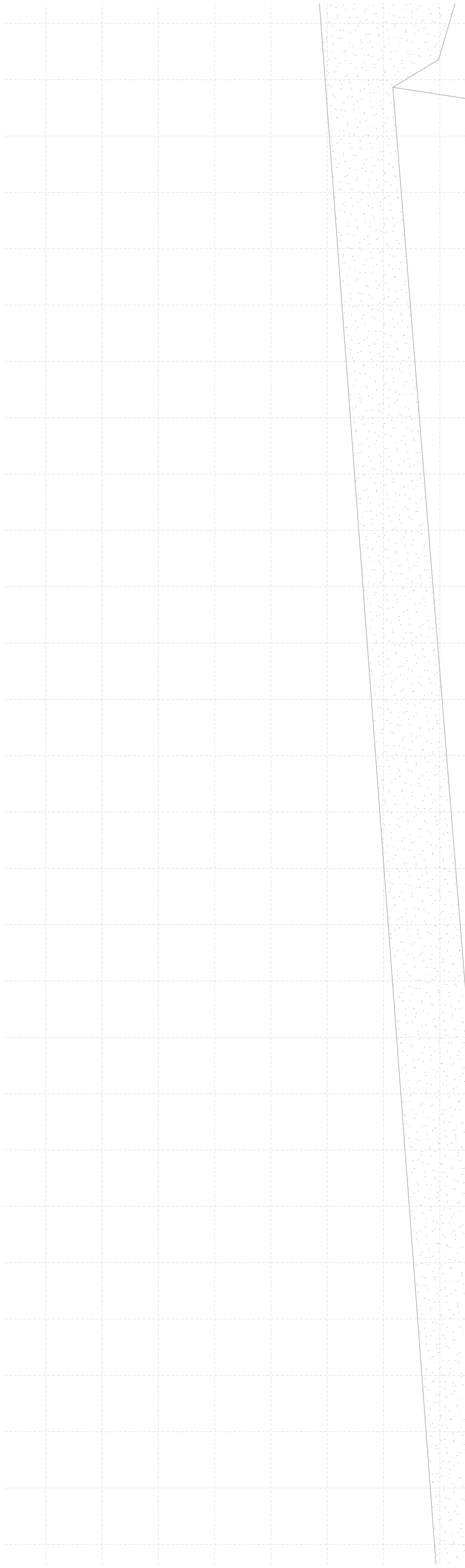
The design proposal is a showroom on the site of the construction firm EVIA, in Lindome, south of Gothenburg.

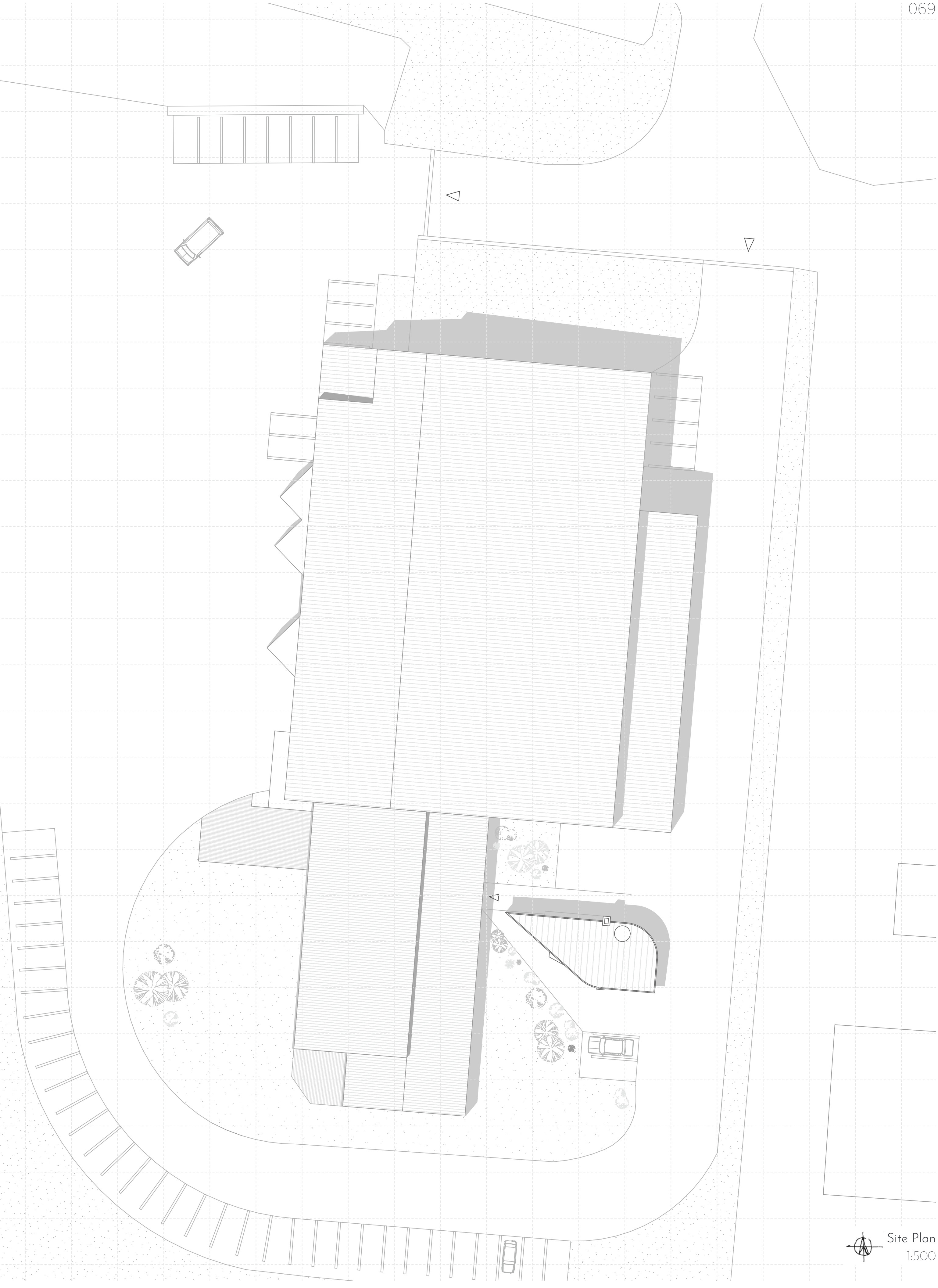
The project aims to showcase the application of hemp-based materials in a small architecture design. It offers a space for the industry's visitors to experience being in a hemp-lime building, to touch, feel, and explore the acoustic and aesthetic properties of the material.

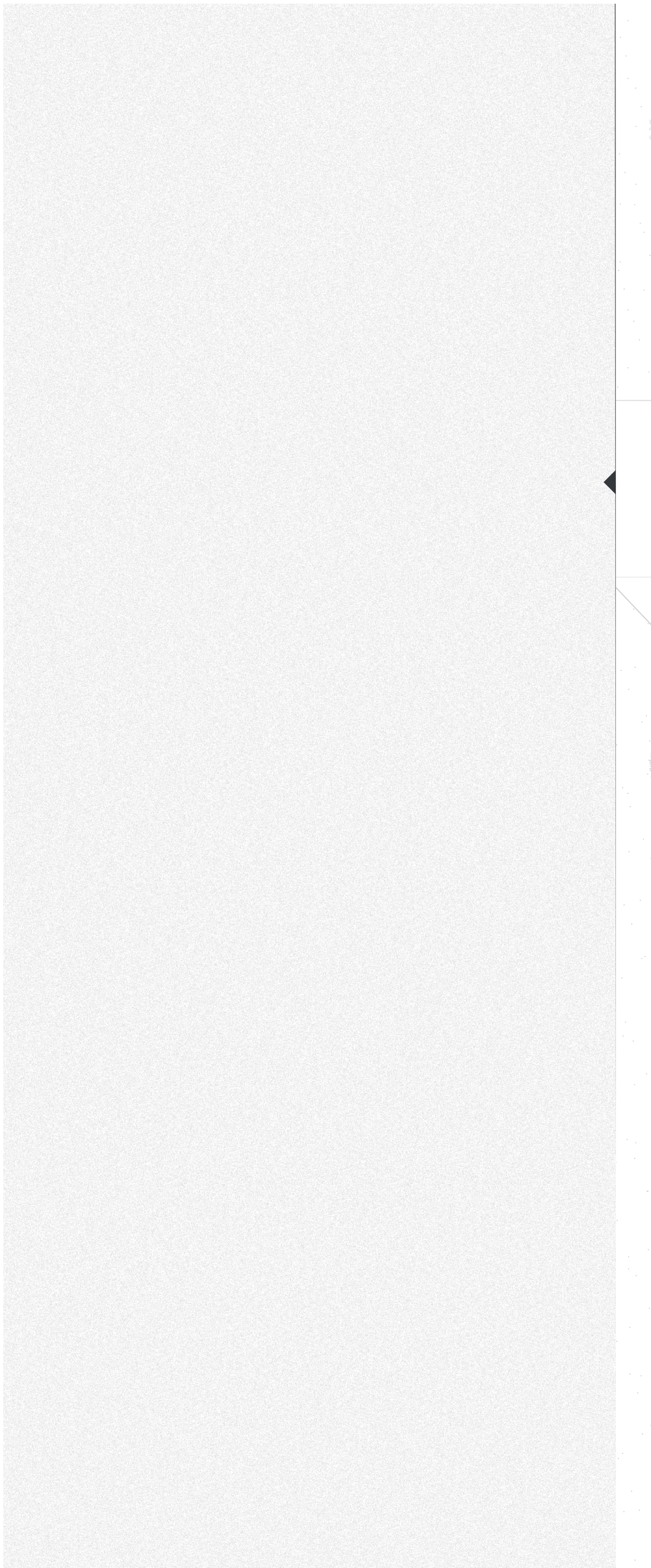
Two curved walls welcome a meeting space and form the main structure, guiding the visitor from the parking to the company's building. A thick wall host a *finnoven* or thermal stove to showcase the thermal performance of hemp-lime as well as a water point and integrated seating. The heating system interacts with the thermal mass of the walls that store the heat and release it gradually throughout the day.

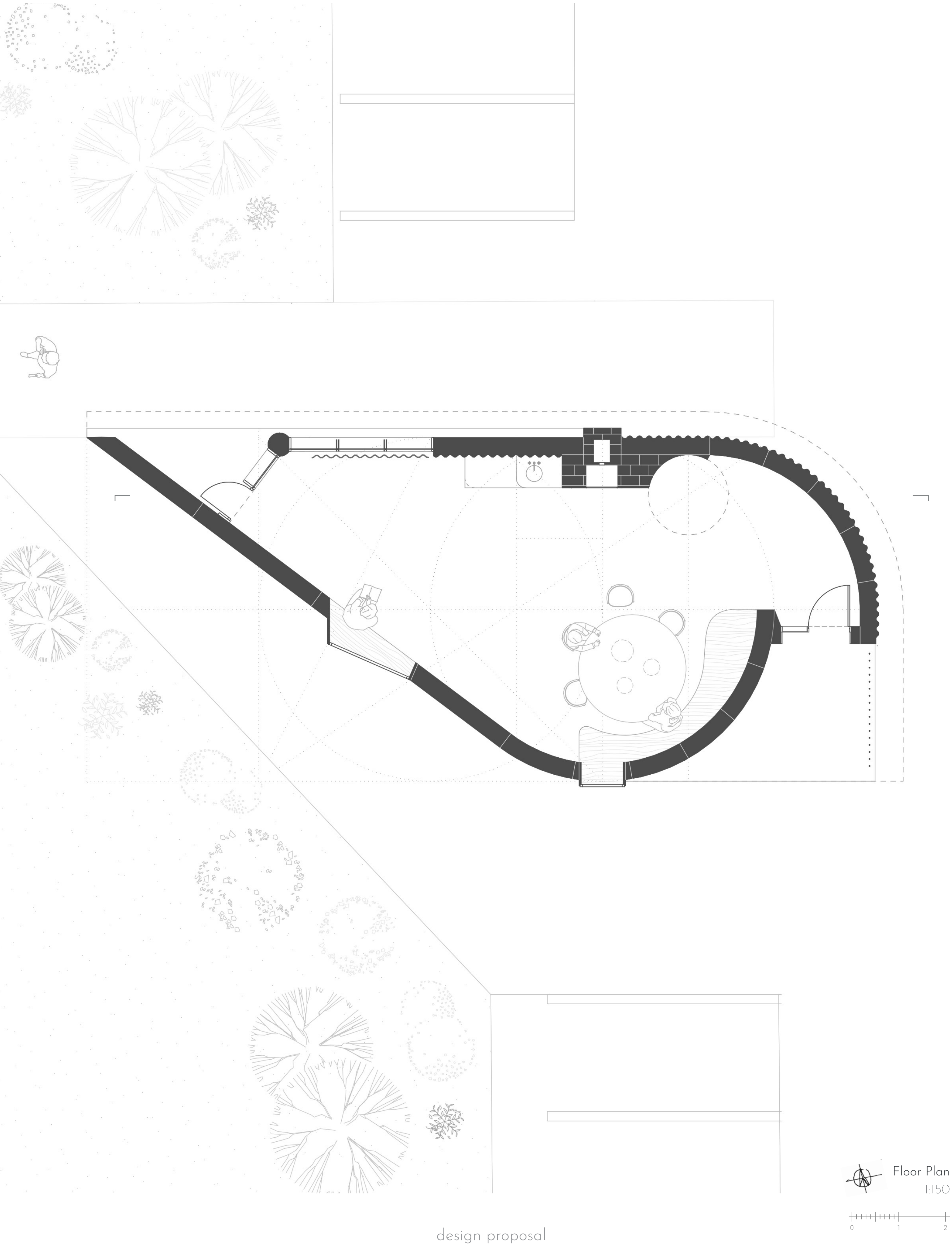
Located on a manufacturing site, the project aims to strengthen the connection between architecture and construction processes, raising awareness of what lies within the walls we inhabit.

Heljesvägen 12, 437 36, Lindome

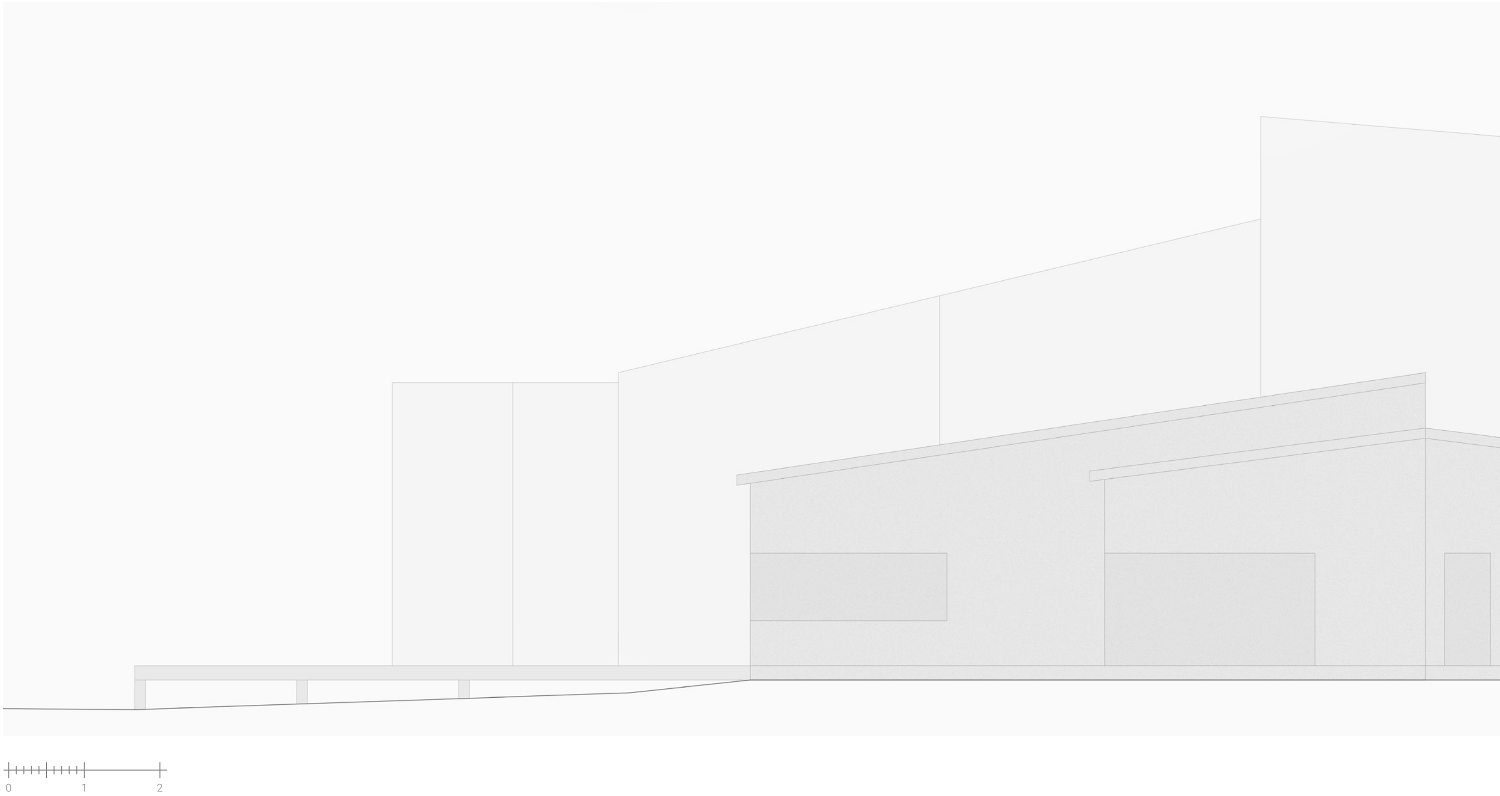


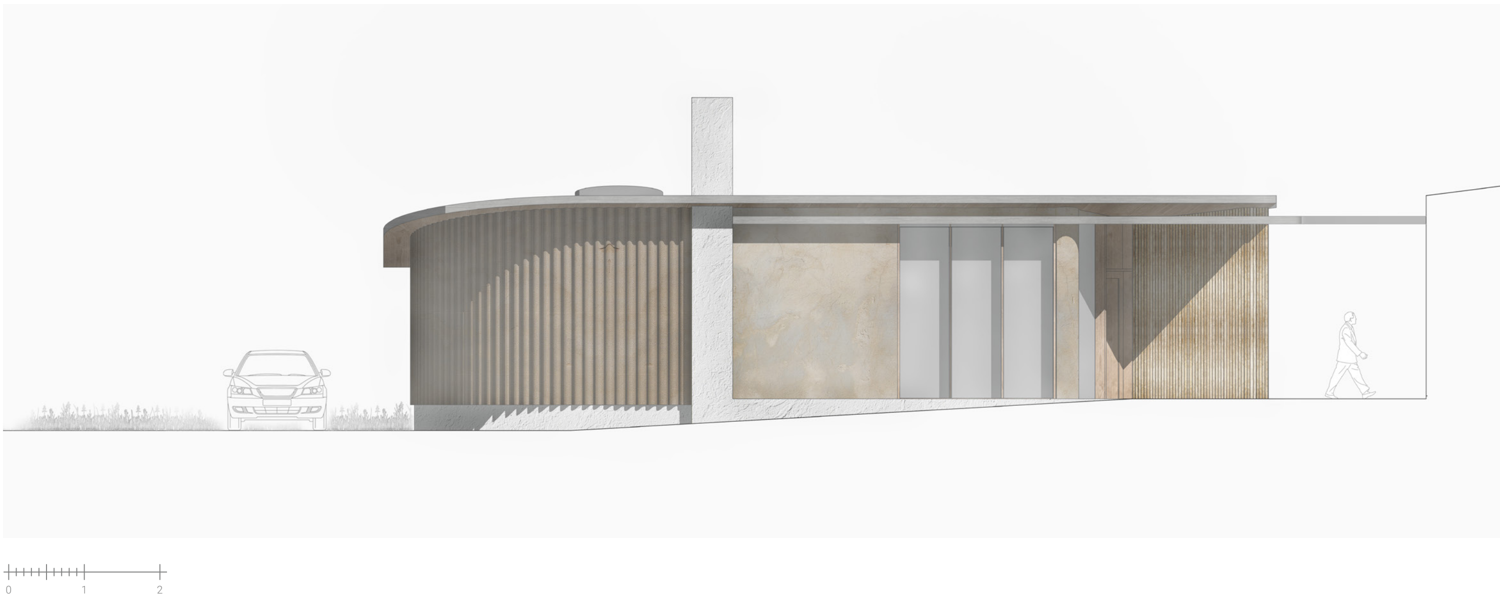

Site Plan
1:500

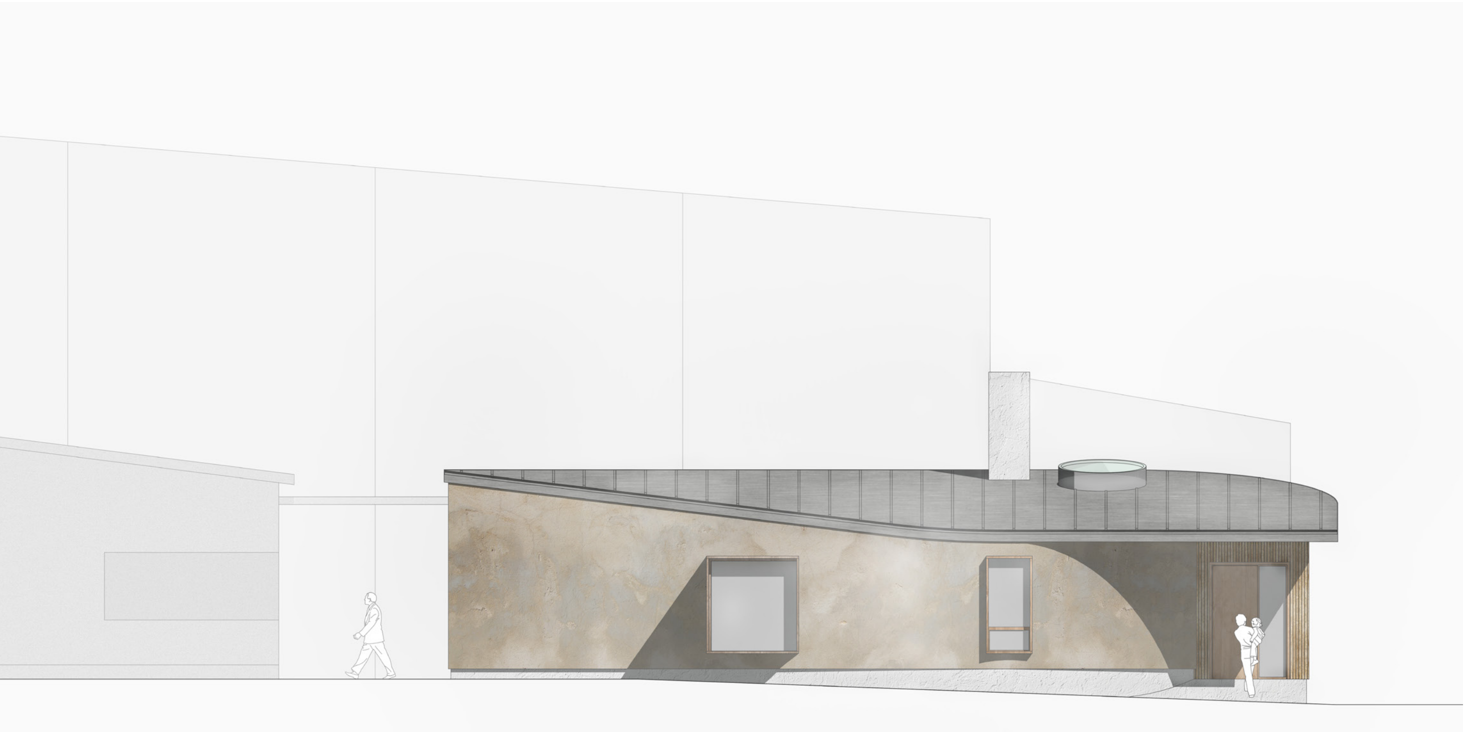




Floor Plan
1:150

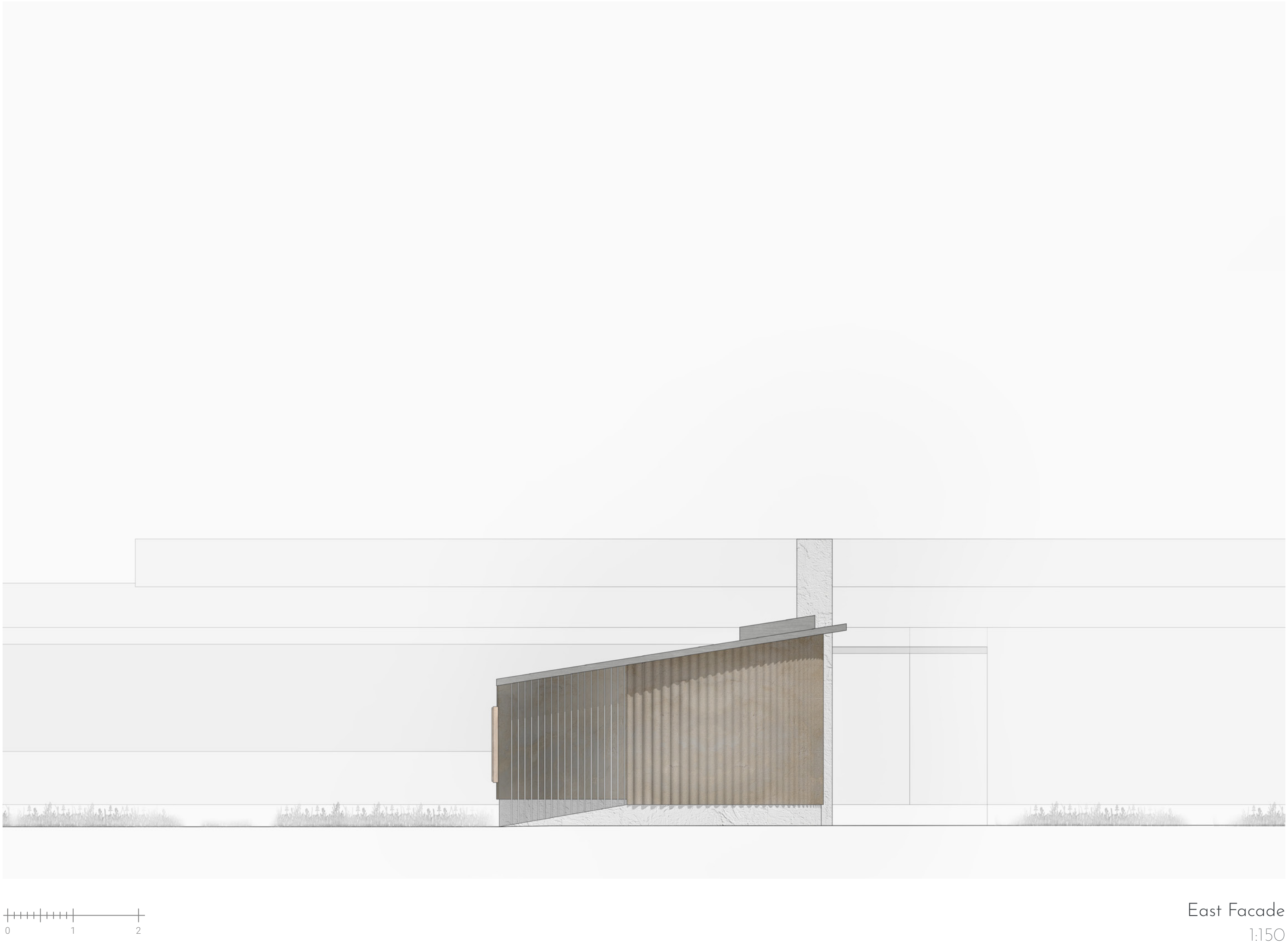






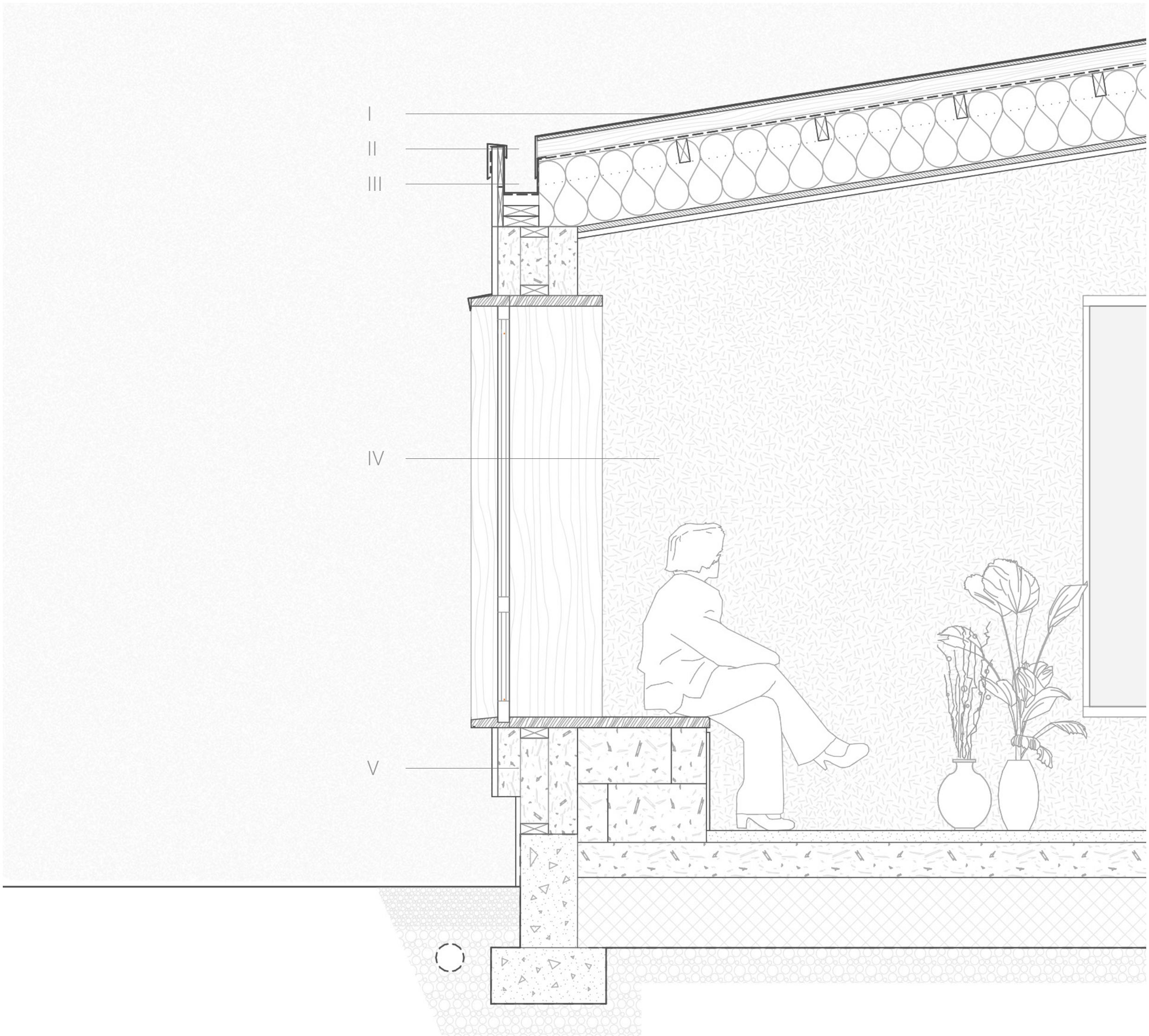
South Facade
1:150

North Facade
1:150



East Facade
1:150

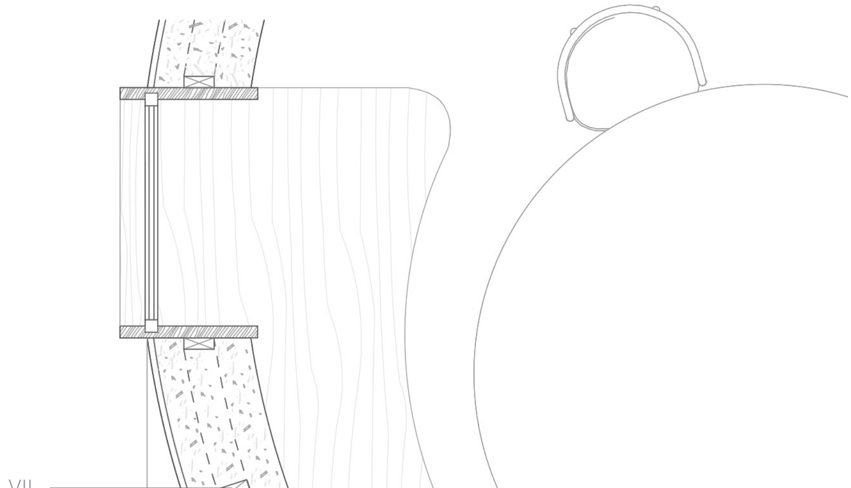
Longitudinal Section
1:150



I zinc sheet roofing
II battens 100x45mm
III hidden gutter

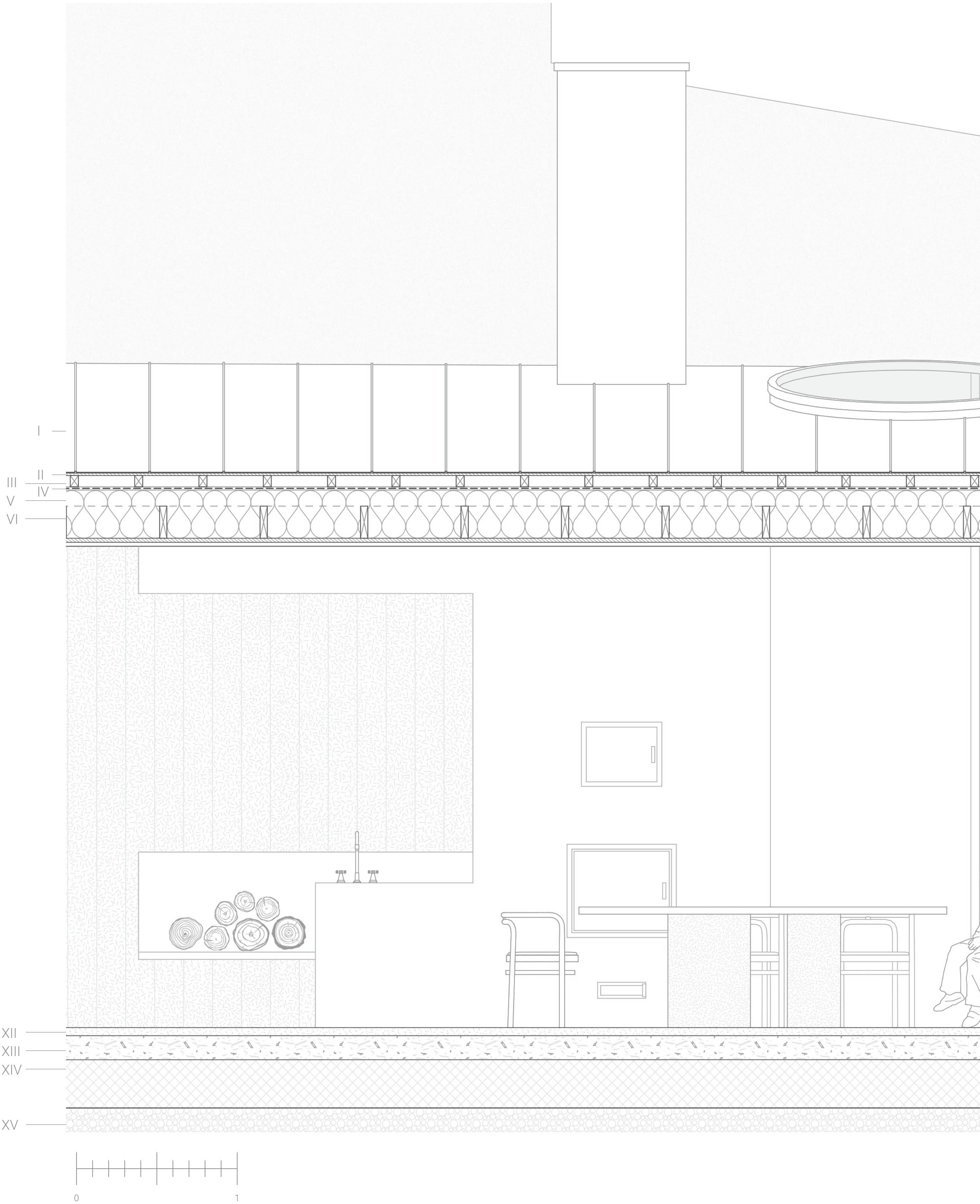
IV visible hemp-lime
V hemp-lime prefabricated panels

VII structural wooden studs
VIII lime render

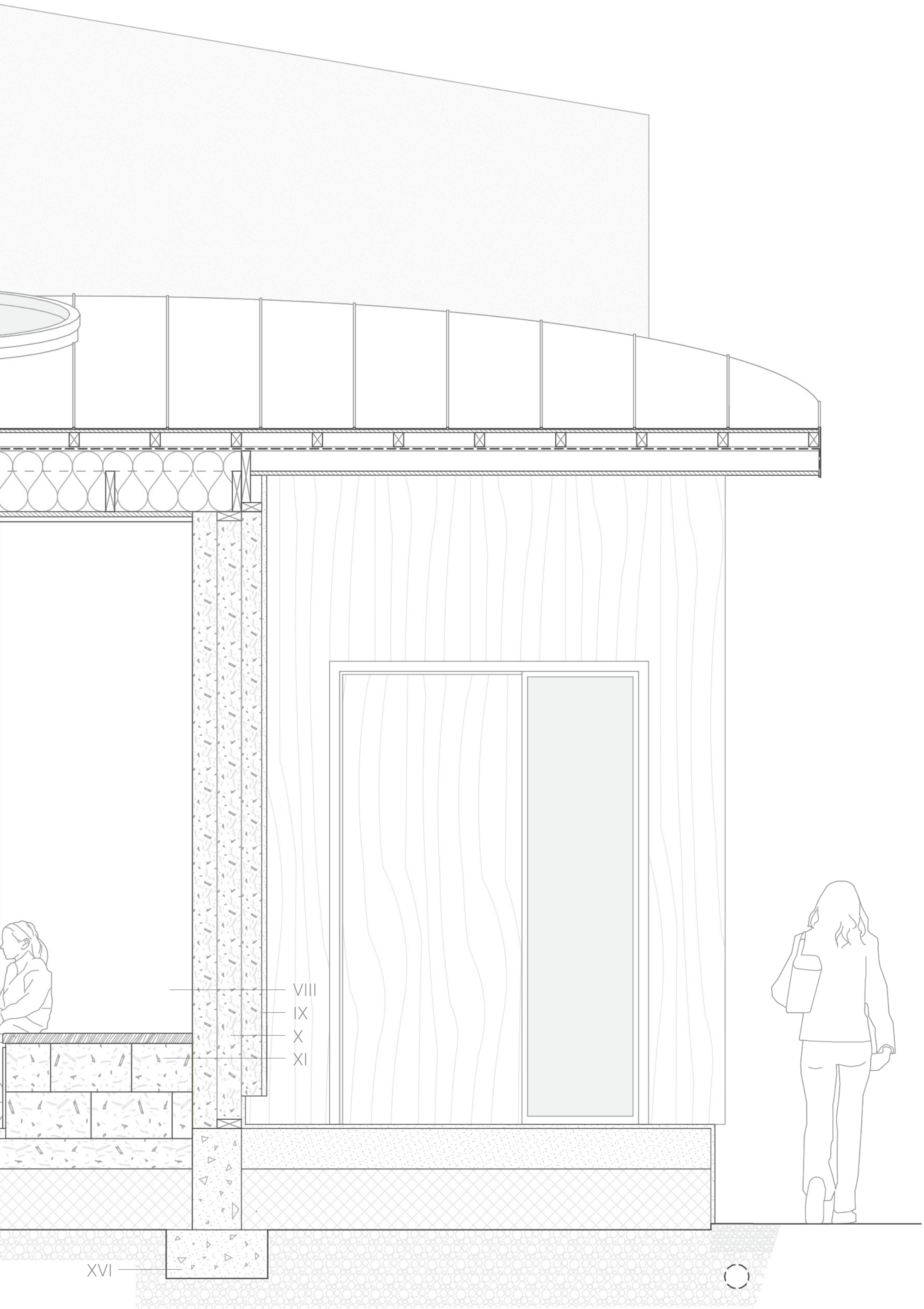


0 1

Detail Drawing 1
1:30



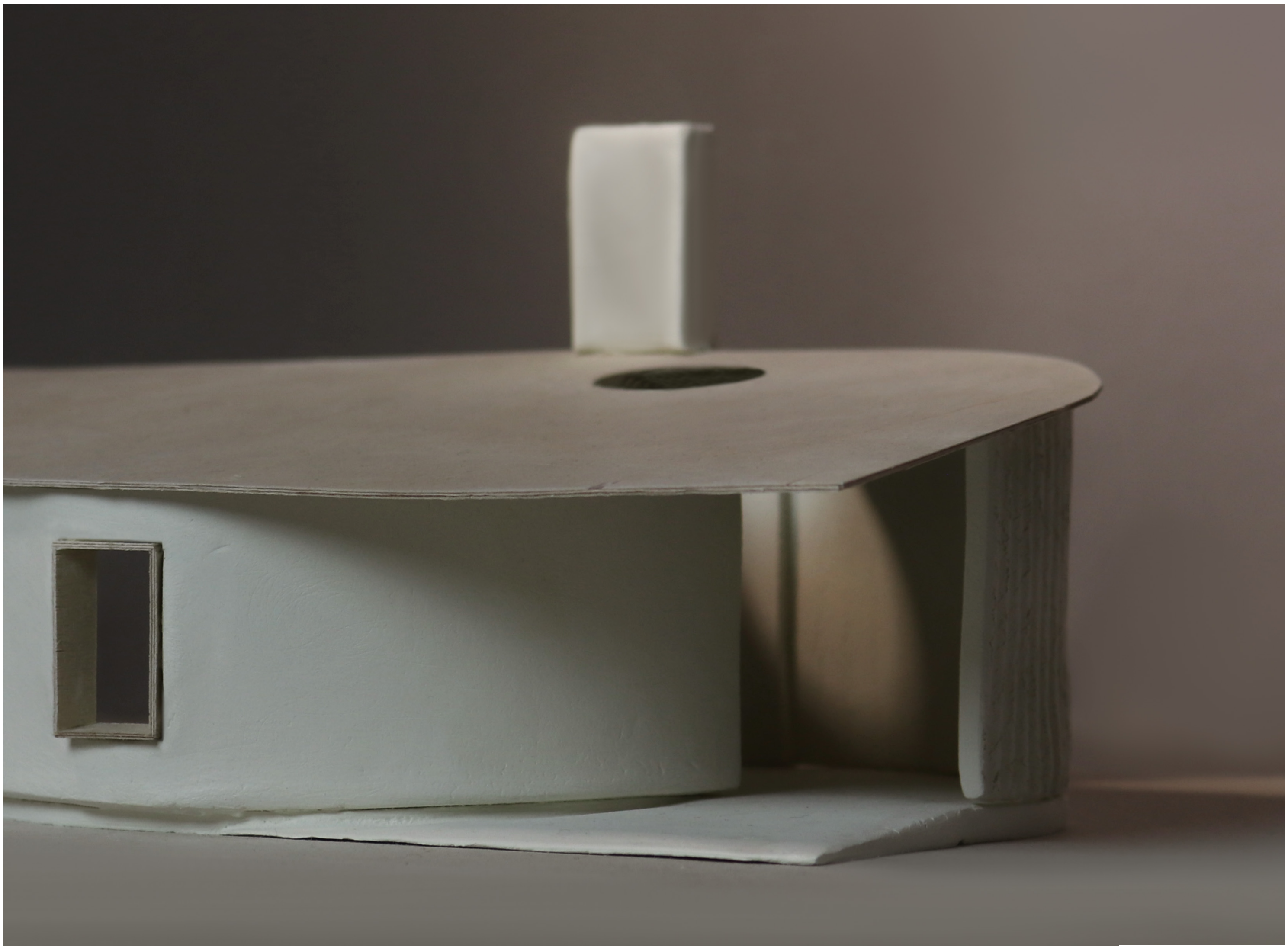
material application



I	zinc sheet roofing
II	OSB boards 20mm
III	counter battens 70x50mm
IV	vapor membrane
V	light hemp-lime 300mm
VI	rafters 200x45mm
VII	boards 25mm
VIII	lime plaster 25mm
IX	lime render 25mm
X	hemp-lime prefabricated panel
XI	hemp-lime blocks
XII	lime screed 50mm
XIII	hemp-lime slab 150mm
XIV	foam glass 300mm
XV	gravel bed 150mm
XVI	limecrete foundations

Detail Drawing 2
1:30

Interior Perspective



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discussion

thesis aim

This thesis aims to explore alternatives to conventional building materials in order to support sustainability and circularity in the built environment. It addresses the issue of chemical pollution and the responsibility of the construction industry: how can we eliminate plastics and harmful chemicals from the walls that surround us? As we spend more time indoors, often in spaces with poor air quality, this research focuses on both human and environmental health. Guided by the belief that architecture can do more than simply minimize harm, this thesis focuses on a material capable of generating positive impacts at many scale, from seed to building material.

research questions and findings

The question "How can hemp-based materials help architecture move toward more sustainable and regenerative practices?" was explored by looking at key stakeholders in Sweden's hemp supply chain. Early in the research, attending the Hemp Symposium in Staffanstorp led to a visit to Sweden's largest hemp fiber processing facility, opened in 2024. Hemp is grown locally, processed nearby, and supplied to manufacturers like EVIA, which builds hemp-based prefabricated walls in South Gothenburg. With the potential use of Swedish lime, these wall systems could soon be entirely sourced and produced within the country.

These findings raised questions about innovation and market demand. The resources and knowledge are already in place, so what's still holding back the wider adoption of materials like hemp?

Collaboration with a construction company in Gothenburg revealed the complexity of developing a new product and bringing it to market. Innovation often depends on demand, as Paulien Strandberg observed in her 2005 PhD on hemp. At the time, the problem wasn't big enough to trigger real change.

Architects and construction stakeholders seem to play a key role in shifting mindsets and practices: by sharing knowledge, embracing new alternatives, and daring to build with unconventional materials. These options may not always be the cheapest or most convenient, but they carry the potential for a more ethical and forward-thinking approach to building.

The two following questions, "What are the construction possibilities of hemp-lime materials and how do they help provide energy efficiency and indoor comfort?" and "What are the architectural possibilities and challenges of hemp-lime prefabricated modules?", were addressed by exploring the plasticity of the material through sample making. The possibilities in terms of density, mix recipe, and construction techniques seem endless, as do the design expressions. While the tests in the lab turned out to be more complex than expected, they provided valuable insights into the challenge of meeting industry standards with bio-based materials.

One question that arose towards the end of the research was how the presence of cement in a lime binder impacts both the environmental footprint and the hygroscopic behavior of the material. The answer is complex, as new technologies are making cement more sustainable, but the hygroscopicity of the material does seem to be influenced by the mineral content. Hydraulic lime seems to be a better option than cement, in terms of sustainability and thermal behaviour (Strandberg, 2025).

Another area of ongoing research is the potential load-bearing capacity of hemp-lime. This is especially relevant for one-storey buildings, which typically require a minimum load-bearing capacity of 3 MPa. Currently, hemp-lime blocks have a compressive strength ranging from 0.3 to 1 MPa. If load-bearing, hemp-lime blocks could offer a fast and efficient construction method, serving both structural and insulating functions (Strandberg, 2025). However, in situations where high insulation is the primary need, aiming for load-bearing hemp-lime may not be ideal. A higher density would mean more lime and less fiber, which would significantly reduce the material's insulation properties.

thesis process & methods

Expectations had to be redefined along the way due to time constraints and unexpected results. Hands-on experiments and lab tests were time-consuming, and while the analysis of the economic and circularity impacts of hemp cultivation could have been more detailed, covering a wide range of topics was enriching. However, this broad approach meant compromising, which limited the ability to deeply explore certain aspects.

Researching a material significantly informed the design process, prompting reflection on the relationship between materials and architecture. It raises questions about the authenticity and honesty of a building, particularly when materials are left visible, showcasing the construction process. In contrast, much of modern architecture conceals multiple layers of insulation, vapor barriers, making the building envelope complex, difficult to maintain and repair, and a source of considerable waste.
The research process was greatly enriched by the addition of practical experiments, enabling a close connection to be established between construction processes and architecture. The design was highly informed by the material and its properties.

conclusion

In terms of sustainability and architecture, hemp-lime shows great potential in Sweden. Ideally, lime from Gotland would be used alongside Swedish hemp. Further research is needed to expand the design possibilities and refine the mixture, but hemp-lime walls are certainly a great option for healthy habitats.

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Interviews

Elena Yaneva - CEO & Co-founder of Hempstatic
Online meeting 31.01.2025

Laura Commere - Architect & Student at Chalmers University of Technology
Online meeting 08.02.2025

Vera Matsdotter - Architect & Sustainability Strategist at Wingårdhs
Online meeting 16.04.2025

Paulien Strandberg - Bio-based Researcher & Senior Lecturer at the Division of Building Materials, Lund University
Online meeting 12.05.2025

Use of Artificial Intelligence

AI was used for the following purposes:

-To find relevant references and links.
-To verify the correctness and clarity of English language usage.

The following prompts were used during this process:

«Check the grammar and syntax of the following sentence.»
«Find reference projects using hemp and lime in Sweden.»
«Find industries involved in hemp manufacturing and processing in Sweden.»

illustrations

Figures

Fig 1: European Commission. (n.d.). *Hemp*. European Union. Retrieved May 12, 2025, from https://agriculture.ec.europa.eu/farming/crop-productions-and-plant-based-products/hemp_en

Fig.02: *«Shely Fiber Breaker.» (1892, June 25). Scientific American, 66(26).*

Fig.03: Adapted by author from © Solano, M. (2023, July 4). *Press release – Carbon storage in hemp and wood raw materials for construction materials*. European Industrial Hemp Association.

Images

06: © DuChanvre. Retrieved from https://duchanvre.com/projets/projet-lachine/

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Master's Thesis
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Profile: Building Design and Transformation for Sustainability

Supervisor: Tina Wik
Examiner: Walter Unterrainer

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