Material Matters

contemporary architecture with low impact materials

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Master Thesis Spring 2020
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Thank you!

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Abstract

This thesis seeks to examine the implementation of natural, less processed and renewable materials in a building design and how it could drastically lower the structure's environmental impact while meeting present-day standards. The intent is to renew how these materials are viewed within the building industry by providing tangible examples of their application and performance in an urban context.

Even though the concepts of sustainability are becoming more mainstream, emission of greenhouse gases, excessive use of resources, and loss of biodiversity are, among other factors, crucial aspects where the building industry still fails to meet the conditions for sustainable development. The energy efficient buildings of today cause their main environmental impact during construction and by the processing and production of building materials, therefore it has become increasingly clear that buildings that use little energy during their operational phase or measures of compensation is not enough.

The method used is to formulate a Low Impact Material-strategy for a Swedish setting and through it develop a design proposal for a commercial building in central Gothenburg. This example then supports discussions around how and with what our built environment is constructed, how it can have a more symbiotic relationship with our planet and will also demonstrate the architectural qualities gained from building with Low Impact Materials.
Through this process the ambition was to gain the understanding necesary to develop examples of real applications of these values based on the prerequisites of a Swedish context and building industry. Knowledge that we will bring with us into the profession.

It is important to show that it is possible to rethink our elements of construction, because it matters how the sourcing and processing of building materials impacts the ecosystems and biodiversity. It matters where the materials we use come from, how they are fabricated, how they develop during their use and what happens to them after the building has outlived its lifetime.

Materials matter more than we might have thought.

Keywords: Sustainability, Natural Materials, Lifecycle, Construction Details

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1.

Introduction

"A design strategy that embraces rather than snubs, low-impact high-maintenance materials could not just dramatically cut construction associated emissions but help to re frame the conception of architecture."
(Smith & Harper, 2019, p.11)

Background

Problem statement & motivation

Concrete buildings with plastic or mineral wool insulation and bitumen layers are still the norm in the Swedish conventional building industry; some of them are even claiming to be the result of sustainable design. These highly processed materials and products requires large amounts of energy in manufacturing, have a severe ecological impact through their resource extraction and are rarely recycled or reused, let alone can they be composted.

Globally the building industry plays a big part in the human strain on the environment and the fact that it needs to change drastically is clear. The 2019 Global Status Report for Buildings and Construction by the International Energy Agency and the United Nations Environment Program came to the conclusion that the global building construction sector is still responsible for around 40% of greenhouse gas emissions and that it keeps failing in lowering those numbers as the energy demand in buildings was still on the rise during 2018. The predictions also point out that the pace of construction will grow exponentially with a global building stock that is set to double by 2050.

It is clear that the building sector is not where it needs to be in terms of climate action, to achieve set goals from the Paris agreement in limiting the global warming to 2°C even though it is more pressing than ever.

Swedish studies show that, when more thoroughly mapping the emissions from upstream processes of extraction and production, building materials count for around 84% of the buildings initial climate footprint (IVA, 2014).

Alongside the emissions of greenhouse gases, the extraction and production stage is also where many building materials have an irreversible impact on ecosystems, land and water. If we look at the example of concrete, the most widely used construction material in the world, efforts are being made to develop concrete containing cement with lower levels of CO_2 emissions from its production, providing an arguably "green" product. However, the use of concrete has many other less obvious implications. Jonathan Watts writes "***the most severe, but least understood, impact of concrete is that it destroys natural infrastructure without replacing the ecological functions that humanity depends on...***" (The Guardian, "Concrete: the most destructive material on earth", Feb 2019, para. 13) and mentions the acquisition of sand and the excessive use of water as examples.

Following understandings like this while considering the fact that systems to lower operational energy demand have been developed, there seems to be an increasing cohesion that focus now needs to shift from operational energy demand to the choice of building materials
(Miljö- och klimatnämnden, 2018). This in an explicit strategy mentioned in the city of Gothenburgs plan to become fossil free by 2030. (Fossilfritt Göteborg 2030 – Vad krävs?)

To conclude, the situation we find ourselves in requires immediate attention, the industry needs to re-think its modes and means of construction to alleviate its impact on the environment. The insights mentioned as to what strategies that are deemed most constructive could, and should, work as fuel to flames such as the one sparked by Smith & Harper in their call for a building material re-evaluation and strategies utilizing low impact materials in construction.

Aim

The aim of this project is to show, by an exemplifying design, that employing natural materials with a minimal level of processing is a way to not only lower the initial amount of energy or fossil based components needed, but also to enhance architectural qualities.. By designing mainly with wood, clay and straw the proposal will demonstrate a low impact approach based on the preconditions of a Swedish setting.

The choice of site and program for the proposal aims to actualize the use of this strategy for an urban project of a larger scale.

This will then be complemented by discussions on potential obstacles and hinders a strategy like this might face and what could be done to overcome them. The building industry is strong in defending their business as usual, the task is therefore to acquire solid knowledge and present the tangible examples needed to argue for the use of low impact materials.

Research questions

- *Why are low impact materials not used commercially today?*
- *How can low impact materials be incorporated in the design of a commercial building within contemporary architecture?*

Impact

Outcome

The outcome of this thesis is a thorough research on Low Impact Materials like wood, clay and straw and examples of their application in an urban scale design project. It aims to fill the gap in the literature that we perceive between speculation and application in this particular field.

The design project is a proposal for a multi-story, mixed-use building in central Gothenburg. Mixed-use, to demonstrate that the use of Low Impact Materials is suitable for a variety of functions and programs. Central Gothenburg because it is important to show that projects like this have a place within an urban settings and scale as well.

This thesis is thought to broaden the spectrum for Low Impact Material strategies from smaller scale "Eco-dwellings" to urban, multi-storey buildings in a Swedish context. By focusing on the choice of construction materials and strategies, this thesis will propose a possible strategy to minimize the buildings impact on the environment. This work shall motivate people to demand building concepts with these type of materials. It will work as a reference and support the argumentation for the use of Low Impact Materials when demanding for the building industry to change their ways.

Audience

The intention is that this thesis will reach and inspire other architects and students to dare to use unconventional, less processed materials and to provide a source of knowledge on how to do so.

It is an effort made to collect and present the research behind, and provide examples of, minimal impact construction. It is written to benefit professionals, within the building industry and beyond, who wants to learn more about building with and fully utilizing Low Impact Materials like clay, wood and straw and how that can provide healthy and environmentally sound structures.

Method

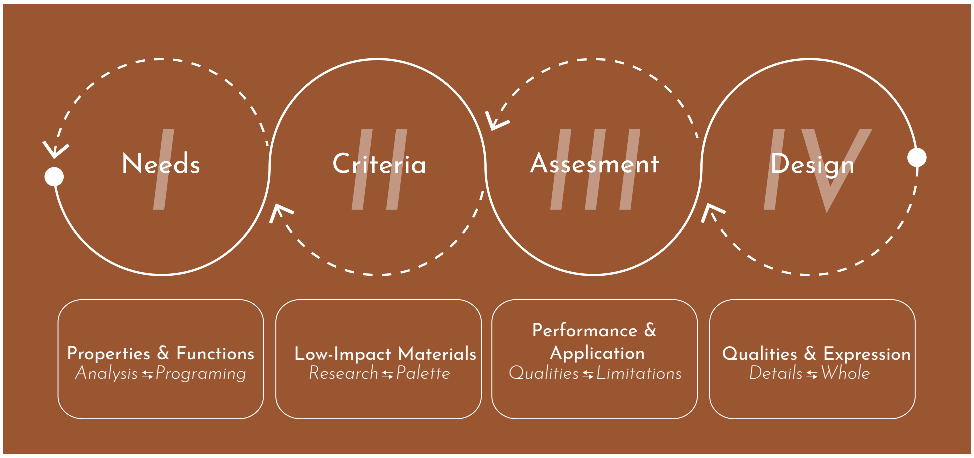


Figure 1. Diagram depicting methodology and process

This thesis is based on a research by design approach. The initial phase consisted of organizing the program and evaluating the performative needs for the design.

Criteria were then formulated that guided our definition of low impact materials, and subsequently, through research on possible materials extraction, processing and production, dictated our material palette. This palette and the materials inherent performances and limitations informed sketches, models and systems that acted as a framework for the design.

The process of designing the example project started early in order for it to provide a structure for the continued research and make it possible to apply the research outcomes directly.

During the continuation of the process, the design and research were both kept ongoing in parallel, informing each other and both parts driving the project forward. Investigations on vernacular building methods were made through historical references and meetings with experts. Material properties and possible applications was explored through the study of literature and reference projects, meetings with relevant actors and experts as well as the participation in a clay plastering project to explore the material hands on.

To be able to propose a holistic low impact approach, evaluative tools were used to consider the designs' initial energy useage by making estimates, simulations and life cycle analyses.

The project and the arguments presented are then discussed with reference to current discourse on sustainable design and in relation to the conventional building industry as well as other established sustainable building concepts.

Delimitations

This thesis will:

- be based on a Swedish context
- discuss today's building industry in regards to building materials and sustainability
- explore solutions to substitute environmentally heavy building materials in the main construction
- focus on wood, clay and straw as possible low impact materials based on design criteria
- be informed by research on vernacular building techniques in relation to today's building practice
- propose a design project which demonstrates the implementation of low impact materials in a realistic project
- compare the design proposal with a corresponding conventional building based on a LCA
- discuss the possibilities and problems in today's building practice when implementing low impact materials and discuss solutions

This thesis will not:

- work with reused materials
- work with social sustainability
- present detailed accounts regarding economic aspects or calculations for building costs
- focus on the LCA stages beyond A5, the possibility of material recovery is considered
- calculate the bearing structure, the construction is developed through research and input from experts
- calculate the operational energy demand, principles for energy efficient constructions are taken into account
- elaborate strategies concerning the technical systems such as HVAC and sewage, material based and low-tech strategies are considered
- perform a thorough LCA for the whole design project, the analysis is based materials and components separately
- go into detail about the construction techniques for the design proposal

Reading instructions

1. Introduction

Giving an overview over the goal of the master thesis. Explaining the background, expected impact and used method.

2. Theoretical Context

Positioning the thesis in the broader discourse of sustainable architecture. Setting the context regarding environmental challenges and goals, introducing theoretical models and current strategies for sustainable design and framing this in the context of Swedish of building construction.

3. Low Impact Materials

Defining Low Impact Materials. Showcasing the research on wood, clay and straw and their possible applications in a building.

4. Design Project

Applying the research on Low Impact Materials to a design project. Demonstrating how material properties influence the construction and design.

5. Discussion

Concluding the thesis and discussing the mentioned topics deriving from it.

2.

Theoretical Context

"... why is it, that in a time when sustainability is on everyone's agenda, we're building houses with shorter lifespans than ever, in materials fatal to the environment?"
(Hejdelind, V, 2018, para.3)

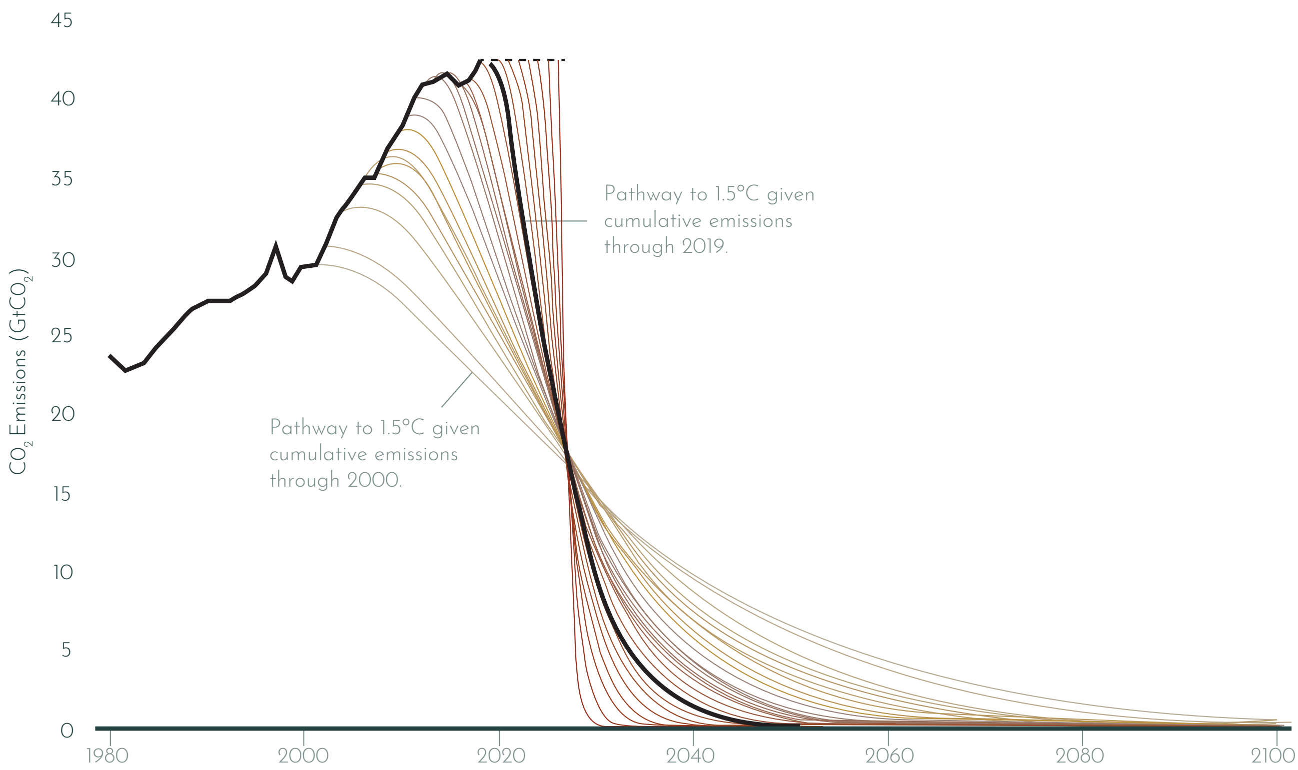


Figure 2. Historical CO2 emissions from the Global Carbon Project. 1.5C carbon budgets based on the IPCC SR15 report. Original figure from Robbie Andrews. Chart by Carbon Brief using Highcharts

Urgency

The graph on the opposing side is based on UNEP's annual Emissions Gap Report and their latest prediction on what time there is left to lower the levels of greenhouse gas emissions in order to achieve the goals defined within the Paris Agreement and avoid irreversible consequences brought on by climate change.

The data shows that a drastic and immediate cut of greenhouse gas emissions is required as every year we fail to do so dramatically amplifies the efforts needed to keep us out of harm's way and, consequently, the costs of doing so.

One could argue, given the data available, that we need to be radical and conceive buildings that initially emit far less greenhouse gases during their fabrication, even if they are efficient over time or that it is hard to achieve without re-thinking and looking beyond the most commonly used materials and methods of today.

The choice of materials with which we construct now stands out as the focal point with the most potential to curb green house gas emissions caused by construction and the abolishment of fossil based matter seems unavoidable.

Embodied Energy

An important factor within assessing a building's ecological impact is the concept of Embodied Energy, often called grey energy. It is defined as the amount of energy a component demands throughout its life cycle, from extraction, manufacture, transport, installation and disposal (Ece, 2018).

The Embodied Energy of materials is responsible for 84% of the buildings initial climate footprint (IVA, 2014). As an example, by using Low impact materials like straw instead of mineral wool, the embodied energy in conventional building insulation can be reduced by 85-90% (LCA calculation based on IBO database, see appendix). The embodied energy for building materials is specified in MJ/m3 or MJ/kg.

Global Warming Potential

The Global warming potential (GWP) or CO_2 Equivalent measures the contribution of the emissions of greenhouse gases to the global warming relative to CO_2 and is specified in kg CO_2 eq/kg (IBO, n.d).

The amount of embodied energy, through e.g. processing and transports directly effect the materials GWP.

Life Cycle Assessments

In recent years efforts have been made to more effectively map and classify the environmental effects of construction. This can be done by measuring the aggregated impact of both complete structures as well as separate elements in the form of Life Cycle Analyses (LCA). The life cycle is divided in multiple phases where stages A1-A5 represents the processes from the extraction of raw material to the completion of construction.

These initial steps is where the Embodied Energy is accumulated and the ecological effects of resource extraction are generated, therefore they are important in order to differentiate and compare the impact or resource efficiency of building materials (Boverket, 2015).

In the Netherlands and Switzerland is enforced by law to account for an LCA in Sweden no legislation have yet come in place to enforce the use of it, although some directives is said to be implemented in 2022. Until then it is mainly a criteria environmental certifications take it into account when evaluating projects.

Culture of construction

The construction industry in Sweden

The commercial building industry in Sweden utilizes almost exclusively heavily processed, industrially manufactured materials and components with high demands on efficiency, predictability and affordability but with little attention to their ecological implications. Concrete still constitutes the most common load bearing structures while steel, glass, plastics, mineral wool and synthetic sealants make up the building envelopes.

Much of the conventional building materials as well as the linear economic framework that dictate our current construction industry were born during early and mid 1900's. The first AMA, the Swedish guiding document for material demands and execution was AMA 1950, (Carlson, 1950). This was a time of completely different values, flavoured by the emerging consumerist society, an industrial over reliance and environmental negligence. In the US plant-based renewable resources constituted around 50% of all materials used during 1900, by 1990 it was less than 8% (Geiser, K. 2001).

Buildings are conceived as assembled products, providing expressions of global supply chain logistics and product catalogs rather than place or identity. Industrial prefabrication of elements that are assembled on site is customary in order to minimize manual labour and thereby costs (Golden, E.M. 2018). This development has to a large extent been fueled by the economic gains of standardization and mass production, which made it possible to provide the broader public with higher building standards while keeping construction economically viable.

Handcraft vs industrialization

In connection to less processed low impact materials, the role of manual labour and handcraft is often brought up. Most low impact materials bare a history of construction from pre-industrial times when handmade structures of locally occurring natural materials were the norm.

According to the Cambridge dictionary Handcraft is a *"**skilled activity in which something is made in a traditional way with the hands rather than being produced by machines in a factory**."* considering that definition it is easily understood that the role of handcraft has been superseded by industrial processes in conventional building production.

Industrial means of production, standardization and mass production can be viewed as a way to eliminate or replace the *"skill"* associated with handcraft. It is a way to streamline and replace traditional, empirical knowledge with easily attainable, applicable universal norms (Golden, E.M. 2018). The industrial process aims to enhance precision, efficiency, predictability and reliability but most importantly it reduces the cost. In an economic framework were labour is expensive and productivity top priority, also removing the *"hands"* from the process becomes rational and enables big savings.

Standardisation & building regulations

For a material to become validated and accepted as building material it is crucial to attain reliable performance certification which correlate to norms and building regulations. The material needs to enter the system on a bureaucratic and legal level to give engineers, architects and building officials the tools to guarantee the safety of a construction. The criteria for classification stretch from the load bearing capacity, to the ability to withstand fire, to the thermal and acoustic performance to almost any thinkable aspect of the construction(Golden, E.M. 2018).

This is frequently seen as an obstacle for Low Impact Materials which can have varying qualities due to their low level of processing, as opposed to F.I steel which, trough its variable and controlled composition, provides exact and predictable performance. Low Impact Materials often lack the testing and research needed to certify them according to existing standards.

This becomes obvious when talking to the wood craftsman Ulrik Hjort Lassen who emphasizes the quality differences in natural timber compared to industrially processed glulam beams. Timber's characteristics as a "living" material with swelling, shrinkage and deformations makes it more complex to asses and calculate structurally. This problematic has further on led to the increased use of steel instead of timber (Berge, 2009).

The diving forces to standardize naturally occurring materials have previously been weak since these classification systems became operational at a time when process-heavy industrial materials were uncritically accepted.

However, during the nineties the German government funded research to develop guidelines and standards for earth and clay construction, this led to an ancient, natural building material obtaining more insight and understanding within the last twenty years than in the previous thousand. The new thoughts on how to optimize and make better use of the material radically enhanced the performance through new developed applications (Golden, E.M. 2018).

This serves as a good example of that "rudimentary" materials may not need refinement as much as our understanding of them does.

Figure 3. Embodied Energy of Building Materials (IYvengar, 2015) Adapted Illustration

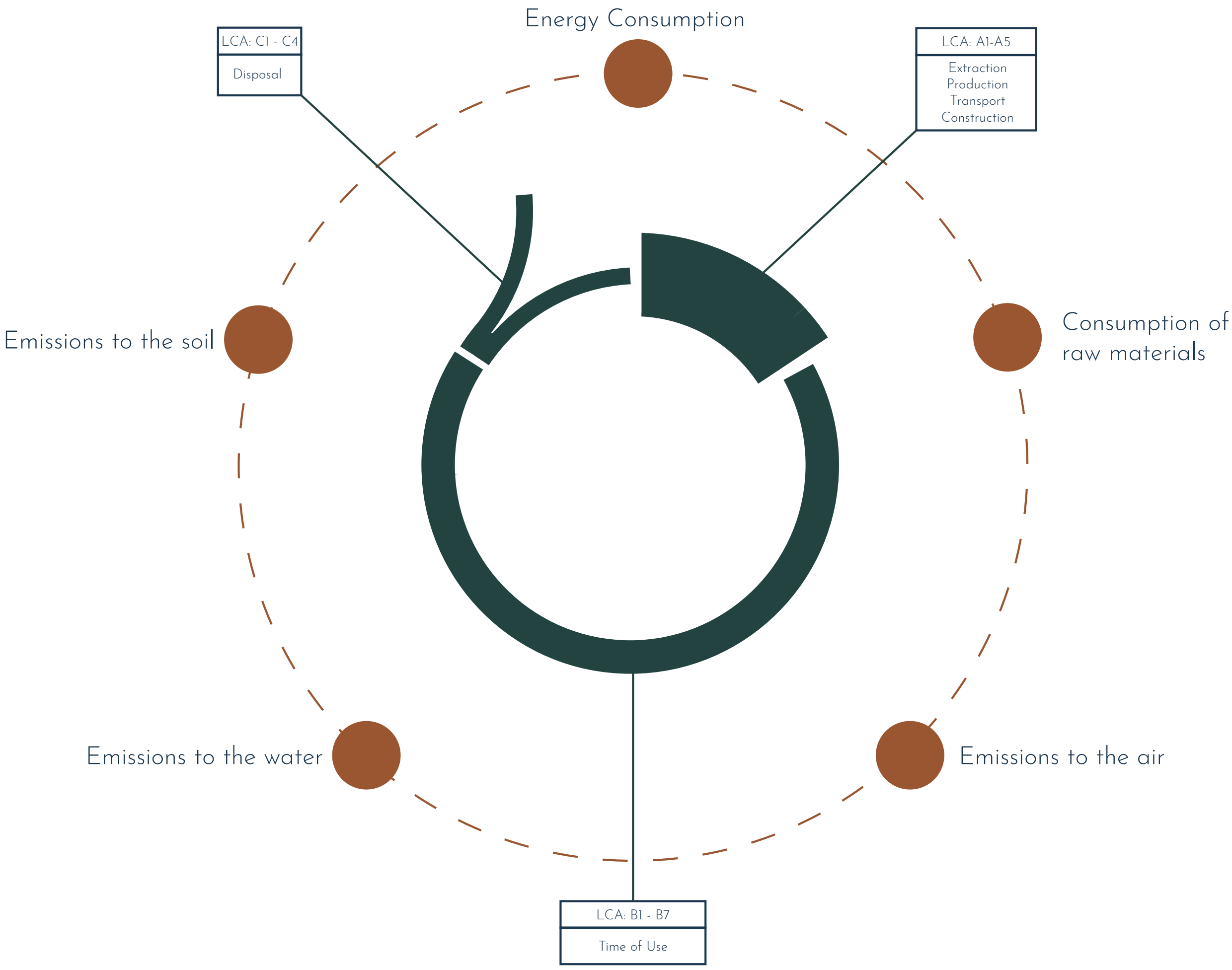


Figure 4. Environmental Consequences of a Building component over time.

Concepts for sustainable construction

Passive House

The passive house concept aims to minimize te operational energy demand through passive measures. The most relevant goal is to reduce the annual heat demand to 15 kWh/m2. The main strategies are using high levels of thermal insulation and air tightness, reducing thermal bridges, efficient windows that receive solar gains and ventilation with heat recovery (Passive House Institute, 2018). Passive houses succeed to minimise the energy demand during use, which was a revolutionary achievement when the concept entered the market in the 80s However, conventional passive houses are not responsive to either nature or humans and rely on mechanically controlled systems and fossil based materials that ultimately will land on a landfill (Harper, 2019).

Low Impact

A Low Impact Building is described by Simon Dale a building that is constructed in harmony with nature by being non-toxic, energy efficient and ecological (Dale, 2007). These types of buildings are typically found in ecovillages, where they are designed and constructed by the users themselves. Materials origin mostly from local, natural resources or are recycled. This alternative way of constructing makes the buildings not just low impact but also low-cost (lammas.org.uk, 2020). According to Anders Nyquist, huge potential lies in self-building and self-sufficiency when it comes to the supply of energy, materials, water and food in order to develop sustainable cities. Buildings need to function in symbiosis with nature during the whole lifecycle and strive for holistic low-tech solutions based on natures ecocycles (Engblad, 2018).

Zero Energy

Zero-Energy-Buildings aim to reach a zero balance when it comes to the energy demand during operation. The annual primary energy demand of Net-Zero-Energy buildings may not exceed the energy produced on site by renewable resources (Lenz, Schreiber, Stark & Schreiber, 2013).

Zero Emission

The Zero Emission Concept doesn't just concentrate on the operation phase but aims to reduce emissions during the whole life-cycle of the building by working with a life cycle analysis. According to the level of ambition, the emissions from product and construction stage (A1-5), use stage (B1-5), end-of-life stage (C1-4) and the benefits and loads beyond the system boundary (D) are included in the calculations. These emissions are compensated over time by renewable energy production (Kristjansdottir et al., 2014).

Figure 5. The Linear Economy

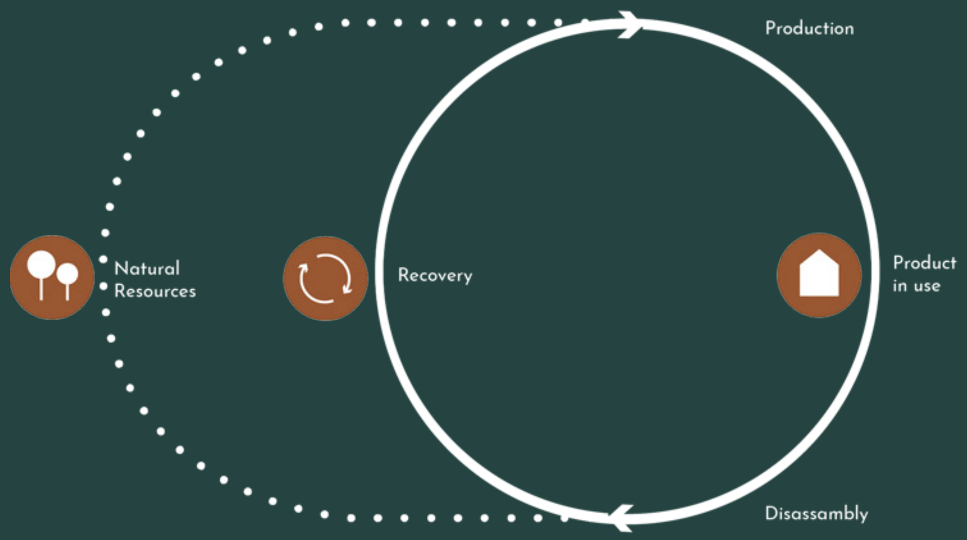


Figure 6. The Circular Economy (Ellen MacArthur Foundation, 2019) Adapted illustration

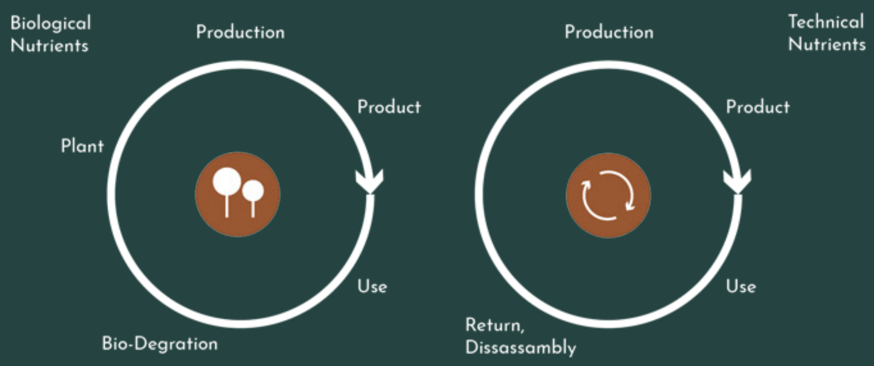


Figure 7. Cradle to Cradle (EPEA, n.d.) Adapted illustration

Alternative modes for sustainable construction

The Circular Economy

The Circular Economy proposes an alternative to our current linear industrial system which is based on extracting resources and creating waste. It is based on three principles: eliminate waste and pollution, keep materials and products in circular loops and to regenerate natural systems (Ellen and MacArthur Foundation, 2017).

Cradle to Cradle differentiates between technical and biological nutrients which operate in separate cycles. Biological nutrients can be reintegrated in natural systems, like wood that can compost to soil and thereby regenerate living systems. Technical cycles recover and restore products, components and materials by reuse, repair, re-manufactured or (in the last resort) recycling (Ellen and MacArthur Foundation, 2017).

The building industries impact

The building industry is responsible for a significant amount of waste production. In a typical European city, 10-15% of building material is wasted during construction and 54% of demolition materials are landfilled, (Ellen and MacArthur Foundation, 2017).
This makes it obvious that it is crucial to implement the methods of circular economy into architecture in order to minimise the environmental impact of the building industry.

Circular strategies in architecture

A prerequisite to implement the circular economy in architecture is that, if the structure don't allow enough flexibility for its functions to change over time, the building and its components can be dismantled. This ensures that building materials and valuable substances can be recovered and recycled in separate material cycles. It is crucial to use raw materials efficiently and avoid and reduce waste by making repairs, ensuring durability, material recovery and recycling. To achieve this, it will also be necessary to change user's behaviours and practices when it comes to building materials (Hillebrandt, Riegler-Floors, Rosen, & Seggewies, 2019, p. 6).

The extraction, production and transportation of materials emits waste in form of Co2. Therefore it is essential to choose materials that have a low Embodied Energy and a low Global Warming Potential. Materials from the biosphere have a lower potential of polluting the air than fossil based materials and are preferably used (Hillebrandt et. al., 2019, p.. 30).

In order to ensure a continuous reuse without loss of quality, constructions must be designed for material recovery from the beginning. This doesn't only demand separable structures but also the use of non-toxic materials and a consistent responsibility for products (Hillebrandt et. al., 2019, p. 10).

To reach a circular economy in the construction sector, it will be necessary to create a new political framework as well as to set the closed loop potential as a design parameter (Hillebrandt et. al., 2019, p. 108).

Regenerative Design

To regenerate means to grow again or to improve a place or system. Regenerative Design can be seen as the foundation of the Circular Economy (Ellen and MacArthur Foundation, 2017). The term Regenerative Design was introduced by John T. Lyle as a strategy for designing urban landscapes that should regenerate lost ecosystems. Meaning that in order to reach a sustainable development, supplies for energy and materials must be able to continually renew themselves. The way human activity operates today is not aligned with nature's cycles because resources are exploited without regarding the impact on the environment. Regenerative design on the other hand, sees humans as integrated in nature's ecosystem that can take but also give services and even have a positive impact on it (Hes and Du Plessis, 2015).

Regenerative Design in the building industry

Today, the life-cycle of building materials from extraction over processing, fabrication, transport, installation to the building use and the eventual disposal, pollute air and water, destroy habitats and exploit natural resources (Iyengar, 2015). Concrete, for example, has alarming impacts on the environment. The extraction of sand is extremely disruptive to the local ecosystem, the production of cement is energy intensive and the recovery of concrete after demolition is problematic (Delestrac, 2013). Even renewable and supposedly sustainable materials like wood have to be considered with care because intensive forestry can cause biodiversity losses (Sing, Metzger, Paterson and Ray, 2017).

Regenerative strategies in architecture

Following the guiding principle of Cradle to Cradle, "less bad is not good enough", it is not enough to reduce the ecological footprint, become CO2 neutral and centre the sustainability discourse around energy efficiency like it has been done for decades. A regenerative paradigm shift in architecture towards positive impact design is crucial in order to actively improve biodiversity, the quality of air and water, promote health as well as being energy positive (Michael Braungart; Attia, 2018, p.xii; p.xi).

Sustainability issues need to be included into the design process right from the beginning (Attia, 2018, p.3). The three main design strategies for regenerative design include "Selection of a Construction System", "Defining of Design Elements and Their Performance" and "Choice of Regenerative Materials" (Attia, 2018, p.26-30).

Building materials should be chosen in order to follow regenerative principles (Attia, 2018, p.24-25). Preferably biosphere materials like clay, wood, straw, bamboo or hemp should be used. For some construction components like foundation, windows, special equipment or safety devices it might not be possible to avoid materials from the technosphere. However they should be designed for disassembly, not contain toxic substances and not pollute the environment during production. (Attia, 2018, p.30).

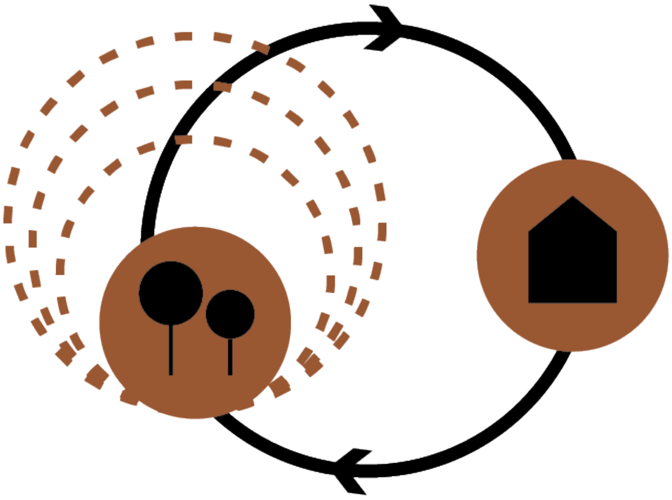


Figure 8. Illustration, principle of Regenerative Design.

The Eco-Economy

The Ecological Economy, understands our economic system as a part of the earth's ecosystems and seeks to stabilise the relationship between them. Today, ecosystem services like clean air and water are generally perceived as free of charge. This implies that market prices do not represent the impact of the damage caused to the environment and the actual value of environmental goods to nature's ecosystems. The consequences of exploiting ecosystems ultimately have a much higher cost in the long run (Brown and Morishima, 2002).

Sustainable Place-Making

An approach to combine ecology and economy is "Sustainable place-making". It emphasises the importance of place in creating holistic solutions for sustainable development. Place-making argues for short chains between producer and consumer and the use of local knowledge (Marsden and Farioli, 2015).

The Eco-Economy in architecture

When implementing the Eco-Economy in architecture, inspiration can be taken from traditional and vernacular architecture. Vernacular design concepts are based on the local climate, bioclimatic design, local renewable materials, low-tech and low-cost solutions, optimisation, traditions and culture and thereby incorporate an economic and ecological strategy (Hackel et al., 2019). By empowering self-building and low-tech solutions in today's architecture, a direct connection between materials, construction and humans can be established. This direct link fosters a feeling of pride and responsibility which increases the willingness for maintenance and results in a higher valuation of natural resources and thereby more careful dealings with them (Engblad, 2018).

Today, the Swedish building industry only focuses on the initial investment costs of a building which leads to the choice of cheap materials and insufficient solutions. A radical change in the economic system is necessary that perceives buildings as long term investments. The yearly operational costs, the whole building lifecycle as well as costs for society need to be taken into account. This paradigm change can lead to higher quality constructions, healthier buildings for humans and more responsible dealings with natural resources (Engblad, 2018).

3.

Low Impact Materials

Material Definition

For this project, Low impact materials are defined as materials that occur in nature, are locally available in Sweden, are non-toxic and require a low level of material processing. They can be reused, are suitable for cascading and have a low potential to create waste. Wood, Clay and Straw are materials that fulfil these criteria. Wood and straw are renewable materials. They can simply compost after use and regrow in nature. Clay's hardening and softening process is reversible and means that the same material can be continuously reused.

Low Impact Materials have the potential to follow the principles of the Circular Economy and Regenerative Design, since they can continuously be reused or renewed and have a minimum impact on the environment during their whole life-cycle.

Implementing Low Impact Materials in contemporary construction will drastically lower the building industries impact on our planet. It is the measure we so urgently need to stay within the Planetary Boundaries, to reach the Sustainability Goals and to secure a sustainable future.

Natural

A material created by and existing in nature.

Renewable

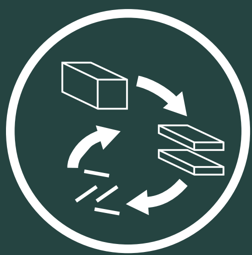
A material that renews itself by a natural process of regrowth.

Local

A material that is available to harvest or collect within a given distance

Low Level of Processing

A material that is mainly unaltered in terms of composition and properties but shaped or adjusted to perform within a structure.



Reusability & Cascading

A material or component that is kept unaltered and detachable will hold a higher value and potential to be fit for a new use after its initial application, either as it is or as raw material for a lower grade product.

Reversible

A material able to regress to its initial state or form without technical processing.

No waste

A material that is biologically degradable and/or able to be reused.

non-toxic

A material that is free from hazardous chemicals and compounds.

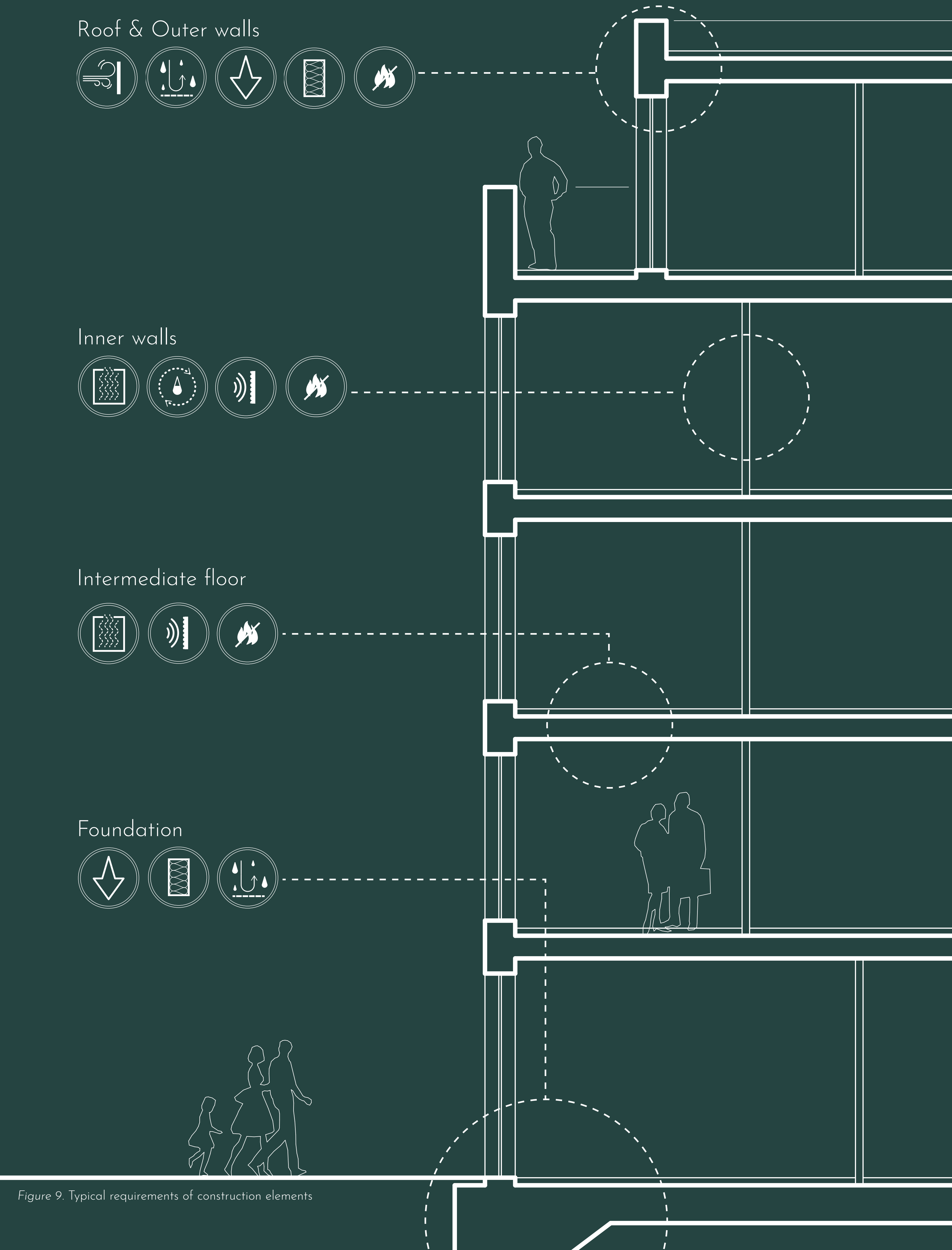
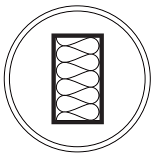
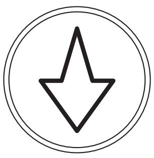


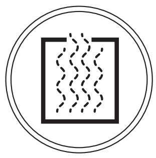
Figure 9. Typical requirements of construction elements

Requirements towards materials in the construction


thermal Insulation


moisture buffer


Load bearing


thermal inertia


air tight


acoustic


weather
protection


fire proofing

The choice of materials

The construction materials in conventional buildings

In conventional buildings, the technical requirements towards the construction are fulfilled by highly processed and specialised products. These "product innovations" have questionable composites and alarming environmental impacts. The testing of materials for their suitability and performance and their optimisation through craftsmanship have become oblivious (Hillebrandt et. al, p. 58).

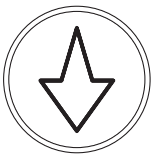
Low impact materials as construction materials

A variety of low impact materials can be applied to fulfil the required functions in a building.

Wood, Clay and Straw is a combination of low impact materials that manages to fulfil most of the functions in a building and are therefore the focus of this project.

They have a long tradition as building materials and can even fulfil the requirements of contemporary construction. These high quality building materials can not only substitute conventional building materials but also bring additional benefits. They contribute to a healthier and more comfortable indoor climate as well as minimising the need for heating, cooling and ventilation. Their different properties allow a variety of applications in the building and they can be formed to a number of different building materials which allows an adaptation to all different purposes and types of construction.

Wood

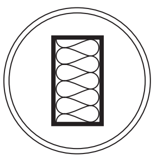


Suitable for load bearing elements due to high resistance towards compression and tensile strength

Airtight when joints are developed seamless

High durability when exposed to weather

Good moisture-buffering qualities due to the porous structure of natural fibres



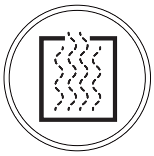
Good thermal insulation based on low heat conductivity, possible fabrication to insulation products

Clay

Clay materials can function as air as well as vapour tightening layers

Clay minerals can bind and release water vapour to the air

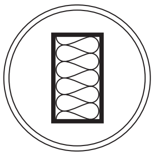
Good acoustic properties due to the dense mass



Thermal buffer due to dense mass

Mineral materials are non-combustible

Straw



Good thermal insulation based on low heat conductivity, needs a minimum of processing

Good acoustic insulation

Good moisture-buffering qualities due to the porous structure of natural fibres

Reed is suitable for roof thatching and wall cladding

Other relevant materials

Besides wood, clay and straw there are other interesting low impact materials that can be used to compliment the construction and to fulfil specific functions.

Flax and Hemp can be used to tighten the gaps between window and wall as well as for footfall insulation. Lime plaster can be applied as a weather protection layer on the facade.

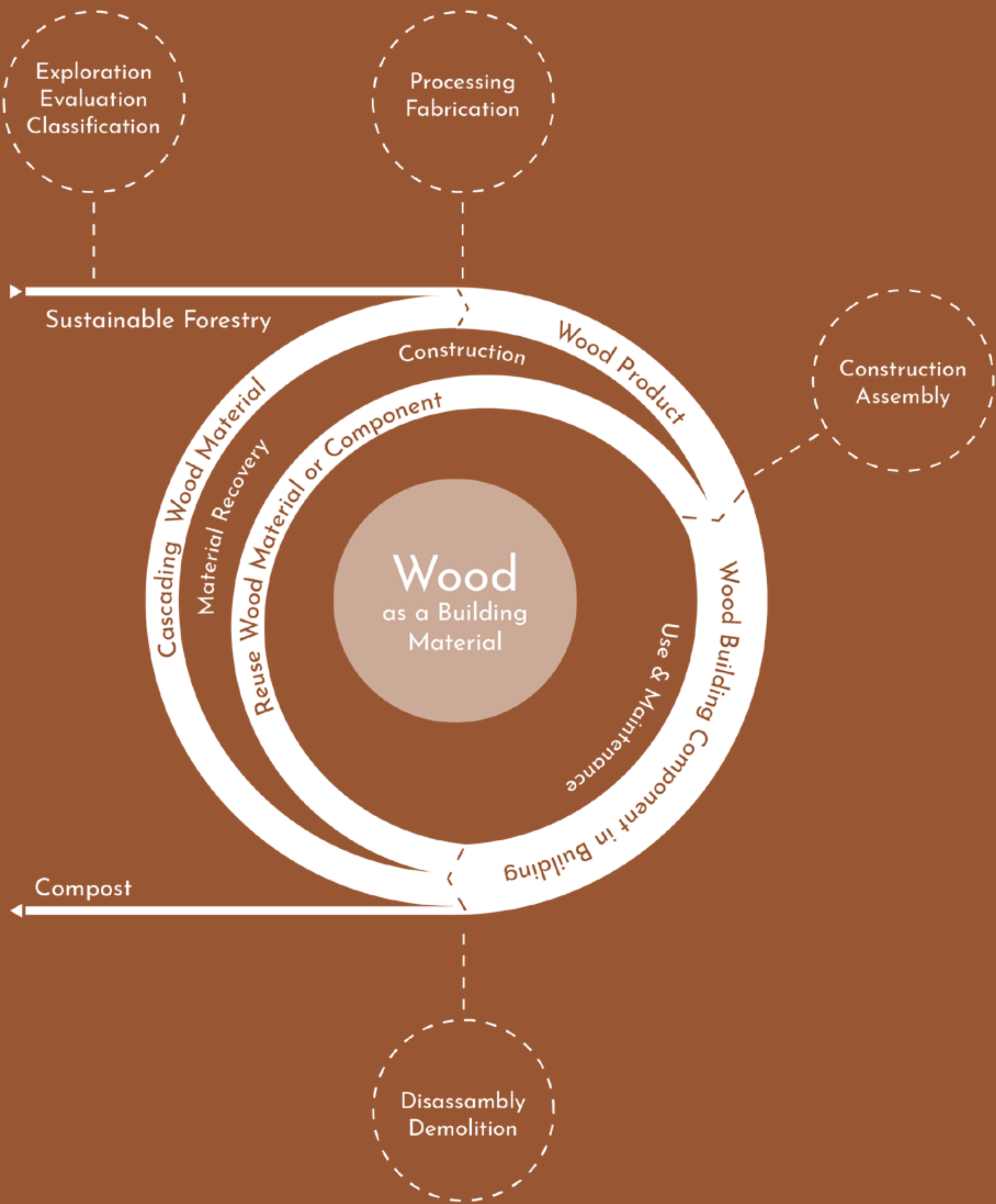


Figure 10. Typical life cycle of Wood.

Wood

“We got concrete, then came buildings made of concrete, concrete buildings, then came the revival of wood, then came concrete buildings of wood“ (Mattias Delin, 2019)

About the material

Why wood?

In Scandinavia timber has a long history as building material. This does not mean that its abilities are outdated. The characteristics found in a piece of wood are on the contrary close to what we could only hope to achieve when developing new materials for tomorrow.
It captures carbon and has the ability to cultivate biodiversity during its production, it is renewable, produces no toxic emissions, it can mitigate both heat and humidity in a single material, it is easy to model and workable with simple tools and exudes a comfort, warmth and sensory experience unlike any other material available.

The use of timber seems like an obvious choice, yet all natural wood is hardly ever used in contemporary building construction (Hudert & Pfeifer, 2019).

Constructing with wood

Wood tradition in Sweden

Some of the oldest building components found in Sweden, dating back over 800 years are made of wood. A testament to both the materials tradition and longevity. The use of wood ranged from broad axed log cabins to more delicate carpentry and complex roof structures.

Within this tradition immense amounts of knowledge is embedded, a complex understanding of wood as a material developed over hundreds of years. Much time was spent in the forest, assessing and singling out trees that would provide the right properties. Today we favour lumber that is fast grown with half the age and density of what was earlier custom as our needs for its performance has changed. It is grown to fit new economical forestry models and to be easier on the equipment used to process it.

Despite its rich tradition, the use of wood in construction was for a period of time reduced to the point where it was mainly valued as an interior material. Today the use of wood is experiencing a global renaissance. Fueled by the notions of sustainability wood is presented as the answer to the many questions posed on how we are to keep building to meet ever increasing demands without harming the environment beyond repair.

The production of "Wood"

In spite of the newfound fascination with "wood" as a building material, it is hardly ever used in its natural form. "Wood-based" products dominate entirely, arguably refining and optimizing the material beyond its raw potential.

The wood-based products used in construction today are mostly expansions on the invention of wood plastic composites (Glue laminated wood) that allowed the production of curved beams of any dimension (Zwerger, 2019). Since then many alterations of the same principle have been developed with the ambition to further eliminate the limitations of the material.

Kiel Moe writes in Rethinking Wood (2019) that even the term "wood" is a dangerous abstraction, that it has very little to do with the "forest". He argues that we cannot claim to work sustainably by using wood while disregarding the ecosystem behind it. Unlike its raw material, wood-based products require no differentiation in how the timber is grown or what kind of forest that yields it. The by-passing of the natural "defects" in the material processing enables a demand which is measured in quantity and volume with no need for quality. The criteria is cost efficiency and reproducibility to demand (Zwerger, 2019).

The Swedish association "Ekoskog" promotes a certification system for sustainable forestry based on the concept of continuous cover forestry. This strategy strives for a sensitive ecosystem based management of forests that keeps valuable old trees and local kinds of trees and thereby improves biodiversity and ecosystem services (Ekoskog, n.d.). Considering the heavily increased demand for wood and the current uncritical view towards excessive resource extraction, this management strategy is crucial in order to sustain forests as a recourse for wood as well as a functioning ecosystem.

Adhesive free products and natural glues

The addition of plastic based adhesives have been deemed acceptable when matching the improved structural capacity against the impairment of other qualities of the wood itself. Except disrupting the materials capacity to buffer heat and moisture, or its ability to residue free return to its natural cycle, most of the adhesive compounds used today are problematic in the sense that they are fossil based and toxic(Bokalders & Block, 2010).

Progress is being made in attempts to develop lignin or yeast based glues. Today it has only been tried in veneer products such as plywood but could in the future offer a more suitable alternative to phenol or formaldehyde.

There are alternatives to the use adhesives as well, such as nail or dowel laminated timber elements. Dowel laminated elements (DLT) is 100% wood and presents the same structural capacity and beneficial production format as CLT without the use of adhesives. Both DLT and CLT however could for many applications be seen as ineffective alternatives considering the large amount of material required.

Building with all-natural wood

Traditional timber framing is a resource effective approach utilizing high quality, slow grown timber. Because of its labour intensive process and structural limitations it is no longer seen as viable option for commercial building and mainly used for preservation purposes. It has a rich history of inventive, complex designs formed by a deep understanding of the materials structure and composition. The development of new design tools, fabrication processes as well as research on the material that has taken place in recent years could maybe be put to good use in developing new forms of constructing with additive free timber. It could provide a resource efficient way of building with higher complexity and precision while encouraging the growth of a healthy raw material and making the most of all the unique qualities that all natural timber has.

Fire safety, obstacles & Possibilities, norms standardisation

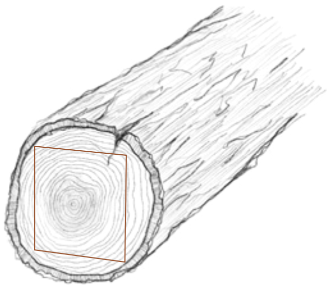
The major obstacle to overcome in order to build in accordance with all natural wood and its inherent qualities is knowledge. Present day construction processes and competences are deeply programmed by other material palettes and tries to bend wood to fit into it instead of working the other way around (Delin, 2019). The skill and understanding of wood within the building industry is not where it needs to be in order to present reliable assessments of more complex timber structures.

Among others, the organization Stolpverk Nordern is currently working on new standardization procedures to asses and certify natural timber and to transfer much of the knowledge present in the conservation guild to the commercial building sector.

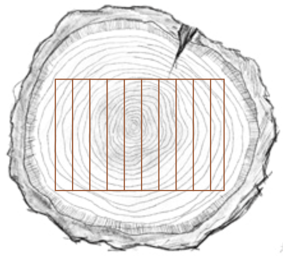
Regarding fire safety, most issues with wood occur in buildings that are designed with other structural systems in mind but then built in wood with inadequate understanding of the structure as a whole as a result. The behaviour of hybrids during fires are also an issue with "delaminating" effects in glue laminated products, which during a fire makes them more combustible while weakening the structure. High density natural timber on the other hand burns slower and more predictable which is crucial for fire safety assessments (Delin, 2019).

Wood building materials

Overview over wood products/functions

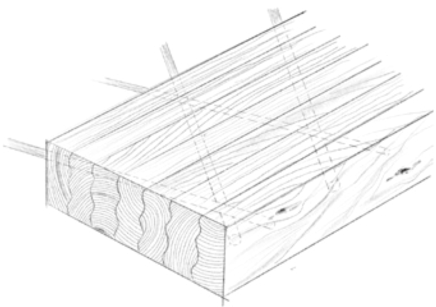


Timber
- Load bearing structures
- Massive Timber - Rich in heartwood
- High quality achieved through slow growth and long lived trees. Ideally 120 + years and a density of around 750 kg/m3
- Homogeneity utilizes the materials ability to buffer heat and moisture.
- Properly dried it contains or emits no toxins or added chemicals
- Heartwood is rich in sap & resin which impedes rot and mold.
- Thicker dimensions makes for longevity

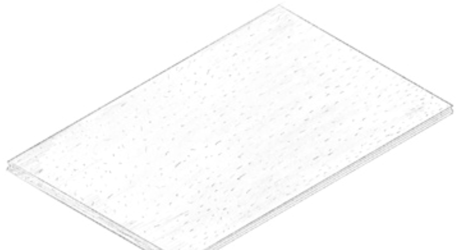


Lumber
- Load or non load bearing structures - Carpentry - Flooring - Cladding Roofing
- Mixed quality - Heart and softwood
- Standardized dimensions, well known and classification systems and structural behaviour
- Younger fast grown trees in used to ensure undemanding processing
- Thinner dimensions, more sensitive to moisture
- No additives (except if chemically preserved)

Cross Laminated Timber (CLT)
- Structural glulam panels
- Similar properties to Glulam
- Adhesives problematic
- Reusable as elements
- Resource heavy compared to "frame structures"



Dowel Laminated Timber (DLT)
- Similar properties to CLT
- Bearing or non load bearing elements Slabs, Roofs or Walls
- All Wood - No additives
- Fast grown raw material
- Smaller manufactures
- Resource heavy



Glulam

- Load bearing structures
- Structurally stable, less deformations
- Variable size/shape/dimensions
- Lower quality softwood
- <10% glue
- Adhesives are problematic, (formalaldehydes or polyurethane) emits toxins & have higher energy content

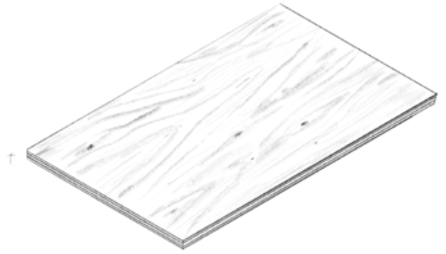
Fibre Boards

Dry Processed: LDF, MDF, HDF, OSB

- Wall boards,Sub flooring, carpentry
- 5-10% Urea Formaldehyde glue.

Wet Processed: Hard, medium or porous

- Insulation (sound, thermal), wind breaker
- Wood fibre diluted with water.
- Contains less sugars of interest to fungus and mould.
- Lignin as binding agent, <2% Glue

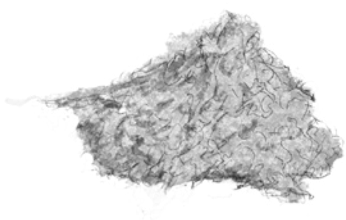


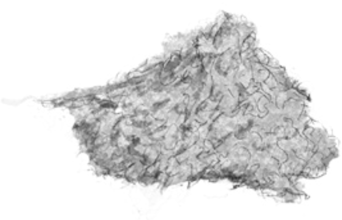
Birch Bark

- Protects from rain or ground moisture
- Used as "in-between" material with wood and materials with different moisture and/or thermal properties
- Contains Suberin, makes it resistant to bacteria & fungi

Veneer Products

- Plywood etc. sheeting boards
- Softwood and hardwood
- Glue content: 5-10% of weight
- Air tight if sealed seams
- Adhesive and conserving treatments problematic.





Cellulose Insulation

- Recycled paper fibres
- λ: 0,04W/mK
- Additives: Boric acid, Borax, Sodium silicate or ammonium polyphosphate (fire retardant, insect and fungi repellent)
- <14-25% of weight = Additives

Wood fibre Insulation

- Wood chips, ground, diluted with water and then compressed under heat.
- λ: 0,037W/mK
- Lignin acts as binding agent
- Ammonium polyphosphate added as fire retardant
- Wood fibre insulation boards with adhesives should be avoided.

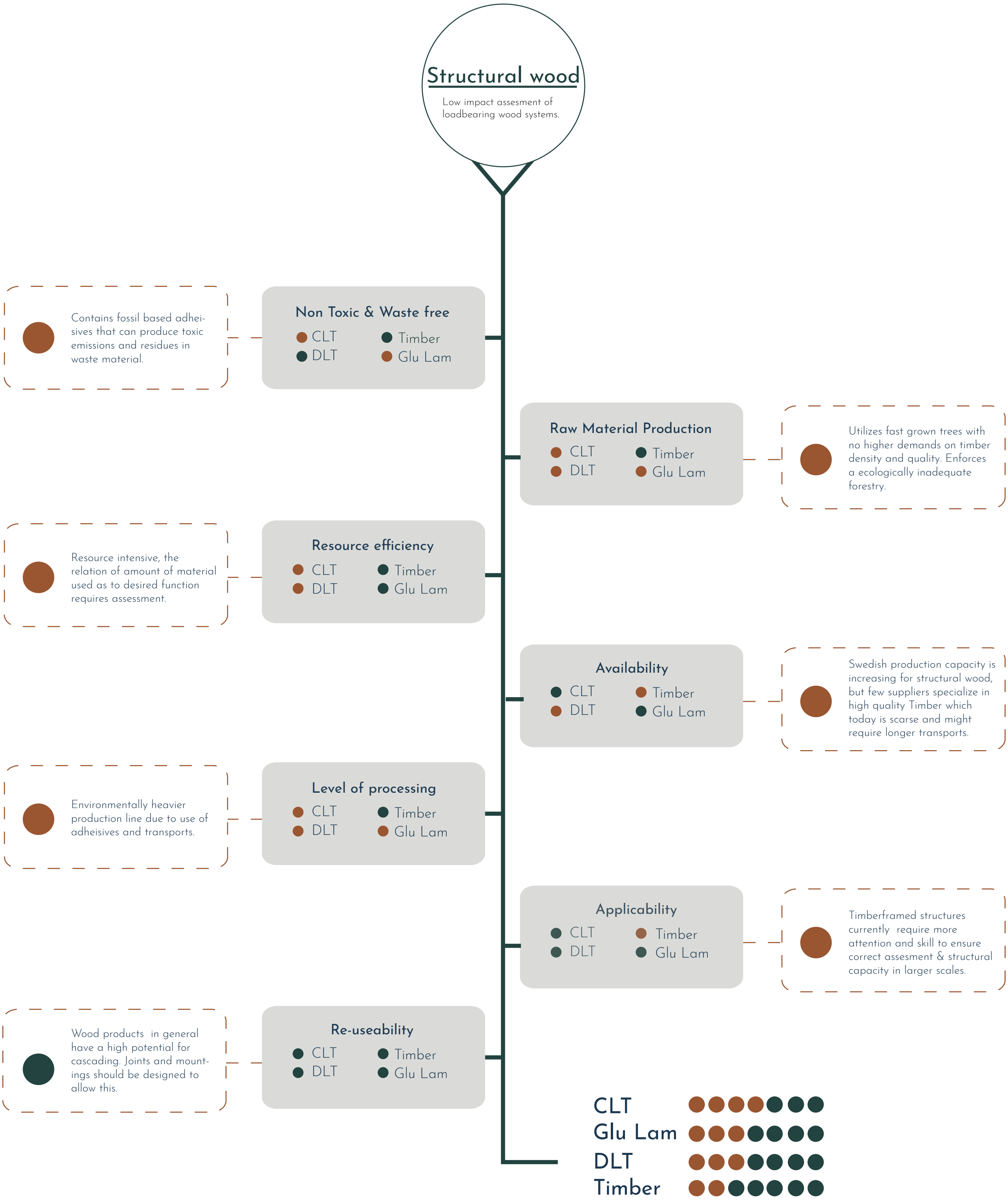


Figure 11. Low-Impact assesment of structural wood systems.

Figure 12. Assembly of CNC milled timberframe, Barnyard 2016

Figure 13. CNC milled timber joints SWG Schraubenwerk, Gaisbach 2016

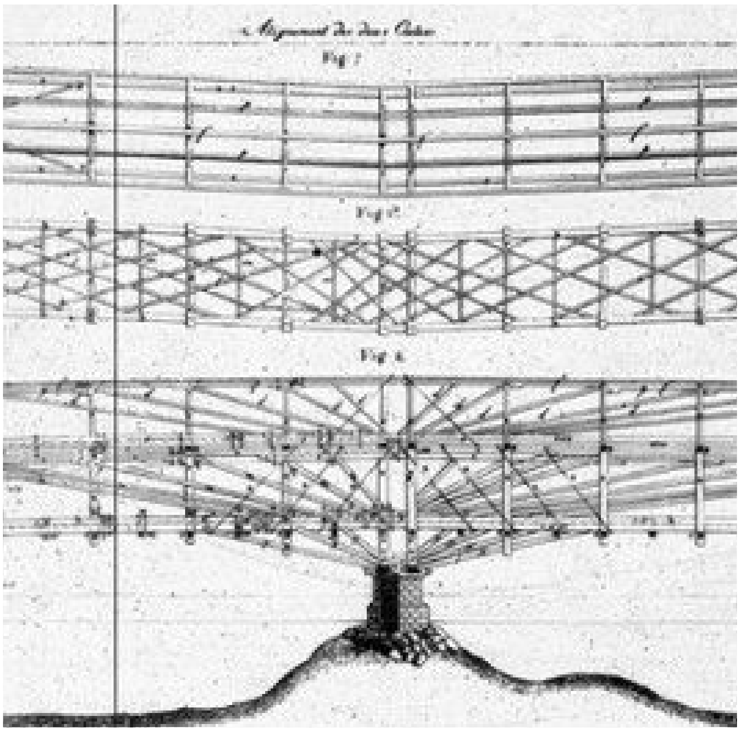


Figure 14. Drawing of Rheinbrücke, Killer 1985

Figure 15. Image of German Timber frame house, no author

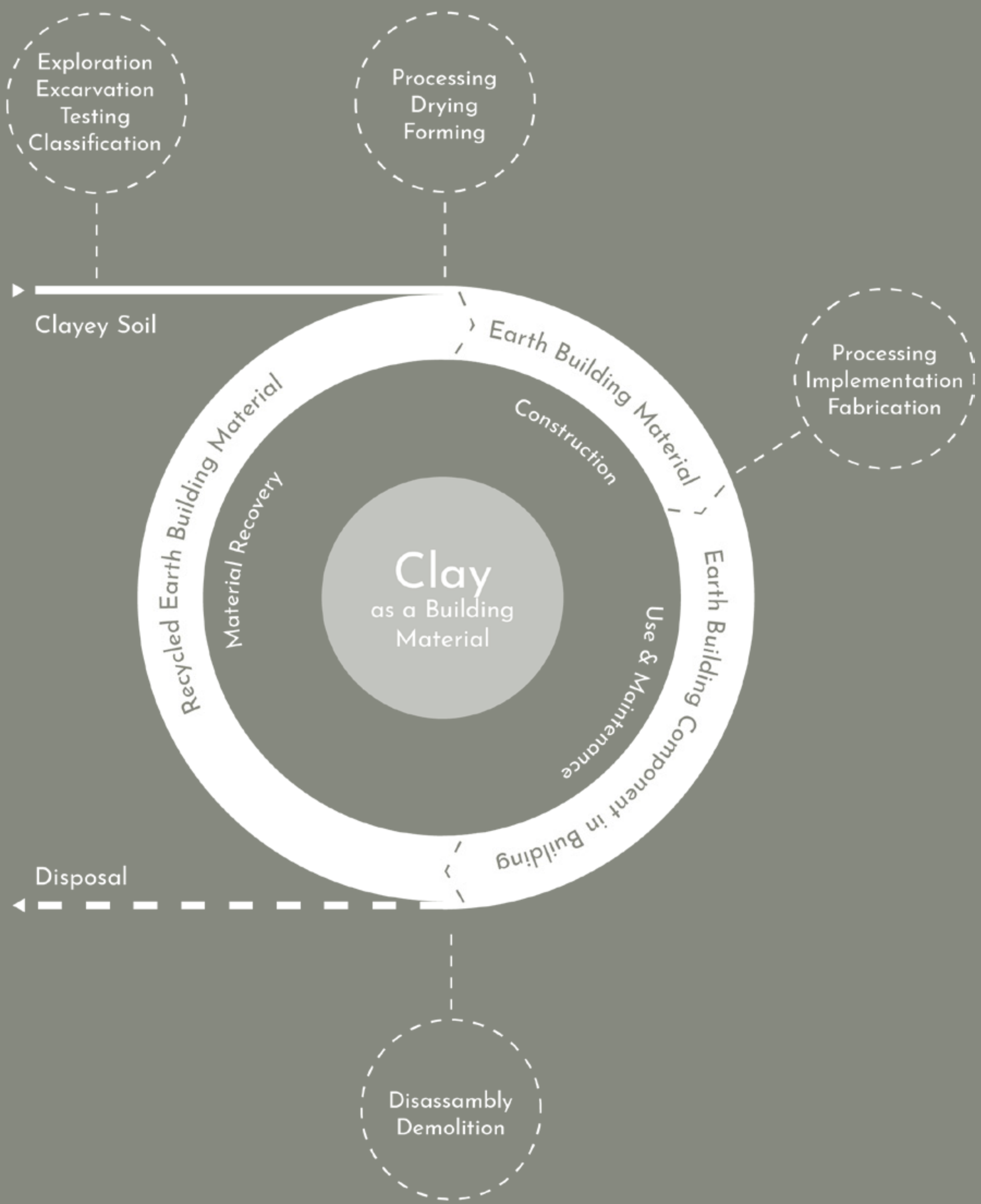


Figure 16. Clay as a building material (Dachverband Lehm, 2014) adapted illustration

Clay

"The envelope that surrounds us should be able to breathe and diffuse in the same way as our bodies. My buildings are therefore deliberately not encapsulated, sealed, or made smooth with synthetic or high-density, energy-intensive materials; rather, they are assembled and finished in raw form, like sushi – left uncooked!"
Martin Rauch, clay expert
(Sauer, 2015, p. 9)

About the material

Why clay?

Clay is a natural material that originates from the weathering of rock and occurs in the topmost layer of the lithosphere. It is a mixture sand with different grain sizes and contains clay minerals which function as adhesives and bind the rougher particles (Schreckenbach, 2014).

Clay is locally available, needs very little energy to be processed and doesn't emit toxins. Due to the material's ability to buffer moisture, it can improve the indoor climate. Thanks to the dense mass, clay possesses very good acoustic and thermal qualities. Clay is even suitable for creating tightening layers in the building envelope. It is a material that can be used in many different ways. As a loose filling, as mortar or plaster, formed to stones and boards and even for load bearing constructions. Clay can be continuously reused in circular systems.

Constructing with clay

Constructing with clay in Sweden and internationally

Clay has a long building tradition. Worldwide, one third of humanity lives in clay buildings, mostly in southern countries. Even Europe has a tradition of building with clay but due to industrialisation and the emergence of other building materials, it has lost relevance over the past century (Schreckenbach, 2014).

In Sweden, traditional clay buildings are mostly found in the southern parts. There, clay was predominantly used for filling timber framed structures but also as an air tightening layer on the inside of log cabins (Grey, 2013).

In Sweden today, clay is mostly used for renovation purposes and small scale projects. It is usually self builders and people interested in natural materials that chose to build with clay. There is growing interest in the material out of a suitability perspective but there seems to be a gap when it comes to implementing clay on a bigger scale. This can be based on a lack of knowledge, prejudices against the material, lacking regulations or a lack of interest from the building industry.

Handcraft vs industrialisation

Traditionally, clay building is closely linked to manual work. Even in Sweden, this building practice is strongly based on handcraft. Mixtures are often produced directly on site and the application is usually labour intensive and can demand long drying periods. On the other hand allows this way of construction the use of locally available material and participation of untrained workers, for example the future residents, in the building process.

There is a trend for prefabrication in order to adapt clay building to an industrial way of construction. Clay boards can be prefabricated and substitute gypsum boards in dry construction. Thereby they only require a thin top layer of plaster that is applied on site. Traditionally rammed earth walls are constructed on site using a sliding formwork. The walls can be prefabricated in a factory, transported in smaller parts and assembled on site. Furthermore, there are a variety of machines that can be used to ram earth or apply clay plaster.

Norms & regulations

Sweden's clay building practice today is greatly relying on empirical knowledge. The fact that Swedish building regulations are based on meeting specific functions, opens up the possibility to implement alternative materials like clay more easily. The Swedish research institute RISE is currently performing fire resistance tests on clay to bring out Swedish standards.

Other countries have a quite different approach and have gone much further when it comes to regulations and norms. Germany for example has come up with building codes for standardised clay products: DIN 18945 for clay stones, DIN 18946 for clay mortar and DIN 18947 for clay plaster. If non standardised mixtures are used, the framework of regulations for clay constructions "Lehmbauregeln" published by the organisation "Dachverband Lehm e.V." can be used as a guideline for material tests and properties (Schreckenbach, 2014).

Qualities, possibilities & obstacles

Clay material dries at air and can be made plastic again through adding water. This process requires a minimum of energy, is completely reversible and can be repeated an infinite amount of times as opposed to materials like concrete and gypsum. The water-solubility makes the material easy to process and allows easy repair and maintenance. However this also means that clay material is sensitive to weather and moisture. Therefore weather protection during the construction process is required and extra care needs to be given towards clay elements that are exposed to moisture.

Surfaces consisting of clay material can be sensitive towards mechanical strain and might require extra protection through surface treatment. When choosing a surface finish a balance needs to be considered between creating a durable surface and not diminishing the moisture-buffering capacities.

The high density of clay material gives high thermal inertia and can reduce high frequency radiation.

Nowadays there is a development towards an ever air and vapour tighter building envelope. While air tightness is essential for energy efficiency, constructions open to some degree of vapour transmittance can be beneficial. Clay materials form an air and vapour tight layer but still allow moisture diffusion between the construction and the interior which minimises the risk for condense water in the construction.

Clay material has a lower structural strength compared to other building materials. Bearing constructions are possible but less relevant for large scale projects.

Building with clay materials can demand long drying periods. These can be minimised by working with prefabricated elements.

Clay has outstanding aesthetic qualities. A broad spectrum of natural colours is available and due to different mixtures and surface treatments, it is possible to achieve a variety of looks and create different atmospheres (Schreckenbach, 2014).

Indoor climate

Materials not responsive to moisture can create problematic indoor climates with low levels of relative humidity and a greater concentration of airborne pollutants. Through the use of natural, climate-responsive materials like clay but also wood and fibres, the indoor climate can be balanced. Clay has moisture-buffering qualities that are three times higher than gypsum. It can regulate the indoor climate by binding and releasing water vapour from the air as well as airborne pollutants. This natural regulation can reduce the need for mechanical ventilation and create a more comfortable indoor climate for humans (Klinge, 2016).

Thermal inertia

Dense clay elements have a great thermal mass and by that the ability to store heat. Thereby they can harmonise the variations in indoor air temperature that occur between the changes from day to night. This is especially relevant for buildings with a light construction, for example timber frame structures. Through the delay of temperature changes and the balance of indoor air temperatures, the need for mechanical heating and cooling can be minimised as well as it creates a more stable and comfortable indoor climate (Schreckenbach, 2014).

Clay building materials

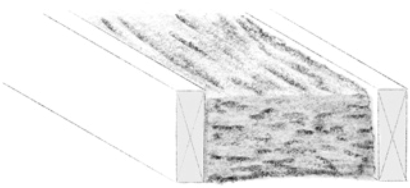
Overview over clay products/functions

Rammed Earth
- 1700-4700 kg/m3
- bearing and non bearing walls, earth blocks, flooring
- lean-fat compressible mixtures
- mineral or organic fibres (<10cm)

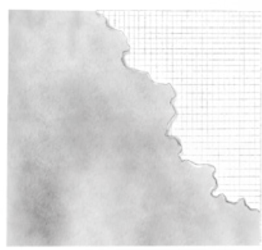
Cob
- 1400-1700 kg/m3
- bearing and non bearing walls
- all types of mixtures, not too fat, not too stony
- long straw fibres (30-40cm)

Fibre Clay
- 1200-1700 kg/m3
- non bearing walls, intermediate floors, blocks, boards
- lean to very lean mixtures
- soft short organic fibres

Light Clay
- 300-1200 kg/m3
- non bearing walls, intermediate floors, facing shells, blocks, boards
- lean-fat mixtures
- mineral material or organic fibres



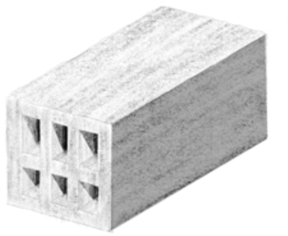
Clay Filling
- 300-2200 kg/m3
- Intermediate floors, cavities
- all types of mixtures
- mineral material or organic fibres



Clay Plaster & Mortar
- <1200 kg/m3
- plaster for inside use, mortar for masonry, filling, facing shells
- not too lean mixtures, fine grain sizes
- fine mineral or organic fibres

Earth Block
- light (<1200 kg/m3) - heavy blocks
- bearing and non walls, intermediate floors, dry construction
- different types of clay mixtures
- different types of aggregates

Clay Boards
- light (<1200 kg/m3) - heavy boards
- non bearing walls, dry construction
- different types of mixtures
- different aggregates; often reed, wood or bamboo reinforcement



Burnt bricks
- bearing and non bearing walls, intermediate floor, dry construction
- high stability and durability, reusable
- energy intensive and non reversible firing process

Burnt Tiles
- wall and floor surface cover
- durability, reusable
- energy intensive and non reversible firing process

Light Expanded Clay Aggregate
- 260-400 kg/m3
- foundation, drainage layer
- good insulation, stability, light weight
- energy intensive and non reversible firing process

Bentonite
- naturally occurring clay mineral, originates from weathering of volcanic ash
- swells when in contact with water
- foundation, ground water barrier

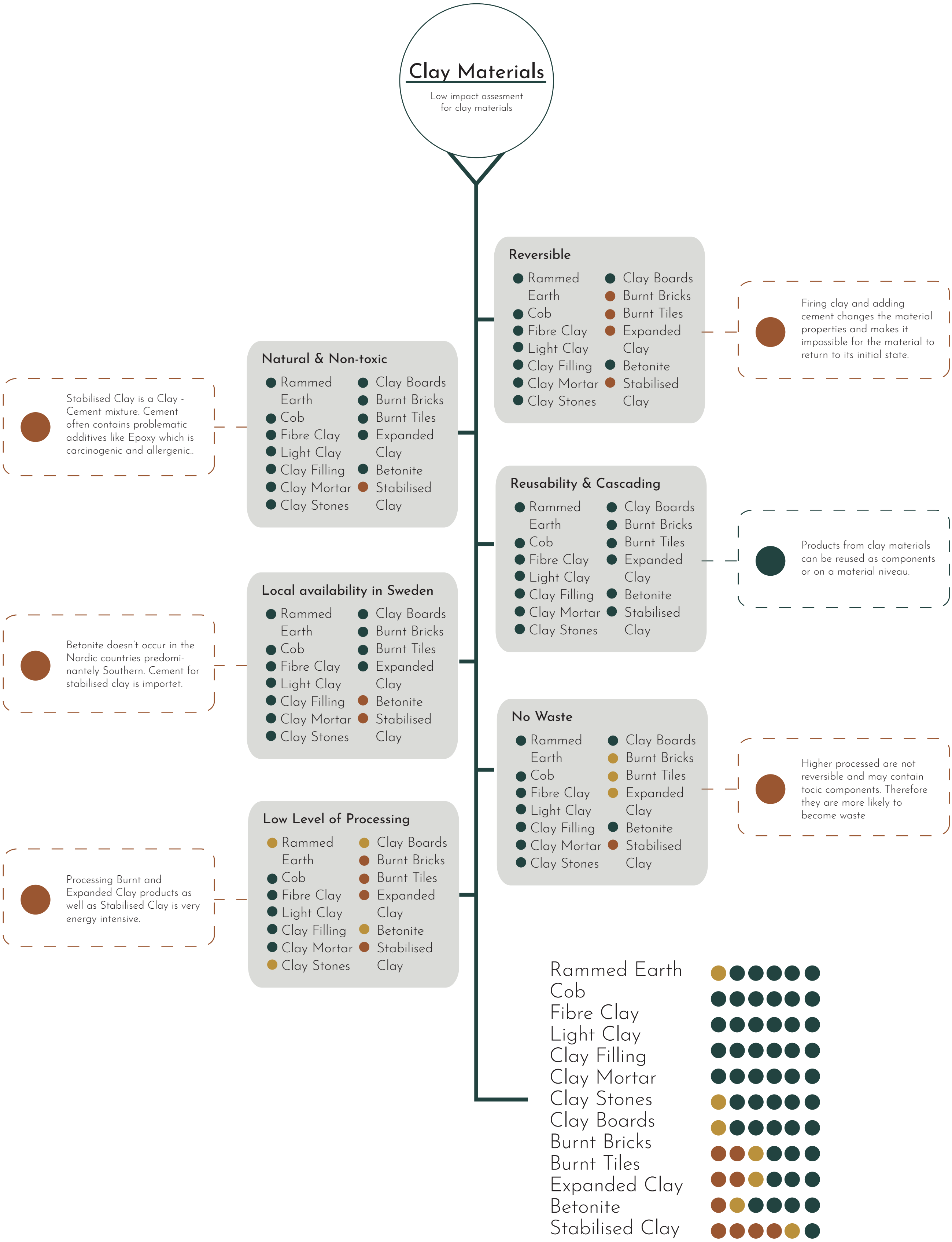


Figure 17. Low-Impact assesment of Clay materials.

Figure 18. Rammed Earth, Schlins (Bühler, 2020) Reprinted with permission.

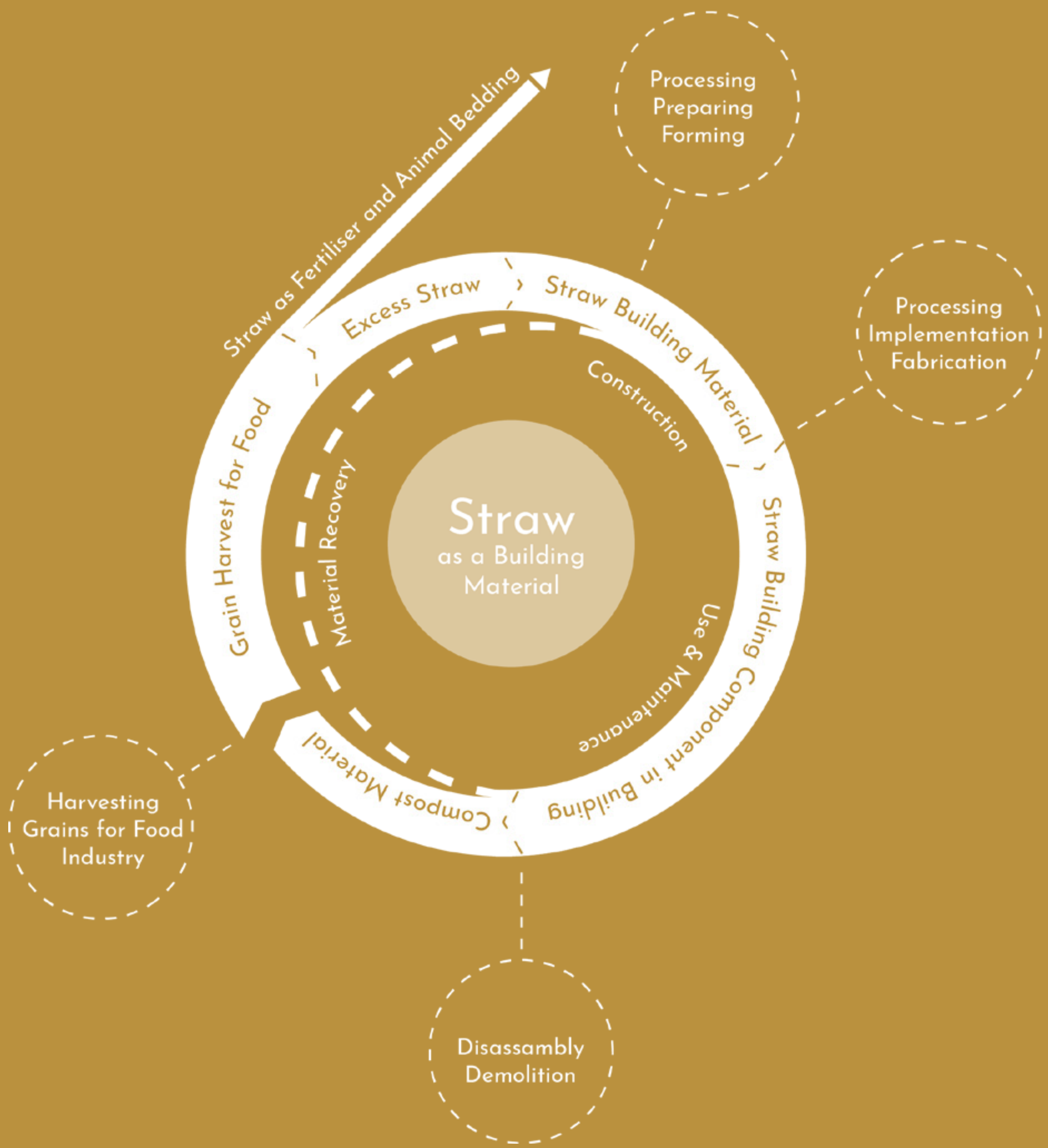


Figure 19 Typical life cycle of Straw.

Straw

"It is better, ecologically speaking, to grow wheat and re-thatch a roof every year than it is to cast it from concrete every century."
(Harper, 2019, p. 23)

About the material

Why straw?

Straw is an umbrella term for the dry stems of cereal plants like wheat, oat, barley, rye and millet or of fibrous plants like flax, hemp and rice (Minke & Mahlke, 2015). Straw is a local material in Sweden and an abundant renewable resource, which means that it is a waste product from the agriculture industry. Most building materials derived from straw require a very low level of processing since the material can be and no addition of glues or other additives. The raw material can be implemented almost directly in the construction which results in very low embodied energy levels. The building material can be used as insulation or roof cladding and fibres can be added to clay building materials. Straw constructions are generally easy to dismantle. The material is non-toxic and can compost after use and is therefore suitable for a circular material flow. Alternatively, the material can be burnt for energy productions.

Reed is included here because it can complement straw materials. Reed is a term for several tall, grass-like plants that grow in wetlands. This material is suitable for roof cladding since it is more durable and fire resistant than straw. Additionally reed can be used as a base and reinforcement for plaster.

Constructing with straw

Constructing with straw in Sweden and internationally

Building with straw bales became first popular in the US due to the lack of other suitable building materials. Initially, buildings were constructed with load bearing straw bale constructions, also known as Nebraska style. In the late 20th century, straw bale building increased in popularity and spread to Europe and other continents. The building techniques developed and today there can be found straw-wood hybrid constructions, prefabricated elements, blown-in straw insulation and straw panels (Minke & Mahlke, 2015). In the Nordic countries, straw bale buildings are most common in Norway and Denmark but even in Sweden and Finland there are several built examples. In Sweden today, straw materials are predominantly used for smaller scale buildings, often constructed by self-builders. In other countries like Germany, USA and Australia, even commercial straw bale buildings can be found. In Sweden, the use of straw as a roof cladding can be traced back to 500 bc. Up until 1800 it was the most common roof cladding, especially in Skåne where wood was rare. From then on, reed was predominantly used. Straw has even a long tradition as a fibre in clay mixtures (Grey, 2013).

Norms & Regulations

Today's building regulations are based on common building materials used in the 20th century like concrete, brick and wood. However it can be proven that straw constructions also fulfil the requirements concerning insulation, fire resistance, structure and durability. Straw bale insulation has been allowed by European building law since 2017. Therefore, the bales have to be certified and show a certain raw density and a maximal moisture content. In some countries like the UK and Switzerland, there are specific building laws for load bearing construction while other countries like Germany require an extra allowance (Liedl & Rühm, 2019). Due to the low heat conductivity, straw materials can fulfil high thermal requirements and are suitable for passive houses. Depending on the construction, straw bale walls can reach a fire resistance of 90 minutes (Minke & Mahlke, 2005).

Handcraft vs industrialisation

Traditionally, load bearing straw bale buildings as well as infill constructions have been constructed manually. The construction is labour intensive but demands little energy, is relatively easy and can be performed by untrained workers. Therefore this technique is even popular among self-builders today. In recent years prefabricated elements have been developed for example by the firms Modcell or Ecococon. They consist of wood frames filled with straw insulation. Due to the prefabrication and the quick assembly on site, this type of construction fits the requirements of today's commercial building industry.

Qualities, possibilities & obstacles

Straw has a low thermal conductivity and therefore excellent insulation qualities. The insulation quality depends on the density of the bales, the direction of the thermal flow parallel or perpendicular to the direction of the stalks, as well as the moisture content. In comparison to mineral building materials, the moisture content of straw has significantly less impact on the thermal conductivity.

Straw bales have a low thermal mass and therefore a low heat storage capacity. Therefore a layer of earth material on the inside can be important to balance light-weight straw constructions.

The good sorption qualities of loose straw have less relevance when the material is densified and rendered in the construction. A layer of clay plaster on the inside can take over the moisture buffering abilities.

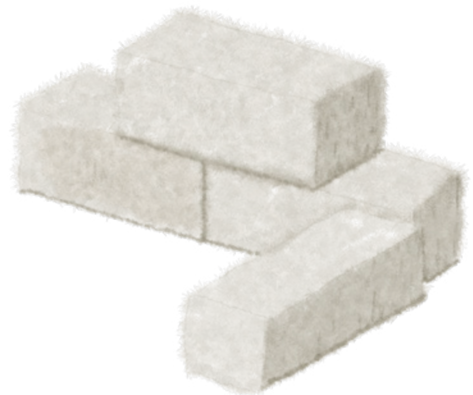
It is important to protect straw from moisture since mould and fungi can't develop on dry straw. Therefore, a correct construction is necessary that ensures the straw's moisture content doesn't exceed 15% for a longer period of time. The material has to either be protected from moisture by a vapour barrier on the inside or needs to be vapour permeable towards the outside in order to allow the construction to dry. The sd value on the inside of the straw insulation should be 10 times the value of the exterior layer but should not exceed 5m. This way, the moisture can partly diffuse to the inside as well. Straw needs to be protected from weather and splash water. Thermal bridges, cavities and gaps at junctions to openings need to be avoided since they increase the risk for condensate.

There is an important distinction to make between hay and straw. Hay is used as feed for livestock. Straw on the other hand doesn't contain any nutrition and is therefore not attractive for insects and rodents. Pressed straw with a density of 90 kg/m3 and more especially when protected with plaster doesn't allow rodents to nest in it either.

While loose straw catches fire easily, this is not the case for compacted straw. The high silicate percentage in straw makes it even less flammable than wood and the high compression doesn't leave enough oxygen for the combustion. Tests from Austria and Germany state that pressed bales with a density of 120 kg/m3 reach the fire classification B2 "Normal inflammability". Plastered with 10mm clay or lime they even reach B1 "difficult to ignite" and a fire resistance of F90. Test results from the USA even show a fire resistance of 120 minutes (Liedl & Rühm, 2019) (Minke & Mahlke, 2005).

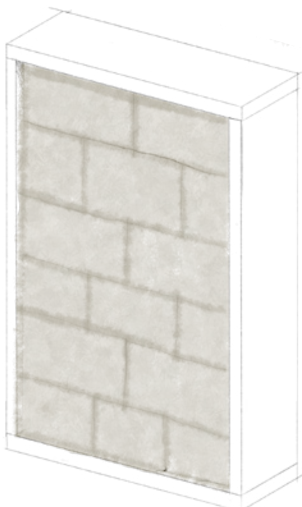
Straw building materials

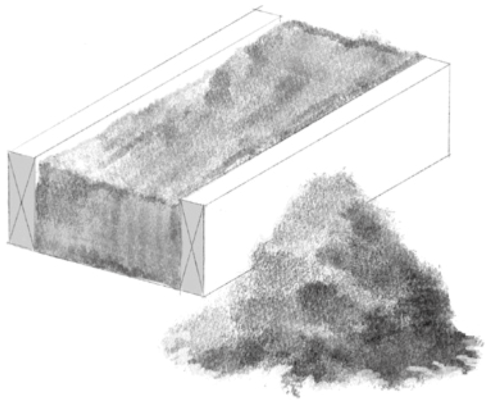
Overview over straw and reed products/functions



Load Bearing
- straw bales as load bearing element
- up to 2-3 stories
- manual construction

Infill (Post & Beam)
- straw bales as infill insulation between load bearing construction
- manual construction



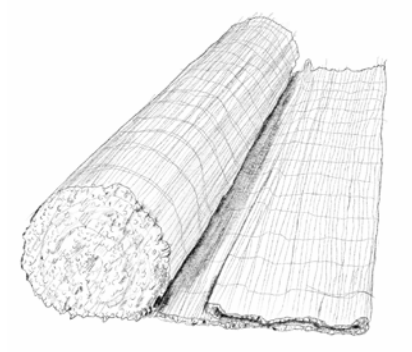


Prefabricated Elements
- prefabricated elements made of straw bales pressed into wooden frames
- load bearing up to 3 stories, above that in combination with additional load bearing construuction

Loose insulation
- insulation for walls and intermediate floors
- blown in, compressed

Facade & Roof Cladding
- roof or facade cladding made from reed or straw
- adds thermal insulation

Boards
- non bearing walls, dry construction
- produced under high temperatures and compression, lignin as binding agent, 2% glue, card board surface



Fibres for clay mixtures
- fibres in clay mixtures for better stability and thermal insulation
- 30-40 cm long for cob
- shorter fibres for light clay and fibre clay

Straw or reed mat
- mats made from long straw or reed stalks, connected with wire
- as underground for plaster or reinforcement in clay boards

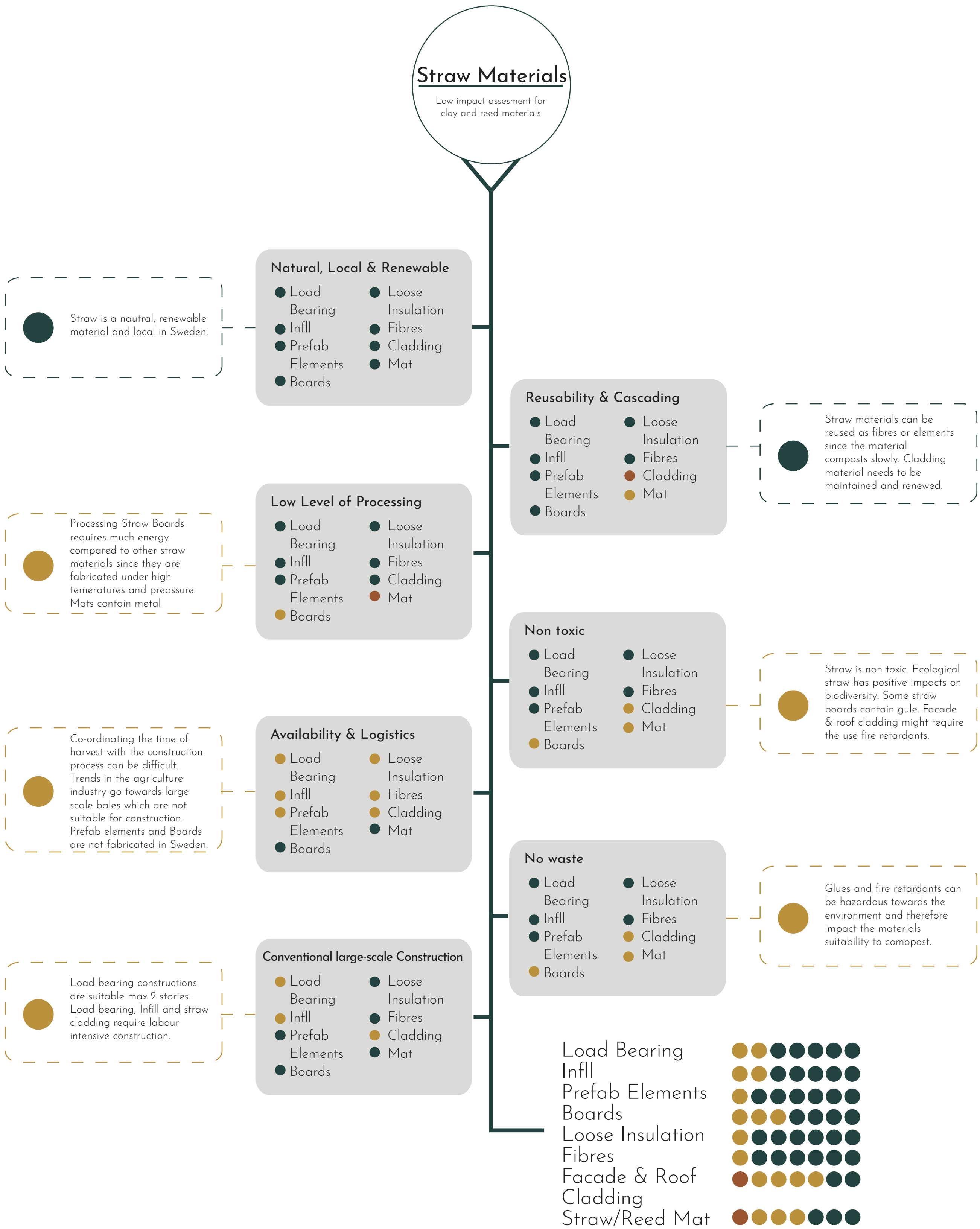


Figure 20. Low-Impact assesment of Straw & Reed Components.

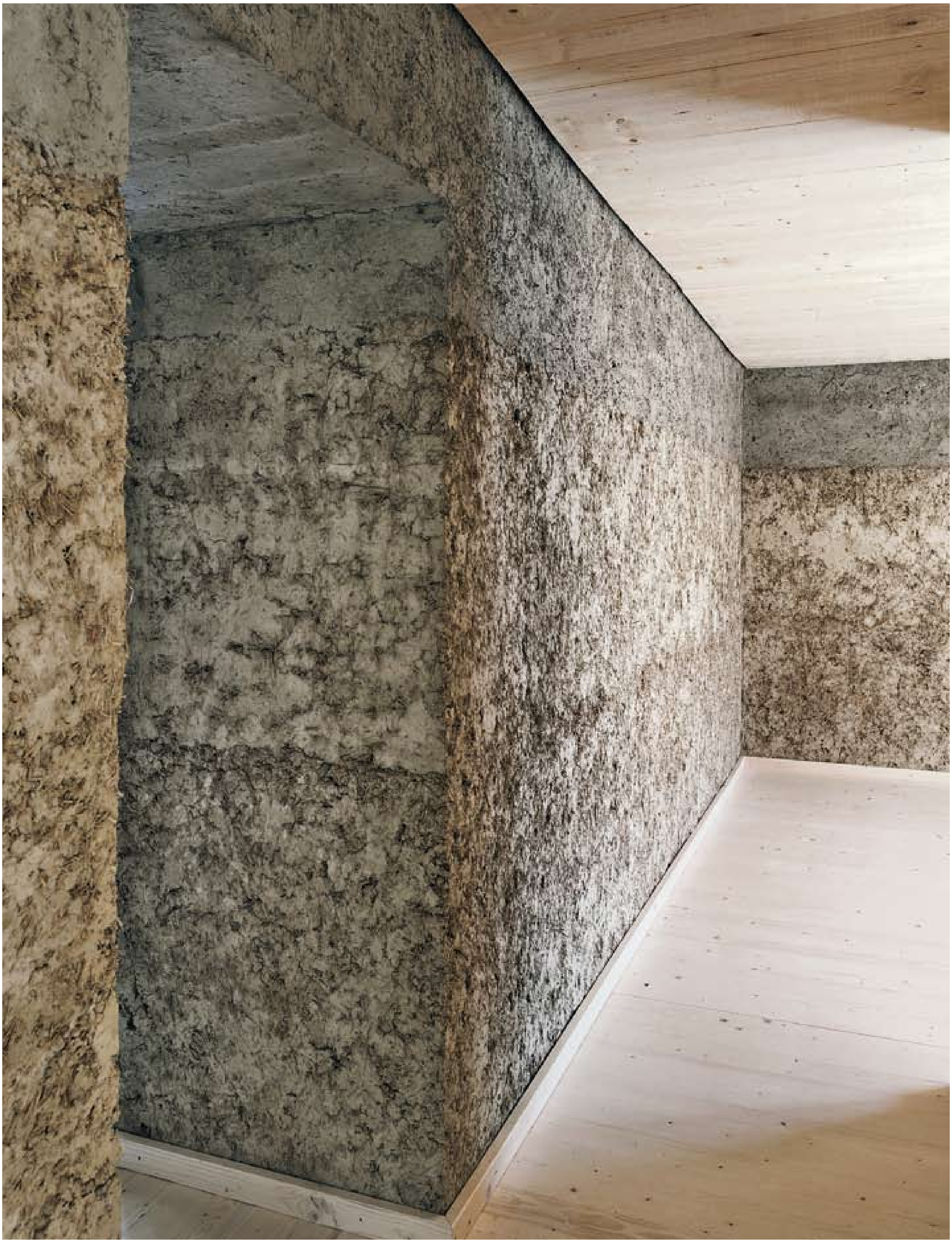
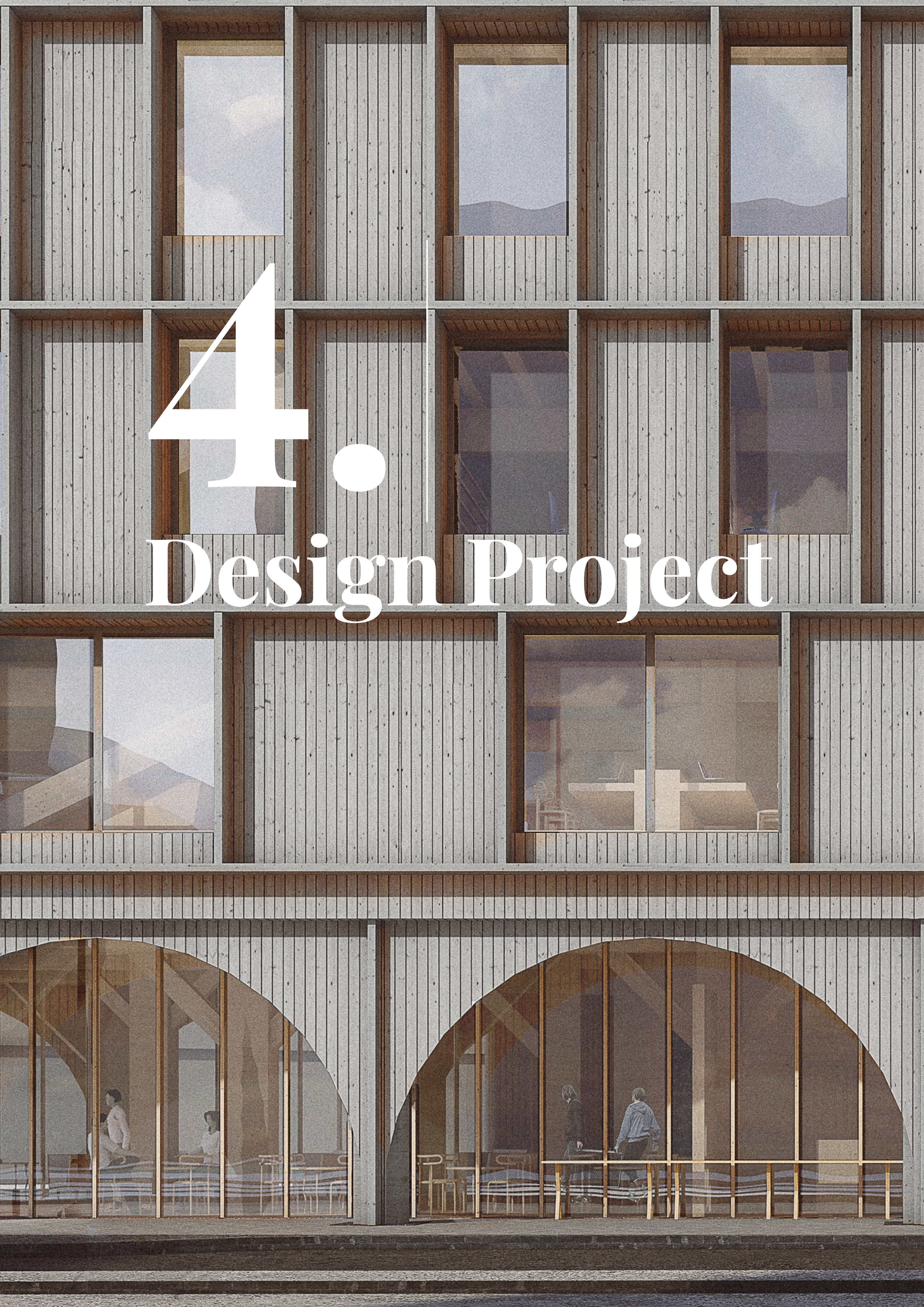


Figure 21. Straw-Clay, Deitingen © www.swebfoto.ch (Weber, 2011)

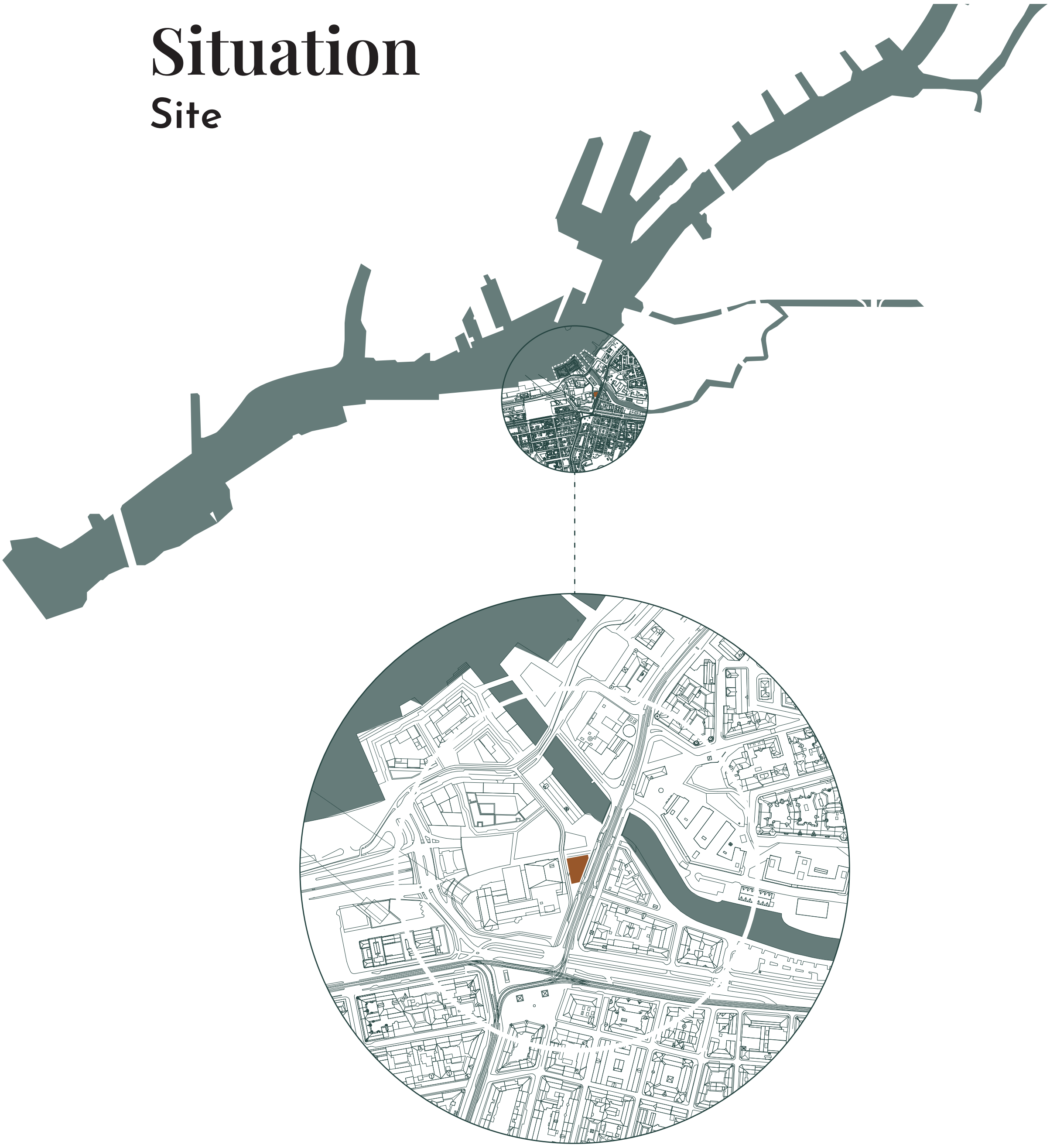
4. Design Project



View from East

Situation

Site



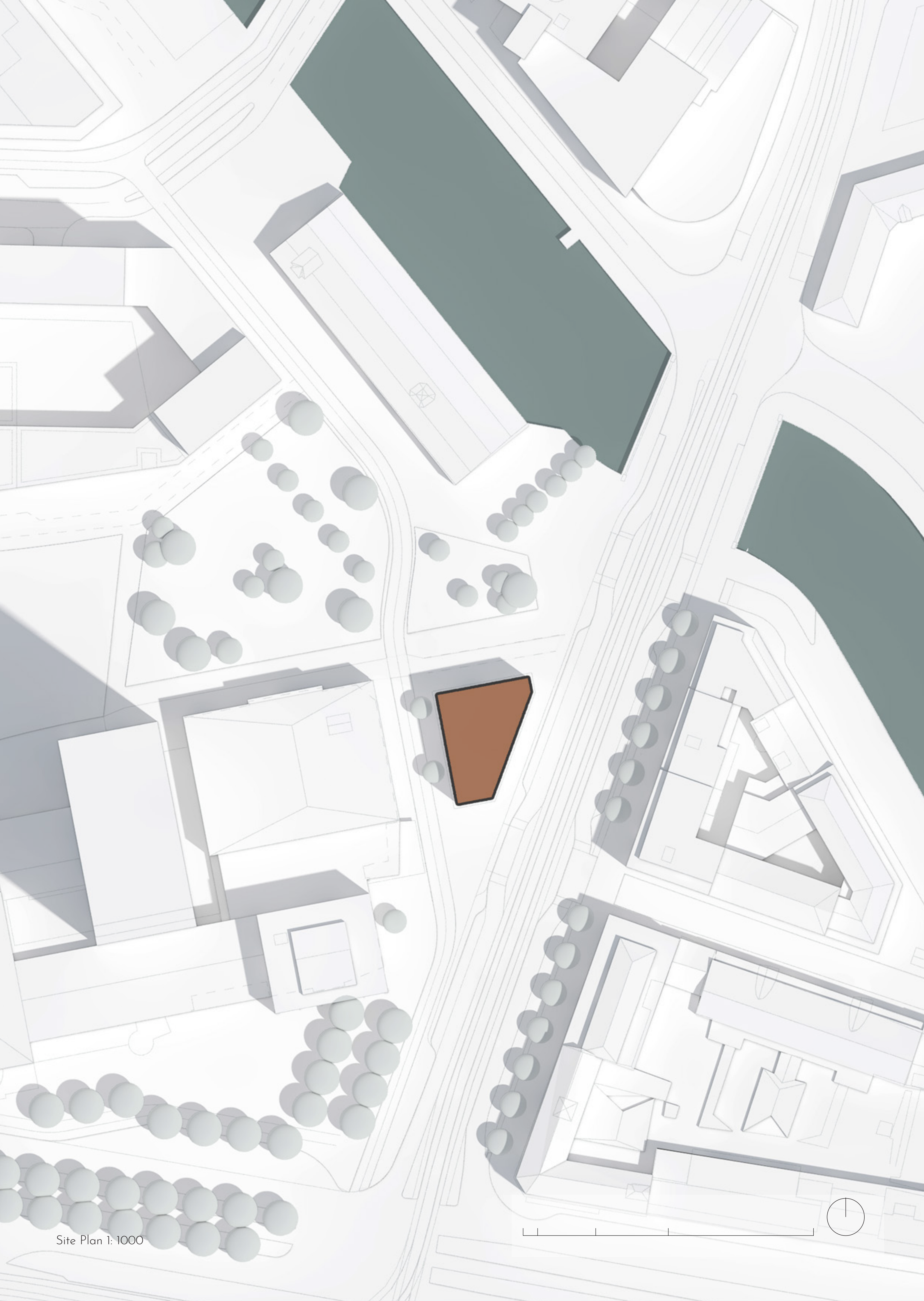
The chosen plot is part of the new zoning-plan for Masthuggskajen, "Järnet" just north of Järntorget in central Gothenburg.

According to the municipality the area is today characterized by its diversity, contrasts and allowing atmosphere. The intent with the new development is to enforce these notions while making the area a leading example in sustainable city planning, construction and circular economy.

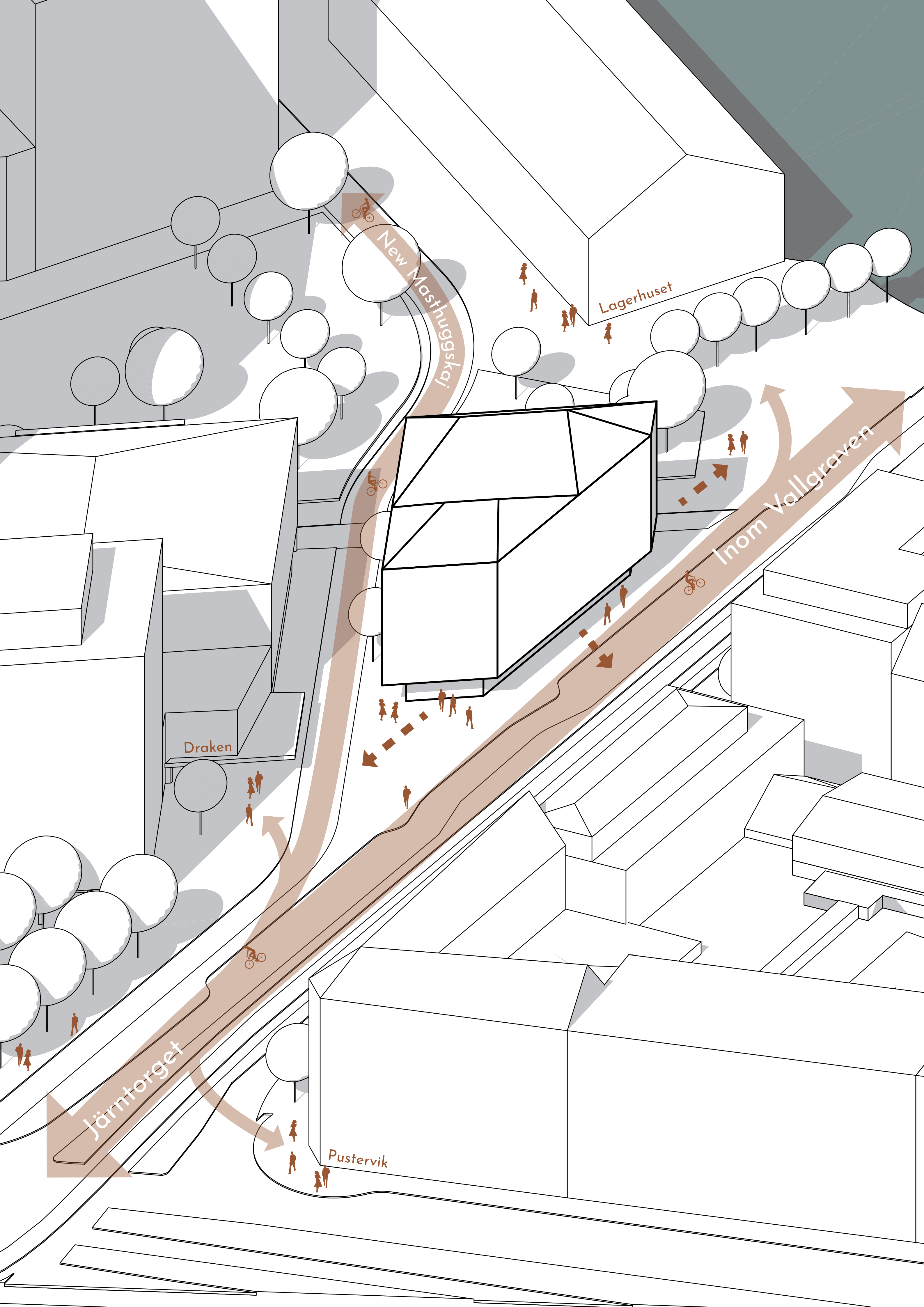
The area is a cultural focal point of the city with Järntorgets venues and bars close by and Frilagret, a municipal house of culture, located in the neighbouring Lagerhuset.

The plot is exposed to the sun towards east and south but rather protected from the low evening sun and western winds by neighbouring buildings.

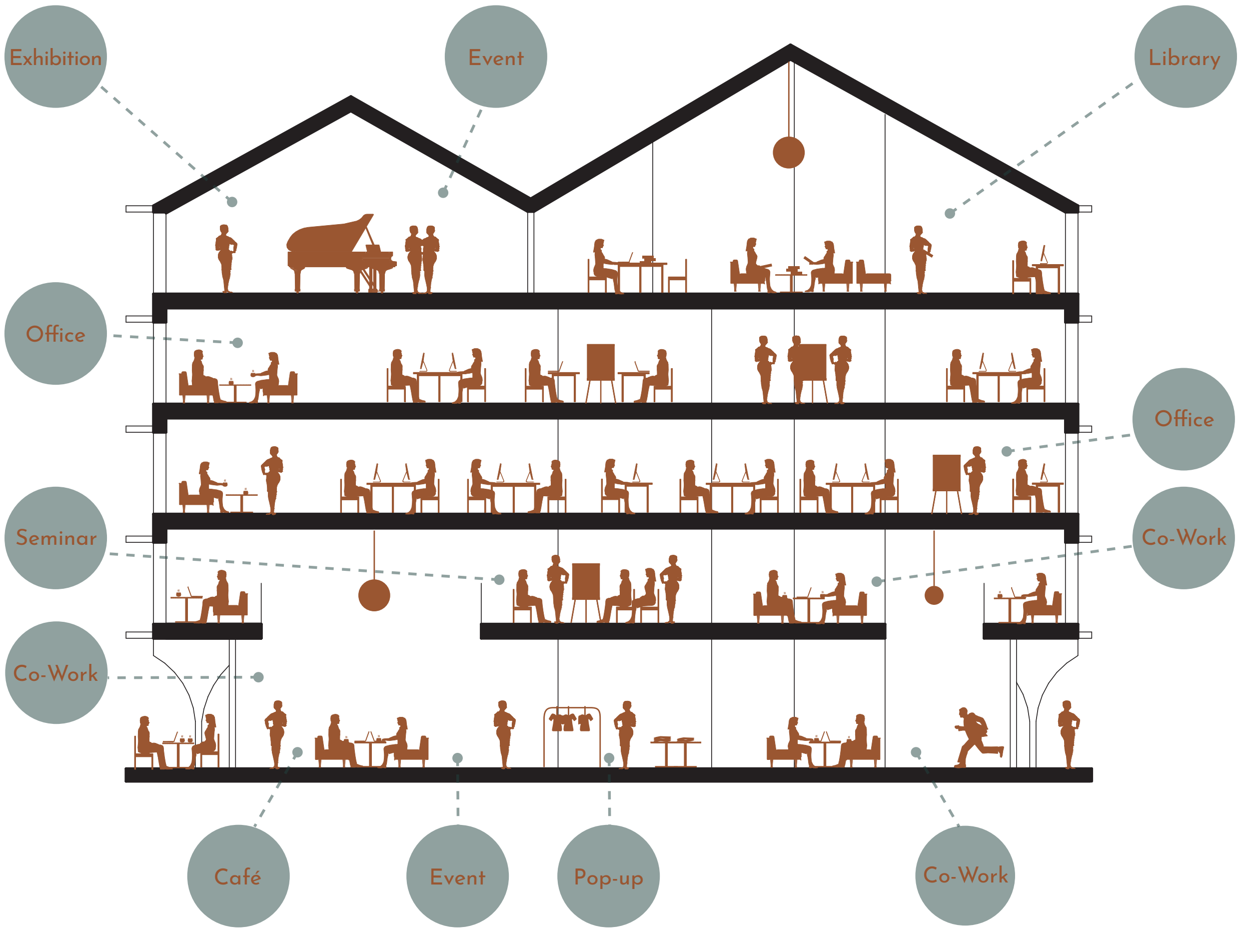
New plazas directly to the north and south makes for a pedestrian axis through the building.

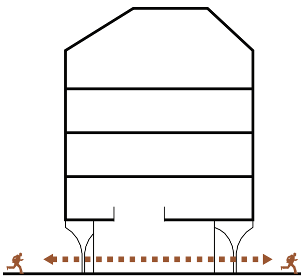


Site Plan 1: 1000

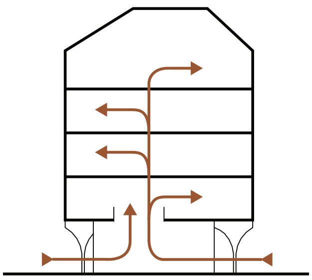

New Masthuggskaj
Lagerhuset
Inom Vallgraven
Draken
Järntorget
Pustervik

Analysis & concept

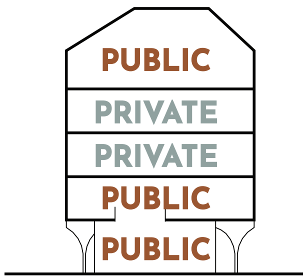




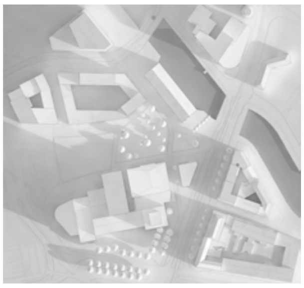
open ground floor



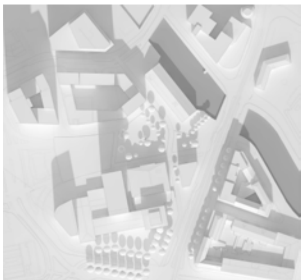
circulation



zoning



Kl 08.00



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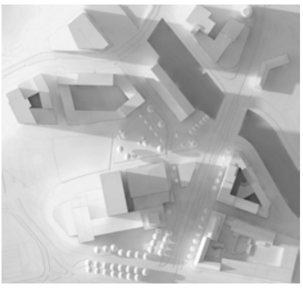


Kl 18.30

Designing with Low Impact Materials

Meeting commercial standards & regulations

- Energy efficiency
- Fire safety
- Soundproofing
- Daylight
- Indoor climate
- Durability
- Aesthetic quality
- Structure - Flexibility

Fire safety

To reach the fire safety requirements, constructive possibilities instead of problematic chemical fire retardants and fire resistant high impact materials are explored.

Straw insulation was recently tested in Austria where it is now allowed for buildings up to 5-6 stories. Cellulose based materials are covered when needed and Clay is used to create fire-retardant surfaces. Since Swedish fire classifications for clay are under development, the established German regulations are used as a reference.

Exposed wooden elements are over-dimensioned and a sprinkler system should be investigated. If necessary, ammonium phosphate can be used which is biodegradable.

Figure 22. Wood element exposed to fire

Soundproofing

Heavy clay materials are used in intermediate floors to improve the acoustic performance within the light construction. Hemp and flax fibres are well suited to acoustically decouple elements and floors are designed with a floating construction.

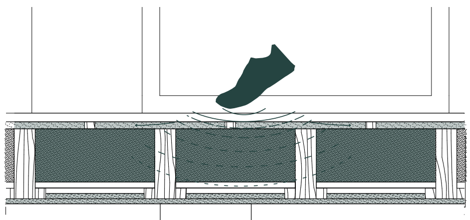


Figure 23. Wood element exposed to fire

Energy efficiency & daylight

For lowering the energy demand during operation, passive and material based strategies are explored. A well insulated building envelope and a smart facade strategy reduce the need for heating and cooling.

In contrast to conventional commercial projects, the use of climate heavy glass is minimised and windows are deliberately positioned to provide optimal daylight. This also reduces thermal losses. The shading strategy provides solar gains in winter by allowing the low standing sun to warm the interior spaces while keeping the high summer sun out and thereby preventing overheating.

Heavy clay materials exposed to the interior minimise fluctuations in room temperature through thermal inertia. Clay and natural fibres also balance indoor humidity levels hence, they have the potential to reduce the need for mechanical ventilation.

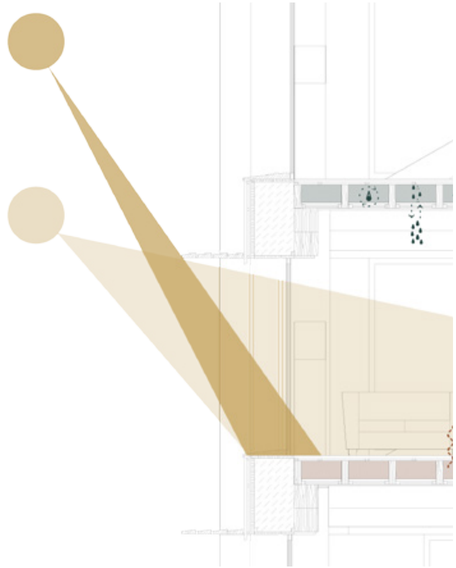


Figure 24. Sun declination Summer & Winter

Figure 25. Clay as thermal mass within floor slabs

Indoor climate

To achieve a healthy indoor climate, clay is exposed to the interior and regulates humidity and temperature as well as it absorbs smell and air pollutants. Materials that can cause health hazards are excluded from the construction.

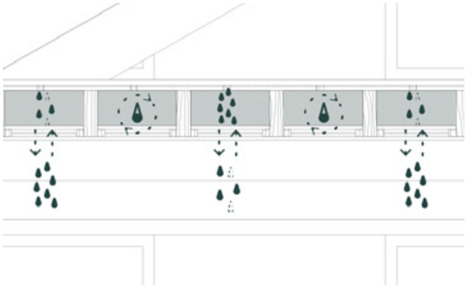


Figure 26. Humidity regulating capabilities of clay

Durability

A public building requires materials which can withstand the wear and tear of daily use. Materials are implemented sensitively and treated with surface finishes if necessary. The concept of maintenance is emphasised when employing low impact materials.

Aesthetic quality

Materials like clay and wood have rich textures and provide a multitude of sensory experiences through their visual appearance, smell and touch. The materials are exposed in various appearances to create a variety of atmospheres.

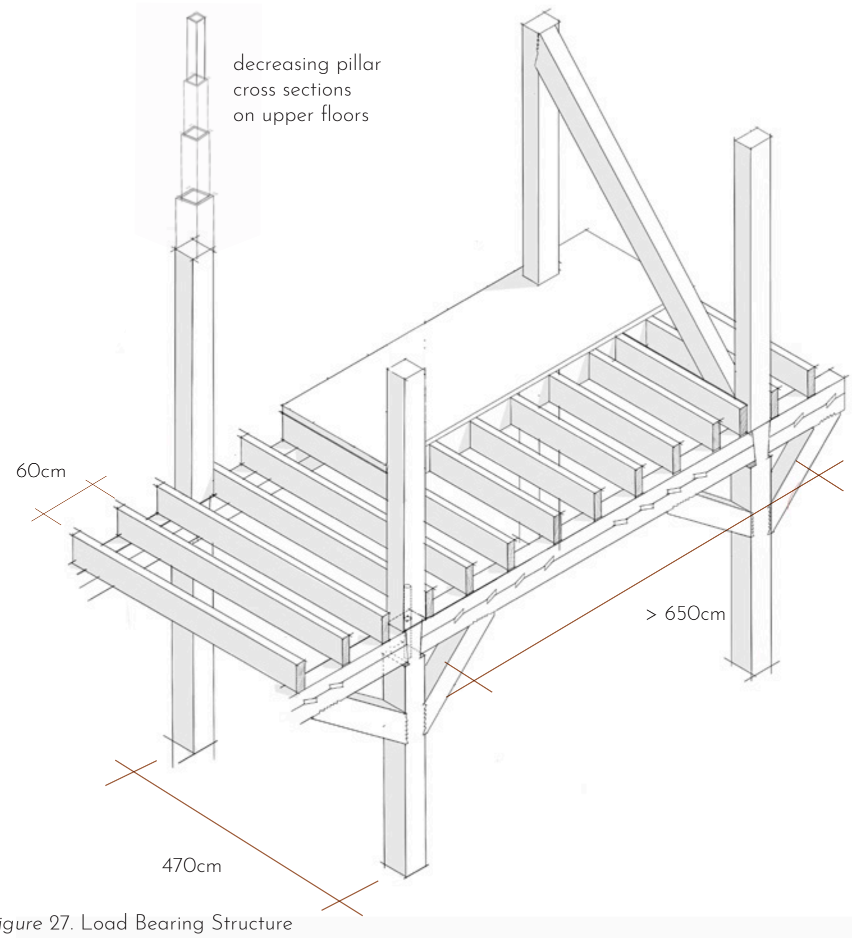


Figure 27. Load Bearing Structure

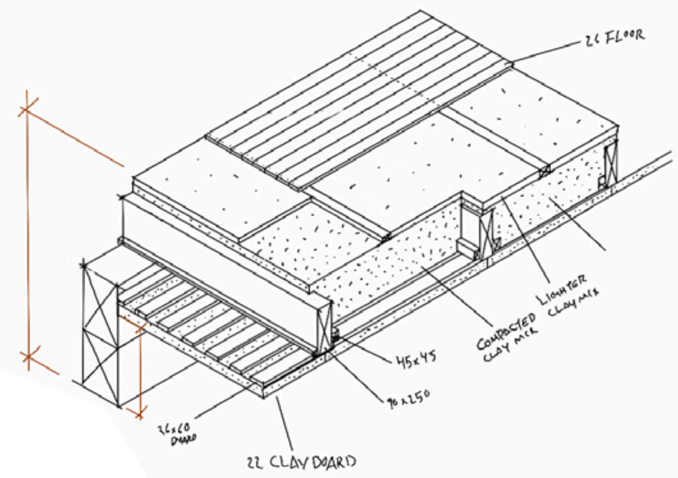


Figure 28. Thickness of Intermediate floors

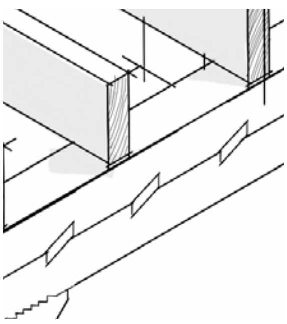


Figure 29. Key Beam

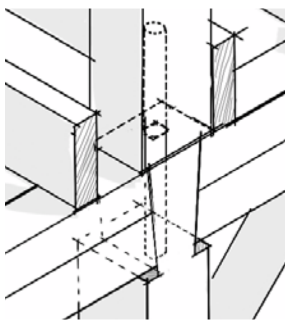


Figure 30. Pillar connection

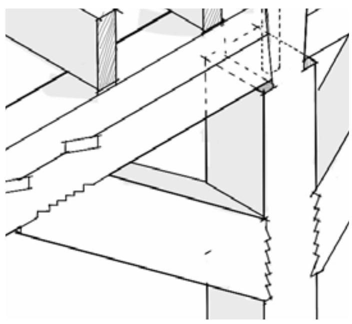


Figure 31. Strut connections

Structure

Input from structural engineers and experts on traditional complex wood constructions instilled confidence that there are ways to meet commercial structural requirements using all natural timber.

- Grid & Spans

Employing the constructional principles to a grid optimized for a commercially viable and flexible layout along with the geometry of the plot poses a challenge. The diagonal grid enables longer spanned mechanically laminated key-beams while the spans for secondary beams are kept within the material capacity without need for lamination. This construction provides flexibility in layout and fenestration.

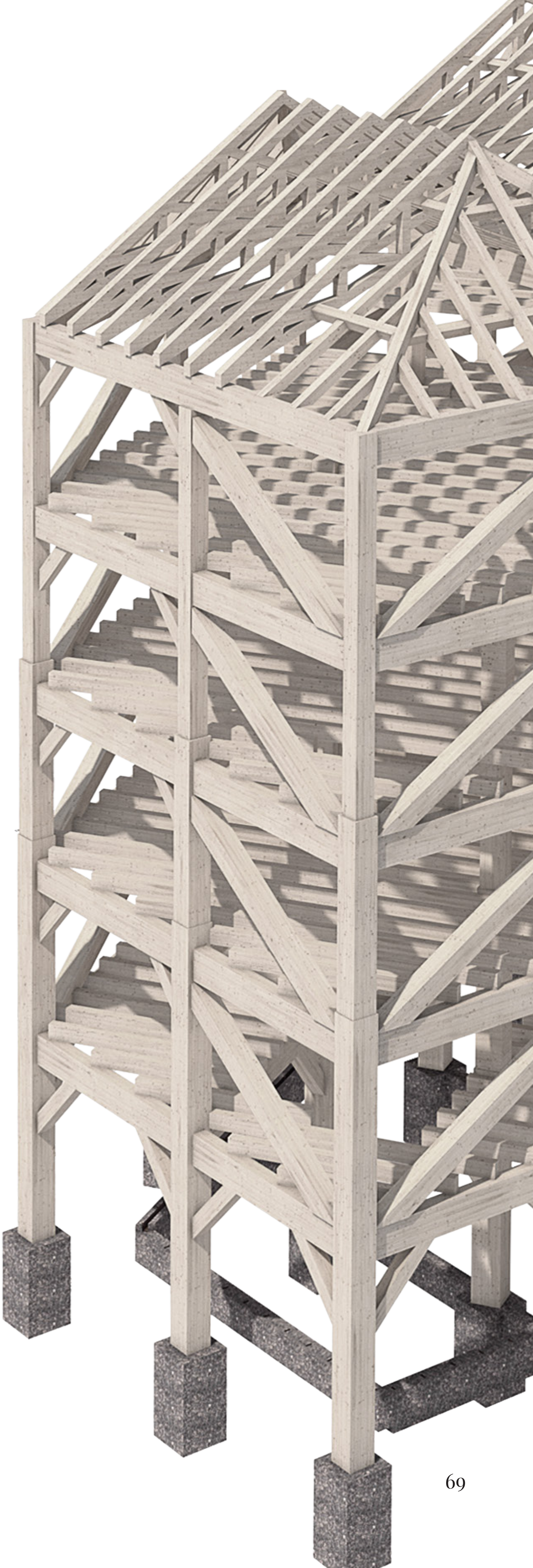
- Intermediate Floors

Regarding thickness of intermediate floors, it is hard for wood to compete with steel or concrete. Therefore, primary beams are left exposed which turns a disadvantage into a spacial feature by creating atmosphere as well as perceived ceiling height & volume.

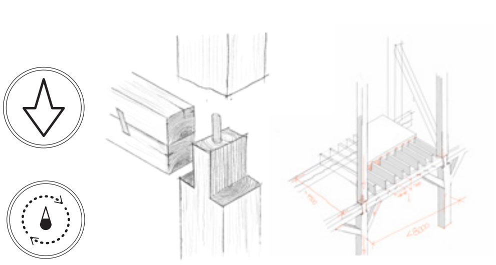
- Reflections

A wood-glue hybrid construction would surely be more predictable, easier to asses and calculate by minimizing the risks of deformation or shrinkage while also providing a ready to go manufacturing, delivery and construction process. It did not however meet our criteria because of its fossil based additives.

The lingering notion after comparing alternatives was also that the optimization of all natural wood found in e.g. the complexity of Hans Ulrich Grubenmanns 18th-century bridge constructions combined with modern technology and methods, like the work of Herman Kaufman architects, is a way to push the envelope towards new more true-to-wood building systems.



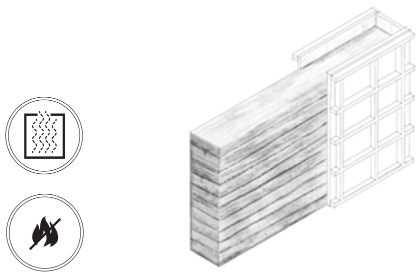
Employing qualities & possibilities



The Massive timber framing utilizes natural wood in thick dimensions to optimize the materials capacity to regulate humidity and compressive strength in homogeneous elements with no additives or excessive processing. It requires high quality timber that stems from old, slow grown trees which in turn demand a more dense and diverse habitat. This fosters a healthier forest, cultivating biodiversity. Compared to massive laminated wood elements (DLT or CLT) its frame construction also allows a more effective use of resources (Hudert, M. Pfeiffer, S (Eds.) 2019).

Birch bark will act as a low impact waterproofing of the structure's roof. This use of Birch Bark has a long tradition in Scandinavian construction. Its harvest does not kill the birches and it has, through examining old structures, proven itself to be a very long-lived material if properly applied

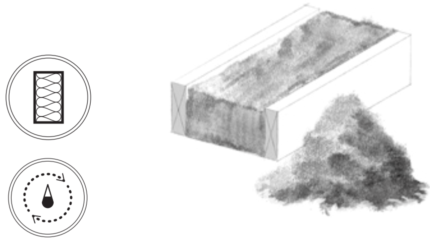
Wet processed wood fiberboards insulates and makes the envelope windproof while allowing moisture to diffuse and not get trapped within the structure. The adhesive is mostly its own lignin (Bokalders & Block 2010). This makes for good weatherproofing without the use of plastics.



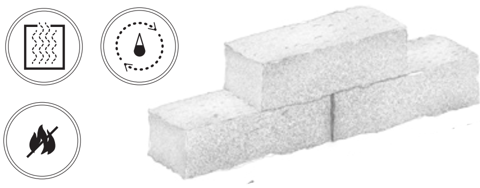
Rammed Earth is used as flooring on street level. This enables a high density, heat regulating floor with high aesthetic values to be build mainly from material found on site.

Clay plaster fulfill numerous functions in the design. Plastered surfaces provide thermal and moisture buffering abilities, providing a high-class indoor climate. It is also used to air tighten the interior and as fireproofing. (Verbraucherhandbuch)

Clay Boards are used instead of plasterboards as interior sheeting material where they clad walls and ceilings. The joints are covered with clay plaster before a second layer is applied to give the desired finish.

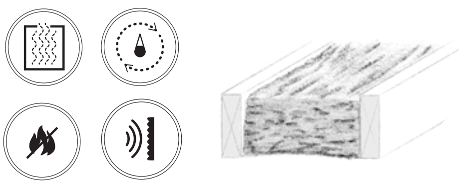


Blow-in Straw Insulation is used to insulate the outer walls and roof. Low heat conductivity and a fast regrowth-cycle makes it a good low impact insulator. It is also suitable in construction open for diffusion.



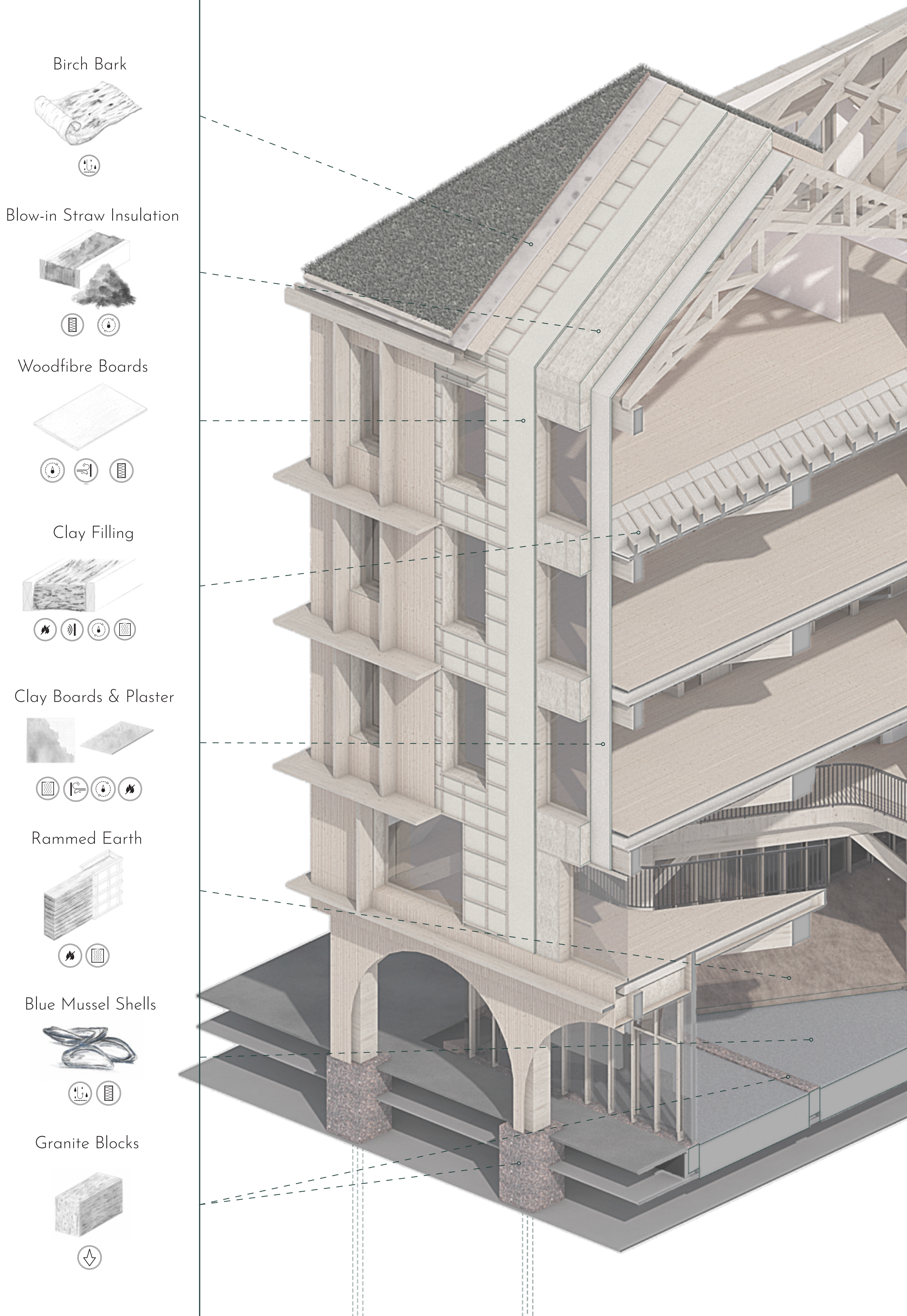
Unfired Clay Stones make up the core of interior walls where there is less need for flexibility. The high density of the stones (1900 kg/m^3) stores heat and cold which lessens the fluctuations of interior temperature. A requirement to achieve a minimal energy demand for heating and cooling.

Straw fibers is mixed into some of the clay mixtures to provide reinforcement and to make the mixture less thermally conductive, hence giving it slightly better insulation capabilities.



Clay Fillings of various mixtures are used in the intermediate floors. Lighter mixtures serve as underfloor screed while more compacted mixtures provide weight, thermal mass and sound insulation to the timber frame structure. The clay also helps to protect and preserve the timber within the construction (Sauer, 2015).

Blue Mussel Shells are used to insulate the foundation. Once compacted the shells constitute a capillary breaking, water repellent layer with decent load bearing capabilities and thermal insulation. In Limfjorden, Denmark around 100 000 metric tonnes of shells are generated annually. (Byggnadsvårdsföreningen, 2017)


Birch Bark
Blow-in Straw Insulation
Woodfibre Boards
Clay Filling
Clay Boards & Plaster
Rammed Earth
Blue Mussel Shells
Granite Blocks

The heavier high density clay is protected from the cold exterior by the lighter, less conductive straw. The structure is open for diffusion allowing moisture fluctuations to self regulate without getting trapped.

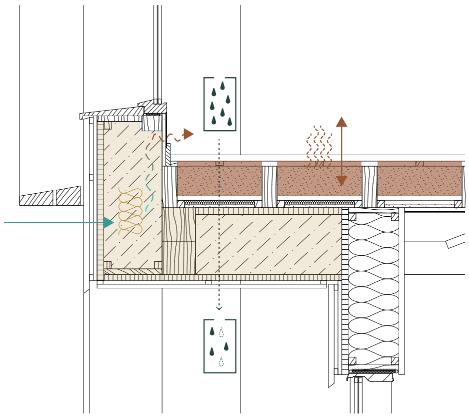


Figure 32. Insulation and Thermal mass

The Clay filled slab construction provide good conditions for desireble sound insulation since the various densities have the potential to both dampen and absorb impact noise.

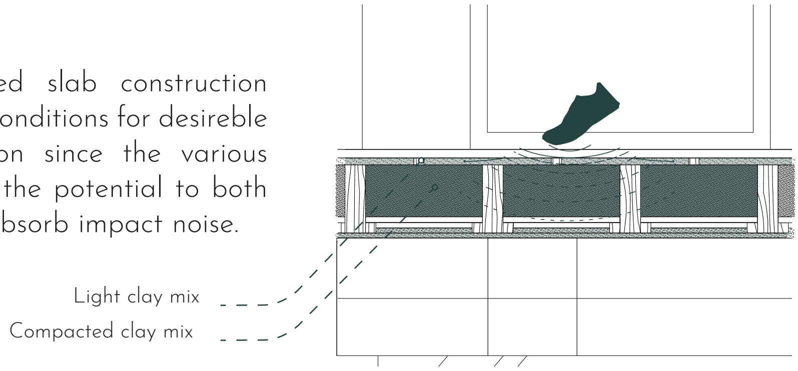
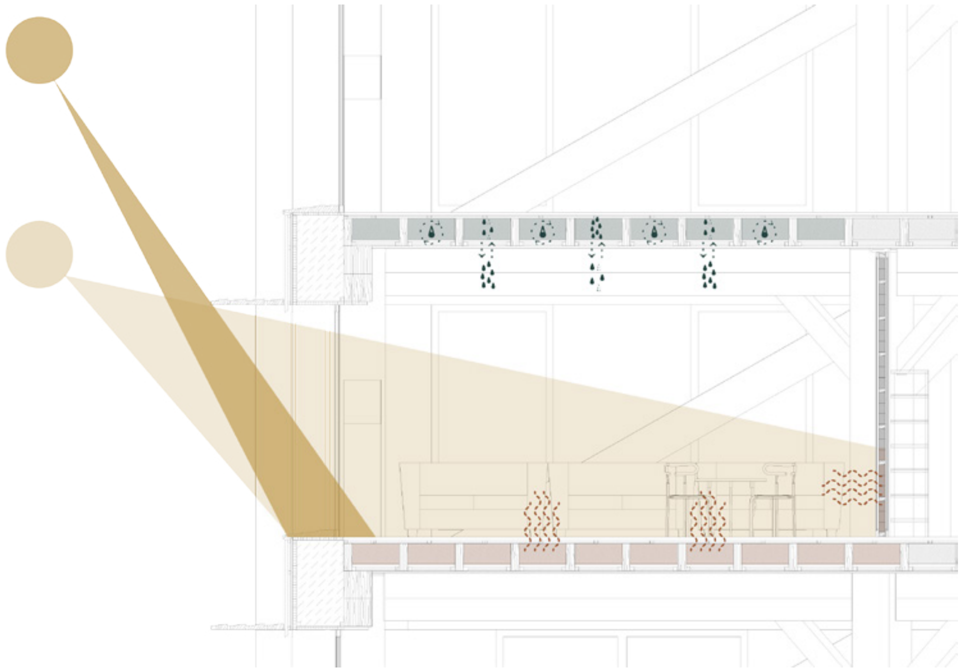
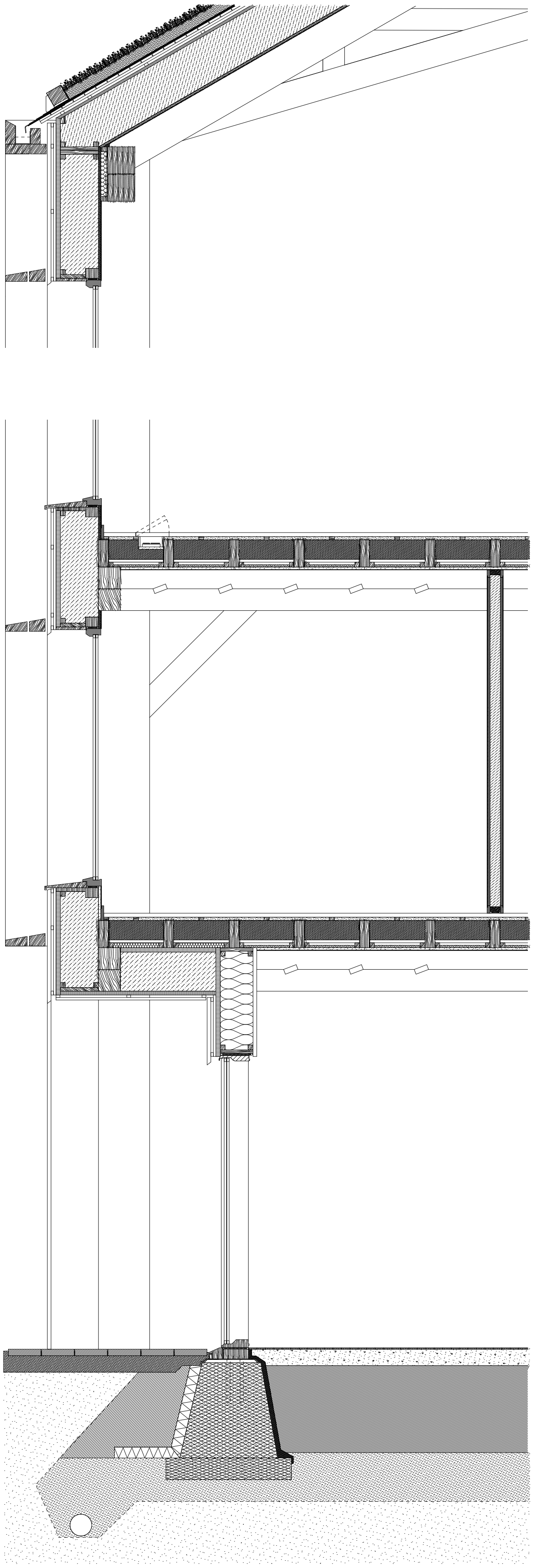


Figure 33. Acoustic behaviour of slabs



The exterior shading grid is thought to block the warmest midday sun during the summer months while allowing the low winter sun to heat the rooms. The clay within the intermediate floors store and release heat and moisture to counteract fluctuations providing a stable and comfortable indoor climate while minimizing the need for mechanical assistance.

Construction details



Roof
Turf covered Birch Bark with Blow-in Straw insulation and Clay boards

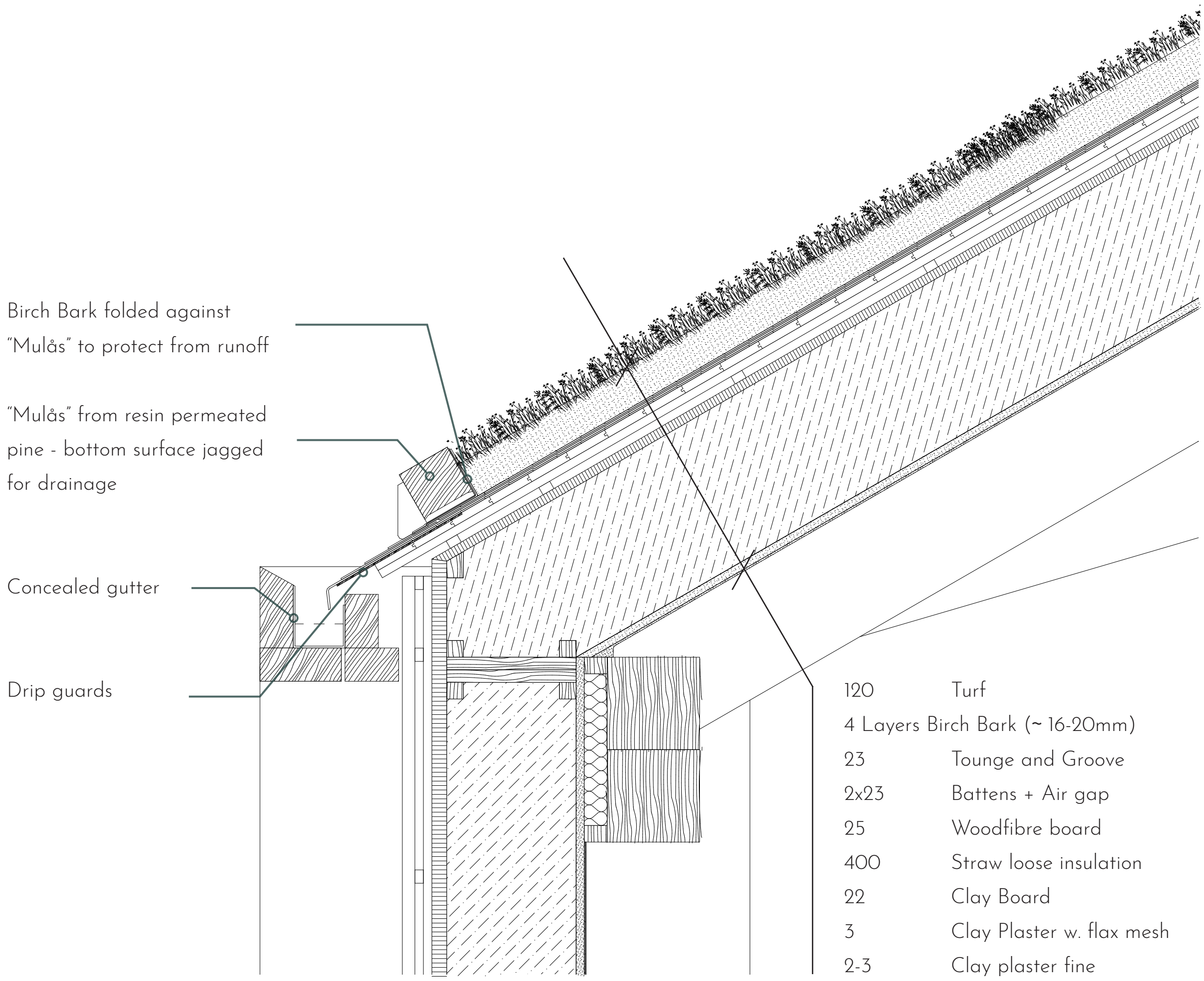
U - value: 0.109

Outer Wall
Timber cladded elements with Blow-in Straw insulation and Clay boards

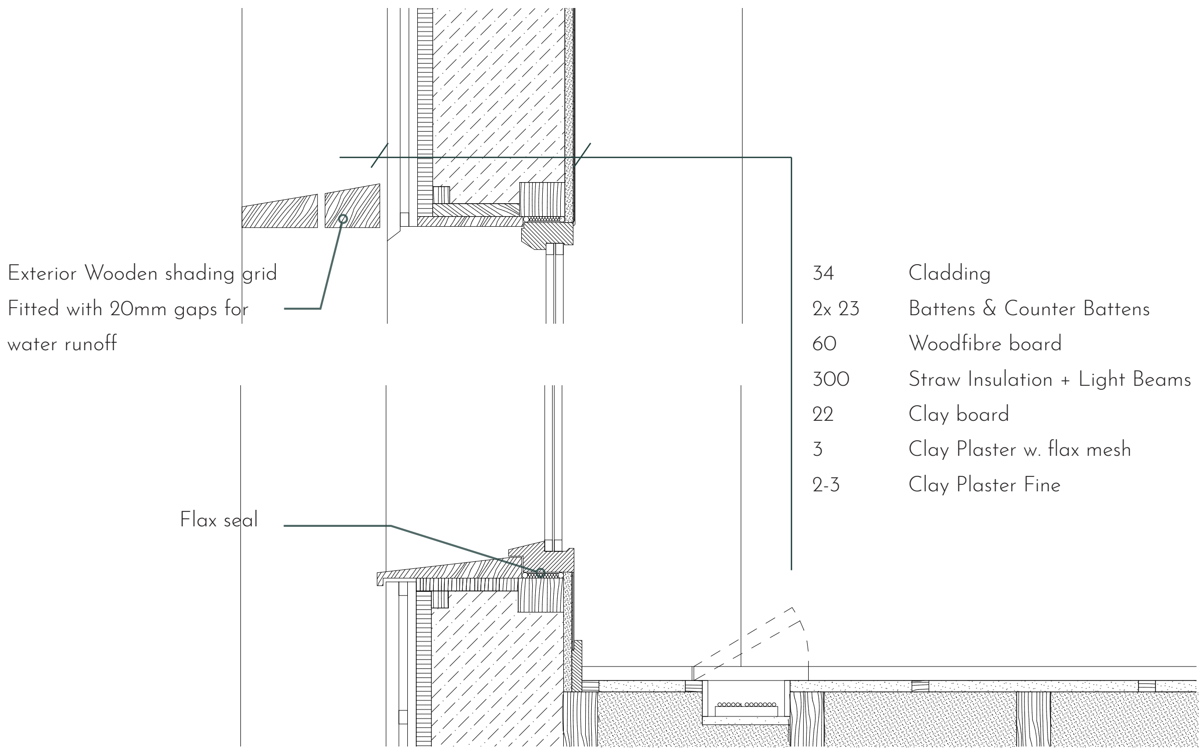
U - value: 0.114

Foundation:
Compacted earth with a Granite block wall and plinths and Blue mussel shell filling

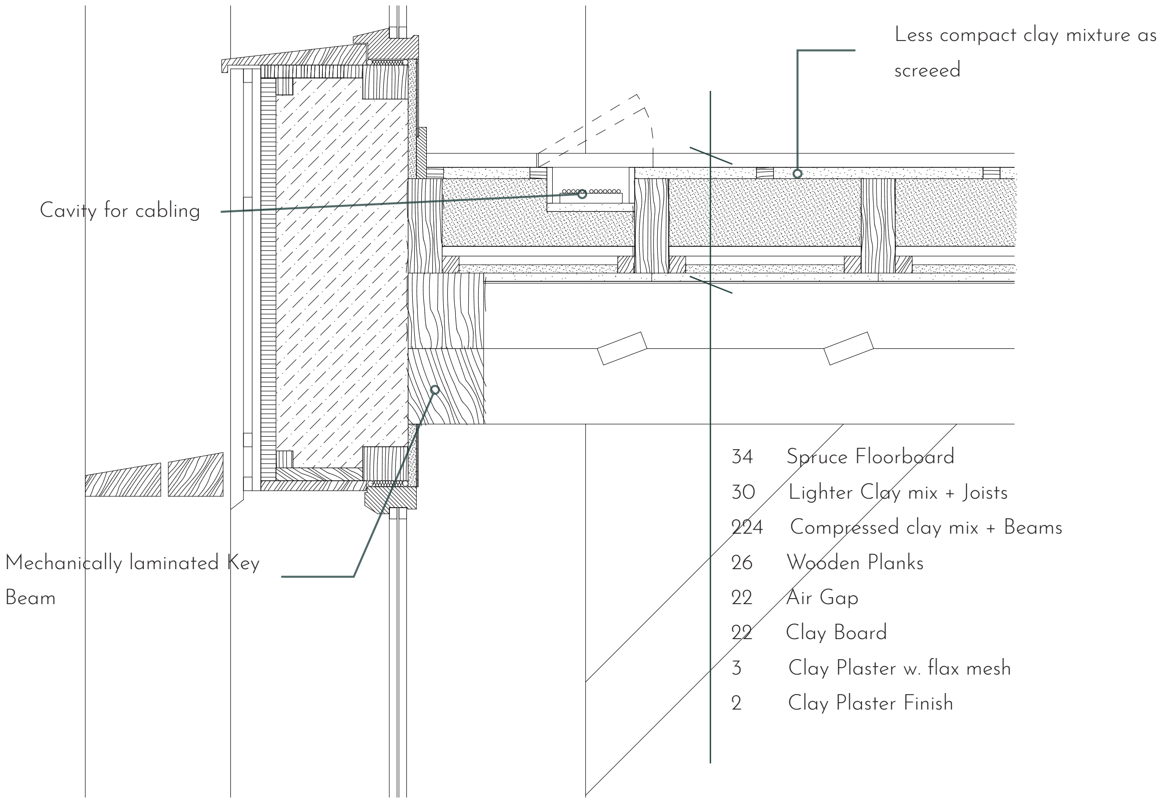
U - value: 0.141



Wall - Roof 1:20

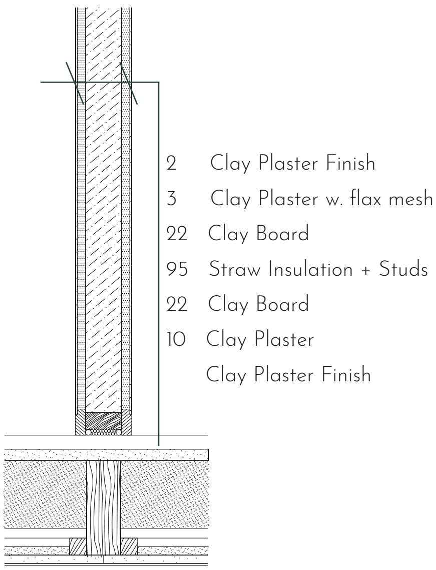


Wall - Window 1:20

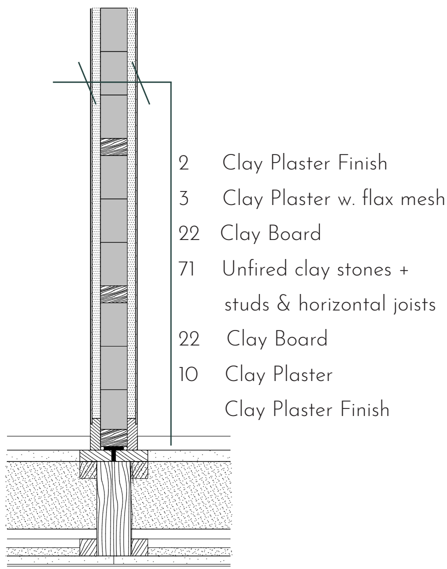


Wall - Intermediate Floor 1:20

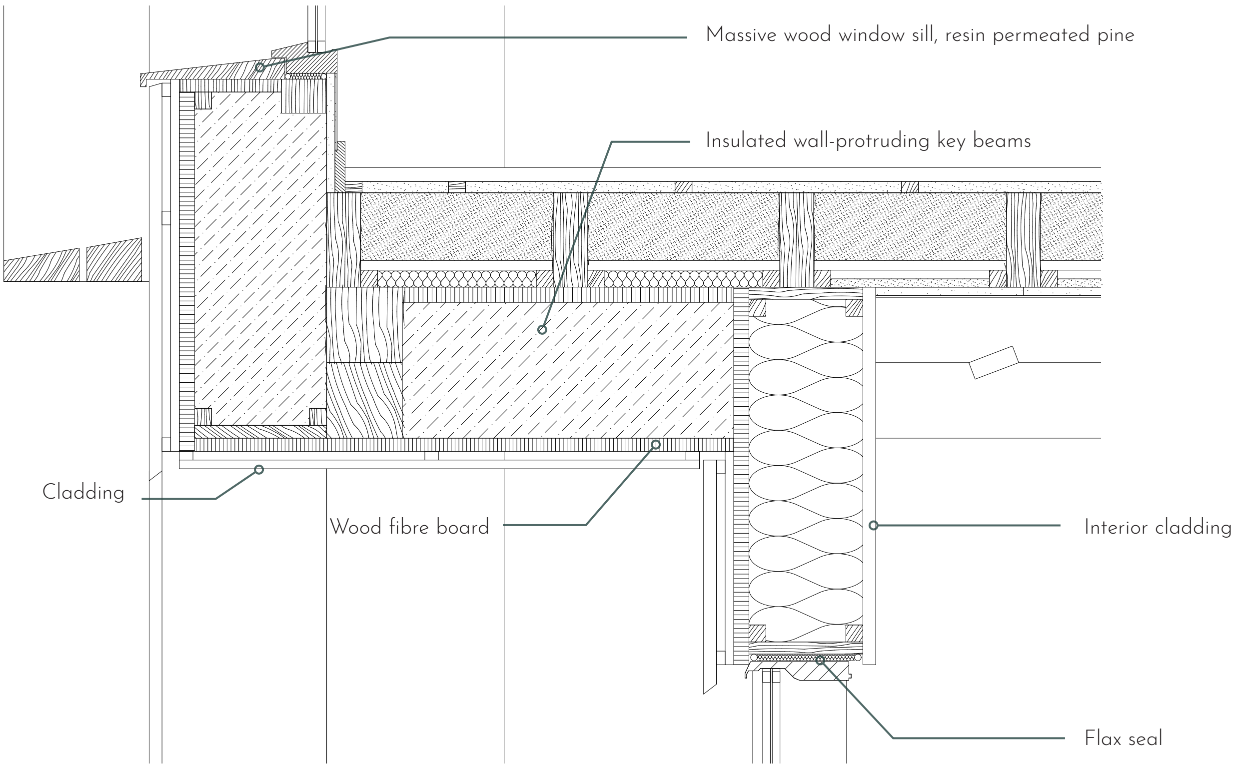
Flexible Lightweight wall system



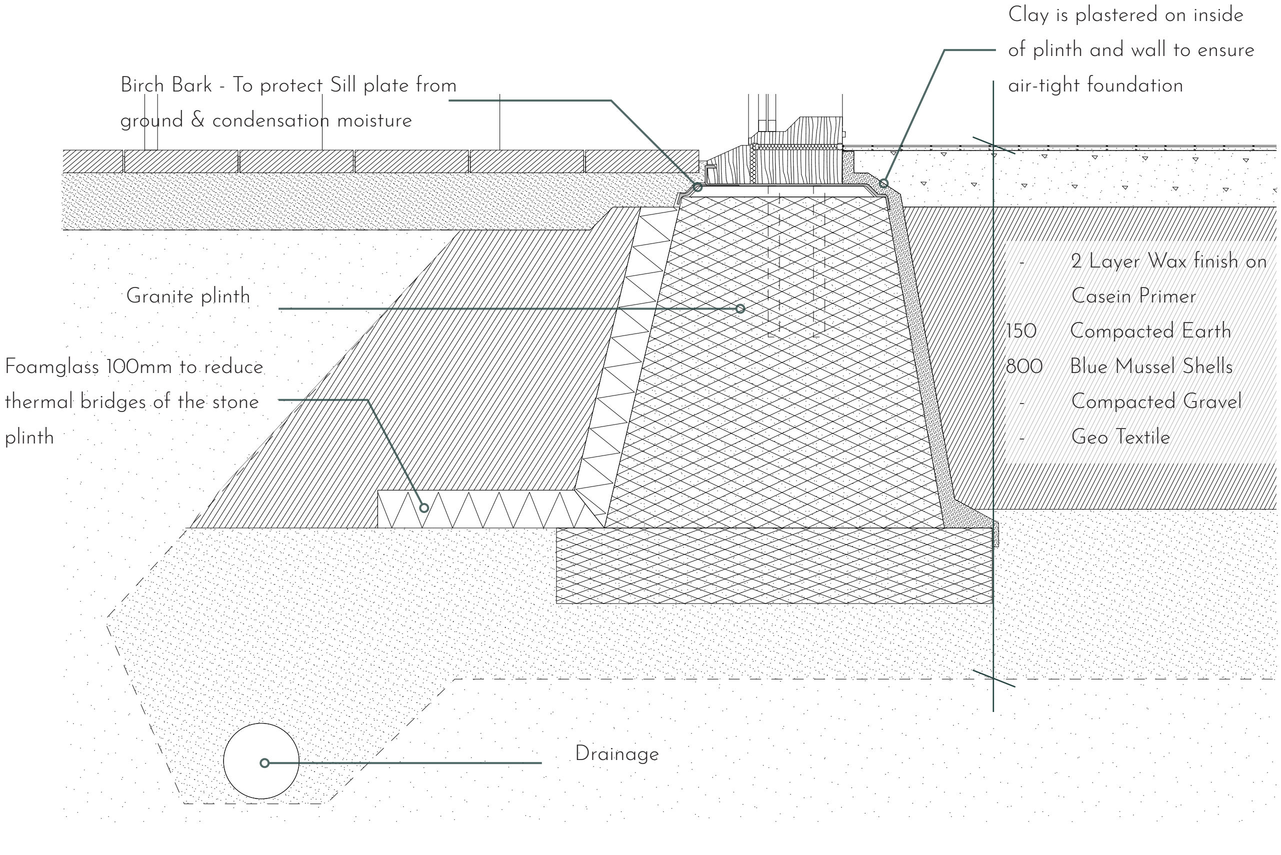
Heavy wall system



Inner Wall - Intermediate floor 1:20



Wall - Intermediate floor - Cantilever 1:20



Foundation 1:20

Life Cycle Analysis

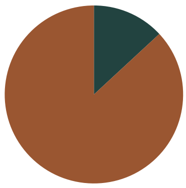
Calculations per 1 m2 building component. For details see appendix.

Conventional building

L.I.M Approach

Roof

Concrete, EPS Insulation,
Waterproof Membrane
Gypsum Plaster



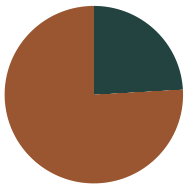
91 kgCo2/m2 14

Roof

Turf, Birch Bark, Straw,
Wood Structure, Clay
Board & Plaster

Foundation

Concrete, XPS Insulation,
Screed, Parquet,
Waterproof Membrane



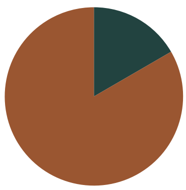
112 kgCo2/m2 36

Foundation

Compacted Earth,
Blue Mussel Shells

Outer Wall

Concrete, EPS Insulation,
Silicate & Gypsum Plaster



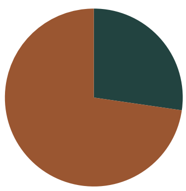
65 kgCo2/m2 13

Outer Wall

Wood Cladding, Woodfibre
Board, Straw, Wood Structure,
Clay Board & Plaster

Inner Wall

Glasswool, Aluminium
Profile, Gypsum Plaster
Board



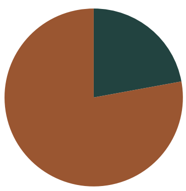
19 kgCo2/m2 7

Inner Wall

Straw insulation, Wood
structure, Clay Board &
Plaster

Intermediate Floor

Concrete, Glasswool, Parquet
Aluminium Profile, Gypsum
Plaster, Wood Chipboard,

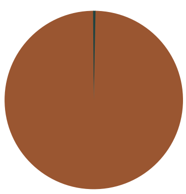


82 kgCo2/m2 23

Intermediate Floor

Wood Floor, Clay Filling,
Wood Structure, Clay
Board & Plaster

Load Bearing Beam
Comparison of 2 beams
with the same load
bearing capacity.
Calculated for 6m span: kgCo2/m2



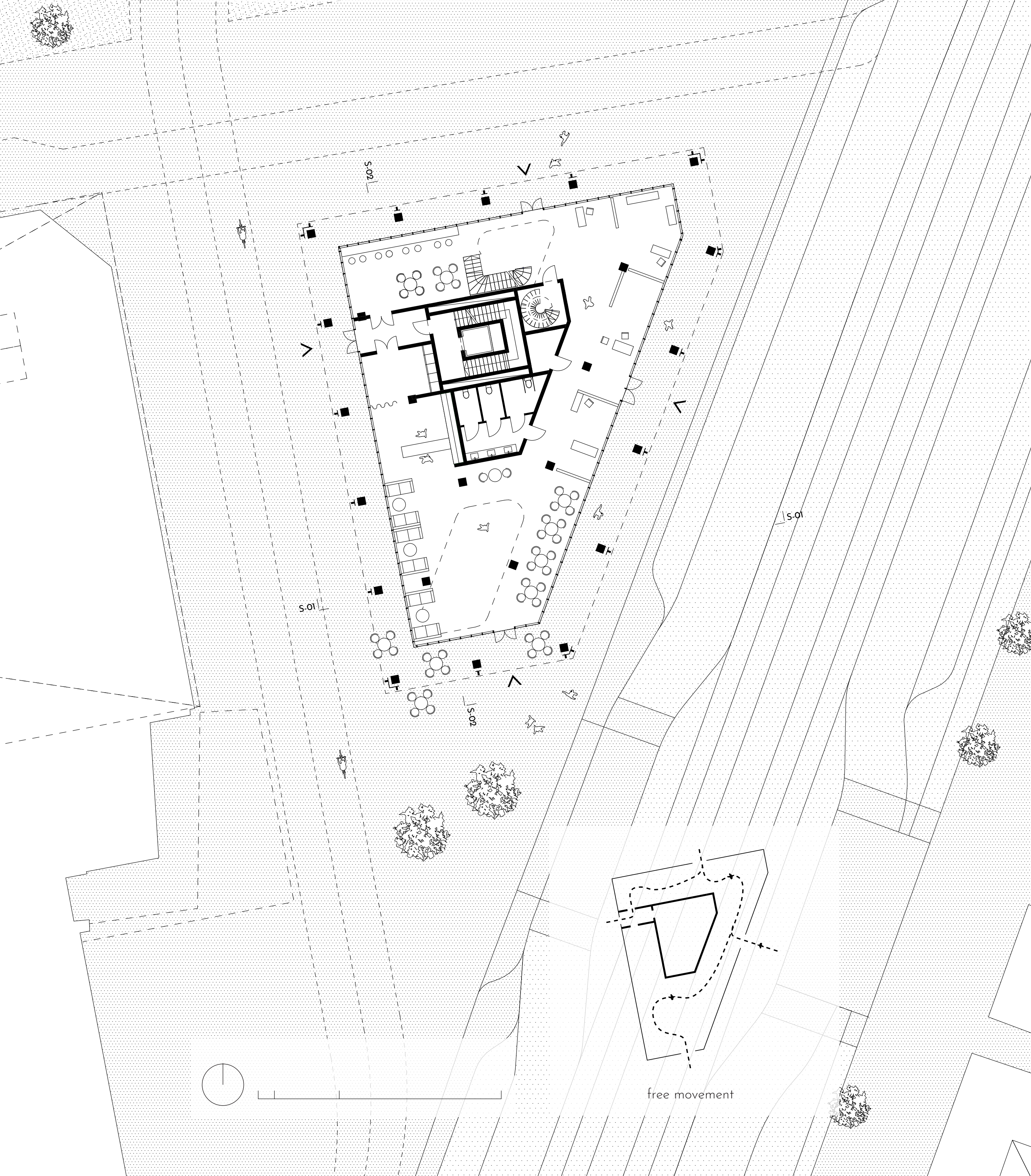
56.078 370

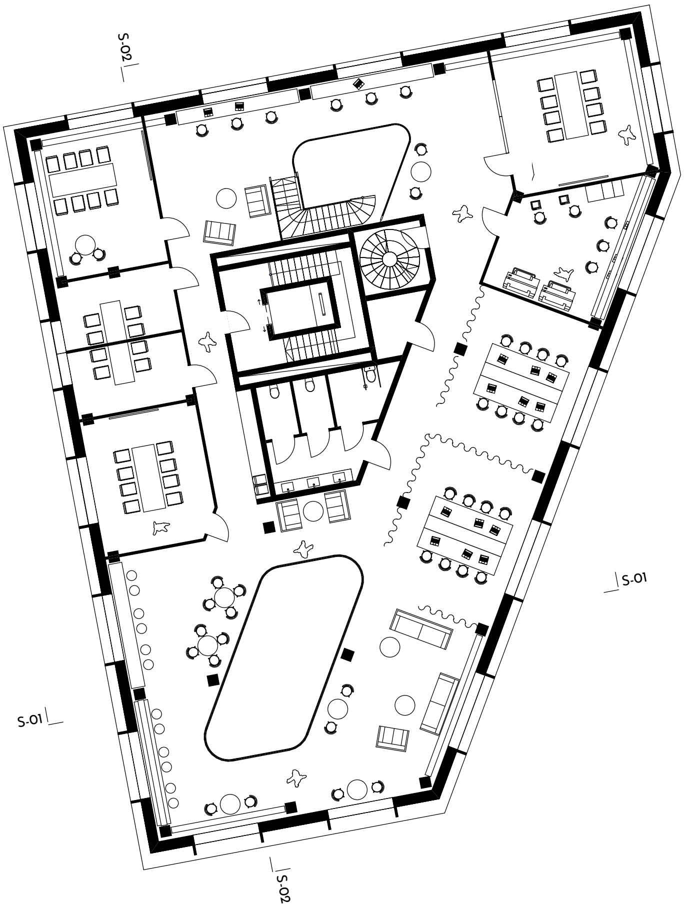
Steel - HEB22
22 x 22 cm

Wood - GL32
24 x 44 cm

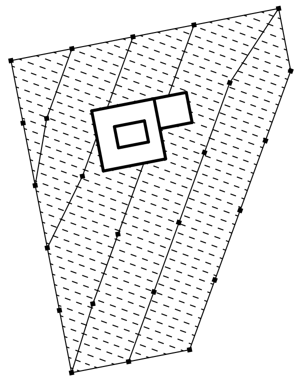
Building design

Plans, sections & elevations

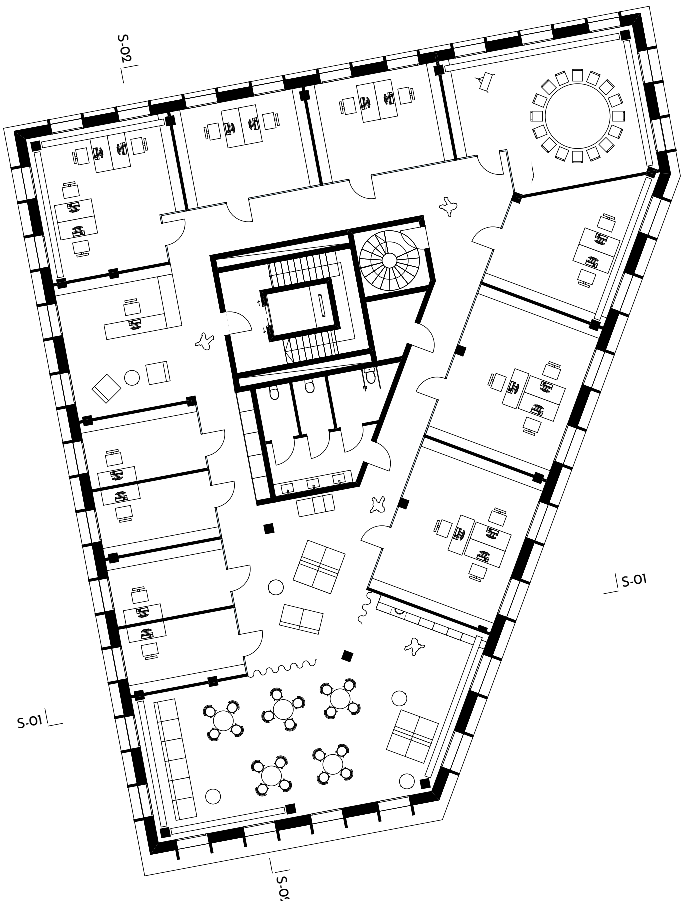




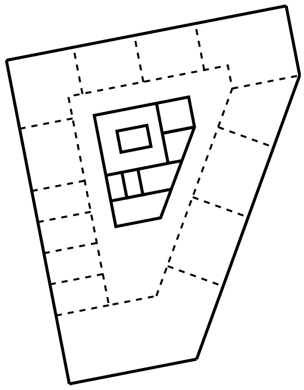
Floor 1



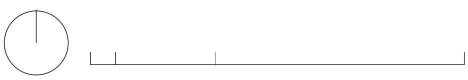
bearing construction

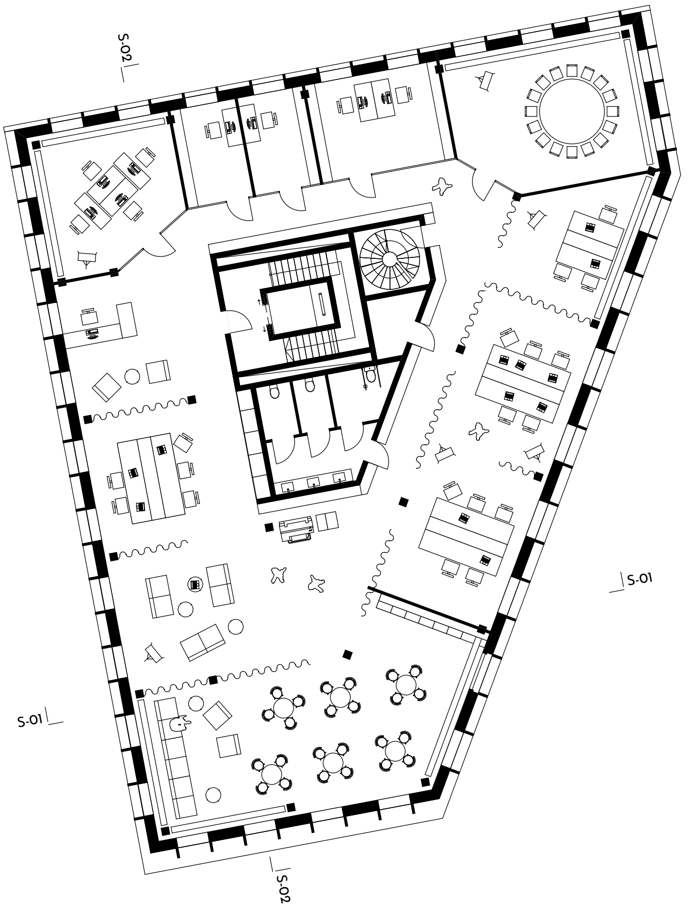


Floor 2

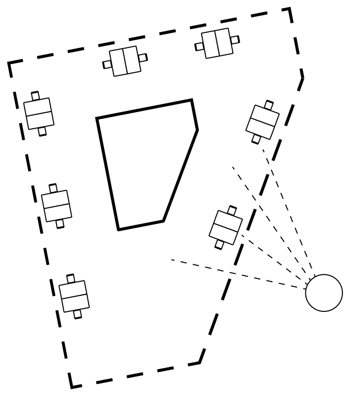


flexible inner walls

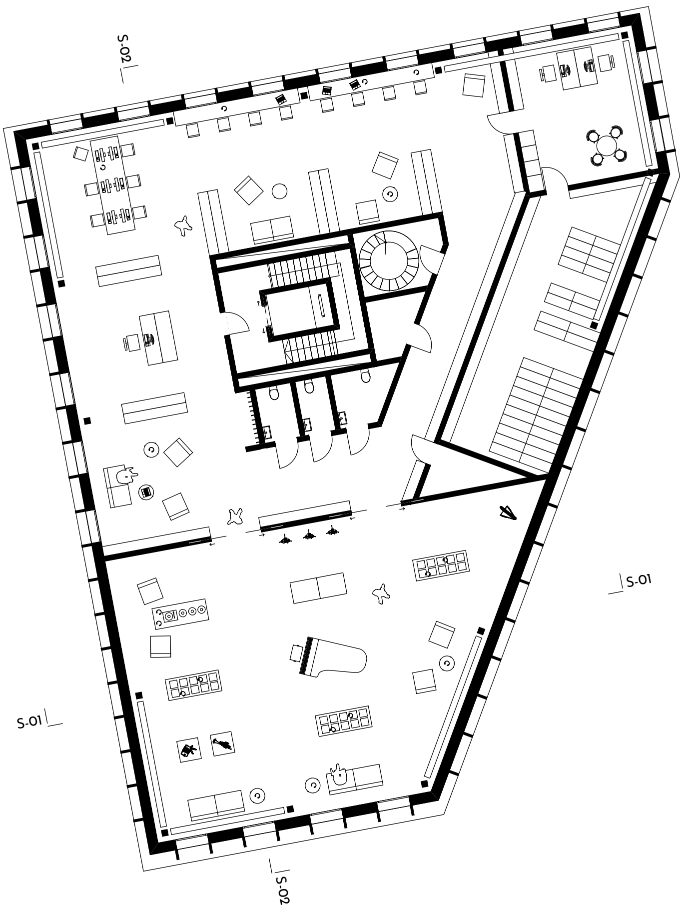




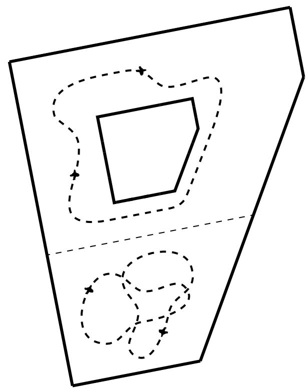
Floor 3



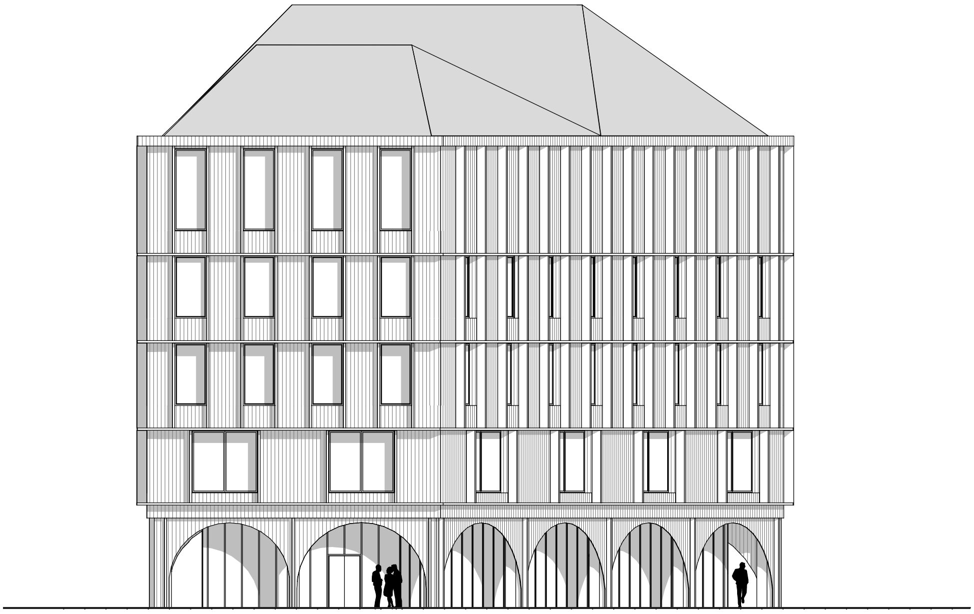
daylight at workstations



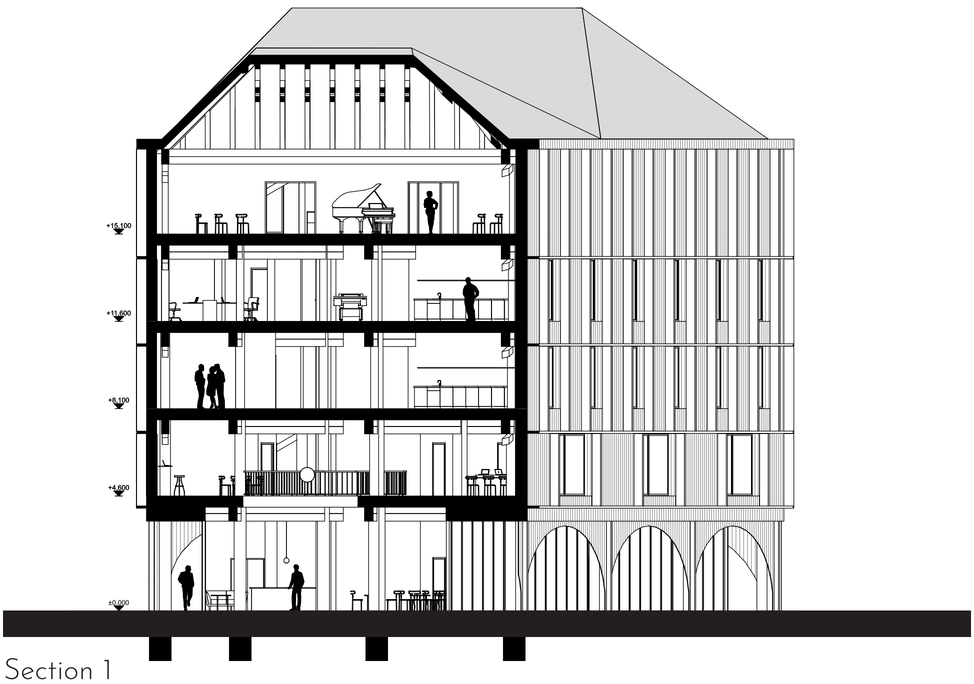
Floor 4



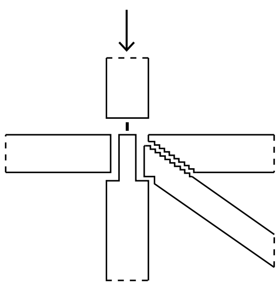
seperate activities



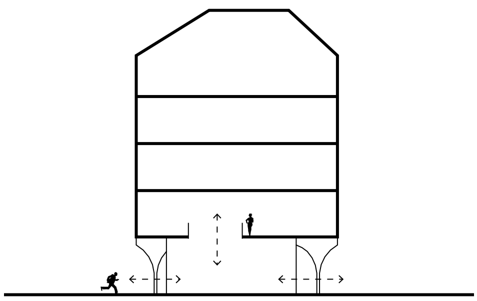
Elevation South



Section 1

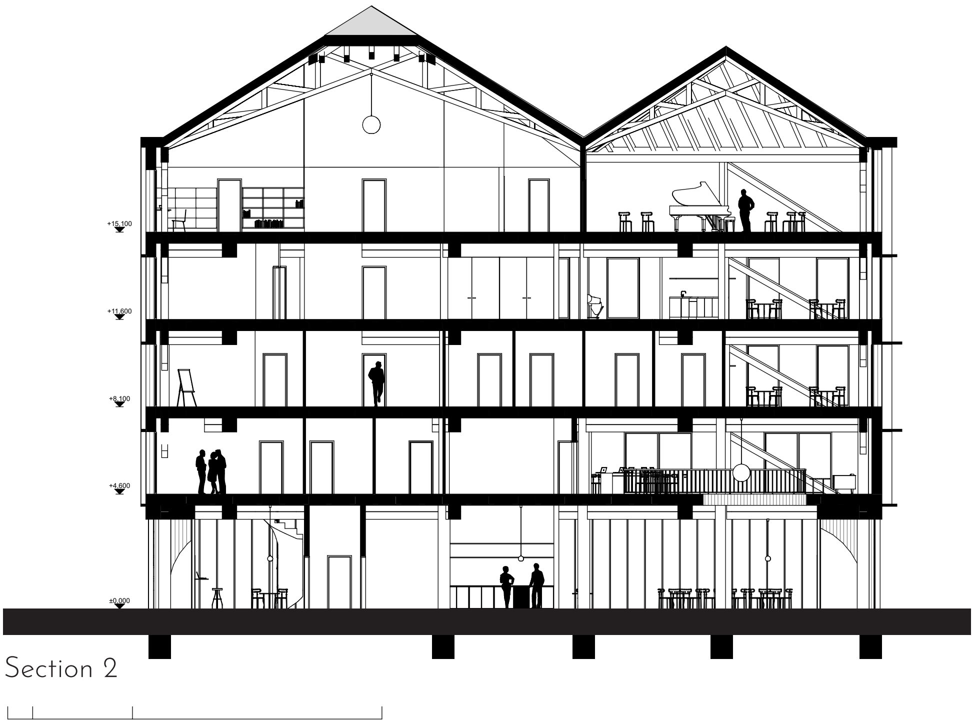


load transfer through pillars

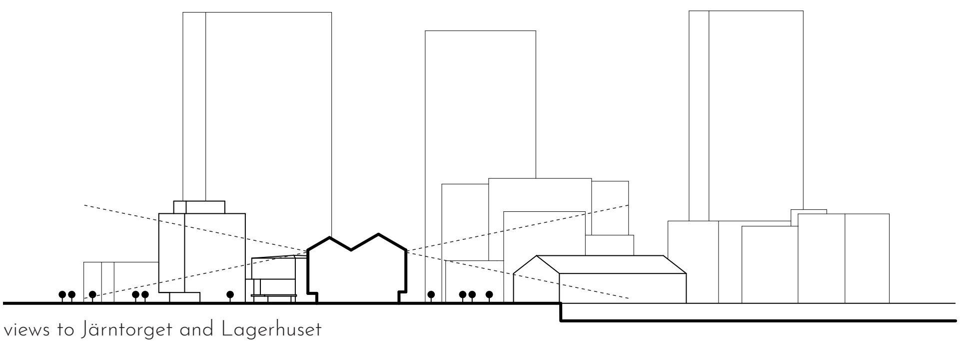


open bottom floor & connection to storey 1

Elevation West



Section 2



views to Järntorget and Lagerhuset

Interior Floor 1
Café & Co-working

Interior Floor 4
Exhibition & Event Space

5.

View from Järntorgsgatan, South east

Discussion

Discussion

Materials

Positive outcomes

This project succeeded in predominantly using low impact materials for the whole construction supported by the low impact material criteria as a guideline.

Using a timber frame structure in a commercial building of this scale turned out as possible and doesn't just generate functional spaces but also aesthetic qualities through the exposed structure. Implementing large amounts of clay resulted in high thermal inertia and moisture buffering and thereby supported the ambition for smart low-tech systems based on the materials properties. It was possible to use untreated straw insulation and to refrain from chemical additives in the rest of the construction.

This project can be constructed with generally conventional methods due to the use of prefabricated elements. This proves that low impact materials can readily be implemented in conventional projects today. Additionally, these materials open up the opportunity for an alternative way of construction that follows a more handcraft and people based approach.

Obstacles, considerations & decision processes

- **Roof**

There is a lack of low impact materials suitable for the water tightening layer in roof constructions Birch bark was chosen for this project since it is a local, traditional material and currently a waste product. However, it needs to be considered that traditional birch bark roofs are material and labour intensive and require a well planned construction.

- **Foundation**

It proved to be difficult to find a fossil free, low-impact solution for the foundation. Finally the choice fell on a granite and mussel shell hybrid instead of e.g. foamglass due to the lower level of processing. However, the energy and landuse for material excavation need to be considered.

- **Timberframe vs. Glulam**

A Timberframe was chosen over glulam due to a lower level of material processing and the avoidance of chemical composites. This choice was also taken in order to promote sustainable forestry, high quality wood and resource appreciation and efficiency as opposed to current mass production and the negligence of material specific properties. While glulam beams can generate greater spans and more flexibility in planning, this project shows that timber framing is a viable alternative with much potential embedded in ongoing efforts to further develop construction techniques.

Compromises

When compromises needed to be made, it was crucial to find solutions that did not diminish the material qualities or possibility for material recovery.

Metal screws are necessary to mount clay and wooden boards and metal reinforcements might be necessary to complement the timber frame structure. Metallic components can be reused and ensures the possibility of disassembly. A foamglass insulation board at the perimeter of the foundation was used due to the lack of a suitable low impact option. Glass has high embodied energy. Therefore, window areas were reduced in this project and the reuse of windows is recommended.

Design project

The design project did turn out to play a central role in developing this thesis. It set a framework for our research and forced us to keep a broad perspective, moving back and forth through theoretical context, material research, regulations and building physics and thereby generated a holistic thesis.

Learning outcome

This project taught us valuable information about the implementation of wood, clay and straw in a realistic design project. Our gained expertise stretches from a theoretical understanding of the materials in relation to the building industry and current developments in construction, over alternative construction principles adapted to low impact materials, to hands on material experience. We learned that knowledge and persistence opens up doors when arguing for low impact materials. This thesis broadened our horizon and the gained knowledge is what we will bring into our profession.

Future investigations

Relevant topics to be further investigated are alternative modes of construction for commercial projects that incorporate handcraft and manual labour, construction possibilities with unprocessed timber and finding low impact solutions for roof and foundation.

Conclusion

Why are low impact materials not used commercially today?

Low impact materials are generally met with scepticism towards their functionality and reliability while faults of conventional materials are accepted without criticism. There is a lack of knowledge in the conventional building sector and a lack of positive examples. The global lobby for building materials is well established and working hard to build up their green image. Today's building regulations are based on conventional building materials and modes of construction and the focus of the industry still lies on the initial investment costs instead for the whole lifecycle. To fully embrace Low impact materials might require a rethinking of the process in terms of the economic and legislative system as well as adapted building system solutions.

How can low impact materials be incorporated in the design of a commercial building within contemporary architecture?

Implementing low impact materials in commercial projects can be done fairly easily in some cases by exchanging conventional components with corresponding products made of low impact materials. In order to reach low impact buildings, holistic solutions and smart alternative systems that are adapted to the materials qualities should be incorporated in the design right from the beginning. Positive references and input from experts should underlay the design process. When arguing for low impact materials, emphasis should be laid on the whole lifecycle costs and overall positive impacts on human health and environment.

Reflections

Culture of construction

Here follows a few examples identified on how the processes around construction could change in order see a wider use of Low Impact Materials.

Today developers are often allowed to build without much responsibility for the finished product in terms of its initial environmental effects, how the building lasts over time or what happens afterwards. Perhaps even selling the project at or before completion, making the act of building a business transaction like any other. Could they be forced to carry a long-term interest in their buildings?

Joint building ventures have proven to act more responsibly as they tend to opt for more ecologically sound materials since they are often building for themselves without profit being the main priority. Enabling such initiatives through planning legislation as well as better economical conditions could start to diversify the format of Swedish construction.

Legislating the implementation of LCA's and similar tools could be a way to further push the established stakeholders to educate themselves and revise their methods.

Pilot projects such as in Örebro (Vi ger arkitekten makten, Orebro.se 2016) could help secure ecological ambitions. Here the land is allocated to an architect office who, together with the municipality, make up the framework for what is to be built, and in a later stage, pick the one out of the applying contractors depending on who seems best equipped to deliver according to the criteria formulated.

In Gothenburg, the city is currently developing a role model for fossil free preschools, which in its second instalment will focus on perfecting the process from the first instead of developing it and hopefully show that fossil free building can be as efficient and economically sound as conventional building, showing how the municipality can encourage development both by making demands but also by leading examples.

A discussion that has permeated writing this thesis has been the format in which such a building would be constructed. These particular materials inevitably raised the question if it is to be a result of craftwork, or if industrial fabrication and processing should somehow to take part.

Handcraft vs industrialization

Industrialization has in general effectively "rationalized" the need for manual labour and with it much of the culture of handcraft, where bespoke is the standard and impromptu ingenuity often informs the result. Industrial production also eliminates the connections handcraft inevitably creates. To manually treat and process a material constitutes a learning process for the person involved and an understanding of the material, its limits and capabilities. When removing the human hand from the process you also exclude much of what used to be a corner-stone in creating and fostering communities and identity as well as our bodily comprehension of the nature of materials.

Even though this discussion have been present throughout the length of the work, most of it has been conducted without taking a clear stand, many elements in the design could be the result of both industrial production or artisanal work, while others clearly demand labour intensive procedures.

Perhaps the lack of clear positioning here is a flaw, yet valid arguments exist for both paths. To be more radical and disregard regulations or economic factors might have resulted in a more intriguing design proposal but maintaining some kind of plausibility in relation to more conventional building processes made more sense concerning the urgency of the task at hand.

The economical implications of some of the procedures, within the prevailing rationality of construction, are understood but the choice was made not to exclude them because of it. Perhaps a alternate rationality is exactly what is needed, in a system where energy consumption and damage to ecological infrastructure would face the same taxation or higher than manual labour, then the act of building would change fundamentally. In theory, such a reform would make the use of Low Impact Materials, and the procedures associated with it, make perfect sense.

Regulations & building codes

A Low Impact Material strategy is not entirely easy to implement while operating within Swedish building legislation and economy.

Micheal Englund and Carl-Henrik Barnekow wrote an article on how planning laws could be changed to promote building of low energy constructions. Their point was to apply the Finish legislation where surface area of the outer walls that exceeds 25 cm thickness is not included in the calculation that determines the land price. (SvD, 21/2-2020) This would end the pursuit of slim exterior walls and could enable a wider use of well insulated low impact material wall constructions.

Sharper ways to regulate energy efficiency than only normative u-values could be developed. An earth construction needs to be about 5 meters thick to achieve the u-value of 0,18 which is the norm (BBR ch.9§2) while little attention to thermal inertia or overall performance of the construction is considered.

Testing and certifying materials and constructions is also important, right now clay is being tested to attain fire classification within the Swedish systems.

Specifying building heights rather than number of floors could simply and somewhat spread the use of thicker intermediate floors not requiring it to be a steel or concrete construction.

High-Tech vs. Low-Tech

Rather than aiming for high tech solutions, striving for smart low tech systems that are based on natural ecocycles and passive principles is a way to reach a holistically sustainable building (Engblad, 2018). The choice of low impact materials goes in line with this strategy. Materials should be used according to their properties and performance (Hillebrandt et. al, p. 58). Thereby, qualities like thermal inertia and moisture buffering, can be utilised and support a low tech concept.

6.

References

South entrance and plaza seen from west

People

Bertil Björk
Telephone Conversation 13.01.2020
Head of operations at STPLN Malmö

Ulrik Hjort Lassen
Meeting 15.01.2020
Carpenter and specialist in timber frame constructions, Member of Kvibergsnäs Bygghantverk and Stolpverk Nord

Ulf Henningsson
Clay Workshop 30.1.-02-02-2020
Clay building specialist and craftsman

Alexander Sehlström
Meeting 24.02.2020
Wood engineer at WSP and Phd student at Chalmers

Annika Cross
Meeting 27.02.2020
Head of department "Ung Kultur" at Lagerhuset for Göteborg Stad

Ylva Sandin
Meeting 27.02.2020
Wood engineer and researcher at Chalmers/RISE

Angélica Karlsson
Meeting 16.03.2020
Projectleader at Lokalförvaltningen Gothenburg for the fossil free primary school Hoppet

Joakim Kaminsky
Telephone Conversation 16.04.2020
Architect, Kjellgren Kaminsky

Literature

- Attia, S. (2018). Regenerative and Positive Impact Architecture : Learning From Case Stufdies. Cham, Switzerland: Springer.
- Bokalders, V., Block, M.(2010) The Whole Building Handbook, Earthscan, London
- Boverket, (2015) Byggnaders klimatpåverkan utifrån ett livscykelperspektiv, Boverket Internt, Karlskrona
- Brown, L. R., & Morishima, A. (2002). Eco-Economy: Dialogue with Lester R. Brown. International Review for Environmental Strategies, 3(1), 63-72. Retrieved from http://proxy.lib.chalmers.se/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=15322422&site=eho st-live&scope=site
- Byggnadsvårdsföreningen. (2017). Isoleringsmaterial från A till W. Retrieved 2020-04-18 from: https://byggnadsvard.se/isoleringsmaterial-fran-a-till-w/
- Carbon Brief, Zeke Hausfather, UNEP: 1.5C climate target ´slipping out of reach´,November 2019 Retrieved 2020-02-20 from: https://www.carbonbrief.org/unep-1-5c-climate-target-slipping-out-of-reach
- Dale, S. (2007). Design: Organic Architecture. Retreived from http://www.simondale.net/intview.htm
- Delestrac, D. (Producer). (2013). Sand Wars. Retrieved from https://chalmers. kanopy.com/video/sand-wars
- Delin, M. (2019) "Kunskapsläget för brandprojektering av trähus", Forskningsdirektör, Brandforsk. Retrieved 2020-03-17 from https://www.traguiden.se/om-tra/byggfysik/brandsakerhet/
- Ece, N. (2018). (2018) Building Biology, Architectural Design & Criteria, Birkhäuser Basel.
- Ekoskog. (n.yd). Om ekoskog. Retrieved from http://ekoskog.org/about.html
- EllenandMacArthurFoundation. (2017). Circular Economy: Concept. Retrieved from https://www.ellenmacarthurfoundation.org/circular-economy/concept
- EllenandMacArthurFoundation. (2017). Circular Economy: Schools of thought. Retrieved from https://www.ellenmacarthurfoundation.org/circular-economy/concept/schools-of-thought
- Engblad, E. (program leader and editor). (2018, January 16). Form Symposium: Anders Nyquist, arkitekt och grundare bakom EcoCycleDesign [Podcast]. Retrieved from https://poddtoppen.se/podcast/1300820034/form-symposium/anders-nyquist-arkitekt-och-grundare-bakom-ecocycledesign
- Englund, M. Barnekow, C.H. (2020-02-21) Liten förändring ger energieffektivare hus [SvD Debatt] Retrievd 2020-03-25 from: https://www.svd.se/liten-forandring-ger-energieffektivare-hus
- Grey, L. (2013). HALM (råg) – en livscykelanalys. Retrieved from https://www.slojdochbyggnadsvard.se/siteassets/sob/halm_lca.pdf
- Grey, L. (2013). LERA – en livscykelanalys. Retrieved from https://www.slojdochbyggnadsvard.se/siteassets/sob/lera_lca.pdf
- Geiser, K. (2001) Materials Matter: Toward a sustainable materials policy, MIT

• Golden, E.M. (2018) Building from tradition, Routledge 2 Park Square, Milton Park, Abingdon, Oxon
• Hackel, M., Hackel, A., Wismadi, A., Agustiananda, P. A. P., Fauziah, M., Kus- hari, B., . . . Fajri, J. A. (2019). Architecture, Ecology and Economy: Synergy or Contradiction? MATEC Web of Conferences, 280, N.PAG. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=edb&AN=136717454&site=eds-live&scope=site&custid=s3911979&authtype=sso&group=main&profile=eds
• Harper, P. (2019). Repair as Celebration. In P. Harper, M. Bogensberger, & H. d. Architektur (Eds.), Gestures in Time: Architecture Yearbook Graz Styria 2019. Barcelona: dpr-barcelona.
• Hejdelind, V (2018, Aug,) Varför bygger vi för livsstilar som inte längre existerar? para. 3. Sveriges Arkitekter. Retrived & translated 2020/01/19 from https://www.arkitekt.se/varfor-bygger-vi-for-livsstilar-som-inte-langre-existerar/
• Hes, D., & Du Plessis, C. (2015). Designing for hope : pathways to regenerative sustainability: Routledge.
• Hillebrandt, A., Riegler-Floors, P., & Rosen, A. (2019). Manual of recycling : buildings as sources of materials: Detail.
• Hudert, M. Pfeiffer, S (Eds.) (2019) Rethinking wood, Birkhäuser, Basel
• IBO. (n.d.). Materialökologie: Umweltindikatoren. Retrieved from https://www.ibo.at/materialoekologie/lebenszyklusanalysen/ibo-richtwerte-fuer-baumaterialien/treibhauspotenzial-primaerenergieverbrauch-versauerungspotenzial/
• International Energy Agency (IEA) & United Nations Environment Program (UNEP), (2019), 2019 Global Status Report for buildings and Construction
• International Passive House Association (2018). Active for more comfort: Passive House: Information for property developers, contractors and clients. Retrieved from https://passivehouse-international.org/upload/Passive_House_Active_for_more_comfort_brochure.pdf
• Iyengar, K. (2015). Sustainable architectural design : an overview: Routledge.
• Klinge, A., Roswag-Klinge, E., Fontana, P., Hoppe, J., Richter, M., & Sjöström, C. (2016). Reducing the need for mechanical ventilation through the use of climate-re- sponsive natural building materials. Retrieved from http://www.h-house-project.eu/images/04_Documents/02_Publications/161128_Lehm_2016/lehm2016_b_klinge-roswag-fontana-hoppe-richter-sjoestroem_en.pdf
• Kristjansdottir, T., Fjeldheim, H., Selvig, E., Risholt, B., Time, B., Georges, L., Dokka, T. H., Bourelle, J., Bohne, R., Cervenka, Z. (2014). A Norwegian ZEB-definition embodied emission. (ZEB Project report, No.17). Research Centre on Zero Emission Buildings. Retrieved from https://www.sintefbok.no/book/index/993
• Kungl. Ingenjörsvetenskaps Akademin (IVA), (2014).
• Klimatpåverkan från byggprocessen - En rapport från IVA och Sveriges Byggindustrier

• lammas.org.uk. (2020). Ecovillage: Natural Building. Retreived from https://lammas.org.uk/en/ecovillage/
• Lenz, B., Schreiber, J., Stark, T., & Schreiber, J. (2013). Sustainable Building Services : Principles - Systems - Concepts. München, GERMANY: Detail Business Information GmbH, The.
• Liedl, P., & Rühm, B. (2019). Gesundes Bauen und Wohnen : Baubiologie für Bauherren und Architekten (1. Auflage. ed.): Deutsche Verlags-Anstalt
• Marsden, T., & Farioli, F. (2015). Natural powers: from the bio-economy to the eco-economy and sustainable place-making. Sustainability Science, 10(2), 331-344. doi:10.1007/s11625-014-0287-z
• Miljö- och klimatnämnden (2018). Fossilfritt Göteborg - Vad krävs? Miljöförvaltningen, Göteborgs Stad.
• Minke, G., & Mahlke, F. (2005). Building with straw : design and technology of a sustainable architecture: Birkhäuser.
• Sauer, M. (2015). Martin Rauch, refined earth : construction & design with rammed earth: Detail - Institut für internationale Architektur-Dokumentation GmbH & Co. KG.
• Schreckenbach, H. (2014). Lehmbau Info Verbraucherinformation. Retrieved from Weimar: https://www.dachverband-lehm.de/pdf/DVL_verbraucherinfo_de.pdf
• Sing, L., Metzger, M. J., Paterson, J. S., & Ray, D. (2017). A review of the effects of forest management intensity on ecosystem services for northern European temperate forests with a focus on the UK. Forestry: An International Journal of Forest Research, 91(2), 151-164. Retrieved from https://doi.org/10.1093/forestry/cpx042
• UNEP, (2018). The Emissions Gap Report 2018, United Nations Environment Program, Nairobi
• UNFCC, (2020) What is the Paris agreement? Retrieved 2020-02-19 from *https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement*
• Volhard, F., & Röhlen, U. (2009). Lehmbau Regeln (D. Lehm Ed.). Wiesbaden: Vieweg+Teubner Verlag.
• Watts, J. (2019, feb 25) Concrete: The most destructive Material on earth. *The Guardian*. Retrieved 2020-03-12 from *https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth*
• Örebro Kommun, (2016) Vi ger arkitekten makten,
Retrieved 2020-04-20 from: *https://extra.orebro.se/byggorebro vigerarkitektenmakten.4.7bb58d5d154d257e2bcc852.html*

Images

Own pictures, illustrations, drawings and diagrams not listed under References

- Figure 2. Hausfather, Z. (2019) Carbon Brief [Reworked chart] Retrieved from: https://www.carbonbrief.org/unep-1-5c-climate-target-slipping-out-of-reach.
- Figure 3. Iyengar, K. (2015). Sustainable architectural design, Embodied energy of building materials [Reworked Chart]
- Figure 6. Ellen MacArthur Foundation. (2019). Circular Economy System Diagram [Online Image]. Retrieved from https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail
- Figure 7. EPEA. (n.d.). Cradle to Cradle [Online Image]. Retrieved from https://epea.com/en/about-us/cradle-to-cradle
- Figure 12. Assembly of CNC milled timberframe, Barnyard, 2016 Retrieved 2020-04-22 from http://www.thebarnyardstore.com/blog/detail/?id=588
- Figure 13. CNC milled timber joints, SWG Schraubenwerk, Gaisbach 2016 Retrieved 2020-04-22 from: https://www.hkarchitekten.at/en/project/swg-schraubenwerk-gaisbach/
- Figure 14. Drawing of Rheinbrücke, Killer,J. 1985 Die werke der Baumeister Grubenmann. [PDF] Birkhauser, Basel
- Figure. 15. Image of German Timber frame house, no author, no date Retrieved 2020-01-15 from: https://www.skyscrapercity.com/threads/germany-at-the-end-of-the-19th-century-before-wwii-historical-photos.196145/page-64#post-100370929
- Figure 16. Dachverband Lehm. (2014). Lehmbau·info: Verbraucherinformation [PDF]. Retrieved from https://www.dachverband-lehm.de/pdf/DVL_verbraucherinfo_de.pdf
- Figure 18. Bühler, B. (2020). Rauch House in Austria by Roger Boltshauser with Martin Rauch [Online Image]. Retrieved from https://www.architectural-review.com/buildings/earth/rauch-house-in-austria-by-roger-boltshauser-with-martin-rauch/10046393.article
- Figure 21. Weber, S. (2011). Eco-Friendly House in Deitingen [PDF] Photo courtesy of © www.swebfoto.ch. Retrieved from https://www.detail.de/fileadmin/uploads/10-PDFs/Sonderpreis_Green_Architecture_2011_Wohnhaus_Flury.pdf

7. Appendix

View from Järntorget

Passive house
Construction U-values

Byggnad: Material Matters Master Thesis

Kilformade byggnadsdelar (isolering med fall på platta tak) och luftspalt -> se sekundär beräkning till höger

Byggnadsdel nr	Beskrivning av byggnadsdel
1	Outer wall

Värmeövergångsmotstånd [m²K/W] inre Rsi: 0,13; yttre R_{sa}: 0,10

	Sektion 1	λ [W/(mK)]	Sektion 2 (frivilligt)	λ [W/(mK)]	Sektion 3 (frivilligt)	λ [W/(mK)]	Summa bredd Tjocklek [mm]
1.	Cladding	0,130					34
2.	Air gap		Battens	0,130			46
3.	Woodfibre Board	0,050					60
4.	Insulation iso-stroh	0,043	Wood beam	0,130			350
5.	Clay Board Lemix	0,353					22
6.	Clay Plaster Oberputz fe	0,910					3
7.	Clay Plaster Feinputz 06	0,910					2
8.							

Procentandel för sektion 2: 10,0%
Procentandel för sektion 3: 1,0%
Summa: 51,7 cm

U-värde: 0,114 W/(m²K)

Tei

R''T

Byggnadsdel nr	Beskrivning av byggnadsdel
2	Roof

värmeövergångsmotstånd [m²K/W] inre R_{si}: 0,13; yttre R_{sa}: 0,04

	Sektion 1	λ [W/(mK)]	Sektion 2 (frivilligt)	λ [W/(mK)]	Sektion 3 (frivilligt)	λ [W/(mK)]	Summa bredd Tjocklek [mm]
1.	Turf (estimated)	1,000					120
2.	Birch Bark	0,075					16
3.	Tounge and Groove	0,130					23
4.	Air Gap		Battens	0,130			46
5.	Woodfibre Board	0,050					25
6.	Insulation iso-stroh	0,043	Battens	0,130			400
7.	Clay Board Lemix	0,353					22
8.	Clay Plaster 2 layer fir	0,910					5

Procentandel för sektion 2: 10,0%
Procentandel för sektion 3: 8,0%
Summa: 65,7 cm

U-värde: 0,109 W/(m²K)

Tei

R''T

Byggnadsdel nr	Beskrivning av byggnadsdel
3	Foundation

Värmeövergångsmotstånd [m²K/W] inre R_{si}: 0,13; yttre R_{sa}: 0,10

	Sektion 1	λ [W/(mK)]	Sektion 2 (frivilligt)	λ [W/(mK)]	Sektion 3 (frivilligt)	λ [W/(mK)]	Summa bredd Tjocklek d_i [mm]
1.	Rammed Earth	1,000					180
2.	Blue Mussel Shells	0,120					800
3.							
4.							
5.							
6.							
7.							
8.							

Procentandel för sektion 2:
Procentandel för sektion 3:
Summa: 98,0 cm

U-värde: 0,141 W/(m²K)

Tei

R''T

LCA Analysis - Low Impact Materials

Values Based on IBO Database

2

Foundation

Area: 1 kvm

	Type	Material	Thickness	cc	Trp km	Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
wax					50,0	0,000	0,000	0,000
primer					50,0	0,000	0,000	0,000
	Concrete	Clay - massive clay 2,000kg / m³	0,180	1,0	50,0	0,008	0,000	0,002
	Add.your.own.epd	Blue mussel shell (not confirmed values)	0,800	1,0	50,0	0,024	0,000	0,001
gravel					50,0	0,000	0,000	0,000
geotextile					50,0	0,000	0,000	0,000
					50,0	0,000	0,000	0,000
					50,0	0,000	0,000	0,000
					50,0	0,000	0,000	0,000
					50,0	0,000	0,000	0,000
	Climate emission foundation					**0,032**	**0,000**	**0,004**
					kg CO2/m2:	35,6	0,00	
					Conventional	112,28		

5

Roof

Area: 1,00 kvm

	Type	Material	Thickness	cc	Trp km	Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
turf	Other	plant substrate	0,120	1	50	0,001	0,000	0,00
bark	Wood	Sawn wood rough, air-dry.	0,002	1	50	0,000	0,001	0,00
	Wood	Sawn wood rough, air-dry.	0,023	1	50	0,001	0,019	0,00
	Wood	Sawn wood rough, air-dry.	0,046	0,1	50	0,000	0,004	0,00
	Insulation.material	straw	0,400	0,9	50	0,005	0,059	0,00
	Wood	Sawn wood rough, air-dry.	0,400	0,10	50	0,002	0,033	0,00
	Concrete	Clay building board	0,022	1	50	0,002	0,002	0,00
	Mortar.Gypsum.Bo	clay plaster	0,005	1	50	0,000	0,000	0,00
						0,000	0,000	0,00
	Climate emission Outer wall					**0,012**	**0,118**	**0,001**
					kg CO2/m2:	13,8	117,76	
					Conventional	91,34		

4

Intermediate floor

Area: 1,00 kvm

Type	Material	Thickness	cc	trp km	Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Wood	Sawn wood rough, air-dry.	0,034	1,00	50	0,002	0,028	0,000
Concrete	Clay - light clay 600-800 kg / m³	0,030	0,90	50	0,004	0,005	0,000
Wood	Sawn wood rough, air-dry.	0,030	0,10	50	0,000	0,002	0,000
Concrete	Clay - massive clay 2,000kg / m³	0,224	0,90	50	0,009	0,000	0,003
Wood	sawn wood rough, air-dry.	0,224	0,10	50	0,001	0,018	0,000
Wood	sawn wood rough, air-dry.	0,026	1,00	50	0,002	0,021	0,000
Concrete	Clay building board	0,022	1,00	50	0,002	0,002	0,000
Mortar.Gypsum	clay plaster	0,005	1,00	50	0,000	0,000	0,000
					0,000	0,000	0,000
					0,000	0,000	0,000
Climate emissions intermediate floors					**0,020**	**0,077**	**0,003**
				kg CO2/m2	23,3	77,14	
			Conventional		81,99		

7

Load Bearing GENERAL GLULAM GL32 (20x44cm)

Area: 0,088 kvm

Type	Material	Thickness	cc	trp km	Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Wood	Sawn wood rough, air-dry.	6,000	1,00	50	0,031	0,431	0,002
-					0,000	0,000	0,000
-					0,000	0,000	0,000
					0,000	0,000	0,000
-					0,000	0,000	0,000
-					0,000	0,000	0,000
-					0,000	0,000	0,000
-					0,000	0,000	0,000
-					0,000	0,000	0,000
Climate emissions windows					**0,031**	**0**	0,00
				kg CO2/m2	370,17		
			GENERAL HEB22		56.078		

3

Inner Wall

Area: 1 kvm

	Type	Material	Thickness	cc	Trp km	Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
1) light								
0,010	Mortar.Gypsum.Board	clay plaster	0,010	1,000	50,0	0,000	0,000	0,00010625
0,044	Concrete	Clay building board	0,044	1,0	50,0	0,004	0,005	0,0001375
0,095	Insulation.material	straw	0,095	0,9	50,0	0,001	0,014	0,0001539
0,095	Wood	Sawn wood rough, air-dry.	0,095	0,1	50,0	0,001	0,008	3,2063E-05
2) heavy				0,1	50,0	0,000	0,000	0
0,010	Mortar.Gypsum.Board	clay plaster	0,010	1,00	50,00	0,000	0,000	0,00010625
0,044	Concrete	Clay building board	0,044	1,0	50,00	0,004	0,005	0,0001375
0,052	Concrete	Mud brick 2000 kg / m³	0,052	0,9	50,00	0,002	0,000	0,000585
0,052	Wood	Sawn wood rough, air-dry.	0,052	0,10	50,00	0,000	0,004	0,00001755
				0,10	50,00	0,000	0,000	0

	1) light	2) heavy	1) light	2) heavy		
Climate emission load bearing and inner walls	**0,006**		**0,027**	**0,010**	1) light:	**0,0004**
kg CO2/m2:	7,1		26,95	9,525504	2) heavy	**0,0008**
Conventional	18,9					

6

Outer Wall

Area: 1,00 kvm

Type	Material	Thickness	cc	Trp km	Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Wood	Sawn wood rough, air-dry.	0,034	1	50	0,002	0,028	0,00
Wood	Sawn wood rough, air-dry.	0,046	0,1	50	0,000	0,004	0,00
Wood	Fiberboard, porous 270 kg / m³	0,060	0,1	50	0,002	0,002	0,00
Insulation.material	straw	0,300	0,9	50	0,004	0,044	0,00
Wood	Sawn wood rough, air-dry.	0,300	0,1	50	0,002	0,025	0,00
Concrete	Clay building board	0,022	1	50	0,002	0,002	0,00
Mortar.Gypsum.Board	clay plaster	0,005	1	50	0,000	0,000	0,00
					0,000	0,000	0,00
					0,000	0,000	0,00
Climate emission roof					**0,012**	**0,105**	**0,001**
				kg CO2/m2:	12,9	105,06	
			Conventional		64,56		

LCA Analysis - Conventional Construction

Values Based on IBO Database

2

Foundation	Efo 01 a Plattenfundament, oberseitig gedämmt, Nassestrich				Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Area		1 kvm					
Type	Material	Thickness	cc	Trp km			
Flooring.and.textile	parquet adhesive	0,010	1,0	50,0	0,011	0,000	0,000
Mortar.Gypsum.Bo	screed concrete	0,050	1,0	50,0	0,012	0,000	0,001
Insulation.material	Rigid polyurethane foam	0,010	1,0	50,0	0,002	0,000	0,000
Insulation.material	Polystyrene extruded CO2-foamed (XPS)	0,240	1,0	50,0	0,038	0,000	0,000
Profing.films	Aluminum bitumen waterproofing membrane	0,004	1,0	50,0	0,008	0,000	0,000
Concrete	Normal concrete	0,150	1,0	50,0	0,033	0,000	0,002
Profing.films	Construction paper horziontal	0,0003	1,0	50,0	0,000	0,000	0,000
Concrete	Splittschüttung (slightly cement-bound)	0,150	1,0	50,0	0,003	0,000	0,002
Profing.films	Fleece (PP)	0,0002	1,0	50,0	0,000	0,000	0,000
			1,0	50,0	0,000	0,000	0,000
Climate emission foundation					**0,108**	**0,000**	**0,005**
				kg CO2/m2:	112,28	0,50	

5

Roof	DAm 03 a Stahlbeton-Flachdach als Warmdach				Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Area		1,00 kvm					
Type	Material	Thickness	cc	Trp km			
Concrete	Splittschüttung (slightly cement-bound)	0,060	1	50	0,001	0,000	0,00
Profing.films	Polymer bitumen waterproofing membrane	0,008	1	50	0,007	0,000	0,00
Profing.films	Vapor pressure equalizing layer	0,002	1	50	0,001	0,000	0,00
Insulation.material	Polystyrene expanded (EPS) -W20 insulation board	0,360	1	50	0,030	0,000	0,00
Profing.films	Aluminum bitumen waterproofing membrane	0,001	1	50	0,003	0,000	0,00
Profing.films	Vapor pressure equalizing layer	0,002	1	50	0,001	0,000	0,00
Concrete	Normal concrete	0,200	1	50	0,044	0,000	0,00
Mortar.Gypsum.Bo	gypsum areas	0,003	1	50	0,000	0,000	0,00
					0,000	0,000	0,00
Climate emission Outer wall					**0,088**	**0,000**	**0,004**
				kg CO2/m2:	91,34	0,07	

4

Intermediate fl	GDm 02 a Stahlbeton-Geschoßdecke, Distanzboden				Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Area		1,00 kvm					
Type	Material	Thickness	cc	trp km			
Flooring.and.te	parquet adhesive	0,010	1,00	50	0,011	0,000	0,000
Wood	Wood chipboard cement bonded (<	0,032	1,00	50	0,007	0,012	0,000
Insulation.mater	Glass wool MW-WF	0,080	0,99	50	0,004	0,000	0,000
Steel.and.metal	aluminum sheet	0,080	0,01	50	0,013	0,000	0,000
Concrete	Normal concrete	0,200	1,00	50	0,044	0,000	0,003
Mortar.Gypsum	gypsum areas	0,003	1,00	50	0,000	0,000	0,000
			1,00	50	0,000	0,000	0,000
			1,00	50	0,000	0,000	0,000
					0,000	0,000	0,000
					0,000	0,000	0,000
Climate emissions intermediate floors					**0,079**	**0,012**	**0,003**
				kg CO2/m2	81,99	12,35	

7

Load Bearing	GENERAL HEB22				Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Area		0,0027636 kvm		0,008826			
Type	Material	Thickness	cc	trp km			
Steel.and.metal	Unalloyed steel	6,000	1,00	50	0,154	0,001	0,001
-					0,000	0,000	0,000
-						0,000	0,000
					0,000	0,000	0,000
-					0,000	0,000	0,000
-					0,000	0,000	0,000
-					0,000	0,000	0,000
-					0,000	0,000	0,000
-					0,000	0,000	0,000
Climate emissions windows					**0,154**	**0**	0,00
				kg CO2/m2	56078,10		

3

Inner Wall	IWI 01 a Ständer-Scheidewand, nichttragend				Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Area		1 kvm					
Type	Material	Thickness	cc	Trp km			
Mortar.Gypsum.Board	Plasterboard	0,010	1,0000	50,0	0,002	0,000	0,00005625
Insulation.material	Glass wool MW-WF	0,075	0,9900	50,0	0,004	0,000	2,2275E-05
Steel.and.metal	aluminum sheet	0,075	0,0100	50,0	0,013	0,000	1,3125E-05
Mortar.Gypsum.Board	Plasterboard	0,010	0,1000	50,0	0,000	0,000	5,625E-06
				50,00	0,000	0,000	0
				50,00	0,000	0,000	0
				50,00	0,000	0,000	0
				50,00	0,000	0,000	0
Climate emission load bearing and inner walls					**0,019**	**0,000**	**0,0001**
				kg CO2/m2:	18,90	0,3846	

6

Outer Wall	AWm 01 a Stahlbeton-Außenwand, WDVS				Emissions [ton CO2]	Storage [ton CO2]	Transp [ton CO2]
Area		1,00 kvm					
Type	Material	Thickness	cc	Trp km			
Mortar.Gypsum.Board	gypsum areas	0,003	1	50	0,000	0,000	0,00
Concrete	Normal concrete	0,180	1	50	0,039	0,000	0,00
Insulation.material	Polystyrene expanded (EPS) -F fac	0,320	1	50	0,021	0,000	0,00
Mortar.Gypsum.Board	Silicate plaster (without synthetic re	0,002	1	50	0,001	0,000	0,00
			1	50	0,000	0,000	0,00
			1	50	0,000	0,000	0,00
			1	50	0,000	0,000	0,00
					0,000	0,000	0,00
					0,000	0,000	0,00
Climate emission roof					**0,062**	**0,000**	**0,003**
				kg CO2/m2:	64,56	0,01	

Master Thesis Spring 2020
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