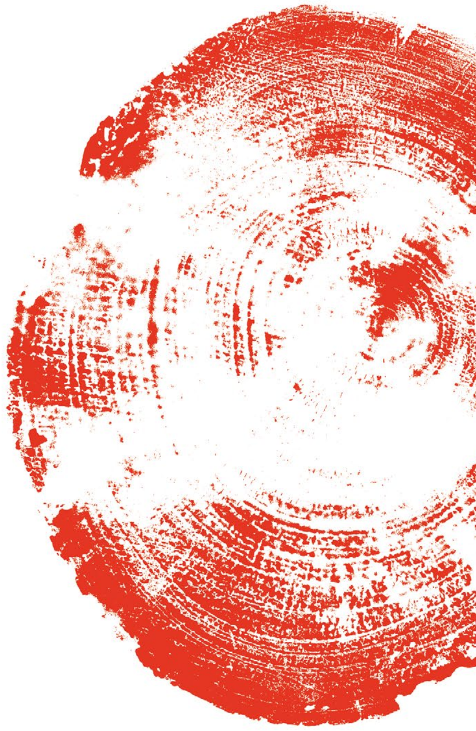
Marc Schweiker | Chalmers School of Architecture | **2026**



**EN 14081-1 C24**

How Can Timber Architecture
Achieve Holistic Sustainability?

Department of Architecture &
Civil Engineering
examined by Walter Unterrainer
supervised by Carrie Bobo Gibbs

EN-14081-1 C24
How Can Timber Architecture Achieve Holistic Sustainability?

Chalmers School of Architecture
Department of Architecture & Civil Engineering
Architecture and Planning Beyond Sustainability (MPDSD)
Building Design and Transformation for Sustainability
Examiner: Walter Unterrainer
Supervisor: Carrie Bobo Gibbs

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## ABSTRACT

This master thesis explores how timber architecture can be genuinely sustainable – from the first act of harvesting, through the manufacturing and building process to the reuse and disassembly of a building at the end of its life. It questions the contemporary notion of "sustainable" wooden construction, which has been criticized for an overreliance on complex assemblies, and an abundance of materials, while neglecting the quiet intelligence of simplicity and the respect for wood as a natural material.

The investigation is rooted in the idea that progress in timber architecture does not necessarily mean adding more layers and creating increasingly complex shapes, but rather removing what is unnecessary and working within the limits of the material. Inspired by the philosophy of Einfach Bauen by Florian Nagler, this thesis seeks to rediscover an architecture that builds less to achieve more – where design decisions are formed from the material itself and from a local context rather than technological excess. By analyzing built examples and their building methods, the thesis aims to initiate a rethinking process that demonstrates that sustainable solutions do not entail a downgrade in quality, but rather a refinement.

Through a critical examination of the entire timber construction process, techniques are examined that enable more responsible, material-conscious timber construction. For the investigation, a field trip was taken to gain firsthand knowledge of building practices passed down through generations. Analytical diagrams visualize areas of concern, and a catalogue of detailed drawings with various assemblies explores comparisons between contemporary methods and more sustainable approaches. Model building served on one hand to understand structural differences and on the other to demonstrate materiality and performance at a 1:1 scale.

Ultimately, EN 14081-1 C24 – the European classification for structural solid timber – serves both as a technical reference and as a metaphor for this investigation. It symbolizes both the standardization of a natural material, as well as its potential when handled with respect and precision. This thesis aims to reframe the narrative of sustainability in timber architecture – not as a pursuit of perfection, but as an act of awareness and care towards the material that has built our past and could define our future.


[1] Chopped timber logs under a simple roof; Vorarlberg, Austria; photography by the author

Keywords: Wood, Sustainability, Construction, Circularity, Reduction

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## GLOSSARY

**anisotropy**

the property of being directionally dependent, as in having different physical properties or characteristics in different directions

**calamity wood**

timber that becomes available as a result of a natural disaster or environmental crisis

**cambium**

a layer of cells in the roots and stems of some plants that divide to produce new tissue, such as xylem and phloem

**carcinogen**

a substance that causes cancer

**checking**

a natural process where wood fibers separate and form cracks as the timber dries and shrinks

**Cross Laminated Timber (CLT)**

an engineered wood panel made by stacking and gluing multiple layers of solid-sawn lumber, where each layer is oriented at a 90° angle to the layer below

**coarse wood debris**

fallen dead trees, large branches, and stumps resting on the forest floor or in rivers and wetlands

**compression wood**

a type of abnormal, dense reaction wood that forms in trees on the underside of leaning stems or branches

**Computerized Numerical Control (CNC)**

a manufacturing process where pre-programmed software dictates the movement and operation of factory tools and machinery

**coniferous**

a tree producing cones, and having leaves that do not fall off in the winter

**constructive wood protection**

the practice of designing and building with wood in a way that naturally prevents deterioration from moisture, weather, and pests

**cradle to grave**

something that spans the entire life span, from birth to death

**cupping**

wood deformation or warping where the edges of a wooden board rise higher than the center

**deadwood**

dead branches or trees

**to dowel**

to fasten or reinforce materials – usually wood or masonry – using small cylindrical pins or rods

**embodied emissions**

the total greenhouse gas (GHG) emissions generated during the entire life cycle of a product or service

**empirical knowledge**

information and understanding gained through direct observation, sensory experience, or experimentation

**engineered wood products**

man-made building materials created by binding or fixing together wood with adhesives to form strong, uniform, and structurally reliable composite materials

**Equilibrium Moisture Content (EMC)**

the specific moisture level at which a hygroscopic material neither absorbs moisture from the air nor releases moisture into it

**Fachwerk**

buildings with an exposed wooden framework where the spaces in between are filled with materials like plaster, clay, or brick

**Fiber Saturation Point (FSP)**

the critical moisture state in wood where the cell walls are completely saturated with bound water, but there is no liquid "free water" left in the cell cavities

**formaldehyde**

$CH_2O$: a colorless, strong-smelling, and flammable gas

**Global Warming Potential (GWP)**

the potential of the system to trap greenhouse gases in the atmosphere, leading to climate change

**Glue Laminated Timber/ glulam (GLT)**

an engineered structural wood product made by bonding layers of dimensional lumber together with moisture-resistant structural adhesives

**gridling**

the deliberate process of stripping or cutting a continuous band of bark around the circumference of a tree or branch

**heart-ripewood-trees**

type of tree showing heart- and ripewood in its crosssection

**heartwood**

the dense, dead, central wood of a tree trunk or branch, typically darker than the surrounding sapwood

**holistic sustainability**

an approach that integrates environmental protection across all stages of a certain process from raw material extraction to the end-of-life

**hygroscopic**

a substance absorbing water from the air

**industrial wood**

all wood used for industrial purposes, like engineered wood products, paper and lumber

**kiln**

a type of large oven used to dry wood

**lignin**

a substance found in the edges of some plant cells that makes the plant hard like wood

**logging**

the activity of cutting down trees in order to use their wood

**longitudinal**

extending along the long axis of an object (the opposite of transversal)

**lumber**

wood that has been processed and cut into uniform sizes for use in building and construction

**Laminated Veneer Lumber (LVL)**

a high-strength engineered wood product made by bonding multiple layers of thin wood veneers together with structural adhesives under heat and pressure

**Melamine Urea Formaldehyde (MUF)**

a thermosetting resin used as a strong, water-resistant adhesive and binder

**mineral wool**

a fibrous insulation material made by spinning or drawing molten minerals, such as volcanic rock or glass

**monolithic**

something that is massive, solid, and made of a single piece

**neolithic period**

the New Stone Age, is the final and most advanced stage of the Stone Age lasting roughly from10,000 BC to between 4,500 BC and 2,000 BC

**non-coniferous**

trees or shrubs that do not produce cones and typically have broad, flat leaves

**patina**

a thin surface layer that develops on something because of use, age, or chemical action

**phloem**

the type of plant tissue that transports food from the leaves to the other parts of the plant

**polyfunctionality**

the ability of performing multiple, simultaneous functions

**Polyurethane (PU)**

a type of synthetic plastic polymer without hardener

**Polyvinyl Chloride (PC)**

a type of synthetic plastic polymer

**Portland Cement**

a fine, powdery, hydraulic binder produced by heating limestone and clay, grinding the resulting clinker, and adding gypsum

**Primitive Hut**

Marc-Antoine Laugier's term for the first man made shelters as described by Vitruvius

**radial growth**

an increase in the girth, radius, or diameter of a structure or organism over time

**rhytidome**

the outer, dead layer of bark on a tree or woody plant

**ripewood**

the dead inner wood of certain tree species that retains a similar color to the living sapwood, but has a lower moisture content in the growing tree

**rock wool**

a type of mineral wool, created by melting volcanic rock and spinning it into fine strands

**roundwood**

timber that has been felled but not yet subjected to industrial processing

**sapwood**

the soft, living, and often lighter-colored outer layer of wood in a tree trunk or branch

**sideboard**

boards cut from the outer zones of the log, outside the central heart section

**slab board**

the outermost section of a log removed during the first stage of sawing

**slash debris**

unmerchantable wood left behind on the forest floor after logging operations, storms, or natural disasters

**splitting**

the formation of cracks, checks, or separations along the grain of timber that occur mainly during drying due to uneven shrinkage

**Spolia**

the reuse of building materials, architectural elements, or decorative sculptures from an earlier structure in a new construction

**SUV-architecture**

term coined by Prof. Schürmann, "oversized" architecture, often parametric or complex experimental shapes

**technical annex**

a supplementary document attached to a main report, contract, or research proposal that details specific methodologies, data, or technical specifications

**thermal inertia**

the ability of a material to resist changes in temperature

**transversal**

used to describe something that is at right angles to something else

**warping**

damaged by bending or twisting

**waste wood categories**

location dependend categories to classify wood after the end-of-life

**wood fuel**

wood burned to generate energy

**woody debris**

the dead, aboveground wood of trees and shrubs found in various stages of decomposition

**xylem**

the type of plant tissue that carries water and minerals from the roots to the leaves and gives support to the stem or trunk

## HISTORICAL BACKGROUND

Wood has historically played a huge role in architecture. From simple construction as in Vitruvius' *Primitive Hut* with vertical supports, horizontal beams and triangular pediment, to today's age with parametric shapes and large spans. Its cultural impact is undeniable and its potential as a long-term carbon sink unmatched. However, in the current age mass production and overcomplicated manufacturing processes have led to a majority of wooden buildings being not genuinely sustainable. Whether it being the place or way of sourcing, the transport, processing, construction, preservatives, the deconstruction and the disposal, all must be considered when we talk about sustainability in terms of timber architecture (see "What Is Sustainability" on page 12).

Timber is the most known material to mankind, due to its early use as thermal source and basis for many tools, and later for boats and carriages. The first wooden buildings date back to the *Neolithic period* and were made from stacked tree trunks, forming simple log houses (Krötsch & Müller, 2021). This concept is present till today as a form of solid wood construction (see figure 2). In areas with fewer timber resources, poles were stuck in the ground to form a framework that was filled with clay bricks or clay-plastered wattle. This method used less wood and laid the groundwork for today's skeleton and timber frame construction (see "Carpentry & Construction", page 48) (Krötsch & Müller, 2021).

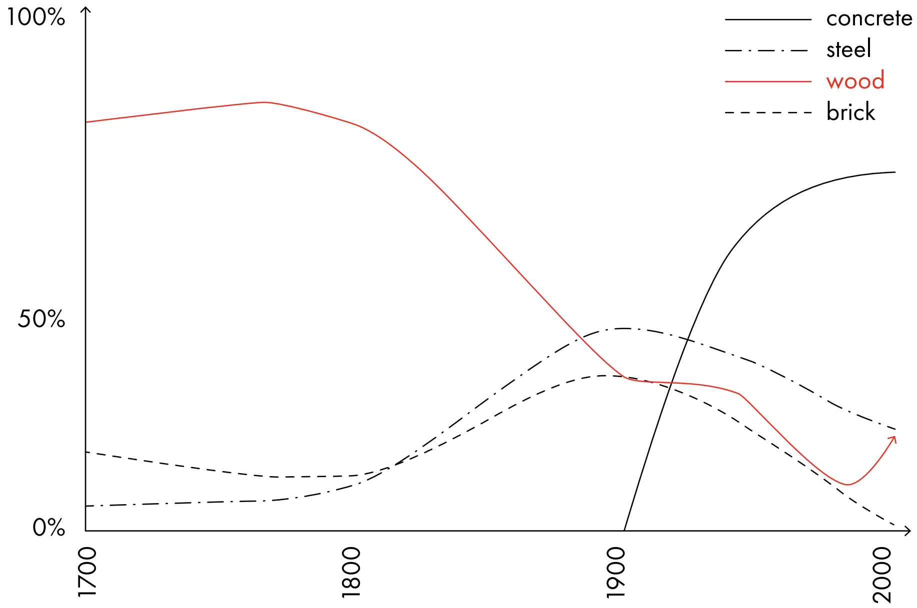
Until the Middle Ages, half-timbered *Fachwerk* buildings became the predominant construction method. This construction technique originated in southern Europe in ancient times and spread north of the Alps in the 12th century (Krötsch & Müller, 2021).

Vertical wooden poles were supported by diagonals that formed a stable framework, behaving like windowpanes and bracing the building immensely. The spaces between the framework were usually filled (German: "ausgefacht") with a mixture of straw or brick and clay (see figure 5). The widespread use of half-timbered buildings in the construction sector over the years has not only led to an immense understanding of constructive wood protection, but also to the prefabrication of components for problem-free assembly on site, which has become increasingly important. Carpenters recognized the importance of planning ahead and started drawing construction plans to hand over to the workers.

In the 19th century, timber was largely replaced by brick and steel during the Industrial Revolution (see figure 3). These "new" materials not only allowed for less resource use but also made larger spans and new shapes possible. Around 1900, glue-laminated timber was invented (patented in 1906 by Otto Hetzer), opening up for new opportunities in the timber building sector by enabling larger spans and simple parametric shapes.

However, the use of concrete after the invention of *Portland Cement* by Joseph Aspdin overshadowed this development. In Modernism the new developed material took over due to its higher durability, load capacity and new aesthetic. By pouring the liquid mixture of water, aggregates and burnt cement into a formwork and reinforcing it with steel bars, almost any shape could be made and was highly resistant to pressure and tension.

In the last centuries tackling climate change became a predominant topic in the world of architecture, since the building sector alone makes up 34% of all CO2 emissions worldwide (UNEP & GABC, 2025). More and more clients and architects resort back to the material, that not only is regenerative but most importantly stores carbon. Today, timber architecture is experiencing its renaissance.




[2] Corner detail of loghouse; Reppen, Norway; photography by the author

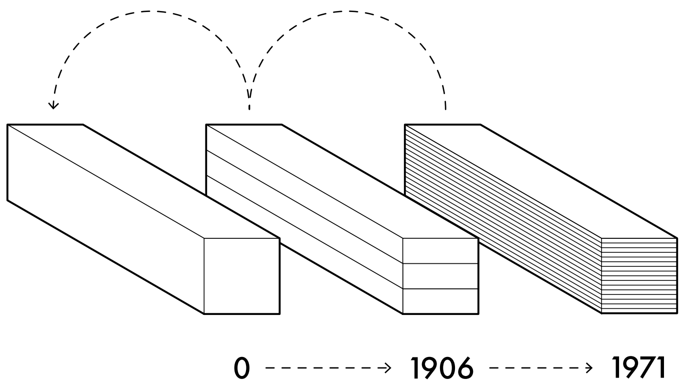
[3] Relative proportion of building materials used in load-bearing structures (adapted from Schweiz Z Forstwes 160 (2009) 12)

## OUTLOOK

With this millennia-old knowledge in mind, is today's approach to timber construction the right one? The obsession of having to develop everything further, adding layers, automated systems and striving for more *SUV-architecture* must be replaced. Because the answer for the future lies in the past and has been overlooked in the last years.

Supposedly "modern" sustainable solutions like the reuse of material and cement or chemical free, raw use of material have already been present in ancient times. The romans used *Spolia* from destroyed buildings and incorporated them in a way that is perceived as beautiful today. What is described as hyper locality today was a standard practice back then. Using what was available, sourcable, and could be manufactured locally was the only possible way.
So why not draw on the knowledge that has accumulated over time? Why attempt to reinvent the wheel when it has worked perfectly well for so long?

Wood as a natural material has its limits and does not have to be used beyond its capabilities. The addition of adhesives and chemicals does not advance the material; it instead diminishes its unique characteristics.
Reembracing wood and respecting it as a natural material that has shaped our past, can unlock its potential to shape a genuinely sustainable future.




[4] Development from solid wood products to glue laminated timber (GLT) and laminated veneer lumber (LVL) over time

[5] Traditional Fachwerk building; Tübingen, Germany; photography by the author

## PROBLEM DESCRIPTION

Today, the building sector accounts for 34% of all global greenhouse gas emissions and uses 37% of electricity globally (IEA, 2024). This is not only due to the extensive use of concrete (Teischinger, 2009), but also to the improper use of wood in timber buildings. Not all wood is the same. For instance, in the case of an engineered wood product, such as *glued laminated timber*, the adhesive component accounts for approximately 50% of $CO_2$ emissions (Frischknecht & Ramseier, 2020), significantly impacting the environment more than solid wood products do.

Additionally, approved standard construction methods in timber framing today consist of about 11 different layers of various materials (dataholz.eu, Aussenwand awrhhi01a), whereas, as recently as 1977, people were still debating the necessity of insulation in new construction (Wilfried Pauer, Zimmerei Grünspecht (2024)). This shows that today's building methods have become overly complex to meet every possible demand for a building. Moreover, these layers rely on non-recyclable materials, such as plastic sheeting used as vapor barriers, and unsustainable insulation materials, such as *mineral wool*.

For this master's thesis, showcasing the current state of timber architecture, a 1:1 scale model of a wall section was built using *rock wool* gathered from a nearby construction site. This demonstrates that these materials are still very frequently used. The suspicion that carcinogenic fibers may be leaking (Baan & Grosse, 2004) and the fact that the material is disposed of as "hazardous waste" (DUB, 2026) do not seem to be a factor into this matter. With the construction sector causing one third of the global waste (UNEP & GABC, 2025) it is clear however, that reducing waste should be a key priority in today's construction industry.

Since 1970, our planet has experienced a 73% loss in species, and biodiversity continues to decrease year after year (WWF, 2024). Unsustainable harvesting methods in the timber industry, such as clear cutting, lead to deforestation, which clearly contributes to this loss (UNEP & GABC, 2025).

However, timber architecture is often perceived as "sustainable" simply because it uses wood, while ignoring how the wood is used and where it comes from (see figure 6). The general public therefore seems to lack an understanding of what sustainability truly entails and that it cannot be achieved solely by using large quantities of wood in a wide variety of projects.


The Guardian

'Pushing the limits' ... the Anthony Timberlands Center. Photograph: Tim Hursley

Arkansas, USA

First conceived as a 'spider's web of sticks', this vast wooden wonder may end up being a template for the environmentally sound buildings of the future

Oliver Wainwright
Tue 26 Aug 2025 17.43 CEST

Share

The built reality looks like the model after a steroid-fuelled weight-training routine. The structural members have been reduced in number but vastly beefed up, while the number of tilting roof planes was also cut on cost grounds. But the sheer heft makes the space no less impressive. Rather than feeling like a scaled-up barn, it now has a heroic, almost Roman quality. While early classical architecture was based on timber carpentry techniques translated into stone, this feels like the logic of concrete construction transmuted into glued-together tree trunks.

Meter-wide columns of glulam (glued laminated timber) plunge from the six-storey-high ceiling, intersecting with equally fat beams, scaled to carry the weight of a five-tonne gantry crane, allowing full-size building prototypes to be hauled back and forth.

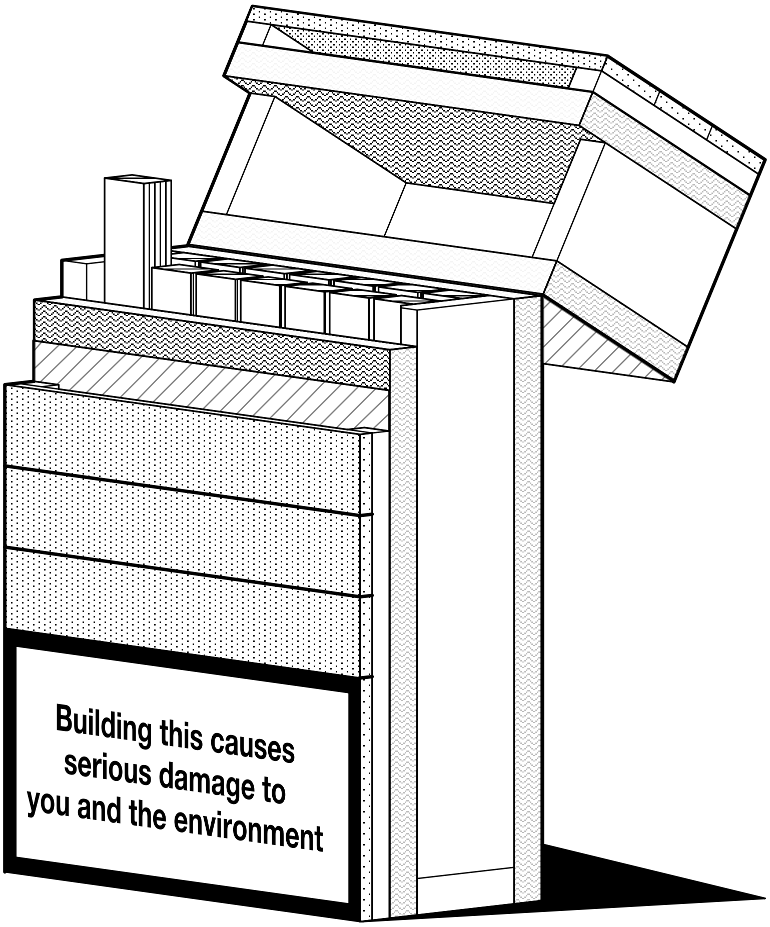
allowing the wide working area below to be column-free. Just like Grafton's Kingston Town House in London, an unlikely marriage of library and dance studios, the visual connection between the studio and workshop was key. As MacKeith puts it: "We wanted a building where thinking and making were inseparable." (Triple glazing helps muffle the whirring robots.)

Beefed-up structural members. Photograph: Oliver Wainwright

"We were originally hoping that the state's mass timber industry would be sufficiently competitive by the time of construction," says assistant professor Jonathan Boelkins, who was instrumental in steering the project. Arkansas had manufactured big glulam beams before, for the Crystal Bridges art museum, but the firm went out of business. Only one cross-laminated timber manufacturer survives, which made the floor and wall slabs for the project,

but the primary structure came from Austrian giant Binderholz, shipped and trucked to the site in lengths of up to 12 metres.

the Austrian product still wins on price and precision.




< [6] Collage of arcticle published in The Guardian (2025)

^ [7] Cigarette-box-shaped wall assembly illustrating environmental and health impacts of current timber construction

## WHAT IS SUSTAINABILITY?

look at entire lifecycle

architecture

**1** the idea that goods and services should be produced in ways that **do not** use resources that cannot be replaced and that do not damage the environment.

wood as renewable material

**2** the ability to continue at a particular level over a period of time.

demands on buildings

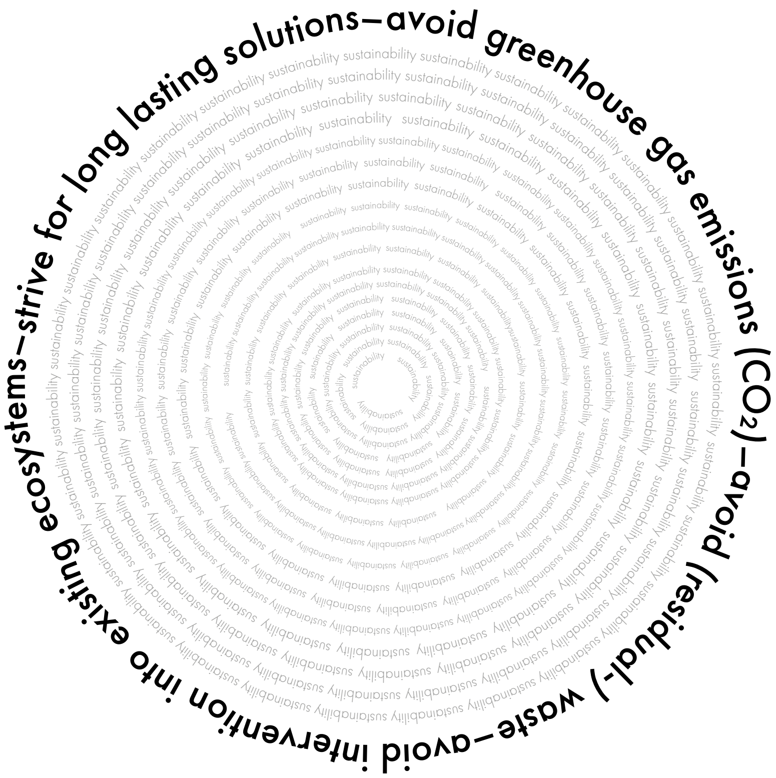
$CO_2$, waste, ecosystems

**3** the quality of causing little or no damage to the environment and therefore able to continue for a long time.

long lasting solutions

The Cambridge Dictionary offers three main definitions of sustainability (see above).
When applied to timber architecture, it can be concluded that architecture should be evaluated not only in its final state, but also throughout the entire process leading up to it. Therefore, simply measuring a building's sustainability by its end product and the materials used while disregarding how those materials are produced and how the structure is built does not do it justice. Additionally, it is important to avoid using finite resources and causing environmental harm.
To set a framework for the evaluation, the building demands as well as the time frame are of importance.
The goal is for the building and the resources used in its production to last as long as possible. Moreover, causing environmental damage should be avoided.
This includes the production of greenhouse gases, such as carbon dioxide, having a significant negative environmental impact. Secondly, the production of non-biodegradable waste is also harmful and thirdly, intervention in existing ecosystems is harmful (UNEP, 2025).

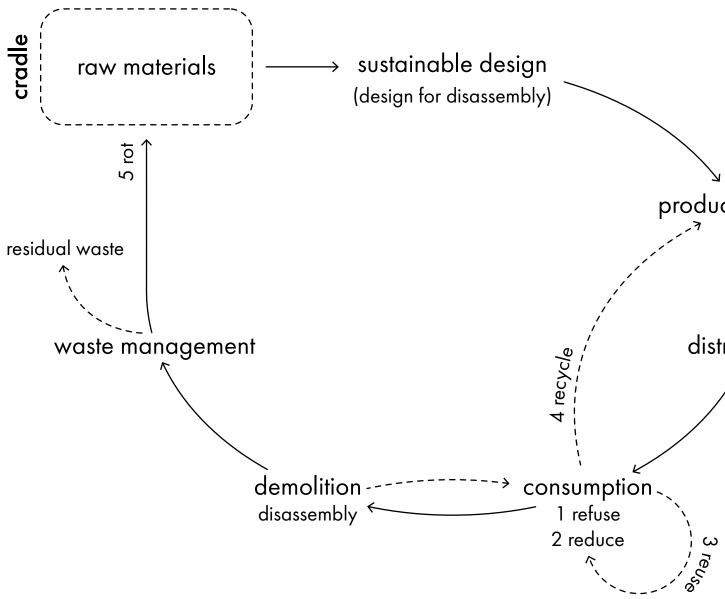
In conclusion, to achieve holistic sustainability, architecture must sustain for as long as possible while minimizing greenhouse gas emissions, waste production, and impact on existing ecosystems throughout the entire process.




< [8] Definitions of "Sustainability" according to the Cambridge Dictionary with remarks by the author

^ [9] Parameters protecting sustainability in the timber industry

## THEORETICAL FRAMEWORK




[10] Circular Economy Model (including Cradle to Cradle & Design for Disassembly)

### Circular Economy

"The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended" (European Parliament, 2023).
It offers a clear contrast to the linear industrial economy, where products are produced, consumed and disposed of as waste at the end of their life. This results not only a double financial loss (loss of resources and waste management costs) (Stahel, 2019), but also a large impact on the environment. Therefore, the circular economy model implies reducing waste to a minimum and reusing products or building material as much as possible. This can be made possible through hierarchical strategies as described in the chapter "The era of 'R'" of Walter R. Stahel's book "The Circular Economy – A User's Guide" (2019) which later served as inspiration for "Upcycling" (2020) by Daniel Stockhammer and was mirrored on the building sector as five key factors that should be taken into account, here displayed by Roger Boltshauser (2022):

1 Refuse: no new construction, but rather preservation, maintenance, and repair; property exchange instead of replacement (construction); from building to not building
2 Reduce: reduced impact on the ground and minimal construction work on existing structures: reden-

sification, renovation, and expansion
3 Re-use: dismantling, deconstruction, component preservation, component reuse
4 Recycle: demolition, separation of building materials, and recycling or reuse, downcycling and upcycling
5 Rot: waste-free and pollutant-free demolition of the structure

With the rise in the world's population and the resulting scarcity of resources, the choice of material gets increasingly important (Lysgaard Vind, 2022). Consequently, when a product reaches the end of its life, its materials should be kept within the circle by re-using, recycling or a waste free disposal and return to the biosystem. This means that "Cradle to Cradle" and "Design for Disassembly" are inherently tied to the Circular Economy (see figure 10).

### Cradle to Cradle

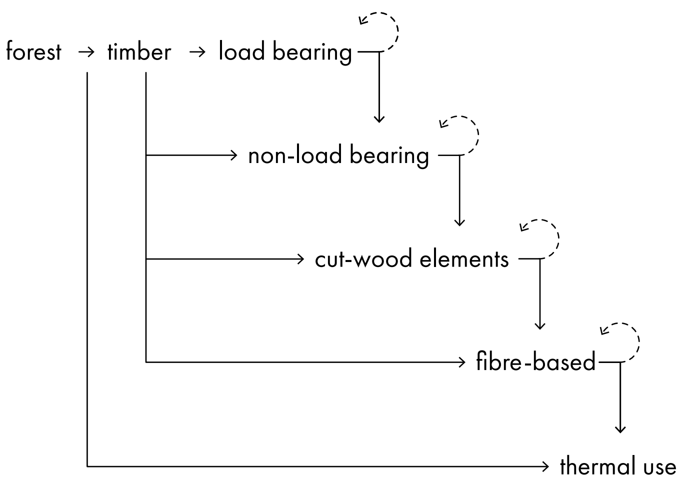
Beyond the idea of *cradle to grave* – where resources are extracted, consumed and then disposed – "cradle to cradle" introduces a concept conforming to the model of circular economy.
The term was coined by Michael Braungart and William McDonough (2005) implying an extracted resource should have a positive impact on the environment after its use as a product. Therefore, the material should return to its cradle where it once removed from (Braungart & McDonough, 2021). To make sure the strategy works, it is necessary to follow its principles right from the beginning and to be uncompromising throughout the process because "less bad is not good" (Braungart, 2023). This means that a *glulam* beam, for example, does not become more sustainable simply by using less adhesive, since its basic composition alone prevents the product from being fully recycled at the end of its life cycle. Accordingly, the materials used in a building should be free of chemicals and environmentally harmful substances, not only to reduce the environmental impact but to eliminate it entirely. An organic material therefore actually has a positive impact at the end of its life cycle, as it can, for example, serve as biomass to provide nutrients for a new material.

### Design for Disassembly

"Recent standard ISO 20887:2020 has defined [Design for Disassembly] DfD [...] in the context of Architecture, Engineering, and Construction (AEC) as: approach to the design of a product or constructed asset [...] that facilitates disassembly [...] at the end of its useful life, in such a way that enables components [...] and parts to be reused, recycled, recovered for energy or, in some other way, diverted from the waste stream" (Ostapska et al., 2024). This means that in Design for Disassembly buildings should be constructed in such a way that a component's life cycle can be renewed after use without any loss of quality. The design method has grown increasing popularity with the aim of minimizing waste in the construction sector (Ostapska et al., 2024), which currently accounts for one-third of global waste (UNEP & GABC, 2025). In the timber construction sector, this means that plug-in connections and non-glued assemblies and components are becoming increasingly important.

### Cascading use of Timber

The concept of a cascading use was introduced by Sirkin & ten Houten (1994) as a method to optimize the consumption of products. As they state, the concept has been present for a long time. "Clothes, for example, were passed down the line as 'hand-me-downs' or else got re-sewn into something else. After the fabric became worn out it was cascaded to dust clothes and rags, and eventually, could be salvaged to the production of high-quality drawing paper" (Sirkin & Houten, 1994).
In timber architecture, the concept is used to create a long-term carbon sink. This is done by maximizing the lifetime of a product and downcycling it one step at a time. This approach contrasts with the traditional view of timber as a waste material that can only be burned after its initial use. It can significantly reduce the release of carbon dioxide into the atmosphere (Hafner & König, 2021). Currently, the by-products of the timber industry are mostly used in horizontal practices, such as turning sawdust or wood chips produced when cutting lumber into composite boards. However, there is still room for improvement in vertical use (Hafner & König, 2021). For example, a solid wood beam that once served a load-bearing purpose could be repurposed as a non-load-bearing façade element in a second phase. Then, in a




[11] Cascading use of timber (adapted from Höglmeier (2015))

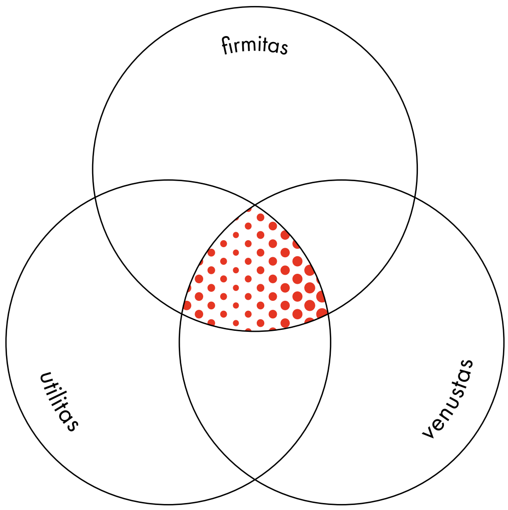
third phase, this element could be further processed to serve a new function, such as *particleboard*, until it serves its final purpose as an energy source. To ensure a problem-free transition from one cascade to another, wood products and structures should be designed with maintenance, dismantling, and recycling in mind from the planning stage onward.
An extension of this concept involves reusing materials within a single cascade. This allows the further processing stage – or downcycling – to be postponed even further (see figure 11).

### Hyperlocal Architecture

Hyperlocal Architecture is a design theory that emphasizes on the importance of a context specific architecture. It is a radical and thought-provoking idea on how architecture can be responsive to its direct surroundings in terms of the building process, as well as its connection to the environment it is built in.
"The principle of modern design was severed from realities of a building as an environmental intervention by relying on technology to overcome conditions rather than adapting to them." (Michler, 2015)
Hyperlocal architecture criticizes the use of modern automated systems, as it destroys the distinctiveness of place. For example, when local materials are exported and manufactured abroad, buildings lose their connection to their surroundings. Traditional construction methods and regional identities fade, making it increasingly difficult to recognize where a building belongs. This detachment undermines cultural continuity and environmental responsiveness – core values that hyperlocal design seeks to restore (Michler, 2015).
By sourcing materials locally, manufacturing close to the site and using traditional and context specific techniques a resilience is created, that not only results in a very sustainable approach, but also gives the building a distinct local identity.

### The Vitruvian principles of architecture

According to Vitruvius' "De architectura libri decem" (20-30 BCE) every architecture "must be built with due reference to durability, convenience, and beauty" (Morgan, 1914) – in Latin firmitas, utilitas, and venustas. Today, these principles are often used in the design phase to ensure a complete and well-balanced architectural concept. They continue to serve as a timeless framework for evaluating how buildings perform structurally, functionally, and aesthetically.

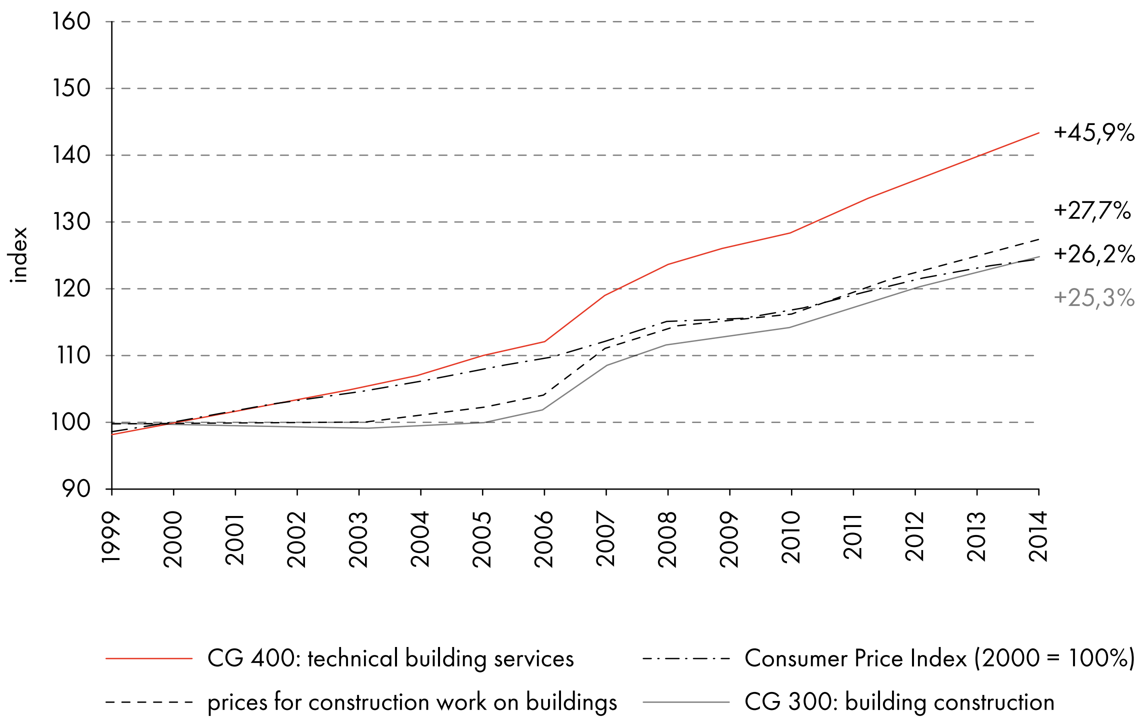



[12] Sweet spot that good architecture should reach according to Vitruvius

## EINFACH BAUEN

Inspired by Projects like "2226" from architecture firm Baumschlager Eberle – a building solely relying on its 76cm thick brick walls, without a conventional heating and cooling system and without mechanical ventilation or exhaust ventilation systems – a group of architects and engineers under the direction of professor Florian Nagler launched the research project "Einfach Bauen" at TU Munich.

Their guiding question is whether todays demands can only be achieved with increasingly more and complex technical systems or if building simply (in German: "einfach bauen") again can solve this as well (Nagler, 2022).
Demands on buildings in terms of heat-, fire- and sound protection have been increasing for years. To tackle those demands often technical systems are installed to ensure cost reduction for the building's owner and user. Consequently, as seen in figure 13, costs for cost group 400: technical building systems have increased significantly faster than the total construction cost and other construction services (BUNBR, 2015).




[13] Price trends of different construction services (adapted from Bericht der Baukostensenkungskommission (2015))

[14] Wooden research building; Bad Aibling, Germany; photography by the author


ABI A 5555

By reducing the complexity and developing *monolithic* assemblies in concrete, brick and wood the goal of Einfach Bauen was to create a basis for simple and robust buildings.
After simulating over 2000 different room layouts and variations the team looked for a shape that benefits with its geometry, window size and material, as well as the climate and user behavior.

The outcome was six guiding principles (see below) that resulted in three research buildings identical in shape – made from lightweight concrete, perforated hollow brick and solid wood. Today, there are three additional buildings also testing hybrid construction on the research campus in Bad Aibling (see figure 15).

**Principles for "Einfach Bauen" (Nagler, 2022):**

1 Reducing the building's surface. Increase building density.

2 Select window size of 10-15% for natural light rooms.

3 Use the *thermal inertia* of the building components for indoor climate. Allow for post-ventilation.

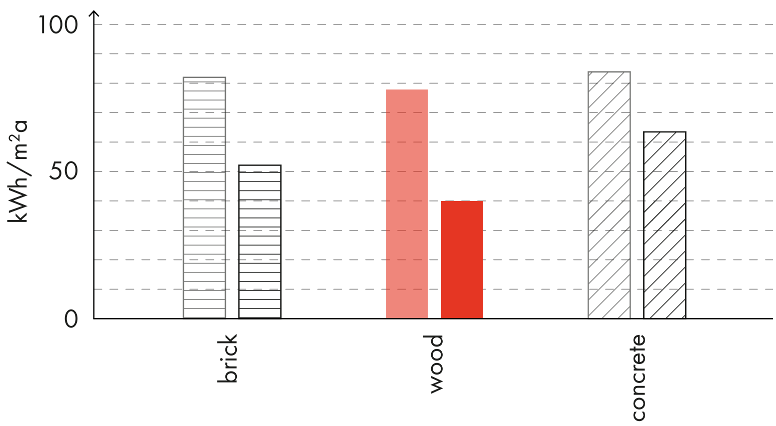
4 Use robust technical systems that take the user's behavior into account.

5 Prepare future changes. Separate technical systems from construction.

6 Few, single-material component layers making up robust and long-lasting constructions.

The construction process, as well as the use of the research buildings was documented and evaluated, and resulted in quite astonishing outcomes where most expectations were exceeded (see figure 16).

Today, the term "Einfach Bauen" is much more than just a research project. It is rather a philosophy on how architecture can return to its essential purpose: creating spaces that are functional, sustainable, and human-centered – without relying on excessive technology or complexity. It challenges the industry to reconsider what is truly necessary and encourages a mindful approach to building that values simplicity and durability.




< [15] research buildings in process; Bad Aibling, Germany; photography by the author

^ [16] energy consumption expected vs. actual (adapted from Einfach Bauen II: Erkenntnisse (2024))

## DELIMITATIONS AND FOCUS

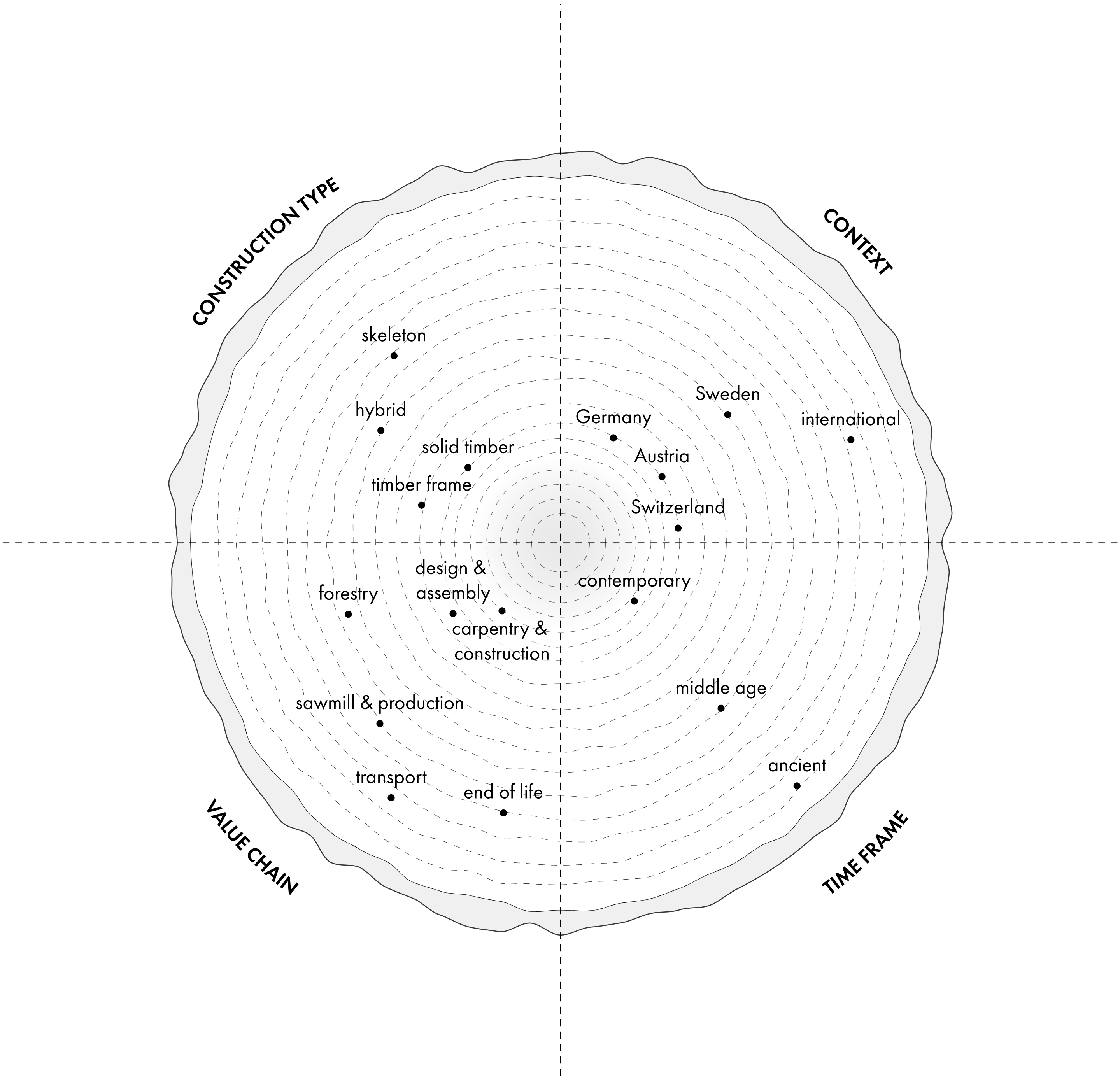
Since the thesis evaluates how timber architecture can achieve *holistic sustainability* the focus material is of course wood. Within the material the main focus is on timber frame and solid wood constructions as they are the most common forms of timber construction today (DGfM, 2017). Their impact is therefore the highest. Sustainable hybrid timber constructions (without cement) are still in the early stages of development in the building sector, so they could not be analyzed to the same degree as other areas.

Geographically the scope of the investigation mainly includes references and knowledge gained from the DACH region (Germany, Austria & Switzerland). This focus is justified by the study excursion to that area (see "Methods", page 24) and by the preference for conducting research in the corresponding language. The extensive history of timber construction in the Alpine region also provided a large body of expertise to draw from and is widely regarded as one of the leading wood-working regions today.

Since architects have the greatest influence on the design and construction of buildings, these two areas are at the center of the analysis.
In a *technical annex* to the construction contract specifications, architects can, moreover, define and therefore partially influence certain manufacturing processes, sourcing methods, and other material requirements. Understanding forestry, sawmills, production, and the end of a building's life helps explain choices in terms of sustainability.

The study focused on contemporary and future-proof solutions, driven by a critical evaluation of current timber construction practices and the need to explore alternative approaches. Therefore, the assemblies selected in the "Catalog of Assemblies" (pages 55-63) were chosen so they are applicable today. Research and references from the Middle Ages, as well as ancient times solely served to explain the development and connection to today's practices.

The thesis excludes temporary solutions, as they are not intended for long-term use and therefore do not align with the study's definition of sustainability (see "What Is Sustainability?", page 12).
Flat roofs are also excluded due to the increased complexity of constructive wood protection (see "Design & Assembly", page 64).
Interior walls are not considered, as they are not exposed to external conditions and can already be constructed in a relatively sustainable manner.
Regulations, legislation, and costs are only addressed superficially due to their continuous change.




^ [17] Illustration showing the thesis' focus zones

## METHODOLOGY

Within the context of this research, *empirical knowledge* is considered a particularly valuable foundation for generating robust understanding since the timber industry in the DACH region relies on a lot of knowledge passed on for generations in family-run businesses (Küng & Hochschule Luzern, 2024). Therefore, by visiting carpentries and building sites firsthand most of the insights were gained.

The selection of the contacted companies and visited buildings was based on a vast literature and technical research in the early stages of the project. Therefore, case studies were analyzed and interviews prepared, that were later conducted during the trip (see figure 19, page 26).

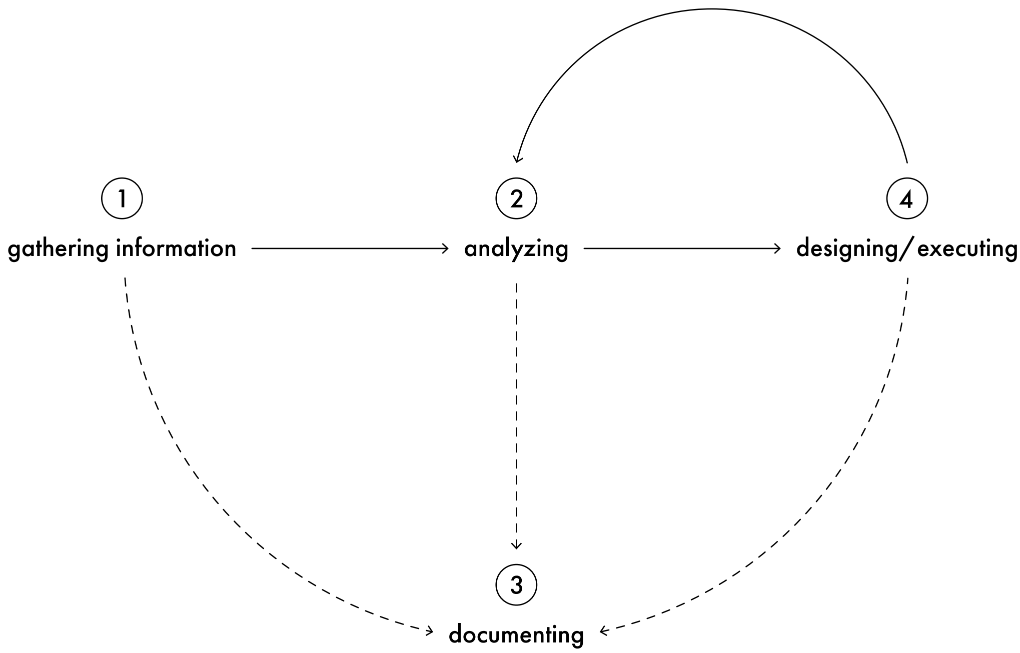
To document the findings, analog photography played a significant role, as it allows for a quick and direct visual capture of observations. This was particularly valuable since the trip was undertaken individually and involved constant movement between company visits and guided tours. By capturing moments exactly as they unfold and fixing them irreversibly on film, the analog photography offers an authentic glimpse into aspects that normally remain unseen and prevents the image from being shaped by endless retakes.

Additionally, knowledge that could not be captured through photography was documented through field notes and quick sketches, which also simplified follow-up questions and a more detailed exchange with the contacts.

After the field trip, the gained knowledge was transformed and applied into different design applications.
Process diagramming helped to visualize and give an overview to the different stages in the timber construction process. Moreover, those identified stages built the framework for the investigation in this master's thesis (see "Investigation", page 33)

Within the different stages, the diagramming of data combined with illustrations followed the principles of graphical excellence as described by Tufte (2001). Complex ideas within the process phases were presented with an emphasis on clarity and precision. This laid out a basic understanding and put detailed drawings in a catalog of assemblies into their context (see "Catalog Of Assemblies", pages 55-63). The sustainable assemblies are compared with a current standard to show differences in layers and their function.

Lastly model building was used on one hand to directly understand the complexity and differences in construction of three different assemblies. On the other hand, it showcases those assemblies in their materiality and performance, and compares them in a 1:1 scale.




1. preliminary research and site selection
   literature & technical research
   case studies
   site visits
   interviewing

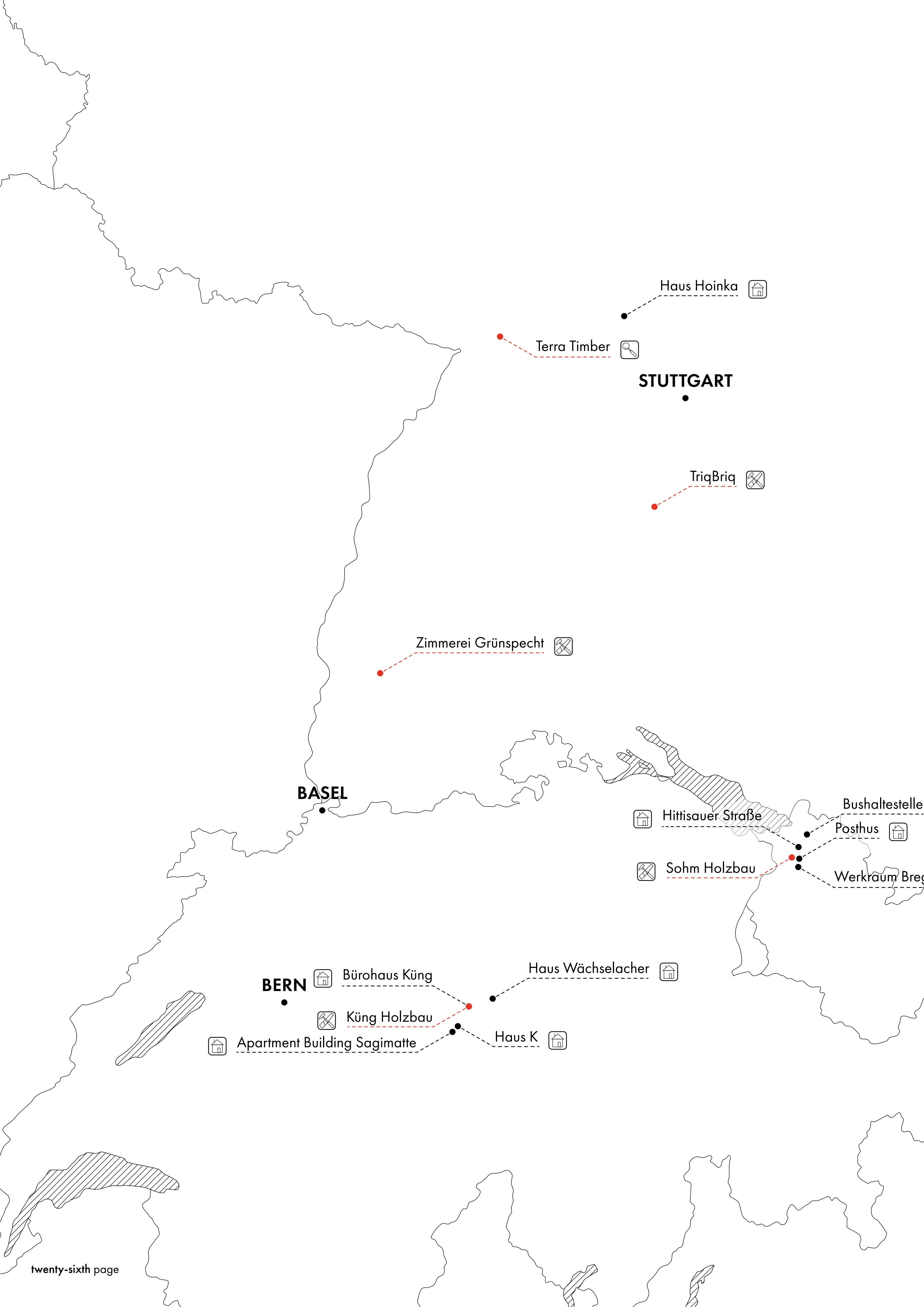
2. data analysis
   process diagramming
   data diagramming

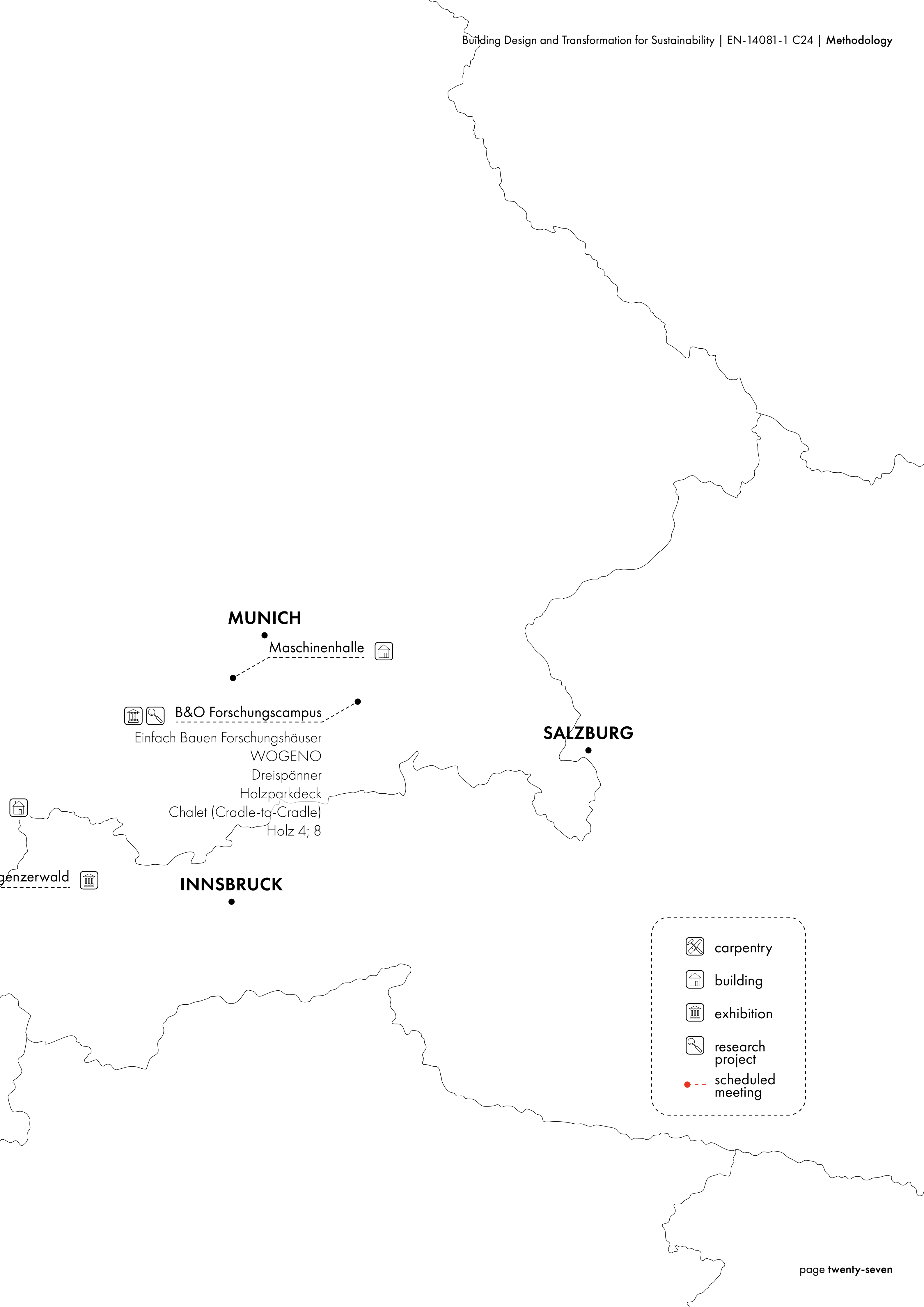
3. photography
   sketching
   field notes

4. process illustrations
   detailed assemblies
   model building

^ [18] Illustration showing methods along the thesis' process

> [19] Map of stops during the field trip


Haus Hoinka
Terra Timber
STUTTGART
TriqBriq
Zimmerei Grünspecht
BASEL
Bushaltestelle
Hittisauer Straße
Posthus
Sohm Holzbau
Werkraum Breg
BERN
Bürohaus Küng
Haus Wächselacher
Küng Holzbau
Apartment Building Sagimatte
Haus K


MUNICH
Maschinenhalle
B&O Forschungscampus
Einfach Bauen Forschungshäuser
WOGENO
Dreispänner
Holzparkdeck
Chalet (Cradle-to-Cradle)
Holz 4; 8
SALZBURG
genzerwald
INNSBRUCK
carpentry
building
exhibition
research project
scheduled meeting

Zimmerei Grünspecht
**Straw Wood Construction**
Freiburg, Germany.

TriqBriq
**Briq-System**
Tübingen/Stuttgart, Germany.

Sohm Holzbau
**Diagonal Dübel-System**
Alberschwende, Austria.

Atelier Kaiser Shen
**Haus Hoinka**
Pfaffenhofen, Germany.

Seiler Linhart
**Haus Wächselacher**
Sarnen, Switzerland.

Hermann Kaufmann
**Holzparkdeck**
Bad Aibling, Germany.

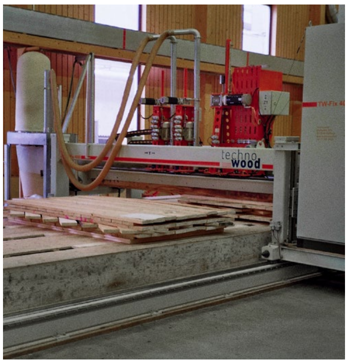
Florian Nagler
**WOGENO**
Bad Aibling, Germany.

Florian Nagler
**Maschinenhalle**
Irschenhausen, Germany.

Hermann Kaufmann
**Hittisauer Straße**
Krumbach, Austria.

Hermann Kaufmann
**Dreispänner**
Bad Aibling, Germany.

Schankula Architekten
**Holz 4**
Bad Aibling, Germany.




Küng Holzbau
**„holzpur" System**
Alpnach, Switzerland.

Werkraum Bregenzerwald
**Exhibition unplugged**
Andelsbuch, Germany.

Küng Holzbau
**Apartment Building**
Alpnach, Switzerland.

Seiler Linhart & Küng Holzbau
**Bürohaus Küng**
Alpnach, Switzerland.

Seiler Linhart
**Haus K**
Alpnach, Switzerland.

Ludescher + Lutz
**Posthus**
Egg, Austria.

Hermann Kaufmann
**Bushaltestelle**
Krumbach, Austria.

Florian Nagler
**Forschungshäuser**
Bad Aibling, Germany.

Ruumfabrigg
**Chalet**
Bad Aibling, Germany.

Schankula Architekten
**Holz 8**
Bad Aibling, Germany.

## AIM & FRAMEWORK

The motivation for this master's thesis is grounded in a personal interest in simple wooden buildings, encountered when hiking and ski touring. Due to their remote locations, those buildings do not stand out because of an extravagant appearance but rather through straightforward design and serving the fundamental purpose of providing shelter and a space for people to gather.

Over time studying architecture, it became increasingly frustrating to rely on standardized construction assemblies that are widely used despite their evident lack of sustainability. During the research phase of this master's thesis, it became clear that these assemblies are tied to the complexity and interconnectedness of the timber process. Therefore, the goal was, on the one hand, to point out the current problem areas within the process and, on the other hand, to develop a "new standard" within the timber construction sector.

This thesis seeks to encourage a more critical reading of the standardized approaches and to reconsider what is currently being designed. At the same time, it intends to demonstrate how construction can be approached in a more sustainable way by offering practical examples. Through the insights gained in the study visits and case study analyses, examples are adapted by the author to fulfill the extracted "parameters to achieve sustainability" (see figure 20) and marked within the process investigation in red. This approach also simplifies navigation between the assembly documentation and the main text.

The objective is not to deliver a definitive solution to the challenges of timber architecture, but rather to offer a critical impulse to rethink current practices.
Inspired by the philosophy of Einfach Bauen (see "Einfach Bauen", page 18), this thesis advocates for a simpler, more restrained approach: building with less to achieve more. It calls for a reevaluation of expectations, a reduction of demands, and a return to straightforward, effective processes rooted in sustainability, locality, and lifecycle awareness.
Therefore, the natural limits of timber are respected. The use of natural materials and the reuse of resources are promoted, as well as building in a way that allows materials to last, be repurposed, or ultimately return to their natural cycles.

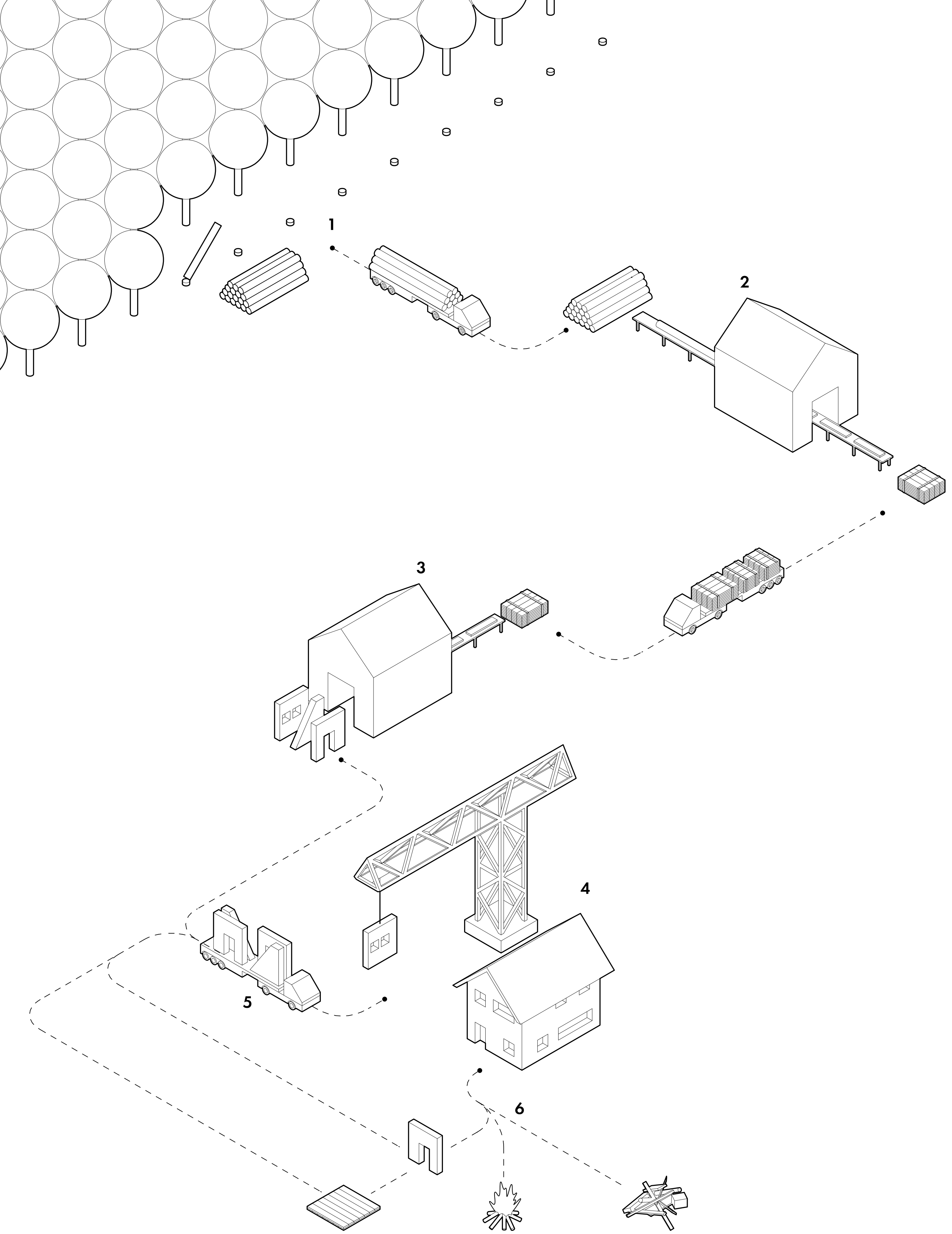
**avoid greenhouse gas emissions ($CO_2$)**

**avoid (residual-) waste**

**avoid intervention into existing ecosystems**

**strive for long-lasting solutions**

^ [20] Parameters to achieve sustainability (see chapter "What is Sustainability", page 12)


1
2
3
4
5
6

## INVESTIGATION & RESEARCH QUESTION

To take a holistic view on the process of timber architecture, it is important to define the full scope. The decisive factor here is to go beyond what is visible, meaning, the process before and after the finished building should be considered likewise.

Questions regarding where the wood comes from, how it is cut, manufactured and installed, which building methods are used, how these are translated into a built structure, and what happens to the material after the building's lifecycle are particularly valuable for this investigation. Therefore, the following is divided into the six main phases that are necessary to regard timber architecture in its entirety.

### 1. Forestry

The first section explores how current timber stocks are handled, as well as how the wood grows and differences in harvesting methods with their environmental impact.

### 2. Sawmill & Production

Here, the focus lies on how the wood is cut, processed and dried to explain certain qualities. The therefore resulting by-products of the manufacturing process and their potential use are also examined.

### 3. Carpentry & Construction

This chapter introduces construction types and presents a catalog of assemblies – floor slabs, outer walls, intermediate slabs, and roofs. Comparisons between current standards and selected sustainable alternatives encourage reflection.

### 4. Design & Assembly

This part breaks down how the design influences the longevity of the building and its material.

### 5. Transport

Here, distances in timber construction with their environmental impact, as well as the importance of locality are underlined.

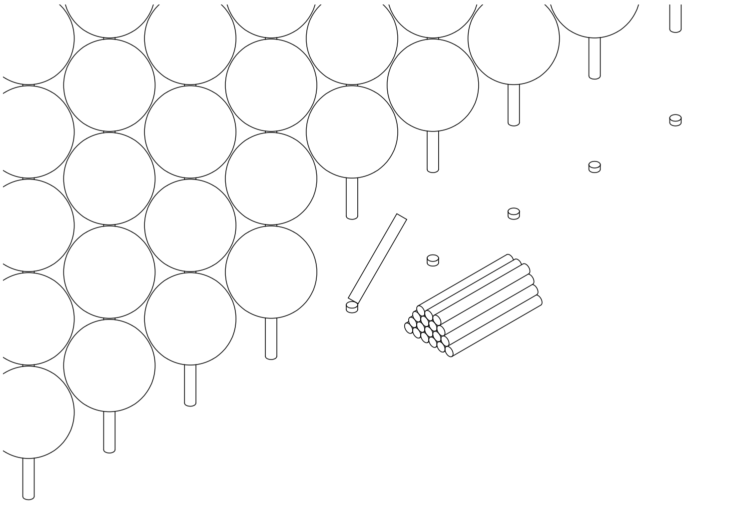
### 6. End-of-Life

The final section addresses what happens to a timber building after its lifespan, outlining the three main options – reuse, thermal use, and residual waste – along with their feasibility and challenges.

Considering the entire lifecycle of timber architecture shows the complexity and interconnectedness of each phase. By examining these six stages a comprehensive foundation for understanding where current practices fall short and where potential lies for more sustainable approaches are explained. From this the central research question emerges:

How can timber architecture achieve holistic sustainability?

< [21] Pictogrammatic illustration showing timber building process with its different phases



## 1 FORESTRY

30% of the Earth's landmass is covered by forests, making up 4 billion hectares of land. While this figure is decreasing by approximately 3.3 million hectares every year, the area of forest in the EU, however, has increased by 5% between 1990 and 2010. This has led to sustainably replenished timber stocks, with 180 million hectares, or 41% of the landmass, covered by forest (Wegener, 2017)

### Distribution of harvested timber

Globally, 3.9 billion cubic meters of timber are harvested (1.4 billion $m^3$ of *coniferous* and 2.5 billion $m^3$ of *non-coniferous* wood), of which slightly less than half is used as *wood fuel* for energy use (49,2 %; 1,93 bio $m^3$). The remaining 51% is used for industrial purposes (see figure 22) (FAO, 2022). Nearly half of the harvested wood is burned for its primary use. This is a highly problematic number since carbon is released immeadiatly, contributing to the $CO_2$ footprint. A cascading use can bypass, delay, and control this (see page 16).

Additionally, around 400 million tons of *industrial wood* are used for paper production each year (FAO, 2022). This results in large amounts of waste after just one initial purpose. To counteract, the construction industry has developed a today well-established method: using paper waste as cellulose insulation (see assembly 2.1 on page 58).

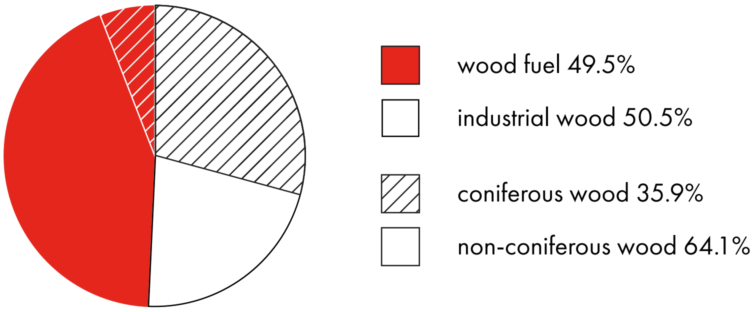
440 million $m^3$ of wood are used for *lumber* and 390 million $m^3$ for *engineered wood products* (see figure 23) (FAO, 2022).

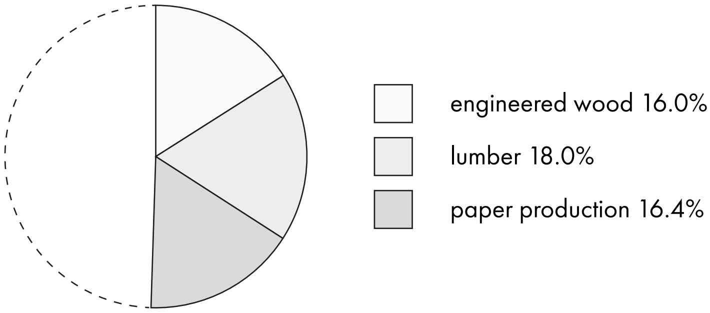
### Calamity wood

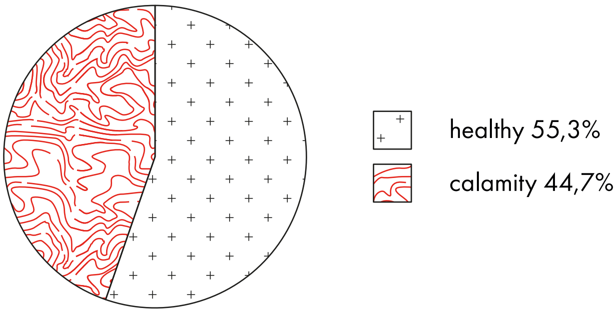
A significant share of timber harvested today consists of *calamity wood* (up to 50% in European countries) (Hýsek et al., 2021). This type of wood is damaged by the results of climate change, like storms, droughts and insect infestations. In Germany 44,7% of all harvested wood is *calamity wood* (Destatis, 2025) (see figure 24). This wood is typically seen as lower quality due to its visual and structural damages and is predominantly directed toward thermal utilization, releasing its stored carbon almost immediately upon combustion (Behrends, 2025).

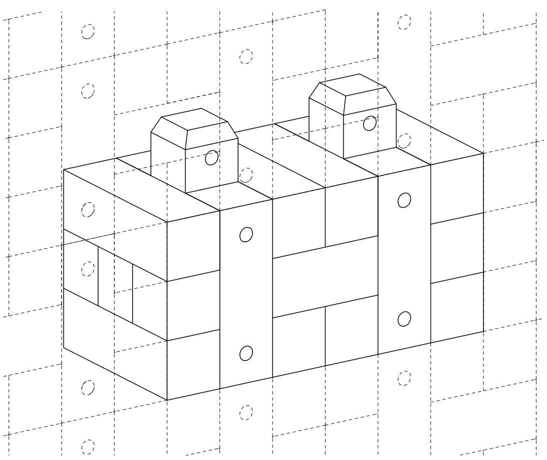
*Calamity wood* however does not necessarily mean lower load bearing capabilities (Hýsek et al., 2021; sdg21, 2021). The use of this salvaged wood in construction, therefore, is quite beneficial not only for the environment, but also economically. Since the damaged wood can be breeding ground and food for harmful insects in the forest (Hýsek et al., 2021), as well as catalyst for wildfires, the timber should be removed from the forest to prevent further damage (Collins et al., 2012). Consequently, its price on the market is significantly lower than for "healthy" timber (Behrends, 2025).

Innovative engineered systems like "TriqBriq" accommodate small and irregular cross-sections of *calamity wood*, which extend the material's service life immensely by integrating it into load-bearing applications. The solid wood system consists of dowelled wooden blocks, which are stacked and doweled together to create the structural framework of a solid timber wall (see figure 25). Therefore, the carbon in *calamity wood* is stored over long periods before eventually reaching the energy recovery stage. Moreover, "TriqBriq" allows for disassembly and can serve multiple reuses throughout its lifetime.



[22] Distribution of globally harvested roundwood

[23] Distribution of global industrial wood

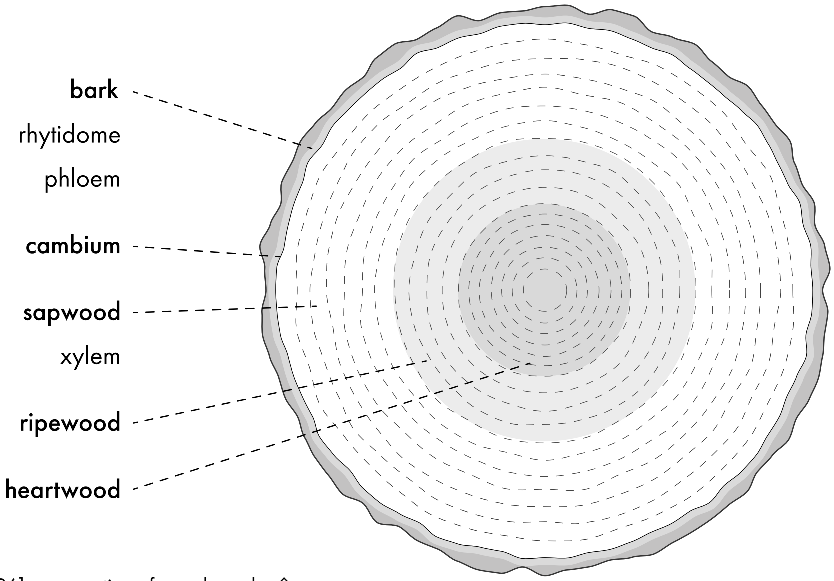
[24] Amount of calamity wood in Germany

[25] WS25 TriqBriq: doweled timber brick made of calamity wood

## Wood qualities

To understand the differences in wood qualities, it is essential to consider how it grows and the characteristics that result from this. A cross-section of wood makes the distinct functions of its layers legible (see figure 26).

On the outside, there is the bark with the *rhytidome*, which is made up out of dead wood cells that protect the *cambium* and the timber trunk from drying and mechanical damages (Volz, 2003). The *phloem* transports the food, produced during photosynthesis in the leaves, to all parts of the plant. *Radial growth* occurs through cell division in the *cambium*, where *phloem* is built to the outside and *xylem* to the inside. *Xylem* is part of the "active" wood, called *sapwood*. Here water and nutrients are brought from the roots all the way to the leaves. The further inside the less active this layer gets (USDA, 2016). *Sapwood* is generally softer and not as durable as *ripewood* and *heartwood*.




[26] cross section of roundwood

*Ripewood* is similar in color to the surrounding *sapwood*, whereas *heartwood* is darker, due to its storage of many extractives. Those protect the center from harmful factors, like fungi or bark beetles. Both wood types are relatively dry and dense, which gives the tree its supporting structure.

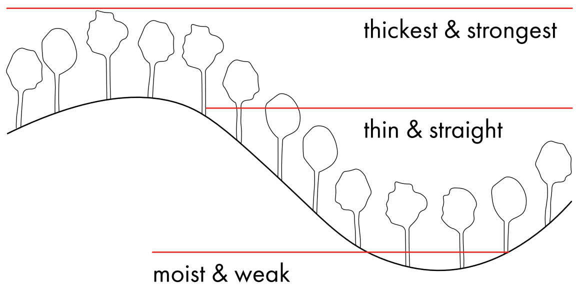
Whereas the bark, *cambium* and *sapwood* are essential for every tree, the other layers can vary depending on the type of tree, resulting in different characteristics. *Sapwood trees* like birch or alder do not have any *ripe*- or *heartwood*, making them relatively less durable. Spruce- and beech trees are part of the *ripewood trees*, durable but not as resistant to insect and fungal attack as *heartwood trees* like larch, pine or oak. Lastly, *heart-ripewood-trees* like ash trees can show both heart- and ripewood (Rosina, 2021).

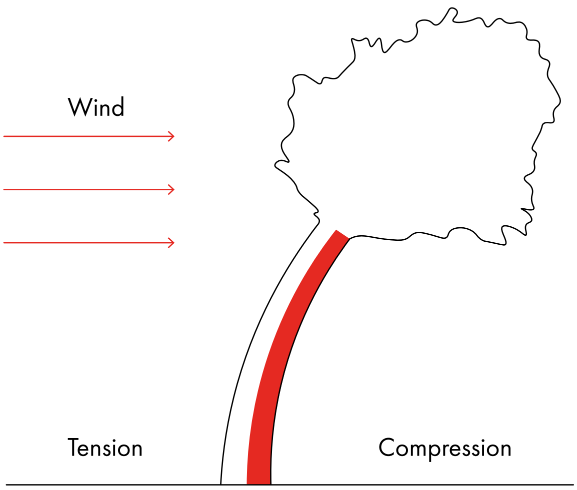
## Harvesting

Basic principles must be taken into consideration when harvesting wood to ensure a certain quality. Location, sun exposure, wind, soil, altitude, and moisture are all outside factors that play a role in wood texture and quality (Bauer & Pauli, 2024).
As seen in figure 27, trees grown at higher elevations or in deserts often produce denser and more resilient wood due to their climate and slower growth rate. The most vigorous trees grow above the midpoint of a mountain where they receive plenty of natural sunlight and air circulation. Trees below the midpoint that compete for sunlight sprout quickly before branching. This results in relatively

straight and thin trunks with few knots. Lastly, trees in valleys have a higher moisture content, which causes them to be less durable and considered lower quality. They are typically used for secondary construction elements.

When exposed, trees are impacted by wind, which leads to denser wood and differences in fiber structure on the compression and tension sides (see figure 28). These compression trees are avoided during harvesting because their asymmetric structure causes quality losses during processing. Moreover, the type of soil largely impacts the quality of wood. Nutrient-rich soil leads to faster and healthier growth, whereas clayey and sandy soils can lead to traces in the woodcut (Bauer & Pauli, 2024).




### Wood harvesting time

According to old traditions the most durable wood is harvested around Christmas in the winter months from November till February (Teischinger, 2001). However, different sources contradict each other on this (TUD, n.d.). Some believe that during these months, trees hold the least amount of water, and some even claim that lunar cycles directly impact the density (Zürcher, 2003), whereas others claim to prove this research to be invalid. Only the conditions for *logging* – such as frozen ground, which facilitates the transport of the timber – are more favorable at that time (Teischinger, 2001).

Also, traditional *logging* techniques, like *gridling* must also be viewed objectively. With the help of an approximately four centimeter deep cut through the *phloem* and *cambium* into the *sapwood*, the tree is left in the forest and slowly "dies" as it can no longer supply the roots with nutrients. The waterflow into the tree is therefore cut and all the excess water is transpired by the needles or leaves to carry out photosynthesis (Wehenkel, 1998). As a result, wood similar to *ripewood* is produced that is denser and more durable. This natural drying process can help to decrease *embodied emissions* by up to 30%, as more wood can be carried and the time for drying is reduced. (Küng & Hochschule Luzern, 2024). The technique seems to be quite effective (Reque & Bravo, 2007), however, it may only work for certain types of trees and when carried out properly (Wehenkel, 1998).

[27] Influence of location on wood quality (adapted from Bauer & Pauli (2024))

[28] Compression wood caused by wind (adapted from Bauer & Pauli (2024))

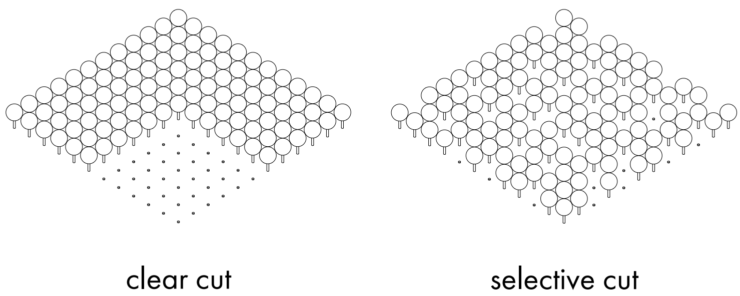
### Wood harvesting types

*Logging* typically involves either clearing large areas or selectively cutting down individual trees or groups of trees (see figure 29). In this case, clear cutting offers the most cost-effective alternative (Keenan & Kimmins, 1993).

However, its ecological downsides are enormous, since the resulting fallow land ends up significantly more exposed. Fluctuations in temperature are far more severe, surface temperature can triple and wind speed increases near the ground (Keenan & Kimmins, 1993), which, together with left over *slash debris*, can be a catalyst for wildfires (CPAWS, 2020). Additionally, entire ecosystems are disrupted and annual waterflows can double – a direct cause for increased flooding risk (Keenan & Kimmins, 1993). By extracting valuable biomass not only wildlife habitats are disrupted, but also the soil strength is weakened, which can cause landslides.
Also, soil nutrients are decreased and therefore clear cutting is also not comparable to natural disasters like wildfires (Thiffault et al., 2007). Small benefits, like an increased rate of photosynthesis in moderate climatic environments (Keenan & Kimmins, 1993) thus are largely overshadowed.

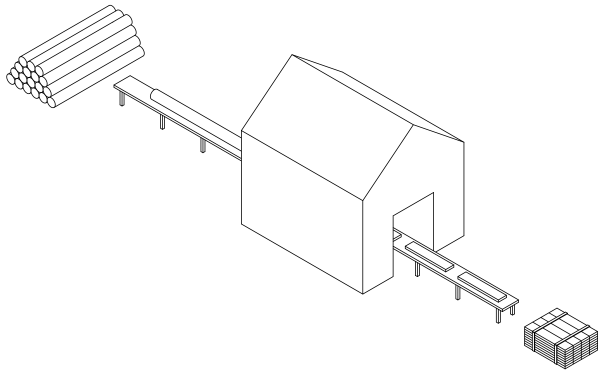
Solely, in cases of wildfire risk by large amounts of *deadwood* without protecting canopy or a bark beetle invasion of a certain area, clear cutting can be beneficial to lower spreading hazards.

Less problematic or even beneficial is leaving behind unused *woody debris* in selectively cut forest areas.
Commercially used wood is typically all wood larger than seven centimeters in diameter, including bark (DBFZ, n. d.). Everything else is regarded as *woody debris* and normally left in the forest. However, this is not problematic because "woody debris has an important influence on carbon retention in forest ecosystems" (Müller-Using & Bartsch, 2009). It stores nutrients in the long term and promotes biodiversity. It is crucial to ensure that enough *woody debris* is left behind because too little can decrease biodiversity. Morepver, leaving only fine *woody debris* – smaller than seven centimeter in diameter – is not sufficient in this case (Müller-Using & Bartsch, 2009). Since soil is the leading carbon pool at 46% and 329 Gt, it is especially important to protect it (FAO, 2025). *Coarse wood debris* decomposes and forms the humus layer, storing carbon and nutrients in the soil.




[29] Timber harvesting types with equal amount of yield

[30] Tree with view over Lake Lucerne; Horw, Switzerland; photography by the author



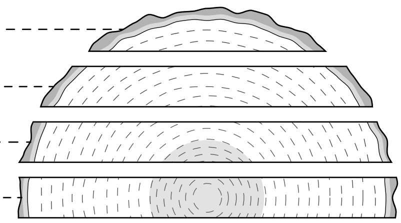
## 2 SAWMILL & PRODUCTION

Uncut *roundwood* is applicable only for a few areas, like log houses, telephone poles or fences. Therefore, the timber log must be cut into *lumber* to be used for further purposes.
The goal in a sawmill is to produce as much high-quality wood as possible while generating no waste. How the tree has grown influences this. Depending on their location, trees experience varying amounts of wind throughout their lifetime, resulting in more or less curved growth (see figure 28, page 37). No tree is perfectly straight, which is why automated systems in sawmills use laser scans to align the *roundwood* for optimal orientation and maximum yield (GAUG, 2009).

### Step 1: removing the bark

First, *slab boards* are cut from the *roundwood* to ensure a straight working surface.
These slabs are usually used for thermal purposes and sometimes for secondary purposes, such as "Skigard" fences in Scandinavia. Rarely they are used in construction because they are less durable and are most likely to be infested by insects or fungi since this layer is most exposed during tree growth. (Hýsek et al., 2021). When checked properly however, the slab wood can not only provide a distinctive, non-uniform aesthetic that contrasts with highly processed timber, but can also fulfill a protective function. As outside cladding in the "Skigard Hytte" by Mork Ulnes Architects for example, it acts as a outside cladding and weathering layer that helps shield the inner structure of the building from moisture and environmental exposure. In this sense, the retained bark layer can be understood as regaining its original role of protecting the inside from external influences such as humidity, temperature fluctuations, and biological degradation.

What remains after removing the slab wood can already be used as a whole for constructive purposes. In the case of a dowel beam ceil-



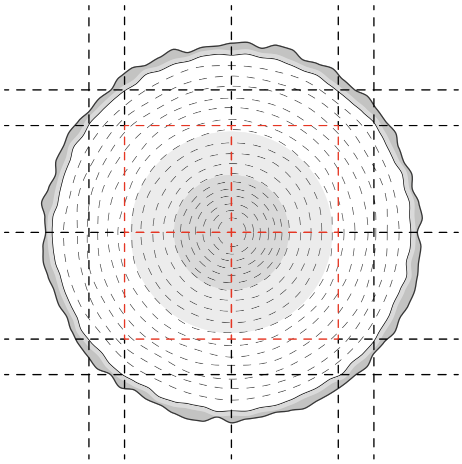

[31] Terminology of timber boards with their according position in the cross cut

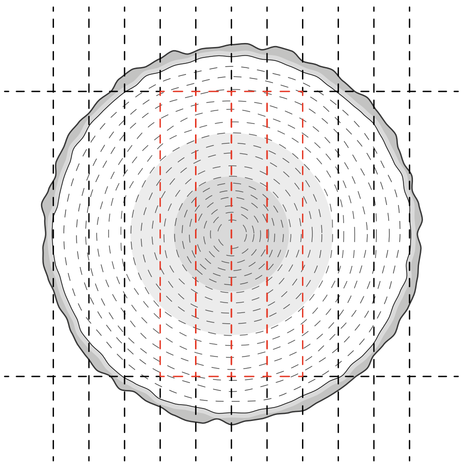
ing for example, up to 80% of the original tree is used, leaving minimal off cuts and affording very little energy (see assembly 3.2, page 61) (Oberndorfer Hybrid Systems, 2024).

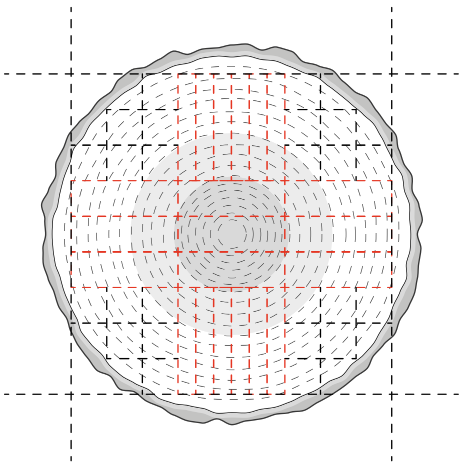
### Step 2: cutting the log

The cutting pattern and grain orientation are key factors determining the wood's quality and longevity.
After crosscutting the roundwood to the desired length, longitudinal cuts can be made either tangentially or radially to the fiber direction. The *anisotropy* of wood causes shrinkage after drying to double as high in tangential direction compared to radial (Plößl, 2008; Volz, 2003). Consequently, a cut timber board experiences *cupping* and *warping* after drying (see figure 36). Cuts perpendicular to the growth rings result in the most homogeneous fiber structure and the least shrinkage in the end product. This high-quality, durable wood is known as "riftwood."

No matter how the wood is cut, however, there are always side and by-products next to the main stock (see figures 32; 33; 34). *Sideboards* are cut tangentially, resulting in severe cupping and low quality and durability. This is why sawmills often struggle to sell them (Küng & Hochschule Luzern, 2024). Although this shrinkage behavior seems negative at first glance, it can be turned into a positive. In solid wood assemblies, like the "holzpur" system by Küng Holzbau, warped stacked timber planks create stagnant air pockets between the layers, resulting in better insulation. Additional insulation is therefore unnecessary,




[32] Cutting pattern for heartwood beams

[33] Plain cut pattern for boards and planks

[34] Rift cut pattern: high quality of main product due to "standing" growth rings

and the assembly relies solely on wood (see assembly 2.3, page 59). In this case, the lower quality wood is even preferred.

In addition to *sideboards*, other byproducts are generated during the process. Cutting, milling, and planing wood to the desired dimensions produces large quantities of wood chips, fibers, and sawdust. These are typically used as *wood fuel* or processed further into *engineered wood products* (NDR, 2016) (see page 46). To avoid this, or at least reduce the amount, less processed and rough-sawn wood should be used where it does not matter, such as inside the construction (see assemblies 2.2, 2.3, page 59).
This can also be beneficial as a plaster base, as the rougher surface allows for a better interlocking between the layers (see assembly 2.2, page 59).

Moreover, studies show that waste wood in the form of wood fibers can be used as loose-fill insulation in buildings. Its thermal conductivity is comparable to that of other organic insulation materials (Cetiner & Shea, 2018), and studies at Holzbau Küng have also proven the fear of increased settlement behavior to be unfounded. In the case of blow-in insulation with wood fibers and chips, 100% of the harvested log can be used for construction purposes and storing the carbon. However, wood's *hygroscopic* nature must be considered. While it can be beneficial in regulating indoor humidity, problems arise when moisture cannot escape inside the construction and mold forms. (Cetiner & Shea, 2018).

### Step 3: drying the wood

As a last step in the production process of a solid wood product, the cut piece must be dried to the desired *equilibrium moisture content* (EMC). This value is depended on the surrounding environment in which the product will be placed and usually lies around 8-12% moisture content for indoors (Perré, 2007). Drying can prevent dimensional changes and defects, such as *warping*, *checking*, and *splitting*, which can occur due to shrinkage or swelling when installed. Additionally, lower moisture content leads to less water activity and prevents biological attacks. (Perré, 2007).

In order to reach the indoor EMC, wood must always be dried mechanically in a *kiln*.
Freshly cut wood has a moisture content between 80-120% in the *sapwood* (Perré, 2007), so that drying wood mechanically also saves an immense amount of time (Martínez-Alonso & Berdasco, 2015).
However, drying wood too fast can lead to quality losses. Wood is an *anisotropic* material and shrinks approximately 20 times as much *transversal* compared to almost no shrinkage *longitudinal*. This is caused by the vertical cell structure, since, in a living tree, the cells transport water from the roots up to the leaves. In the cut piece the cells hold free water inside, which dissipates first in the drying process until the *fiber saturation point* (FSP) is reached (approximately 30% moisture content). Till this moment there is no change in volume. Drying the wood further causes the water in the cell walls to dissipate, compacting the cells

[35] Container filled with wood chips and fibers; Alpnach, Switzerland; photography by the author

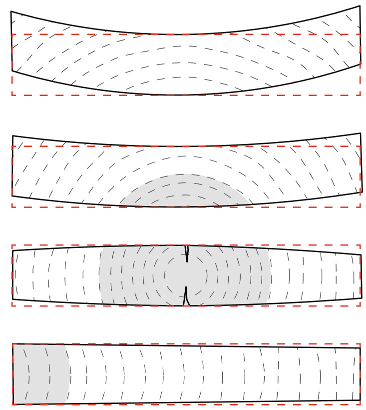
and ultimately changing the volume of the wood. In a *kiln* wood dries from the outside to the inside. A fast drying process can cause the outer layers to reach the FSP much earlier than the inside. Consequently, the outer layer compresses, resulting in a lot of tension. When water inside wants to escape, it finds the weakest point in the dry outer layer, causing checks and cracks. (Perré, 2007).

To bypass this problem, the wood can either be dried slower (e.g. airdried) or the relative humidity inside the kiln can be increased. This way the moisture gradient between inside the wood and the outside air is gentle and the wood can dry almost homogenously (Perré, 2007).

*Compression wood* provides an exemption in the drying process. Long-term wind impact causes the cell structure on the tension side to vary significantly compared to the compression side. Consequently, unlike regular wood, *longitudinal* shrinkage is much more severe on the tension side, resulting in twists and bows. (Perré, 2007)

### Environmental impact of kiln drying

In the sawmill process, *kiln drying* wood planks contributes up to 97% of the GWP impact. It uses 75.3% more energy than air drying cut lumber. Therefore, the impact on greenhouse gas emissions is undeniable. Reducing the amount of time planks spend drying in the *kiln* and increasing the time they spend drying in the open air decreases the *global warming potential* (GWP) impact (Martínez-Alonso & Berdasco, 2015).




[36] Amount of cupping dependent on different wood cut and grain direction

[37] Cut lumber stacks at Sohm Holzbau; Alberschwende, Austria; photography by the author

## Engineered wood products

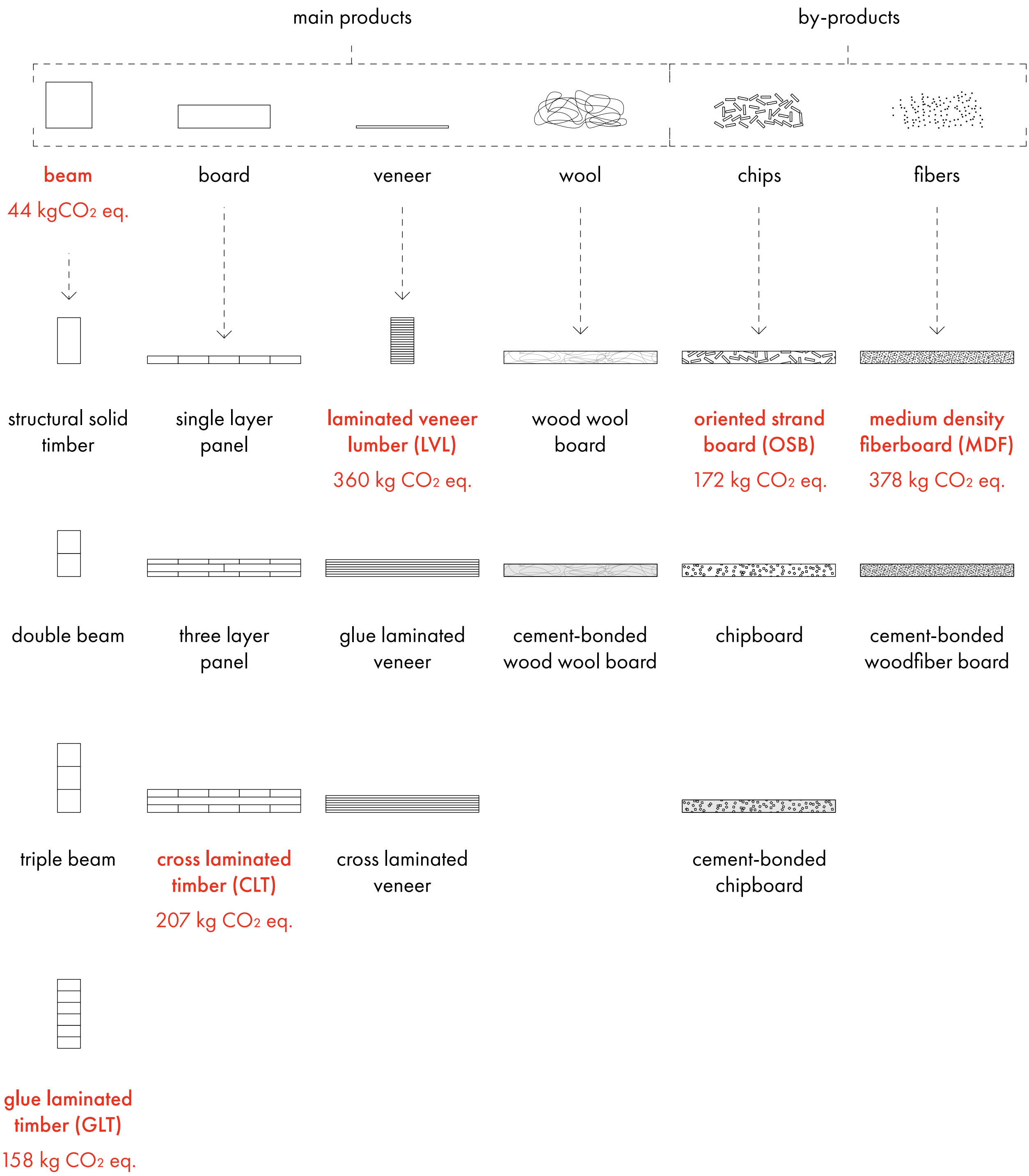
Historically, wood was limited by its natural dimensions until *glue laminated timber* (GLT) was invented in the early 20th century (see "Historical Background" page 6). This development marked the beginning of wood products bonded with adhesives and laid the foundation for *engineered wood products*.
The resulting products offer more predictable performance and homogeneity, enabling applications that go beyond the natural capabilities of solid wood (Messmer, 2015). However, the adhesives typically used are fossil fuel-based, affecting both environmental impact and potential health risks.

The by far largest share of adhesives with approximately 90% is based on *formaldehydes* (Messmer, 2015).
They have been the industry standard since the 1930s and with the addition of heat and hardeners (ratio 100:60) they form an irreversible, water-resistant bond. However, the gasses produced from *formaldehyde* are classified as a human *carcinogen* by the department of health and human services and are linked to nose and throat cancers (ATSDR, 2015). Substantially they contribute to air pollution and long-term health risks. (Messmer, 2015)

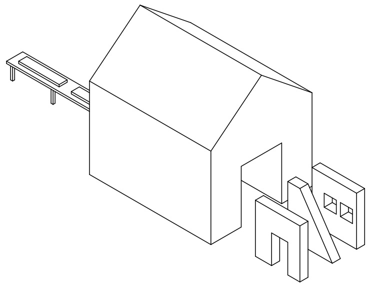
*Melamine urea formaldehyde* (MUF) has the largest market share due to its low cost, which is two-thirds that of the more sustainable adhesive, *polyurethane* (PUR). PUR only makes up approximately 5% of today's market (Messmer, 2015).
The production of PUR is more time-consuming and complex, however, it is formaldehyde-free and requires no additional hardener because the adhesive finds its catalyst – water – directly in the wood to be bonded. Additionally, less than half the amount of PUR is needed to form an equivalently stable CLT compared to MUF. While it is less harmful to the air and environment, it still has a large ecological footprint because it relies on the extraction of fossil fuels. (Messmer, 2015)
To put it in Prof. Braungarts words: "Less bad is still not good" (2023).

In a *glue-laminated timber* (GLT) beam, the adhesive accounts for about 50% of total greenhouse gas emissions despite making up only approximately 1% of the beam's weight (Frischknecht & Ramseier, 2020).
Furthermore, the recyclability and source-separated disposal of engineered wood products are greatly impacted by their use (see "End Of Life", page 70).

One solution to this problem is bio glues, such as wood's own *lignin*, tannin, cashew nut shell liquid, and castor oil. However, they have not yet been proven effective in engineered wood production other than in some chip and fiber boards (Messmer, 2015). Therefore, glue-free assemblies, such as plug and dowel connections, remain the most sustainable solution (see "End Of Life", page 70).




^ [38] Overview of common engineered wood products and their solid wood basis (most used with GWP in red) (source: ÖKOBAUDAT)



## 3 CARPENTRY & CONSTRUCTION

In carpentry, cut *lumber* is transformed into various construction elements. Prefabrication is indispensable today and offers several key advantages.

### Prefabrication

Compared to other construction methods, timber construction is relatively lightweight. This makes it possible to prefabricate entire elements because they can be easily transported by trucks. The only real restriction is the loading capacity dimensions (Huß, 2021).

In a carpentry, heavy equipment is always nearby and ready to use, making the process efficient and precise. *Computerized numerical control* (CNC) milling machines can construct elements with millimeter precision, saving time during construction and assembly (Heinzmann & Karatza, 2025). This is extremely valuable, as traditional on-site construction relied heavily on weather conditions. Construction can be delayed if it takes too long, exposing the wood to high humidity for extended periods, which can result in the loss of the *EMC*. Prefabrication therefore minimizes the risk of moisture damage by reducing the time spent on site (Huß, 2021).
Furthermore, precise prefabrication increases the potential for reusing timber elements, even for highly complex shapes (Bechert et al., 2025).

Although time is saved in the execution phase, the overall process is not shorter. In a modern prefabricated timber construction, the planning process is complex, offsetting the time saved in the execution phase. However, since the project remains virtual for a longer period, changes can be made throughout the process without impacting the real world directly. This minimizes waste and energy consumption (Huß, 2021).

[39] Prefabrication of "Diagonaldübel" wall elements at Sohm Holzbau; Alberschwende, Austria; photography by the author >

Often, carpentries specialize in a particular construction method to establish themselves in the market and develop expertise. This is particularly true for innovative, sustainable systems. For example, the visited carpentry "Zimmerei Grünspecht" specializes in timber frame construction with straw insulation, and "Küng Holzbau" specializes in solid timber construction without additional insulation.

### Skeleton construction

In skeleton construction, beams and pillars transfer vertical loads as point loads. Consequently, a large amount of force is concentrated on small bearing areas, which requires larger cross-sectional dimensions. Engineered wood products, such as *GLT* or even *LVL* beams, are often used to combat this.
Additionally, the load-bearing structure is usually separated from the building's envelope and is located either inside or outside the building. Therefore, skeleton constructions are not included in the catalog of assemblies in the following chapter.

### Timber frame construction

Timber frame walls transfer loads linearly and are the most material-efficient construction method in timber. Additionally, the spaces between the structural elements can be filled with insulation, resulting in smaller assemblies. This is why it is the most widely used construction method today (DGfM, 2017).
However, it is also the most complex construction method, as it relies on many different materials to ensure optimal thermal properties while avoiding condensation and ensuring airtightness (see figure 42, page 53).

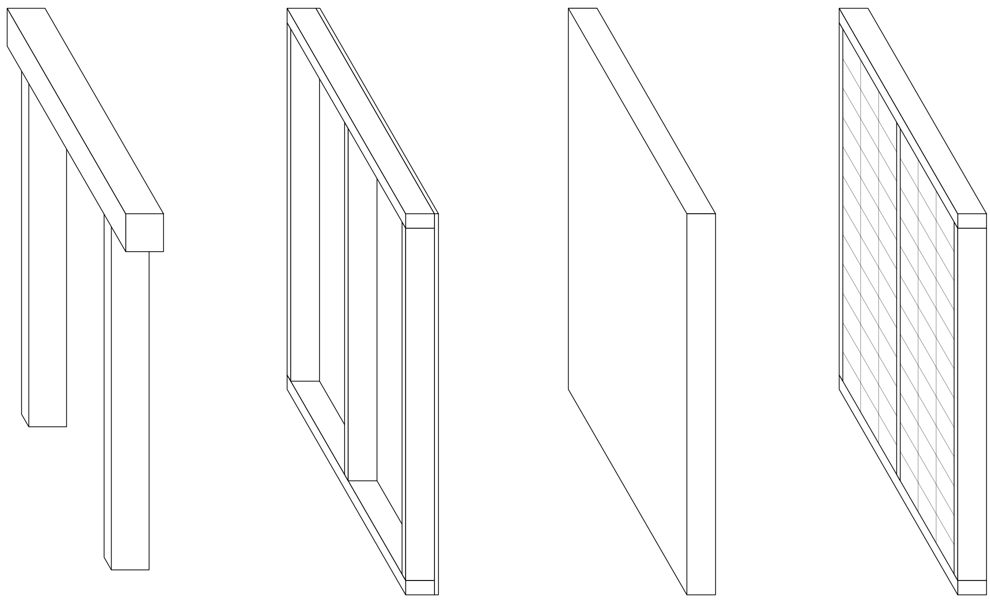
### Solid wood construction

Due to their surface-based design, solid wood constructions often have polyfunctional properties. The load-bearing structure can act as a diaphragm and serve as an airtight layer. Solid wood constructions use the most timber, which typically leads to the greatest stability.
The industry standard for this, however, is *CLT*, which relies on adhesives. This can be replaced by *dowelled* assemblies that may offer slightly lower load-bearing capacities but can be recycled and disposed of as pure, single-material components.
Moreover, studies have shown, that the thermal conductivity of solid wood assemblies has been found to be more effective than initially predicted, leading to the elimination of additional insulation in certain instances (Nagler et al., 2024).

### Hybrid timber construction

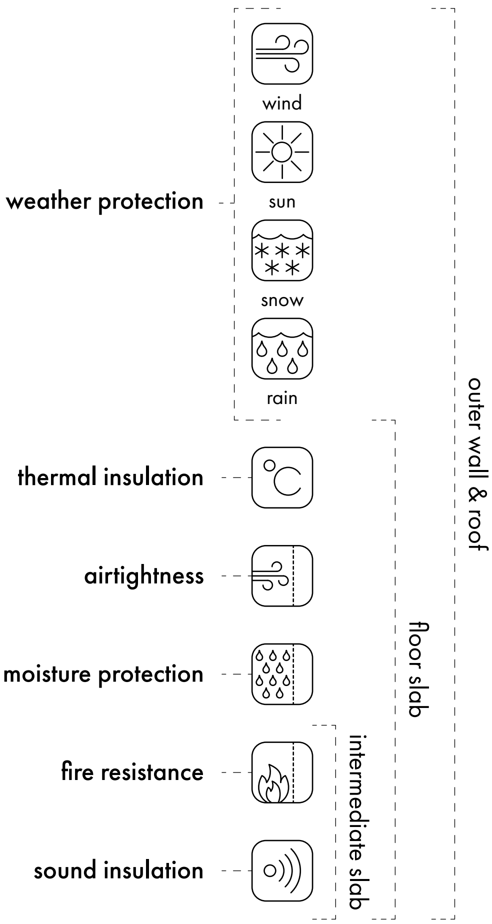
Hybrid timber constructions are characterized by the addition of a second material to wood. The aim is to leverage the strengths of both materials. Concrete is commonly used because it can withstand high compressive forces, while timber carries tensile forces. However, due to its significant environmental impact and low recyclability, concrete should be avoided. A material with similar characteristics, such as clay, should be used instead. Furthermore, clay can benefit the wood physically because it is more *hygroscopic*, which keeps the wood dry and creates long lasting assemblies like the historical Fachwerk buildings.

The construction methods can also occur in combined form.



| skeleton construction | timber frame construction | solid timber construction | hybrid timber construction |
|---|---|---|---|
| (excluded) | 2.2<br>3.1<br>4.1<br>4.2 | 1.2<br>1.3<br>2.1<br>2.3<br>3.2<br>3.3<br>4.3 | 3.1<br>3.2 |

^ [40] Timber construction methods with the corresponding detail number for the assemblies in the catalog




[41] Icons for protective functions of the building envalope (adapted from Kohaus & Kaufmann (2021))

#### Demands on the building envelope

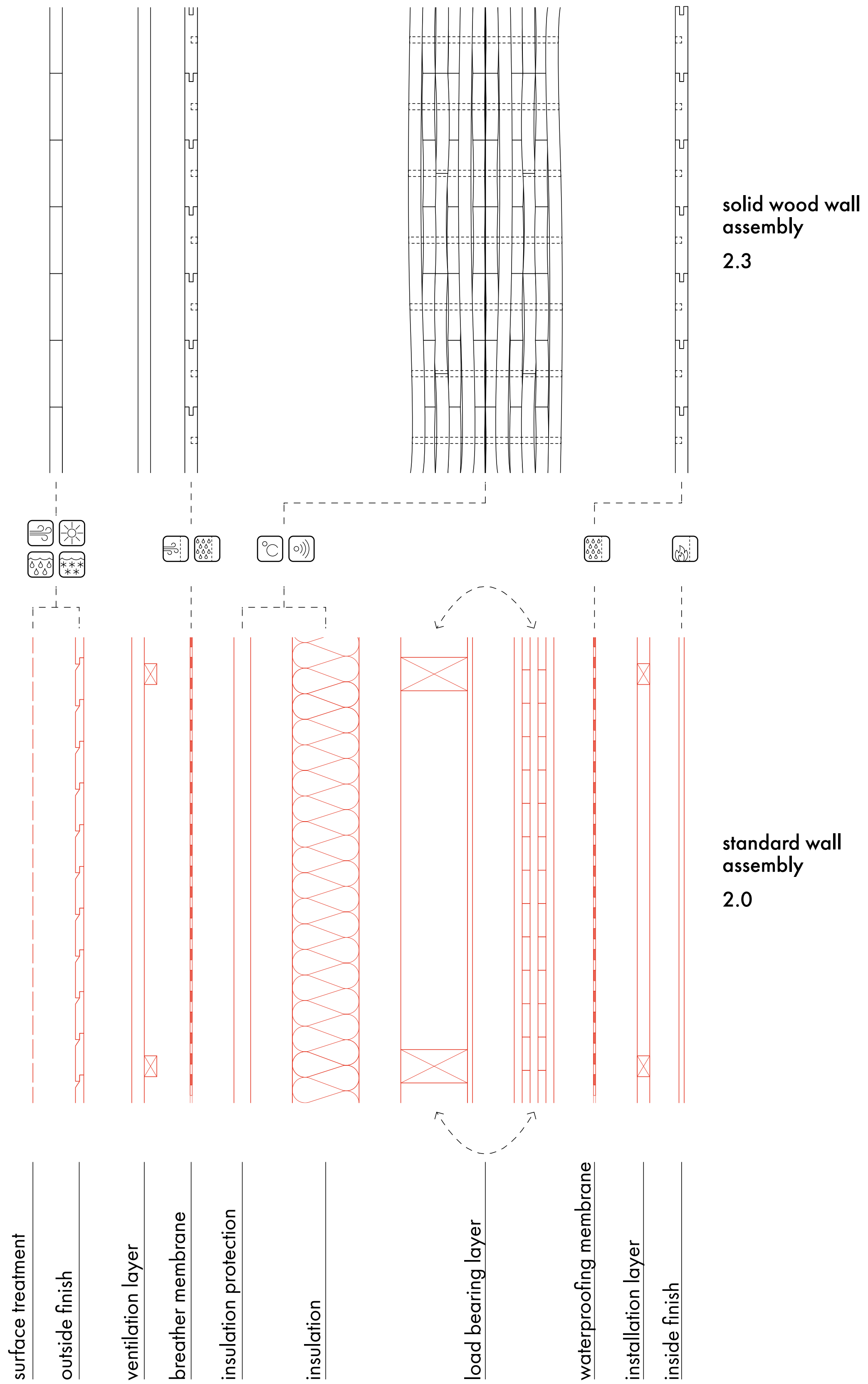
The demands on the building envelope are constantly rising, resulting in an increasing number of functions it must perform (Strauß & Goos, 2025). This works with a variety of layers, each of which takes on a specific function (see figure 42).

In certain cases, a single layer can perform multiple functions. For example, a diagonal cladding with an interlocking tongue-and-groove joint can brace the structure, act as a moisture barrier and provide airtightness (see assemblies 1.2, 2.1, 4.1; pages 57, 58, 62). This behavior is described as *polyfunctionality*, which can significantly simplify an assembly. Moreover, it can reduce the complexity of the component joints, which is why this type of reduction is desirable. Special attention, however, is required at the element connections: With low-layer assemblies, distinguishing the layers becomes harder, making it more difficult to connect them to the same layer of other components (Kohaus & Kaufmann, 2021).
To clearly demonstrate the functions of each layer, small icons are placed next to each assembly in the catalog of assemblies (see figure 41).

#### Current standard vs sustainable

The building envelope carries loads and protects against wind and weather, ensuring interior comfort.

Therefore, the outside layer is designed weatherproof. For exterior walls, this means ensuring that the wood is of sufficient quality. Chemical treatment of this outside layer should be avoided (see "Design & Assembly", page 64).
Separation from the rest of the structure using a ventilated cavity is also beneficial, as it simplifies future maintenance and reduces radiant heat as well as protects the timber from moisture and fungal decay.
To ensure a dry insulation and wind protection, typical assemblies use breather membranes, often made from unrecyclable synthetic materials. By using natural, vapor-permeable materials and interlocking connections, this issue can be avoided while maintaining the same function.
Insulation can be installed within the construction or on the exterior (see "solid & timber frame construction," page 51). An additional exterior insulation is, moreover, used to minimize thermal bridges. However, insulation becomes redundant when the load-bearing element itself provides enough mass for adequate thermal performance.
Outdated constructions often include a waterproofing membrane to prevent moisture from reaching the load bearing and insulation layers. However, this can also inhibit the outward diffusion of moisture from within the construction, potentially leading to mold growth. Therefore, this layer should only be added when necessary (e.g. in rooms with high humidity such as bathrooms) and with great caution. In general, the principle is to design the assembly as permeable as possible and as airtight as necessary.
The installation layer on the interior can often be integrated within the construction or insulation layer.



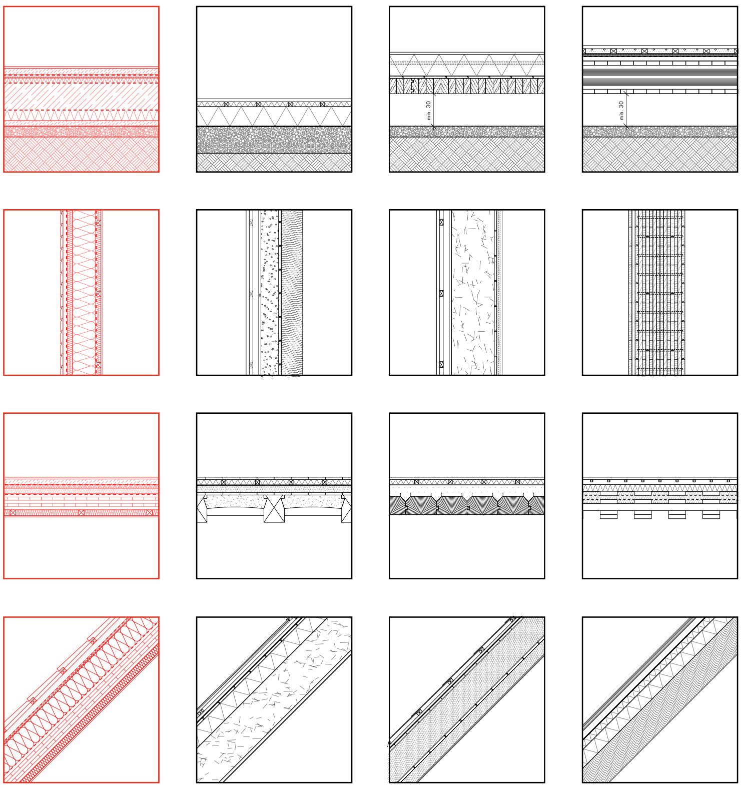

[42] Benefits of polyfunctionality using the example of the "holzpur"-assembly by Küng Holzbau compared to a typical assembly

## CATALOG OF ASSEMBLIES

Standardization plays a crucial role in contemporary timber construction by simplifying planning, approval processes, and execution. Established building systems and tested assemblies improve efficiency, reduce errors, and facilitate the broader adoption of timber construction.
However, many current standards rely on synthetic materials such as plastic-based vapor barriers derived from fossil fuels. While technically effective, they can limit recyclability and increase embodied emissions.

A deeper understanding of the functions within a building assembly reveals that these materials can often be substituted by organic materials or by carefully designed constructions that achieve the same performance through geometry, material properties, and layer arrangement. For this reason, the following catalog compares one currently approved standard detail with three alternative solutions. Small icons indicate the functions of each layer and encourage a critical reading of construction details.

current standard sustainable solutions



1 floor slabs

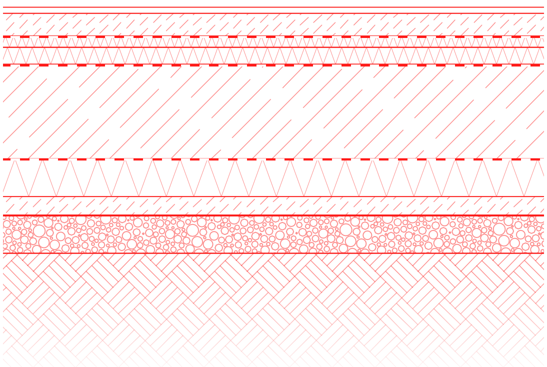
2 outer walls

3 intermediate slabs

4 roofs

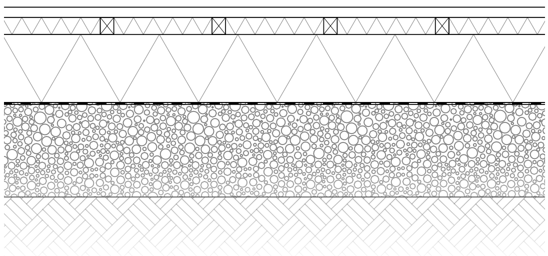
< [43] Straw insulation at Zimmerei Grünspecht; Freiburg, Germany; photography by the author

^ [44] Overview of the assemblies appearing in the "catalog of assemblies"



## 1.0 CURRENT STANDARD

| | |
|---|---|
| flooring | 20 mm |
| wet screed | 60 mm |
| separation layer | |
| impact sound insulation | 30 mm |
| additional insulation | 45 mm |
| sealing layer | |
| reinforced concrete | 250 mm |
| sealing layer | |
| XPS insulation | 100 mm |
| blinding layer | 50-100 mm |

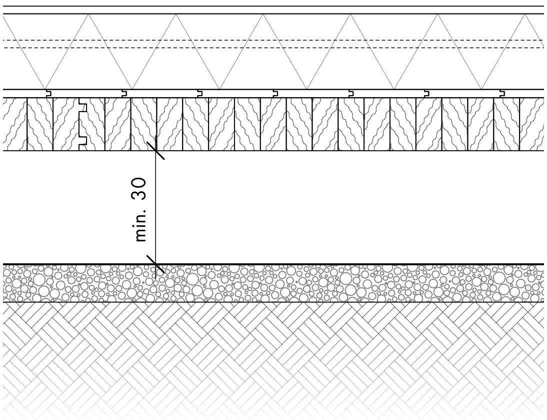


## 1.1 CEMENT FREE GROUND TOUCHING

| | |
|---|---|
| floorboards | 27 mm |
| woodfiber insulation<br>with wooden battens | 45 mm<br>36/45 mm |
| woodfiber insulation | 180 mm |
| bitumenous sheeting | |
| foamglas gravel | 200-300 mm |

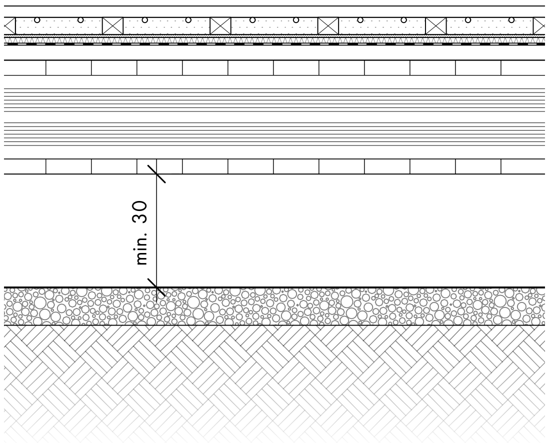
[45] adapted from dataholz.eu; Sockel awmxsom01

[46] adapted from Forschungshaus 4, Florian Nagler Architekten, Bad Aibling, Germany




### 1.2 DOWELED FLOOR SLAB

| | |
|---|---|
| floorboards | 20 mm |
| woodfiber insulation with installation | 200 mm |
| diagonal cladding (tongue-and-goove) | 22 mm |
| doweled stacked timber elements | 140 mm |
| ventilation layer | min. 300 mm |

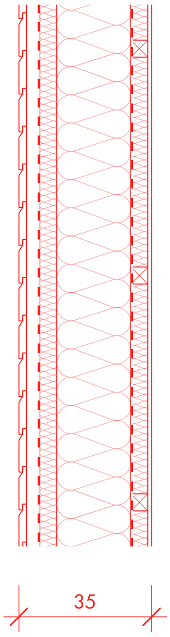


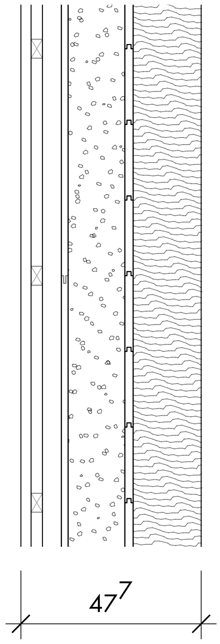

### 1.3 SOLID TIMBER WITHOUT INSULATION

| | |
|---|---|
| fir floorboards | 30 mm |
| battens | 45/55 mm |
| inlaid loam blocks (integrated heating pipes) | 45 mm |
| impact sound insulation | 8 mm |
| impact sound insulation | 20 mm |
| vapor barrier | |
| crushed lime fill | 40 mm |
| solid sprouce system with airpockets | 300 mm |
| ventilation layer | min. 300 mm |

^ [47] adapted from Gartenhaus, Florian Nagler Architekten; Munich, Germany

⌐ [48] adapted fromHaus Hoinka, Atelier Kaiser Shen; Pfaffenhofen, Germany




## 2.0 CURRENT STANDARD

| | |
|---|---|
| treated wooden cladding | 20 mm |
| counterbattens with airgap | 35 mm |
| breather membrane | |
| insulation protection | 45 mm |
| timber frame with mineralwool insulation | 195 mm |
| vapor barrier PE-foil | |
| installation layer with mineralwool insulation | 45 mm |
| OSB board | 10 mm |

U-value: 0,15 W/m²K

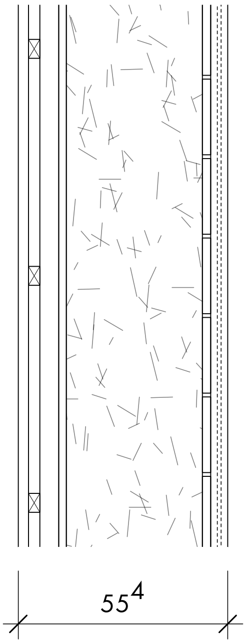
## 2.1 DOWELED SOLID TIMBER WALL

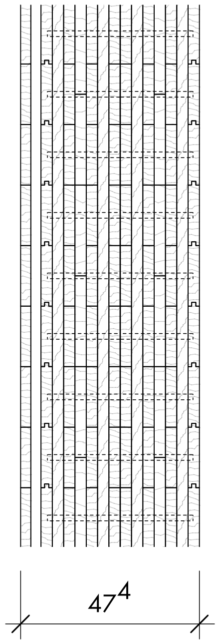
| | |
|---|---|
| cladding | 27 mm |
| battens | 30 mm |
| counterbattens | 50 mm |
| wood fiber board (tongue-and-groove) | 18 mm |
| insulation cellulose | 150 mm |
| diagonal cladding (tongue-and-groove) | 22 mm |
| doweled stacked timber element | 180 mm |

U-value: 0,16 W/m²K

[49] adapted from isover.se; YT:18 Ventilerad träfasad

[50] adapted from Sohm Holzbau; Alberschwende, Austria




## 2.2 STRAW INSULATED TIMBER FRAME

| | |
|---|---|
| cladding | 27 mm |
| battens | 30 mm |
| counterbattens | 50 mm |
| clay plaster (2 layers) | 20 mm |
| timber frame<br>with straw insulation | 360 mm |
| diagonal cladding unedged | 22 mm |
| clay plaster<br>with installation | 50 mm |

**U-value: 0,14 W/m²K**

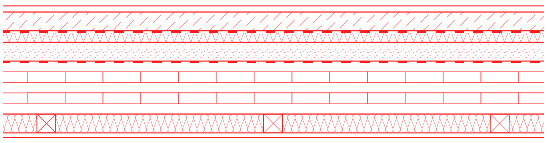
## 2.3 SOLID TIMBER WITHOUT INSULATION

| | |
|---|---|
| cladding | 27 mm |
| counterbattens | 30 mm |
| cladding<br>(tongue-and-groove)<br>doweled to<br>solid timber element<br>(second grade timber) | 180 mm |
| solid timber element<br>(second grade timber)<br>doweled to<br>cladding<br>(tongue-and-groove) | 206 mm |

**U-value: 0,19 W/m²K**

^ [51] adapted from Bürohaus Küng, Seiler Linhart; Alpnach, Switzerland

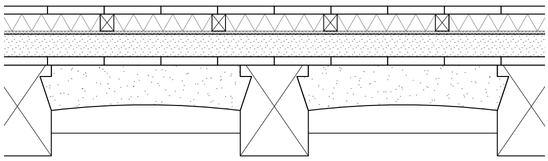
⌜ [52] adapted from Haus Hoinka, Atelier Kaiser Shen; Pfaffenhofen, Germany



## 3.0 CURRENT STANDARD

| | |
|---|---|
| flooring | 20 mm |
| wet screed | 50 mm |
| separation layer | |
| impact sound insulation | 30 mm |
| filling | 50 mm |
| sealing layer | |
| cross laminated timber | 140 mm |
| battens | 40/50 mm |
| insulation | 50 mm |
| gipsum board | 12,5 mm |

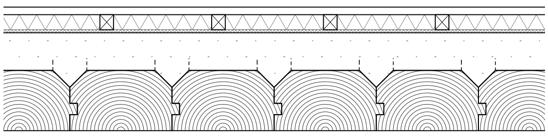
[53] adapted from dataholz.eu; Geschossdecke gdmnxa02a

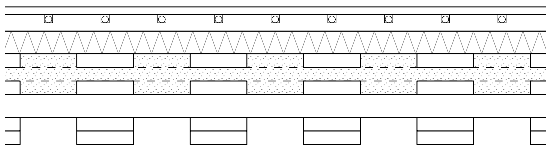


## 3.1 TIMBER BEAMS WITH RAMMED EARTH

| | |
|---|---|
| flooring | 21 mm |
| woodfiber insulation<br>with wooden battens | 40 mm<br>40/36 mm |
| cork floor mat | 8mm |
| granular filling | 60 mm |
| diagonal cladding | 22 mm |
| beams | 160/240 mm |
| rammed earth vault | 120 mm |
| tie rod | |

[54] adapted from HORTUS; Herzog & De Meuron; Allschwil, Switzerland





### 3.2 TIMBER BEAMS WITH LOAM

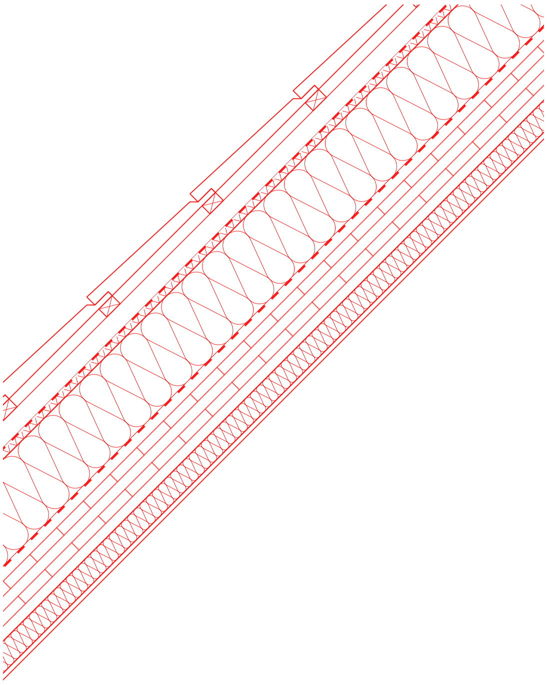
| | |
|---|---|
| flooring | 20 mm |
| woodfiber insulation<br>with wooden battens | 40 mm<br>40/36 mm |
| cork floor mat | 8 mm |
| cork-loam-trass-lime filling<br>compressed | 100 mm |
| timber beams<br>(trimmed on three sides) | 160 mm |

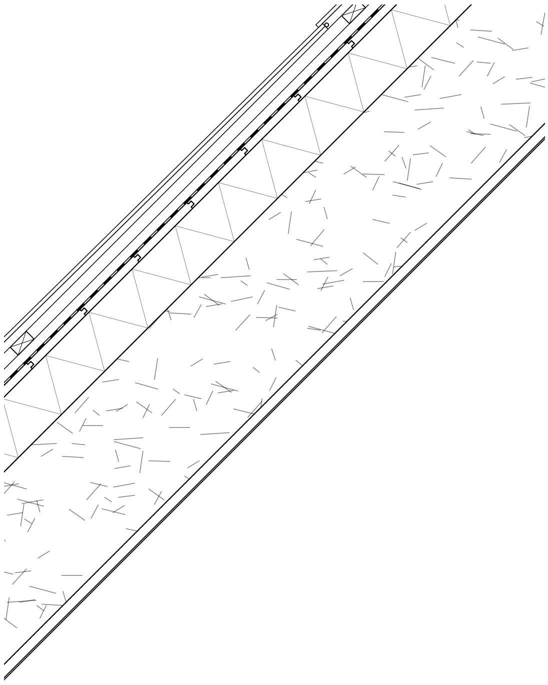
### 3.3 CROSSLAID PLANKS WITH LIME FILLING

| | |
|---|---|
| flooring | 20 mm |
| grooved solid wood<br>with heating pipes | 44 mm |
| woodfiber insulation | 60 mm |
| three layer wood grid<br>with limestone filling | 150/36 mm<br>150 mm |
| grooved solid beech | 60 mm |
| two layer beech grid | 150/36 mm |

[55] adapted from Bürohaus Küng, Seiler Linhart; Alpnach, Switzerland

[56] adapted from Haus Hoinka, Atelier Kaiser Shen; Pfaffenhofen, Germany





## 4.0 CURRENT STANDARD

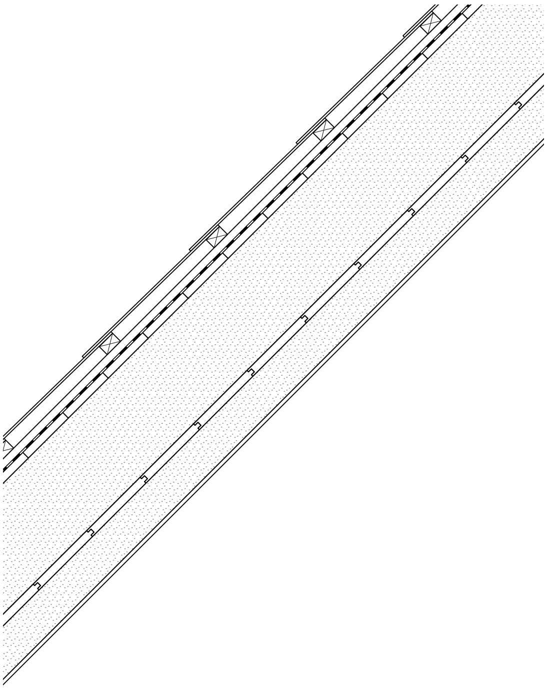
| | |
|---|---|
| roof tile | |
| battens | 30/50 mm |
| counter battens | 50 mm |
| underlay | |
| wood fiber insulation | 22 mm |
| mineralwool insulation between rafters | 200 mm |
| waterproofing membrane | |
| cross laminated timber | 140 mm |
| installation layer | 60 mm |
| gypsum board | 12,5 mm |

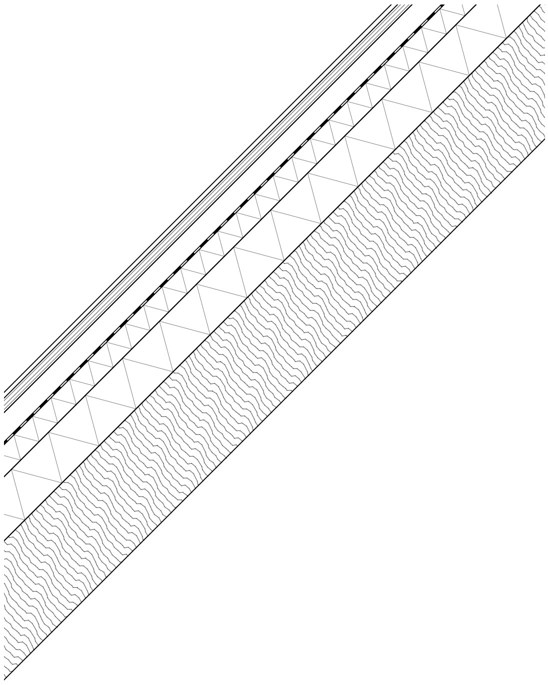
## 4.1 STRAW INSULATED

| | |
|---|---|
| in-roof solar panel | |
| battens | 60/30 mm |
| counter battens | 30 mm |
| underlay | |
| diagonal cladding | 22 mm |
| woodfiber insulation between rafters | 140 mm |
| straw bale insulation | 360 mm |
| clay building board | 25 mm |
| clay plaster | 4 mm |

[57] adapted from dataholz.eu; geneigtes Dach sdmhzi03a

[58] adapted from Haus Hoinka, Atelier Kaiser Shen; Pfaffenhofen, Germany





### 4.2 SEAWEED INSULATED

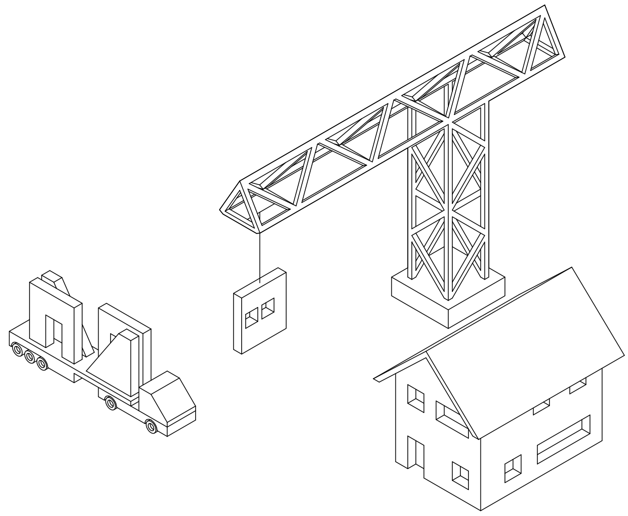
| | |
|---|---|
| slate tiles | 6 mm |
| battens | 30 mm |
| counter battens | 25 mm |
| felt sealing layer | |
| roof boards | 21 mm |
| seaweed insulation between rafters | 245 mm |
| diagonal cladding | 22 mm |
| seaweed insulation with installation | 100 mm |
| textile | |

### 4.3 SOLID TIMBER

| | |
|---|---|
| welted sheet | 3 mm |
| wood boarding | 27 mm |
| battens | 60 mm |
| sealing layer | |
| insulation wood fiber | 60 mm |
| insulation wood fiber | 120 mm |
| doweled stacked timberelement | 260 mm |

^ [59] adapted from Bürohaus Küng, Seiler Linhart; Alpnach, Switzerland

⌐ [60] adapted from Modern Seaweed House, Vandkunsten Architects; Læsø, Danmark



## 4 DESIGN & ASSEMBLY

According to Vitruvius, a good design has to balance durability (firmitas), convenience (utilitas) and beauty (venustas) (Morgan, 1914) (see "Theoretical Framework", page 17). While beauty is highly subjective, and convenience is dependent on the use of the building, durability can largely be influenced by an adequate approach. This leads to longer-lasting buildings and increased stored carbon time, which is why it is the focus of this chapter.

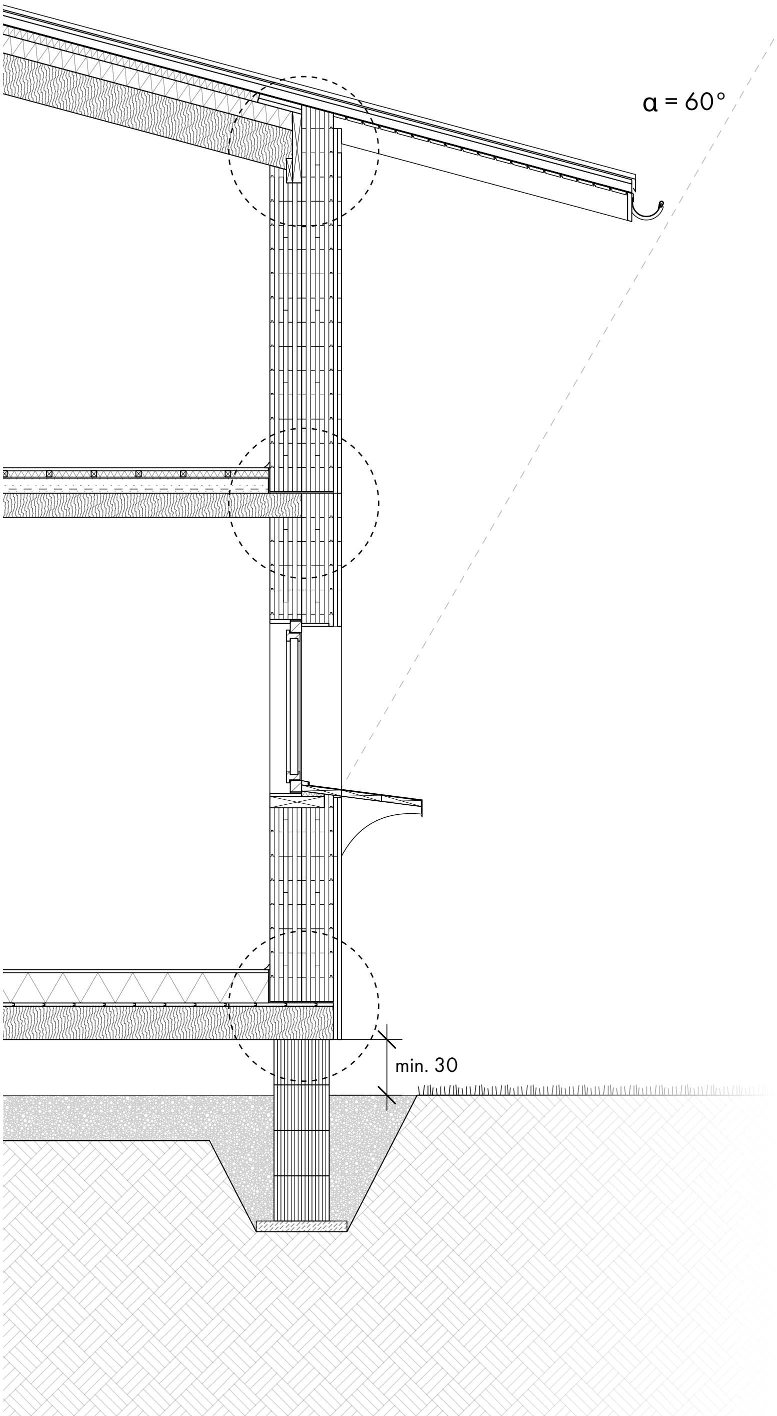
The threshold value for wood is an moisture content of 20%. Exceeding this level increases the risk of fungal growth and insect infestations, as those thrive in wet and warm environments. (Volz, 2003). Both impacts can be treated chemically, but this should be avoided because the chemicals can be washed off over time with constant exposure to rain, contaminating the groundwater. Additionally, single-material disposal (cradle-to-cradle) is only possible to a limited extent at the end of the product life cycle. Chemicals have also proven to be less durable than constructive design measures (UBA, 2019).

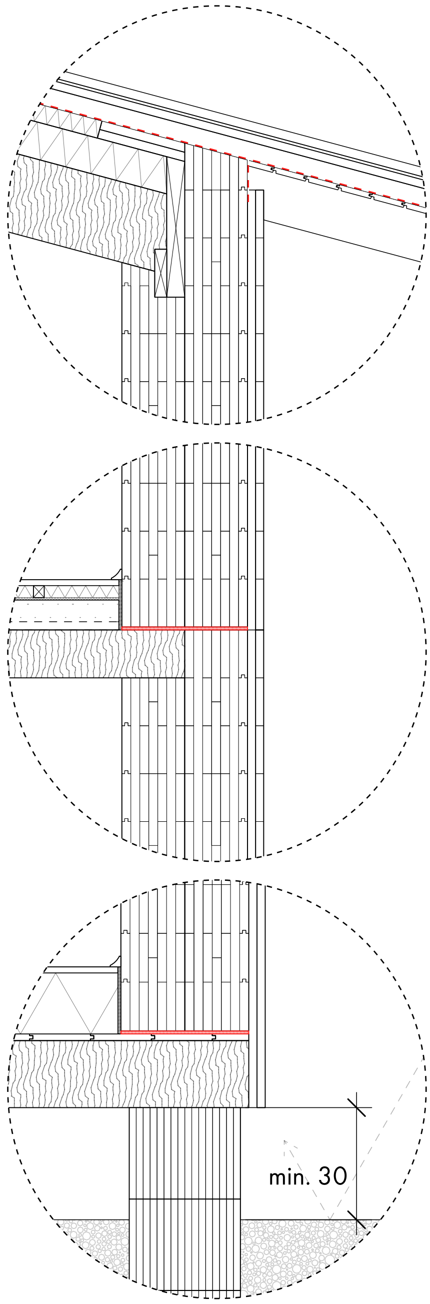
### Constructive wood protection

For *constructive wood protection*, the German standard DIN 68800 requires that precipitation be kept away from the timber or drained off quickly (Frese et al., 2025). This means that flat roofs should generally be avoided, and that a sufficient roof overhang as well as an adequately elevated base should be provided to protect the timber from rain and splash water (see figure 61).

As a general guideline, driving rain is assumed to hit at a 60° angle. Therefore, the roof should project far enough to ensure that the entire timber façade remains untouched at this angle. If this is not feasible structurally, recesses in the façade and secondary protective canopies can be used (Frese et al., 2025).

In timber construction, plinths are typically designed so that the




[61] facade section of a solid timber building with constructive wood protection

[62] connection details with joint sealing tapes marked in red

wood is kept at a minimum distance of 30 cm from the ground. To further improve this, gravel or vegetated ground can be used around the base so that water can infiltrate as quickly and easily as possible (Frese et al., 2025) (see figure 62).

Naturally durable wood species with a low proportion of sapwood can often provide sufficient enough protection (Volz, 2003). However, these species are frequently tropical hardwoods, which involve long transport routes and contribute to the deforestation of endangered forests; for reasons of sustainability (see "Transport", page 68), their use should therefore be avoided. Thermally modified woods, whose durability has been enhanced through heat treatment, are also associated with increased $CO_2$ emissions and should likewise not be used.

An exception in wood protection is wood that remains permanently wet. Because no oxygen is available in such conditions, neither fungal nor insect attack can occur. In all other situations, increasing exposure to moisture results in a reduction of the building's service life (Frese et al., 2025).

Historical timber buildings often demonstrate well-coordinated principles of constructive wood protection, preserving both built heritage and embedded practical knowledge (Frese et al., 2025). Over time, the natural *patina* of the wood allows the building to visually merge with its surroundings and become part of the natural environment.

**Fundamental principles of constructive wood protection**

- Rapid drainage of precipitation must be ensured.
- Moisture accumulation must be prevented.
- End grain must not be directly exposed to weathering.
- Durable wood species should be used.
- Small cross-sections are preferable to large ones.
- The natural drying capacity of the timber must be allowed to develop as effectively as possible within the construction.

### Fire protection

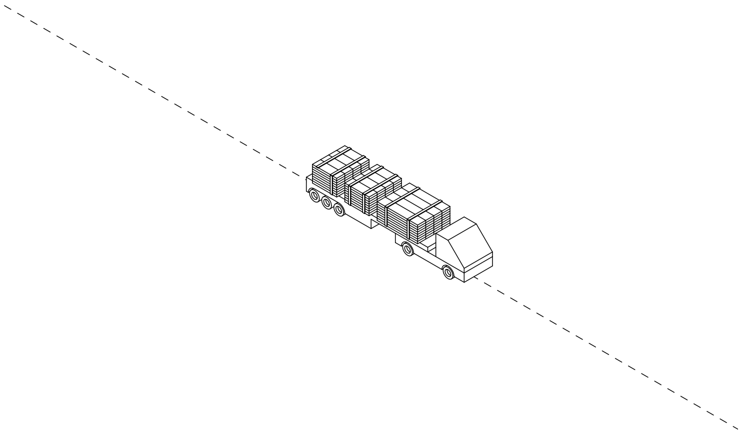
Since wood is a combustible material, it must be considered in fire protection design. However, contrary to common assumptions, timber buildings are not statistically more prone to fire than masonry or concrete structures (Wagner & Zeitter, 2003).

When wood burns, the process proceeds from the outside inward. This is due to the formation of a natural char layer that acts as an insulating barrier, protecting the underlying wood from further heating. Consequently, unlike steel, timber can retain its load-bearing capacity even at high temperatures. For visibly exposed structural members, safety is often ensured through oversizing, with elements specified according to their charring rate (e.g., ISO 60 = loss of load-bearing capacity after 60 minutes) (Neuhaus, 1994).

In general, larger cavities, such as those in timber frame construction, should be filled with insulation; otherwise, the presence of oxygen can accelerate fire development (Wagner & Zeitter, 2003).

[63] Large overhanging roof protecting the facade of the "Maschinenhalle"; Irschenhausen, Germany; photography by the author

[64] Fundamental principles of constructive wood protection according to Frese at al. (2025)



## 5 TRANSPORT

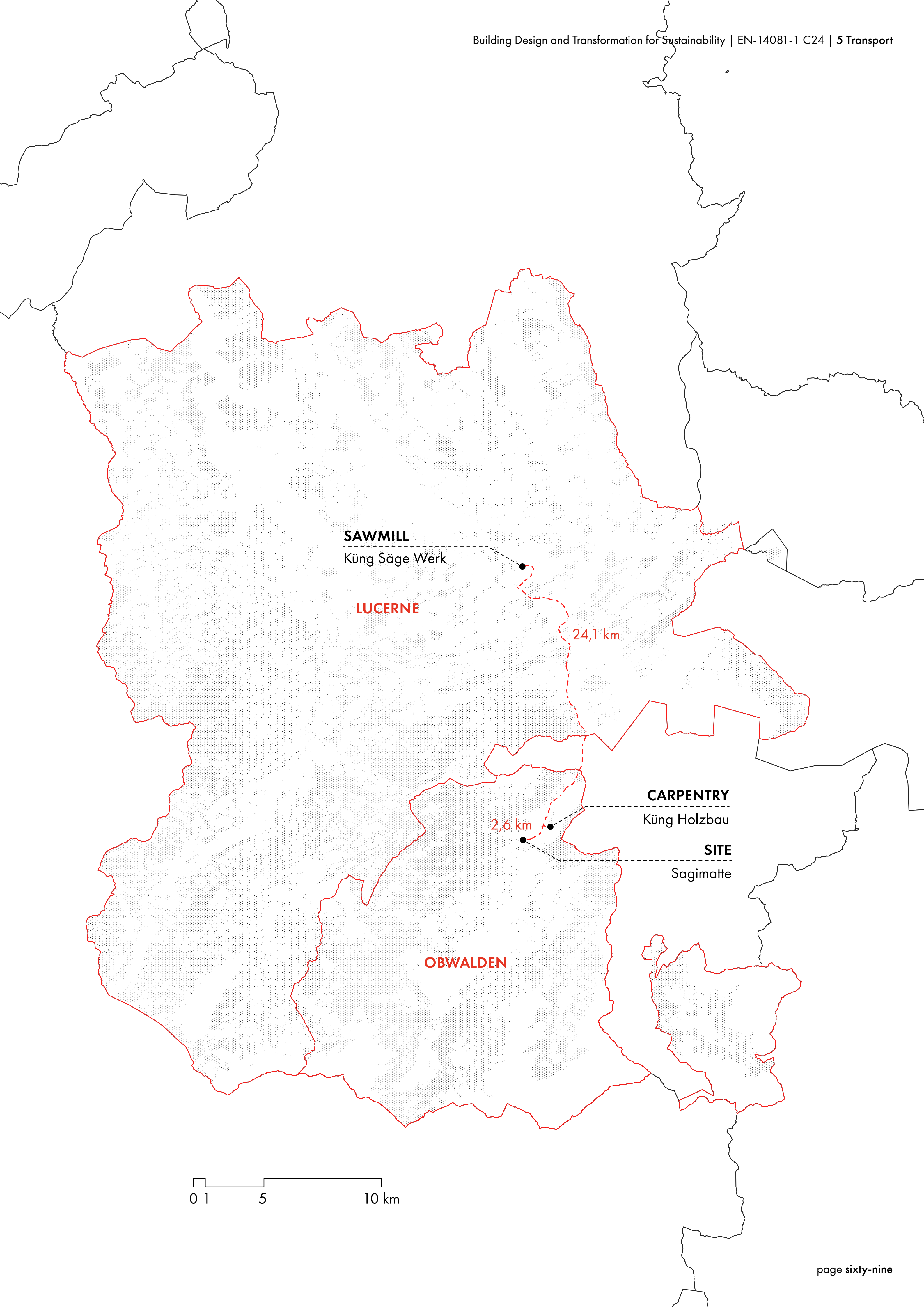
Throughout the entire process, transportation plays a recurring role – whether in moving felled trees from the forest to the sawmill and production facilities, transporting materials to the carpentry workshop, delivering prefabricated elements to the construction site, or finally transporting the timber after dismantling or demolition at the end of the building's life cycle.

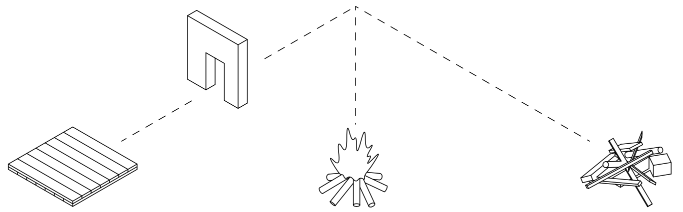
As the impact of transportation depends heavily on the geographical location of each stage in the process, its overall contribution is difficult to precisely quantify. However, globally, transport ranks second within the construction sector, accounting for 23% of its $CO_2$ emissions (Hemmati et al., 2021). Therefore, reducing transport distances in construction would lead to a significant reduction in emissions. A study on the transportation of *CLT* elements found that shipping generated the highest *GWP* impact, followed by rail and then truck transport (Hemmati et al., 2021). Since shipping is predominantly used for long-distance routes, reducing long transport distances should be prioritized.

Furthermore, transport distances clearly demonstrate the local character of timber buildings. An example of this is the multi-family houses Sagimatte in Alpnach (see figure 65). The carpentry firm responsible for the project, Küng Holzbau, operates its own sawmill and sources timber from the cantons of Lucerne and Obwalden. This results in very short transport distances to the sawmill. Subsequent transport distances are equally minimal: 24.1 km from the sawmill to the workshop and 2.6 km to the construction site.
This site-specific construction approach creates a strong local identity and strengthens local businesses.

In conclusion, genuinely sustainable timber construction can only develop where the necessary infrastructure and local wood supply are available.

[65] Map of transport distances for multi family houses "Sagimatte" by Küng Holzbau >


SAWMILL
Küng Säge Werk
LUCERNE
24,1 km
CARPENTRY
Küng Holzbau
2,6 km
SITE
Sagimatte
OBWALDEN
0 1 5 10 km



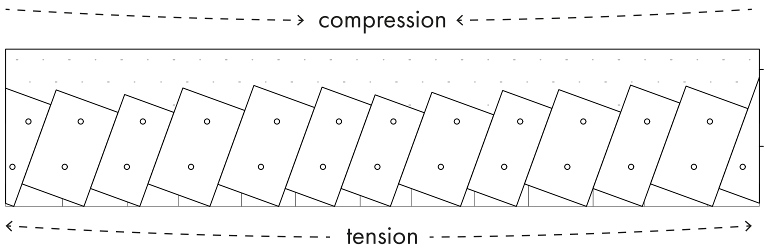
## 6 END OF LIFE

At the end of a building's life, there are three options for its materials. Ideally, the phases of reuse and recycling of wood, as described in the "Cascading Use Of Timber", page 16, are fully optimized. The timber is used without adhesives or chemical additives, enabling energy recovery and clean material separation while eliminating waste.

### Reuse and recycling

Before even dismantling components into their raw materials, timber buildings can be fully relocated or designed in a way that allows entire elements to be disassembled. While the former is often associated with a considerable energy demand, the latter is generally preferable. With careful planning, a building can be deconstructed back into its prefabricated elements (David et al., 2024).

Problems occur when there is a "material mix of metallic, organic, and mineral components" (TUB, 2024). This is mainly due to strongly glue bonded, chemically treated, and heavily nailed or screwed connections, which challenges dismantling building elements and separating the components into their raw form. To ensure optimal conditions for material reuse, construction should therefore aim for material purity and adhesive-free connections. Glued joints, nailing, and screw connections should therefore be reduced to a minimum, and simple plug-in or interlocking connections should be preferred.
In timber construction, wooden dowels can effectively achieve this. The *hygroscopic* nature of wood and its swelling behavior when it absorbs moisture can be utilized here: The dowels are dried to a lower moisture content than the surrounding timber. After insertion, the dowels absorb moisture, swell, and create a tight, form-locking connection that holds the structure together (see assemblies 1.2, 2.1, 2.3, 4.3; pages 56-63).




## Upcycling

One way of repurposing waste wood is displayed in a research project at the Karlsruhe Institute of Technology (KIT). With the help of an automated robot, the collected waste wood is sorted and dowelled together to form a stacked timber deck. This modern technology allows the waste wood to remain largely unaltered while generating minimal additional waste. The stacked timber deck is subsequently covered with a layer of clay, which interlocks with the voids and irregularities of the waste wood, thereby functioning as a hybrid construction system (see figure 66; see "Carpentry & Construction", page 50).
The only downside so far is that the reuse of waste materials for commercial purposes is illegal in Germany. This means that the system cannot be implemented yet.

## Downcycling

In Germany, about 20% of waste wood from construction projects is reused or recycled. The remaining 80% is used for thermal purposes or disposed of as residual waste, even though nearly 90% of this wood falls under *waste wood categories* A1 (untreated/clean) or A2 (lightly treated) (TUB, 2024; Daniel Fischer, 2026).
Since waste wood is increasing in Europe in general (Mancini & Rinnan, 2023), this needs to change in order to store carbon long-term before its release through combustion.

Waste wood is primarily shredded and downcycled to produce chipboards. However, this should only be done when the wood can no longer serve its initial purpose, such as bearing loads. For the downcycling of wood, the following hierarchy applies:

1 Load-bearing function
2 Non-load-bearing function
3 Reconstituted wood products (e.g., chipboard)
4 Fiber-based wood products (e.g., fiberboard)
5 Thermal use

Ensuring compliance with this cascading use principle maximizes the carbon storage duration of wood over its entire life cycle.

^ [66] TerraTimber/ReSidual research project at Karlsruhe Institute of Technology, Germany

^ [67] Sorting of wood into waste, wood fibers, and wood chips; Allgäu, Germany; photography by the author

### Thermal use

Typically, waste wood is classified into different categories to ensure its safe and non-harmful reuse. Depending on the class, wood is treated differently for combustion: the more heavily treated the wood, the more complex and energy-intensive its thermal use becomes.

Untreated solid wood can be safely burned, whereas painted, coated, varnished, or glued wood requires more elaborate and energy-demanding combustion processes. Wood coated with *polyvinyl chloride* (PVC) or heavy metals may only be burned in small quantities, and wood treated with chemical preservatives falls into the highest waste wood category allowed for thermal utilization (Bayrisches Landesamt für Umwelt, 2012).

Consequently, avoiding and minimizing the use of chemical additives is essential to enable safe and efficient thermal recovery of wood.

Due to the renewable nature of wood, its use for energy purposes is significantly more sustainable compared with conventional energy sources, like fossil fuel.
Furthermore, the residual ash after combustion can have a positive impact, as it can be reused as a fertilizer.

### Residual waste

In private households, only untreated solid wood may be used as fuel. Consequently, any wood that has been treated – even only lightly – must be classified as residual waste.

Within the construction sector, treated wood (up to Category III) may, under certain conditions, be reused both thermally and materially by specialized wood-processing facilities.
Chemically treated wood classified as Category IV, however, is considered residual waste and may only be used for energy recovery in dedicated large-scale facilities equipped with appropriate flue-gas treatment systems.

Wood containing polychlorinated biphenyls (PCBs), which were formerly used in certain wood preservatives, is classified as hazardous waste. Such materials require specialized disposal procedures to prevent the release of toxic emissions (Landesanstalt für Umwelt BW, n.d.).

< [68] Heizwerk (=heating plant) run by woodchips; Bad Aibling, Germany; photography by the author

## DISCUSSION

This thesis has shown that timber – despite extensive efforts toward grading, standardization, and industrial optimization – remains an organic, and therefore inherently variable, building material. Wood carries its own biography, shaped by location, soil, wind exposure, altitude, climate, and forest management practices. These factors make the material unpredictable and ultimately resistant to complete standardization. Precisely because of this variability, classification systems are essential: they help make differences legible and provide a structured basis for decision-making. Yet even the most sophisticated classification can never fully capture the complexities of a material grown in a living, dynamic ecosystem. Timber remains fundamentally non-uniform, and any industrial process must work with, not against this.

This tension is mirrored across the entire value chain. The most cost-efficient logging or processing methods, such as clear cuts, simple profiling, or flat sawn cutting without orientation, commonly result in the lowest environmental performance and the poorest material quality. Although these approaches promise short-term financial savings, they often generate long-term losses: reduced durability, increased waste, ecological degradation, and a higher likelihood of future repair or replacement. At the same time, the industry's "gaps" or overlooked resources, such as calamity wood or the intelligent use of sideboards, demonstrate how supposed by-products can become valuable if they are properly understood and placed in the right context. This points to a broader need to rethink what is considered "usable" or "high-quality" material.

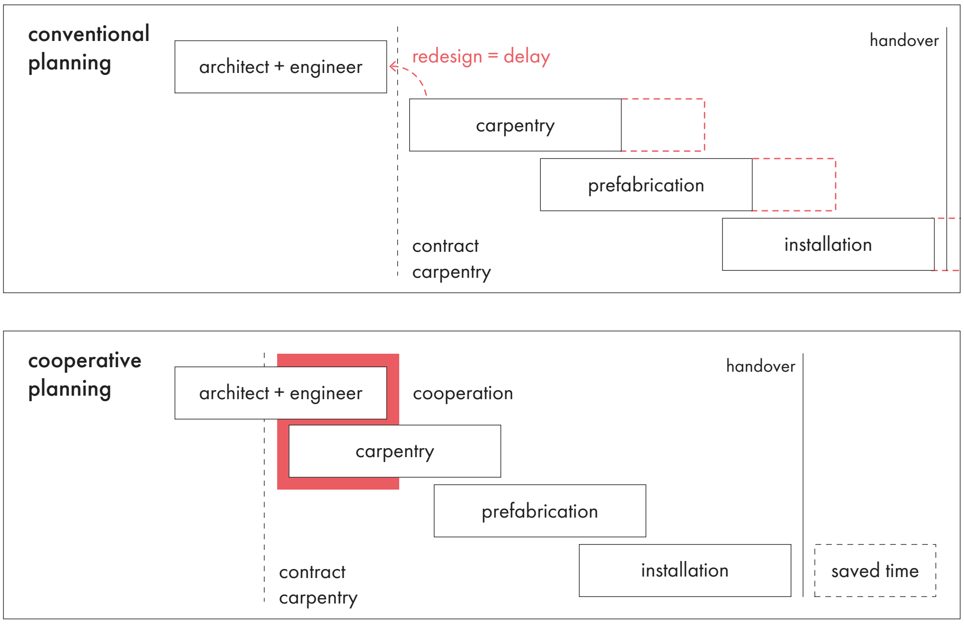
Timber processing never becomes routine. No tree grows identically to another. Even with increasing automation, laser scanning, optimization software, and advanced sorting technologies, the material itself resists predictable, repetitive workflows. Automated systems can ease the workload and increase yield, but they cannot replace the deep expertise that has been passed on for generations. Phenomena such as compression wood, for instance, are not always visually detectable to non-experts and require interdisciplinary knowledge at every step of the process.

For this reason, cooperation across all stages of timber production and construction is indispensable. Forest management, harvesting, sawmilling, drying, further processing, assembly, and installation rely on carefully synchronized workflows between multiple actors. Quality and sustainability emerge only when these processes align, when the decisions made in one stage are understood and supported by those downstream. For example the type of wood harvested directly influences how it can be cut and what it can be used for in the finished built assembly. Timber construction therefore functions less as a linear production chain and more as a collaborative system that demands communication and shared expertise.

It is the architect's responsibility to understand these relationships. Through close collaboration with the responsible timber contractor from the earliest stages of the design process, a shared solution can be developed that meets architectural, technical, and material-specific requirements alike. This not only reduces time, costs, and potential complications, but also enables the development of the most sustainable solution possible (see figure 69).

Based on the identified "Parameters for Sustainability" (see page 31), a framework has been established that allows design and construction decisions to be evaluated from a sustainability perspective. The findings suggest that true sustainability is often achieved through restraint rather than through addition, compensation, or technological intervention. Strictly speaking, holistic sustainability – whether in timber architecture or any other field – can only be fully achieved when construction is avoided altogether. In that sense, the research question, "How can Timber Architecture achieve Holistic Sustainability?", can only be answered by acknowledging that the most sustainable building is the one that is never built.

When construction is nevertheless necessary, the various options must be carefully assessed using the identified parameters. Consequently, sustainability in timber construction is rarely a matter of clear-cut right or wrong decisions. However, once the purpose and performance requirements of each layer within the building envelope are understood, individual layers can often be substituted, combined, or eliminated altogether.




[69] conventional vs. cooperative planning (adapted from Kaufmann et. al. (2021))

As a result, an engineered wood product may in some cases prove more sustainable than solid timber if the latter would require excessive material consumption or significantly compromise the durability of the building. It is therefore essential to evaluate each project individually and to work with materials in a manner that respects their inherent properties and capabilities.

The "Catalog of Assemblies" (see pages 55-63) demonstrates that there is no single perfect solution for a sustainable building assembly. Rather, there exists an almost limitless range of possible combinations and approaches, all of which contribute to guiding contemporary timber construction toward a more sustainable future.

Moreover, European forests currently contain sufficient wood volume, this does not translate into the widespread adoption of massive timber construction. Changing forest compositions, driven by climate change, further complicate material availability. With increasing proportions of hardwoods, whose evolutionary younger cell structures respond differently to climatic stress, the nature of the future wood supply will shift. These developments underline the necessity of material-efficient, function-oriented building methods.
Assemblies must be designed with context in mind: species-specific behavior, growth conditions, drying properties, performance requirements, and lifespan expectations. Material-appropriate construction becomes not just a technical principle, but an ethical and ecological framework for design.

This thesis aligns the layout and design approach with these values. Sustainability is understood not as an end result, but as a design methodology – one that responds to the material's inherent logic. Designing with wood means acknowledging the temporal, ecological, and structural realities from which it emerges.

## Outlook

A natural next step would be to extend the insights of this thesis into concrete architectural applications. Possible future directions could be an architectural design that incorporates different wood qualities into a coherent structural system, showcasing the importance of working with the material, rather than making it fit todays purposes.

In conclusion, working with wood requires complexity thinking. It demands cooperation, expertise, humility, and adaptability. At the same time, it offers a unique opportunity to rethink architecture as a dialogue between forest and building. This thesis marks only one step toward such an architectural culture, but it demonstrates the potential that lies in building with care, deep knowledge, and respect for the material's natural logic that has built up for millennia.

[70] Terrace entrance of Haus Wächselacher; Sarnen, Switzerland; photography by the author >

## ACKNOWLEDGEMENTS

to Carrie and Walter for guiding me along this thesis.

to Stephan Küng and Küng Holzbau, Reinhard Hagspiel and Sohm Holzbau, Timo Schlageter and Zimmerei Grünspecht, TriqBriq, Daniel Fischer and the TerraTimber/ReSidual team at KIT for their insights.

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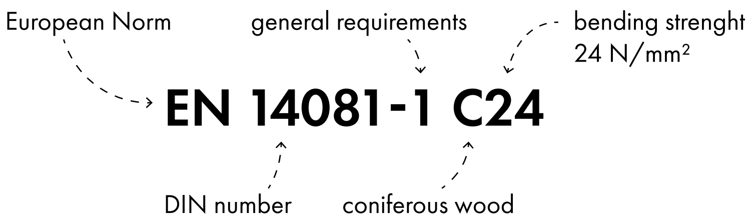


[71] Explanaiton of the thesis' title: the European classification for structural timber

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[44] Overview of the assemblies appearing in the "catalog of assemblies"; illustration by the author

[45] adapted from dataholz.eu; Sockel awmxsom01; illustration by the author

[46] adapted from Forschungshaus 4, Florian Nagler Architekten, Bad Aibling, Germany; illustration by the author

[47] adapted from Gartenhaus, Florian Nagler Architekten; Munich, Germany; illustration by the author

[48] adapted fromHaus Hoinka, Atelier Kaiser Shen; Pfaffenhofen, Germany; illustration by the author

[49] adapted from isover.se; YT:18 Ventilerad träfasad; illustration by the author

[50] adapted from Sohm Holzbau; Alberschwende, Austria; illustration by the author

[51] adapted from Bürohaus Küng, Seiler Linhart; Alpnach, Switzerland; illustration by the author

[52] adapted from Haus Hoinka, Atelier Kaiser Shen; Pfaffenhofen, Germany; illustration by the author

[53] adapted from dataholz.eu; Geschossdecke gdmnxa02a; illustration by the author

[54] adapted from HORTUS; Herzog & De Meuron; Allschwil, Switzerland; illustration by the author

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[61] facade section of a solid timber building with constructive wood

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[62] connection details with joint sealing tapes marked in red; illustration by the author
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## AI-APENDIX

ChatGPT and DeepL were used in the preparation of this thesis, strictly as linguistic support tools. Their contribution was limited to wording suggestions, grammatical refinement, and translations.

All conceptual development, research, and conclusions are the result of the author's own work. No AI-generated knowledge or unverifiable content was used.

## REFERENCE LIST

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