Erasmus+ Project 2022-1-NO01-KA220-HED-000087893

This Erasmus+ Project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the European Commission and Erasmus+ National Agencies cannot be held responsible for any use which may be made of the information contained therein

BIM-LCA Construction Project

Title: Use of Timber as Building Material

1 – Aims

The objectives of this Timber tutorial are as follows:

- Learning about the environmental advantages of using wood as the main construction material in buildings.
- Knowing about state of technology to manufacture timber elements for building structures.
- Knowing about the typology of timber structure systems for buildings.
- Knowing the results of a life cycle assessment (LCA) that compares environmental impacts of a building in timber with the impacts of the same building in concrete.

2 - Learning methodology

The teacher will give an explanation about Timber as Building Material of about 30 minutes.

Students will read this tutorial and follow the steps shown in the tutorial, namely:

- The benefits of timber as a building material. (Ted talk video included).
- Forest management.
- Timber Construction Standards and Design Guides.
- Structural Systems in timber construction.
- Structural elements in timber construction.
- Connections in Timber Structures.
- Seismic Resistance in Timber Structures. (Video included).
- Timber and Fire safety.
- Timber Deterioration due to Biological Agents.
- Mass timber design software.
- Example of design of a mass timber building. Stora Enso. (LCA study included)

In order to evaluate the success of the application, a questionnaire will be held for the students.

3 - Tutorial duration

The implementation described in this tutorial will be carried out through the BIM-LCA Project website by self-learning.

3 lesson hours are suitable for this training.

4 – Necessary teaching recourses

Computer room with PCs with internet access.

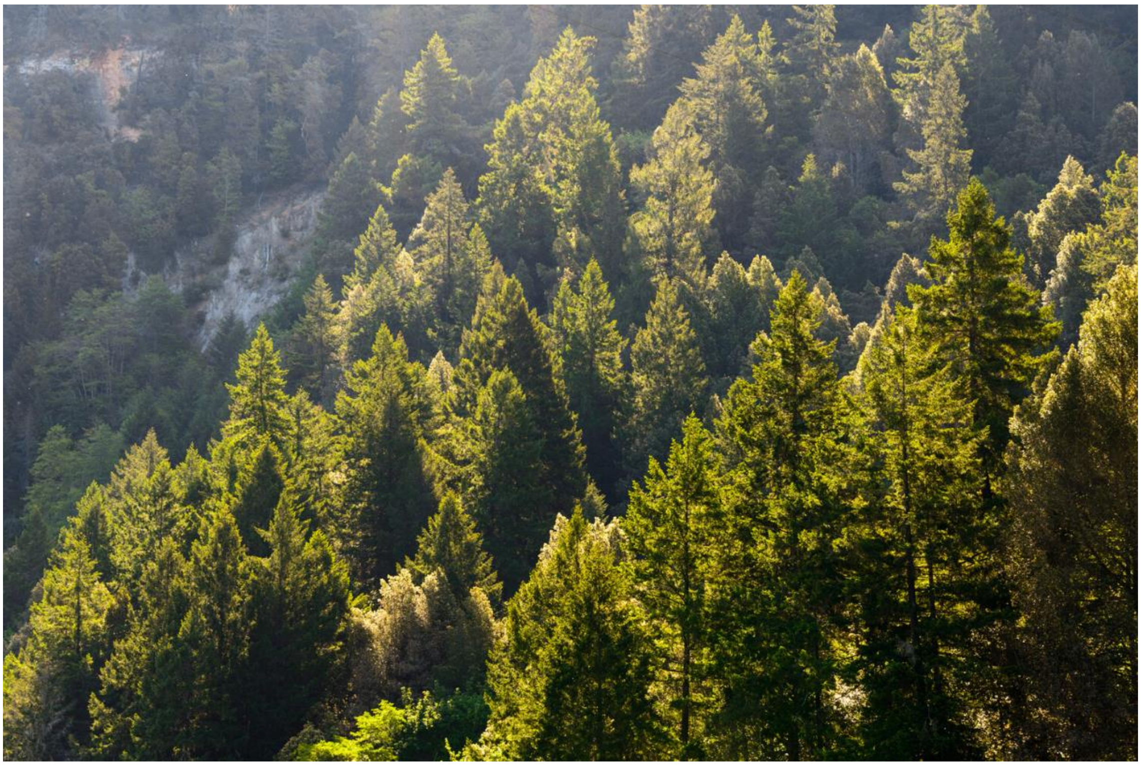
Required software: Microsoft Office.

5 – Contents & tutorial

5.1 – Introduction. The benefits of timber as a building material

5.1.1. Maximum sustainability

Timber stands out as an exceptionally renewable construction material, excelling in sustainability. During their growth, trees capture and retain harmful carbon dioxide, effectively sequestering CO2 within the wood rather than emitting it into the air. Hence, it's crucial to only harvest trees once they have reached full maturity and ceased their CO2 absorption, ensuring maximum environmental advantages. When forests are overseen with responsible stewardship by owners who prioritize replenishment over depletion, you can have confidence that the timber you employ has been harvested in an eco-friendly manner [1].



Embodied energy encompasses the total energy needed to manufacture a product or provide a service. In the construction sector, this includes energy expended during the processes of building, production, and transportation, typically constituting approximately 30-50 percent of a project's overall carbon footprint. Converting trees into timber for construction involves minimal energy consumption, and the construction process typically demands only a fraction of the transportation required for concrete.

These factors contribute to timber receiving the lowest rating for embodied energy among commonly used building materials.

For instance, consider a wooden floor beam, which requires approximately 80 megajoules (MJ) of energy per square meter of floor space and emits 4 kilograms of CO2. In contrast, a square meter of floor space supported by a steel beam necessitates 516 MJ and emits 40 kilograms of CO2, while a concrete slab floor requires 290 MJ and emits 27 kilograms of CO2.

Timber not only boasts exceptional strength and durability but also maintains high-quality standards, even when considering construction speed. Timber structures can endure for centuries and are more cost-effective and easier to maintain compared to alternative materials.

5.1.2. Thermal efficiency

The inherent characteristics of this material also contribute to its environmentally-friendly reputation. Timber, being a natural insulator, contains tiny air pockets that restrict its capacity to transmit heat. This feature reduces the energy required for heating and cooling residences, resulting in reduced reliance on fossil fuels. Moreover, timber frames offer more room for insulation compared to brick structures, thus improving thermal efficiency.

5.1.3. Ease of assembly

Timber, known for its lightweight and adaptability, offers ease of handling and installation. This simplifies the construction process, making it quicker, more cost-effective, and less disruptive. It becomes an ideal choice for brownfield site development and urban construction, creating quieter, more peaceful, and cleaner construction sites.

Additionally, timber excels in off-site manufacturing, significantly reducing build times by up to 50%. Timber frames can be precisely pre-cut and easily assembled with fewer workers, fewer on-site deliveries, and minimal wastes. Manufacturing in a controlled factory environment eliminates weather-related issues, reduces the likelihood of defects, and lowers the risk of injuries. Furthermore, increased automation in the manufacturing process reduces reliance on traditional skilled labour. In terms of cost savings, timber construction stands out as a considerably more cost-effective alternative to traditional building methods.

5.1.4 A classic material or the main building material in the future?

Michael Green, an architect from Vancouver, is a leading advocate for building skyscrapers out of wood in North America. In his TED talk, he said that wood is the most advanced material he can use and talked about the need to create a significant achievement, like the Eiffel Tower, using wood.

Video 1

5.2 – Forest management

5.2.1. Forestry and timber

In today's interconnected world, we need to think about forests and wood in different ways: in our local areas, nearby regions, and all around the world. Right now, about 30% of the land on Earth, which is roughly 4 billion hectares, is covered with forests. But these forests have been getting smaller for many years because of practices like burning the land to clear it for agricultural land, turning it into farmland, and cutting down trees illegally. However, the speed at which forests are disappearing slowed down a bit from 2010 to 2015. Even though people are planting about 4.3 million hectares of new forests every year, we're still losing 3.3 million hectares of forest annually.

The forests in different parts of the world, like tropical, subtropical, cold, and template areas, are crucial for getting wood we can use. But, when it comes to making wood products, the cultivating forests in Europe are the focus. These forests are managed in a way that's good for lots of things, not just getting wood. They help protect the environment, provide places for people to enjoy, and support a variety of plants and animals.

On the other hand, there's a big industry around the world that plants and grows certain types of trees, like eucalyptus and fast-growing pine, mainly to make things like wood for energy, paper, and other products. They grow these trees in large groups, and it is not as good for the environment.

Every year, Earth's forests give us a lot of wood, about 3.7 billion cubic meters (that's like 2.2 billion tons). Of that, about half is used for making energy, and the other half is turned into different products, like timber for building structure. So, wood is still really important as a material we can keep using, and it is one of the top three materials we use the most that comes from nature.

5.2.2. Present and future of timber resources in Europe

For many centuries, people in Europe have been taking care of their forests and even growing special forests to get wood for building things like houses. In the European Union, which has 28 member countries, there are 180 million hectares of forests, covering about 41% of their land. Surprisingly, the amount of forested land actually increased by 5% from 1990 to 2010, and in Germany alone, it went up by 48,000 hectares from 2002 to 2012.

These forests in Europe have a lot of wood in them. For example, in Germany, there are about 3.7 billion cubic meters of wood, and in the whole EU, it is even more, about 22.5 billion cubic meters. Germany has the most wood reserves in the EU, except for Switzerland and Austria. On average, there are about 336 cubic meters of wood per hectare of land in Germany. And in Germany, about 120 million cubic meters of wood grow back on the surface every year, with around 80 million cubic meters of that being used as raw logs.

All these numbers tell us that Germany has plenty of this raw material, and it's not running out anytime soon. In fact, **a calculation showed that all the new buildings constructed in Germany could be made with just one-third of the country's average amount of wood that they can get sustainably from their forests.**

To use wood in a sustainable way, we need to make sure we take good care of our forests and help them grow back. One way to do this is by having diverse forests that match their specific locations and climate. These diverse forests will be more like natural ones, and they will stay healthy over time. They will have lots of different types of trees, more hardwood, and more dead and decaying wood, which is good for the environment.

In Germany, they have looked at how their forests are growing and how much wood they can get in the future. They used something called the "Waldentwicklungsund Holzaufkommensmodellierung" (WEHAM), which is a fancy way of modeling forest development and wood resources. According to this model, they expect to have about 80 million cubic meters of raw logs available every year for the next 40 years. This means that the amount of wood in German forests will increase to about 3.9 billion cubic meters.

However, they also predict that the type of wood they get will change. Right now, most of the raw logs they use for construction come from spruce trees (about 44%).

But by 2027, the amount of spruce logs available will go down to about 35%. Instead, they will have more softwood from trees like pine and Douglas fir. They will also see a big increase in beech and oak trees. This change is because of climate change, which will make deciduous and mixed forests more important for getting wood in Europe.

5.3 - Timber Construction Standards and Design Guides.

Americans:

- The American Wood Council (AWC) and International Code Council have released a joint publication, ***Mass Timber Buildings and the IBC***, providing an overview of requirements for mass timber construction as found in the 2015, 2018, and 2021 *International Building Code* (IBC).
- **The 2018 National Design Specification (NDS) for Wood Construction** was developed by the American Wood Council's (AWC) Wood Design Standards Committee and has been approved by ANSI as an American National Standard. The 2018 NDS is referenced in the 2018 International Building Code. Significant additions to the 2018 NDS include new Roof Sheathing Ring Shank nails and fastener head pull-through design provisions to address increased wind loads in ASCE 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures.
- The ANSI/AWC *2021* ***Special Design Provisions for Wind and Seismic (SDPWS)*** **provides criteria for proportioning, designing, and detailing engineered wood systems, members, and connections in lateral force resisting systems.** Engineered design of wood structures to resist wind or seismic forces is either by allowable stress design (ASD) or load and resistance factor design (LRFD). Nominal shear capacities of diaphragms and shear walls are provided for reference assemblies.
- **Engineering Design in Wood CSA 086, Canadian Standards Association, 2014.**
- **International Code Council. International Building Code. Country Club Hills, Illinois, U.S.A. 2018.**
- **International Code Council. International Residential Code. Country Club Hills, Illinois, U.S.A. 2018.**
- **APA-The Engineered Wood Association. Standard for Performance-Rated Cross Laminated Timber, ANSI/APA PRG 320. Tacoma, Washington, U.S.A. 2020.**

.

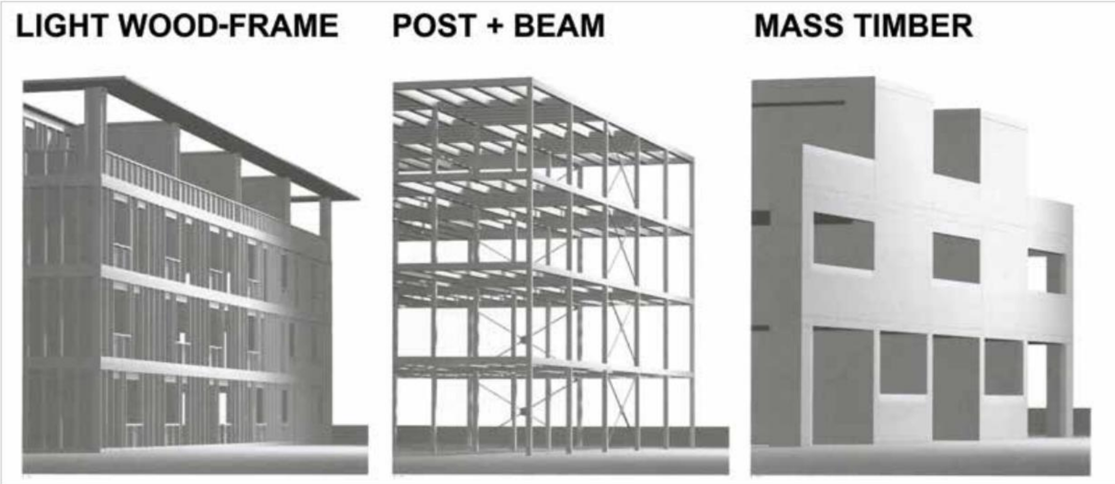
Europeans:

English title	Description
EN 338	EN 338 - Structural timber ? Strength classes
ETA-14/0349	European Technical Assessment ETA-14/0349 of 02.10.2014
Expertise Rolling shear - no edge gluing, H.J. Blass	Expertise on Rolling shear for CLT
EN 1995-1-2	EN 1995-1-2 - Eurocode 5 — Design of timber structures — Part 1-2: General — Structural fire design
EN 14080	EN 14080 - Timber Structures - Glued laminated timber and glued solid timber - Requirements
DIN EN 1995-1-1	EN 1995-1-1 - Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings
DIN EN 1995-1-1 NA	EN 1995-1-1 - National Annex – Nationally determined parameters – Eurocode 5: Design of timber structures – Part 1-1: General ? Common rules and rules for buildings
Technical expertise 122/2011/02: analysis of load bearing capacity and separation performance of CLT elements	Verification of the load bearing capacity and the insulation criterion of CLT structures with Stora Enso CLT
Technical expertise 2434/2012 - BB: failure time tf of gypsum fire boards (GKF) according to ON B 3410	Expertise on failure time tf of gypsum wall fire boards according to ON B3410 and gypsum wall boards type DF according to EN 520
EN 1990	EN 1990 - Eurocode ? Basis of structural design
Fire safety in timber buildings - technical guildeline for Europe	Fire safety in timber buildings - technical guideline for Europe; publishes by SP Technical Research Institute of Sweden
National specifications concerning ÖNORM EN 1995-1-2, national comments and national supplements, chapter 12	ÖNORM EN 1995-1-2 - National specifications concerning ÖNORM EN 1995-1-2, national comments and national supplements, chapter 12
DIN EN 1995-1-2_NA	DIN EN 1995-1-2 - Germany - National Annex - Eurocode 5: Design of timber structures ? Part 1-2: General ? Structural fire design ? National specifications concerning DIN EN 1995-1-2, national comments and national supplements
Expertise Rolling shear, H.J. Blass	Expertise on rolling shear strength and rolling shear modulus of CLT panels
ÖNORM EN 1995-1-1_NA, chapter 7.3	ÖNORM EN 1995-1-1 - Austria - National Annex – Nationally determined parameters – Eurocode 5: Design of timber structures – Part 1-1: General- Common rules and rules for buildings; chapter 7.3

- **Designers' Guide to Eurocode 5: Design of Timber Buildings: EN 1995-1-1.** EN 1995, or Eurocode 5, describes the principles and design rules to be used for the design of timber and wood-based materials in building and civil engineering structures. Designers' Guide to Eurocode 5: Design of Timber Buildings provides guidance on the interpretation and use of the main design requirements of Part 1.1. Common rules and rules for buildings, with additional guidance on the principles, requirements and rules of Part 1.2, Structural fire design.
- **Cross-Laminated Timber Structural Design.** Basic design and engineering principles according to Eurocode. proHolz Austria. Working group of the Austrian timber industry for promotion of the application of timber. Vienna/ Austria. 2014. ISBN 978-3-902926-03-6

5.4– Structural Systems in timber construction

The most commonly used structural systems for single or multi-storey buildings are shown in the following figures [2]:



5.2.1. Light wood-frame construction

Wood is frequently selected as the primary framing material for single-family residences, multi-family dwellings, and commercial structures owing to its cost-effectiveness, widespread availability, and straightforward assembly procedures. Light-frame construction techniques are commonly employed in the construction of retail establishments, healthcare facilities, educational institutions, and various commercial buildings [3].

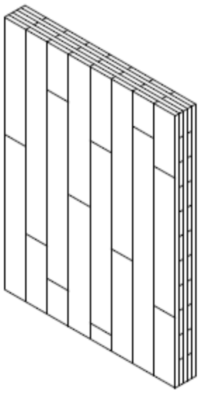
Progressively, components of light-frame structures are being manufactured off-site and subsequently assembled at the construction site.

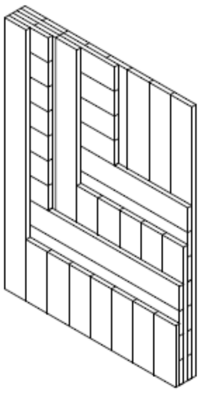
5.2.2. Mass timber construction

Mass timber is a category of framing styles typically characterized by the use of large solid wood panels for wall, floor, and roof construction. It also includes innovative forms of sculptural buildings, and non-building structures formed from solid wood panel or framing systems of 2 m or more in width or depth. Products in the mass timber family include

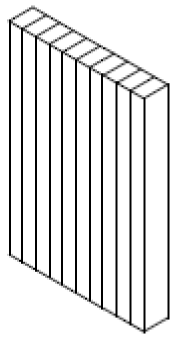
Mass timber represents a classification of framing methodologies, conventionally distinguished by the utilization of substantial solid wood panels in the construction of walls, floors, and roofs. It also encompasses inventive configurations of architectural constructions and non-building structures, formed from solid wood panels or framing systems with dimensions exceeding 2 meters in width or depth. The spectrum of mass timber products includes: [2], [4], [5]:

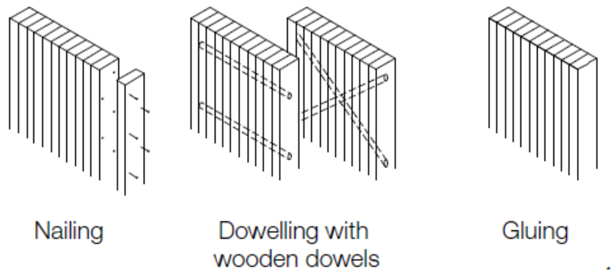
Cross-Laminated Timber (CLT).





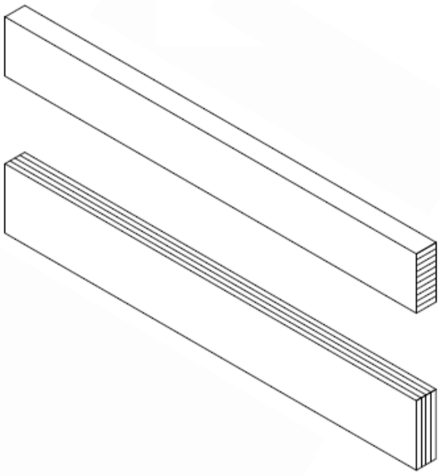
Cross-Laminated Timber (CLT) comprises layers of dimensioned lumber, typically numbering three, five, or seven, which are arranged at right angles to each other and bonded together to create structural panels characterized by exceptional strength, dimensional stability, and rigidity. These panels present a notably cost-effective solution for multi-story and large architectural projects. Some architects consider CLT as both an autonomous construction system and a versatile building material that can be seamlessly integrated with other wood products, lending itself to hybrid and composite applications. CLT finds suitability in flooring, wall, and roofing applications and can even be left exposed on interior surfaces for aesthetic purposes. The cross-laminated nature of CLT confers it with two-way spanning capabilities. Additionally, CLT can be custom-manufactured in various dimensions, with panel sizes varying across different manufacturers.**Dowel-Laminated Timber (DLT)**





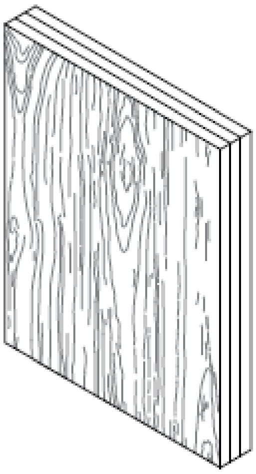
Dowel laminated timber structures were ınitially conceived as slab components, constructed from economical, lower-grade boards that are assembled to create high-quality, load-bearing solid wood structural elements. The cohesion of multiple boards is orchestrated to offset their inherent inhomogeneities. Dowel laminated timber partitions consist of solid wood planks, typically softwood, ranging from 20 to 60 mm in thickness, meticulously interconnected. Vertical wall units, designed to accommodate straightforward on-site assembly, are usually manufactured in widths that facilitate practical handling. These boards may span the entire length of the structural element, be joined by finger joints, or exhibit staggered connections. The thickness of these elements is limited primarily by the maximum board width, commonly reaching up to 240 mm or, in rarer instances, extending to 280 mm. In their nascent form, individual boards were bound together using nails, predominantly of steel composition, which could significantly hinder subsequent alterations. However, when boards are united through hardwood dowels, often fashioned from beechwood, the resultant components become amenable to post-fabrication modifications and recycling, akin to solid wood.

Glued-Laminated Timber (glulam)



Glued laminated timber, commonly known as Glulam, is constituted by individual wood laminations, specifically selected and arranged based on their performance attributes, and subsequently bonded together utilizing durable, moisture-resistant adhesives. The grain orientation of all laminations is maintained parallel to the longitudinal axis of the member. Glulam exhibits remarkable strength and stiffness characteristics and is offered in a variety of appearance grades suitable for both structural and architectural purposes. Although conventionally employed as beams and columns, designers have the option to utilize glulam in a plank orientation for floor or roof decking applications. The adaptable nature of glulam manufacturing enables the creation of glulam 'panels,' capable of facilitating intricate curvatures and distinctive geometrical designs. In cases where such innovative configurations are employed for floor and roof panels, glulam is regarded as an extension of the mass timber product family and is sometimes referred to as Glulam Timber (GLT).

Laminated veneer lumber (LVL)



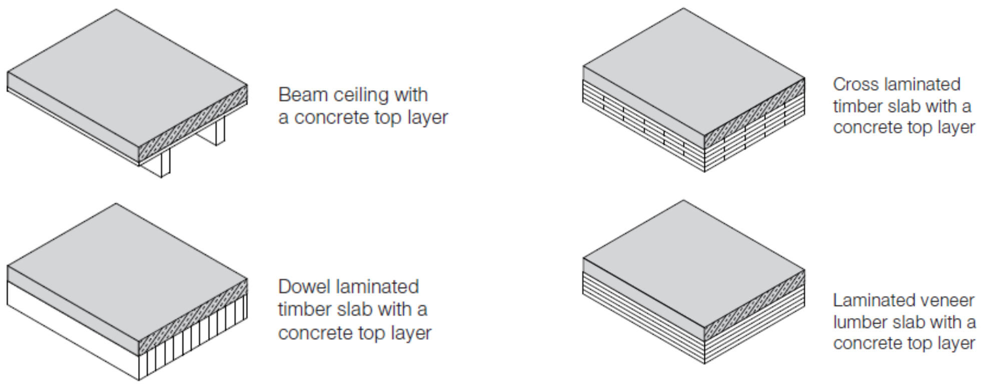
Laminated Veneer Lumber (LVL) represents a mass timber product boasting twice the strength-to-weight ratio of steel, rendering it an optimal choice when demanding attributes such as strength, dimensional stability, and substantial load-bearing capacity are prerequisites. LVL is crafted from multiple layers of strength-graded, kiln-dried wood veneers meticulously bonded within a controlled factory setting. The adaptability and proven structural reliability of LVL have precipitated a rapid surge in its adoption within the realm of mass timber construction.

As one of the most robust wood-based construction materials relative to its mass, LVL presents an ideal solution when a load-bearing material that is both sustainable and reliably dimensionally stable is mandated. LVL lends itself to precision prefabrication and seamless integration with diverse materials.

The LVL product offered by Stora Enso (https://www.storaenso.com/en/products) is manufactured by bonding 3 mm thick veneers together employing high-strength adhesives. The logs employed in the production of LVL undergo a process of peeling and drying, which ensures the even dispersion of any natural wood defects across the veneer. This, coupled with the laminating process, yields a linear and uniform material endowed with remarkable strength and stiffness.

LVL beams and columns are attainable in panel dimensions of up to 24,000 mm x 2,400 mm x 75 mm, which can be custom-cut to meet specific project requirements. For thicknesses exceeding 75 mm, Stora Enso offers LVL G beams and columns, produced by re-bonding LVL panels in a flatwise configuration [6].

Composite timber-concrete slabs



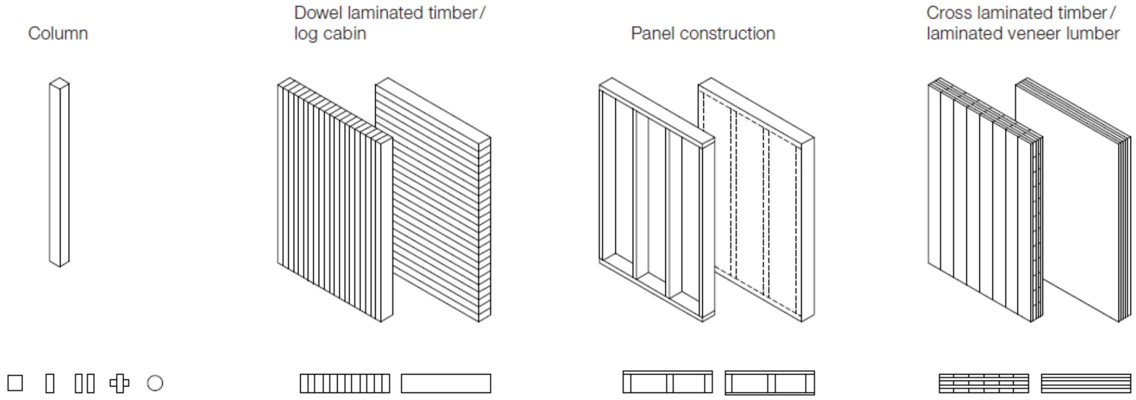
The concept of composite timber-concrete slabs was first pioneered in the 1920s with the primary aim of diminishing the quantities of concrete and steel utilized in slab constructions. Following World War II, this technique found renewed relevance, primarily for reinforcing and refurbishing aging timber beam ceilings.

Since the 1990s, there has been a resurgence in the application of composite timber-concrete slabs, particularly in contemporary construction projects. Presently, these slabs constitute the most prevalent hybrid components in timber-based construction. In comparison to structures exclusively composed of timber, they offer enhancements in structural integrity, acoustic insulation, and fire safety characteristics. Additionally, their added mass serves to mitigate undesirable vibrations. Consequently, composite timber-concrete slabs are especially well-suited for constructing medium to long spans [5].

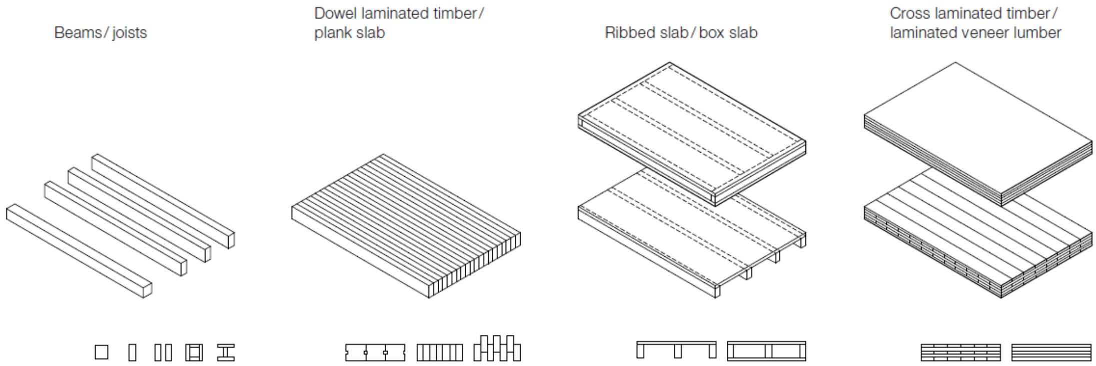
5.5– Structural elements in timber construction

The following figures illustrate the most common structural components typically employed in timber-based building constructions [5].

Vertical structural elements:



Horizontal structural elements:



5.6– Connections in Timber Structures

The cost implications of connections within a mass timber structure can exert a significant influence on the overall project budget. However, the complexity of mass timber connection design transcends mere structural considerations, encompassing aesthetic concerns, adherence to fire-rating regulations, construction feasibility, accommodation for timber's dimensional changes due to moisture, and moisture protection measures. Consequently, the quest for an optimal solution becomes a multifaceted challenge for designers.

To facilitate this intricate process, WoodWorks has issued a user-friendly catalogue of timber connections aimed at elucidating the array of available structural and architectural mass timber connections. The objective is to simplify the selection of cost-effective connection types while balancing other critical factors [7].

This catalogue, referred to as the Mass Timber Connections Index, serves as a tool for selecting suitable connection types for a given project. These connection types necessitate structural assessments to verify their strength and rigidity. Furthermore, they must be adequately safeguarded against moisture and fire risks, in accordance with the applicable design codes for timber structures, whether European or American.

For access to the catalogue, please click here.

To systematize this index, structural connections have been categorized into three distinct 'Connection Classes,' grouping those with shared attributes related to cost, constructability, and fire rating. These classes are elucidated and exemplified in Table 1 as Class 1, Class 2, and Class 3. Class 1 connections exclusively require mass timber elements and structural fasteners. Class 2 connections entail custom-fabricated steel components, such as plates and angles, in addition to structural fasteners. Conversely, Class 3 connections are comprised of prefabricated proprietary connectors offered by suppliers like Simpson Strong-Tie, Rothoblaas, MiTek, among others. Class 3 connections often come with corroborative tests substantiating their strength and fire rating.

Broadly, Class 1 connections represent the most economical and straightforward option for installation, although they may not invariably align with other project requisites. In contrast, Class 2 and 3 connections generally incur higher costs. However, Class 3 connections might be particularly pertinent when concealed connections are preferred, or when fire-resistance ratings carry paramount significance.

TABLE 1: **Connection Classes**

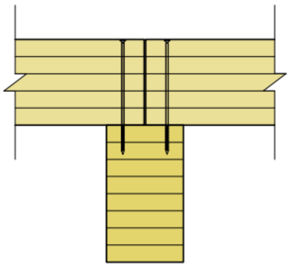
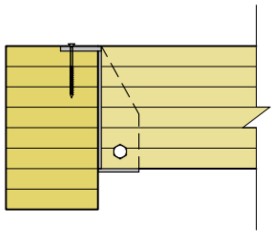
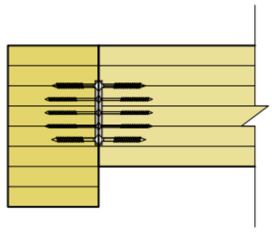
Connection class	**Class 1**	**Class 2**	**Class 3**
Class description	Requires only mass timber elements and fasteners	Utilizes steel fabricated elements, with components such as angles and plates, and includes fasteners	Prefabricated proprietary connectors
Connection example			
	Beam Bears on Girder*	Beam Bears on Steel Bearing Seat with Knife Plate*	Beam Connected to Girder with Proprietary Concealed Connector*

Table 8 in the* ***Index of Mass Timber Connections*

5.7– Seismic Resistance in Timber Structures

Title of the video: "Comparing Timber and Non-Timber Solutions: An Exploration of 8 Seismic and Wind Lateral System Options for Mass Timber Structures"

In this video presentation, we delve into the array of systems available for imparting seismic resistance to mass timber structures. Specifically, we focus on the vertical lateral force resisting systems, which play a pivotal role in withstanding lateral wind and seismic forces within the context of mass timber constructions.

Traditionally, vertical lateral force resisting systems in mass timber buildings have often deviated from timber-based framing solutions. However, a notable shift has occurred in recent times, with an increasing number of projects adopting timber-centric systems. These include light wood-frame shear walls, Cross-Laminated Timber (CLT) shear walls, and timber braced frames. In parallel, there are instances where non-timber lateral systems present compelling advantages.

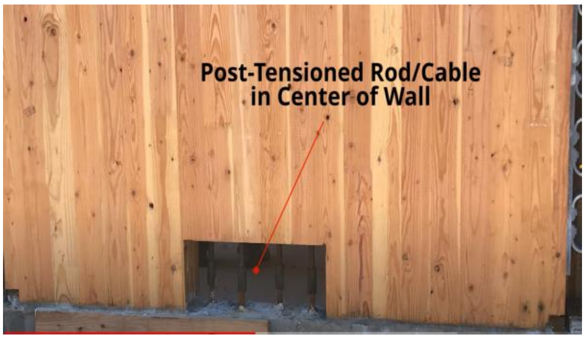
This video presentation serves as an illustrative resource, offering insights into 8 common lateral systems employed in the design and construction of mass timber buildings.

Video 2

The following figure shows four seismic lateral system options in timber.

Timber op. 1: Light-frameshear walls

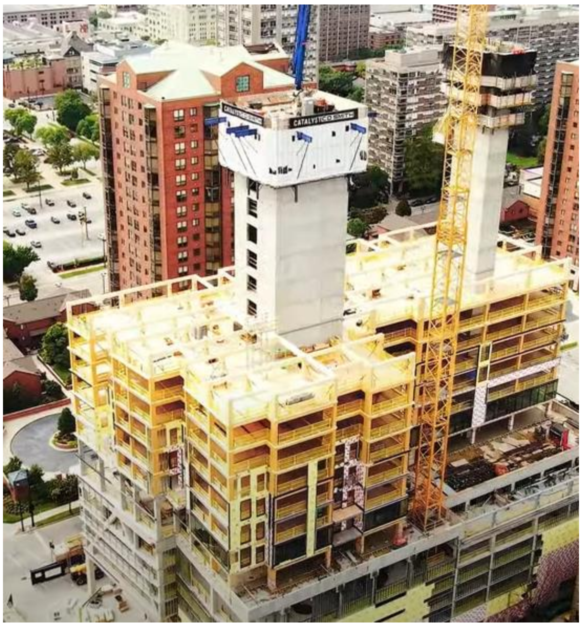
Timber op. 2: Mass timber shearwalls



Timber op 3: Mass timber rocking shearwalls

Timber op. 4: Mass Timber Braced frames

And now four non-timber seismic lateral system options are shown:



Non-timber op. 1: Concrete shear walls

Non-timber op. 4: Cold-formed steel strud shearwalls

Non-timber op 3: Mansonary shearwalls

Non-timber op. 2: Steel braced/moment frames

The European reference Standard for designing earthquake-resistant buildings is:

- EN 1998-1:2004 Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings

On the other hand, the ANSI/AWC 2021 Special Design Provisions for Wind and Seismic (SDPWS) provides criteria for proportioning, designing, and detailing engineered wood systems, members, and connections in lateral force resisting systems.

5.8– Timber and Fire safety

The combustibility of timber remains a primary factor leading to stringent building regulations and standards that significantly curtail its utilization as a construction material. Fire safety stands as a critical determinant in fostering a sense of security and plays a pivotal role in the selection of materials for building projects. A fundamental prerequisite for expanding the application of timber in construction hinges upon ensuring robust fire safety measures [8].

Internationally, numerous research initiatives have undertaken the study of fire behaviour in timber structures over recent decades, with a primary aim to furnish essential data and insights for the safe incorporation of timber in construction practices. This concerted effort has yielded innovative fire design concepts and models, underpinned by comprehensive testing protocols. Enhanced knowledge in the domain of fire-resistant design for timber structures, coupled with technological interventions, particularly the implementation of sprinkler systems and the availability of well-equipped fire services, has paved the way for the secure integration of timber in a wide spectrum of applications. Consequently, several nations have initiated revisions to their fire regulations to accommodate an increased reliance on timber.

Harmonization of fire test and classification methods has occurred recently within Europe, although regulatory building requirements continue to be largely determined at the national level. European standards exist at the technical level, but the governance of fire safety remains within the realm of national legislation and is thus a matter of political discourse. Consequently, national fire regulations are expected to persist, but the newfound harmonization of European standards holds promise for expediting reforms in national regulations.

Noteworthy disparities among European countries have come to light, encompassing variations in the number of storeys permissible in timber structures and the specific limitations imposed on the visibility of wood surfaces in both interior and exterior applications. Some countries lack explicit regulations or do not impose restrictions on the number of storeys for timber buildings. Nevertheless, a practical and economic threshold of eight storeys is frequently considered for timber structures. Notably, this limit may extend further for applications like façades, linings, and floorings, as these components are also commonly integrated into concrete structures, exemplifying the adaptability of timber across various architectural contexts."

5.8.1 European standards on timber fire safety

The following Eurocode 5 document deals with the subject

- EN 1995-1-2:2004 Eurocode 5: Design of timber structures - Part 1-2: General - Structural fire design.

There is also a guide for fire protection of timber elements in buildings:

- Östman, B., Mikkola, E., Stein, R., Frangi, A., König, J., Dhima, D., Hakkarainen, T., & Bregulla, J. (2010). *Fire safety in timber buildings: Technical guideline for Europe*. SP Report No. 2010:19

5.9 - Timber Deterioration due to Biological Agents

The primary biological factors posing a threat to the structural integrity of wood encompass wood-decay fungi, saproxylic beetles, termites, and marine molluscs and crustaceans. In a majority of scenarios, wood-decay fungi assume the predominant role as agents responsible for wood deterioration.

Eurocode 5 indicates how to proceed to protect the structural elements from the attack of organisms:

Timber and wood-based materials shall either have adequate natural durability in accordance with EN 350-2 for the particular hazard class (defined in EI\J 335-1, EN 335-2 and EN 335-3), or be given a preservative treatment selected in accordance with EN 351-1 and EN 460.

NOTE 1: Preservative treatment may affect the strength and stiffness properties.

NOTE 2: Rules for specification of preservation treatments are given in EN 350-2 and EN 335.

5.10 – Mass timber design software.

Software for the global analysis of the timber by means of finite elements:

SAP2000

Dlubal RFEM 5

SOFiSTiK

This three software are commercial finite element software. To model the structure of timber elements with these programs it is necessary to be careful when introducing the stiffness of the structural elements.

In the case of LVL panels, the stiffness related to bending forces and normal in-plane forces are different in the direction of grain and in the direction perpendicular to grain.

In the case of CLT panels, because they are built of layers oriented in orthogonal directions, a particular stiffness matrix is required for the shell elements that model these panels. With the **CLT desingner** software, this stiffness matrix can be calculated in order to input it into the Sap2000 or RFEM 5 programs. In the case of Sofistik FEA software, we can model multilayer 2D structural elements, therefore, this software properly calculates the stiffness matrix of the Shell elements used to model the CLT panels.

Software for design verifications of timber structure according to European Standards:

CLTdesigner
holz.bau forschungs gmbh

[CLTdesigner - CLTdesigner]

CLT design software offers, among others, the required verifications for the ultimate limit state (ULS) with respect to bending and shear for permanent and transient loads as well as accidental (fire) design situations, and the verifications for the serviceability limit state with respect to deflection and vibrations according to EN 1990 or EN 1995 for continuous systems such as cross laminated timber plates.

storaenso Calculatis

[Calculatis – Services and Digital Tools | Stora Enso]

Calculatis by Stora Enso is a free timber design tool for engineers. Efficient and fully web based, Calculatis allows you to analyse structural elements in our mass timber products, including products from our Sylva™ by Stora Enso range.

Developed to fit the needs of engineers working with wood construction, Calculatis includes design modules for floors, roofs, columns, beams, headers, supports, and connections for structures made from CLT, LVL, glued laminated timber and solid timber. The tool can also conduct hygrothermal (U-value, Glaser Diagram and condensation) and fire design (R, E and I criteria) analysis according to Eurocode and Swiss building code (SIA).

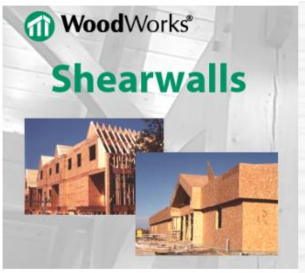
Calculatis supports all steps of your timber construction project with an efficient workflow and accurate results. With easy and clear parameterization, ready-to-use modules and illustrative reports, the tool helps you save time and access all calculations in one place.

Software for design verifications of timber structure according to American Standards:

WoodWorks®
SOFTWARE FOR WOOD DESIGN

http://woodworks-software.com/us-edition/

With WoodWorks® Sizer, size beams, joists, columns, wall studs and panels constructed from lumber, timber, glulam, structural composite lumber, I-joists and CLT.



WoodWorks® Shearwalls, design wood frame structures up to 6 stories. At the push of a button, wind and seismic loads are generated, forces are distributed, and shear walls are designed.

With WoodWorks® Connections, you can design connections consisting of bolts, lag screws, wood screws, nails, heavy steel plates, and more. The results are displayed as fully dimensioned CAD quality drawings.

5.11 – Example of design of a mass timber building. Stora Enso.

The Swedish company Stora Enso (About us | Stora Ensohttps://www.storaenso.com/en) is a distributor of timber elements for buildings. In their website we can find several examples of buildings built with timber structure.

5.9.1. Building description

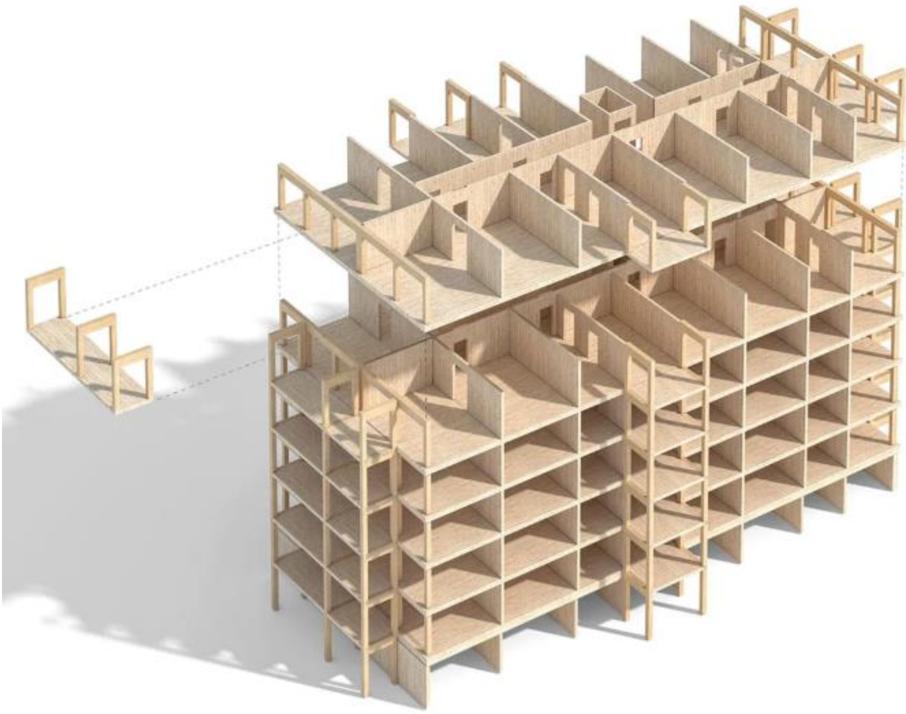
One of these examples is an 8-storey residential building shown in the figure below. It is built in Central Helsinki, Finland in 2023.

Its main features are:

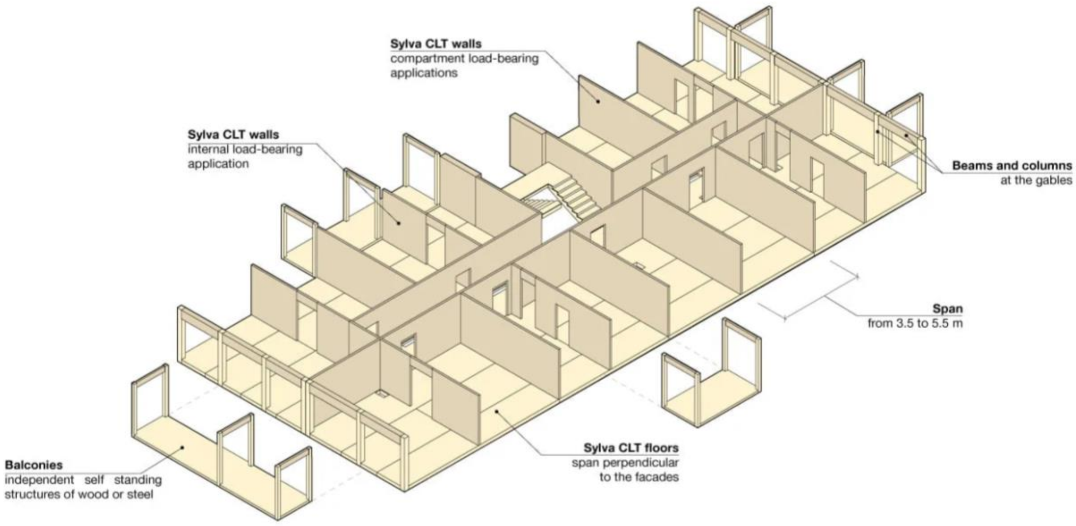
- **Wood-Hybrid System**: This system merges the advantages of a load-bearing mass timber structure with a highly prefabricated, non-load-bearing building envelope.
- **Modular Design Principle**: It employs a straightforward design principle that is adaptable for modular application on various sites, accommodating buildings up to 8 stories in height.
- **Design Flexibility**: The system offers flexibility in apartment configurations, allowing for the combination of spans ranging from 3.5 to 5.5 meters without compromising cost-effectiveness.
- **Space Optimization**: The timber frame external envelope is notably slimmer than similarly insulated alternatives, potentially expanding internal floor area by up to 5%.
- **Environmental Benefits**: This system significantly reduces carbon emissions by approximately 22% when compared to a mineral-based benchmark over the entire life cycle (from A1 to D5 stages, spanning 50 years). Additionally, it curtails embodied carbon by approximately 29%, encompassing all building materials from foundations to cladding.
- **Innovative Balcony Solutions**: The system also proposes innovative, self-supporting balcony designs that eliminate the need for penetrations through the building envelope.

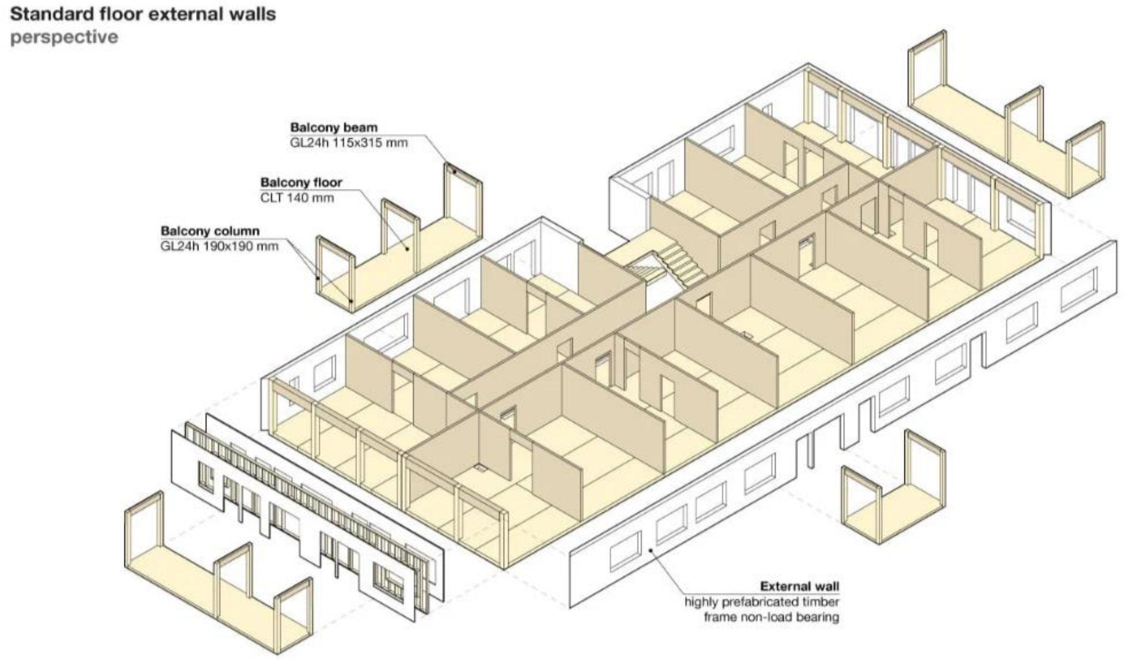
The following figures show several wooden elements of the structure and enclosures of the building.

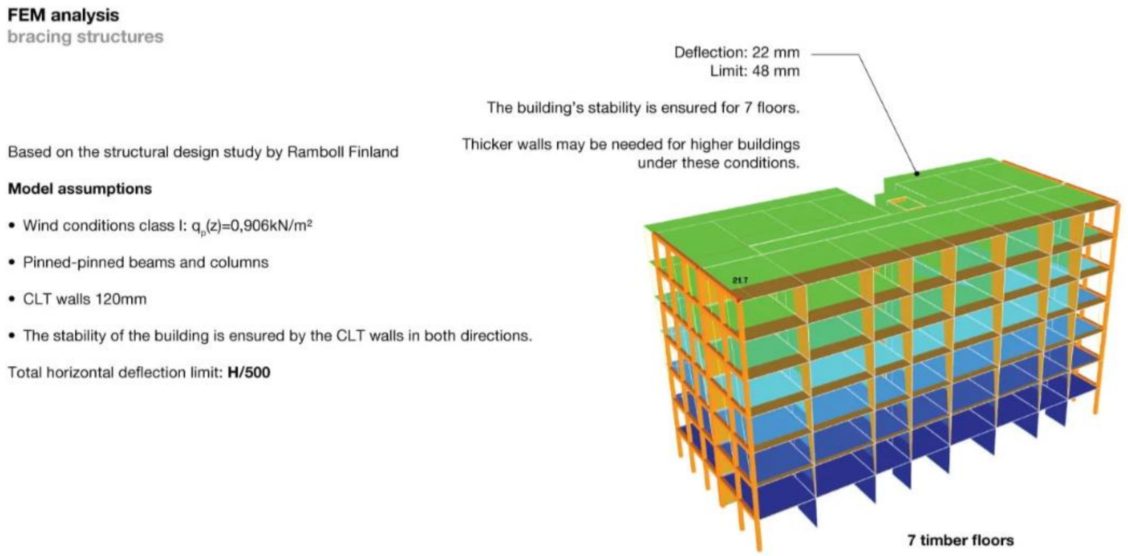
Timber structure.



Standard floor structure principles
perspective







5.9.2. Cost of the mass timber building.

Here is the cost estimation for the timber structure from a specialist sub-contractor to a main contractor:

- Reference cost: 582 EUR /m² [total timber area, floor and roof surface]
- Duration of the installation: Approx. 16 weeks
- The cost Includes:
  - Sylva kit, including walls, floors, stairs, balconies, beams, and columns.
  - Connectors,
  - Assembly
  - Frame contractor margin, risks and premium.

5.9.3. Life Cycle Analysis of the mass timber building.

A comprehensive life cycle analysis of this timber-based building is accessible on the Stora Enso website and can be downloaded as a PDF document (LCA pdf).

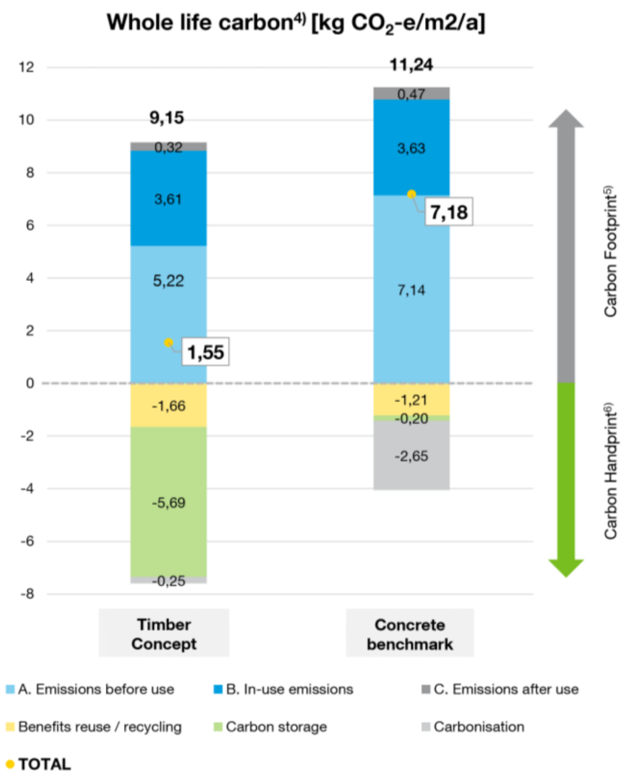
The key attributes of this study, conducted by Stora Enso, are as follows:

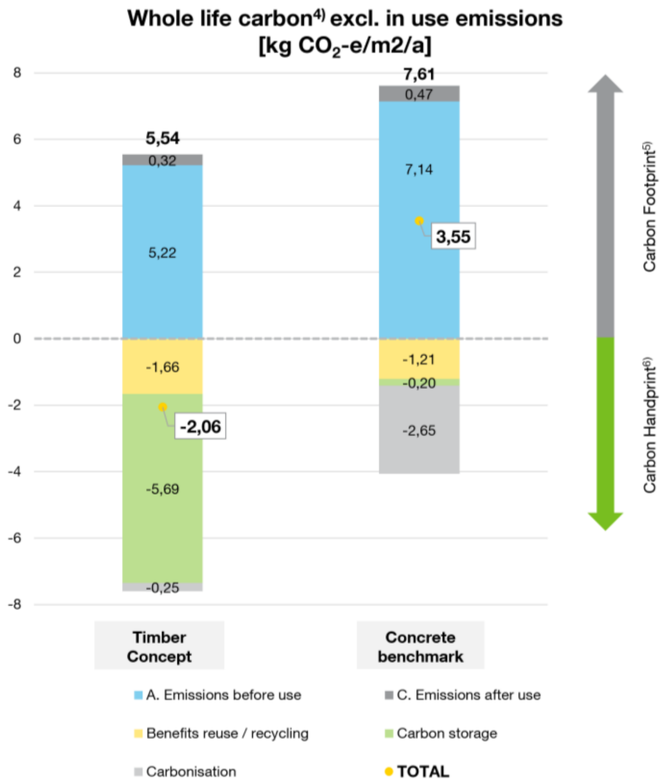
- **Comparative Analysis**: The study includes a comparative assessment between a timber frame design and an alternative concrete frame design. It examines the CO2 emissions per square meter of floor area for both options over a building's service life of 50 years. The analysis also identifies the most influential materials and services in terms of emissions.
- **Whole Life Carbon Assessment**: The assessment of the building's whole life carbon footprint was conducted using the Life Cycle Assessment (LCA) model, employing the 'Method for the Whole Life Carbon Assessment of Buildings' (the 2021 edition) as prescribed by the Ministry of the Environment of Finland. This method is grounded in the sustainability framework known as Level(s), developed by the European Commission, and adheres to established standards for sustainable construction.
- **Calculations with OneClickLCA**: The computations were executed using the OneClickLCA tool, a recognized platform for life cycle assessment in the construction industry."

The features of the building considered in this LCA study are:

- Gross internal floor area: 4465 m^2
- Heated net area: 4298 m^2
- Construction site area: 587 m^2
- Number of floors: 8
- Service life of framing structure: 50 years
- Heating type: Geothermal heating
- Estimated electricity consumption / year: 267 MWh

Main findings from this comparative LCA study:





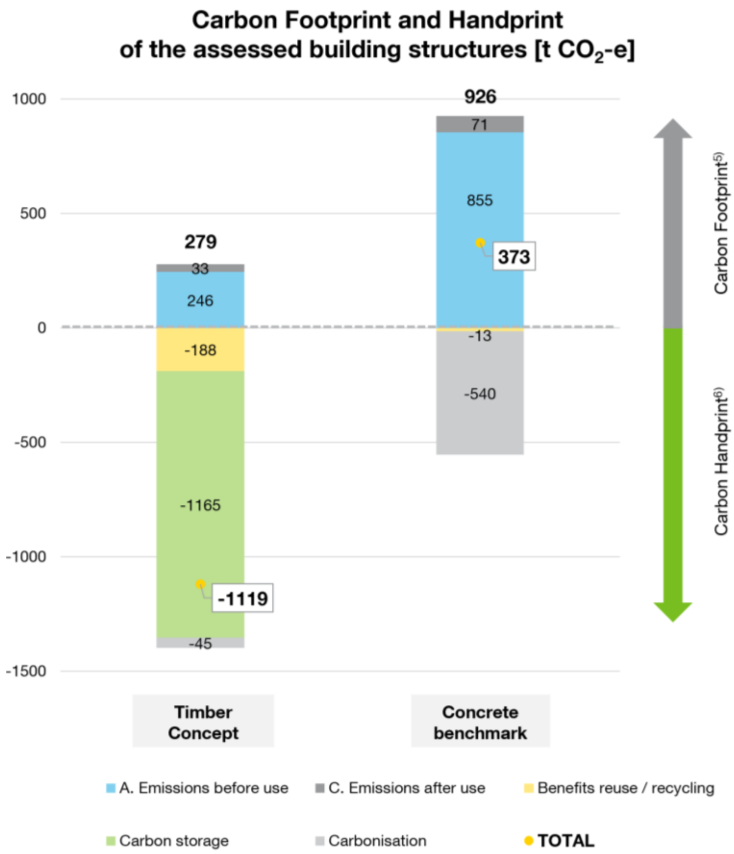
Comparative Carbon Emissions Analysis:

1. **Total Life Cycle Emissions (Excluding Credits):**
   - Wood Construction: 9.15 kg CO2-e/m²/year
   - Concrete Construction: 11.24 kg CO2-e/m²/year
   - Result: Wood construction exhibits 22% lower CO2 emissions compared to concrete construction throughout the entire life cycle, without accounting for reuse/recycling credits, biogenic carbon storage, or carbonation.
2. **Total Life Cycle Emissions (Including Credits):**
   - Wood Construction: 1.55 kg CO2-e/m²/year
   - Concrete Construction: 7.18 kg CO2-e/m²/year
   - Result: Wood construction demonstrates a remarkable 78% reduction in CO2 emissions compared to concrete construction over the entire life cycle, incorporating credits from reuse/recycling, biogenic carbon storage, and carbonation.
3. **Total Life Cycle Emissions (Excluding Usage Emissions and Credits):**
   - Wood Construction: 5.54 kg CO2-e/m²/year

- Concrete Construction: 7.61 kg CO2-e/m²/year
- Result: Wood construction exhibits 27% lower CO2 emissions compared to concrete construction throughout the entire life cycle, excluding emissions during usage (electricity, heating, cooling) and any credits from reuse/recycling, biogenic carbon storage, or carbonation.

4. **Global Warming Potential (Excluding Usage Emissions and Credits):**

- Wood Construction: -2.06 kg CO2-e/m²/year (Negative Contribution)
- Result: Wood construction results in a negative contribution to the global warming potential of -2.06 kg CO2-e/m²/year, excluding emissions during use.



Structural Frame Comparison:

1. **Total Life Cycle Emissions (Excluding Credits):**

- Structural Timber Building Frame: 279 tons CO2-e
- Concrete Structural Frame: 926 tons CO2-e

- Result: A structural timber building frame emits 70% less CO_2 over the entire life cycle compared to a concrete structural frame, without considering credits from reuse/recycling, biogenic carbon storage, or carbonation.

2. **Carbon Storage Impact:**
    - The wooden building concept stores 318 tons of carbon over its life cycle.
    - This implies that 1,165 tons of CO_2-e are sequestered and stored within this building throughout its entire lifetime.

3. **Total Life Cycle Emissions (Including Credits):**
    - Structural Timber Building Frame: -1,119 tons CO_2-e (Negative Contribution)
    - Concrete Structural Frame: 373 tons CO_2-e
    - Result: The structural timber building frame yields a substantial negative contribution of -1,119 tons CO_2-e to the global warming potential when considering credits from reuse/recycling, biogenic carbon storage, and carbonation. In contrast, the concrete structural frame contributes 373 tons CO_2-e.

References

[1] 'The benefits of timber as a building material - Specifier Review', Mar. 16, 2018. https://specifierreview.com/2018/03/16/timber-building-benefits/ (accessed Sep. 18, 2023).
[2] 'Mass Timber in North America', *Think Wood*. https://www.thinkwood.com/continuing-education/mass-timber-north-america (accessed Sep. 18, 2023).
[3] 'Light Frame Wood Construction', *Think Wood*. https://www.thinkwood.com/light-frame-wood-construction (accessed Sep. 18, 2023).
[4] T. W. c/o S. L. Board, 'Mass Timber Design Manual'. https://info.thinkwood.com/masstimberdesignmanual (accessed Sep. 18, 2023).
[5] K. Hermann, S. Krötsch, and S. Winter, *Manual of Multistorey Timber Construction*. 2018. doi: 10.11129/9783955533953.
[6] 'Laminated veneer lumber (LVL) - Wood products | Stora Enso'. https://www.storaenso.com/en/products/mass-timber-construction/building-products/lvl (accessed Sep. 18, 2023).
[7] 'Index of Mass Timber Connections', *WoodWorks | Wood Products Council*. https://www.woodworks.org/resources/index-of-mass-timber-connections/ (accessed Sep. 18, 2023).
[8] 'Fire Safety in Timber Buildings: First European Guideline - SFPE'. https://www.sfpe.org/publications/periodicals/sfpeeuropedigital/sfpeeurope3/issue3feature2 (accessed Sep. 18, 2023).

6 - Deliverables

To evaluate the success of the application, students will have to answer an online questionnaire.

7- What we have learned

The environmental benefits of timber construction

That the state of knowledge, technique, and standards about timber allow us today to design much more sustainable buildings than those of concrete, steel, and bricks.

The types of timber elements available for designing timber structures.

A list of computer tools for the design of the timber structure of a building.

Wood can be the material of the future with proper forest management.

The importance of LCA analyses to compare environmental impacts of buildings in timber with those produced by concrete buildings.