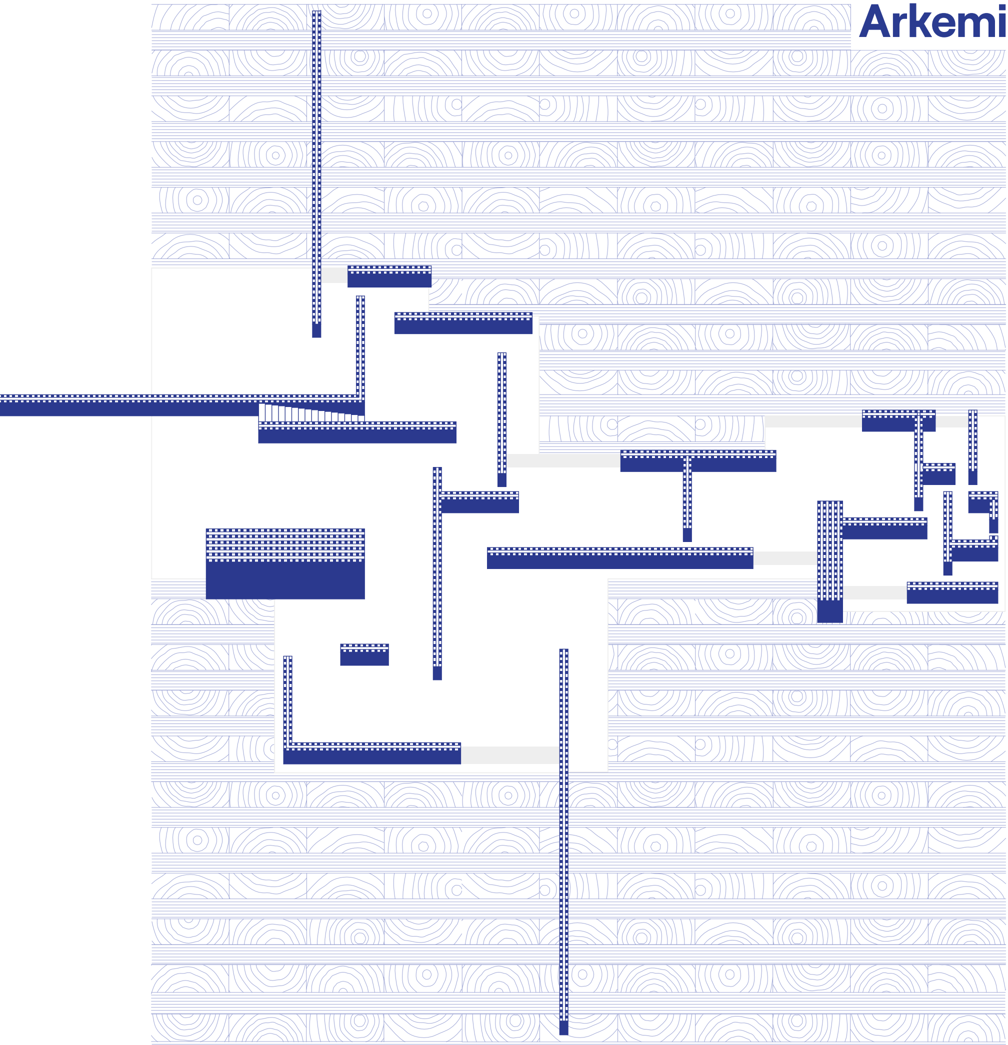
Arkemi*



architectural guidelines for early stages

HOW TO CLT

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Introduction

- Acknowledgements
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Acknowledgements

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Foreword

Cross Laminated Timber, CLT, is a prefabricated, engineered wood product made by gluing together layers of sawn boards into panels capable of carrying loads in all three major axes. Since its introduction in the early '90s in Austria and Germany, its use has spread steadily throughout the world and is currently seen as one of the most important materials of mass timber construction.

The interest for mass timber construction in general, and CLT in particular, has been intensified by the ever-looming threat of climate change. The somewhat conservative Swedish building industry, in 2019 said to be responsible for about 21% of the country's domestic CO2 emissions, has been slow to adapt. In 2020 only 2/10 newly constructed apartment buildings were constructed in wood – an embarrassingly low figure considering that Sweden, where 70% of the land is covered in forest, is home to one of the world's leading forest industries.

Most Swedish builders, or architects for that matter, currently have little or no experience with budgeting, planning and building CLT-buildings. Without suitable methods, standards and experience, constructing larger buildings in anything but concrete and steel is, understandably, seen as unnecessary risk-taking. The resulting reluctancy to change is not only disadvantageous to the progression of the industry but also poses a great hurdle to overcome on our path to a sustainable future.

Urged on by the slow-moving wheels of the industry we decided to take matters into our own hands, an effort resulting in the publication you are currently reading, and the digital tools it comes with. We see an opportunity for the architects, our target group, to bridge the current gap in knowledge and with the help of this publication influence their clients in making better, more informed and more sustainable choices.

Being one of the first consultants involved, the Swedish architect's influence typically peaks in the initial design phases and then gradually declines as the project gets more defined and other experts and stakeholders are involved. We have therefore limited our scope of this project to only include architectural work in early stages. To be able to be more precise and concise, we have chosen to limit our work to only deal with CLT-buildings of the most common type: residential buildings of 3-8 floors with a load-bearing structure more or less completely made of CLT.

The results of the project have been summed up in three products or components, meant to address different topics, tasks and challenges of the early stages of designing with CLT. Although the components are possible to use independently from each other, we recommend that you try to follow our proposed workflow.

Finally, it is crucial to mention that CLT's potential environmental benefits depend entirely on where the raw material comes from. There have been many alarming reports from NGOs such as Naturskyddsföreningen and WWF seriously questioning the Swedish forest industry's sustainability claims. Clearcutting, a serious threat to the biodiversity of our forests, has for example been widely used since the 1950s.[1] Another relevant concern is the ongoing colonialization of Sápmi in northern Sweden, a topic which is usually overlooked.[2]

Forests are our last viable hope in solving the climate crisis. It is not enough to create new products, services, and energy from the forests to call it sustainable economy.[3] It is equally important to make sure that the forest we use are managed sustainably. Remember: the use of timber or CLT in a project does not automatically make it sustainable architecture.

Workflow

Handbook

The first component of this project, the Handbook, includes practical information about designing and building with CLT. Being a prefabricated material, some design questions regarding CLT-structures need to be handled carefully from the very early stages. This handbook highlights these questions and guides the reader towards a preliminary design that can effortlessly be developed into a viable, efficient, and sustainable CLT-building.

In the first chapter of the book we discuss different structural systems and the individual CLT-elements they are made of. Here the reader will find information on common systems, what their benefits and drawbacks are and what types of projects they are suitable for. The elements (floor, wall, roof etcetera) are then presented individually; their properties, limits and uses explained more in depth.

This is followed by a chapter presenting rules of thumb regarding the dimensioning of CLT. Here we present limiting factors such as production, transportation and structural capabilities and their effects on the design of the CLT-elements. The chapter is concluded by a library consisting of commonly used build-ups of floors, walls and roofs with dimensional tables.

Grasshopper Script

The second component of this project, the Grasshopper script, is a digital tool aimed to bridge the gap between performing early estimates on a CLT-project and the industry's lack of methods standards, and experience to perform them. With a simple plan sketch and some general building parameters (e.g. number of floors) as input, the user will quickly and automatically be provided with a parametric 3D-model and economical and ecological estimates.

The script-generated estimates could prove to be very useful when persuading a client to build in CLT. It provides answers to many of those risky "unknowns", and the hesitant client is able to make a comparison of the different alternatives earlier than was ever possible before.

Throughout the process of generating an early estimate the user is visually supported by a preview of the parametric 3D-model that the numbers are drawn from. The preview can at any point be extracted (baked) into Rhinoceros, creating solids and surfaces that can be further modified. Alternatively, the extracted model can be exported and used as a sketch in another software.

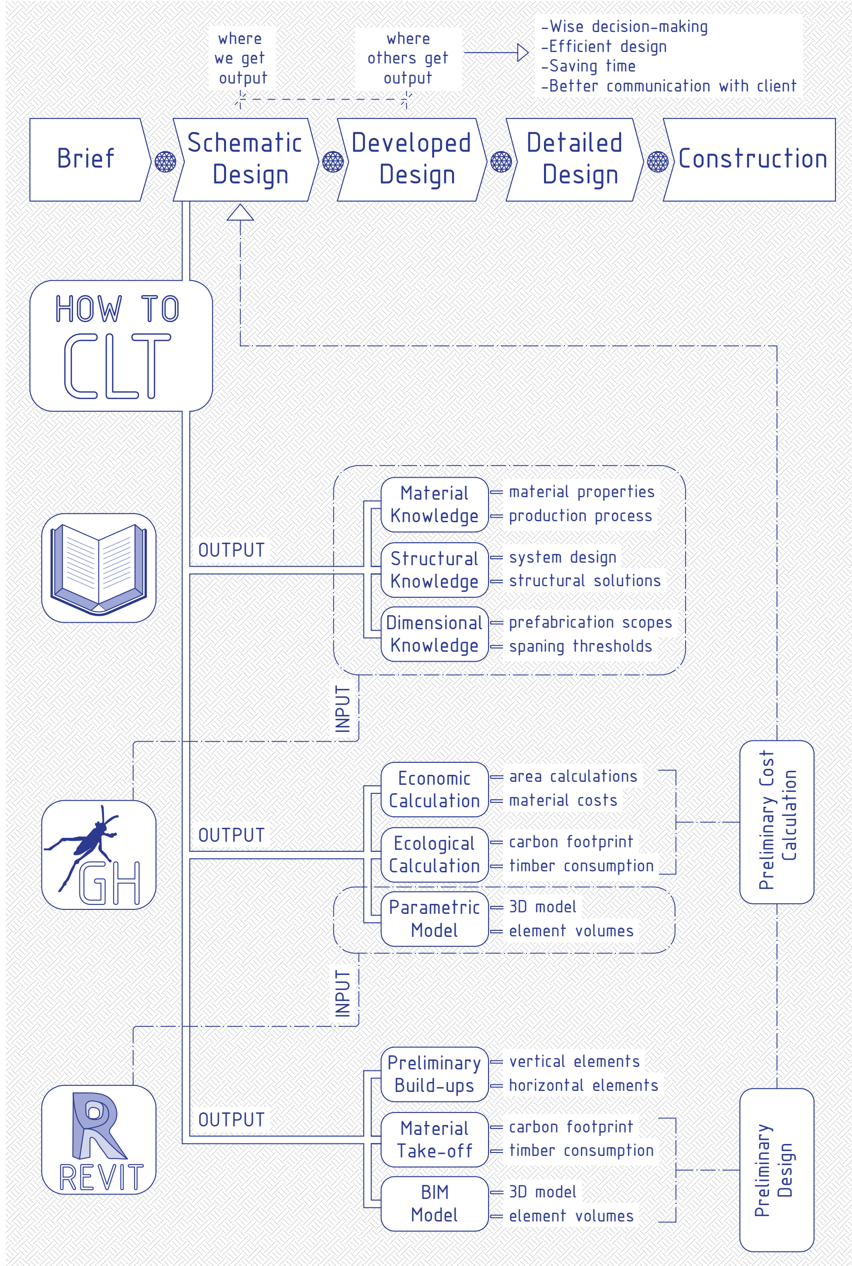
Revit File

The third component of this project, the Revit file, provides different tools to aid with the further development of a design. Here the user will find a BIM-version of the library of build-ups provided in the Handbook, as well as ready-to-use schedules that automatically calculate material and quantity take-offs. The file is not meant for modelling but should rather be used as a library from where objects and charts can conveniently be copied to other project files.

The BIM-model and its schedules provides a more detailed understanding of a project, for architect and client alike, and could act as a good starting point for bringing a project from the Schematic- to the Developed Design phase. By this point we hope that you, the reader, have successfully come up with a preliminary design and estimate that has proved helpful in influencing the sustainable development of the project.

Best of Luck with your CLT endeavors! **// Arkemi**

1 Naturskyddsföreningen, 'Sanningen om den svenska skogen', Naturskyddsföreningen's website, 2022, accessed 2022-08-30.
2 N. Salim, 'För vem sker det en "hållbar" utveckling i Sverige', Peacework's website, 2021, accessed 2022-08-30.
3 P. Westman & L. Berglund, 'WWF: Vi har inte ett hållbart svenskt skogsbruk', WWF's website, 2017, accessed 2022-08-30



- Proposed workflow to integrate this product in the architectural design process -

02 CLT & Swedish Forestry

- Debate on sustainable forestry
- Designing with reduced impact

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Debate on Sustainable Forestry

Building with CLT is often celebrated as a sustainable practice that actively mitigates climate change. While CLT and other wood construction materials are great ways to keep carbon stored for a long time, the forestry industry that provides the raw material should also operate in a sustainable way. In recent years, the dominant forest management methods in Sweden have become the subject of national debate. As a result, the popularity that building with wood has garnered within the construction industry has also been called into question.

In this chapter, we present the defining features of standard Swedish forestry practices and summarise the often confusing debate surrounding them. We conclude by highlighting the conditions in which building with CLT can truly be considered sustainable.

Forests play multiple roles that are important to both human and other species' wellbeing. Forest management can, therefore, only be considered truly sustainable if it supports the ecological and social functions of forest lands at multiple scales, and not only the economical function.[1] Organisations with varying agendas from Naturskyddsföreningen to Skogsindustrierna support this view but disagree on which methods should be prioritised to achieve the holistic functionality of forests.

Swedish Forestry Model

How are the majority of Sweden's forests managed?

Sweden's 28 million hectares of forest are a cultural cornerstone, and make a significant contribution to the country's balance of trade. The Swedish forestry model is defined by its focus on maximising tree harvest. The forestry industry formally established operations in the 1850s with pulp and paper production. Since then, natural forests are being converted to plantations with single-age tree stands of the same species. This process was made more efficient in the 1950s with the introduction of government-approved clear cutting. The trees typically grow for 70- 110 years before they are harvested and new saplings are planted in their place. [2] Planting, fertilisation, ditching, use of genetically improved seedlings and afforestation of abandoned arable land have increased the standing timber volume since the mid 1900s.[3] This policy of expansion is also considered a valuable response to pressing sustainability challenges —an attitude firmly grounded on the optimistic view that forest resources can be regenerated indefinitely.

However, organisations like Naturskyddsföreningen and Greenpeace are sceptical of the seemingly unlimited capacity of forests to provide for the needs of all stakeholders. Instead, they support less intervention in forests and a more integrated approach to conservation that is exemplified by forms of Continuous Cover Forestry (CCF).

Storing Carbon

Does maximising net yield mean more carbon storage?

One of the key points of contention is which method enables forest lands to sequester the most carbon. Clear cutting in Sweden has had a good track record in increasing the standing volume of trees. The forestry industry also argues that the capacity of forests to store carbon is renewed with each clear cut whereas the amount of carbon stored in a natural forest reaches full capacity in 150 years.[4] Although there is a limit to how much carbon is stored by natural and CCF models, they maintain a consistent amount of carbon both in biomass and in the soil. Clear-cut forests, on the other hand, undergo periods of thinning and in the first 20 years even emit carbon back into the atmosphere due to soil scarification during the clear-cutting process.[5] The environmental accords Sweden has signed are time-sensitive with net emission caps set within the next 7 to 27 years. These deadlines have been set due to the widely accepted concept of climate tipping points. If our forest lands are to play an active role in helping us reach climate goals within the set time frame, we cannot afford to wait for clear-cut plantations to grow back.

Providing Raw Material
Is maximising production of wood the best use of forest resources?

Carbon sequestration is not the only role forests play, especially in Sweden. Since the start of industrial forestry in the 1850s, pulp and wood have grown to become one of Sweden's biggest export sectors. They have contributed significantly to GDP and perhaps more crucially, the country's balance of trade. The Swedish Forestry Act introduced in 1903 to regulate forestry has focused on ensuring forest yield for most of the 20th century, illustrating the legacy of economic significance the industry holds. It was only in 1993 that environmental and social goals were introduced alongside the original production objectives of the regulation. The growing development of wood-based products in the early 2000s consequently presented a strategy that could potentially address both the economic and environmental ambitions of Swedish forestry policy.

The substitution of fossil-based products with 'renewable' and 'carbon-neutral' forest-based alternatives have thus become the main selling point of a 'sustainable' Swedish forestry model. Some consider forest-based material to be carbon-neutral because it stores carbon that would otherwise be released during decomposition. This only holds true for the approximately 20% of wood that is used for long lasting products like furniture and buildings. The remaining 80% of timber harvested is burned for fuel or used for products with a short lifespan resulting in the carbon in these products being released quickly.[6] Moreover, for the substitution effect to occur, increasing the reliable supply of pulp and wood is only one part of the equation. Unless the production and eventual burning of forest-based alternatives is accompanied by a decrease in supply of fossil-based material, the amount of carbon emitted into the atmosphere will not be reduced. Actors across the political spectrum, therefore, recognise the need for cooperation across multiple industries to reduce fossil fuel extraction and ensure that there are robust recovery systems available to keep forest-based material in use for as long as possible.

It is also important to note that although forest-based material harvested from plantations can theoretically be regrown unlimitedly at a reliable volume, climate change threatens the current reality. Studies analysing the resilience of boreal forests under warmer conditions show that increasing environmental stressors could diminish their ability to survive, let alone act as a natural carbon sink.[7] This calls into question how much we can rely on the forest as an unlimited source of raw material in the coming years.

The uncertainty surrounding the boreal forests' health poses a threat to both extremes of the forest management debate. On one hand, clear-cut forests may not be able recover fast enough at the end of each rotation period to sustain high yield while, on the other hand, even conserved forests may increasingly become carbon sources instead of sinks as they become more susceptible to disease and fires. Continuous Cover Forestry (CCF) which is often criticised for its lower yield and higher costs offers a more resilient form of management because of unevenly-aged tree stands. In areas like the south of sweden that are especially vulnerable, CCF may eventually become a more economically sustainable forestry method.

Providing Ecosystem Services
How much is enough and all are types of conservation valuable?

The threat that clear-cutting poses to biodiversity in forest lands is another one of the fiercely debated points of forest management. Around 1,400 species found in Swedish forests are on the list of endangered species. Over 90 percent of Sweden's forests have been clear-cut since the 1950s, which has affected the many species that are dependent on a living environment constantly covered with trees.[8] Other practices that support plantations, like digging ditches, not only threaten the multitude of microbes found in the soil but also leak mercury into water bodies, affecting fish and other aquatic species.

Traditionally, industry players have claimed to mitigate the loss of biodiversity by marking on average 3% of clear-cut areas for tree retention.[9] Private forest owners have also voluntarily set targets for water and soil quality. However, individual ecosystem targets that are external to the general forestry operation fail to address the complex and interlinked nature of ecosystems. For instance, retaining trees should not be confused with ecological conservation. In order for ecosystems to be functional, conservation areas need to be a representative mix of forest with links for ecological dispersal.

CCF is widely accepted as a better method to protect biodiversity and has been adopted by companies like Sveaskog in some of their forests. Plockhugget, a recent player in forest management, take a bolder step in this direction. They reject clear-cutting and instead provide wood from forests with tree stands of varying species, ages and sizes maintained together. This results in bio-diverse stands that enhance visitor experience and provide food as well. Plockhugget's method also protects the soil from scarification, allowing carbon dioxide to remain sequestered in the soil. This model helps forests to remain part of a well-connected system in the landscape, with functioning dispersal routes for species. CCF models similar to Plockhugget's have been used in countries like Germany and France since the 1980s but it remains to be seen whether boreal forests commonly found in Sweden benefit as much from it.

Exactly what percentage of managed forests should be CCF is also debated. While Plockhugget only uses CCF, Skogsforsk recommends setting aside 10% of managed forests for CCF as an optimal amount for both environmental and economic goals to be attained. This recommendation is based on current environmental, political and cultural norms which prioritise the profits and growth of forest owners, followed by the fulfilment of isolated environmental goals such as deadwood volume. Meeting the socio-cultural needs of other communities, although included in the Swedish Forestry Act with 'equal weight', is in practice seen more as an act of goodwill.

Supporting livelihoods and well-being
Are all the forest-dependent livelihoods respected fairly?

For the indigenous Sámi, the forest is not just a recreational venue but the source of their livelihood. The Sámi's close cultural and economic ties with reindeer husbandry make them reliant on healthy forest landscapes.

Lichen, which are the primary source of food for reindeer, are disappearing due to the dominant forestry process. More than 70% of Sweden's lichen-rich forest has disappeared in the past 60 years. [10] Despite Sweden's supreme court giving the Sámi common law rights to specific areas of land, they are not always consulted by the companies that own the land. This is because the Swedish Forestry Act only requires large forest companies to consult Sámi regarding their forest management. The lack of legislation requiring small forest owners (often members of huge forestry cooperatives such as Södra) to consult with other forest-dependent communities will only lead to further exclusion of Sámi from key decisions regarding land that they have been custodians of for centuries.

Conclusion

The conflict between the goals of bioenergy production and biodiversity protection as well as between strategic economic goals and local livelihoods are acknowledged by all forest-related actors. Current regulations, which are the most relaxed they have been since the Swedish Forestry Act's introduction in 1903 do not specify how this balance should be achieved. Business as usual will no longer be sufficient since it is only becoming clearer how important forests are as public commons. At the same time, private owners cannot be held solely responsible for the greater good. More specific implementation tools and regulations are needed to ensure that forestry develops in line with Swedish values as well as changing environmental and economic conditions.[11] This balancing act will take years of policy fine tuning and experimentation with silviculture models. It is also worth noting that although there is an urgent need to improve forestry practices, using harvested wood in buildings where they are stored for a long period of time, is preferable to using wood for products with a short shelf-life. CLT is in no way a panacea for the environmental damage wreaked by the construction industry but remains a relevant structural material in the era of climate change.

1 Food and Agriculture Organization of the United Nations, 'Sustainable Forest Management', FAO's website, 2023, accessed 2023-04-19.

2 Skogsforsk/R. Björheden (Ed.), 'Climate Impact of Swedish Forestry', Skogsforsk's website, 2019, accessed 2023-02-28.

3 U. Jansson, L. Wastenson & P. Aspenberg (Eds.), 'National Atlas of Sweden. Agriculture and Forestry in Sweden Since 1900 a Cartographic Description', Norstedt, 2011

4 T. Pukkala, 'Does management improve the carbon balance of forestry?', Forestry: An International Journal of Forest Research, Volume 90, Issue 1, 2017, pp. 125-135.

5 Skogsforsk/R. Björheden (Ed.), 'Climate Impact of Swedish Forestry', Skogsforsk's website, 2019, accessed 2023-02-28.

6 International Renewable Energy Agency, 'Bioenergy from boreal forests: Swedish approach to sustainable wood use', IRENA's website, 2019, accessed 2023-04-19.

7 W.R.L. Anderegg & O.S Chegwidden et al., 'Future climate risks from stress, insects and fire across US forests', Ecology Letters, Volume 25, Issue 6, 2022, pp. 1510-1520.

8 T. Kuuluvainen, 'Forest Management and Biodiversity Conservation Based on Natural Ecosystem Dynamics in Northern Europe: The Complexity Challenge" AMBIO: A Journal of the Human Environment, Volume 38, Issue 6, 2009, pp. 309-315.

9 Swedish Forest Agency/I. Wigrup (Ed.), 'Swedish Statistical Yearbook of Forestry', Official Statistics of Sweden, Jönköping, 2012.

10 P. Sandström, N. Cory & J. Svensson et al., 'On the decline of ground lichen forests in the Swedish boreal landscape: Implications for reindeer husbandry and sustainable forest management', AMBIO: A Journal of the Human Environment, Volume 45, Issue 4, 2016, pp. 415-429.

11 I. M. Hertog, S. Brogaard & T. Krause, 'Barriers to expanding continuous cover forestry in Sweden for delivering multiple ecosystem services', Ecosystem Services, Volume 53, 2022

- Formerly clearcut plantation forest with even-aged stands in Bollnäs -

- 85 year old stand of Douglas fir in the process of transformation to a continuous cover forest -

Designing with reduced impact

Architects participate further along in the supply chain and therefore have limited influence on forest management. How can we then use CLT responsibly in the immediate future when our actions are the most crucial in preventing the occurrence of irreversible tipping points?

Do not demolish buildings

Buildings standing today required a significant amount of carbon to construct, and even more to demolish. Protecting and retrofitting these buildings are vital to reducing emissions from the building industry.

Use as little raw material as possible

Design for material efficiency so that not more material is used than necessary. For instance, in buildings up to four stories, a wooden (engineered or otherwise) frame construction system may be more suitable than a CLT panel system. Where it is possible, reuse materials. Platforms like CCbuild offer a growing pool of secondhand building elements- even glulam arches.

Use traceable material

Whenever possible, it is important to use traceable wood so that you can do your due diligence on how the wood was harvested. This may be a difficult task since clear cutting is the industry's current norm. However, there are temporary solutions like the certification for "hyggesfri trävara" or wood products free of clear cutting offered by Plockhugget. This allows you to buy timber from any local supplier with the guarantee that the same volume of timber from a forest managed through a CCF model will be introduced to the market.

Design with foresight

As mentioned earlier, the benefit of sequestering carbon in wood products is only reaped if it can be stored in the long run. This means that we as architects have the responsibility to design for flexibility, durability, and disassembly so that buildings, spaces and elements can be used far into the future.

Use your political voice

As one of the stakeholder groups in the construction industry, architects should use their voice to lobby for change. This could include demanding for more transparency in sustainability reporting or calling for stricter criteria in certification systems like PEFC and FSC that are already widely adopted by the industry so that smaller forest owners also have the responsibility to consult with multiple stakeholders including the Sámi.

Educate yourself

Lastly, since research on forestry practices is ongoing and often produces conflicting conclusions, it is important to stay updated on best practices and policy changes. This is a necessary condition to be able to make informed design and political choices with regards to material use. Why not start with the following list of...

Further reading

Independent Scientific Sources
Journal of Forest Policy and Economics
Forestry: An International Journal of Forest Research
Royal Swedish Academy of Sciences and Future Earth's Webinar on Boreal Forests and Climate Change

Public Sources
Naturskyddsföreningen
Skogsforsk
Architects Climate Action Network (ACAN)

Documentaries
More of Everything (Protect the Forest, Sweden & Greenpeace Nordic)
Slaget om skogen (SVT)

Glossary

Rotation Period
starts with establishment of the forest stand and finishes after several decades, when most of the trees are harvested and regeneration of the forest stand is achieved.

Ecosystem Services
are outputs, conditions, or processes of natural systems that directly or indirectly benefit humans or enhance social welfare.

Substitution Effect
refers to the fossil greenhouse gas emissions that have been avoided. For example, the use of wood products in construction displaces products with higher emissions, such as concrete or steel.

Tipping Points
are a critical threshold that, when crossed, leads to large and often irreversible changes in the climate system.

Clear-cutting
is a logging method in which resilient natural forests are harvested and replaced with man-made tree plantations that do not replicate the ecosystem services of a healthy forest.

Continuous Cover Forestry
is an approach to forest management that seeks to create more diverse forests, both structurally and in terms of species composition, by avoiding clearfelling.

Retention Forestry
is the practice to retain living or dead structures for conservation purposes during final harvesting.

Carbon Leakage
occurs when there is an increase in greenhouse gas emissions in one country as a result of an emissions reduction by a second country with a strict climate policy.

Public Commons
are the cultural and natural resources accessible to all members of a society, including natural materials such as air, water, and a habitable Earth. These resources are held in common even when owned privately or publicly.

Silviculture
is the growing and cultivation of trees

03

Collaborate with CLT

- Background
- 6 Principles of Collaboration

Background

"The development of digital design and fabrication is enabling an expanding inter-relationship between technology and design", writes Rivka Oxman, architect and researcher on computational design and methods. The progress has given rise to what she calls a Material-based design, defined as a "computational informing process that enhances the integration between structure, material, and form within the logic of fabrication technologies". [1]

CLT-construction is in many ways a child of this on-going evolution within the construction industry. It is an engineered building material, requiring methods of digital design and CNC-driven pre-fabrication to create a highly precise, on-site assembly that dictates much of the formal and structural logic of a building.

In her research Oxman concludes that the shift towards a material-based design will deeply challenge and re-formulate how architects, structural engineers, fabricators etc. collaborate. As buildings must deal with an increasingly complex set of challenges (not least to do with their environmental impact) and the dynamics between consultants change, the time is ripe to establish close collaboration as the industry standard.

The current situation could be compared to the industry's shift from CAD to BIM in the 2000s. An opportunity that promised revolutionary changes to interdisciplinary collaboration, that in many ways seem to have been lost due to an unwillingness to change traditional processes. The still relatively liquid state of processes and methodology regarding CLT could be seen as yet another chance to improve interdisciplinary collaboration, especially between architects and structural engineers. [2]

In this chapter, we propose 6 principles for a closer collaboration between architect and structural engineer that we believe will foster innovation, architectural quality and efficiency when working in CLT construction projects. The overarching theme, "how architects and structural engineers collaborate and how this collaboration could be made better", has in a Swedish context been researched by a limited number of, mostly bachelor's and master's level, academic papers. On top of these academic sources we have carried out an in-depth interview with CLT veteran Tomas Alsmarker (head of innovation and research at Svenskt Trä) followed by a questionnaire sent to architects and structural engineers who have worked on exemplary wood projects.

The benefits of a tighter collaboration are generally agreed upon throughout our sources and respondents, but considerable barriers exist for it to become an industry norm. Close collaboration between architects and structural engineers in the early stages must, for example, in some form include a cross-disciplinary formulation and testing of conceptual designs. In our general experience, working with structural engineers is a rather linear process and occurs in the later stages of the building project. The conceptual design of a building is on the other hand an iterative process, going back and forth between sketching and evaluation.

The difference in methodology and the costs it would add, makes it unreasonable to include a structural engineer as an equal part of the conceptual design. Such a set-up would also risk putting too many technical limitations on the design in a stage that thrives from creative thinking. The collaboration that we propose in the following principles should rather be thought of as an early engagement of the structural engineer as a sounding board, available to evaluate the structural challenges of a sketch or an early design. This way of working is currently common in reconstruction projects, where architectural limitations are naturally set by the load-bearing capabilities of an existing structure.[3]

1 R. Oxman, 'Informed tectonics in material-based design', Design Studies, Volume 33, Issue 5, 2012, pp. 427–455.

2 Arkemi, Interview with Tomas Alsmarker, Head of Innovation & Research at Svenskt Trä, conducted 2023-11-17.

3 K. Bosaeus, 'En bärande idé? Ett explorativt examensarbete om samspelet mellan konstruktion och arkitektur', Master thesis in civil engineering and architecture, Luleå Tekniska Universitet, Institutionen för samhällsbyggnad, 2011.

10 Good Reads for a Closer Collaboration Between Architects & Structural Engineers

An Engineer Imagines
by Peter Rice (1996)

Architect and Engineer: a study in sibling rivalry
by Andrew Saint (2008)

Arkitektur och Bärverk
by Dan Engstöm et al (2004)

Collaborations in Architecture and Engineering
by Clare Olsen (2014)

Conceptual Structural Design: bridging the gap between architects and engineers
by Olga Popovic Larsen & Andy Tyas (2003)

Constructing Architecture
by Andrea Deplazes (2018)

Introducing Architectural Tectonics
by Chad Schwarts (2016)

Structure as Architecture: a source book for architects and and engineers
by Andrew Charleson (2018)

Studies in Tectonic Culture
by Kenneth Frampton (2001)

The Structural Basis of Architecture
by Bjørn Sandaker, Arne Eggen & Mark Cuvellier (1989)

6 Principles for a close collaboration

1. Start collaborating as early as possible

If the structural engineer enters the early stages of a project too late for any meaningful collaboration on conceptual design to take place, many of the benefits are in danger of being lost.[1] A major reason for not collaborating on a conceptual level is a lack of time and/or resources. If more time and money is allocated to the conceptual stage, architects and structural engineers would be given the opportunity to provide the client with a considerably more feasible and accurate early design. Unfortunately, these stages are usually the ones that pose the highest risk of failure for the client/developer, meaning that it might be hard to convince them to increase the budget to cover anything outside the norm.

As the saying goes: “Money talks”. Explain the possible cost benefits of engaging a structural engineer early on to the client, the most obvious one being limiting the risk of costly re-designs in later stages. In our experience, early design-support from a structural engineer comes at a very reasonable cost, as their linear way of working ensures efficiency and an early involvement gives them higher chances to be contracted in later stages.

An, architecturally speaking, ambitious client might also listen to arguments regarding quality of the outcome and architectural stringency in regards to the structure. If all else fails, be open to the idea of slightly limiting your own work in the early stages, allocating room in the budget for some structural consultancy.

2. Establish a common goal

Establishing a shared goal for both architect and structural engineer in each project is a great way to create common ground for both to collaborate closely. Often, the architect’s goals in the early stages are to provide options for programmatically feasible and profitable building volumes. The structural engineer’s goals on the other hand are derived from the architect’s proposal and focus on verifying the structural integrity of the proposals while minimizing the cost. Cost-effectiveness, therefore, may seem like an obvious common goal to work towards. However, conflicts can arise over how to use the allocated budget, creating a greater divide.

More holistic and value-based goals provide the benefit of guiding how available resources are used in the project that transcends discipline-specific priorities. Urban planning strategies and goals set by the municipality, often documented in the form of a report, are a great example of such value-based common goals. Environmental goals, especially if they involve obtaining certification, also naturally require cross-disciplinary collaboration and feature well-documented routines for such collaboration in the early stages. To comply with BREAAM standards, for instance, a designated coordinator should organize a joint workshop with consultants including architects and structural engineers to establish environmental goals and discuss best practices for the project.

3. Build trust and let go of prestige

Trust is a fundamental prerequisite for successful collaboration. It is hard to define within a project and is highly dependent on personal and group dynamics. This makes it difficult to formally work with building trust in a construction project.

The stereotypical relationship between architects and structural engineers seems to be defined by the adage, "an architect's dream is an engineer's nightmare". It positions their respective roles as fundamentally opposed to each other. Such historical representations lead to a general mistrust on an industrial level. [2] The perceived likelihood of conflict and consequent aversion of the perceived conflict prevents architects and structural engineers from getting involved in each other's work.

If we were to treat trust as an intentional practice as opposed to an outcome of indiscernible factors, we could then perhaps, in very practical terms, actively forge a sense of trust between the two professions. Since the issue spans two levels, one on an industry level and one on a personal level, the strategies to tackle them should also be two-pronged.

On an industrial level, interdisciplinary professional associations like the Swedish TränätverkA have the potential to bridge the gap. However, in its current setup, the network is geared towards architects with few participating structural engineers. On an individual project level, in-person workshops and regular meetings are a great opportunity to not only generate ideas and establish a shared vision together but also to build trust and understanding between architect and engineer.

4.Understand each other's expertise

Architecture and structural engineering are interrelated disciplines. Yet there is a divide, especially in the professional world, that can only be bridged through an interest in and respect for each other's training. This can be developed through an understanding of the basic principles used in each profession. Architects work based on more formal and spatial principles such as rhythm, flow, proportion and scale while structural engineers work with physical principles such as strength, ductility, and loads.

The use of professional jargon pertaining to the respective principles can be a barrier to communication in the construction industry as it reinforces the boundaries between different disciplines and preserves the status quo. [3] In interdisciplinary teams, a common vocabulary and semantics on the other hand indicate knowledge construction across disciplinary boundaries. [4] Don't hesitate to ask for an explanation, clarification or simplification when needed. More often than not, other members of the team are also in need of it.

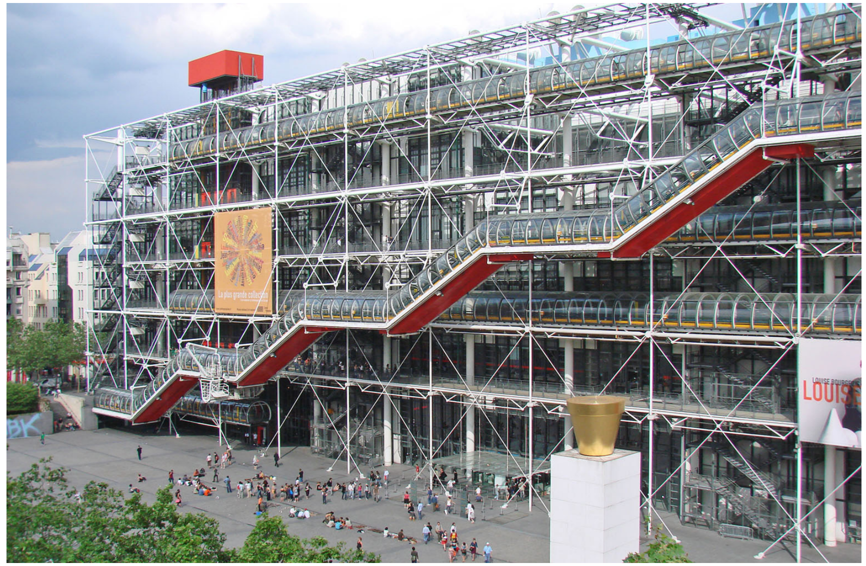
On page 27 you will find a list of literature recommended by us and/ or our respondents. All titles included are addressing issues regarding both professions and should be of equal interest whether you are an architect or an engineer. Some of them even address the subject of this text and could be helpful when evaluating and developing your own methods of cross-disciplinary collaboration.

5.Create interoperable methods and tools for working
Currently, it is more common than not for tools to differ between the fields. As previously stated, architects typically employ an iterative process with focus on design and the structural engineer follows a more step-by-step process with focus on technical aspects. What we do have in common is the use of a tool renowned for its communicative power and swiftness: the hand drawn sketch. Hand sketching was also our respondents number one activity, when asked what an early stage, cross-disciplinary workshop should include. [5]

On the other end of the digital-analogue spectrum we find the "How to CLT" Grasshopper script, an iterative tool built around the technical aspects of CLT. The script aims to be easy enough to be used by a complete novice. Moreover, its capabilities of instantaneously providing volume, proposed build-ups and data from a simple sketch and a limited number of technical parameters, makes it useful for real-time cooperative sketching during meetings and workshops.

Try to early on initiate a discussion on how the benefits of a closer collaboration can be translated to later stages of the process. Is the project manager open to making use of the BIM-environment's full potential for collaboration through the use of a collaborative model-file? Does the project-group have experience or interest in so-called "big-room meetings" where you actively work together in the same room during parts of the process? [6] Dare to challenge the standard operating procedures!

6. Transcend disciplinary boundaries through Tectonics
From canonical projects like Gaudí's Sagrada Famillia to Elding Oscarsson's recent and highly cross-disciplinary wooden addition to Stockholm's Tekniska Muséeum, Wisdome, [7] most if not all of



- Two divisive buildings by starchitects in France, each on extreme ends of the tectonic scale. -

Piano/Rogers/Franchini seemingly chose a tectonic approach for their Centre Pompidou in Paris, turning the building inside-out by embracing the structural and technical elements as integral parts of the design concept . Frank Gehry went the other direction for his LUMA building in Arles, hiding the extremely complex and irrational building-skeleton with his signature metal plates.

Arkemi's favorite instances of building culture have been borne from an integrated approach to architecture and structure. In fact, there is an entire branch of study dedicated to this approach, Architectonics or simply Tectonics, which is unfortunately somewhat lost when students transition to the professional world.

The typical process of collaboration between Swedish architects and structural engineers has since long instead been characterized by a strict division of labor. A decrease in shared knowledge has been observed by many, a gap that according to some engineers gets wider and wider with every year of freshly graduated architects entering the job-market. [8] The result is a slower design process, more conflicts and an architecture where form and structure are separate entities. [9]

Speaking of tectonics, one of the structural engineers who answered our survey, Tomas Gustavsson, divides the relationship between architecture and construction in two distinct groups:

- The structure is subordinate to the spatial design
- The structure is one (of several) starting points to the spatial design

The latter is what we define as a tectonic approach and is naturally the more collaborative-friendly out of the two as it has less of an in-built hierarchy. Although both strategies can lead to fantastic outcomes (Gustavsson however warns that the subordination of structure has a tendency to lead to a "coulisse-like" result)[10] we urge the architect to not underestimate the impact of their early design. Instead we recommend you to make an early and conscious choice of how architecture and structure relate to one another in the project.

A close collaboration between disciplines involves shifts on multiple levels, from changes in individual attitudes and methods of working to larger industry norms. We hope that the 6 principles we outlined in this chapter provide tangible tactics to aid this transition towards a "material-based" design process that we at Arkemi firmly believe in.

1 M. Al-Ameri & S. Asani, 'Samspelet mellan arkitekten och konstruktören', Thesis in building technology and architecture, Lunds Tekniska Högskola, Institutionen för arkitektur och byggd miljö, 2018.

2 K. Grange, 'Arkitekterna och byggbranshen: Om vikten av att upprätta ett kollektivt självförtroende', Doctoral thesis in architectural theory and history, Chalmers Tekniska Högskola, Sektionen för arkitektur, 2005.

3 Ö. Wikforss, 'Kort sagt: 33 kolumner om det tänkta och det byggda', Arkitekturanalys Sthlm AB, 2011.

4 A. Dong, 'The latent semantic apporach to studying design team communication', Design Studies, Volume 26, Issue 5, 2005, pp. 445-461

5 Arkemi, Responses by Swedish architects and structural engineers to Questionnaire, 'How to CLT: Utvärdering av det tidiga samarbetet mellan A och K i träbyggnadsprojekt', Google Forms, accessible online: https://forms.gle/rFSKuhVeBKPnEvBE6, 2023.

6 K. Bosaeus, 'En bärande idé? Ett explorativt examensarbete om samspelet mellan konstruktion och arkitektur', Master thesis in civil engineering and architecture, Luleå Tekniska Universitet, Institutionen för samhällsbyggnad, 2011.

7 Arkemi, Interview with Tomas Alsmarker, Head of Innovation & Research at Svenskt Trä, 2023-11-17.

8 K. Bosaeus, 'En bärande idé? Ett explorativt examensarbete om samspelet mellan konstruktion och arkitektur', Master thesis in civil engineering and architecture, Luleå Tekniska Universitet, Institutionen för samhällsbyggnad, 2011.

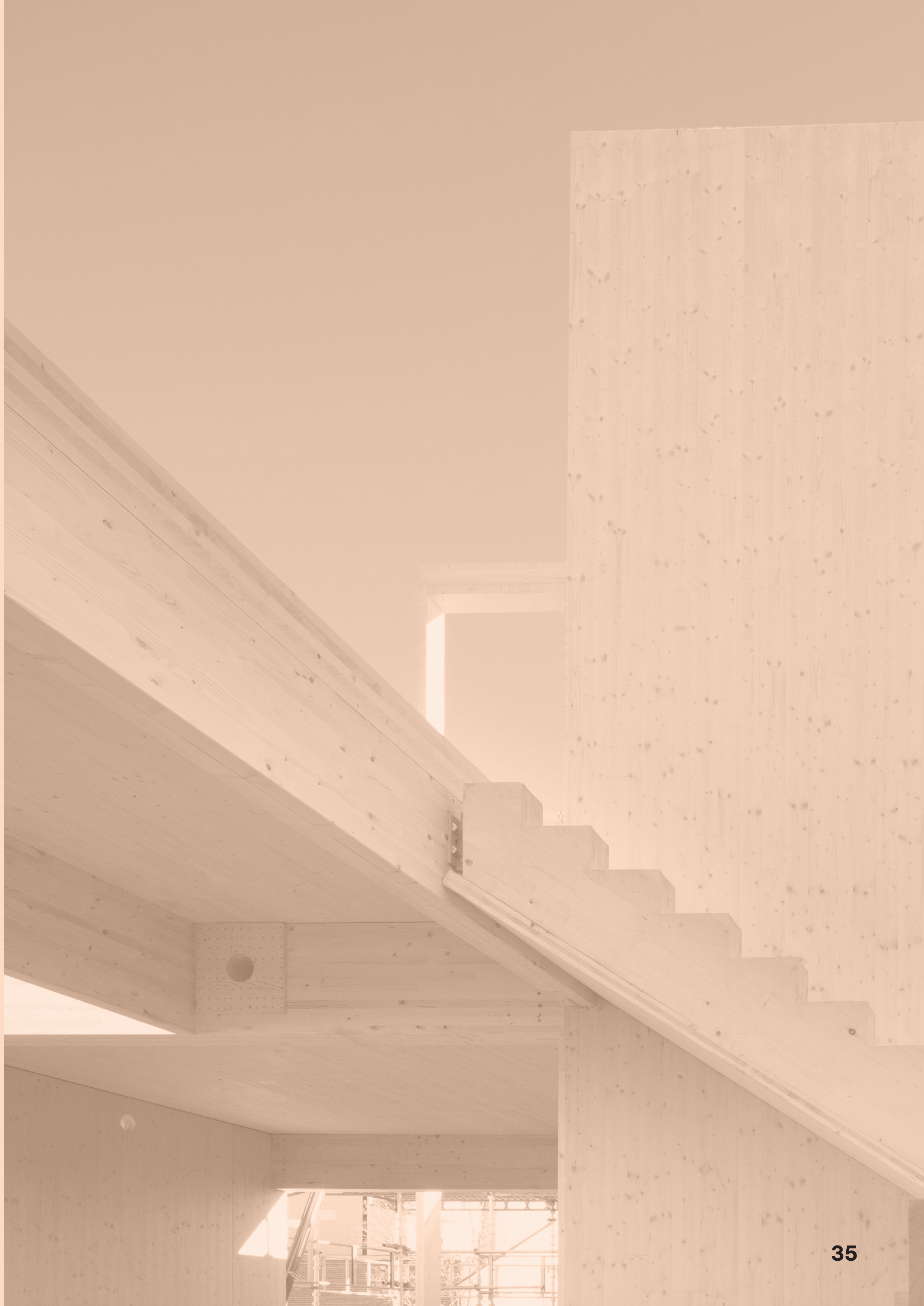
9 J. Löfstedt & K. Stern, 'Arkitekter och konstruktörer: En studie av professionernas samverkan i designprocessen, Bachelor thesis in civil and environmental engineering, Chalmers Tekniska Högskola, Institutionen för arkitektur och samhällsbyggnadsteknik, 2021

10 T. Gustavsson, 'Så vill jag arbeta', Website of Tomas Gustavsson Konstruktioner AB, acessible online: https://www.konstruktioner.se/doc/tgk-244.htm, accessed 2023-12-11.

04

Design with CLT for Early Stages

- Structural Systems
- CLT Elements



Structural Systems

CLT can be used to construct both load-bearing and non-load-bearing elements. A non-load-bearing application of CLT does not use the material's full potential but can still highlight some of its other qualities, for example its materiality or technical performance in regards to creating a good interior climate.[1] This handbook will however only focus on discussing applications where CLT forms part of the structural system.

Panels or 3D-Modules?

In practice, there are two main common approaches to build with CLT. The most common approach is to prefabricate the desired panels in a factory, transport them to the building site and put them together on site so they form a stable assembly. In this guide we refer to the outcome of this approach as a *Panel System*.[2]

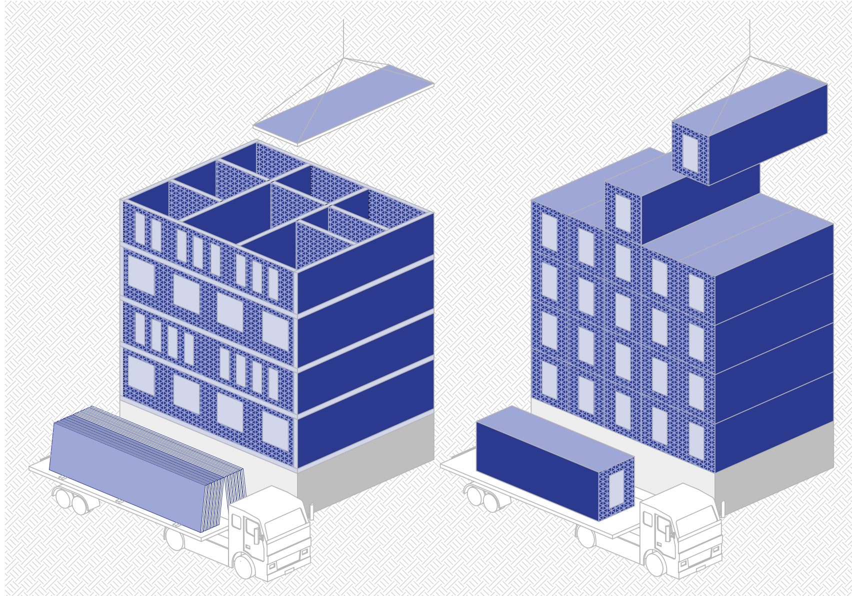
The other approach would be to prefabricate and assemble the panels in a factory to form portable and stable three-dimensional modules, transport them to the building site and then stack them in a way that sufficiently maintains the stable assembly. In this guide we refer to the outcome of this approach as the *3D-Module System*.[3]

3D-Module Systems

Building with 3D-modules has benefits, the most important ones being:

- It is very fast to assemble: Since a big part of the construction is done in the factory, the time spent on site is minimized. The controlled factory environment also means that a lack of daylight and bad weather doesn't interfere with production. This makes it a good choice for buildings being constructed in harsh climates, very dense urban areas, or any other situation in which spending time for on-site construction is expensive, problematic, or not preferred.

- It can be very resource efficient: The repeatable processes of production, the precision of CNC-routing and the forgiving nature of timber provides conditions for an optimized use of material and man-hours.



- Building constructed with panel system and 3D module system -

- It creates a clear design configuration: As the modules are room-sized and stable in themselves there is an opportunity for the architect to explore different arrangements or ways of stacking the modules. If employed correctly this could result in especially clear and sharp designs.

Although 3D-modules are suitable for many types of projects, especially when budget is tight, it also comes with some drawbacks. Of particular concern for the architect are that:

- It limits the structural configuration: The size of the modules are bound to the limits of the trailer that transports the module to the site, effectively deciding the maximum span widths of the entire building. The stability of the assembled building furthermore requires the modules to be stacked with their longitudinal load-bearing walls aligned on top of each other, resulting in a rather rigid system.

- It requires high levels of repetition to be cost effective: As with all industrial manufacturing, putting time and money on stream-lining the production is only beneficial if the same process can be used over and over again. This requires the products, in our case the modules, to be plentiful and more or less identical to each other.

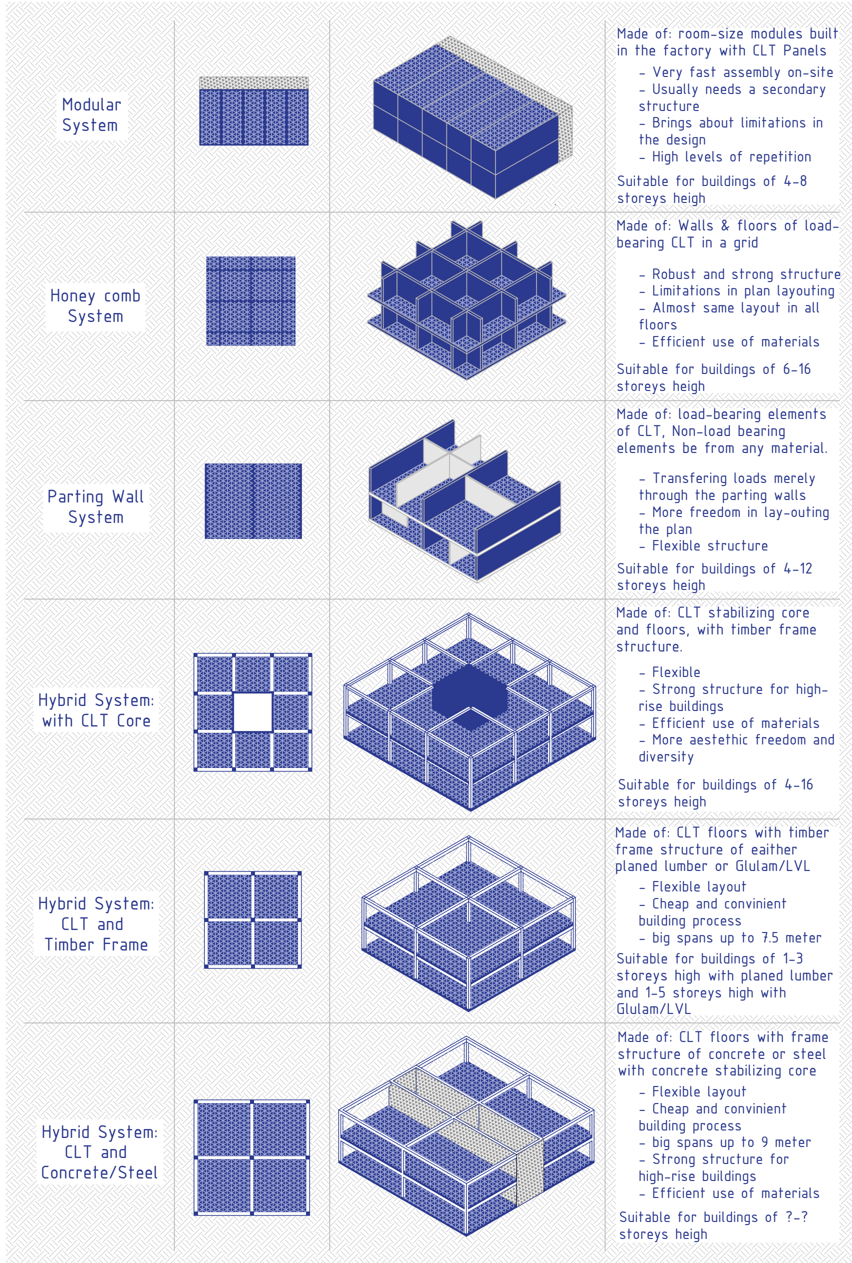
- It limits the design and the influence of the architect: The limits of the structure and high levels of repetition naturally puts restrictions to the sizes and organization of apartments and rooms as well as the composition of volumes and facades. Additionally, many producers offer (more or less well thought through) modular systems of their own design, stream-lining their production while further limiting the influence of the architect.

- It results in double layers of CLT: Since every module comes with its own floor, walls and roof the stacking of them will result in double layers of CLT (separated by a small gap) wherever two modules meet. Not only is that causing a loss of area and an ineffective use of material, but it might also put limits to moisture control and fire-safety in the finished building.

With this in mind we can conclude that, although the use of 3D-modules may result in well-designed and cost-effecient outcomes it greatly limits the design. This generally makes said application of CLT less interesting from an architect's point of view compared to using it in a Panel System.

Panel Systems
Of particular importance to the early design is to decide whether the structure will consist mainly of CLT panels acting as load bearing walls and slabs or if it is mainly framed, using more refined solid timber products acting as beams and columns carrying slabs of CLT.[4]

This handbook and the tools it comes with is aimed to aid the design of buildings more or less exclusively using load-bearing elements made of CLT panels. These structures are often used in Swedish mass timber housing and form the skeleton of what is normally referred to as a CLT-building. They can be further divided into two categories:



- Variations of structural solutions using load-bearing CLT elements -

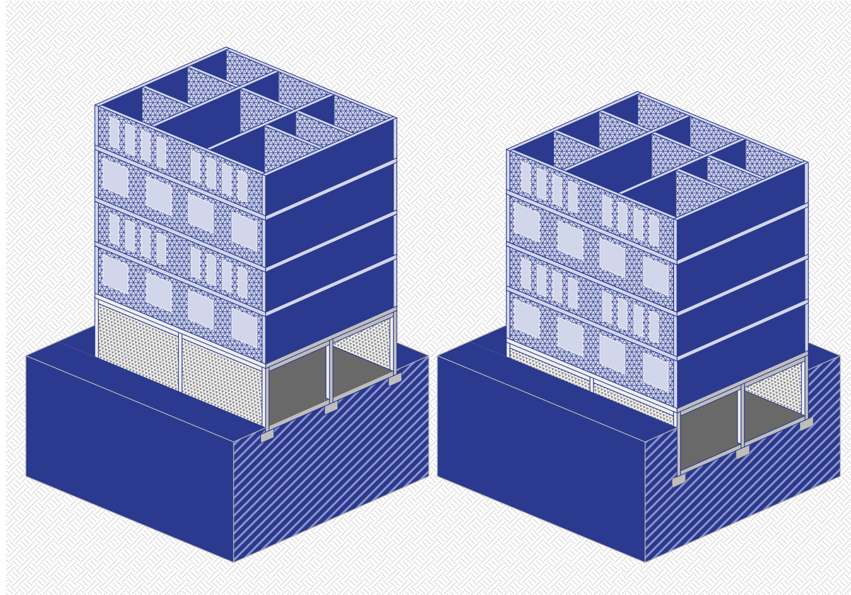
- <u>Honey Comb Layout:</u> This system is comprised of a grid of load-bearing CLT walls where a majority are structural. This spreads the loads efficiently and reduces the wall and floor panels to a minimum thickness. As the forces in this system need to be transferred through lined-up walls, the layout of the plans needs to be more or less the same for every floor, limiting the building's flexibility. On the other hand, the system forms an extremely robust and efficient structure that allows great freedom of design in the non-load-bearing facade. The honey comb layout is suitable to use in complex buildings.[5]

- <u>Parting Wall Layout:</u> In this system the core walls, exterior walls and parting walls in between apartments are load bearing. The walls and slabs are made out of CLT panels with glulam or steel beams being used where wider spans are necessary. It provides full flexibility within the apartments and allows a certain flexibility of layout over the building as a whole since the structural capabilities are met as long as the parting walls line up between storeys. The system suits various heights and shapes of buildings of lesser complexity.[6]

Both of these are easy and quick to assemble, cutting on-site costs and man-hours. As stated however, they both require relatively fixed locations of walls/reasonably constant floor layouts, affecting the functionality and flexibility of the building. In cases where these limitations are unacceptable a hybrid between a framed and a load-bearing wall system may be more suitable.[7]

Hybrid Systems

Many projects end up being hybrid solutions, with walls around key elements such as lift shafts and stair cores being built out of CLT panels to provide stiffness and a grid of columns and beams being used where greater flexibility is required. It is also possible to use CLT around the perimeter of the building while using a framed system in the interior. Although more complex and technically demanding, the hybrid system provides for a high grade of flexibility as structural elements are kept to a minimum.[8]

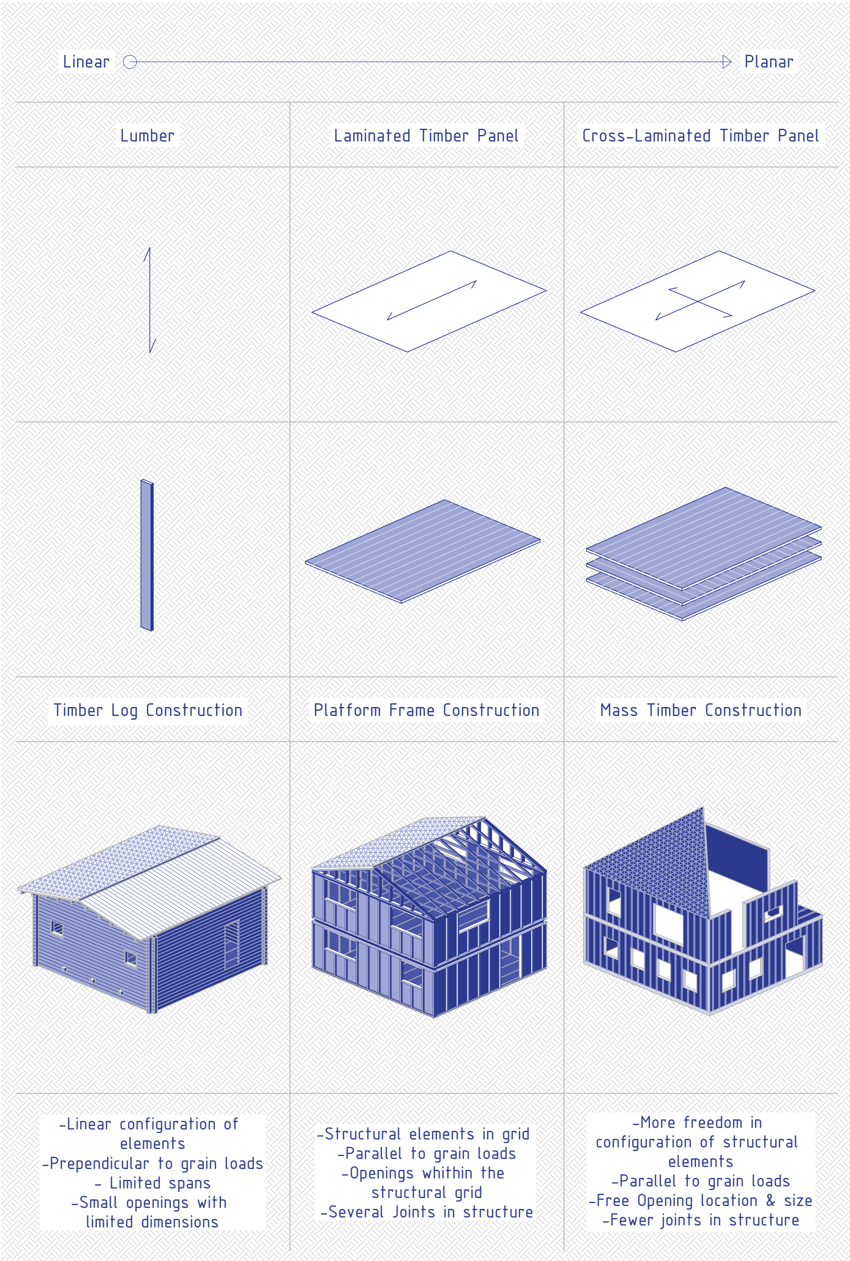


- Concrete ground floor/basement and foundation: two common foundations of CLT buildings -

Ground floor and Foundation

Usually, a CLT building is built on top of a podium level made of concrete, raising the timber from the ground and keeping it from getting wet and dirty. The podium can also assist in transferring loads across the ground floor where the program, particularly in residential developments, often require a different internal arrangement than the floors above it. This makes it possible to provide suitable spaces for entrance hallways, shared spaces, retail or parking accessible from the street level.[9] Concrete can also be used when basements or partial basements are needed, acting as the foundation of the mass timber building.[10]

1 Waugh Thistleton Architects, '100 Projects UK CLT', Waugh Thistleton Architects, 2018, p. 46.
2 A. Deplazes, 'Constructing Architecture: Materials, Processes, Structures', Springer Science & Business Media, 2005, p. 94.
3 Waugh Thistleton Architects, NU living and Ramboll, 'NU Build Modular Design Guide', Swan Housing Association, 2019.
4 J. Norman, 'Structural Timber Elements: a Pre-scheme Design Guide 2nd Edition', TRADA Technology Limited, 2016, p. 11.
5 P. Zumbrunnen, 'Pure CLT – Concepts and Structural Solutions for Multi Storey Timber Structures', Internationales Holzbau-Forum IHF, 2017, p. 6.
6 P. Zumbrunnen, 'Pure CLT – Concepts and Structural Solutions for Multi Storey Timber Structures', p. 6.
7 J. Norman, 'Structural Timber Elements: a Pre-scheme Design Guide 2nd Edition', p. 23.
8 J. Norman, 'Structural Timber Elements: a Pre-scheme Design Guide 2nd Edition', p. 25.
9 Waugh Thistleton Architects, '100 Projects UK CLT', p. 49.
10 J. Norman, 'Structural Timber Elements: a Pre-scheme Design Guide 2nd Edition', p. 37.



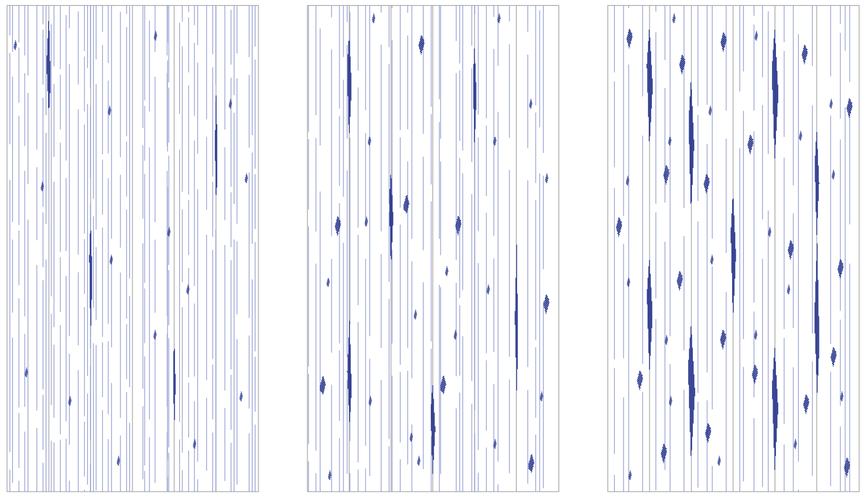
- Timber architecture evolving from linear to planar -

CLT Elements

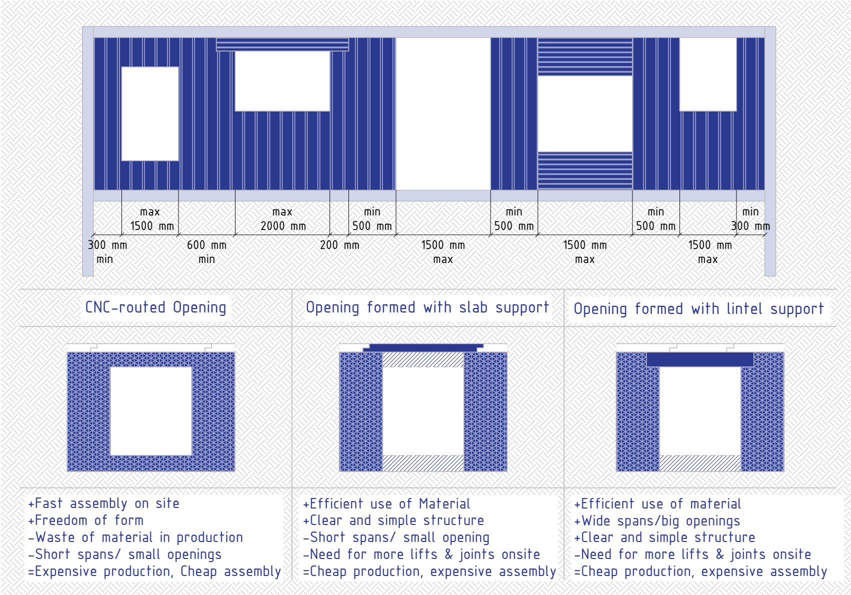
The cross-lamination of a CLT panel, creates a structure that spans in two perpendicular directions. In contrast to traditional timber components (logs, rafters, studs etc.) which are linear in nature, CLT is considered as a planar component. Thus, its use in buildings is, structurally, more similar to pre-cast concrete panels. Its planar characteristic makes it compatible to be used both vertically, as a wall, and horizontally, as a floor and roof structure.

CLT as a Wall

CLT producers offer panels with different qualities of surface finish. This includes visible quality, industrial quality, and built-in quality panels. For exposed interior use, the first two qualities of CLT may be used and the finish can be further enhanced by directly applying surface treatments such as paint, varnish, wax or oil . However, regulations regarding fire, acoustics and work environment may require plastering or gypsum to be added to the CLT wall as a finishing layer.



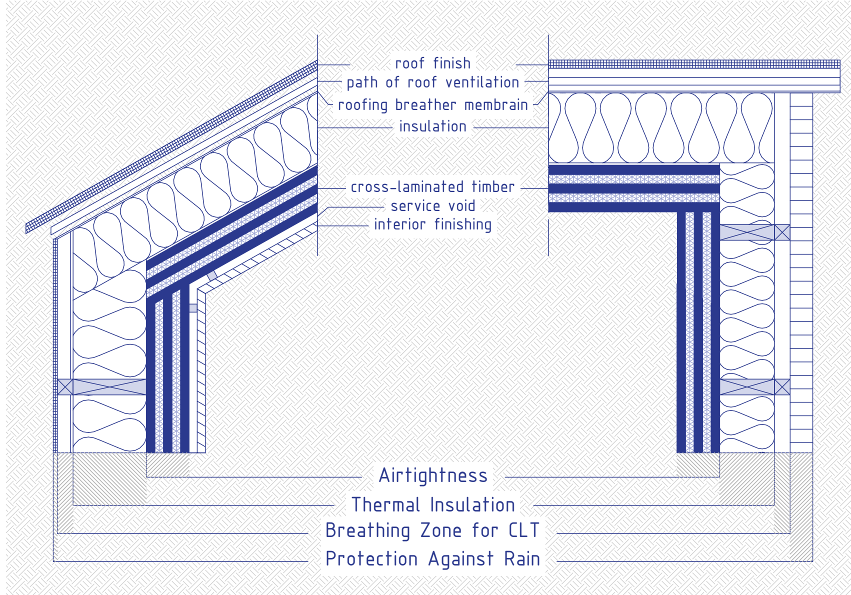
- Surface finish qualities of CLT panels, each suitable for different applications -



- Common types of openings in a CLT structure and their respective, approximate maximum dimensions -

A benefit from the cross-lamination is that CLT allows several openings for doors windows and services to be cut out of a panel without jeopardizing its structural capabilities. Openings should always be managed in a conscious way to minimize waste and maximize the structural stability of a panel. Openings are generally made in three different ways that each come with their pros and cons: CNC-routed, formed and formed with lintel support.

Since CLT is made of kiln-dried and essentially untreated soft wood it is rather susceptible to moisture and weathering. CLT panels, when used as external walls, must therefore be supplemented with a suitable envelop. A suitable envelop is a continuous shielding layer that protects the CLT structure from the rain and moisture, provides airtightness, and insulates the building. Good detailing of the envelop and choice of right materials, will boost the performance of CLT as a natural material and ensures a good environmental comfort within the building. Handling the envelop correctly will to a great extent contribute to the life span of the building.



- A well designed and constructed envelop ensures a pleasant indoor enviroment and protects the structure -

As previously stated, CLT can also be used as interior walls. However, for economical and practical reasons, the use is generally limited to load-bearing walls, such as walls separating two apartments. CLT is lightweight compared to materials such as concrete and gypsym. Since mass influences acoustic performance a satisfactory level is usually achieved by adding supplementary layers of sound insulating material covering the CLT or by using double CLT structures with insulating layers in-between.[1] Generally speaking these are cheaper ways of improving the acoustic performance than increasing the panel thickness, unless a thicker panel is required for structural reasons.[2]

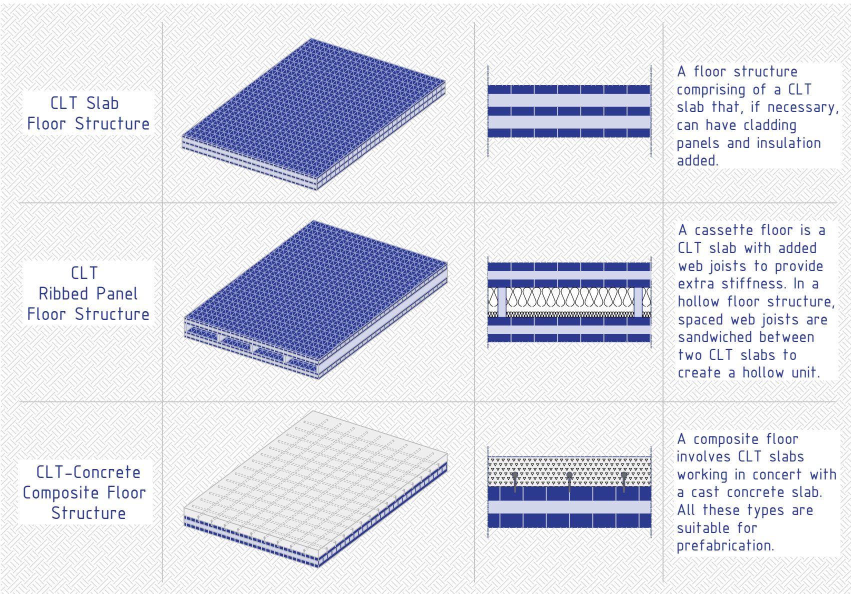
CLT as a Floor Slab

Using CLT panels as floor slabs is one of the most common applications of the material, as they can be used not only in pure mass-timber structures but also in many different hybrid solutions. CLT floor slabs are usually placed on two supports where the support may run along the whole length of the panel or be point supported at set intervals.[3]

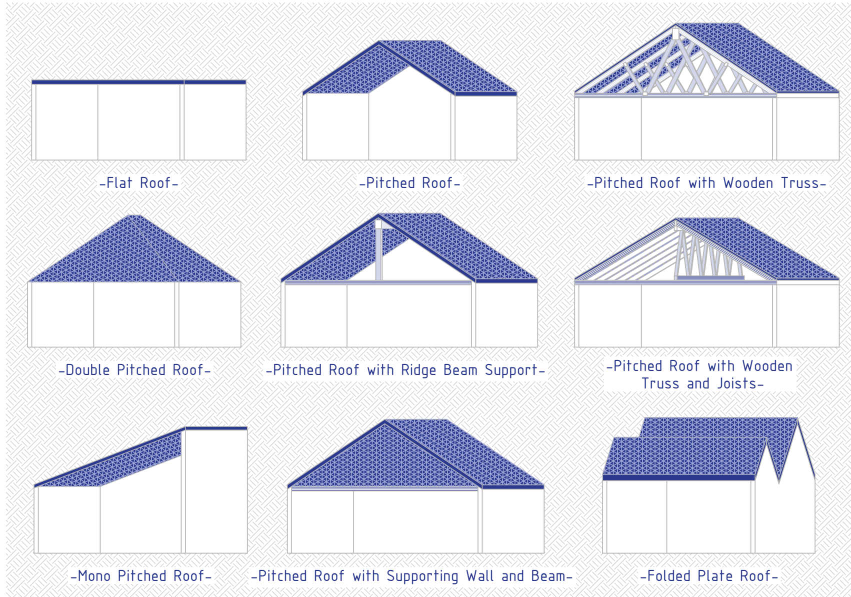
CLT floor structures have the advantage that they, due to their structural homogenity, are very good at distributing and transfering loads to the adjacent structures. This means that comparably large holes for shafts can be cut without the need of reinforcement.[4]

The simplest form of a CLT floor is composed of a CLT panel with sufficient thickness to meet structural demands. However, similarly to walls, CLT floor slabs will generally need to be supplemented by other materials to meet acoustic regulations. This is usually solved by adding a suspended ceiling or by covering the CLT with insulating layers of different densities.

Other common uses of CLT in floor structures are as structural layers in cassette floors and similar hollow structures, and as the bottom layer of a composite CLT-concrete floor. Due to their enhanced insulating properties these structures generally ensure sufficient acoustic performance without the need of bulky additions.



- CLT floor slab types and common Build-ups -



- Different types of roofs possible to construct in CLT -

CLT also has a good heat storage capacity and low thermal conductivity. A mass timber surface will thus feel warmer to the touch than materials such as concrete and has the ability to positively contribute to the thermal experience of a room, particularly during the colder months.[5]

CLT as a Roof

Similarly to floor slabs, CLT roofs are good at transferring loads to the adjacent structure and are able to include substantial openings without the need of additional support. Benefiting from the workability of the timber, suspended ceilings, systems for MEP and similar additions are easily installed.

For buildings requiring particularly long, unsupported spans, a CLT roof will impose less loads to the supports than concrete decks of similar span. However, this may result in unjustifiable thicknesses of CLT and often it may prove more economical to reduce the span of the roof, thus reducing the thickness of the CLT, by for example introducing intermediate beams.

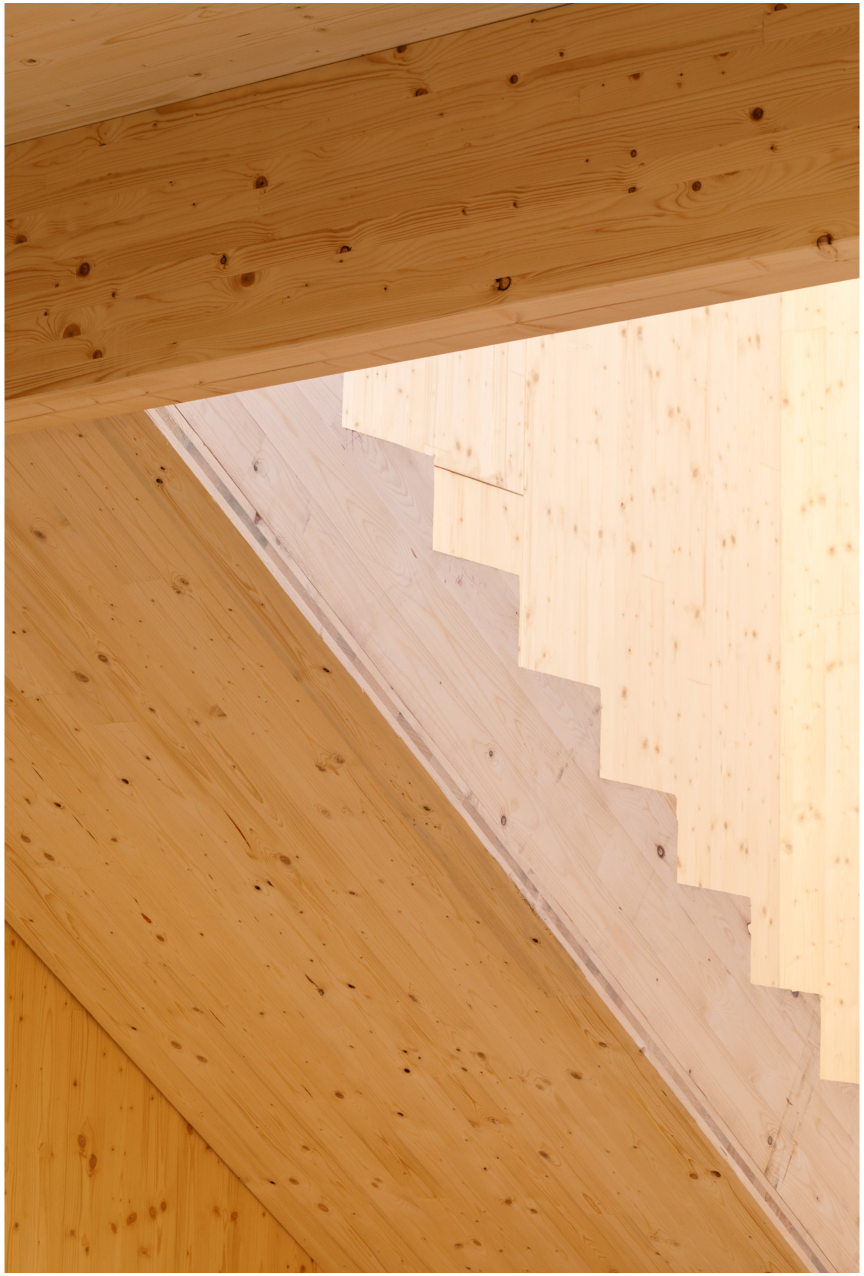
CLT panels can be effectively used for pitched roof construction, whether mono pitch or double-pitch. For double-pitch roofs of limited dimensions CLT panels may be tilted against and fixed to one another without supporting members. For larger roof spans portal frames, trusses, or beams can be introduced in order to avoid increasing the thickness of the CLT panels.[6]

CLT as Stairs and Services

Besides aformentioned general applications, CLT can be used as a structural member of more specialized building elements, for example lift shafts and service cores. The factory's high levels of accuracy and the materials workability allows for smooth installation and rapid fixing of equipment and services.[7]

Stairs made out of mass timber are lightweight and can be an economical alternative to the omnipresent pre-cast concrete stairs. This is especially true if one manages to construct them out of offcuts from other CLT components, making use of otherwise wasted material. They can be made as straight stairways, dog leg stairs, or can be custom-designed for a more architecturally appealing form.[8]

1 E. Borgström, J. Fröbel, 'The CLT Handbook: CLT structures – facts and planning', Svenskt Trä, 2019, P. 154.
2 Exova BM TRADA, 'Cross-laminated Timber: Design and Performance', Exova BM TRADA, 2017, P. 82.
3 E. Borgström, J. Fröbel, 'The CLT Handbook: CLT structures – facts and planning', P. 25.
4 E. Borgström, J. Fröbel, 'The CLT Handbook: CLT structures – facts and planning', P. 25.
5 Exova BM TRADA, 'Cross-laminated Timber: Design and Performance', P. 19.
6 Exova BM TRADA, 'Cross-laminated Timber: Design and Performance', P. 63.
7 N. Crawley, 'Cross Laminated Timber: A design stage primer', Routledge, 2021, p. 267.
8 Stora Enso Wood Products GmbH., 'CLT Stairs by Stora Enso – product brochure', Stora Enso Wood Products GmbH., 2017, p. 5.



- CLT stairs: simple, strong and fast to erect -

05 Rules of Thumb

- Rough Dimensional Rules
- Dimensional Tables and Library of Elements

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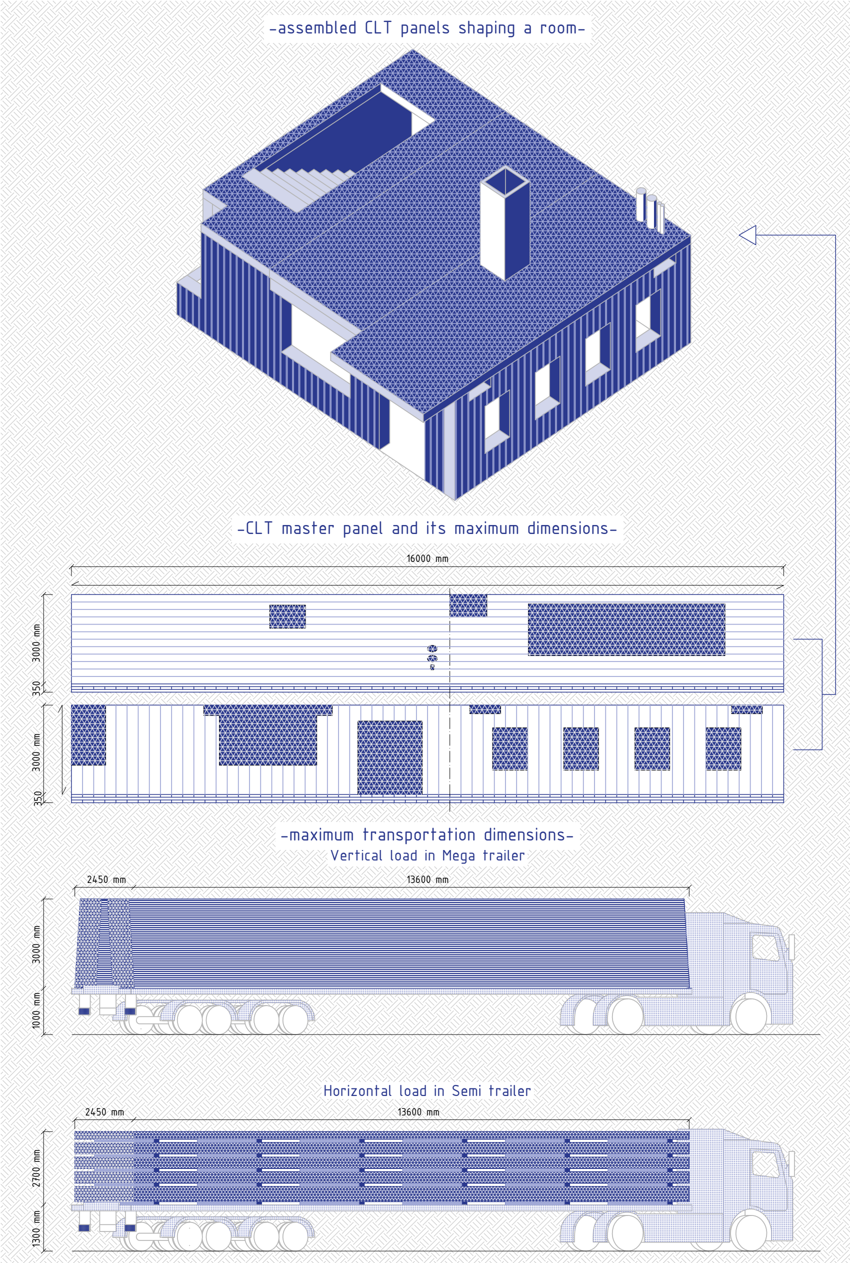


- The CLT master panel and the Dimensional limits to keep in mind when designing with CLT -

Rough Dimensional Rules

The Master Panel

The CLT panels' cross-section consist of an odd number of layers of wooden boards. Thus, the top layer in a master panel has the same board orientation as the bottom one and this direction in turn determines the main structural axis of the CLT panel. A panel can have either longitudinal or transverse board orientation.[1]

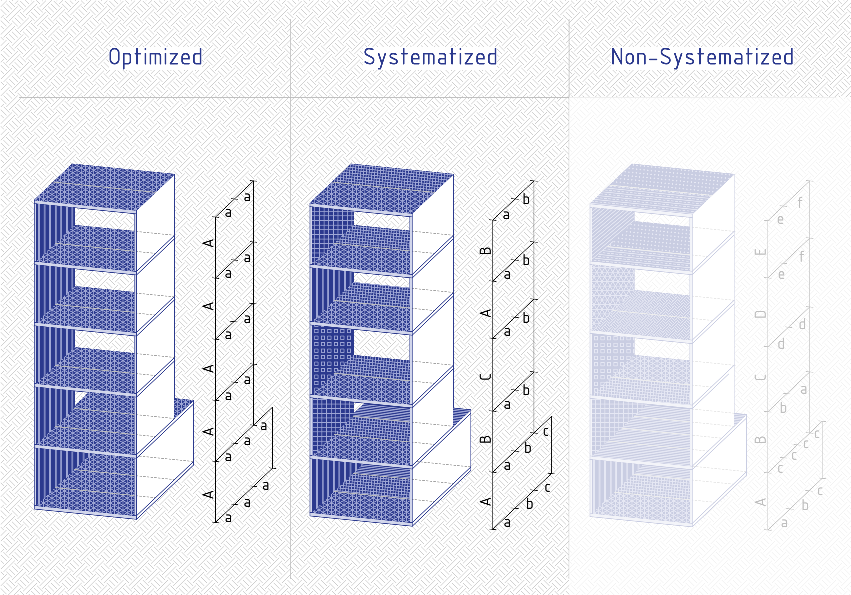
All CLT elements should be designed to be able to fit within the maximum dimensions of a master panel.[2] The maximum dimensions of the master panel depends on the capacity of the factory's machines, and thus varies between different producers. However, they usually have an approximate dimension of 16 m (up to 20 on demand) in length, 3 m (up to 4,8 on demand) in width, and up to 350 mm in thickness.[3]

It is further recommended that all panels, especially the ones that are nested on the same master panel, are made equally wide as this will minimize waste and facilitate mounting and packaging. It is therefore important to, already in the initial stages of design, develop a system of dimensions of wall heights and floor span widths.

Having less joints and trying to combine different elements into bigger panels is structurally more favourable as it will create a more coherent structure with less critical points. However, when designing continuous panels it is important to keep in mind the maximum dimensions of a CLT master panel.

Transportation

The limitations of dimensions connected to transporting the panels to a building site are generally equal to or more restrictive than the producer's maximum dimensions.[4] Therefore they are crucial to take into account when considering floor heights and the size of the individual panels. Regulations differ between countries and permits can be obtained to be able to transport goods exceeding the regular limitations. However, such transports are expensive and logistically complicated and should, whenever possible,



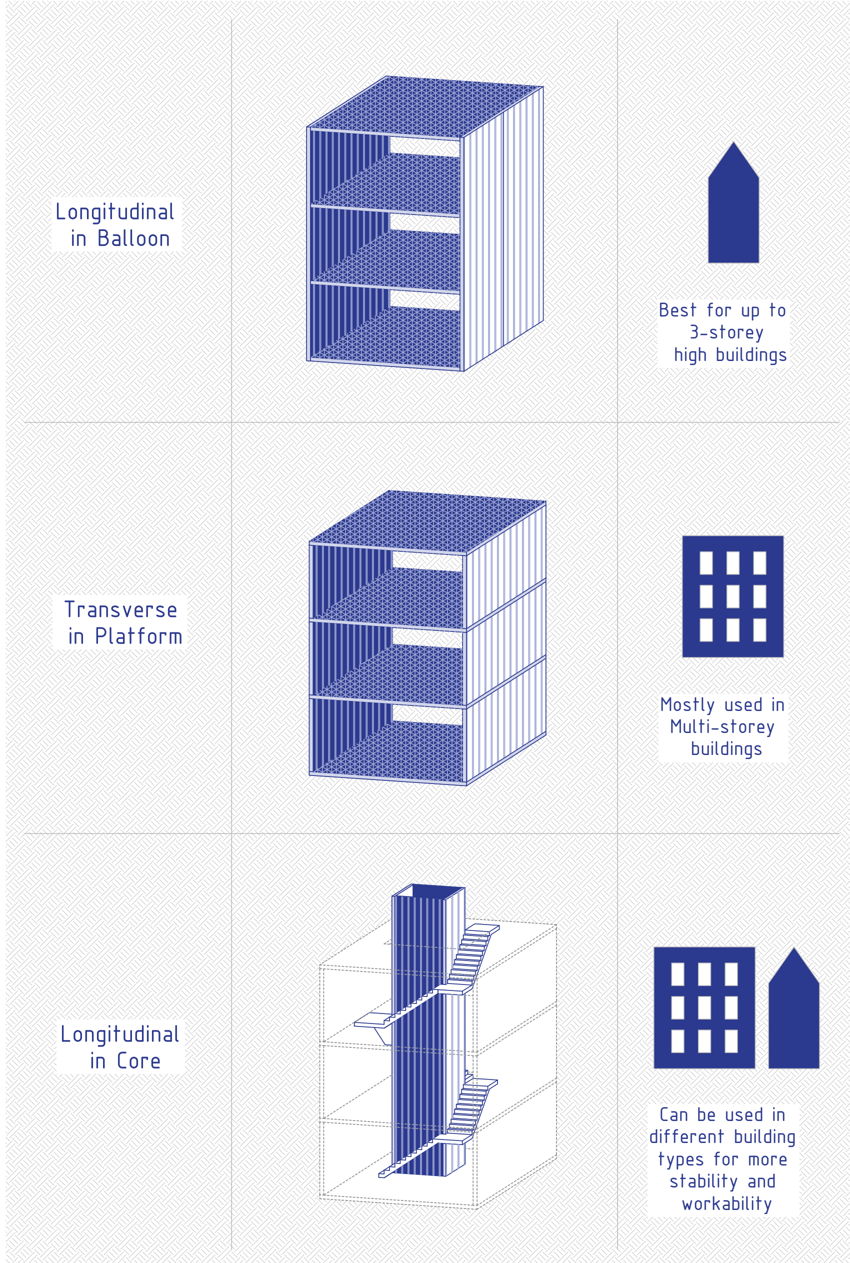
- A dimensional system is important to establish when creating efficient and easily constructable CLT buildings -

be avoided. A simple rule of thumb is to stay within the limits of the rather universal standards of the two most common forms of trailers: the semi-trailer (13,6 x 2,45 x 2,7 m) and the mega-trailer (13,6 x 2,45 x 3,0 m).

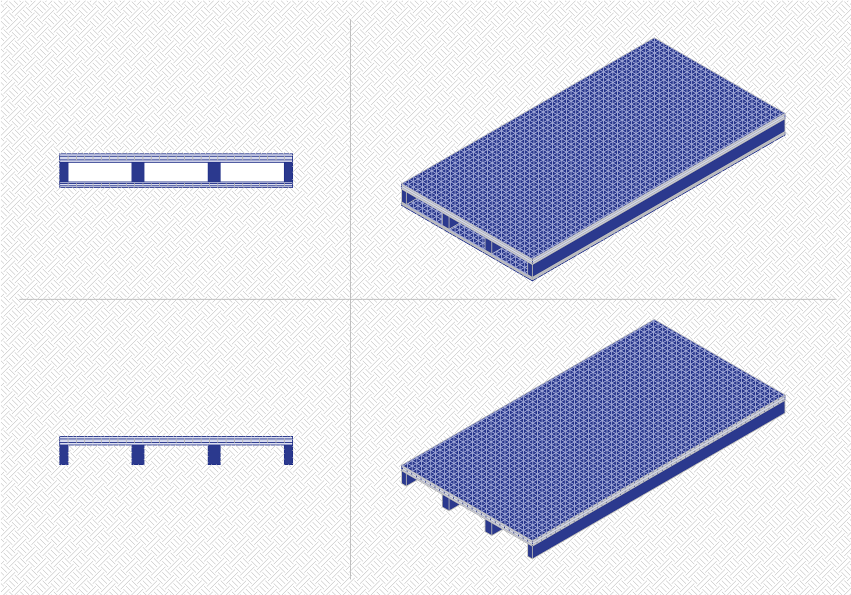
Wall

The thickness of a CLT panel for a wall is mostly determined by two main factors: the imposed load and the required fire resistance class. Both factors depend on the intended use and number of floors of the building. It is therefore possible, but not necessarily economical or practical, for wall panels to be thicker in the lower floors than the upper ones.

CLT panels for walls in a 3-8 floor building intended for housing purposes normally have a thickness of between 140 mm-220 mm. The panel height normally corresponds to the full width of the master panel, usually around 3 m. For balloon-frame structures, service cores and communication shafts it is however possible to use the panels longitudinally, with maximum heights of about 16 m.



- Common types of transverse and longitudinal applications of CLT panels -



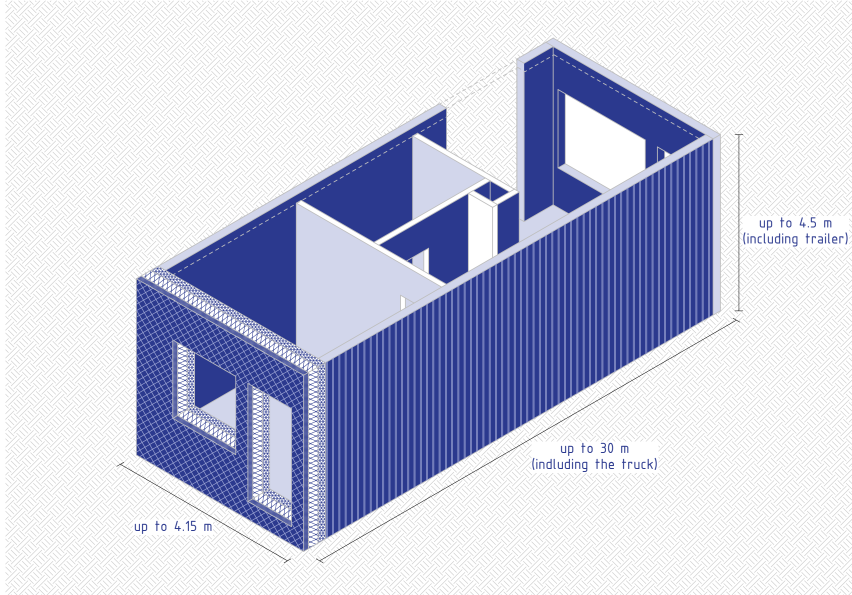
- Ribbed CLT panel: reinforced with LVL/Gluelam beams to be able to span further -

Slab

The thickness of a CLT slab is mostly determined by its span and acoustic design.[5] The most basic forms of CLT slabs are able to span up to 7 meters but spans up to 9 meters are achievable by reinforcing the CLT panels with for example Glulam beams or concrete.[6] CLT panels for slabs in a 3-8 floor building intended for housing purposes normally have a thickness of between 200 mm-260 mm.

Roof

The roof panels' thickness is mostly determined by the span of the structure and the amount of snow load being imposed on the building. CLT roofs usually span up to 7 meters but can similar to floor slabs be reinforced by other materials to increase its capabilities. CLT panels for roofs in a 3-8 floor building intended for housing purposes normally have a thickness of between 140 mm-180 mm.



- CLT 3D module and its maximum dimensions regarding transportation-

3D-Modules

When designing with CLT 3D-Modules, the determining dimensional factor is whether it is possible to transport the module to the site. The limits of the desired route is especially important to consider if the site is located in a dense urban area. However, for practical purposes, transports of stable modules are allowed to be wider (up to 4.15 m), higher (up to 4.5 m including trailer) and longer (up to 30 m including truck) than what is the case with planar elements. Permission to transport even larger modules can be obtained if actions such as escorting, road blocks and an approval of the transportation route is carried out.

1 Mayr-Melnhof Holz Holding AG., 'MMCrosslam- Cross-laminated timber- Technical Data', Mayr-Melnhof Holz Holding AG., 2020, p. 5.
.2 Waugh Thistleton Architects, '100 Projects UK CLT', Waugh Thistleton Architects, 2018, p. 48.
3 Based on the technical brochures of the CLT producers: MM Crosslam, Stora Enso, Hasslacher, KLH, Setra, Leno, and Martinsons.
4 ZÜBLIN Timber GmbH., 'Leno Cross Laminated Timber (CLT)- Technical Brochure', ZÜBLIN Timber GmbH., 2018, p. 10.
5 A. Esbjörnsson, P. Magnusson, J. Ford, ' URBAN TIMBER: a resilient timber architecture in the city and a vision for mass customization', Chalmers University of Technology, 2014, p. 61.
6 E. Borgström, J. Fröbel, 'The CLT Handbook: CLT structures – facts and planning', Svensk Tra, 2019, P. 94.

Dimensional Tables and Library of Elements

In this chapter, we have provided preliminary design dimensions for CLT buildings. These dimensions are intended for more or less pure CLT structural systems and would differ in case of hybrid solutions. The tables provide dimensioning for 3-8 storey residential buildings in Sweden, with Swedish regulations and requirements in mind and considering CLT products available on the Swedish market. The same dimensions and parameters are implemented in our Grasshopper script and Revit file, which you can use to model and quantify your early-stage CLT project.

The CLT industry lacks a common system of dimensions and properties. Instead each producer currently provides a "handbook" of their own in which they present their products. This makes it harder for the architect to provide preliminary figures on dimensioning since the choice of producer is often a decision left for later stages.

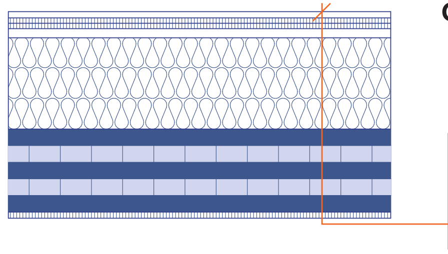
To get around this issue we collected and compared data from all of the Swedish producers as well as several interviews with a construction engineer specialized on mass timber buildings. These inputs provided us with information necessary to put together a limited library of commonly used elements, dimensioned according to their structural constraints.

It is important to understand that the choice of one element may have effects on the build-up of another. In our case we have designed the scheme to adapt to the choice of a light or heavy floor super structure, but there might be other equally important aspects to factor in.

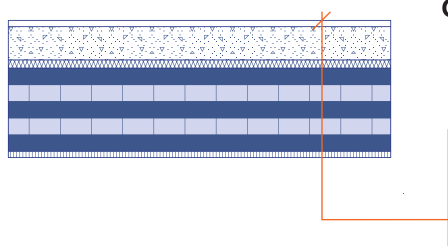
Please note that these dimensions are only intended as an assistance for the preliminary stages and can not replace a full static calculation.

Floor Slabs

CLT with light superstructure



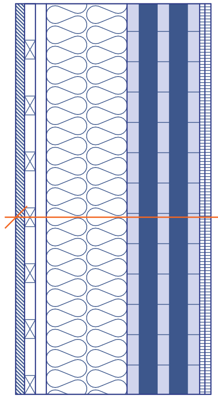
CLT with heavy superstructure



CLT Dimensioning Table for Floor Slabs				
Span (m)	Light Floor Superstructure		Heavy Floor Superstructure	
	CLT (mm)	Total (mm)	CLT (mm)	Total (mm)
< 5	200	498	220	350
5-7	240	538	260	390

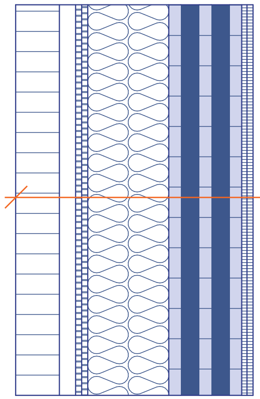
Exterior Walls

Exterior wall clad with Wood Panels



22 mm	VERTICAL FACADE PANEL
25 mm	BATTEN
27 mm	COUNTER BATTEN
-	WIND BARRIER
200 mm	INSULATION
140-200 mm	CLT
13 mm	GYSPSUM BOARD
15 mm	FIRE RESISTANT GYPSUM BOARD

Exterior wall clad with Bricks

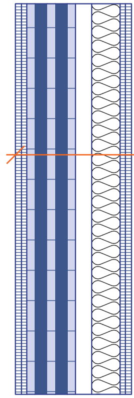


108 mm	FACADE BRICK
40 mm	VENTILATED CAVITY
30 mm	WIND RESISTANT SHEATHING
200 mm	INSULATION
140-200 mm	CLT
13 mm	GYSPSUM BOARD
15 mm	FIRE RESISTANT GYPSUM BOARD

CLT Dimensioning Table for Exterior Walls						
Floors (num.)	Light Floor Superstructure			Heavy Floor Superstructure		
	CLT (mm)	Total (mm)		CLT (mm)	Total (mm)	
		Panel	Brick		Panel	Brick
I-III	140	442	546	160	462	566
IV-VI	160	462	566	180	482	586
VII-VIII	180	482	586	200	502	606

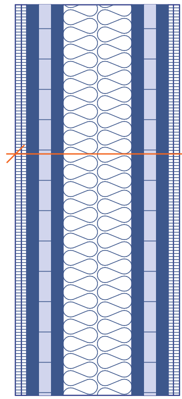
Partitioning Walls

Partitioning Wall with Single CLT



15 mm	FIRE RESISTANT GYPSUM BOARD
13 mm	GYSPSUM BOARD
120-180 mm	CLT
40 mm	VENTILATED CAVITY
70 mm	INSULATION + STUDS
13 mm	GYSPSUM BOARD
15 mm	FIRE RESISTANT GYPSUM BOARD

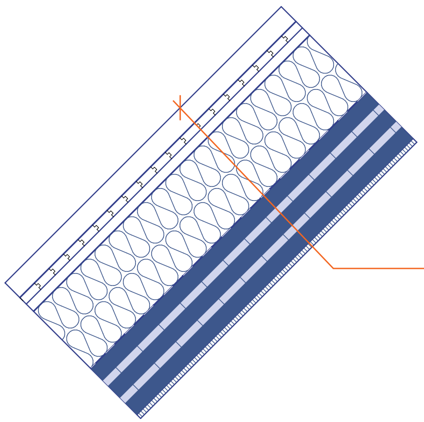
Partitioning Wall with Double CLT



15 mm	FIRE RESISTANT GYPSUM BOARD
13 mm	GYSPSUM BOARD
80-110 mm	CLT
170 mm	INSULATION
80-110 mm	CLT
13 mm	GYSPSUM BOARD
15 mm	FIRE RESISTANT GYPSUM BOARD

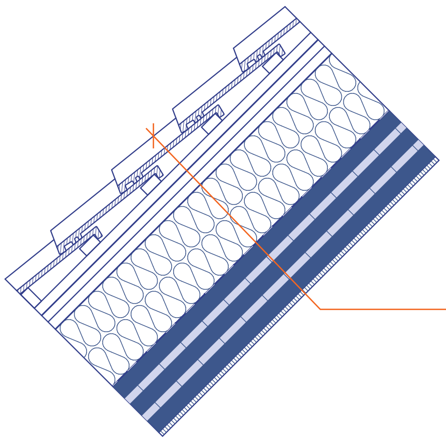
CLT Dimensioning Table for Partitioning Walls								
Floors (num.)	Light Floor Superstructure				Heavy Floor Superstructure			
	Single (mm)		Double (mm)		Single (mm)		Double (mm)	
	CLT	Total	CLT	Total	CLT	Total	CLT	Total
I-III	120	286	80+80	386	140	306	90+90	406
IV-VI	140	306	90+90	406	160	326	100+100	426
VII-VIII	160	326	100+100	426	180	346	110+110	446

Roof



Roof clad with metal

50 mm	SEAMED METAL ROOFING
1 mm	UNDERLAYMENT PAPER
22 mm	TONGUE AND GROOVE BOARD
25 mm	VENTILATED CAVITY
-	WIND BARRIER
200 mm	INSULATION
-	VAPOUR BARRIER
140-180 mm	CLT
13 mm	GYPSUM BOARD



Roof clad with tiles or shingles

80 mm	SHINGLE/TILE ROOFING
25 mm	BATTEN
25 mm	COUNTER BATTEN
1 mm	UNDERLAYMENT PAPER
22 mm	TONGUE AND GROOVE BOARD
25 mm	VENTILATED CAVITY
-	WIND BARRIER
200 mm	INSULATION
-	VAPOUR BARRIER
140-180 mm	CLT
13 mm	GYPSUM BOARD

CLT Dimensioning Table for Roofs

Span (m)	Snow Zone 1-3.5			Snow Zone 4.5-5.5		
	CLT (mm)	Total (mm)		CLT (mm)	Total (mm)	
		Metal	T/S		Metal	T/S
< 5	140	451	531	160	471	551
5-7	160	471	551	180	491	571

06 Postface

- Image References
- References

Image references

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The interest for mass timber construction in general, and Cross Laminated Timber (CLT) in particular, has been intensified by the ever-looming threat of climate change. Urged on by a lack of standards and the slow-moving wheels of the Swedish building industry we decided to take matters into our own hands, an effort resulting in the publication you are holding in your hand and the digital tools it comes with.

We see an opportunity for the architects to bridge the current gap in knowledge and with the help of this publication influence their clients in making better, more informed and more sustainable choices.

Arkemi*

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