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How can we future-proof our built environment?

"By reducing the climate impact"

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How can we future-proof our built environment?

Abstract

Future-proofing our built environment means addressing a number of environmental issues. This article focuses on the construction and property sector's contribution and work to reduce climate impact, where the sector accounts for 21% of Sweden's total greenhouse gas emissions. In order to limit the temperature increase to 1.5°C and meet the Paris Agreement, Sweden adopted a climate policy framework in 2017 with a long-term goal that Sweden should have net zero emissions of greenhouse gases to the atmosphere by 2045.

However, the political framework and legal requirements are not keeping up and are not aligned with the net zero target. Many companies and organisations in the construction and property sector are ambitious and go beyond legal requirements through sustainability certification, sustainability auditing and by setting their own climate targets to reach net zero. However, for the sector to meet the national and global climate target of net zero, greater political will and clarity in legal requirements and regulations are needed to align with and achieve net zero greenhouse gas emissions by 2045.

1. Political goals to achieve the Paris Agreement

Future-proofing our built environment means tackling a number of environmental issues. This article focuses on the construction and property sector's contribution and efforts to reduce climate impact. Reducing greenhouse gases and limiting climate change is one of the most urgent and complex challenges of our time. The consequences of climate change are extensive and global, ranging from melting polar ice caps and rising sea levels to hurricanes and floods.

This requires determination and resolve to limit carbon emissions and limit the temperature increase to 1.5°C and meet the Paris Agreement. These changes also force our societies around the world to work in parallel to address new realities and implement climate adaptations.

In 2017, Sweden adopted a climate policy framework. The framework consists of a climate law, climate targets and a Climate Policy Council. The long-term goal is for Sweden to have no net emissions of greenhouse gases into the atmosphere by 2045, and to achieve negative emissions thereafter. The purpose of the framework is to create a clear and coherent climate policy to ensure long-term conditions for business and society to implement the transition required for Sweden to achieve its climate goals. The climate policy framework is a key component in Sweden's efforts to fulfil the Paris Agreement. (www.naturvardsverket.se)

The Climate Change Act entered into force in 2018. The act imposes a responsibility on current and future governments to pursue policies based on climate targets. The Climate Act states that every four years the Government must produce a climate policy action plan. The purpose of the action plan is to show how the Government's policies in all relevant expenditure areas together contribute to achieving the interim targets for 2030 and 2040 and the long-term emissions target for 2045. (www.naturvardsverket.se)

The long-term goal for Sweden is to have no net emissions of greenhouse gases to the atmosphere by 2045, and to achieve negative emissions thereafter. The target means that emissions of greenhouse gases from Swedish territory must be at least 85% lower by 2045 than emissions in 1990. The remaining emissions down to zero can be achieved through so-called supplementary measures. (www.naturvardsverket.se)

Sweden Green Building Council's (SGBC) members represent the construction and property sector. This sector accounts for a significant proportion of Sweden's total greenhouse gas emissions and has a major challenge in reducing greenhouse gas emissions to meet national targets.

SGBC's annual Novus study on Swedes' knowledge and attitudes about sustainability in the construction and property sector shows that Swedes' concern and disappointment with politicians' lack of commitment to sustainable construction is clear - a clear majority (59%) believe that our politicians are not taking their responsibility for the sector's transition. (www.sgbc.se)

At the same time, 52% are concerned that sustainability efforts are stalling due to the current security situation. Carbon dioxide emissions are ranked as the most important sustainability issue for Swedes. However, four in ten (44%) feel that there is not enough support for individuals and housing associations to take action to reduce the climate impact of their homes. (www.sgbc.se)

2. Climate impact from the built environment

In 2020, the construction and property sector accounted for domestic greenhouse gas emissions of approximately 9.8 million tonnes of carbon dioxide equivalent, corresponding to 21% of Sweden's total greenhouse gas emissions. The sector also contributes to large emissions abroad, around 6.1 million tonnes of carbon dioxide equivalent through imported goods. Total greenhouse gas emissions were 15.9 million tonnes of carbon dioxide equivalent. (www.boverket.se)

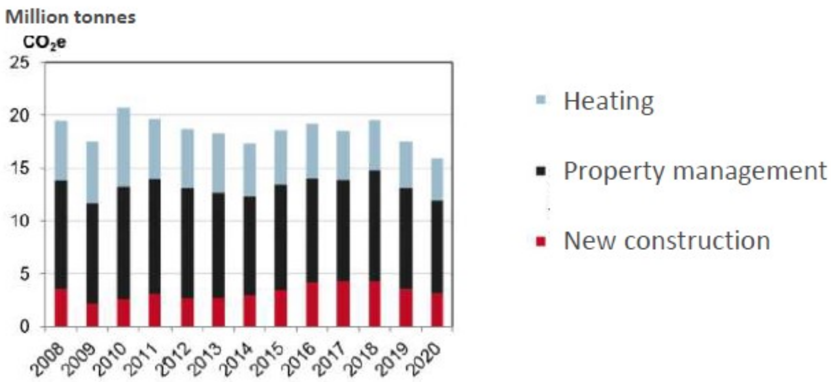

Figure 1: Total greenhouse gas emissions from the construction and property sector by sector (Source and illustration: Boverket/SCB).

Figure 1 shows greenhouse gas emissions by the sectors of new construction, property management (including renovation, extension and other property management) and heating (of buildings). Of the total emissions (domestic and imported) from the sector, new construction accounts for just under 20% in 2020, heating for 25% and property management (including renovation, extension and other property management) for the largest share of emissions at 55%. (www.boverket.se)

Statistics from Boverket (the Swedish National Board of Housing, Building and Planning) show that almost 60% of emissions from the sector come from domestic production. The statistics also show that the construction and property sector's domestic greenhouse gas emissions have decreased during the period 1993-2020. There has been a decrease in emissions from the heating of buildings, while emissions from construction and renovation have not changed significantly over time. (www.boverket.se)

3. How does the sector work to reduce emissions?

3.1. Legislation versus ambition in the sector

For the built environment, reducing climate impact has long been associated with reducing energy use and carbon dioxide emissions from energy use. Several incentives and requirements were introduced after the oil crisis in the 1970s to improve energy efficiency and reduce oil use. Sweden then introduced a carbon tax in 1991 as one of the first countries in the world. In 2006, legal requirements for energy declarations were introduced in Sweden for the construction and property sector. Statistics from Boverket (the Swedish National Board of Housing, Building and Planning) show that this has produced results and a clear reduction in greenhouse gas emissions from the heating of buildings.

Statistics from Boverket show that greenhouse gas emissions from construction and renovation have not changed significantly over time. In recent years there has been more focus on life cycle assessment and the carbon footprint of construction materials. The introduction of mandatory climate declarations was the next political step and was introduced as a legal requirement in 2022 for new construction. The purpose of the law is to reduce the climate impact of the construction phase. The new law means that the developer must report the climate impact that occurs during the construction phase in a climate declaration.

Today, the legal requirement, i.e. the mandatory climate declaration, means that built-in building components, but not all of them, must be reported in the climate declaration. There are no limit values or requirements for greenhouse gas emissions. The legal requirement may be seen as a first step and in 2025, limit values for greenhouse gas emissions will probably be introduced in the climate declaration to more clearly steer towards a lower climate impact for the construction and property sector. However, the legal requirements are far from sufficient to achieve the net zero target by 2045.

Many property owners and companies in the sector are ambitious and want to go beyond legal requirements. More companies than the law requires produce a sustainability report and set their own emissions targets for their operations, often with a long-term goal of achieving net zero emissions. Companies often report carbon dioxide emissions from the entire life cycle of the building and thus go much further than the climate declaration.

To assist in sustainability reporting and target setting, many companies use the Science-based Targets initiative (SBTi) and the Greenhouse Gas Protocol (GHG Protocol) frameworks. The GHG Protocol provides a standardised method for calculating and reporting greenhouse gas emissions and covers a range of activities. This allows companies to get a complete picture of their climate impact. SBTi helps companies to define science-based climate targets that are in line with the objectives of the Paris Agreement.

3.2. Sustainability certifications and climate neutral initiatives

The Sweden Green Building Council (SGBC) is Sweden's largest and leading sustainability organisation in the built environment. SGBC works to influence decision-makers, raise the level of expertise and create favourable conditions for the climate work of the building industry.

SGBC offers several environmental and sustainability certifications for both new and existing buildings. Our certification systems are important tools for working with environmental issues in a concrete way. In all of the certification systems, the building's climate footprint is a significant part of the certification. All certification systems set requirements and reward low energy use. In recent years, certification systems have been supplemented with criteria and requirements for the building's climate impact over its entire life cycle.

SGBC's most advanced certification system is called NollCO2 and focuses on low climate impact. The NollCO2 certification system has been developed to drive the work towards net zero climate impact of the built environment sector by 2045. To certify a building as NollCO2 is to align with the nationally set climate targets.

NollCO2 has two main tracks to achieve net zero carbon balance. On the one hand, NollCO2 sets requirements and limit values to significantly reduce greenhouse gas emissions for the manufacture of building components and construction processes, and on the other hand, requirements are set to reduce the building's energy use. NollCO2 then sets requirements for balancing the remaining climate impact through climate measures to net zero climate impact over the entire lifetime of the building.

For projects to achieve NollCO2 certification with its limit values on greenhouse gas emissions, a determined effort is required. The projects review system selection, quantities and material selection to find systems and materials with as low a climate impact as possible.

The area where the greatest shifts are now taking place to reduce the carbon footprint is the production phase. The climate impact from the construction phase comes primarily from the manufacture of building materials, mainly from concrete and steel. Here, a further shift can take place when it comes to design, materials and collaboration to find new solutions.

We can already see a shift in material choices towards more wood, less steel and green concrete. By requiring environmental product declarations (EPDs) that present the carbon footprint of products, competition is created that rewards products and material choices with lower carbon footprints. The construction sector is also moving more towards circular flows through more efficient use of resources, increased reuse and recycling of materials.

Since legislation has not been sufficiently aggressive to meet the nationally set targets, many actors in the sector have used NollCO2 as a tool and framework to align with the 2045 emission targets. A number of local initiatives and networks have also been launched, such as LFM30 and Klimatarena Stockholm, which work towards a climate-neutral building and construction sector. These initiatives and certifications together fulfil an important function in moving the sector forward.

NollCO2 wants to steer towards as low a climate impact as possible and significantly reduce greenhouse gas emissions from the manufacture of building components and construction processes. However, today we cannot build with zero climate impact and therefore NollCO2 and several of the other initiatives have climate measures to balance the climate impact to net zero. The climate measures authorised by NollCO2 include both long-term carbon sinks and avoided emissions. There is a discussion in the sector about which climate measures should be allowed, but to reach net zero, climate measures in some form must be included.

3.3. What is required for the sector to reach net zero by 2045?

The sector needs to reduce its climate impact from construction and property management in line with national emission targets. This requires the following:

- Policy makers must demonstrate the drive and commitment to meet national emission targets to net zero.
- The sector needs long-term and predictable regulations and legal requirements that are in line with the national emission targets.
- Long-term policy instruments that contribute to the sector's transition.
- The entire sector needs to become even more proactive and cooperate across the entire chain to accelerate the transition.
- The sector needs business models that favour reuse and make it less profitable to use new materials and materials associated with high greenhouse gas emissions.
- Requirements for climate declarations for buildings for the entire life cycle perspective and limit values.
- Requirement for construction products to report their climate impact with EPDs.
- Incentives that promote energy efficiency and resource-efficient renovation of the existing property portfolio, justified from an LCA perspective.
- All organisations and companies in the sector should report on sustainability and set their own climate targets.
- Better conditions to foster innovation, such as for materials in buildings and for climate measures such as long-term carbon sinks.
- Climate measures and long-term carbon sinks are essential to meet net zero climate targets. This requires political guidance that enables a faster creation of a functioning market for long-term carbon sinks such as bio-CCS and biochar.

3.4. How to adapt the built environment to climate change?

In parallel with the work to reduce climate impact, the built environment must be climate adapted.

Many SGBC members are working hard to adapt both new and existing buildings to climate change. We know that there is research, tools and expertise to take the necessary action, but we also see that developments are moving faster in other parts of the world. In Sweden, there is a lack of action from decision-makers. If the recent torrential rain has taught us anything, it is that adaptation must take place now. It is the highest priority in the EU and should also be in Sweden. Our cities need to become more resilient and sustainable. To enable this, better incentives are needed to future-proof all new construction and especially existing buildings. (www.dagenssamhalle.se)

Tomorrow's climate requires buildings to be more resilient to change, which needs to be incorporated into the detailed planning and design of projects today. A new climate adaptation strategy is expected in 2023, but progress is too slow. If we are to succeed in future-proofing our buildings, we need clearer incentives, higher requirements and greater political will. (www.dagenssamhalle.se)

4. Summary

The construction and property sector accounts for 21% of Sweden's total greenhouse gas emissions. The sector also contributes to large emissions abroad through imported goods. The sector is working to reduce its greenhouse gas emissions and many companies are reporting on sustainability, obtaining sustainability certification and setting long-term goals to become climate neutral. But the legal requirements for steering towards reduced greenhouse gas emissions do not align with the emission reduction required to achieve the net zero target. This means that the sector will have difficulty reaching net zero emissions by 2045.

The following is needed to future-proof the built environment from a climate perspective, with a focus on reduced climate impact but also parallel work on climate adaptation:

- Policy makers must demonstrate the drive and commitment to meet national emission targets to net zero.
- The sector needs long-term and predictable regulations and legal requirements that are in line with the national emission targets.
- The sector needs business models that favour reuse and make it less profitable to use new materials and materials associated with high greenhouse gas emissions.
- Long-term policy instruments that contribute to the sector's transition.
- The entire sector needs to become even more proactive and cooperate across the entire chain to accelerate the transition.
- All organisations and companies in the sector should report on sustainability and set their own climate targets.
- Better conditions to foster innovation, such as for materials in buildings and for climate measures such as long-term carbon sinks.
- Climate measures and long-term carbon sinks are essential to meet net zero climate targets. This requires political guidance that enables a faster creation of a functioning market for long-term carbon sinks such as bio-CCS and biochar.
- Clear incentives, higher requirements and political will for faster climate adaptation.

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From national programs to European collaboration –case: from Finland to European Wood Policy Platform

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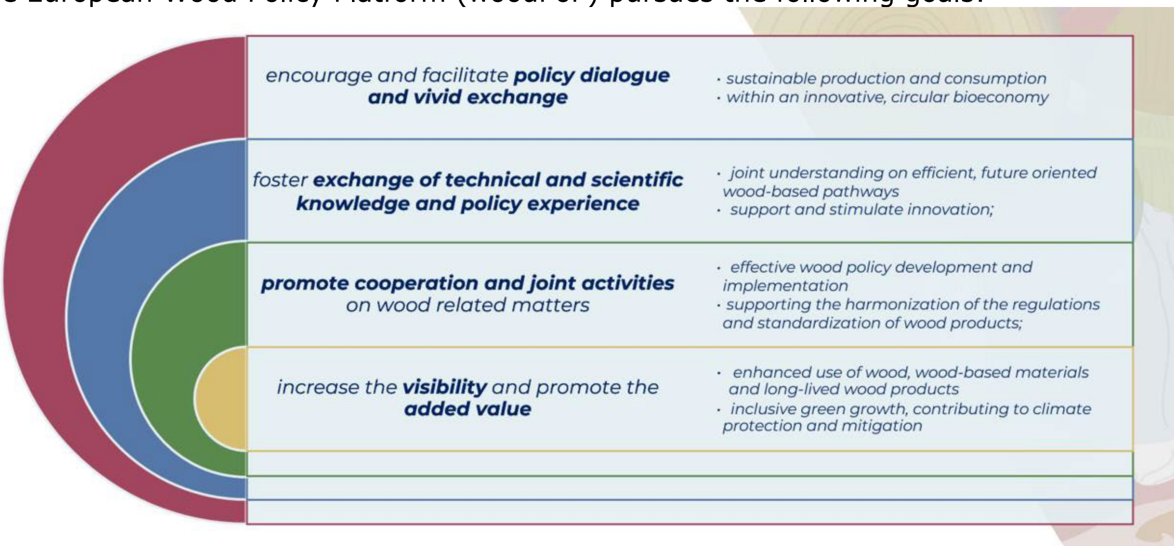
The European Wood Policy Platform (woodPoP)

Abstract

In the context of combating climate change, a growing number of countries, regions, cities and communities in Europe, as well as in other parts of the world, aim to enhance the sustainable use of wood and other renewable materials by fostering a forest-based bioeconomy. The renewable resource wood and other wood-based materials play a vital role in enabling the transformation towards a carbon neutral circular economy and climate positive society.

Against this background, The 'European Wood Policy Platform' (woodPoP) has been initiated by Finland and Austria. Both countries have a long tradition in using wood as a construction material as well as wood-related policy development. Both countries have joined forces to upscale wood related activities at the European and global level.
woodPoP provides a dedicated forum for multilateral policy, knowledge and experience exchange between public and private actors from the wood sector at national and regional level to share best practices and opportunities of coordinated approaches in developing policy solutions to enhance the sustainable production and consumption of wood and its contribution to an innovative, circular bioeconomy.

The European Wood Policy Platform (woodPoP) pursues the following goals:



Participants of the platform:
- Government officials and representatives from the Pan-European region working with wood policy and wood-related matters;
- Representatives of wood-related international, regional, stakeholder and research organisations;
- Experts in the respective field and technical subject matters;
- Interested participants, including from other regions, can join as observers upon expression of interest.

Co-Chairs of the platform
Mr. Georg Rappold, Head of Division Wood-based Value Chain, Ministry of Agriculture, Forestry, Regions and Water Management of Austria and
Mr. Petri Heino, Director of the Wood Building Programme, Department of the Built Environment at the Ministry of Environment of Finland
Meeting formats

The High Level Meeting (HLM) is the main decision-making body, attended by delegations from Pan-European ministries led by high-level government officials (for instance Ministers, Secretaries of State, Director Generals, Directors) with the participation of regional and stakeholder organisations, as well as observers.

The Expert Group Meeting (EGM) serves as main forum for exchange on an operational level, with the participation of national and regional ministries and private sector, representatives from stakeholder, research, as well as regional organizations and networks.
Technical Working Groups (TWG) provide thematic fora in order to discuss specific subject matters in view of identifying issues of joint interest and developing recommendations and policy solutions. Participation is open to representatives from public and private sector, interest groups, research organizations and networks, government officials and invited experts.

Overview on the Technical Working Groups:

How to join woodPoP
Everybody interested in the European Wood Policy Platform (woodPoP) is warmly welcome to participate! Depending on your field of profession and expertise there are many opportunities to get actively involved. Please contact us via holz@bml.gv.at to find out was is your best fit. You can also join our LinkedIn-Page if you are generally interested in the woodPoP activities.

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https://ym.fi/en/wood-building

Austria:
The Austrian Forest Fund:
https://www.waldfonds.at/
The Austrian Wood Initiative
https://info.bml.gv.at/en/

Reuse of Wood – the Nordic Model

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Reuse of Wood – the Nordic Model

Abstract

The Nordic countries are spearheading sustainable solutions in various sectors that can contribute to a circular built environment, including the innovative reuse of wood in construction and design. A holistic investigation for establishing a circular built environment implies not only investigating technical aspects, but also other aspects such as context (e.g. logistics, stakeholders). This comprehensive look at finished and ongoing research and innovation projects by consortia or single stakeholders in the Nordics delves into its current landscape, prospects, and the intricate web of stakeholders involved, from key industry players to government bodies. This article '*fingerjoints*' insights from a literature review with the authors' experiences in Omtre AS to illuminate what the Nordic Model of the Reuse of Wood entails.

1. A Deep Dive into Sustainability and Innovation

In our rapidly changing world, where the climate crisis looms ever larger, Nordic countries—Denmark, Finland, Iceland, Norway, and Sweden—are at the forefront of developing and implementing sustainable solutions contributing to a circular built environment. A holistic investigation for establishing a circular built environment implies not only investigating technical aspects, but also other aspects such as context (e.g. logistics, stakeholders) (Pomponi & Moncaster 2017).

This article wants to illuminate the emerging Nordic model for reusing wood, a practice that combines tradition, modern technology, and holistic sustainability, but also faces challenges related to the geography and climate conditions. This comprehensive article unpacks the intricacies of this model, touching upon current developments, prospects, key projects, stakeholders, and some challenges.

Reuse of wood implies preparing for reuse (reusing the intact solid element or resizing) (Ramage et al. 2017). This is different than recycling which refers to reuse of the matter (Ramage et al. 2017) However, in this article reuse can also refer to recycling wood waste, with the use of digital technologies, to make it ready or in the right dimension for timber construction product manufacturing, especially in the context of industrial scale/transformation (See section 3).

The approach of the Nordic countries to wood reuse in construction is deeply rooted in tradition. Long before the industrial revolutions and modern sustainability movements, Nordic societies have well-established practices for reusing timber, a tradition that is likely shared by regions such as the Baltics, Russia, China, and others. The prevalence of log houses, for example, extends far beyond just the Nordic countries, suggesting a wider regional adoption of these sustainable building methods. These traditions are still visible in iconic structures like stave churches, cultural museums, and UNESCO World Heritage sites like Røros. These architectural gems are not merely relics of the past but living testaments to the timeless virtues of resourcefulness and sustainability. They showcase early techniques of reclaiming and repurposing wood, hinting at a circular economy long before the term was coined (Nordby 2009).

Today, the same spirit of sustainability is given new life through modern technology and innovative practices. Within this context, scenarios involving low-tech, high-tech, and high-efficiency methods come into play, each providing different solutions tailored to modern demands while respecting the wood resource's intrinsic value. Digital solutions might provide leverage points for a circularity transition of construction sectors and the built environment (Çetin et al. 2021). Advanced machinery, digital platforms, and state-of-the-art research are all leveraged to revitalize this ancient practice, forming emerging resawmill initiatives, facilities enabling the reuse (and recycling) of construction timber (Asa et al. *submitted*).

2. The Context: What's Already in Place

Wood is more than just a material in the Nordic design and architectural landscape—it's a legacy. However, the aim for sustainability presents an interesting paradox. While several projects are designed with the future reuse of wood in mind (Cristescu et al. 2020), it remains uncertain whether these easy-to-disassemble wooden structures will be repurposed half a century from now.

That said, society has an untapped reserve of unused timber that can be reclaimed. This can be achieved either through repurposing existing wooden buildings or deconstructing them to relocate the timber for other uses (Ghobadi & Sepasgozar 2023).

In the Nordic countries, several projects have either been concluded or are currently underway to promote the reuse of wood. Among these initiatives are 'InFutureWood', a finished 'ForestValue funded project, which searched answers for "How easy is it to reuse wood from current buildings especially as structural material?" (InFutureWood 2023). Another noteworthy project is the 'ReWood project' of the biggest building material trader in the Nordics, that is interested in circular business models like renting building components or modules and reselling secondary wood materials (STARK 2023).

Additionally, there are Norwegian Green Platform projects, like the industry-driven project 'SirkTRE' (SirkTRE 2023) and its sister academic research-focused project 'CircWood' (CircWood 2023) which also aim to advance wood recycling and reuse in the Norwegian timber construction by investigating future reuse, optimizing manufacturing processes to reduce waste in the process and reclamation and reintegration of wood waste in new building or renovation projects. These projects consist mostly of demonstration projects, which use a mix of low-tech and high-tech methods for quality assurance (Wuyts et al. 2023b), but with a lot of potential to scale up.

The new Horizon Europe project 'WoodCircles' has initiated the 'Urban sawmill - wood circles' project, led by DTI (WoodCircles 2023). Besides architectural challenges they want to start prototypes of factories in cities that process wood waste in high-value product. The pilots will be in Estonia, Italy and the Netherlands. However, in the Nordics pilot prototypes of urban sawmills or resawmills are established. In Norway, Omtre is collaborating with partners Viken Skog and Ragn-Sells to develop a resawmill in more rural Nordic areas (Asa et al. *submitted*). Figure 1 explains how a resawmill is addressing a current gap in the value chain to close the loop and initiate the emergence of value cycles.

Another Norwegian project, '1-2-Tre-Steg,' operating under the Norwegian University of Science and Technology and in partnership with Hunton, is researching reverse logistics and other circular business models to facilitate wood reuse (1-2-Tre-Steg 2023). Vyrk, in Norway, is also working on sustainable panels with circular business models, namely a take-back model (Vyrk 2023). These are just a few of the initiatives by companies and projects in the Nordics that might disrupt the timber construction sector in the next years.

2.1. Environmental and Social Dividends

The timber industries can benefit of reusing wood in multiple ways. In addition to environmental benefits of the use of virgin woods, such as carbon storage (Churkina et al. 2020), more environmental benefits can be created by keeping the carbon even longer in society before it is burned for energy recovery. These environmental dividends can be useful when regulations and requirements are changing and taking the lead of Denmark with this new building code introducing a threshold value of 12 kg CO_2e/m2/yr for all new buildings larger than 1000 m^2 which got effective recently (Andersen 2023). The supply of wood, as one of the most promising materials for climate neutral strategies, needs to follow building trends: the building industry delivers new built areas on the size of Paris every week. In addition, the world knows various ecological crises and tipping points, with higher frequencies of drought, fires, beetles, that threaten to reduce the quality and volume of fresh timber. To reduce the climate and other negative impact of (clear-cut) felling trees for new construction materials, a new supply of high-quality products with reclaimed wood can bring more stability in the fluctuating wood market and mitigate and avoid environmental negative impacts. Social benefits are also plentiful, with community engagement lying at the core of various initiatives like the ReWood project of the Stark Group where the social economy is reactivated. In other countries as in Belgium, we see low-tech timber reuse hubs where people with distance to the labour market also find a (repetitive) task, a role and new meaning (Insights from interviews, unpublished yet). These initiatives foster communal interaction, knowledge sharing, and cultivate a collective sense of responsibility toward resource conservation.

2.2. The Logistics Puzzle

Transporting wood for reuse comes with its own set of challenges, especially in the vast, sparsely populated landscapes of Nordic countries with climatic challenges. Nordic countries like Sweden and Norway have vast geographical areas with sparse populations. The Nordic model means circular solutions for rural neighborhoods too (Wuyts & Majidi 2022). This makes the distribution of building materials more challenging. Due to sparse populations and lower demand, achieving economies of scale in logistics can be more challenging.

Many locations in Nordic countries are remote and difficult to access, requiring specialized logistics solutions. Countries like Finland have numerous islands, which complicate logistics further. Transport by boat or ferry can be slower and more expensive. Norway and parts of Sweden have mountainous terrains that are difficult to navigate, requiring specialized vehicles and infrastructure (Wuyts & Majidi 2022). Heavy snowfall and icy conditions can make roads impassable or dangerous. This delays transportation and can result in higher costs. Due to the severe winters, the building season is often shorter, which means materials need to be sourced and used within a constrained timeframe. Remote areas may lack well-maintained roads or harbors, complicating the logistics.

All these challenges contribute to higher logistics costs, which can make construction more expensive in Nordic countries. Innovative solutions like digitization, optimizing supply chain management, and advanced planning are often necessary to overcome these challenges. Perhaps we can learn from logistics in spacecraft, which also deal with similar conditions, how to reduce the logistic costs for a Nordic model for reuse of wood.

2.3. Who's Who: Stakeholders in the transition

The successful transition to sustainable wood reuse hinges on the cooperative efforts of multiple players across the forestry and timber construction value chain. Prominent stakeholders driving this initiative include waste management firms like Ragn-Sells, as well as building material traders such as Optimera and Stark Group. These traders are particularly essential, because they have pre-existing systems and user networks for building materials (Kummen et al. 2023; Litleskare & Wuyts 2023). Some even engage in partnerships with social circular economy initiatives, like the STARK group.

In Norway, collaborators under the SirkTRE 2023 project are forging strategic alliances with governmental bodies and standardization authorities like Standard Norge. This collaboration aims to facilitate the industrial-scale implementation of wood reuse practices. National, regional and local governmental bodies are implementing projects to support the (smart) circular transition.

However, the transition has also highlighted gaps in the value chain, especially in roles like urban mining, wood waste sourcing, sorting, reprocessing, and reclassification for mainstream production. Omtre, along with its partners, is actively addressing these lacunae in the Nordic countries (Fig. 1). Research institutes are contributing to this effort by developing guidelines and assessment tools for both technical and environmental evaluations.

Digital solution providers are emerging as another significant component. They are continually innovating and refining digital tools like material passports and platforms (e.g. Wuyts et al. 2023a), with examples in Norway including Loopfront, Madaster, Tvin Solutions, Materia, and Rehub. However, there are still many barriers regarding data management, governance and cost benefit allocation (Bellini & Bang 2022, Litleskare & Wuyts 2023). Finally, an evolving trend, already established in countries like the Netherlands and Belgium, involves demolition companies like Resirquel diversifying their services. They're investing in storage spaces and offering them as a service, thus filling another crucial gap in the circular economy for wood (Findings from interviews, unpublished yet).

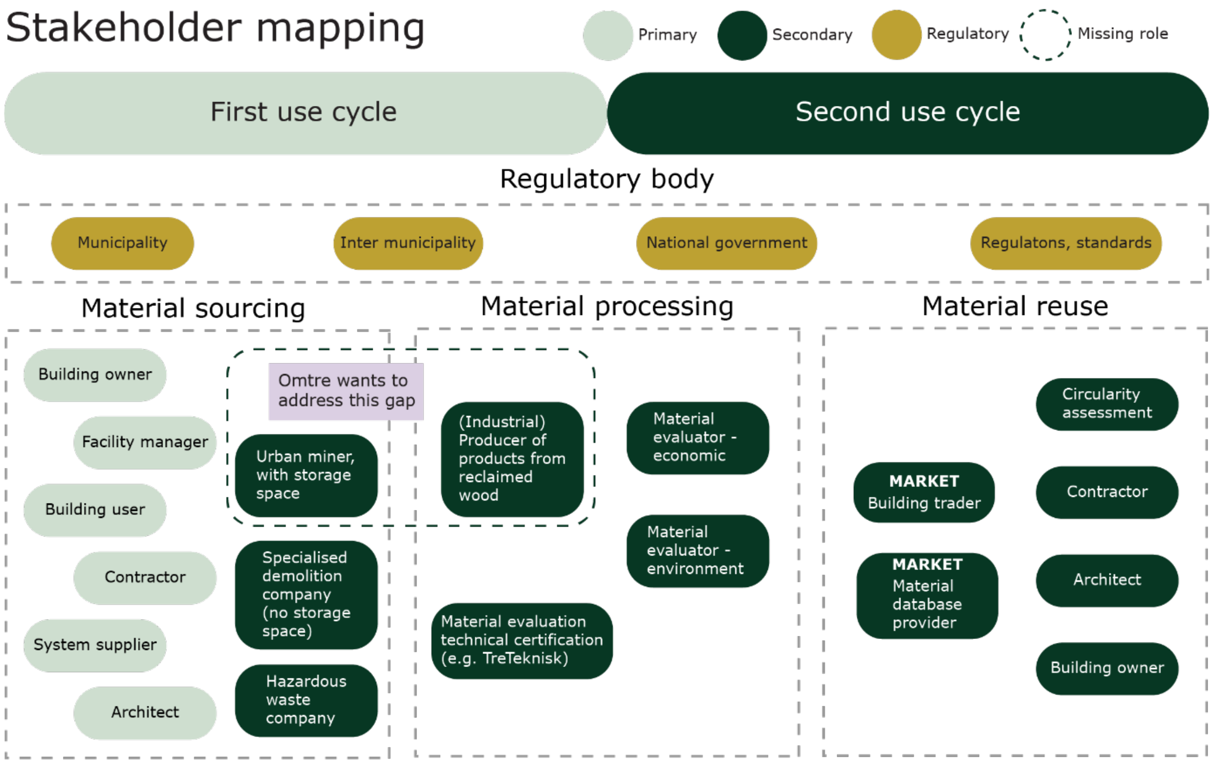

Fig. 1: Stakeholder mapping of the Nordic wooden value cycles.

2.4. "Different language" and need for dictionaries

One of the main challenges in sustainability traditions and co-creation are the use of "different language" or jargon to express the same but in different ways. For example, the waste management industry measures wood waste or reclaimed wood in tonnes. However, the market uses cubic meters. Omtre, which takes this role of missing link in processing wood waste into industry-ready products, is often in this role of translation or bridging this. However, there are no clear guidelines which player should take this role or for translations or some sort of dictionaries needed to navigate in the world of reuse.

2.5. Regulations: The Norwegian Case

Norway offers instructive example when it comes to regulations governing wood reuse. For example, sections 9-6, 9-7, 9-8, and 9-9 of the country's technical building regulations focus on sourcing. For instance, the updated Norwegian version of Section 9-8 now requires

a waste separation rate of 70% (TEK17 2023). These rules are part of a broader legislative framework that also mandates planning for the reuse and recycling of materials in new construction projects. Although the buildings constructed today might be seen as tomorrow's raw materials, these regulations ensure a sprout on the needed framework for their future repurposing. Another example can be found in requirements for projects. Although there are initiatives with requirements for reclaimed material, they are expressed in weight, which leads to choices for more high-weighted materials instead for reclaimed wood.
Another important nuance to consider is that while our building regulations mandate the mapping of potential reuse, there is currently no standardized template or methodology for this. Initiatives such as the DIPLOM project in Trøndelag are actively working to address this gap by developing templates for mapping reuse (Trøndelag 2023).

3. The Industrial Transformation in Reuse (and Recycling)

The industry is on the way of a transformative change, one that aims for the large-scale, industrialized reuse of wood. This significant paradigm shift is often dubbed the resawmill initiative. Spearheaded by Omtre, the initiative engages in extensive research and development, partnering with leading European researchers. Their collective efforts focus on adapting reclaimed wood for integration into traditional production lines, particularly for engineered wood materials like glulam, CLT, and LVL. To navigate the complexities of this transition, Omtre and its partners are examining three distinct scenarios in a forthcoming position paper (Asa et al. *submitted*): low-tech, high-tech, and high-productivity.

These scenarios help to isolate key factors that could shape the future of wood reuse, such as the heterogeneity of reclaimed materials, the balance between automation and human resources, the diversity of end-products, and the assurance of quality.
In the low-tech scenario, the focus is on manual or semi-automated processes. This approach works well when dealing with a high degree of material heterogeneity, as humans can adapt quickly to varying wood types and conditions. The role of skilled artisans and craftsmen is prominent here, facilitating quality assurance through hands-on interaction with the materials. However, this model may limit the variety of end-products due to the time and labor-intensive nature of manual operations (Asa et al. *submitted*).

Other scenario envisions a highly automated environment that minimizes human intervention. Advanced technologies, including robotics and machine learning algorithms, take over the tasks of sorting, reprocessing, and reclassifying wood (e.g. Tomczak et al. 2023). Digital solutions like Loopfront, Madaster, Tvin Solutions, Materia, and Rehub play crucial roles in managing information and traceability of the reclaimed wood. The high-tech route can handle a broader variety of end-products but may struggle with the heterogeneity of reclaimed materials without significant investments in adaptable technology. In an upcoming paper, we will elaborate more upon this (Asa et al, *submitted*).

Each scenario comes with its own challenges and opportunities, but they all share a foundational reliance on digitalization to mitigate the uncertainties typically associated with using reclaimed materials. The potential of digital tools in tracing the lifecycle of products, ensuring quality, and optimizing logistics cannot be overstated.
Omtre and its partners are not only pioneering research but are also actively engaging with regulatory bodies and standardization authorities. They are working together to develop frameworks that can accommodate these different approaches while ensuring sustainable and efficient wood reuse. Regulations, like Norway's updated waste separation requirements and planning protocols for reuse, can serve as an inspiring model for what governance in this emerging sector might look like.

The ongoing efforts in research, technology, and governance all point toward an imminent industrial revolution in wood reuse - a revolution that promises not just environmental sustainability but also an innovative and robust economic model for the timber industry.

4. Critical Takeaways of the Nordic model

1. **Industry Disruption**: Nordic timber construction and the waste handling sectors are undergoing a paradigm shift.
2. **Standardization**: Norway is leading the charge, laying the groundwork for European-wide reuse standards.
3. **Smart Logistics**: Smart logistics will be key factor for making the economics of wood reuse work in not so densely populated areas as pioneering countries like Japan, the Netherlands and Belgium.
4. **Digitalization**: The Nordic technological process is crucial for scaling up the industry.
5. **Market Trends**: Building traders are increasingly recognizing the potential for large-scale buying of reclaimed wood, facilitated by proper documentation and verification.
6. **Regulatory changes**: European and national regulations will disrupt the way we build and handle end-of-life of construction.

5. Looking Ahead

As regulations continue to shape sourcing and building practices, companies can future-proof against risks due to climate change by opting for reclaimed timber. This opens up avenues for a dual supply chain, reducing the industry's vulnerability to volatile factors.

As the Nordic model of wood reuse continues to evolve, it offers invaluable lessons for merging environmental stewardship with industrial ingenuity, balancing technological advancements with timeless traditions and localized wisdom.

The Nordic model for reusing wood is an intricate blend of heritage, technology, and governance aimed at mitigating the pressing issues of climate change and resource depletion. With projects like SirkTRE and collaborations with research institutions across Europe, the model is rapidly evolving. By revisiting the ancient wisdom encapsulated in traditional structures and applying modern scientific and technological advancements, the Nordic countries are carving a path that promises a sustainable and innovative future.

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New innovations elevating wood

Saki Boukas
Head of Emerging Businesses
Stora Enso

New innovations elevating wood

Innovation plays a key role in Stora Enso's work to respond to customer and end-consumer demand for a more sustainable future, with solutions that reduce carbon footprint, promote circularity and enhance biodiversity.
In the face of ever-increasing global challenges, businesses, governments, institutions and society are reevaluating how resources are used, how communities and cities are built and maintained, how businesses operate, and how goods are produced and transported. Our sustainability framework provides a long-term direction that steers our innovation efforts – we want to contribute proactively to solving customer and stakeholder issues and deliver value, looking at how positive sustainability impacts can be accelerated.

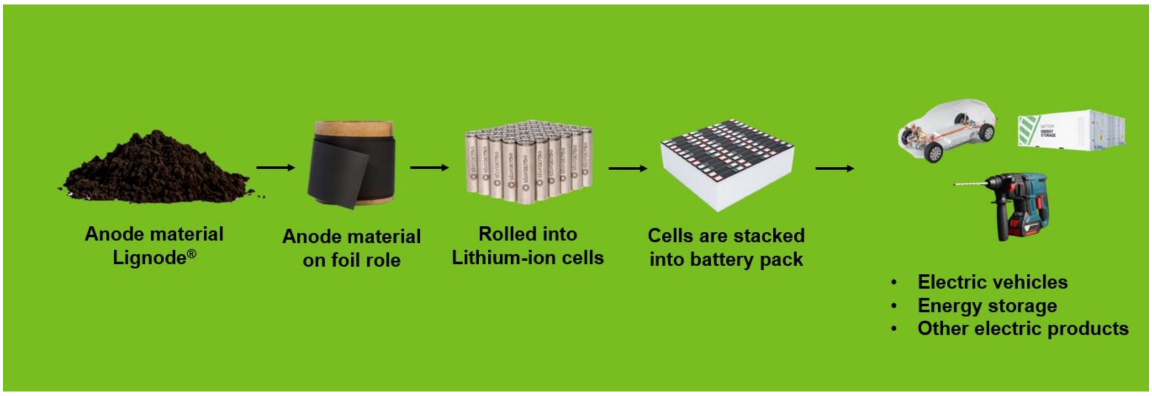
Why? Our planet is no longer able to cope with the way we are living.

July 28 this year (2023) was the date when humanity had used all the biological resources that Earth regenerates during the entire year, this means that we would need almost two planets to sustain our current lifestyle - and even more than two if we only look at the way developed nations are living.
This is happening because we still haven't found a way to live the lives we want to live, while preserving the environment and not run out of finite resources. The next coming years are crucial, they must see the most profound transformation the world has ever known.

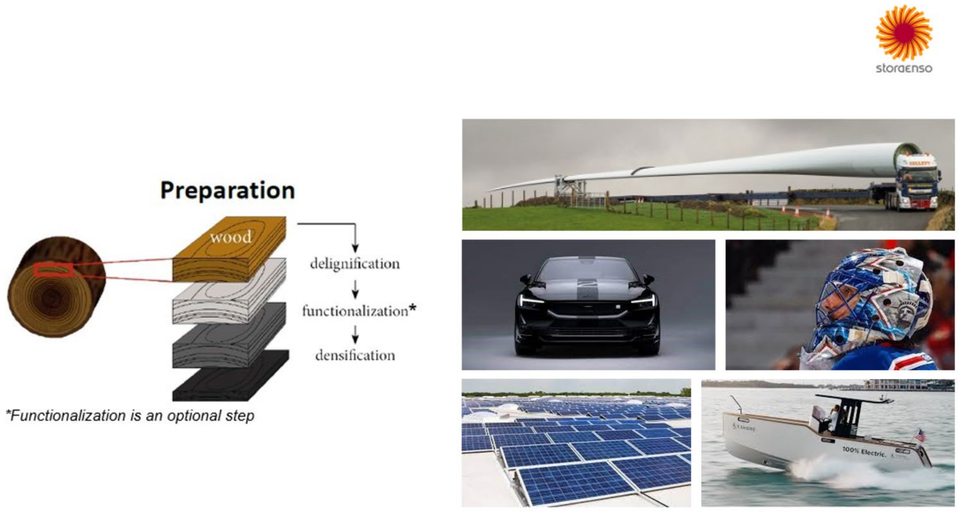
Through innovation, research and collaboration, Stora Enso focuses on developing new and existing products as well as improving processes and supply chain efficiency and resilience. This we have done for more than 700 years, and the forest has been the heart and foundation of our business. This presentation will touch upon some of the exciting innovations being developed within our industry that we believe will keep us in business for a further 700 years!
Our products substitute materials from finite, fossil-based sources with products and solutions that are renewable, recyclable and store carbon, helping our customers and the world at large to reduce their CO_2 emissions. We want to raise the stakes and proactively help solve global challenges by accelerating positive sustainability impacts through our regenerative product and solution.

Making batteries from trees

Today's batteries rely heavily on non-renewable or fossil-based materials. This is where Lignode ® by Stora Enso comes in: It can replace non-renewable materials in batteries, such as graphite mainly sourced in China, with lignin-based hard carbon for anode materials produced close to European customers.
This enables sustainable electrification and mitigates the impact of climate change. In 2022, Stora Enso and Northvolt, battery cells and systems supplier, joined forces to create sustainable batteries for applications from mobility to stationary energy storage, using Lignode®.



Lignin is one of the main building blocks of a tree
It acts as the glue holding the tree together. In pulp mills it has mostly been burned for energy. But now there are new ways of making use for lignin to replace fossil materials. For instance replacing phenols for adhesives and to make carbon fibres as well as fuels and bioplastics. We are just at the beginning of the development and the future looks promising.
We will tell you how wood can replace components in asphalt, cars, sport equipment, boards and solar panels.



Growth opportunities through laminated wood in wind turbine towers

With the current energy crisis and ambitious decarbonisation goals, demand for wind energy is growing. Some hundred meters up in the air the wind is constant. We teamed up with partners to create 100+ meter tall wooden wind turbine towers to reduce the carbon footprint of steel and concrete based towers. We are also partnering to develop wood-based sustainable wind turbine blades.

Building on collaboration

Innovation cannot happen in isolation. Stora Enso welcomes partnership and collaboration as we work across the value chain with customers, suppliers, research and academic institutions and start-ups.

In all our businesses and markets, we work closely with customers to understand their strategies and devise solutions to support a competitive advantage and meet sustainability targets. Our work is underpinned by our expertise in wood and fiber-based renewable materials, industrial processes, supply chain operations, service concepts and importantly sustainable forestry.

Through know-how, strategic collaborations and partnerships, we are working to accelerate breakthrough innovations.

Partnerships to accelerate innovation and reach new customers

Northvolt
European supplier of sustainable, high-quality battery cells and systems

Developing wood-based batteries for applications from mobility to stationary energy storage.

Beyonder
Norwegian energy storage technology company

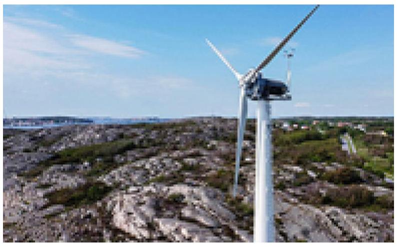
Optimising properties and commercial deliveries of lignin-based anode material for batteries

Modvion
Swedish wind turbine tower builder

Creating 100+ meter tall wooden wind turbine towers

Voodin Blade Technology
German developer of rotor blades for wind turbines

Developing sustainable wind turbine blades from wood



Growth opportunities through laminated wood in wind turbine towers

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The journey towards the world's lowest EPD for CLT

Urban, Blomster
Södra
Växjö, Sweden

The journey towards the world's lowest EPD for CLT

To be able to explain how Södra can reach such a low value in climate impact for cross-laminated timber (CLT), we need to start by describing our beliefs, strategic way of thinking and our product chain - from the family forestry to the finished product.
Södra was founded in 1938 as a member-owned cooperative and has since worked with making the most of the family forestry. New businesses, products, technologies, innovations, and people have come and gone over the years. Forestry and processing of the raw material have been the core of Södra's operations since the beginning and is still today. Södra has a value chain that includes the production of paper pulp, textile pulp, wood products, biofuels, pine oil, electricity, and district heating.

1. The forest and its growth

The timber supply in Sweden, above all the forests of Södra's members, has increased steadily since the first national forest assessment in the 1920s. This is largely thanks to, among other things, increased knowledge about forest management and improved plants that make the forest grow better.

Approximately 70 per cent of the land area in Sweden is forest. The forest area is relatively constant. But Sweden's forests have become twice as rich in timber in 100 years. This is what we mean when we say that we have twice as much forest now as 100 years ago.

The average growth in the forest is 120 million forest cubic meters per year. At the same time, approximately 90 million cubic meters of forest are felled per year. Of Sweden's total forest area, this corresponds to approximately one per cent. For every tree that is harvested in a final felling by Södra, 2–3 new trees are planted.

2. Södra's family forestry

Today's forests are a result of previous generations' management. As mentioned earlier Södra is a member-owned cooperative and has around 52,000 members. Södra most often has a generational ownership, which goes up to 8-9 generations that have engaged in active forestry. It provides the opportunity for long-term and responsible thinking, and acting, when it comes to forestry. Södra's forestry is conducted responsibly and with methods with the forest's biological diversity and ecosystem services in mind. We use the resources we have but makes sure to not overuse them. It is a forestry that considers production, economy, cultural and social values. Through voluntary deposits and conservation management, biological diversity is preserved and strengthened. With environmental considerations in all forestry measures, we work to strengthen biological diversity even in the cultivated landscape.

A medium-sized forest property for a member of Södra is just over 50 hectares. Södra´s family forestry has different objectives for the properties and with a desire to conduct forestry in different ways. Clear cutting is the dominant form of forestry in Götaland. The average felling is 2.3 hectares, and only 15 percent of the felling are larger than four hectares, which is the equivalent of 6 football pitches. Just over 64 percent of Södra's total forest area is certified according to both PEFC and FSC.

Among the members there are those who also practice continuous cover forestry, but it is more difficult and the research that exists shows that the production levels are lower. It is also associated with greater challenges and risks. But the continuous cover forestry may also increase in the future, and we are following the research.

3. Södra's value chain and the benefits with wooden houses

Södra has a value chain that includes the production of paper pulp, textile pulp, wood products, biofuels, pine oil, electricity, and district heating. The production of the various products takes place in symbiosis, which gives us the opportunity to use and take advantage of the entire tree.

It takes around 6,000 cubic meters solid to produce 2,000 cubic meters of sawn timber. It is enough for an eight-storey building with 64 apartments for 130 residents.

Thanks to our symbiosis at our production sites, and the ability to use all parts of the tree. We can create products with different purposes and uses. Some of the products we produce falls under the category "short-lived". But if the short-lived products, such as pellets, are used to replace a fossil material a more climate friendly effect occurs.

The production of sawn timber takes place in sawmills at our production sites. Cellulose chips are delivered to the pulp mills and solid biofuels are delivered to cogeneration plants to produce electricity and district heating.

The pulp mills use pulpwood and cellulose chips as raw materials. Products from the pulp mills are paper pulp to produce paper products, textile pulp to produce textile fibre, solid biofuels to produce electricity and district heating in cogeneration plants, pine oil to produce biofuels and electricity and district heating.

So, what happens when we build a wooden house and take care of all the raw materials from our production?

The total production corresponds to:

- 540 tons of paper pulp - enough for 25 years of paper consumption for the residents.
- 130 tons of textile pulp - enough for 30 years of textiles consumption for the residents.
- 1.5 GWh electricity - enough for household electricity for 6 years for the residents.
- 2.7 GWh district heating - enough for heating for 9 years for the residents.
- 8,200 liters of biofuel - enough for 230 miles of driving per household.

Remember, this is not either or – we get all this if we build the eight-storey building.

It is sometimes said that the forest grows slowly. It's true. But it is also true that the total wood consumption corresponds to about 4 hours of forest growth in the forests of Södra's members.

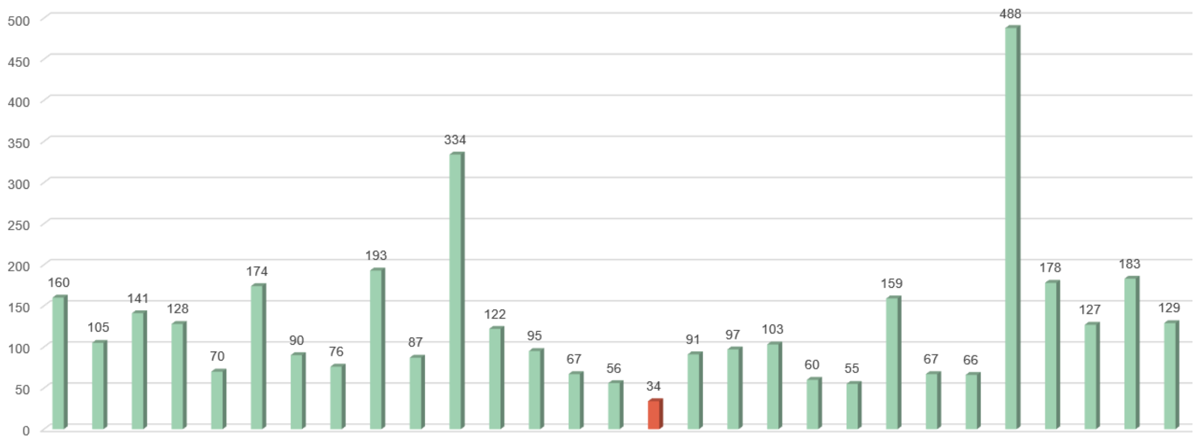
4. Södra's investment in CLT and the combined value in Värö

To be able to participate in and drive the development of wood-based solutions for the construction and housing industry, Södra opted to invest in a production site of CLT in Värö, which is a strategically chosen location for its proximity to several growth regions in the Nordics. And for the logistics to international markets via the port in Varberg or via railway tracks into the combine. The facility is co-located with Södra's sawmill and pulp mill for easy access to raw materials, green energy, and ready-made infrastructure. The pulp mill at the combine in Värö is one of the world's largest and produces 760,000 tons of pulp, which also provides 1.6 TWh of energy and fuel. The combine also has Sweden's largest sawmill with a production capacity of 600,000 cubic meters of sawn goods. It also produces 25,000 tons of pellets. The production capacity of CLT is approximately 100,000 cubic meters. We strive to maximize value by utilizing all parts of the tree. The possibility of being able to use the green energy we produce at the combine means that our production of CLT is completely fossil-free. In our business, it is instead the felling and parts of the transport that account for the largest amount of fossil emissions. Worth mentioning is that the collection area for raw materials for the sawmill in Värö is local and has a radius of 100 kilometers.

5. Södra's CLT has the world's lowest climate impact

With responsible family forestry, our value chain and production symbiosis as a base, Södra can produce CLT with the world's lowest climate impact. The fact that Södra's CLT has the market's lowest climate impact has been clarified when producing an EPD for Södra's CLT. EPD is an environmental product declaration, where the product's environmental impact is summarized in a concise, standardized document. An EPD contains the results of life cycle analysis and other important information about the product. The declaration is reviewed by an independent third party and always follows a specific standard. This makes it easy to compare the climate impact between different materials and components with the same function. This makes it easier to choose sustainable alternatives and make a big difference to the climate.

After calculations and preparation of the EPD, it shows that Södra's CLT has an impact of 34 kg CO2 e/m3. To put this in comparison with, for example, concrete, by choosing to build the frame in Södra's CLT instead of concrete, you can reduce the climate impact by up to 80%. The big difference and effect are possible thanks to our fossil-free nurseries, sustainably managed forests, transportation with biofuels, fossil-free sawmills, and production facilities.



The table shows the EPD values of CLT from several different companies in the world.

New structural applications: Katajanokan Laituri Helsinki

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New structural applications: Katajanokan Laituri Helsinki

Abstract

Katajanokan Laituri is a modern mixed-use building, owned and developed by Varma Mutual Pension Insurance Company. Building will be the new head office of Stora Enso and a hotel and serve as a meeting place for city dwellers, tourists, and service providers in one of Helsinki's finest locations. The property will be a masterpiece of Finnish wood construction. Background and motivation of the project as well as the main drivers of the structural design are discussed.

1. New flagship of wood architecture to be built at the South Harbour in Helsinki

1.1. Background

Stora Enso's old head office in Kanavaranta, Helsinki was designed by one the most recognized Finnish architect Alvar Aalto. Building was completed in 1961 and since then it has been an iconic landmark in Helsinki's cityscape. Stora Enso sold Kanavaranta office in 2008 and continued as tenant for more than ten years in Kanavaranta premises until announced plans to move to a new office. In November 2019 Varma Mutual Pension Insurance Company, one of the largest investors and real estate developers in Finland, and Stora Enso as the future anchor tenant, announced plans regarding new wooden building at the South Harbor in Helsinki.

1.2. Ambitious targets for the new building

Varma Mutual Pension Insurance Company had secured a planning permission for a site in the South Harbour area of Helsinki to build a new head office for Stora Enso as well as a hotel. The gross area of new building should be approximately 22,000 sqm. Varma values successful long-term investments and seeks to build symbiotic relationships with both tenants and wider society. With this approach, the company has succeeded in generating considerable financial as well as social value. Stora Enso is one of the oldest companies in the world, rooted in the Nordic forests. For its success, Stora Enso does not rely only on the richness of its heritage but on strong values and a commitment to innovation. Today, Stora Enso provides low-carbon alternatives across many industries, including construction. Wooden buildings store carbon over their lifespan, help to reduce energy use in buildings and have a low carbon footprint. Stora Enso is leading the way in transition from a fossil-dependent world with finite resources into a renewable, sustainable world. As the renewable materials company Stora Enso wanted the new head office to be located in a wooden office building.

As a visionary statement the new building should reflect the ecological diversity, resilience and most importantly the beautiful sensitivity of the forest. The new building should present the versatile relationship between the Nordic people and their forests, accomplishing this in a uniquely insightful way through a harmonius synthesis of the forest and surrounding urban environments. The look and feel of the building should be defined by a commitment to biophilic design. Aesthetically, the new building shall be attractive and inspiring to staff, but also support the employees' wellbeing and their ability to maintain a work-life balance.

One of the most ambitious goals of the new building is to aim for carbon-neutrality based on extensive use of wood, energy efficient solutions and by using energy from renewable sources. Building is also aiming to the highest levels of sustainability in terms of environmental certificate and aims for LEED Platinum certificate, which takes a wide range of sustainability aspects into consideration.

1.3. Early stages of the development including architectural competition

The South Harbour area is directly connected to the historical centre and the downtown of Helsinki. The harbour is the origin and the roots of Helsinki. A village has grown into a town and town into a city. At the same the relation of the city and the harbour has changed. The City of Helsinki has a strategic goal to vitalize further the old harbour area and the neighbouring historical centre. The new building is situated in a nationally significant cultural environment.

As the anchor tenant of the new office, it was agreed to use Stora Enso's massive wood elements in construction. The new seafront building will also take its shape based on the Office Building Concept by Stora Enso, which was published in 2019. Katajanokan Laituri will also include a hotel and serves as a meeting place for city dwellers, tourists, and service providers in one of Helsinki's finest locations.

Architectural design competition was defined as the best way to secure the functionality, sustainability and aesthetic requirements of the new building in this kind of a unique and valuable site. Architectural design competition was arranged by Varma, Stora Enso, and the City of Helsinki. Six architect offices were invited to participate in a design competition in early 2020. Each of the selected architect offices brought their own unique set of strengths and experience to the competition. Aim of the competition was to create a high standard carbon-neutral premises that coincide with nationally significant cultural environment, and which also consider the opportunity for people to enjoy the seaside location. Architect offices were invited from Finland, Sweden, Norway, and Japan, including ALA Architects (FIN), Anttinen Oiva Architects (FIN), PES-Architects (FIN), White Arkitekter (SWE), Snøhetta (NOR), and Shigeru Ban (JPN).

The winner of the competition was announced in June 2020. All competition entries were evaluated anonymously, without knowing which architect office was behind of each proposal. Winner was Anttinen Oiva Architects with their winning proposal "*Spring*":

Pictures 1 and 2 by Anttinen Oiva Architects:
Winning architectural proposal "Spring"

"Strongly grounded in its site and surroundings, Spring looks towards the future and sets an example in carbon neutrality, sustainable growth and the possibilities of wood construction in a sensitive urban environment. Both urban and natural, it is strong but serene on the outside, while its interior and materiality evoke the dense but tranquil atmosphere of a Finnish forest. Its architecture embraces and elevates its surroundings, extending and reiterating the city's grid and silhouette in harmony with the old. Through a powerful, but open and inviting gesture and presence, it re-activates its surroundings and the city's waterfront.

Building represents sustainable architecture in every meaning of the word: flexible structural solution capable of accommodating a range of different uses during the building's lifespan, adaptable spatial organization and carbon neutrality combined with form and materiality that is true to its values – architecture with a true human approach. It showcases carbon neutral construction with innovative and creative use of standard Stora Enso massive wood products and intelligent technical systems.

Its spatial solutions allow a diverse and flexible interaction between people and the different functions of the building.
Inventive and inspiring, Spring represents dynamic and modern, but timeless and firm architecture that fits and elevates its surroundings while following biophilic design principles. The building and its formal solutions create a clear identity that stems from its historic urban context as much as a Nordic forest and relationship to nature. Spring offers proud and strong urban presence with the warmth, smell and feeling of a Nordic forest after the rain" (Invited Architectural Design Competition – Jury Evaluation Report, 2020).

1.4. Status of the construction site in 2023

Before any new construction started, an old warehouse dating back to 1960 was standing on the site in South Harbour. One of the preconditions for new development was to get approval for new detailed city plan. New detailed city plan was approved by the City of Helsinki in June 2021. Old warehouse was demolished and materials were recycled as far as possible. The building was no longer in use for its original purpose and had no special architectural or aesthetic value. Eventually 99,5% of all materials demolished from the warehouse were able to be recycled. Construction of the new building began with ground-works in January 2022. One of the main challenges in this site was to ensure water tight-ness of trench walls used around the excavation. Excavation achieved level -4.5m below sea level in August 2022, and first sections of base slab for the new building were casted in September 2022 by using green concrete to mitigate climate impacts of structures below the ground. Manufacturing of first wooden elements started in October 2022 at Stora Enso LVL mill in Varkaus, Finland. Majority of all load-bearing structures above the ground are made of wood by using CLT and LVL by Stora Enso. Installations of the wooden frame began at site in March 2023 and will be finalized in October 2023. Katajanokan Laituri, including the office and hotel, is planned to be ready in the Summer of 2024.

The goal of minimizing the climate impact during the whole life cycle of the building has been guiding the design from the beginning. Climate change mitigation is one of key goals of Varma who aims to be a pioneer in reducing the carbon footprint of its properties. Con-struction from Stora Enso's massive wooden elements will help to aim for these climate goals. Sustainability is considered from much wider perspective than just as an environ-mental certificate. Katajanokan Laituri will be nature-respecting, energy-efficient, intelli-gent building made of wood. The building will be a great example to showcase how to use wood in new structural applications as a part of sustainable urban construction.

Picture 3: Katajanokan Laituri construction site in August 2023

2. Structural design

Sweco Finland has been responsible for all structural design from basement through mass-timber frame to façade elements and secondary structures. Katajanokan laituri is a unique building because of its high architectural value, location, size and an emphasis to use engineered wood products for the whole load-bearing frame. These starting points have led to careful and innovative structural plans in order to design a safe and economical structure, which fulfils all regulations as well as architectural demands. Sweco Finland possesses internationally recognized expertise in all-scale timber and hybrid buildings, which enabled a precise structural design with the most effective solutions. High level of BIM is a standard for Sweco and it has been fully utilized in this project to facilitate production of wooden elements as well as to minimize any errors and delays in the design phase of the project.

2.1. Design drivers

The following subchapter is focused on the timber frame above ground level, which is the state of the art in modern mass-timber construction. Key structural design drivers are introduced and specifications related to this project are mentioned.

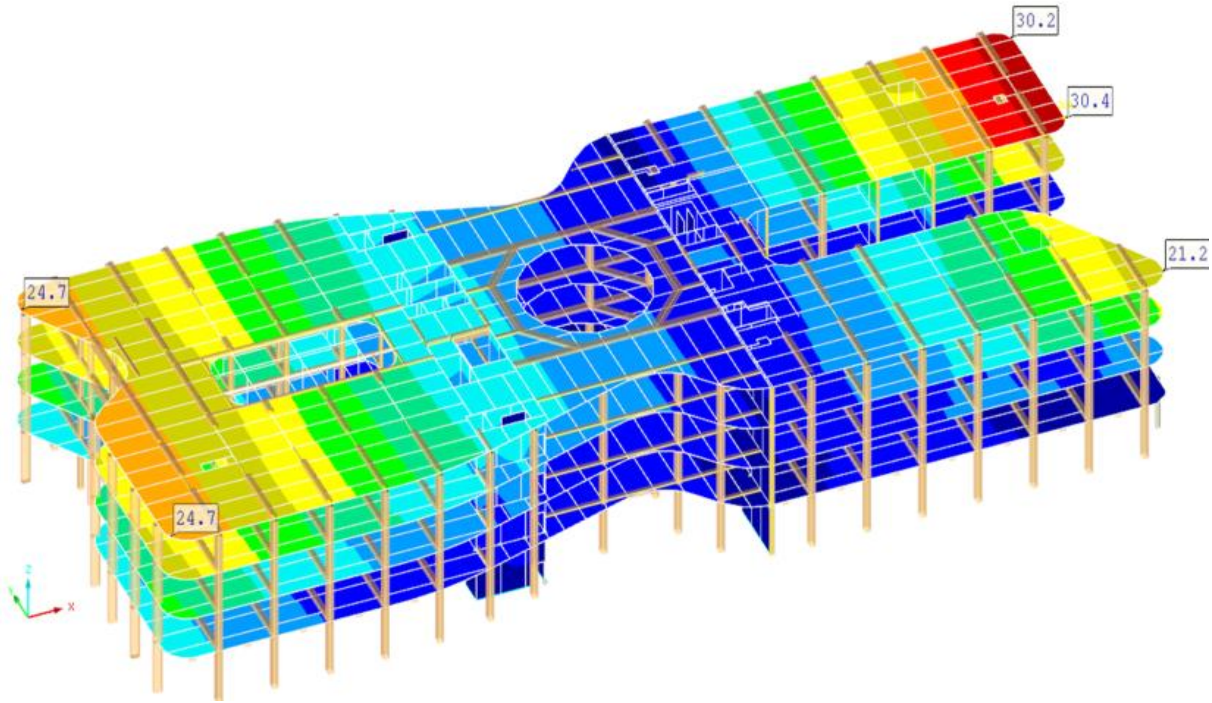
Stability and wind load transfer

The building is located on the seashore, which directly lead to two design considerations. First, future sea level rising was considered in the design solutions by leveling 1st floor to +3,4m above sea level. Moreover, a special attention was put on waterproofing of concrete foundations. The second consequence of the building´s location is exposure to wind. Wind load was even increased due to the 100-year service life of the building.

These conditions required careful design of lateral load transfer system already in the preliminary stage of the project. Both shear walls and intermediate floors play a key role in the lateral load transfer. In this 4-storey high project, all shear walls and intermediate floors above first floor are Cross laminated timber (CLT) with only a few exceptional places in the 1st floor, where concrete was used to fulfil needs of a civil defence shelter.

Preliminary load transfer study was carried out in the beginning of the project in order to determine positions of the shear walls. Later, global stability FEM model was made to ensure that global deformations are below the set limits as well as to simulate lateral load transfer from façade to foundations. Intermediate floors and shear walls consist of CLT elements, which are connected with fasteners. It is crucial to consider stiffness of the fasteners due to semirigid non-continuous orthotropic behavior of the CLT intermediate floor. Lateral load is transferred differently than in rigid continuous (e.g. concrete) slabs. Therefore, FEM model was made in a detailed way considering stiffnesses and positions of connections and semirigid orthotropic behavior of CLT slabs. Connection and detail element design was done based on the results from the FEM model.

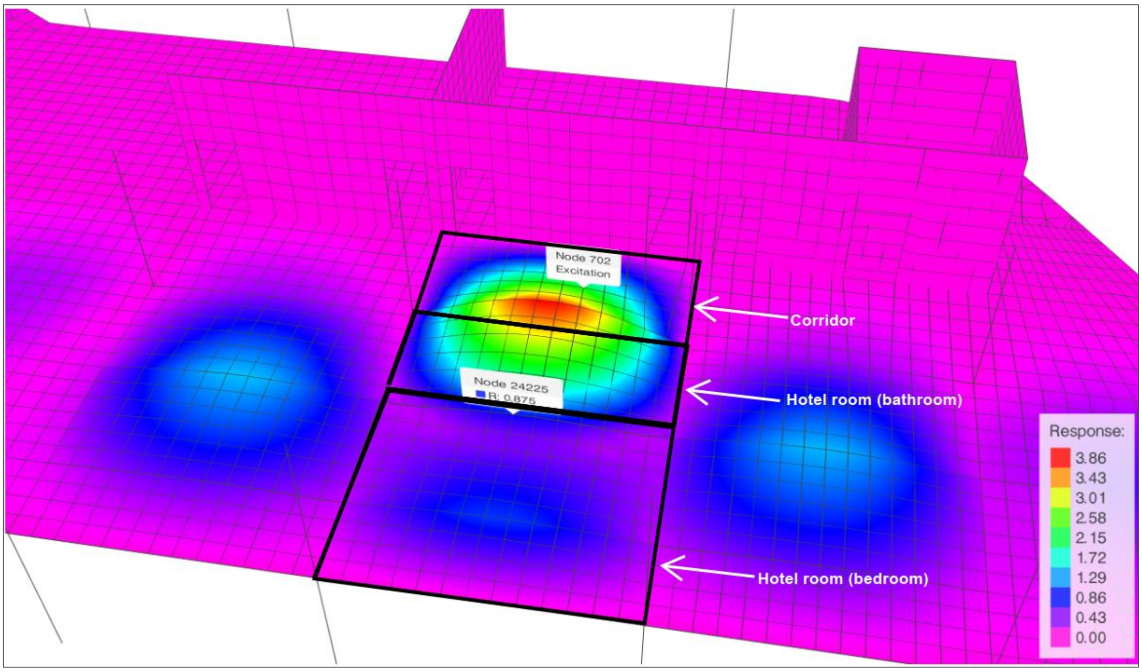
Most of the shear walls are double-storey elements and the positions of vertical wall connections are shifted in the upper floors (see Pic. 6) to maximize the effectiveness of CLT elements in the lateral load response.



Picture 4: Global deformations of Katajanokan Laituri due to lateral load (mostly wind action). Copyright: Sweco Finland Oy

Vibrations

Human-induced floor vibrations were the main design driver for the columns grid as well as for the cross-sections of beams and thicknesses of floor slabs. Due to lack of experimental data for similar timber frame structure, thorough dynamic analysis was carried out for this project. Two types of acceptance criteria were followed. Finnish classification described in *SFS-EN1993-1-1 NA* as well as alternative design method according to new Eurocode 5 draft (*CEN/TC 250/SC 5 N 1241 / SC5.T3 Final draft prEN 1995-1-1, subtask 7 Vibrations*) was considered. Next to the limitations for the floor classifications, detailed analysis of the most critical cases was done. For example (see Pic. 5), dynamic behavior of hotel-sided floor was studied by placing excitation node of vibrations in corridor (somebody walking), and response node was placed in hotel room, where there is no bathroom (somebody was sleeping). The response factor was < 1.3, which fulfilled the SCI P354 requirement for residential buildings during night (limitation 1.4).
The intermediate floor system consists of CLT slabs supported on LVL beams. Combined natural frequency varies between 6,5 – 9,9 Hz in different parts of the building. Acceleration values were studied and compared to different acceptance criteria. Demanding architecture in central lobby led to large cross-sections of LVL beams and thick CLT slabs.



Picture 5: Most critical vibration when walking in corridor and sleeping in hotel room. Dynamic factor in sleeping area < 1.3. Copyright: Sweco Finland Oy

Fire

Fire design of timber structures strictly follows Finnish regulations. The whole timber frame is designed for 60min of fire resistance, which was a design driver mainly for connections. All connectors have to be sufficiently plugged and timber has to be thick enough to transfer load in case of fire and charring.
In this type of construction in Finland, 20% of the fire compartment surface-area is allowed to be exposed structural timber. Hence, some of the CLT walls were left visible. Based on architectural demands, not even wooden plugs could be visible on the visible walls. This created another challenge for connection design and new details. Columns and some of the beams are visible. Sprinklers are used in whole building.

Robustness

Following *SFS-EN1991-1-7 NA* this type of building needs to incorporate safety features in case of accidental loads to minimize any damages. CLT slabs and walls as well as LVL beams and columns need to be tied together to prevent progressive collapse in case of a local failure and ensure ductile behavior. Many connectors were designed only for the purpose of these ties. Empirical equations for tie forces in *SFS-EN1991-1-7 NA* offer rather conservative approach for light-weight timber frame buildings. Further research on effective design methods for robustness of similar types of buildings would be beneficial.

2.2. Structures & Assemblies

The upper timber frame consists of block-glued LVL-X columns and beams as well as CLT walls and floor elements. All the elements are connected with metal plates and fasteners such as dowel-type connectors, screws, concealed plates etc. All wooden elements are prefabricated including cuts and notches. Prefabrication was driven by high-level BIM modelling done by Sweco. Column-beam frame is designed in a way that most of the metal fastening parts are attached to wooden members in the mill in order to minimize the in-situ assembly time and to ensure accuracy of the frame. Some of the assemblies are complicated. E.g. a massive LVL truss 11,4 x 4,8 m with almost 8000 kg weight was brought to the construction site as one assembly (see Pic. 6). Tolerance management as well as humidity control is a crucial part of design to avoid issues with in-situ assembly.

From an architectural standpoint, the 1st floor multi-panel columns are one of the main features of the building. Glued-in rods were introduced as a new solution to connect the columns with the concrete basement (Pic. 6).
Prefabrication of CLT elements made possible to fulfil difficult organic shapes of the floors. 2-span slabs are used where it is possible and 2-storey CLT wall elements assure that the shear walls work efficiently in the lateral load transfer.
Central lobby of the building required special care because of long spans and large circular opening with its diameter 13,7 m. Large block-glued LVL-X beams (600 x 864 mm), thick CLT slabs (320 mm) and unique LVL-X ring beam around the opening (Pic. 6) fulfilled the architectural demand as well as vibrations and other structural design aspect.
The façade consists of prefabricated LVL-X framed double-skin elements. A special attention is paid to thermal and acoustic properties of the façade considering harsh Finnish winter as well as a noise from road and marine traffic.

Picture collection 6: Unique load-bearing structures in Katajanokan laituri

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Paradigm shift in Industrial Construction

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Paradigm shift in Industrial Construction

Abstract

Industrialized construction, also known as offsite or modular construction, presents a transformative approach to building projects. This approach has been around for centuries, it has a great potential of producing high quality homes for a lower cost but so far it often fails to succeed. The purpose of this paper is to give a possible explanation to this failure. Some historic examples are described, and some issues are brought up that are part of the problem. The solutions needed to secure an efficient house production are many, but the article clearly points out some of the most important ones from our perspective.

1. Heading 1

Mature industry has developed their production and design in harmony over the past 120 years! Automotive is maybe the most obvious example there almost all successful industries have a long tradition in development of design, R&D and production.

For several reasons this has not been the case in the construction industry. Other producing industries are learning from each other and push the development by using ideas from earned experience. If not by proper cooperation it happens by people moving between the different industries and companies.

However, the construction industry compared to other industries, has been so different and so far behind so the transfer of technology has not been a fruitful exchange in the past.
In the 50s some major industries developed production units making standardized single-family houses in a very productive way.

- The Swedish AB Elementhus factory in Mockfjard produced over a 20-year period 4 complete houses every day including heating, water, drain, Kitchen & Bathroom.
- In America National Homes produced one complete house (including all) every 9th minute.

https://youtu.be/AuBm6tir-EM

This gave both customers and owners an economical overview hat had not been seen before. With hindsight, we can also conclude that the overall economy for housing has only become worse and worse.

The incredible development in the 50s could have been the start of a revolution, but in the 60s and 70s the demand for variety increased. Architects and clients sought original and personalized creations.

At the time the industrialized housing industry could not handle the demand of design variations and special demand from specific architects/customers. The machines were simply too static and hard to reconfigure to variation in the production.

The special machines from the 50s made standardized components very efficient.
The machine builders adopted as much flexibility as they could to the 50s technology at the price of complex solutions, slower production, and more workforce.

If you want to make flexible production in an industrialized way you need to control the motions of the machine and be able to feed the machine with information.

In the 1970s and 1980s, conditions were created to control machines with PLC technology, which has ever since, been the method for controlling the machines of the home industry.

The problem is the production of DATA. Up to now it has been a very time-consuming work to "feed the beast with DATA". Individual factories in the housing industry, based on flexible machinery driven by DATA, many times have a crew of 50-60 man only working on the DATA production.

Sweden is a pioneering country when it comes to industrial house production. Unfortunately, DATA controlled machines originating from the 50s have not led to the same development as in other industries where design and product belong to the factory and are a natural part of daily R&D work. Instead, the praxis has been that design of houses is made outside of the factory's control, by designers, structural engineers, and architects.

Price, quality, delivery time and consumer need have all been going in the wrong direction and are still doing.

2015 the first wall production line, based on modern 6-7 axis robots, was installed at Moelven in Varmlandsbro, Sweden.
APR Automation faced problem in the DATA production of this line that was a much more flexible machine that the 50s technology.
From 2015 to now a crew at Wiksfors Technology have been focusing on modern Industrial Production.

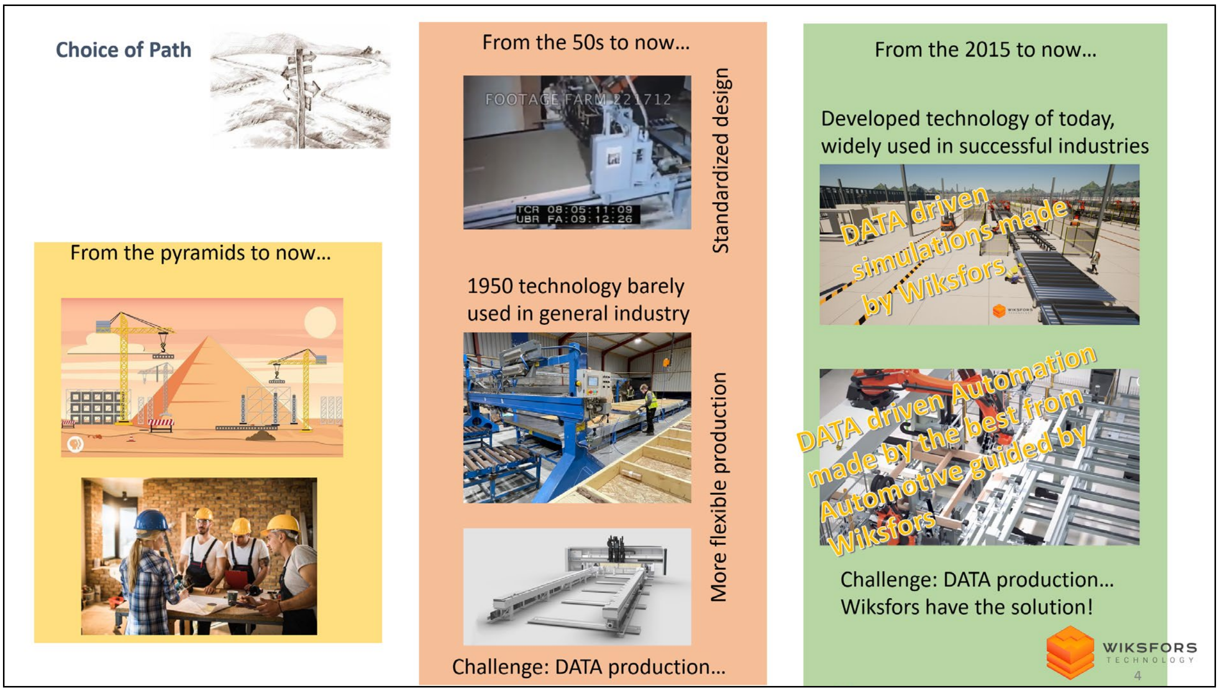

Figure 1, History of industrial construction

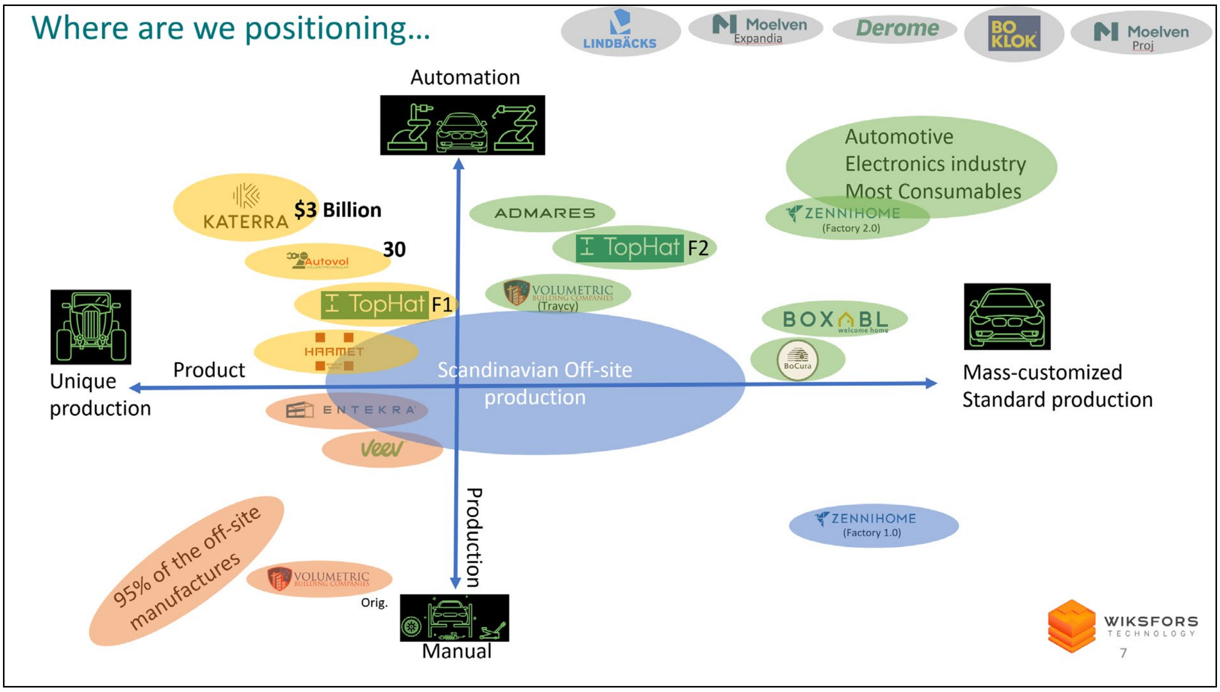

Figure 2, Product flexibility and level of automation matrix

Based on available technology and production methods, in combination with government and architect expectation the industry has located itself in the lower left corner of above diagram. Unique and Manual production. All other industries are aiming for the upper part of the z-axis. And the easiest way is to be in upper right corner there most successful industries are located.

For Wiksfors Technology, the past 8 years in the Housing Industry have been educational.
We have had the privilege of being involved in the first development of robotized machine equipment in 2015 and subsequently involved in the development of Autovol, Idaho, USA, now the most automated factory with approx. 50 robots and 450KSF factory.
After that we worked for TopHat, Derby, UK, that are in the phase of building their 650KSF factory including around 70 robots. The machine supplier is KUKA System in Germany and is one of the largest machine suppliers around the globe.
Today we are working for a number of different clients all around the globe.

Wiksfors is not aiming to necessarily follow the rest of the industries path of making strict standardized products. Rater making a strict standard for production of DATA an connect that to a "Digital Copy" that will virtually run the entire production long before the real factory is created. This means that the automation grade will be high but the x-axis flexible (All the way from "Unique production" to "Standardized production").

The Quote is:
Based on knowledge we have learned from practical experience, both in the more mature general industry and recent years' experience from the most automated housing industry, we offer a new industrialized housing industry that can be safely and securely built. Simulation driven by DATA is going to prove the design as well as the production facility long before the physical factory and machinery is producing real houses.
Design, materials, supply chain, external logistics, internal logistics, internal warehouse, throughput, bottlenecks, production sequence, production method, component selection, manpower requirements, R&D potential, etc., etc., are answers that will give financiers, owners, decision makers courage to take the necessary steps towards long-term and sustainable construction.

Every other industry creates better products at a cheaper price. We must create the conditions for the house industry to be able to do the same.

Quote #1: Make an investigation for a state.

1) How to make livings for its citizens?
2) Investigate if a state has a potential in an export industry.
3) Investigate and realize a government involvement in the Rebuild of Ukraine.
    a. Sustainability.
    b. Design/product & production.
    c. Material development relevant to design and material.
    d. Capacity and delivery time.

Quote #2: Investigate and specify production towards a private owner.

Groundbreaking: automating windows installation with a new fixture system

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Groundbreaking: automating windows installation with a new fixture system

1. Introduction

In the past ten years, various studies were conducted in companies producing wooden single-family houses in Sweden and Germany (a.o. Allhorn & Svensson, 2014; Andersson & Jönsson, 2016; Björk & Andersson, 2016; Fohlin & Ekström, 2017; Johansson et al., 2018). The companies have different ways and fixture systems to install windows into the wall frame structure, yet have in common, that it represents a bottleneck in production. This paper aims at describing different window fixture systems and ways of installing a window. Further, a new fixture system and its suitability for automating windows installation is presented.

2. Different ways of window installation

Different companies have different ways of installing windows. Some are placing the window into the almost finished wall at the end of the production, others apply the fishbone approach, where parts or components of the wall are pre-manufactured in a parallel process and mounted together in the main production line.

2.1. Direct window installation

Companies with rather few and manual working stations, about two or three, often install windows at the end of the production process. The wall is brought into a vertical position and the required working steps conducted. Insulation and sealing are attached at the very end of operations.

For more details about direct window installation, see table 1 below and read e.g. Pooyan and Yousif (2021).

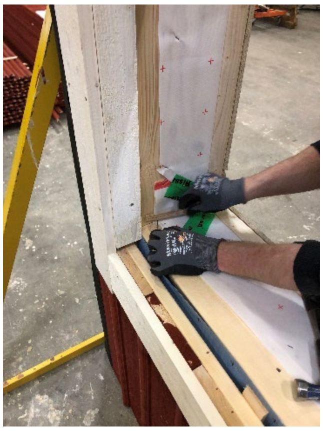

Figure 1: Preparations for direct vertical window installation.

Figure 2: Window about to be installed vertically.

Figure 3: Attaching insulation and sealing in vertical window installation.

2.2. Prefabricated window module

When applying the fishbone approach, companies have their main production line and additional parallel working stations, where e.g. window modules are prefabricated, see figures 4 to 6. In the window working station, a wooden frame is attached to a window, including insulation and sealing. The window module is then either temporarily stored or directly transported to the first working station of the main production line, where it is assembled to a wall frame with the remaining studs. Besides a potential intermediate store, the working station for window prefabrication requires extra resources like e.g. working table, operator and a separate material flow.

For more details about prefabricated window modules see table 3 and read e.g. Andersson and Jönsson (2016) or Björk and Andersson (2016).

Figure 4: Prefabricated window module.

Figure 5: Working station for window module.

Figure 6: Assembly of window module into wall frame.

3. Different fixture systems for window installation

3.1. The Adjufix system

In Sweden, the Adjufix system has been used as the self-evident solution for window installation for decades. One Adjufix set consists of two parts: an anchor, see figure 7, and a corresponding screw, see figure 8. Often, window manufacturers already preinstall the anchors in the window frame, yet in some cases, only the anchor hole is predrilled, and the anchor must be placed by the operator at the window module station when installing the window. The screw is fastened from inside the window frame towards the stud in the wall frame and the drilling hole locked with a plastic cap, see figure 9. The number of required Adjufix sets depends on the size of the window.

Figure 7: Adjufix anchor.

Figure 8: Adjufix screw.

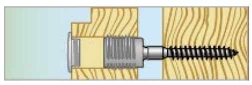

Figure 9: Screw fastened from the left with anchor placed in window frame and drilling hole to the left sealed with plastic cap.

Since the Adjufix screws must be fastened from the inside of the window frame, the operator is confronted with challenging tasks: the window must be opened to reach the predrilled holes, see figure 10; if the window does not need to be opened, the anchor holes are located very close to the window wing, see figure 11. If the anchors are not in place, they must be inserted by the operator before the screws are placed. Yet being pressed for space, the operator must insert the screws in a quite unergonomic way, see figure 12. As the operator sometimes handles metal tools like hooks and chains for lift cranes to open the window, as well as using electric drills, the risk for scratching the glass or coat of lacquer becomes obvious.

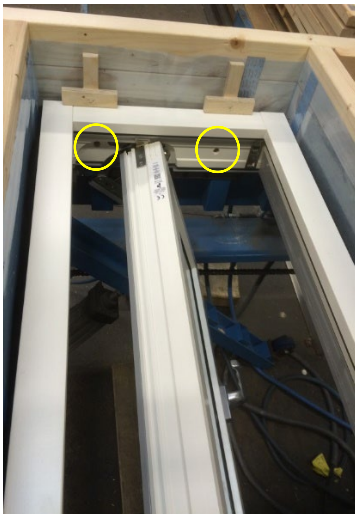

Figure 10: Open window with anchor holes marked yellow.

Figure 11: Closed window with anchor holes marked yellow.

Figure 12: Closed window with operator in unergonomic position when drilling the screw (yellow-marked).

3.2. Click-In fixture system

The Click-In fixture system for window installation has currently been approved and launched on the Swedish market. It consists of two components: a clip in plastic or spring steel, see figure 13, and a screw, see figure 14.

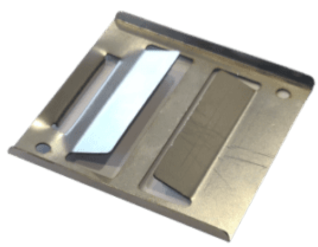

Figure 13: Click-In clip in spring. steel.

Figure 14: Click-In screws.

Figure 15: Attaching a plastic Click-In clip at a window frame.

The clip has either holes for attaching the clip at the outside of the window frame, see figures 13 and 15, or barbs that allow the clip to be pressed into the wooden window frame. For windows with a PVC or aluminum frame, the clip has a matching profile on the backside. In the middle of the clip, a snap joint is placed. The screw must be placed at the correct height in the inside of the window opening, see figure 16, so that clip and screw will fit in their positions when the window is in place, see figure 18. When placing the window into the window opening in the wall frame, see figure 17, the snap joint of the clip will glide over the screw head and a "click" sound will be heard (Click-In, 2022).

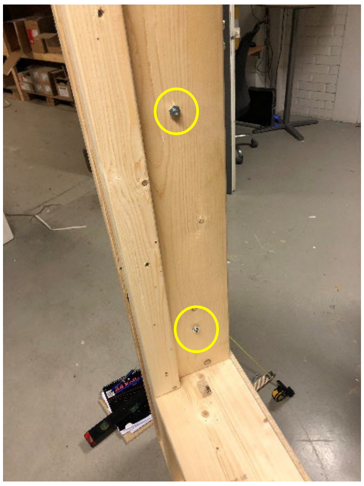

Figure 16: Click-In screws in window opening (marked yellow).

Figure 17: Placing a window into the window opening.

Figure 18: Click-In snap joint glided over the screw head and the fixture system is spring-closed.

4. Comparing fixture systems

To compare the two above presented fixture systems, the working steps for each system were studied; both the direct window installation and the prefabricated window module were investigated.

For the sake of comparability, different pre-conditions had to be fulfilled. First, a relatively similar window size was studied in all three cases. Second, as the Adjufix anchor screws were pre-installed in the window frame, the Click-In clips were pre-installed as well before the window installation. Further, the correct positions for the Click-In screws were identified in advance. Lastly, the installation operations were performed by workers that are used to the respective system.

The working steps for Adjufix and Click-In were observed and listed. For each system, five to seven measurements were done and the average split-time for each system specific working steps were calculated, as was the average total assembly time for each system.

4.1. Direct installation with Adjufix

For the direct window installation with the Adjufix system, working steps 1 – 15 with the respective time-measurements MA1 – MA7 in seconds are presented in table 1. Steps 1 – 12 are specific for Adjufix. Steps 2 – 4, 5 – 6, 7 – 9 and 10 – 11 are related and could not be separated when measuring operation time. Therefore, an aggregated time is presented. The average split-time for the Adjufix specific working steps is 385 seconds.

Working steps 13 – 15 are system independent. The total average assembly time for window installation with the Adjufix system is 987 seconds.

Table 1: Working steps 1 – 15 and time measurements MA1 – MA7 in seconds for Adjufix direct installation.

"Adjufix" fixture system		MA1	MA2	MA3	MA4	MA5	MA6	MA7
1	*placing wooden distance pieces*	23	25	26	26	32	25	23
2	*lifting and attaching window (tasks 2-4)*	39	51	59	58	124	51	44
3	*measuring lateral distance margins*							
4	*locking the window with wedges*							
5	*opening the window (tasks 5-6)*	79	112	93	91	128	112	82
6	*screwing frame screw anchor*							
7	*screwing frame screws (tasks 7-9)*	104	112	195	168	71	82	145
8	*control measuring/adjusting the window*							
9	*removing the wedges*							
10	*closing the window (tasks 10-11)*	17	29	68	119	18	29	40
11	*controlling open/close function*							
12	*sealing holes for frame screws*	40	31	31	24	22	21	26
	split-time working tasks "adjufix" only	302	360	472	486	395	320	360
	average split-time "adjufix" only	385						
13	*caulking with mineral wool strips*	209	219	245	241	192	219	201
14	*caulking with cellular plastic sealing tube*	160	142	143	151	155	142	125
15	*attaching elastic joint sealing*	190	264	245	282	201	264	223
	split-time common working tasks	559	625	633	674	548	625	549
	total assembly time "adjufix"	861	985	1105	1160	943	945	909
	average total assembly time "adjufix"	987						

4.2. Direct installation with Click-In

For the direct window installation with the Click-In system, working steps 1 – 5 with the respective seven measurements MC1 – MC7 in seconds are presented in table 2.

Table 2: Working steps 1 – 5 and time measurements MC1 – MC7 in seconds for Click-In direct installation.

"Click-In" fixture system		MC1	MC2	MC3	MC4	MC5	MC6	MC7
1	*screwing click-in screws according to template*	53	42	40	41	37	35	27
2	*lifting and attaching window*	12	12	12	12	15	12	9
	split-time working tasks "click-in" only	65	54	52	53	52	47	36
	average split-time "click-in" only	51						
3	*caulking with mineral wool strips*	209	219	245	241	192	219	201
4	*caulking with cellular plastic sealing tube*	160	142	143	151	155	142	125
5	*attaching elastic joint sealing*	190	264	245	282	201	264	223
	split-time common working tasks	559	625	633	674	548	625	549
	total assembly time "click-in"	624	679	685	727	600	672	585
	average total assembly time "click-in"	653						

Working steps 1 and 2 are Click-In specific, whilst steps 3 – 5 are system independent. The average split-time for the specific Click-In working tasks is 385 seconds. In total, the assembly time with this fixture system is 653 seconds.

4.3 Prefabricated window module using Adjufix

Working steps 1 – 16 and the respective measurements MP1 – MP5 in seconds for a prefabricated window module using the Adjufix system are presented in table 3. Steps 3 and 10 – 12 are specific for Adjufix, the remaining steps are system independent. The average split-time for the specific steps is 332 seconds. The average total assembly time for a prefabricated window module is 1 814 seconds.

Table 3: Working steps 1 – 16 and time measurements MP1 – MP5 in seconds for prefabricated window module using Adjufix.

"Adjufix" fixture system prefabricated module		MP1	MP2	MP3	MP4	MP5
1	*adjusting window module working table*	88	94	90	45	48
2	*fetching window with vacuum lift*	298	280	312	254	241
3	*preparing for fixing 6 adjufix screws*	130	142	112	105	113
4	*tacking rubber strip inslulation*	62	56	60	58	52
5	*tacking rubber corners*	118	126	138	102	96
6	*placing supporting wood pieces*	20	22	23	20	21
7	*placing window on working table*	40	58	44	41	49
8	*attaching beams around the window*	286	269	305	251	232
9	*pressing and nailing beams to a frame*	334	348	482	304	294
10	*opening window with traverse crane*	60	55	65	58	56
11	*fastening adjufix screws*	129	114	121	115	115
12	*closing window*	32	37	40	29	31
13	*cutting extra wood pieces as filler*	59	55	64	51	49
14	*placing extra wood pieces*	74	89	93	68	66
15	*unfastening module from working table*	55	62	64	49	46
16	*lifting module with crane to palette*	86	98	96	67	62
	split-time working tasks "adjufix" module	351	348	338	307	315
	average split-time "adjufix" module	332				
	split-time common working tasks	1520	1557	1771	1310	1256
	tot. assembly time "adjufix" module	1871	1905	2109	1617	1570
	average tot.ass.time "adjufix" module	1814				

Here, the authors call for attention. The reader must act with caution when trying to compare table 3 with the content of chapters 4.1. and 4.2. Window modules are prefabricated according to the fishbone approach, i.e. parallel to the main production process. Thus, working steps and operations occur that are not related to the window installation process or a fixture system. For example, different insulation types are used, which have varying working steps.

Furthermore, this is the only way of installing windows, where studs, as a part of the wall frame, are assembled parallel to the production line. Moreover, the window module needs to be stored temporarily and transported to the main production line.

4.4 Prefabricated window module using Click-In

In table 4, eleven working steps are listed for prefabricating a window module with the Click-In fixture system, including seven time measures, M1 – M7 for each working step. Working step 5 is specific for Click-In, the remaining working steps are system independent. The average split-time for the Click-In working step is 39 seconds and the total average assembly time is 979 seconds.

Table 4: Working steps 1 – 11 and time measurements M1 – M7 in seconds for prefabricated window module using Click-In.

"Click-In" fixture system prefabricated window module		M1	M2	M3	M4	M5	M6	M7
1	*adjusting window module working table*	88	94	90	45	48	75	69
2	*lifting window on a rotatable working table*	107	301	50	20	57	73	30
3	*tacking rubber strip insulation and corners*	180	182	198	160	148	170	140
4	*lifting window to working table*	40	58	44	30	48	18	48
5	*screwing click-in screws according to template*	32	35	44	43	40	37	39
6	*attaching beams around the window*	149	143	114	91	112	109	140
7	*pressing beams to the window*	90	35	39	32	28	26	24
8	*nailing beams to a frame*	128	102	76	166	156	120	72
9	*lifting window module to another table*	50	71	45	39	27	51	85
10	*mesuring and attaching insulation*	226	105	57	177	108	203	242
11	*lifting module to palette*	17	33	31	57	54	45	28
	split-time working tasks "click-in" system	32	35	44	43	40	37	39
	average split-time "click-in" system	39						
	split-time other working tasks	1107	1159	788	860	826	927	917
	total assembly time "click-in" system	1139	1194	832	903	866	964	956
	average total assembly time "click-in" system	979						

4.5 Summarizing comparison

As can be seen in tables 1 to 4, using different fixture systems for window installation affects the nature and number of working steps, the total assembly time and the risks involved. Applying the traditional Adjufix system generally requires more working steps and takes longer time.

Considering further developing the operations towards a higher degree of digitalization and automation, the fixture systems show differences in suitability. Using the Adjufix system, working steps are not only more but are generally more complicated to automate, especially opening and closing the windows to set the screws, placing and removing wedges or wooden distance pieces.

The Click-In system, on the other hand, requires fewer working steps and those are much easier to automate. For example, the marking of the right position for the screw in the stud could be done in an early stage, based on a CAD drawing, when the studs are cut into the correct length. Alternatively, the holes for the screws could automatically be drilled or the screws already be placed. This depends of course on the current production equipment in the respective company. Yet, due to the functional simplicity of the Click-In system and its components, a great potential for automation or semi-automation exists (Ziada et al., 2022). In the following chapter, an example is given on how this could be achieved.

5. Preparing semi-automated windows installation with the Click-In fixture system

As part of streamlining operations, automation is an important piece of the puzzle, and the installation of windows is an important part of this.

It is possible to prepare for the installation of windows already in the design phase. Orders can be prepared with the needed information about e.g. the position of the screws for Click-In, and that information can be communicated to machines.

Using BIM software, in this case Revit, you can create digital automated objects. Everything in a BIM software is a digital object that in a simplified way reflects what will be built: walls, floors, ceilings, interiors and even windows.

Looking at a window, the digital window should correspond to the information needed for design, ordering and assembly. This means that it will be modelled as it looks in reality. To select the size, color, type of glass, etc. the geometric model is supplemented with parameters to allow the user to adapt the window to the different situations in which it is placed in the model.

To automate the entire workflow adapted to Click-In, the clips must be included in the digital window. Formulas provide an automatic distribution and number of clips based on window size and type, see figure 19, based on the supplier's information.

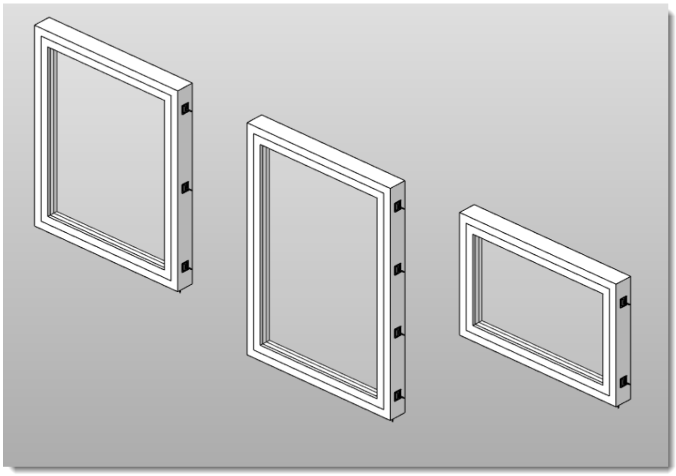

Figure 19. Three different sizes of openable windows with Click-In clips and screws.

In the model, different levels of detail can be chosen. Here, it was chosen to show what an alternative Click-In looks like for clarity, see figure 20. It could as well be just a simple cylinder to mark the position of the screw.

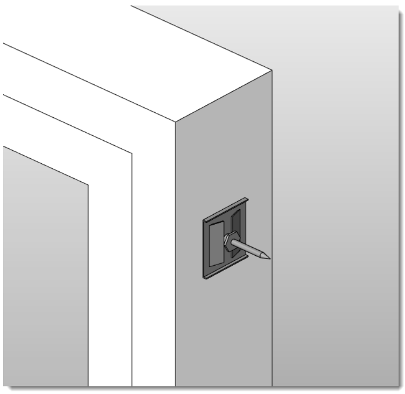

Figure 20. Click-In clip and screw.

Depending on the building system and window type, the clip may need to be positioned towards the inside of the window, in the center or towards the outside of the window. This position is set by values of parameters. In this example, the clip is placed in the center. It is important to set the correct position if these objects are to be used as a basis for ordering and for the clip to be delivered assembled from the supplier and to be sent to production.

The examples at hand show wooden windows. For aluminum and plastic windows with profiles, similar solutions exist.

When families/digital objects are used and contain relevant information and geometry, it is possible to use this information to e.g. order windows and prepare for assembly. With output data, the digital object can therefore control the window order and include information and placement of the Click-In fixture system.

If windows are delivered from the supplier without clip, they must be attached on site in the factory. Here, the assembly instructions and the digital object must match in order for the clip and the screw to fit.

When preparing drawings for manufacturing and assembly, the walls in the BIM software are supplemented with studs and other layers of the wall, see figure 21.

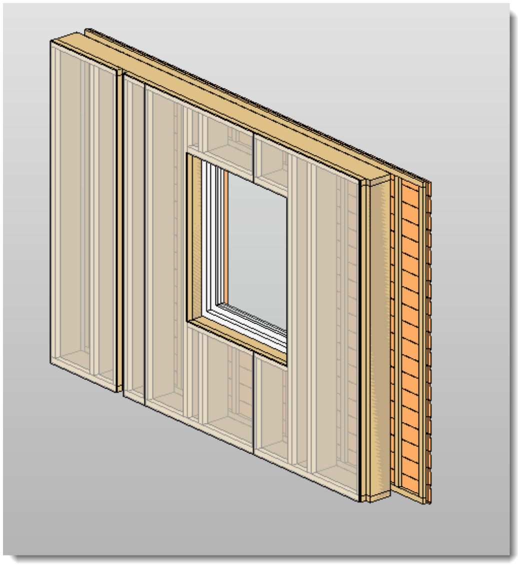

Figure 21. Framed wall – all layers.

Using the add-on program from AGACAD, it is possible to automatically mark where pre-drilling in the studs around the windows must take place, to fasten the Click-In screws later for the window installation, see figure 22. This could also be done by using CNC/robot technology by means of the information that the machines received, see figure 23. Depending on how the machine is equipped, holes can be drilled, which makes it easier to place the Click-In screws into the pre-drilled holes that already have the correct position.

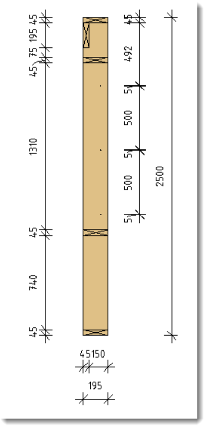

Figure 22. Mark or pre-drilled holes in studs.

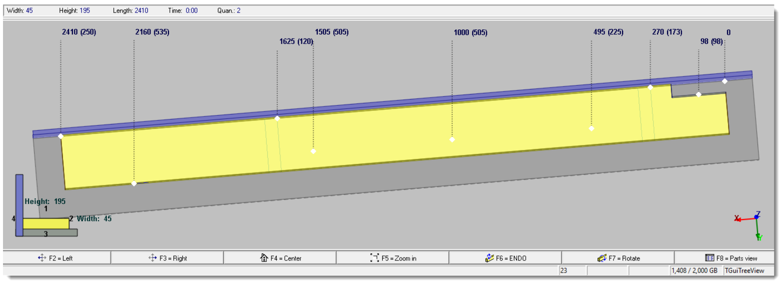

Figure 23. Result when stud with pre-drilled holes are exported to a CNC-machine.

Here, the right BIM software, automated objects, and various outputs can enable a faster and secure window installation with the Click-In fixture system, both on- and off-site.

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Case studies of timber-concrete hybrid buildings - dynamic evaluations

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Case studies of timber-concrete hybrid buildings - dynamic evaluations

Abstract

Timber-concrete hybrid buildings are an innovative solution to increase the amount of timber materials in modern buildings. This type of structural system has gained popularity in recent years due to its numerous benefits, such as a preferable environmental footprint and lightweight elements, compared to traditional building methods.

Dynamic evaluations of two timber-concrete hybrid buildings are presented in this paper. These evaluations include a four-story office building and a nine-story residential building. The evaluations are performed to investigate the dynamic properties and validate structural models used to design the buildings.

1. Types of timber-concrete hybrid buildings

The definition for timber-concrete hybrid buildings used for this paper is a building, in which the structural system above the foundation level includes structural elements made of both timber and concrete.

A previous study analyzed ten building projects in Sweden that were considered timber-concrete hybrid buildings (Larsson and Dorn, 2023). The study identified and categorized four different building types (see Figure 1) where timber and concrete elements were combined in the load-bearing structure.

System type 1 is often used in residential buildings and consists of a timber structure on top of a concrete structure. The concrete elements are chosen to prevent uplift forces and make it possible to change the floor layout on the bottom floors.

System type 2 is a typical solution for office buildings to create open-space floor plans. Concrete shear walls complement the timber elements and are used in these buildings due to their higher capacity than CLT walls.

System type 3 is commonly used for schools where timber slabs are replaced with prestressed hollow core slabs in concrete.

System type 4 is mainly used for taller buildings, replacing timber slabs with solid concrete slabs. This is because additional weight is required to fulfil the requirements of wind-induced vibrations.

The reader should be aware that other definitions of timber-concrete hybrid buildings categorize system type 3 and system type 4 as all-timber buildings, not timber-concrete hybrid buildings (Safarik et Al., 2022).

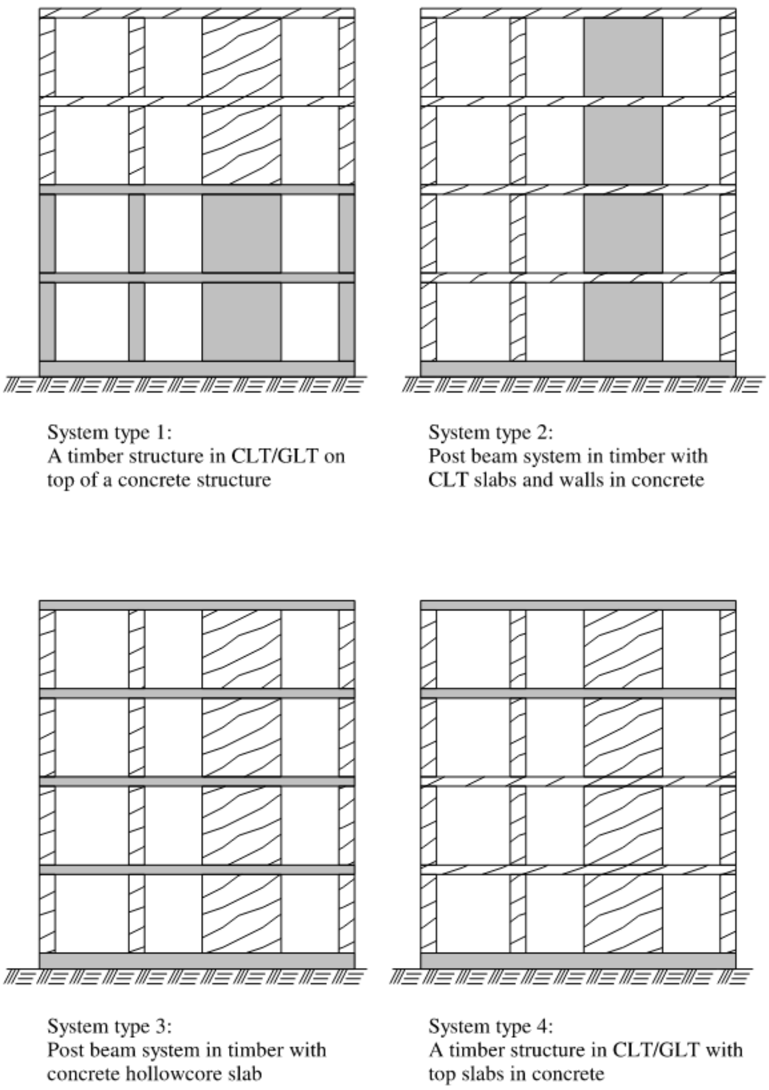

Figure 1: Definition of different types of timber-concrete hybrid buildings in Sweden (Larsson and Dorn, 2023).

2. Dynamic evaluations

The dynamic evaluations are performed with a technique called Operational Modal Analysis (OMA). It is widely used in the field of structural engineering for studying the modal properties of a structure under real-world operating conditions. It is in this paper used to study the dynamic performance of timber-concrete hybrid buildings.

2.1. Long-term evaluation

A long-term evaluation has been conducted in House Charlie, a four-story office building, shown in Figure 2. It is a system-type 2-building with shear walls in concrete placed in two elevator shafts. The timber elements consist of CLT slabs supported by a post-beam system in glulam timber.

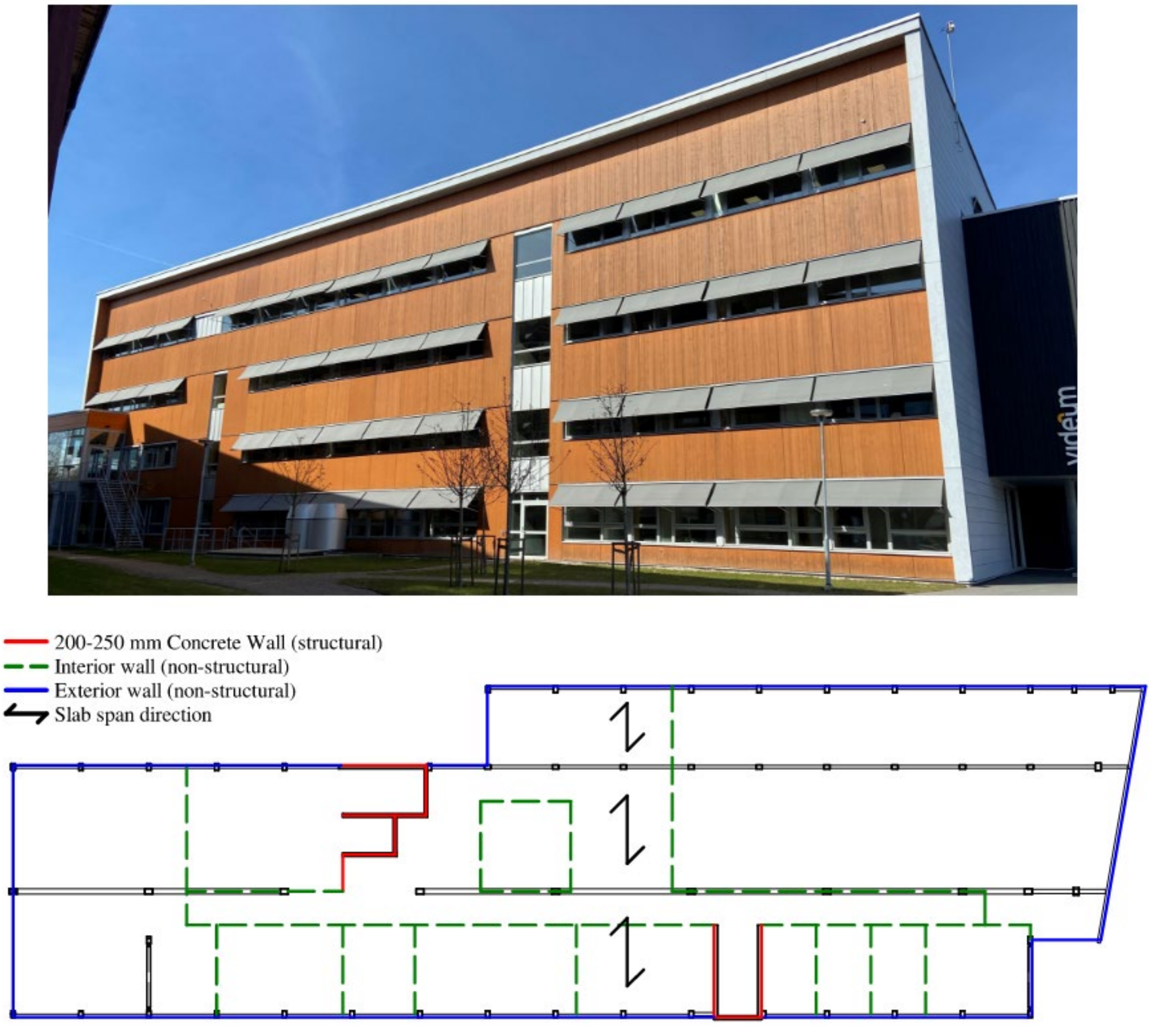

Figure 2: Picture of House Charlie (top) and the floor layout (bottom) (Larsson et al., 2022a).

A fixed monitoring system was installed during construction in 2018, including dynamic sensors (geophones), hygrothermal sensors and an exterior weather station (see Figure 3 for the sensor layout). In 2021, a three-year evaluation was performed, and the results and following analyses are presented in Larsson et al. (2022).

An OMA was performed on the data from the dynamic sensors. The results showed three clear mode shapes of the building with corresponding natural frequencies and damping. The natural frequencies showed a seasonal variation (Figure 4, left), where the highest natural frequencies were recorded during September/October, and the lowest were recorded in March/April. The recorded damping showed no seasonal pattern and was recorded in the interval of 1.5 % to 3.5 % for the corresponding three mode shapes.

The analysis of the hygrothermal sensors showed that the relative humidity in a CLT slab located on the first floor of the building showed a similar seasonal pattern as for the natural frequencies. The readings showed that the relative humidity within the CLT plate was highest during September/October and lowest in March/April.

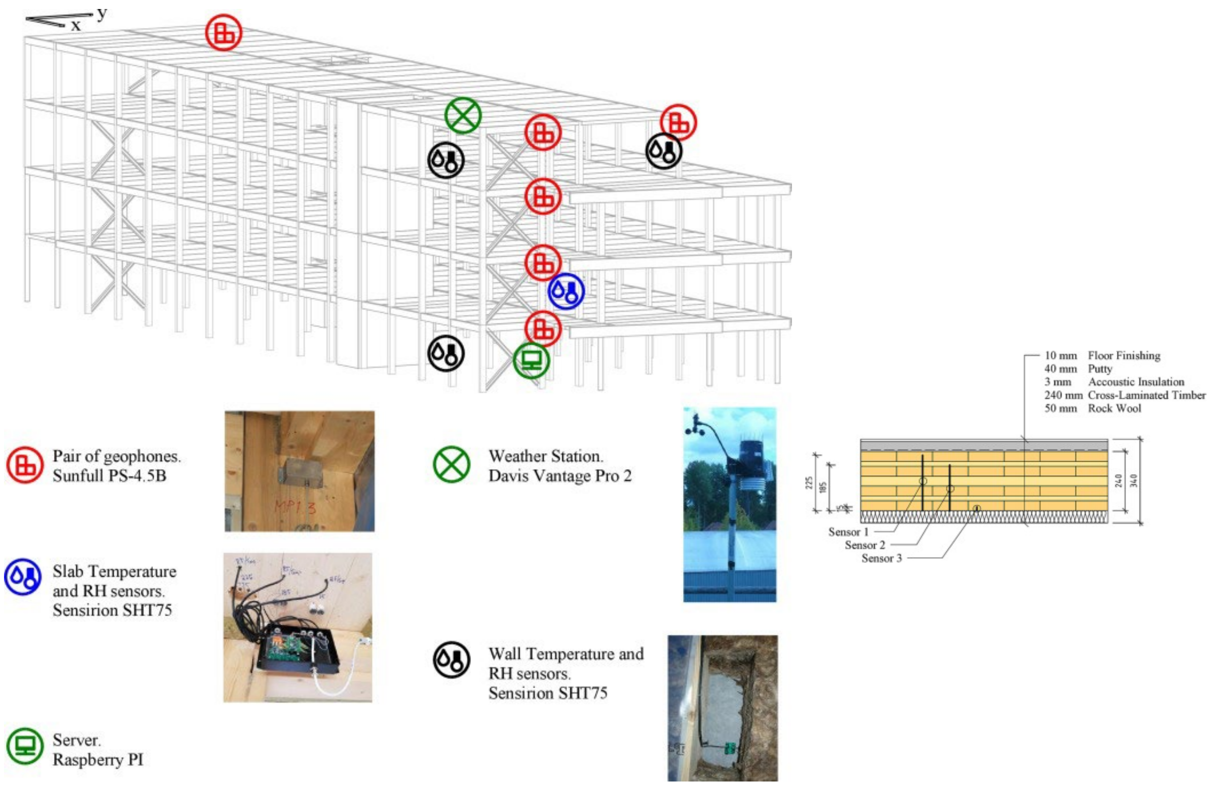

Figure 3: Sensor types and placement at House Charlie (left) and placement within the CLT slab (right) (Larsson et al., 2022a).

The readings from the hygrothermal sensors were recalculated to a moisture content for the CLT plate and showed the same seasonal variation and geometric distribution (Figure 4, right). A correlation analysis between the moisture content (MC) in the CLT slab and the recorded natural frequencies for the entire building gave a clear trend, and correlation coefficients were as high as R2=0.81-0.84. These results clearly indicate that the moisture content within timber material affects the natural frequencies of a timber-concrete hybrid building.

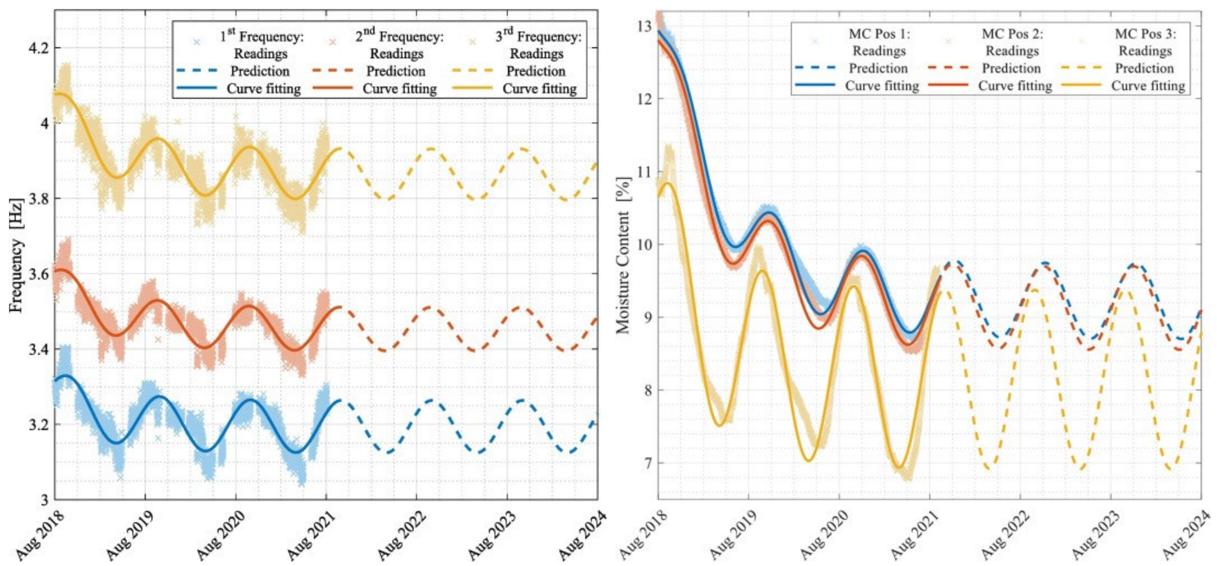

Figure 4: Readings, curve fitting and prediction of the first three natural frequencies of House Charlie (left) and the moisture content within a CLT slab (right) (Larsson et al., 2022a).

In addition, a finite element study was performed in Larsson et al. (2022b). The analysis concludes that the recorded seasonal variations cannot be derived from the varying density and stiffness properties of the timber material in the FE model. The results from the

FE analysis showed that for an increased MC, the natural frequency decreased. This is in line with the original expectation that an increase in moisture content (MC) would result in higher density and mass and decreased stiffness properties, leading to a decrease in the natural frequencies.

However, the results from House Charlie were contrary to this expectation. It was observed that changes in the eigenfrequencies followed changes in the moisture content, suggesting that additional factors influence the measured natural frequencies of the timber in House Charlie beyond density and stiffness properties. It was also shown that non-structural walls had a significant influence on the eigenfrequencies and are non-negligible in these types of analysis, similar to conclusions by others (Devin and Fanning, 2019).

2.1. Short-term evaluations

A mobile dynamic monitoring system has been developed for Ambient Vibration Testing (AVT) (Amaddeo et al., 2023). The system has been used for House Biologen 1, a nine-story residential building shown in Figure 5. The building is a system type 1 building that consists of a basement and the bottom two stories in concrete. The top 3-7 floors consist of CLT slabs and CLT walls.

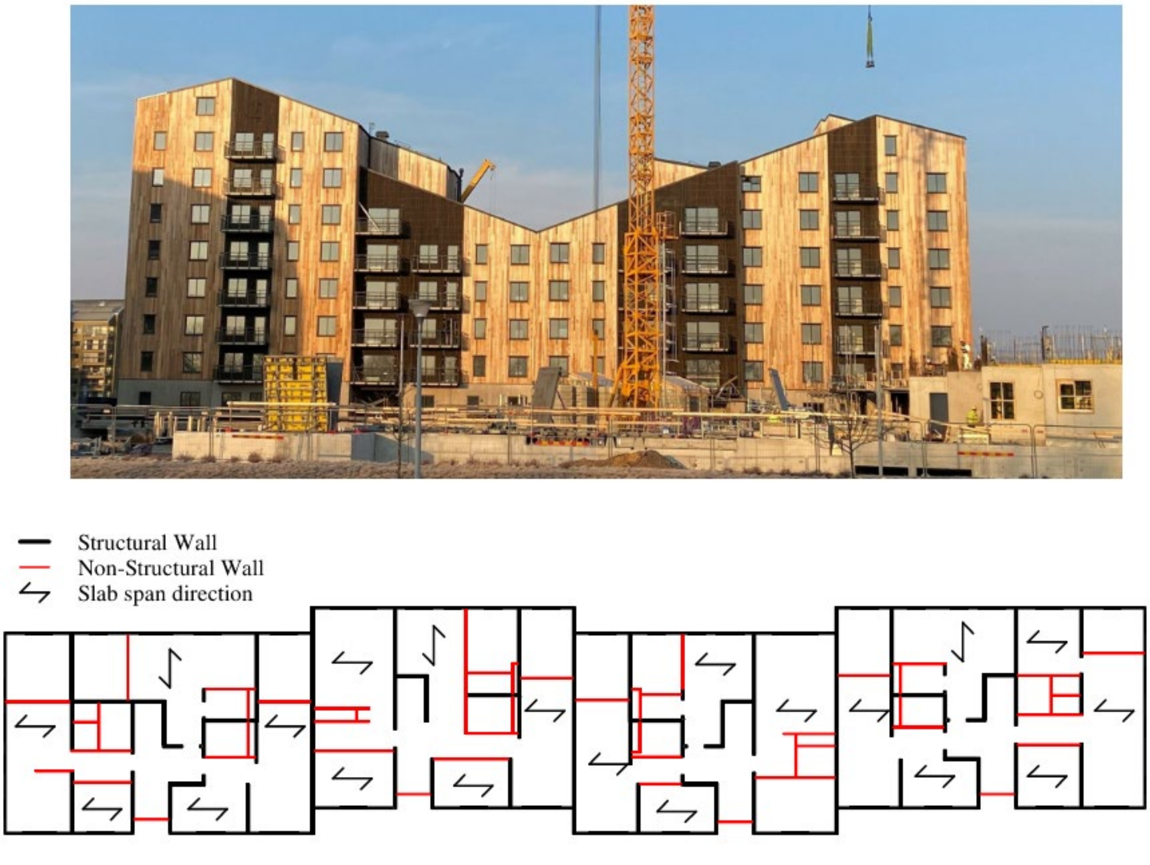

Figure 5: Photo of House Biologen 1 (top) and a typical floor layout (bottom) (Larsson et al., 2023b).

The mobile system was used for seven short-term tests during a construction period of 13 months at various stages of construction. The initial four AVTs conducted during construction identified only one natural frequency. However, the final three AVTs, performed when all structural elements were in place, revealed two clear mode shapes. The results show that the natural frequencies decreased as additional mass was added to the slab. Additionally, it was concluded that there was a slight stiffness increase in the building when the façade and non-structural walls were installed.

With the large number of AVTs available for calibration of a FE model, an investigation of the influence of different parameters on the dynamic characteristics was performed thereafter. The parameters chosen are typically important during the design phase for static and dynamic structural analysis of a building project, e.g., material stiffness, connection compliance, or soil properties. To accomplish this, FE simulations were performed for each of the AVTs (see Figure 6).

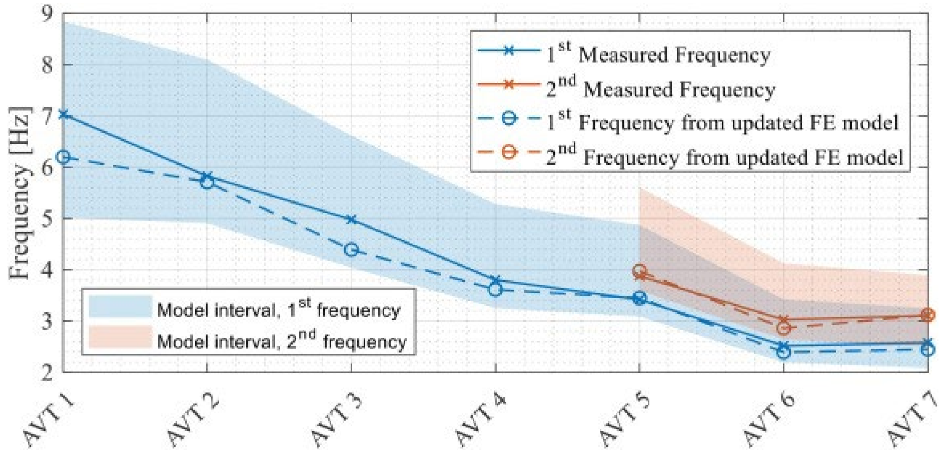

Figure 6: The measured frequencies of House Biologen 1 are presented along with the interval of results of natural frequencies from the sensitivity analysis. The lower value in the interval is a combination of all parameters that decreased the natural frequency in the FE analysis. The higher value is the corresponding combination of parameters that increased the natural frequencies. The dashed line is from the updated FE models using the best fit of parameters (Larsson et al., 2023b).

Through an initial FEA of the building with rough assumptions of model parameters, the eigenmodes and corresponding eigenfrequencies were found to roughly match the experimental ones. The following parameter variation study emphasized the significance of accurately modelling the cross-laminated timber (CLT) material, as in-plane shear stiffness significantly impacted the results. The foundation characteristics and non-structural wall elements were also identified to have a notable effect on the results of the FEA.

Finally, a combination of properties that showed good agreement with the measured eigenfrequencies from the ambient vibration tests (AVTs) was presented. It is emphasized that numerous parameters influence the results in different ways. A “correct” set of parameters was intentionally not presented as such a set cannot be verified uniquely as visualized in the hatched area in Figure 6.

3. Conclusions

Timber-concrete hybrid buildings are shown to be a good solution to implementing more timber elements in modern construction projects. The studied projects successfully use two different types of dynamic measurement systems. The following evaluation of the OMA and the finite element analyses identifies several variables of high importance in structural design and dynamic analysis. These variables include the foundation properties, the in-plane shear stiffness of CLT elements, the correct modelling of mass and the inclusion of non-structural elements. These same results are also seen in other studies, such as a four-story timber-concrete hybrid building in the UK (Kurent et al., 2023).

The current work presents the evaluation of two buildings. Follow-up evaluations are ongoing and planned in seven other buildings, including a 51 m tall high-rise building and two identical buildings, to investigate further the variables affecting the dynamic response.

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Interaction and responsibility – opportunities and challenges in designing timber hybrid buildings

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Interaction and responsibility – opportunities and challenges in designing timber hybrid buildings

Abstract

One of the committees in LFM30 delves into hybrid frame systems to compile opportunities, improvement potential and risks with new material combinations for future buildings. The committee has defined knowledge and ambition needed to succeed. To a considerable extent, this already exists. For knowledge to be used optimally and for the ambition to be taken care of, leadership and agreements that support this are required. Good leadership and well-defined contracts are two key factors to effective planning and likely increased innovation. The committee believe it is beneficial if one structural designer has a coordinating position in the design process with the authority to define boundaries between the other structural designers involved. The agreements should also enable increased cooperation and sharing of ideas within the project.

1. Introduction

As new frame materials or material combinations for frame systems are discussed and pursued in the search for reduced climate impact, the need for knowledge and leadership that promotes interaction increases. It is both about interaction between those who possess the knowledge, but also between these and those who make decisions.

However, procurement and management of construction projects tend not to take this into account sufficiently. In many cases, clients rely on the commitment of designers and assume that any problems will be solved. Here, more proactivity is desired to promote a better interaction with clear expectations, matching division of responsibilities and assumptions during the planning.

The hybrid building committee in LFM30 has identified the interaction and the issue of responsibility as some of the key factors to a successful hybrid building project.

The issues raised in this article rarely lead to any major injuries. Probably because the construction industry consists of a substantial proportion of problem solvers. But the risk of such exists, thus there is not only improvement potential to create something better, but it can also prevent serious damage.

1.1. LFM30 – Local Roadmap Malmö 2030

LFM30[1] stands as Sweden's pioneering industry-led local roadmap, designed to expedite the climate transition and implementation of Agenda 2030 within the building, construction, and real estate management sectors.

The association is a collective force of over 200 affiliated entities spanning research, business, and public operations. Every affiliated company has pledged allegiance to LFM30's climate promise.

The members fuel the engine of LFM30's work. The association is structured into working groups, see *Figure 1.* Collectively, they encompass the entire construction chain, with a

[1] *LFM30* is an abbreviation of Local Roadmap Malmö 2030

focus on fostering innovation, implementing, and disseminating knowledge in climate-neutral construction and management.

Testbed Malmö serves as the stage for these climate-neutral projects. Together, they form a constellation of monuments symbolizing knowledge, innovation, and inspiration. (LFM30, 2019)

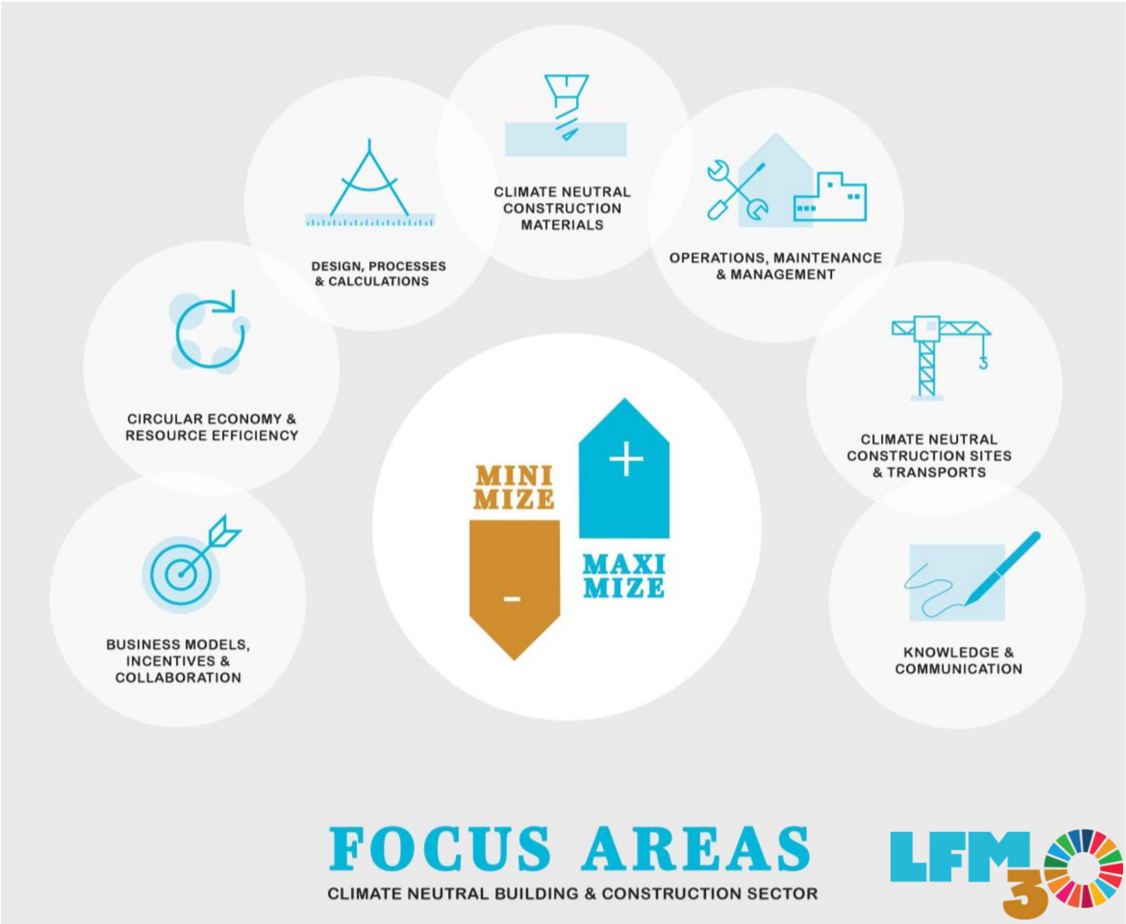

Figure 1 Focus Areas in the LFM30 (LFM30, 2019)

1.2. The hybrid building committee in LFM30

At the end of 2022, a committee was formed within LFM30, connected to focus area *Climate Neutral Building Materials*, to review the possibilities for more and new hybrid building systems in the construction industry. The thesis is the right material in the right place. The committee's purpose is to make it easier for the construction industry to find new material combinations for hybrid systems that lead to reducing the climate impact and to be part of the solution to achieving climate neutrality in 2030.

In the committee, experts from various companies discuss hybrid frame systems. Not least, the opportunity is given to ask each other questions and jointly see opportunities but also what risks may exist. Here is a unique opportunity to also highlight the risks, not only to warn but to find solutions and possible alternatives together.

The committee includes designers, architects, acousticians, fire consultants, moisture experts, sustainability experts from contractors and representatives from material suppliers. At certain meetings, the committee has chosen to delve deeper into some area, and additional experts are involved in these meetings.

The committee's goal to list hybrid frame systems as we know them today. These are evaluated based on opportunities and challenges, for example regarding production, moisture, longevity, acoustics, fire and stability. Also experience regarding planning, projecting, production and management for the projects is added when this is possible. The committee can also think of new hybrid frame systems and evaluate in the same way as we do with existing systems. The result will be a guideline for LFM30's members, in the start of 2024.

1.3. Definition of timber hybrid building

All buildings consist of varied materials, put together in such a way as to utilize the strengths of each material. This is by no means new. However, this report refers to frame systems where individual load-bearing frame components consist of varied materials, of which wood is one. Buildings with, for example, wooden floor structure that are stabilized with concrete or steel are an example. Another is a column-beam system with glulam with concrete elements.

Regarding the combination of timber-concrete building system, (Larsson, 2023) mentions four differnets types, shown in *Figure 2*.

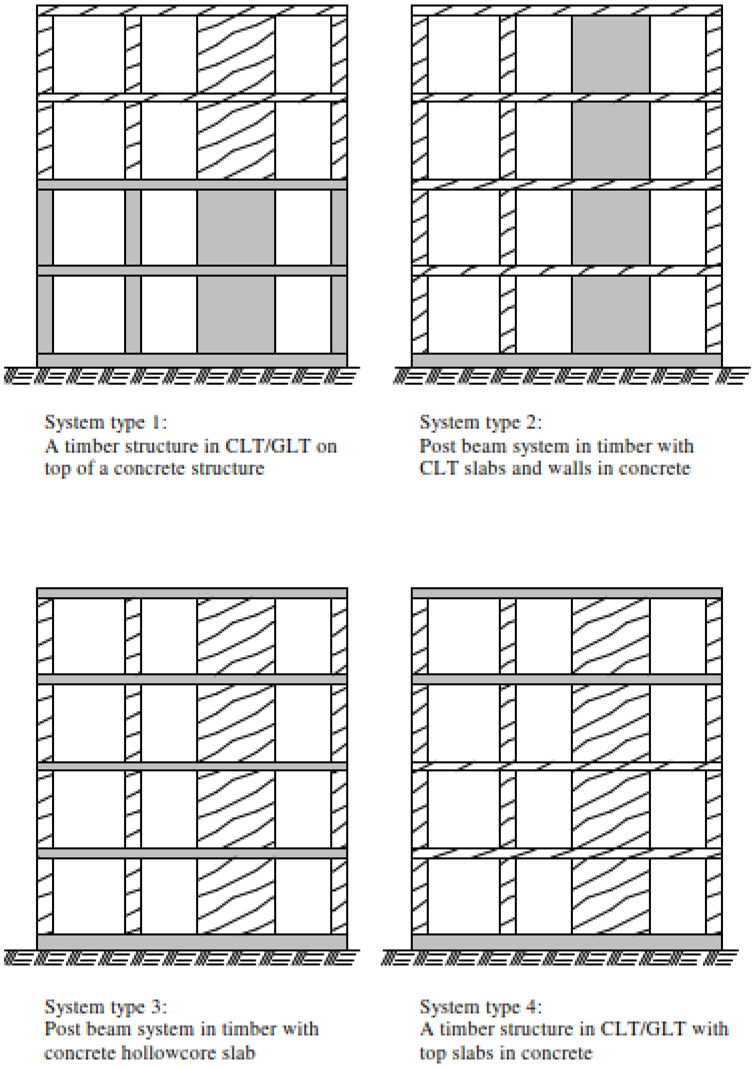

Figure 2 Four types of timber-concrete building systems (Larsson, 2023)

2. Interaction and responsibility

2.1. Knowledge and ambition exist, but the result is not forthcoming.

There is a lot and broad experience. But there is not yet experience about everything. That is something positive, it supports the spirit of innovation and commitment that there are better ways to build in the future, we just have not figured out what or even what is best.

What is abundant, however, is knowledge. People are usually happy to share their knowledge. Most of us are also genuinely interested in making use of experiences, learning new things, satisfying others with expected information, or even better exceeding it.

Why then do many clients of construction projects and contractors experience difficulties in planning, such as a lack of cooperation, coordination and, not least, joint problem-solving by procured consultants? If it is not a lack of knowledge, ambition to contribute or willingness to test new methods, then what is causing the perceived lack of collaboration?

In that case, the question of who is responsible for the interaction should first be asked. It would be too simple to say that all parties are responsible. Because even if everyone involved wants to do their best, there are sometimes limitations and obstacles for them to do what would be best for the project.

2.2. Obstacles for interaction

We ourselves have created and influenced many obstacles. It may be something that is intended as a help, but which rather turns out to work against the project.

Often it is about areas of responsibility and how these are defined. In construction projects where more than one structural designer is involved, this often becomes clear. All structural designers involved, i.e. different companies, have their own agreements and contracts that define their committed scope and responsibilities. When many structural designers are hired within the same project, sometimes parts that are important to the project are missed to be dedicated to one of the structural designers. Not infrequently, individual parts are missed in this way.

The agreements also govern the issue of liability and how the consultants are insured. This affects the extent to which they can go outside their contractual area. We can expect this even more in projects with even more variations of frame systems than we are used to so far. It is about how the involved structural designers are procured and what their contracts and responsibility look like.

Since it is we ourselves who create the agreements, it should be easy to create agreements that are consistent with what is to be done and that reflect the expectations of the parties involved.

2.3. Interaction in designing timber hybrid buildings

To begin with, the interaction between our Nordic countries differs on an overall level. It may be due to tradition or that a way of working has been refined over time or that you simply do what you have always done.

Although it would be interesting to delve into these differences, especially since some countries have shown greater success than others in quickly adopting new methods and being able to develop them, this article is limited to the Swedish "traditions".

It is becoming more common with more and more designing actors in construction projects. Regarding structural design, there is no longer one structural designer (one structural design company) who performs and is responsible for all structural systems in the project. For example, it is becoming increasingly common for parts of the frame to be dimensioned separately. A common part that has long been handled like this is prefab concrete. It can also be about other types of prefabricated elements, steel frames or CLT systems or building components.

Many house building projects are designed at the construction stage with several structural designers involved, where each designer is responsible for his area and has his own contract and scope, see *Figure 3*. Sometimes areas of responsibility overlap, sometimes there are gaps. Both can cause problems or later production adjustments.

It is therefore understandable that this can lead to discussions about who is required to do what. If there are gaps that are not discovered and thus discussed and investigated, there is also a risk of defects in the future buildings. Deficiencies that may have consequences for the building's operations, the building's lifespan or damage.

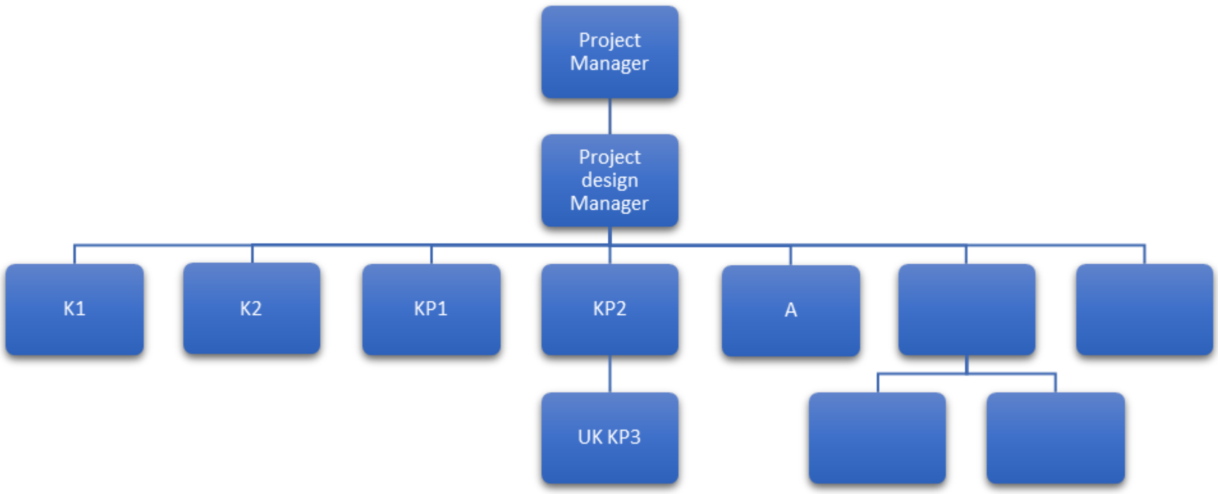

Figure 3 Organization chart for planning construction projects where all structural designers report to the project design manager and are contracted by the project.

Some projects use help of a structural designer with desired overall responsibility, see *Figure 4*, K1:HK. In Sweden, the terms "huvudkonstruktör" and "coordinating structural designer" are used, among other things. In English, the title would be something like "Principal Structural Engineer" or "Head Structural Designer", although its meaning in English-speaking countries may then refer to something else. The term structural designer-leader is also used. Regardless of the title, the aim is often for someone who understands structural engineering to have an overall understanding of what concerns a building's frame system during planning. What that entails, however, differs between each project. Some clients and structural designers have their standard descriptions to bring in established working methods and expectations, but there are still many variants and adjustments are often made during procurement.

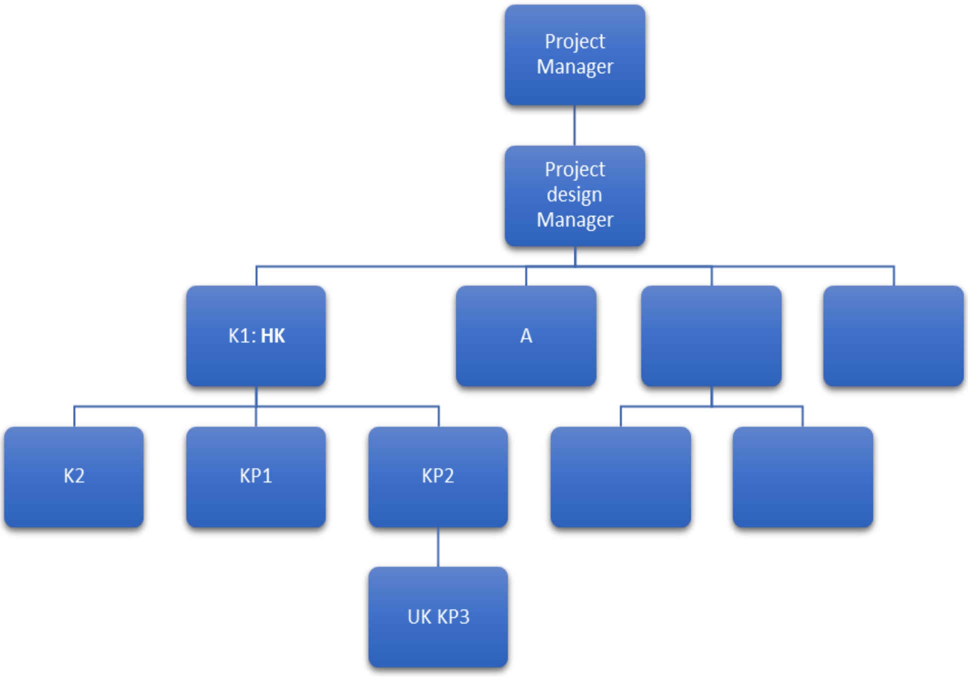

Figure 4 Organization chart for planning construction projects with a focus on structural designers. This with a coordinating structural designer with overall control, "K1: HK".

This article will henceforth use the abbreviation "HK" do denote the designer who is supposed to coordinate and who has overall control.

Often the projects seem to be run in a way that lies in between *Figure 3* and *Figure 4*, with ambiguities as a result. This is because the concept of HK is still interpreted and agreed upon in different ways. Thus, the actual expectations may be something other than what was agreed upon.

2.4. Huvudkonstruktörens uppdrag – The assignment of HK[2]

Innovationsföretagen[3] has drawn up a job description for *HK* This description is intended to facilitate and create consensus and expectations of what such a designer should do in the project.

The description includes, among other things, a definition of role of HK. Innovationsföretagen statement states that HK must have an overall picture of the building's technical properties in terms of load-bearing capacity, stability and durability; carrying capacity in case of fire; moisture safety; sound insulation and thermal insulation.

The description also emphasizes that HK should have powers. This applies to powers such as reviewing the main schedule regarding time for design and review, reviewing contracts between client and supplier regarding the roles of other designers, and time for review. HK must also have the option of rejecting other structural designers' documents if these do not meet the set requirements.

[2] *HK* refers to the Swedish concept "huvudkonstruktör" which refers to something similar Principle Structural Engineer.
[3] *Innovationsföretagen* is a branch and employer organization in Sweden that represents innovative companies within the knowledge-intensive service sector.

The most important task as HK is to define the interface between all involved constructors and coordinate all involved constructors.

Despite this, the commitments expected of the HK are often reformulated when this is contracted. This happens for various reasons and in itself does not need to cause any problems. However, it can create confusion and in the worst-case parts are not projected as required. (Innovationsföretagen, 2014)

Many clients order and expect a HK but write an agreement on something that may only partially correspond to the description that the *Innovationsföretagen* produced. This can also lead to unnecessary discussions, errors or reduce the possibility of getting an optimized framework.

3. Opportunities in designing timber hybrid buildings

3.1. Purposeful and obvious agreements and project focus

A great potential is created when everyone involved has the right conditions to contribute fully and where the planning group's task is to come up with common solutions that are best from an overall perspective for the project, not for each individual designer, see *Figure 5*. Any obstacles to interaction and cooperation are dealt with as early as possible. Everyone should be curious and interested in perspectives other than their own.

Figure 5: Many people and a lot of knowledge, everyone has responsibilities, but how does the distribution of responsibilities match the project’s goals? (Hiller, E. 2021)

Clear areas of responsibility, which are defined in consultation with the HK, create the right expectations. It is also important that all contracted parties have agreements that support the purpose instead of creating obstacles. The project is important.

Having a responsible structural designer, a real structural designer leader, who participates in the procurement of all designers involved, and who coordinates the engineers' work creates good conditions for everything to be taken care of.

Time would likely be freed up for value-creating discussions that would otherwise have been spent discussing afterwards who should have done what, and time for interpretation of unclear agreements. (Hiller, 2021)

Getting more designers involved should be seen as an opportunity. More actors provide the conditions for an increased exchange of knowledge and more knowledge totally in the group. Another positive thing is that more designers are expected to share their expert knowledge, which increases the possibility of good and optimized solutions. A prerequisite is again interaction with others and that everyone knows the objective. An individual optimization otherwise risks becoming a deterioration overall.

3.2. Leadership

How a project is managed not only affects the final result of building, it also affects how much knowledge is generated during the course of the project and what everyone gained after the project is finished.

A clear leadership that also allows questions and questioning is desirable. To contribute to a culture where questions are valued and where everyone is involved in the answers. This is also about putting the best interests of the project in focus before individual parts, see *Figure 6*.

By asking the question, the answer to which broadens both one's own insight, but also that of others, can in the short term result in changes within the team. In the long run, the project will reach better potential.

Figure 6: Asking a question that makes you lose an assignment but gains a trust. (Hiller, 2022)

4. Summary

As buildings are continuously completed, projects that had potential problems with unclear contracts with their constructors, scope descriptions, unstructured leadership, etc. are assumed to have resolved these.

But problems that can be foreseen should be dealt with proactively. Overall, value-creating space should be freed up when the projects can focus on positive discussions instead of problem solving.

Knowledge and ambition exist. However, the constructors' agreements and contracts sometimes limit their ability to use this. Therefore, there is a general demand for clearer interfaces, better coordination and more time for interaction during the design of buildings.

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A hybrid structure – where steel and concrete frame meet wood

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Tyréns
Jönköping, Sverige

Abstract

Located at Östra Strandgatan 24 in Umeå, you'll find the environmentally-conscious office building that offers a modern and sustainable workplace across four floors.
The structure is a cantilevered design where nearly half of the floor area on the three upper office levels hangs within the outer roof structure.

The building is a hybrid construction, combining steel, concrete, and solid wood. Steel is used to support the cantilevered portions, concrete in the stabilizing core, and wood to reduce the weight of the projecting beams.

Thanks to the use of separate contracts, it has been possible to ensure the right materials are in the right places.

The building has achieved the highest certification in environmental construction, which has entailed stringent requirements for factors such as solar heat load, daylight, and noise.

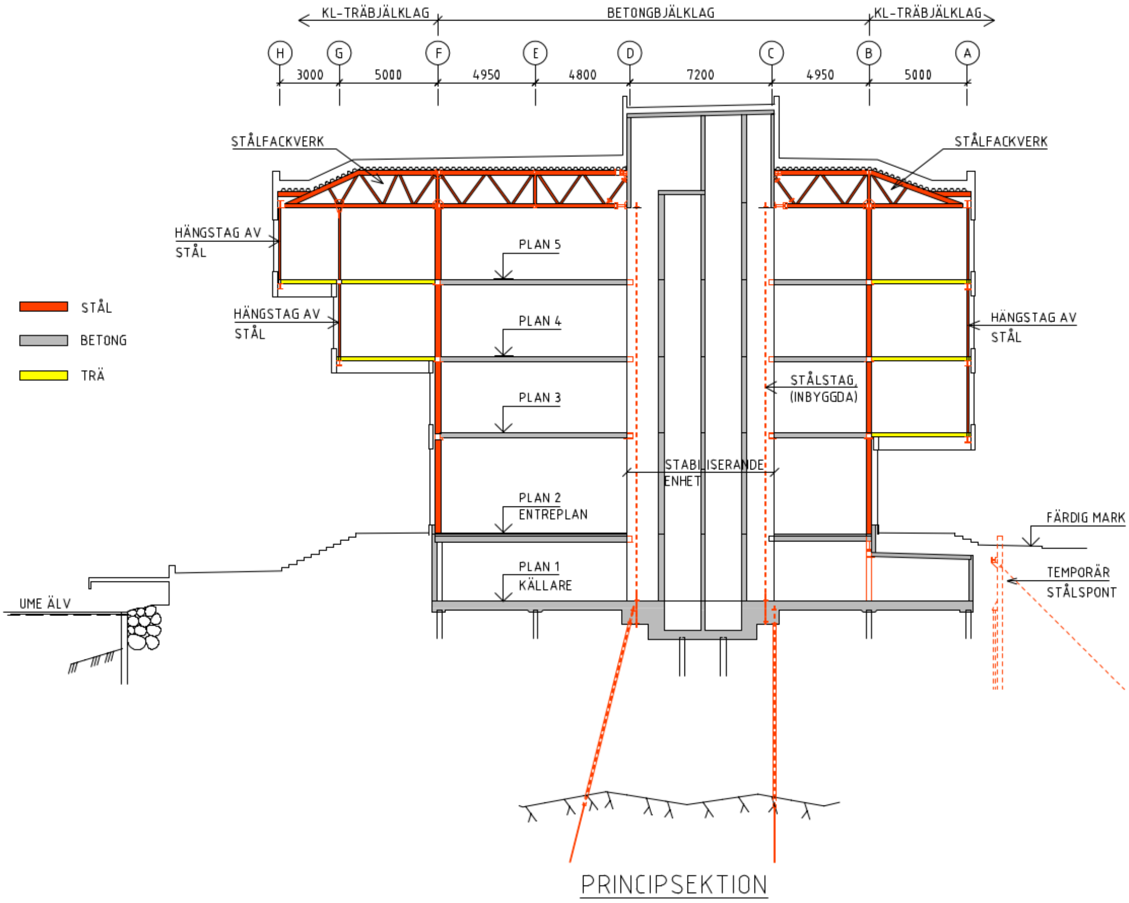
Tyréns has contributed to the construction and acoustics in the project.

1. Structural design

The structure of the building can be described as a suspended structure and it consists of beams and columns of steel and walls of concrete. The floors are made of both prefabricated concrete elements and cross laminated timber elements. Steel trusses are placed in two directions at the steel columns and concrete walls of the top office floor. The trusses extend outside the exterior walls of the second floor and their purpose is to serve as a structure for the roof as well as to hold the suspended floors below by suspension rods. The only stabilizing unit of the building is the stairway shaft of concrete. It contains post tensioned steel rods that are attached to the bedrock far below the building and extends all the way up to the steel trusses at the top of the building.

A material that is very strong compared to its weight is needed to manage the large extensions of the higher floors outside of the exterior of the lower floors. The connection design of the intersecting steel trusses is advanced and vital for the structure. Both the tension rods and their connections needed a material that could manage large tension forces. To fix the stabilizing unit against rotation and tilting it was crucial to use a material that can be prestressed and that also can handle great tension forces. To meet all the requirements above steel is the best material, both when it comes to engineering and architectural purposes as well as economically.

In this structure the use of steel is essential. Other important parameters for this project is the stiffness of the reinforced concrete as a stabilizing unit and the hollow core sections ability to manage wide spans. The cross laminated timber elements in the suspended floors was also important since their low weight led to a significant use of less material. To sum it up: each material is used in an optimal place.



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Fredrik Nordin Byggnadskonstruktör Tyréns

SuperHub Meerstad: the supermarket as a meeting place!

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De Zwarte Hond
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SuperHub Meerstad

Meerstad is the greenest part of Groningen, known for its space, greenery and the lake – the Woldmeer – that was recently created there. It's a place that inspires an energetic lifestyle, where sustainability is the most natural thing in the world. In the coming decades, about 5,000 homes will gradually be built in this area. SuperHub Meerstad will take on the function of the neighbourhood's centre – a function that will grow with the development of the district. SuperHub is about creating the supermarket of the future. The building is more than a supermarket. It's also a meeting place, in the way that the market used to be a place for meetings.

Picture 1: Distant view SuperHub

Building in wood
SuperHub Meerstad is built from wood. We consider timber construction important from the point of view of sustainability and climate. The advantage of building in wood is that the construction site becomes an assembly site. Everything is made in the factory and assembled on site. That means a short construction time, a clean construction site and less chance of mistakes. Wood is light, natural, easily adaptable, has a good insulation value and it captures CO_2 instead of emitting CO_2 like concrete. A wooden building has the pleasant property of providing a healthier indoor climate compared to a traditional building. Wood smells pleasant and provides a natural and warm appearance; it ensures tranquillity and a pleasant quality of stay.

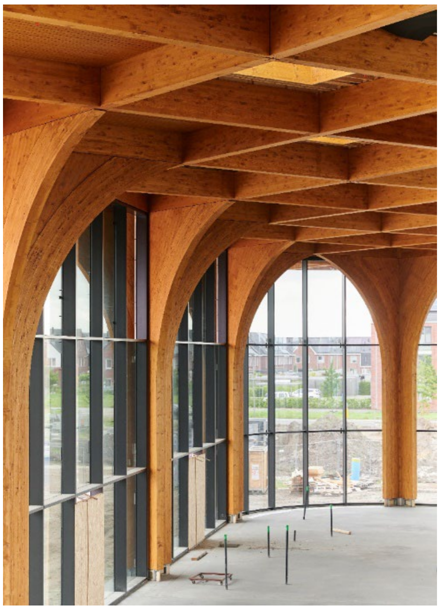
Picture 2: Side view SuperHub

Picture 3: Side view wooden construction and transparent facade

Flexibility and adaptability
The building was deliberately designed with a height and column grid, making it suitable for other functions in the future, such as a community centre or even housing. The floor of the building is designed for a large load and the whole building is one large fire compartment. We have increased the flexibility of the building by not concealing the technical installations in the building, but opting for open installations. The interior and technology are therefore easy to adapt or replace over time.

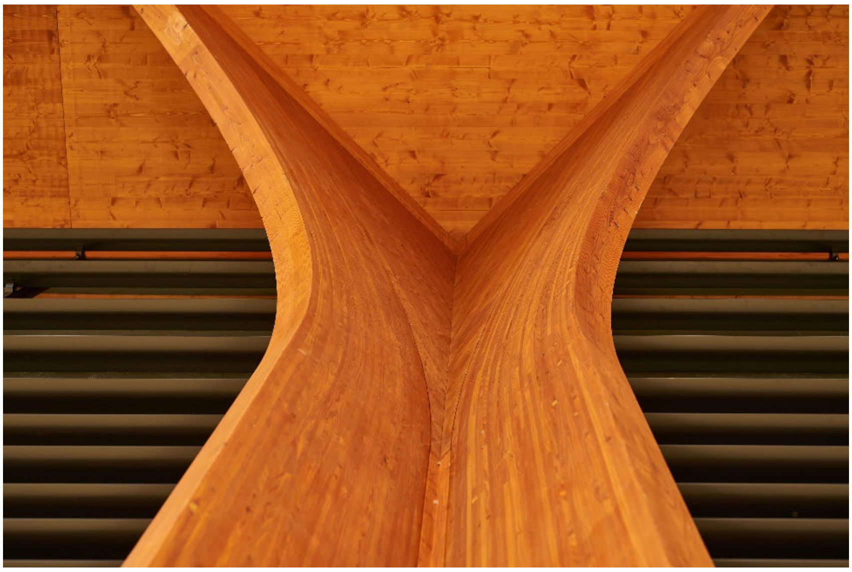
Picture 4: In the future, it will be possible to accommodate other functions

Curved frames and grid
The building consists of a diagonal grid of cross-shaped curved trusses. The shape of the truss changes from a column to a girder thanks to its elegant curvature, which creates a spectacular image. The cross shape of the wooden trusses guarantees the rigidity of the construction and results in a high degree of internal flexibility. With a round or square column the building would fall over, but with this column shape it will remain standing. This means that no large-scale wind bracing is required, ensuring maximum transparency in the façade which has a very slim, steel, storey-high curtain wall with curved corners and with no auxiliary construction. The 10-metre-high building has a large wooden roof with an overhang of five metres. The canopy embraces the environment in an inviting way and shields the transparent building from the sun. The shape of the columns and beams, combined with the diagonal grid, is what creates the cathedral-like experience of the building.

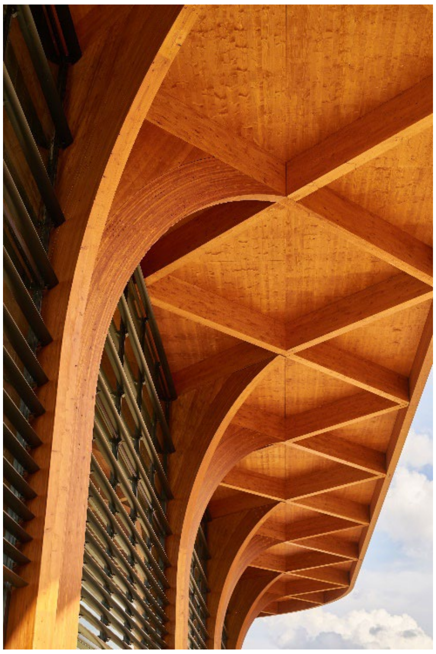


Picture 5: Diagonal grid of cross-shaped curved trusses

Earthquake proof and sustainable roof
Due to its location in this part of Groningen, the building has been made earthquake resistant. The nice thing about wood is that it is light and that it can absorb the vibrations of an earthquake well. If a crack occurs in the wood, further cracking is prevented by the specific use of screws. The roof is also optimally used by installing solar panels and roof plants for bees and other insects. Technology – in the form of an air treatment system and heat/cold storage from the ground – is integrated in the building to ensure an optimal, energy-efficient indoor climate. In the building grid there are several skylights that bring extra daylight into the heart of the building.



Picture 6



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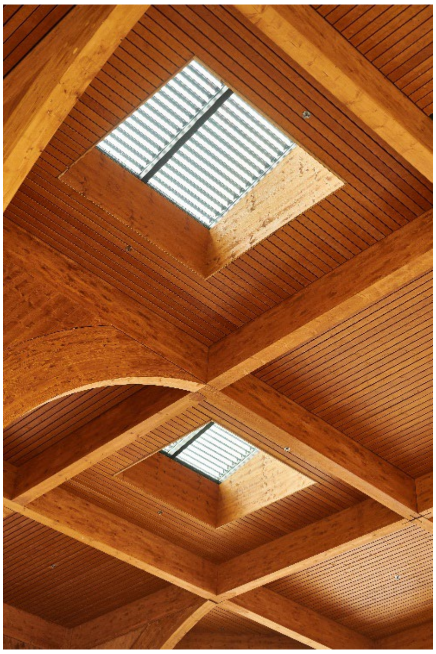

Picture 8

Facilities and experience
The idea behind the design of the building is that it will grow with the developing neighbourhood and continue to offer opportunities for all kinds of functions. Initially a supermarket, later it can also be used as a place to live, or a school, museum or community centre. A pioneering building that grows with the neighbourhood, in addition to providing

basic necessities it also provides spaces for meeting, activity and entertainment. In filling public functions, it acquires a social role. This means that the building will have to be extra attractive to ensure that people enjoy spending time there. The design for SuperHub is currently a spectacular supermarket that offers you views of the surrounding nature while shopping. Shopping here is a special experience. In addition to the supermarket, there is also a café with a terrace in the park and a parcel service point.


Picture 9 & 10: SuperHub Meerstad provides spaces for meeting, activity and entertainment

De Zwarte Hond is a design agency for architecture, urban design and strategy with offices in Groningen, Rotterdam and Cologne. Through a combination of social commitment and craftsmanship, we create high quality projects that are sensitive to their context, the needs of users and the vision of our customer.

Credits Photography
SuperHub Meerstad: Ronald Zijlstra

FYRTORNET: WOOD AS FACILITATOR

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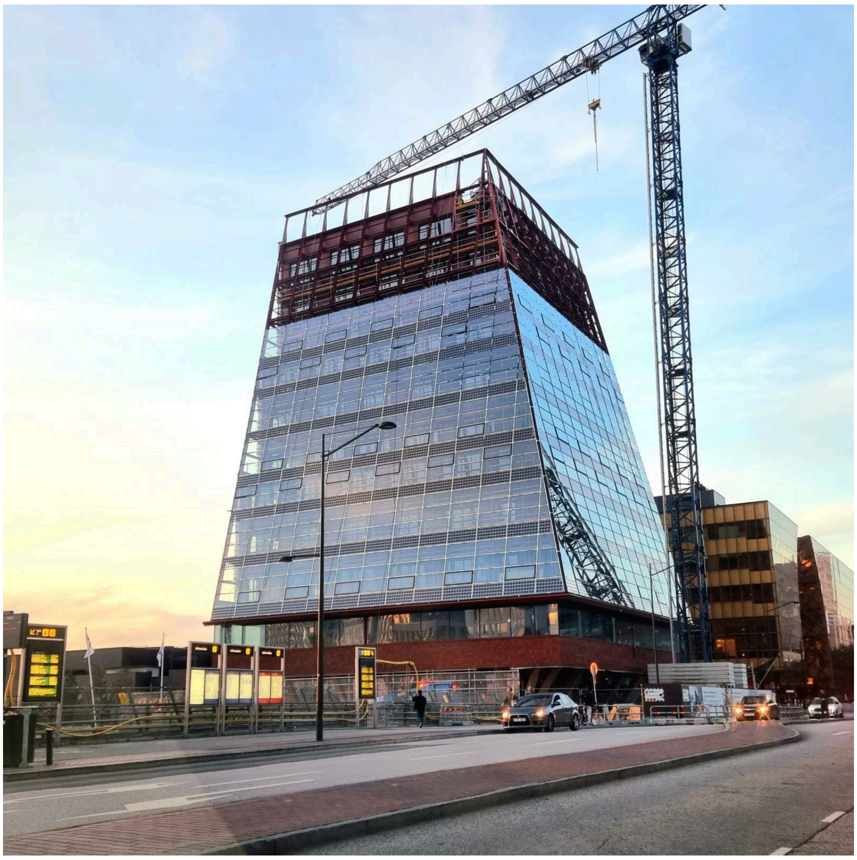
FYRTORNET: WOOD AS FACILITATOR

The Embassy of Sharing exemplifies Wingårdhs process integrating sustainability aspects in an urban development plan. Located in Malmö, the site is an entrance to Sweden from Copenhagen, Denmark. The competition brief, outlined by the municipality, expressed high ambitions for both social and environmental sustainability. The key was to translate this vision and objectives into concrete design principles that responded to the city's actual challenges and needs. Before the first line was drawn a thorough analysis was done of the municipalities guidelines, understanding how the project could contribute and facilitate different aspects of sustainability in the built environment. Parallel to the design development and programming of functions we made contact with local enterprises and possible future key-tenants. Through mapping of local social structures and needs defined by the municipality we managed to create a program of functions that the buildings should respond to.

This process shaped the design of seven independent buildings, connected by a vision of an active, green and diverse public space. Together they share an aspiration to capture a representative cross section of Malmö's diverse population. Each building embodies a concept of solving different aspects of sustainability; The first building to be built is FYRTORNET, Sweden's tallest timber office building. Given the above ambition, wood was the preferred material from the competition onwards. This human-centered, locally anchored and holistic design approach paved way for a progressive detail plan which has been implemented and is now being realized.



Perception of impact sound insulation: psychoacoustics in wooden floor constructions

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Perception of impact sound insulation: psychoacoustics in wooden floor constructions

Abstract

The most popular single-number quantities (SNQs) describing the impact sound insulation (ISI) performance of floors in Europe are $L'_{n,w}$ and $L'_{nT,w}$. They are based on ISI measurements within 100–3150 Hz. Finnish and Swedish building regulations apply $L'_{nT,w}$ $+C_{I,50}$ (50–3150 Hz). Recently, one study proposed that the measurements should be extended even down to 25 Hz for wooden floors, and $L'_{nT,w}+C_{I,25}$ should replace $L'_{nT,w}$ and $L'_{nT,w}$ $+C_{I,50}$. The purpose of this study is to analyze which of these three SNQs predicts the annoyance of natural impact sounds best for wooden floors. First, we built 15 different wooden floors in the ISI laboratory where the ISI was measured by ISO 10140-3 and the SNQ values were determined by ISO 717-2. Furthermore, five types of natural impact sounds (walking, jumping, chair pushing, rubber ball dropping, steel ball dropping) were recorded for each floor. Second, we conducted a psychoacoustic experiment, where 52 participants rated the annoyance of 75 impact sounds (15 floors times 5 sound types). Based on linear correlation analysis, $L_{n,w}$ explained annoyance of natural impact sounds equally well or somewhat better than the other two. From perceptional point of view, it seems to be sufficient to conduct ISI measurements within 100–3150 Hz for wooden floors and assess their impact sound insulation *in situ* using $L'_{nT,w}$ or $L'_{n,w}$.

1. Introduction

The most popular single-number quantities (SNQs) of impact sound insulation in Europe are $L'_{n,w}$ and $L'_{nT,w}$ (Rasmussen, 2019). They are based on impact sound insulation (ISI) measurements within 100–3150 Hz. Finnish and Swedish building regulations apply $L'_{nT,w}$ $+C_{I,50}$ (50–3150 Hz). It requires measurements within 50–3150 Hz, i.e., three low frequency bands are also included (50–80 Hz).

Recently, Ljunggren and Simmons (2022) proposed that the ISI measurements should be extended down to 25 Hz for wooden floors, and $L'_{nT,w}+C_{I,25}$ should replace $L'_{nT,w}$ and $L'_{nT,w}$ $+C_{I,50}$. The proposal was based on a residential survey. However, residential surveys conducted in apartment buildings suffer from at least three sources of uncertainties related to the actual stimulus level: a) actual ISI is not known in every apartment, b) the level, frequency, and type impact sounds produced by neighbor upstairs are different between apartments, and c) masking sound level inside the respondents' apartment varies between apartments. Furthermore, subjective annoyance ratings in apartments are strongly confounded by non-acoustic situational and social factors in apartments. For example, attitude towards the neighbor can significantly moderate the annoyance perception. Therefore, the research proposing extended frequency range down to 25 Hz needs to be verified with a psychoacoustic laboratory experiment before the proposal could be considered.

It is extremely important to use such SNQ in regulations and business that ranks floors in the same order as people subjectively rank them. Objective ranking of ISI is based on measurements using tapping machine as a stimulus. Tapping machine provides a constant and loud broad-band structure borne sound to the floor. Laboratory measurements in one-third octave bands are conducted in laboratory and in buildings by ISO 10140-3 and ISO 16283-2, respectively. Thereafter, the SNQs ($L'_{nT,w}$ and $L'_{nT,w}$ $+C_{I,50}$) are determined by ISO 717-2. However, subjective ranking in residential apartment is based on natural impact sounds that neighbors produce upstairs. For example, walking causes very different sound spectrum compared to tapping machine. Therefore, natural and realistic impact sounds shall be used in experimental studies investigating the subjective performance rating of floors.

Recently, rubber ball (soft/heavy impact source of ISO 10140-3 and ISO 16283-2) has been adopted as an alternative sound source in impact sound insulation measurements, since its sound resembles running children or ball dropping. Therefore, it is reasonable to use rubber ball also in experimental studies.

The purpose of our psychoacoustic experiment was to analyze which of the three SNQs ($L'_{nT,w}$, $L'_{nT,w}+C_{I,50}$, or $L'_{nT,w}+C_{I,25}$) predicts the annoyance caused by natural impact sounds best for wooden floors.

The full version has been published in an international journal (Hongisto et al., 2023a).

2. Materials and methods

2.1. Floors

The first part of the research involved sound insulation tests for 30 different wooden floor constructions according to ISO 10140 and ISO 717. They are reported in the open data journal paper (Hongisto et al., 2023b).

The $L'_{nT,w}$ requirements in Europe vary within 48–68 dB (Rasmussen, 2019). The floors used in psychoacoustic experiment were chosen to cover that range so that the results can be applied throughout the Europe. Out of the data of 30 floors, fifteen were chosen to the psychoacoustic experiment.

Two different load-bearing slabs were used in these floors (Fig. 1):

- Open-box timber 370 mm (O)
- Cross-laminated timber 260 mm (C)

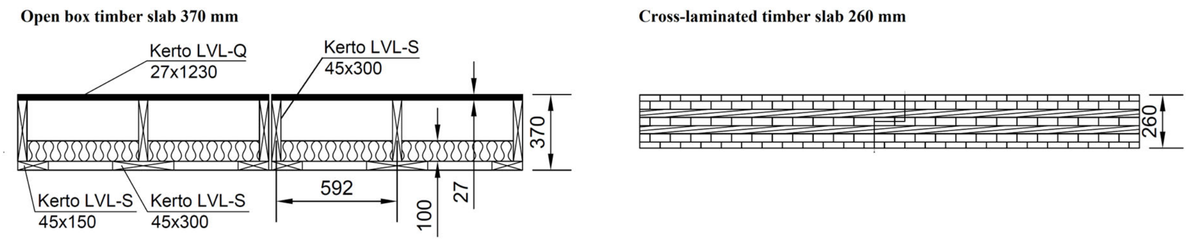

Fig. 1. The load-bearing slabs used in the research.

The floors consisted of the slab, suspended ceiling, floating floor, or both. All floors had laminate covering. Schematic constructions are described in Fig. 2.

The measured values of ISI are shown in Fig. 3 and Table 1. Since we did the measurements in laboratory conditions, we report normalized impact sound pressure levels (L_n). In field measurements, L'_n nor L'_{nT} are used (dash denotation). However, all these three quantities are based on exactly similar measurements so that the conclusions of our study apply to all of these three quantities.

The experimental sounds presented to the participants consisted of recordings made for 15 wooden floors. Since the spectrum of actual living sounds vary a lot, we chose impact sound types varying a lot in frequency content. On each floor, five natural impact sound types were presented and recorded:

- rubber ball drop (2.5 kg, 25 cm drop height)
- steel ball drop (33 g, 25 cm drop height)
- walking on 120 bpm pace (4.3 km/h)
- jumping in place with 140 bpm pace
- chair pushing (4.3 km/h).

These impact sounds were recorded right after the ISI test of the floor. During that, the recording room under the floor was transformed to a low-reverberant space (reverberation time under 0.50 s) to resemble room acoustics of typical living rooms. It was made by installing fixed absorption sheets to fixed positions. The sound pressure level of background noise was under 16 dB L_{Aeq} (under hearing threshold). Recording was made using a condenser microphone and digital recorder in two positions of the room (A and B) to take the variations of sound pressure level in the room (due to room modes) into account. Two positions also enabled us to conduct two independent psychoacoustic experiments A and B. This paper focuses on Experiment A.

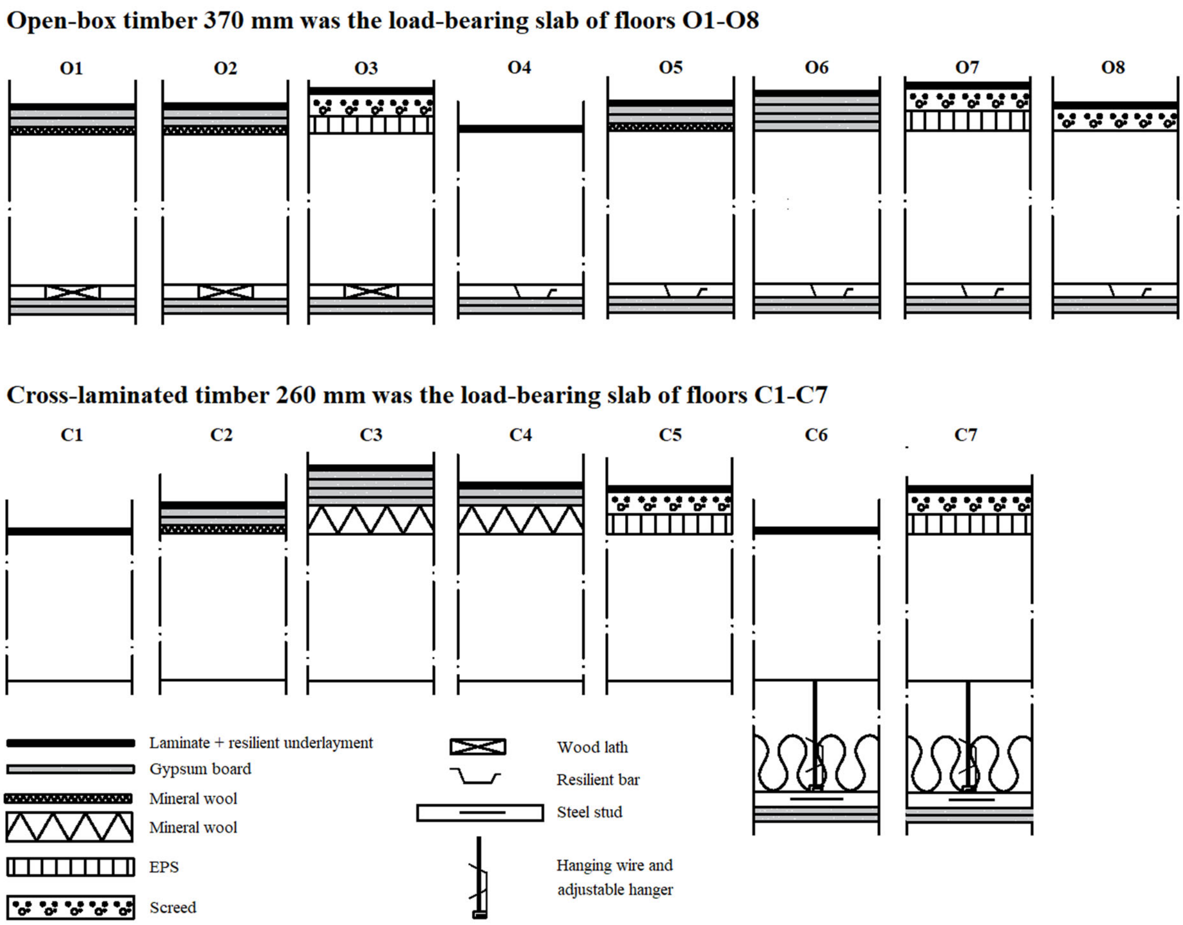

Fig. 2. Schematic constructions of the fifteen studied floors. Slabs are shown here as empty boxes and their constructions are shown in Fig. 1.

The sound samples used in the psychoacoustic experiment were approximately 8 seconds long since it has been proven in several previous studies that subjective rating is formed already after a couple of seconds of listening time: the rating changes very little after that. Sound types 3–5 were presented with their original paces. Sound types 1–2 were presented so that the same impulse was repeated at a pace of 60 bpm.

The recorded sounds were presented to the participants in the psychoacoustics laboratory. The sound level of background noise of the psychoacoustics laboratory was very low, 14 dB L_{Aeq} (under hearing threshold) being smaller than the faintest stimulus (Fig. 4). The sounds were presented to the participants using headphones, which had nearly flat frequency response within 20–3150 Hz (Beyerdynamic DT 1990). Still, the frequency response of headphones was compensated using 1/3-octave band filtering. Playback level was measured using head-and-torso simulator before the experiment to guarantee that the participants hear the sounds exactly similarly as they were recorded. The levels were adjusted so that the measured level was within 1.5 dB L_{Aeq} from the target level measured in the impact sound laboratory.

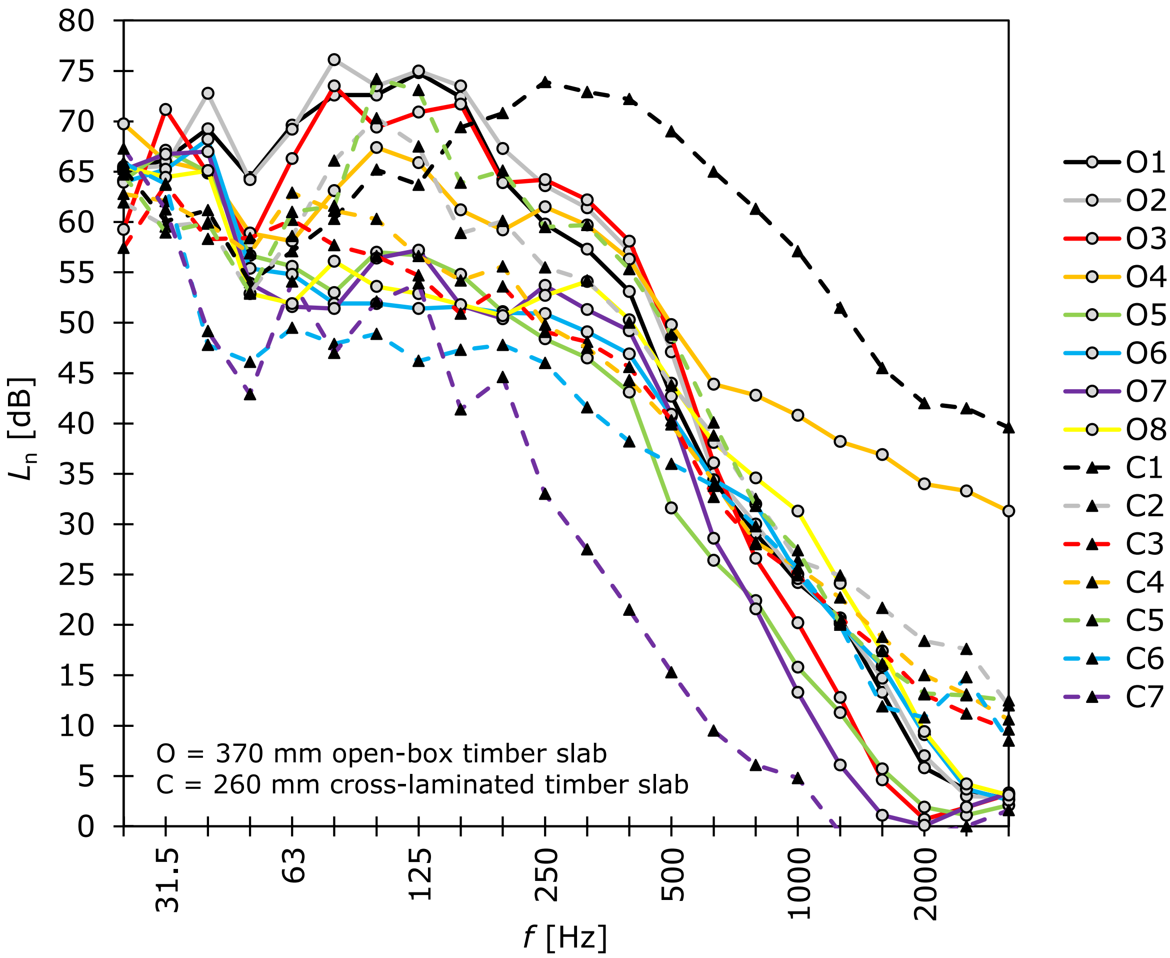

Fig. 3. Normalized impact sound pressure level, L_n, as a function of frequency, *f*, measured in laboratory conditions for the 15 wooden floors.

Table 1. The single-number values of the 15 wooden floors.

Floor	$L_{n,w}$ [dB]	$L_{n,w} + C_{I,50}$ [dB]	$L_{n,w} + C_{I,25}$ [dB]
O1	61	65	66
O2	63	66	67
O3	60	64	64
O4	56	58	60
O5	46	49	56
O6	44	47	57
O7	47	48	57
O8	46	48	56
C1	65	65	65
C2	55	59	59
C3	45	51	54
C4	47	53	55
C5	60	63	63
C6	39	42	53
C7	38	44	54

2.2. Psychoacoustic experiment

The psychoacoustic experiment involved 52 normal-hearing participants (33 female, mean age 27 y). The experimental plan was approved by TUAS ethics committee.

The experiment involved five parts: hearing threshold test, familiarization to sounds, rehearsal or rating, Experiment A (75 sounds), and Experiment B (75 sounds). This paper contains only the results of Experiment A since the results were similar in Experiment B.

The task was to rate the annoyance of each sound using an 11-step rating scale (0 Not at all, 10 Extremely much). The participants had to listen to each sound for 8 seconds before the annoyance rating scale became visible. The sound looped until rating was given.

The list of 75 sounds consisted of 5 blocks (due to 5 sound types) to avoid too chaotic variation of impact sound types. The order of 5 blocks and 15 sounds within each block was randomized between participants.

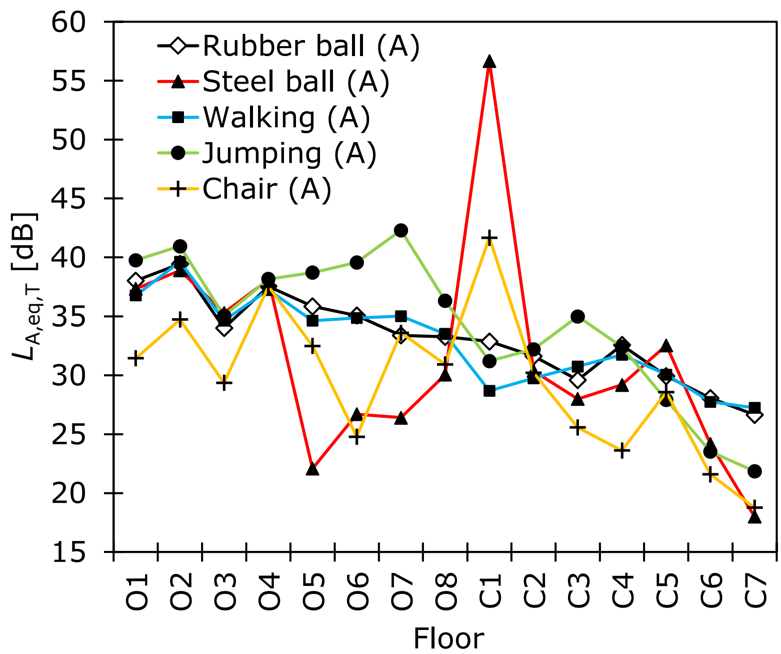

Fig. 4. The A-weighted equivalent sound pressure level of the 75 experimental sounds in Experiment A (5 sound types, 15 floors). The level of background noise during recordings was 16 dB.

The analysis describing the association between mean annoyance of all participants and single-number values of the 15 floors was made using Pearson's correlation coefficient, r_P. This was made separately for each sound type. An example of the analysis method is shown in Fig. 3. Coefficient values exceeding 0.64 are statistically significant ($p<0.01$, 2-way analysis). Mean of 52 participants was justified to be used since the responses of 52 participants were mostly normally distributed.

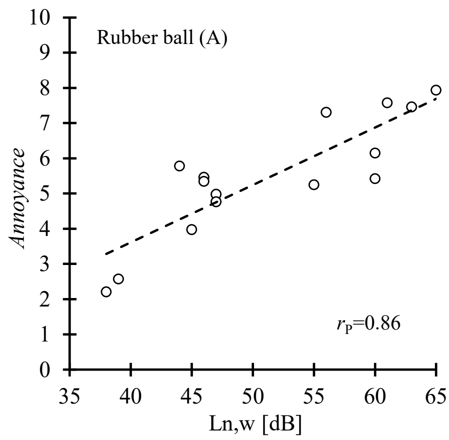

Fig. 5. Visual clarification of the content of the correlation analysis used to derive the main results. The figure shows the association between the mean annoyance (N=52) caused by rubber ball drop and normalized weighted impact SPL, $L_{n,w}$, measured for the 15 floors.

3. Results

The results are shown in Table 2. The larger is the value, the better is the association between the single-number values and perceived annoyance. $L_{n,w}$ obtained the highest value for each sound type. The differences between the correlation coefficients were not statistically significant for any sound type.

Table 2. Pearson's correlation coefficient explaining the association between the annoyance and single-number values of 15 floors in Experiment A. Values over 0.64 are statistically significant.

	Single-number quantity		
Sound type	$L_{n,w}$	$L_{n,w} + C_{I,50}$	$L_{n,w} + C_{I,25}$
Rubber ball	0.86	0.81	0.84
Steel ball	0.80	0.76	0.71
Walking	0.69	0.68	0.68
Jumping	0.59	0.54	0.57
Chair	0.75	0.65	0.64

4. Discussion

$L_{n,w}$ explained annoyance of natural impact sounds equally well or somewhat better than $L_{n,w}+C_{I,50}$ or $L_{n,w}+C_{I,25}$, depending on impact sound type. The finding is against Ljunggren and Simmons (2022) suggesting the opposite. Since our experimental setup is almost free from uncertainties related to stimulus level (each participant heard the same sounds), the scientific proof of these results is very strong. Since these two studies contradict, it is important to have further research in this field.

Although the wooden floors have poor impact sound insulation below 100 Hz, and the linear SPL of natural impact sounds (except for Steel ball) was mostly higher below 100 Hz than above it (not shown in this paper), annoyance perception of natural impact sounds could still be explained by impact sound pressure levels measured within 100–3150 Hz. This may be caused by the fact that hearing sensitivity (equal-loudness curves of ISO 226) reduces more strongly towards low frequencies than the SPLs of impact sounds increase. A psychoacoustic follow-up analysis on this should be made to better understand the perceptional reasons for our finding.

It is evident that measurements down to 50 or 25 Hz do not increase the explanative power of objective rating of wooden floors. From perceptional point of view, it seems to be sufficient to conduct ISI measurements within 100–3150 Hz for wooden floors and to assess their ISI performance using $L_{n,w}$. In field conditions, the counterparts are $L'_{nT,w}$ and $L'_{n,w}$.

Our experimental method of assessing the superiority of the two SNQs was strong since the experiment contained a large span of wooden floors, accredited ISI tests in a fixed laboratory, large number of natural impact sounds with extremely different spectra, large number of participants, highly controlled recording environment, and a qualified psychoacoustic laboratory, which enabled the precise listening of even the faintest impact sounds. In addition, all floors had laminate covering providing constant friction. This is very important to obtain comparable chair pushing sounds. These factors lead to the fact that the stimulus was very well controlled. The participants could focus on the stimulus with very high attention. Therefore, the outcomes of the experiment should reflect the perception of natural impact sounds transmitted by wooden floors to the best possible precision.

The volume of the receiving room of the sound insulation test laboratory was 76 m^3. In that environment, the following relationship holds: $L'_{nT} = L_n - 3.1$ dB.

The results only concern wooden floors within 38–65 dB $L_{n,w}$ (or 35–62 dB $L'_{nT,w}$). It would be useful to conduct a similar experiment also using a steel-reinforced concrete as a load-bearing slab to see how the results deviate from this experiment.

5. Conclusions

$L_{n,w}$ explained annoyance of natural impact sounds equally well or usually better than $L_{n,w}+C_{I,50}$ or $L_{n,w}+C_{I,25}$. Based on perception, it seems to be sufficient to conduct impact sound insulation measurements of wooden floors within 100–3150 Hz and assess their sound insulation using $L'_{nT,w}$ or $L'_{n,w}$.

6. Acknowledgements

This project belongs to Tandem Forest Value 2019 call managed by the Royal Swedish Agricultural Academy. The Swedish work was funded by the Royal Swedish Academy of Agriculture and Forestry and the Finnish work was funded by the Finnish Ministry of the Environment (Agreement VN/14328/2019). We thank the companies who provided construction materials: VVR-Wood Ltd, CLT Finland Ltd, and Saint-Gobain Finland Ltd.

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Vibration Study for Mass Timber Applications with Focus on Wall-to-Floor Connection Systems

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Vibration Study for Mass Timber Applications with Focus on Wall-to-Floor Connection Systems

Abstract

Due to the widespread use of timber products to create versatile building types, regulations about building physics aspects, especially regarding the noise protection have gained more relevance in the frame of architectural and engineering design. In case of mass timber buildings made of CLT, the applied floor layups feature a comparatively high protection against a direct transmission of impact sound. Consequently, minimizing the flank sound transmission is of significant importance to reduce the total impact sound pressure to a tolerable limit. Current detail solutions consist of soundproofing interlayers to decouple the CLT wall and floor components. Unfortunately, they lose a high share of their efficiency if common fastening systems are applied for load transmission in these joints. To face this problem, a novel, sound-optimized angle bracket "SHERPA Sonus", which consists of an additional, inherent decoupling zone, was developed. The present contribution summarizes a related impact sound test campaign, which successfully verifies the positive impact of this novel connector on the size of the vibration reduction index K_{ij}. It can be shown that the novel connector does not significantly decrease K_{ij}, determined for an unconnected joint.

1. Introduction

Due to the development and optimization of powerful and efficient timber products such as glued and cross laminated timber (GLT and CLT) or laminated veneer lumber (LVL), the high grade of pre-fabrication and automation, the development of efficient fastening systems and due to a fast, silent and dry assembly, more and more buildings are made of timber nowadays. As these constructions naturally have a very low carbon footprint they are seen as a relevant measure against global warming by climate politics. This matter will support the ongoing trend in future.

One consequence of the widespread use of timber as a building material is an increasing number of requirements and legal boundary conditions, architects and engineers have to deal with. Multi-storey residential or office buildings, hotels, educational buildings such as schools or kindergartens and healthcare facilities demand for instance much more concentration on the building physics aspects than traditional timber buildings such as single family houses, halls or agricultural facilities do. The nature of timber as a lightweight material especially leads to a challenge regarding the protection of the building users against noise due to airborne or structure-borne / impact sound.

Concentrating on the latter, in the European Union member states there are several national judicial documents of how to handle the noise due to impact sound. In Austria, for example, this is regulated by the OIB-Guideline 5 (OIB, 2023), which limits the weighted normalized impact sound pressure $L'_{nT,w}$ to max. 48 ÷ 55 dB, created in a source room with varying purpose and received in a room with common purpose. Considering both rooms in a way that one is positioned below the other and separated by a wooden floor system (Figure 1), not only the direct impact sound transmission (expressed by $L_{n,d,w}$ as the weighted normalized impact sound pressure level for the direct path in ON EN ISO 12354-2, 2017) but also the one through the building components, which are connected to the wooden floor system (i.e. the wooden wall systems) has to be considered when determining the given value for $L'_{nT,w}$. Following ON EN ISO 12354-2 (2017), the latter property, denoted as the weighted normalized flanking impact sound pressure level for the flanking path ij is given by

$$L_{n,ij,w} = L_{n,eq,0,w} - \Delta L_w + \frac{R_{i,w} - R_{j,w}}{2} - \Delta R_{j,w} - K_{ij} - \left(10 \lg \frac{S_i}{l_0 \cdot l_{ij}}\right), \qquad (1)$$

with $L_{n,eq,0,w}$ as the equivalent weighted normalized impact sound pressure level of the bare floor, ΔL_w as the weighted reduction of impact pressure level by a floor covering, $R_{i,w}$ as the weighted sound reduction index of the floor (i), $R_{j,w}$ as the weighted sound reduction index of element (j), $\Delta R_{d,w}$ as the weighted sound reduction index improvement of an additional layer on the receiving side of the flanking element (j) and K_{ij} as the vibration reduction index for path ij.

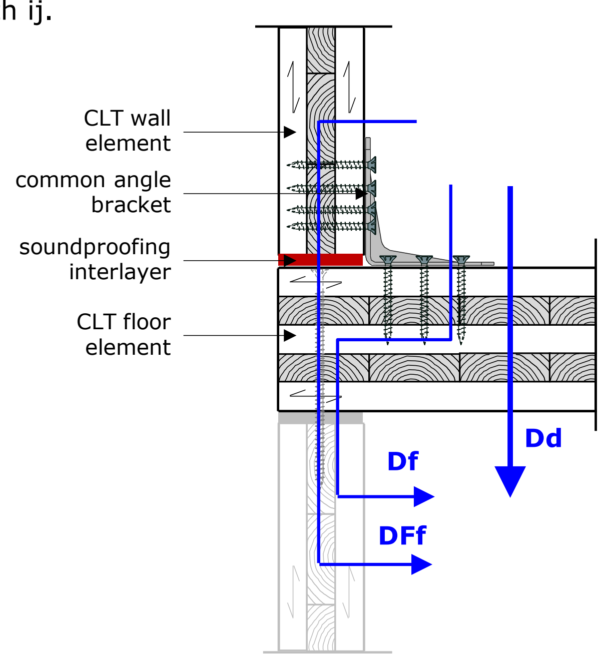

Figure 1: Wall-to-floor-to-wall joint of a typical CLT building with direct (Dd) and flanking transmission paths (DFf and Df)

As $L_{n,d,w}$ and $L_{n,ij,w}$ are summed up on logarithmic level to determine $L'_{nT,w}$ it becomes evident that the impact of $L_{n,ij,w}$ on the size of $L'_{nT,w}$ increases with decreasing $L_{n,d,w}$ (Blödt et al., 2019). Or in other words: the higher the quality of the wooden floor system the more important the flank transmission.

Walls and floors in cross laminated timber as the favored building product for creating so-called "mass timber buildings" feature a high mass and stiffness if e.g. compared to timber frame constructions. Consequently, especially such constructions benefit from a reduced flank transmission, expressed by a high vibration reduction index K_{ij}. The commonly applied way in practice to increase K_{ij} is to decouple the CLT wall and floor elements by arranging soundproofing, resilient interlayers between them (Figure 1). Past investigations where e.g. a PUR-interlayer according to Z-16.32-499 (2018) was applied to separate 3-layered CLT-walls from 5-layered CLT floors in form of an L-joint (the highlighted part in Figure 1) indicate an increase ΔK_{ij} of approx. 10 dB if compared to the same joint without interlayer (ACOM Research, 2023a; ΔK_{ij} as a difference of single values, representing a frequency bandwidth of 50 ÷ 5000 Hz).

Due to mechanical boundary conditions, however, fastening systems such as self-tapping timber screws, angle brackets or hold-downs have to be additionally arranged to connect the CLT elements at these wall-to-floor joints. This measure maintains force equilibrium but has a pronounced negative impact on the size of K_{ij}. Further impact sound measurements, which were carried out in the frame of the aforementioned campaign as well, indicate a loss of ΔK_{ij} of approx. 80 % if conventional angle brackets (e = 500 mm) are applied for this type of connection (ACOM Research, 2023b).

This leads to the conclusion that the application of soundproofing interlayers to decouple CLT walls and floors is only efficient if the fastening system is optimized against impact sound transmission as well. The present contribution deals with this matter, i.e. by comparing the performance of a novel, sound-optimized fastening system with the one of conventional angle brackets in regard to K_{ij}. In the remaining sections, the methodology and outcomes of a related experimental campaign are summarized and discussed.

2. Materials and Methods

2.1. General

It is worth to be mentioned that the experimental campaign presented herein was carried out by the TGM ("Technologisches Gewerbemuseum", Vienna, Austria) under the supervision of the authors of the present contribution. For a more detailed description the interested reader is referred to the related test report (Müllner, 2022).
As introduced in Section 1, the main aim of the test program was to determine the impact of a sound-optimized fastening system on the size of K_{ij}. Besides a related comparison of the fastening system (note: in addition to the novel connector a common angle bracket as well as no mechanical connection were applied for the joint, c.f. Section 2.2) the distance between / the number of fasteners e = {500, 1000, 2000} mm / n = {5, 3, 2} were varied. In addition, different levels of a vertical stress p = {0.18, 0.28, 0.40} N/mm² were applied on the joint, which shall simulate a different number of quasi-permanent storey-loads on this supporting and consequently determine the related impact on K_{ij}. Further parameters such as the dimension and lay-up of the CLT wall and floor elements as well as the dimension of the soundproofing interlayer remained constant.

2.2. Materials

In order to be consistent with the investigations reported in Section 1 (ACOM Research, 2023a), the L-joint, which served to determine the vibration reduction index K_{ij} for the given flanking path was made by a 3-layered CLT wall element with the dimensions l x b x t_{CLT} = 2450 x 2520 x 100 mm³ (30|40|30) and a 5-layered CLT wall element with the dimensions l x b x t_{CLT} = 2450 x 3450 x 140 mm³ (40|20|20|20|40) and was arranged upside down if compared to the detail highlighted in Figure 1. The elements were separated by a PUR-interlayer of type "Regufoam 680" according to Z-16.32-499 (2018) with a thickness t of 12.5 mm.
The angle bracket, which served as a reference for the evaluation of the sound-optimized fastener, was a common product for such a purpose. Its nominal dimensions are h x b x l x t = 105 x 105 x 90 x 3 mm^4. The sound-optimized fastener, which is denoted as "SHERPA Sonus" (type L) and which was specifically developed to maximize K_{ij}, shall be introduced in brief. As illustrated in Figure 2, it consists of two aluminum components, one rectangular sheet with h x b x t = 130 x 235 x 3 mm³, which serves to connect the CLT wall element, and one angle with h x b x l x t = 70 x 66 x 235 x 3 mm^4, which serves to connect the CLT floor element. Both connections are regarded as metal-to-timber shear joints with d = 4 mm nails or d = 5 mm screws as dowel-type fasteners. Furthermore, the angle component consists of 6 boreholes to additionally insert d = 8 mm special screws according to ETA-12/0067 (2022) into the floor element to increase the load-carrying capacity and stiffness of the Sonus-connector.
To achieve an efficient sound isolation, the metal components are decoupled by a PUR soundproofing interlayer of type "Regofoam 990 plus" according to Z-16.32-499 (2018). In a clear contrast to comparable sound-optimized fastening solutions, there is a glued connection between the aluminum and the PUR interlayer (one-component cyanacrylat adhesive) instead of a mechanical one realized with screws or nails. A comprehensive overview of this novel connector is e.g. given in the related product datasheet (SHERPA connection systems GmbH, 2023).

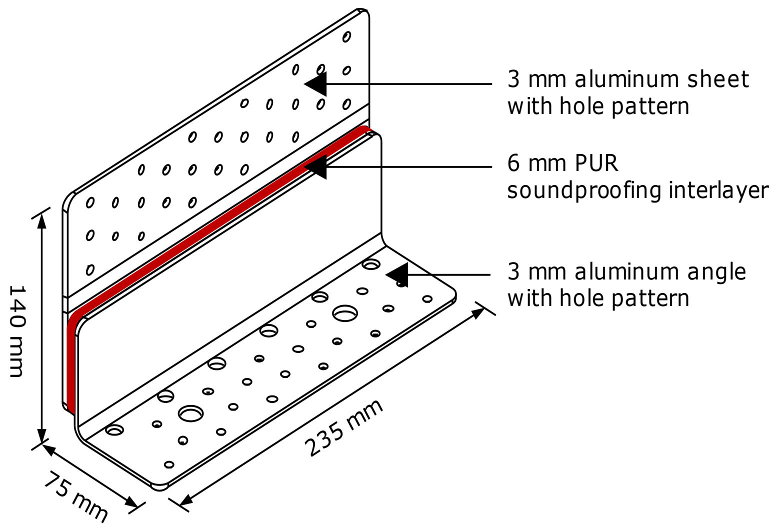

Figure 2: 3D-illustration of the sound-optimized fastener "SHERPA Sonus", exemplarily for type L

2.3. Methods

This Subsection summarizes the applied methodology of the impact sound tests, which are comprehensively described in the related test report (Müllner, 2022). Before the sound test was started, the vertical stress (with varying size) was applied on the supporting area of the L-joint. This was done with two hydraulic cylinders, situated at the third points along the connection line. A constant load distribution was achieved by arranging steel plates and timber beams between the hydraulic cylinders and the top surface of the CLT floor element.
As described by Müllner (2022), the vibration reduction index K_{ij} of the L-joint then was measured according to ON EN ISO 10848-3 (2018) in both path directions, whereby the measurement device "Sinus Messtechnik Soundbook octav" with the software package "SAMURAI 1.7.14" was used. The impact sound stimulation was conducted by an electro-dynamical shaker of type "4809 (B&K) (SN: 85008)" at four positions per path direction (exposition time 10 s). The particle velocity level L_v on the CLT surfaces was measured by vibration sensors of type "Brüel & Kjaer Type 4370" and charge conditioning amplifiers of type "Brüel & Kjaer Type 2635", whereby a spatial average of three measurement positions was determined per stimulation point. For all measurements, third octave filters with a frequency bandwidth of f = 50 ÷ 5000 Hz were applied.

3. Test Results and Discussion

A comprehensive compilation of $K_{ij}(f)$, as average values of several measurement series per parameter configuration, is given in Müllner (2022) in graphical as well as in tabular form in dependence of the frequency f. In the present contribution, only single values of K_{ij} (determined according to ON EN ISO 10848-1, 2018; with $K_{ij}(f)$ as a basis) are considered.
The related results of K_{ij} are given in Table 1 in dependence of the fastener configuration and the vertical stress conditions. Comparing K_{ij} for varying p = {0.18, 0.28, 0.40} N/mm² neither a significant difference in the size nor a certain tendency due to an increasing/decreasing p can be observed. To increase the number of observations it is thus reasonable to treat the dataset independently from p and to average the three test results per fastener configuration.
The averaged values of K_{ij} are also given in Table 1 and graphically illustrated in Figure 3, now with the fastener configuration as the only remaining group of parameters. Thereby, two main observations are worth being discussed: first, for both examined fastening solutions, the same trend in form of a slight increase of K_{ij} with increasing e / decreasing n is given. This confirms the known fact, that the number of contact points (= fasteners), which bypass the soundproofing interlayer in form of a direct impact sound transmission from the floor to the wall element has a negative impact on the vibration reduction. And second,

a clear benefit of the sound-optimized connector if compared to the common angle bracket can be observed. While the application of the common angle bracket decreases K_{ij} of the disconnected joint by a maximum of 8.9 dB (or about 40 %), K_{ij} of the L-joint with the novel SHERPA Sonus L connectors remain on a similar level.

Table 1: Results of K_{ij} (single values) in dependence of the vertical stress and fastener configuration (Müllner, 2022)

<table>
<tr><th rowspan="2">fastener</th><th>distance e</th><th>number n</th><th colspan="4">K_{ij} [dB]</th><th>ΔK_{ij}*</th></tr>
<tr><th>[mm]</th><th>[-]</th><th>0.18 N/mm²</th><th>0.28 N/mm²</th><th>0.40 N/mm²</th><th>average</th><th>[dB]</th></tr>
<tr><td>none</td><td>-</td><td>-</td><td>23.7</td><td>23.8</td><td>23.3</td><td>23.6</td><td>0.0</td></tr>
<tr><td rowspan="3">common angle bracket</td><td>500</td><td>5</td><td>14.5</td><td>14.5</td><td>15.1</td><td>14.7</td><td>-8.9</td></tr>
<tr><td>1000</td><td>3</td><td>16.3</td><td>17.2</td><td>16.6</td><td>16.7</td><td>-6.9</td></tr>
<tr><td>2000</td><td>2</td><td>16.8</td><td>17.2</td><td>16.6</td><td>16.9</td><td>-6.7</td></tr>
<tr><td rowspan="3">SHERPA Sonus L</td><td>500</td><td>5</td><td>21.0</td><td>21.3</td><td>21.1</td><td>21.1</td><td>-2.5</td></tr>
<tr><td>1000</td><td>3</td><td>22.4</td><td>22.2</td><td>21.9</td><td>22.2</td><td>-1.4</td></tr>
<tr><td>2000</td><td>2</td><td>22.5</td><td>22.7</td><td>22.5</td><td>22.6</td><td>-1.0</td></tr>
<tr><td colspan="8">* referred to 'none'</td></tr>
</table>

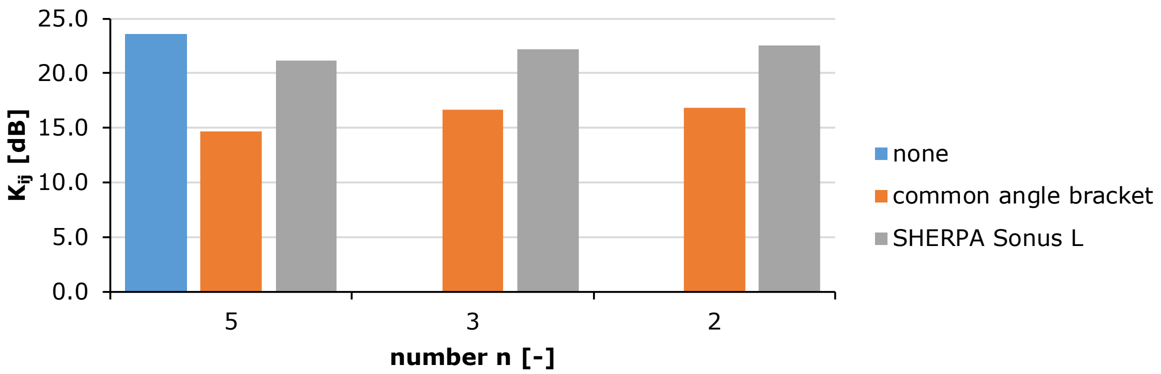

Figure 3: Results of K_{ij} (single values) in dependence of the type and number of applied fasteners

4. Summary and Conclusions

The present contribution summarizes a test campaign, which was carried out to determine the vibration reduction index K_{ij} for CLT wall-to-floor joints with different vertical stress conditions and fastener configurations. The latter comprised a variation of the distance between / the number of two types of fasteners along the joint line, namely a common angle bracket and the novel, sound-optimized connector "SHERPA Sonus" (type L). Based on the results explained in Section 3, the following conclusions can be drawn:

First, for the given test setup and parameter variation no impact of the vertical stress on the size and behavior of K_{ij} was observed. This simplifies the related design process.

Second, the known negative impact of a decreasing distance between / an increasing number of connectors along the joint line on K_{ij} was confirmed. However, as the difference of ΔK_{ij} between e = 500 mm and 2000 mm results to be only approx. 1.5 dB, the lower value of K_{ij} can be considered for the design process without a significant underestimation of the real performance.

Third, for the novel, sound-optimized connector "SHERPA Sonus" a significantly better performance against impact sound if compared to the common angle bracket can be observed. The negative impact of mechanical fastening the wall-to-floor joint could be reduced to a minimum. Taking the ratio of the characteristic capacity against shear loads $R_{2/3,k}$ of the novel connector and the common angle bracket of approx. 3:1 into account, an increase of K_{ij} of approx. 6.5 dB can be achieved.

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Tall Timber Buildings Subjected to Wind Loads - Full Scale Experimental Dynamics

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Tall Timber Buildings Subjected to Wind Loads - Full Scale Experimental Dynamics

Abstract

Wind-induced dynamic excitation is a governing design action determining size and shape of modern Tall Timber Buildings (TTBs). The wind actions generate dynamic loading, causing discomfort or annoyance for occupants due to the perceived horizontal sway, i.e. a vibration serviceability problem. The DynaTTB project, funded by the ForestValue research program, mixed on-site measurements on timber buildings, for identification of the structural system, with numerical modelling of timber structures. The goal was to identify and quantify the causes of vibration energy dissipation in modern TTBs and provide key elements to finite element models. This paper presents an overview of the project.

The paper also presents measurements using forced vibration conducted on the seven-storey timber building Eken in Mariestad in Sweden. The main objective is to estimate the building's dynamic properties from test data. The eigenfrequencies, mode shapes and their scalings are useful to calibrate numerical models. However, the most important outcomes are the estimates of the modal damping values. The test data shows that the modal damping is roughly equal to 2% of the critical viscous ones for the eigenmodes extracted.

1. Introduction

The complexity of the design and construction of a building increases with its height and number of storeys. Tallness is relative to experience, situation, or context so the definition of a Tall Timber Building (TTB) cannot be universal. Complexity is found in the production on the construction site due to a high building's height but also in the need for extra technical systems and control. The increased height means higher vertical loads caused by higher weight but also significantly higher horizontal wind loads. For taller structures, the wind load can generate dynamic effects on the structure which must be included in the serviceability design. The building height for which sway is necessary to consider in the design of the structural system, is lower than for other building materials such as steel or concrete. The number of storeys where wind-induced vibrations govern the design vary dependent on the building system, building shape and wind speed in the actual location.

The dynamic response of a structure is governed by four quantities: the mass, the damping, the stiffness, and the dynamic load. The damping is the one that is hardest to predict; reliable models are rare and most often the damping is taken from tests or as one value of modal viscous damping taken from rule of thumbs. One of the primary objectives of the "Dynamic Response of Tall Timber Buildings Under Service Loads" (DynaTTB www.dynattb.com) project is to broaden the knowledge base regarding damping in timber buildings. Such a data base is useful during the development of future, possibly even taller than the tallest today, high rise timber buildings. For modelling purposes, it is also important to have information regarding resonance frequencies, mode shapes and modal masses.

This paper will present an overview of the main results of the DynaTTB project. Furthermore, the paper will describe the forced vibration test campaign on the building Eken in Sweden. The measurement campaign was performed in the spring of 2022. The paper also presents some of the test results in the form of frequency response functions (FRFs) and modal properties for some of the extracted modes.

The DynaTTB project was done in co-operation between RISE, Linnaeus university, NTNU, CSTB, University of Exeter, University of Ljubljana and InnoRenew with support from the companies Moelven Töreboda, Moelven Limtre, Sweco Norway, Smooth and Wallworks, Arbonis and Eiffage. More in-depth results from the project can be found in (Abrahamsen et al., 2020, 2023; Ao & Pavic, 2021; Flamand & Manthey, 2022a, 2022b; Kurent et al., 2021, 2022, 2023; Landel et al., 2021; Landel & Linderholt, 2020, 2022; Linderholt et al., 2023; Malo et al., 2023; Manthey et al., 2021; Tulebekova et al., 2022).

2. Description of the DynaTTB project

The aim of the DynaTTB project was to give recommendations to structural engineers designing TTBs, but is also aimed for manufacturers of timber building systems, property developers interested in building taller with wood and researchers dealing with dynamic effects on TTBs. The focus is on the design for the serviceability limit state (SLS) of tall buildings with timber structures, their dynamic properties and how wind-induced vibrations can be mitigated.

Figure 1: The buildings tested and their locations in Europe. Partner responsible for measurements and FE-modelling can also be seen below each building.

In the project, a total of eight buildings, see Figure 1, have been tested. In addition to preliminary ambient vibration tests, also forced vibration tests were used to estimate the buildings dynamic properties: eigenfrequencies, normalized modes shapes and damping. One more building has been tested using Ambient excitation and three of the buildings included in the project have also been equipped with long-term monitoring equipment. The buildings vary in height from four to eighteen storeys with several building systems to represent TTBs in Europe today.

3. CASE STUDY - THE BUILDING EKEN

3.1. The building system

The seven-storey building Eken was finished in 2019 and contains 31 rental apartments. It is located in the city of Mariestad in the south part of Sweden, see Figure 2. The height, width and depth of the building are 24, 27 and 19 m respectively. The building was built by the company Stenmarks Bygg and it is owned by Mariehus.

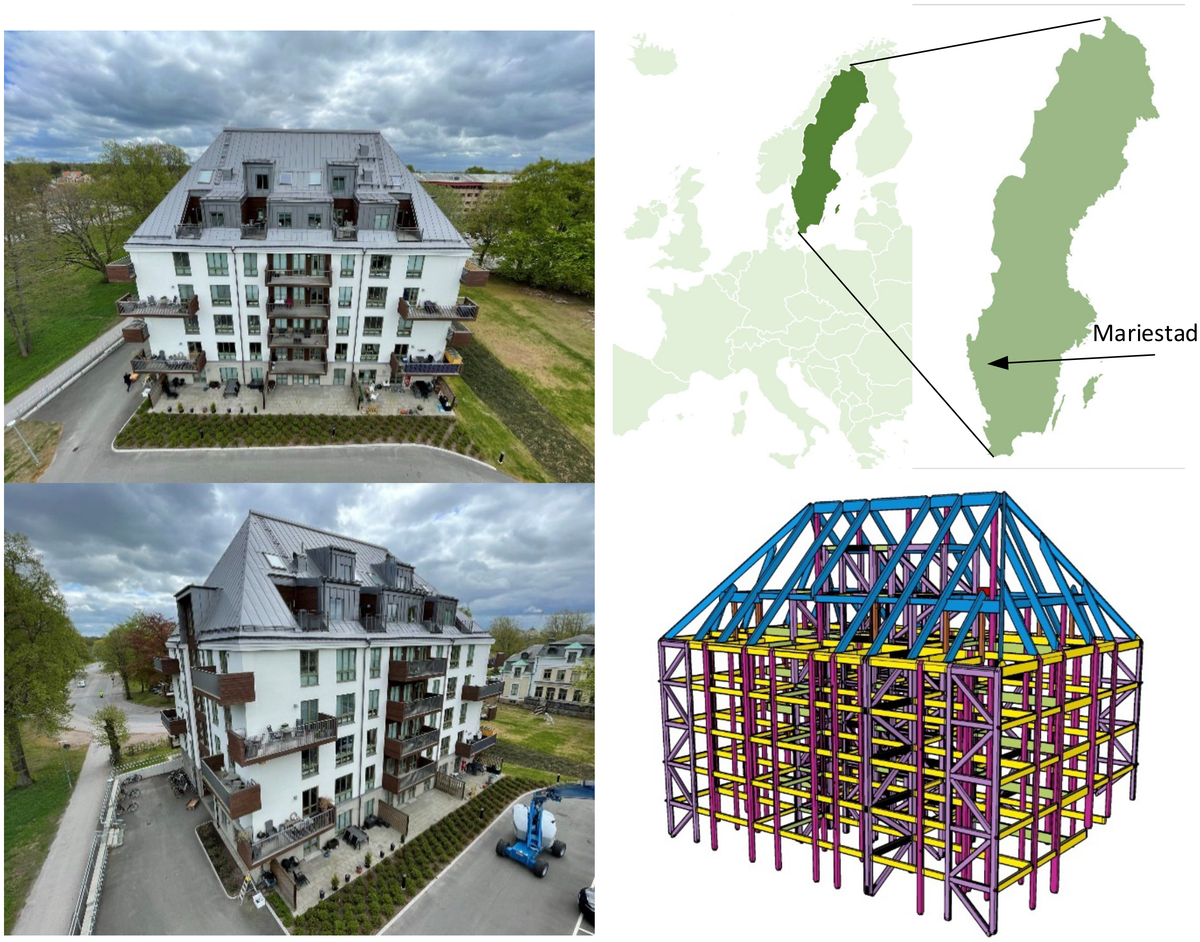

Figure 2: The Eken building in Mariestad with images of the finished building, its location in Sweden and the glulam parts of its structural system.

Half of the bottom floor is made of concrete whereas the other half, the other storeys and the elevator shaft are made of timber. The building is built using the Moelven Trä 8 system. The load bearing system consists of glued laminated timber (glulam) beams and columns whereas glulam trusses form the stabilizing elements, see Figure 2. In total the structure consists of 12 glulam trusses, four in the weak direction of the building and eight in the strong direction of the building. The glulam trusses are, in principle, symmetrically located in the building and the trusses in the middle go through all seven storeys of the building.

The floor system is made of strengthened LVL sheets acting as a diaphragm system. The connections in the glulam trusses are slotted-in-steel-plates fastened with steel dowels. The other glulam beams are fastened using steel hangers screwed to the glulam members. These glulam building components are manufactured and assembled by the company Moelven Töreboda.

3.2. The test set-up

The dynamic performance of the building Eken has been studied during the measurement campaign using a forced vibration set-up. Forced vibration tests have the benefit of enabling more precise damping estimates than ambient vibration tests. IT greatest benefit is that it enables to extract mass scaled mode shapes. Mass inertia forces can be used to excite buildings in forced vibration tests. For that purpose, an APS 420 shaker was used in the Eken measurement campaign, see Figure 3. The shaker was placed in the ventilation room on the top (seventh) floor.

In total 45 accelerometers: PCB 393B12 and PCB 393M62, with the sensitivity 10V/g, were used to measure the response of the building at different positions and in different directions. The steel cubes with the accelerometers were screwed directly on the structure of the building at four different levels in each of the four corners of the building, under the balconies, and in two positions under the main roof beam at the top of the building.

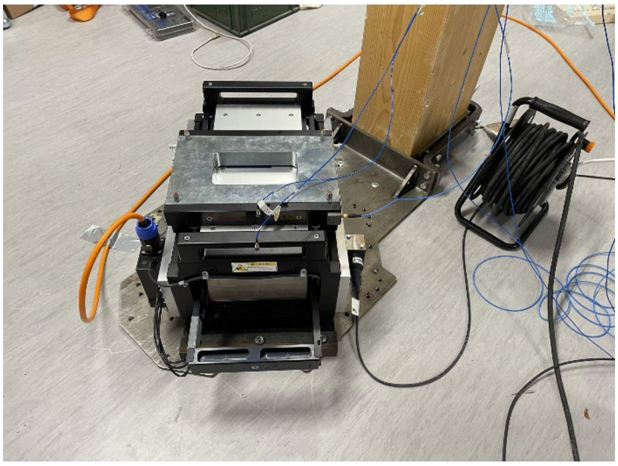

Figure 3: a) Excitation by mass inertia, using an APS 420 shaker, used for stepped sine excitation, fastened to a steel plate fastened to the main glulam structure using screws. In this set-up the shaker is placed in a 45° angle to the buildings main axis. b) Positioning of sensors, with four accelerometer positions along the height in the four corner of the building and two accelerometer positions under the roof (red boxes) and the shaker at the attic room attached to one of the glulam columns.

The forced vibration test was performed using a stepped sine test set-up. Here, the APS 420 inertia shaker was used for stepped sine testing from 2 Hz to 20 Hz. The excitations were made in 0, 45 and 90 degrees in relation to the axis along the width of the building. The steel plate, under the shaker, was used to connect the shaker directly to the load-bearing structure.

3.3. Results

The test data were evaluated using the software Siemens Test Lab. The evaluated parameters in this first basic evaluation were:

- resonance frequencies,
- modal damping,
- mode shapes and
- modal masses.

The data evaluated were in the form of FRFs from which the modal properties were estimated. The first bending mode in the weak direction was found to have a frequency of 2.4 Hz. A preliminary estimation showed that the relative viscous damping was 1.6% for the first bending mode in the weak direction (at 2.4 Hz). It was possible to find fifteen distinguishable modes in the frequency range 2-20 Hz when exciting the building in the Y-direction (the flexible direction). The plot of mode shapes, see Figure 4, show the first bending mode in the Y-direction. The first bending mode is very symmetric and shows an almost pure bending of the building.

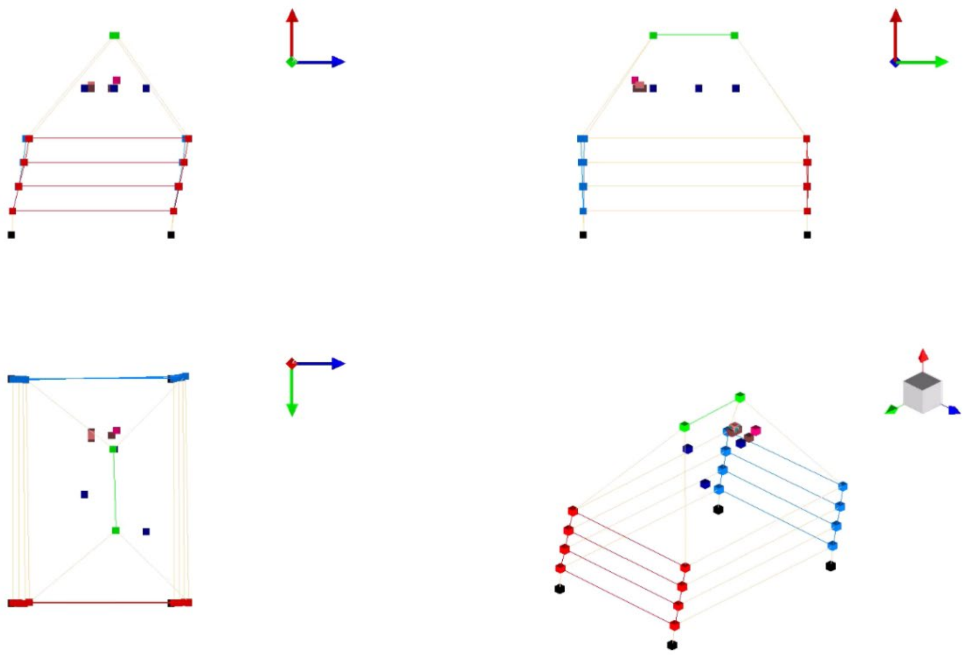

Figure 4: The first bending mode in the Y-direction (the flexible direction).

4. Conclusions

In this paper, the vibrational test campaign made on the seven-story timber building Eken in Mariestad in Sweden is presented. By using mass inertia forces generated by an APS 420 shaker in combination with sensitive accelerometers, 10 mV/g, the fundamental and global modes were successfully extracted from test data even when the excitation force amplitude was low. The estimated damping values agree with estimated damping values from other test campaigns within the project Dyna-TTB. The results contribute to the knowledge base regarding damping in high-rise timber buildings and are thus useful for future design of tall timber buildings.

The collected results of the DynaTTB project show that it is possible to measure the dynamic properties of the buildings using forced vibrations. The results also show that to make an FE model that is valid in its representation of a building's dynamic behaviour in SLS, in terms of eigenfrequency and modes shapes, it is important to take the effect of stiffness in the connections, the foundation and in some cases also non-loadbearing structures such as partition walls, screeds and curtain walls into account.

The results also show that in most cases, TTBs exhibit non-linear damping behaviour, which in some cases might be important to consider. In general, the damping is in the range of 1.5-3% of the critical viscous damping depending on the amplitude of the vibrations.

The results will be gathered in a Guideline for engineers and researchers interested in designing and evaluating TTBs.

Acknowledgement

The research leading to these results has received funding from the ForestValue Research Programme which is a transnational research, development and innovation programme jointly funded by national funding organisations within the framework of the ERA-NET Cofund 'ForestValue – Innovating forest-based bioeconomy'".

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Extended abstract

The competitiveness of CLT – a case for an integrated approach to reduce carbon footprint

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The competitiveness of CLT – a case for an integrated approach to reduce carbon footprint

Summary

Reduction of greenhouse gases emissions in the buildings and construction sector is vital for a sustainable built environment with low climate impact. Achieving this will require deployment of a variety of solutions, including low carbon structural building materials. Cross-laminated timber (CLT) is increasingly proposed as an example of a low-carbon alternative to steel or concrete in mid-rise multi-story structures. In this study, the life cycle carbon footprint of a CLT multi-story building is investigated and opportunities to further improve the carbon footprint are explored, based on an integrated approach involving improved engineering design solutions and life cycle analysis. The engineering design solutions encompass efficient wood utilization for CLT panels, efficient construction systems and connections of CLT elements, and plausible improved service-life risk management in CLT structures. The analysis showed that a reduction of up to 43% of the life cycle carbon footprint can be achieved when employing the integrated approach with more efficient engineering design and solutions. Thus, CLT-based building systems can be further optimized through an integrated approach, which enhances the competitiveness of CLT for multi-story structures.

1. Introduction

Large reductions in anthropogenic greenhouse gases (GHGs) emissions are required to fulfil the Paris Agreement goal of keeping global warming well below 2°C [1]. The building and construction sector accounts for 38% of the world's energy-related carbon dioxide emissions [2]. Therefore, the sector can play a major role in the efforts to mitigate climate change.

A variety of measures may be deployed to minimize the climate impact of new buildings, including the use of low-carbon structural materials. Several life cycle analysis (LCA) studies show that wood-based building systems result in less carbon footprint than equivalent non-wood alternatives [3].

Cross-laminated timber (CLT) is increasingly suggested as an example of low-carbon alternative to the conventional non-renewable construction materials for multi-story buildings, including reinforced concrete and steel [4, 5]. CLT as a structural composite panel product has facilitated the construction of large and tall multi-story buildings in wood-based structures. However, CLT is a relatively young industry and many of the existing CLT multi-story buildings are the firsts of their kind, yet to reach their mid service life. Issues which need to be addressed to improve the competitiveness of the CLT technology in multi-story building construction include material efficiency, building systems and connections, long-term structural performance and life cycle carbon footprint optimisations.

This study explores strategies to improve the carbon footprint of CLT multi-story building systems through an approach integrating structural engineering solutions and life cycle analysis (LCA). It analyses and optimizes the carbon footprint of a CLT-based building from a life cycle perspective, considering the interactions between efficient wood utilization for CLT panels, construction of CLT buildings with efficient connections, and plausible improved service-life risk management of CLT structures.

2. Integrated approach

The study is based on a CLT buildings research project employing an integrated approach [6]. It involves four key aspects of CLT in building construction, with focus on the synergies between the aspects. These are:

- Optimized raw material utilization for CLT panels, concerning efficiency of raw material use and the development of appropriate grading schemes for production of strong and stiff CLT panels.
- Building systems and connections of CLT elements, concerning the development of connectors with optimal material usage and efficiency in the assembly stage of CLT construction.
- Risk management during the building's service-life, concerning assessment and mitigation of plausible risks during the service life of CLT buildings.
- Life cycle assessment of CLT-based buildings, focusing on the optimisation of carbon footprint, and synergies between the structural engineering solutions and life cycle carbon footprint.

3. Methodology

The study begins with a process-based attributional life cycle carbon footprint modelling of a case-study eight-story CLT multi-story building in Växjö, Sweden. Opportunities to reduce and optimize the carbon footprint of the building are then explored, based on an approach integrating new knowledge in structural engineering aspects of CLT buildings and LCA (Figure 1). Table 1 illustrates how the structural engineering aspects are linked to the life cycle carbon footprint modelling.

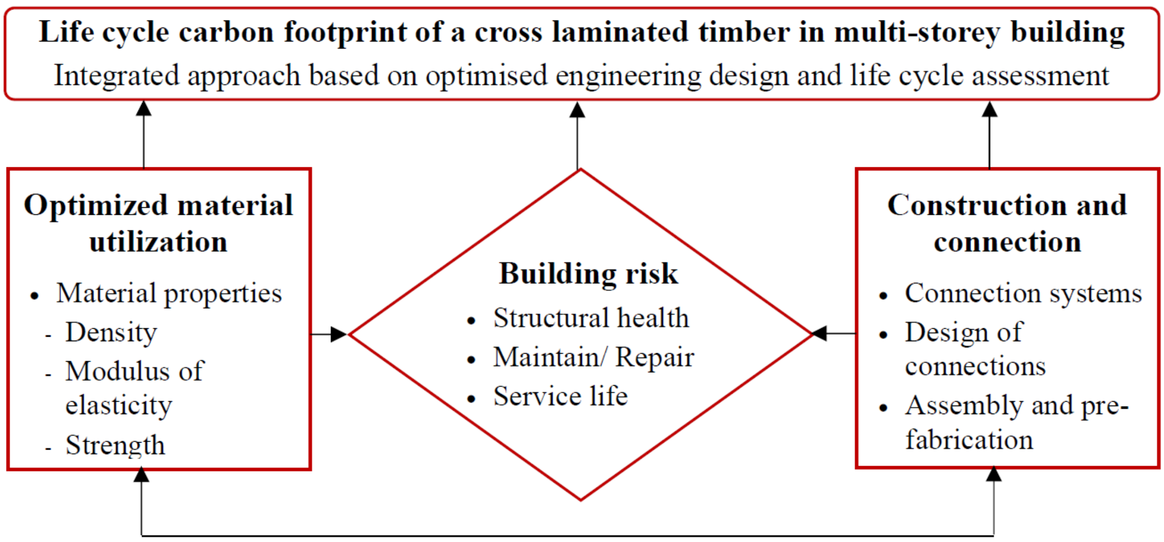

Figure 1: Representation of the integrated approach based on engineering aspects and LCA of CLT buildings.

Table 1: Structural engineering aspects and their implications for the life cycle carbon footprint modelling.

Engineering aspect	Life cycle stage influenced	Description of influence
Optimized material utilization	Production, end-of-life stage & post-use benefits	Amount of CLT used and recovered for post-use management
Connection and construction	Production, construction, end-of-life stage & post-use benefits	Number of fasteners used, assemble & disassemble of CLT, amount of CLT recovered for reuse
Service life risk management	Service life	Early identification of repairs and maintenance needs thereby avoiding major structural replacements

The LCA is conducted following the standard EN 15978 [7] over a 50-year time horizon, considering the material production, construction, service-life and end-of-life stages of the studied CLT building. Data from Ecoinvent (v 3.7) [8], which is generally representative of the typical situation in Europe, are used for the calculations.

4. Results and discussion

The findings show that CLT-based building systems can be further optimized from structural engineering and climate impact points of view. For example, the thickness of CLT structural elements may be optimized and thereby resulting in about a 5 % average reduction of the thickness of typically designed CLT elements. Steel-based screws and fasteners for connection of CLT elements may be greatly optimized, thereby achieving about 20% reduction in the mass of the screws and fasteners without compromising the structural performance. Long-term service life monitoring facilitates prediction of potential damages and hence timely preventive actions in CLT buildings. Subsequently, repairs, replacements and damages of CLT elements are minimized with the improved service life risk management. When considering the interactions between the above structural engineering aspects and LCA, the life cycle carbon footprint of the studied CLT multi-story building is reduced by about 40% (Figure 2). Hence, the integrated approach explored shows promise in improving the competitiveness of CLT in multi-story buildings, through engineering design and reduced carbon footprint.

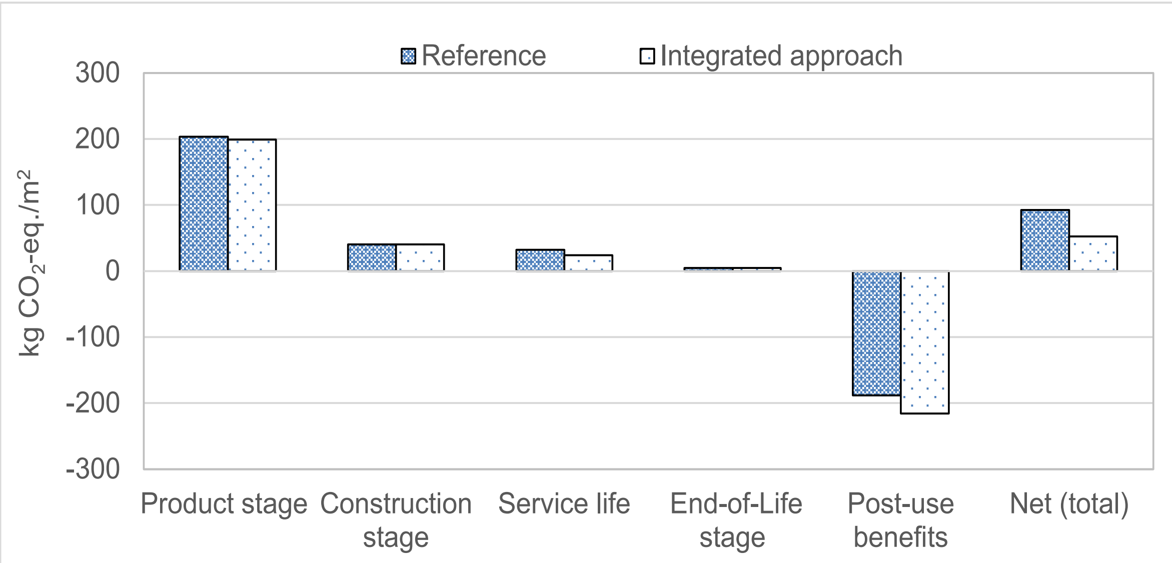

Figure 2. Life cycle carbon emissions for the studied CLT building without (reference) and with (integrated approach) consideration of the investigated strategies.

5. Conclusion

Effective strategies are essential to reduce GHGs emissions in the buildings and construction sector. This paper explored the carbon footprint of a reference CLT multi-story building and examined the extent to which an integrated approach encompassing different aspects of structural engineering design and life cycle analysis can contribute to reducing the carbon footprint of CLT buildings. The analysis examined how optimized CLT utilization, connections in CLT assemblies, risk management in building service-life can contribute to reducing the carbon footprint in the life cycle perspective. The findings indicate that CLT-based building systems can be further optimized through an integrated approach encompassing structural engineering solutions and life cycle carbon footprint, thereby improving the competitiveness of CLT for multi-story construction.

Acknowledgement

This research work was funded by the Knowledge Foundation through the project ‘Improving the competitive advantage of CLT-based building systems through engineering design and reduced carbon footprint’ (20190026). Truong Nguyen, Michael Dorn, Anders Olsson, and Thomas K. Bader have been part of the work reported in the article.

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100% fossil-free construction boards and panels

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100% fossil-free construction boards and panels

Abstract

With a common desire to reduce the fossil dependence in the construction industry, IsoTimber, Moelven Vänerply, Stora Enso and RISE (Research Institutes of Sweden), worked together in a project for 2.5 years with RISE as coordinator.

The project demonstrated that the bio-based binder, NeoLigno®, free from formaldehyde and isocyanate, could be used in the production of fossil-free construction plywood, going from lab scale to pilot scale, and in fossil-free construction panels manufactured up to industrial scale. Process parameters will be further finetuned before potentially being implemented in standard production.

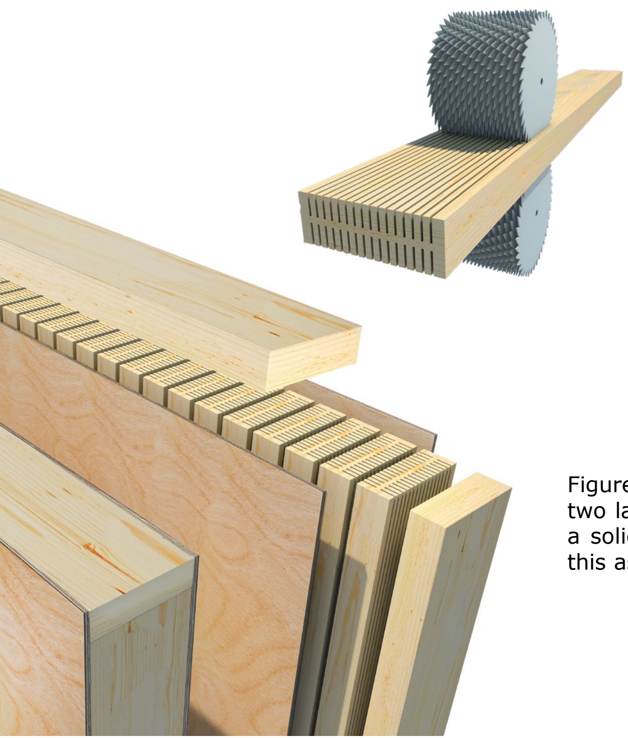
Presented was also one way to extend the material lifecycle, a cascade step of the wood. This was done successfully in lab scale by recycling a fossil-free construction panel and produce OSB- and particleboards with the bio-based binder.

1. Aim of the project

Investigate a bio-based adhesive (1.3) with aim of replacing today's fossil-based adhesive when producing construction boards (1.2) and panels (1.1).

1.1. IsoTimber wall elements

IsoTimber manufacture prefabricated wall elements with a unique construction technology, that enables a heat insulating and load bearing wall consisting of wood and air. The wall element is composed of two or three layers of IsoTimber panels of thickness 60, 100 or 150 mm (IsoTimber, 2022), see figure 1. No wind- or plastic membrane, or other insulating materials, are required. The wall elements are precise and allow a fast assembly at the building site.



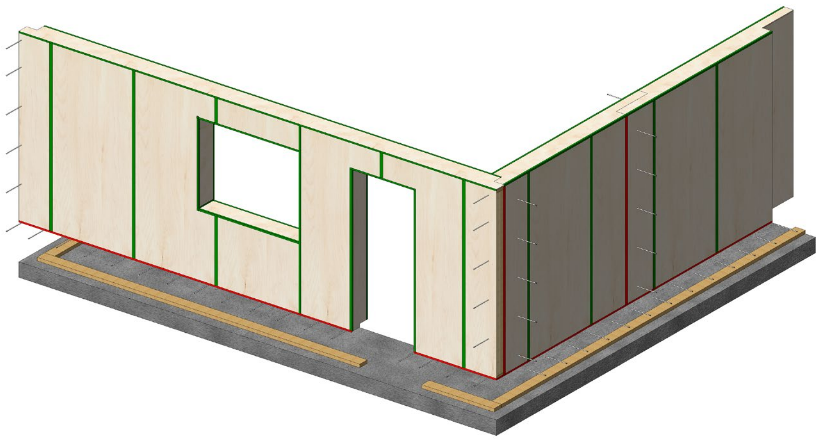


Figure 1: Illustration of IsoTimber wall elements (to the right), with at least two layers of IsoTimber panels (to the left). The IsoTimber panel consists of a solid frame of studs, encapsulating posts with air channels (middle), and this assembly is covered by plywood sheets that are glued to both sides.

1.2. Moelven plywood boards

Moelven Vänerply manufactures plywood boards (Moelven, 2023) of various dimensions to supply the construction industry. They focus strongly on contributing to reduce the carbon foot-print of the construction industry.

1.3. Bio-based binder by Stora Enso

The bio-based adhesive tested in the project is named NeoLigno® and was developed by Stora Enso (NeoLigno®, 2023) with purpose to create safe, healthy living environments – a bio-based binder free from formaldehyde and isocyanate.

1.4. Coordination, tests and evaluation by RISE

RISE has long experience and deep knowledge in wood technology. Their experts have been used to lead the project, run tests and evaluations. Project information can be found at the website of RISE (RISE, 2020).

2. Project results

Test samples were produced by the industrial partners (in some cases with RISE participating), while the tests and evaluation was performed by RISE. The OSB- and particleboards presented in section 2.3. were made by RISE.

2.1. Construction boards – Moelven plywood

It was demonstrated that the bio-based binder could be used to produce fossil-free construction plywood, going from lab scale (0.3 m x 0.3 m) to pilot scale (1.2 m x 1.2m), see figure 2. Tests (EN 314-1) showed that the requirements on a loadbearing construction plywood, class 3 (EN 314-2), were met, see figure 3.

Figure 2: Photo of fossil-free construction plywood produced in pilot scale (1.2 m x 1.2 m).

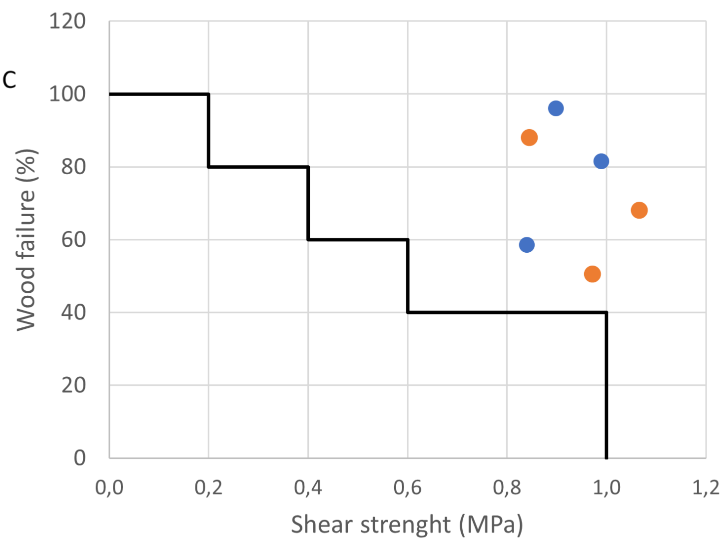


Figure 3: Tests (EN 314-1) demonstrated that class 3 was achieved according to EN 314-2.

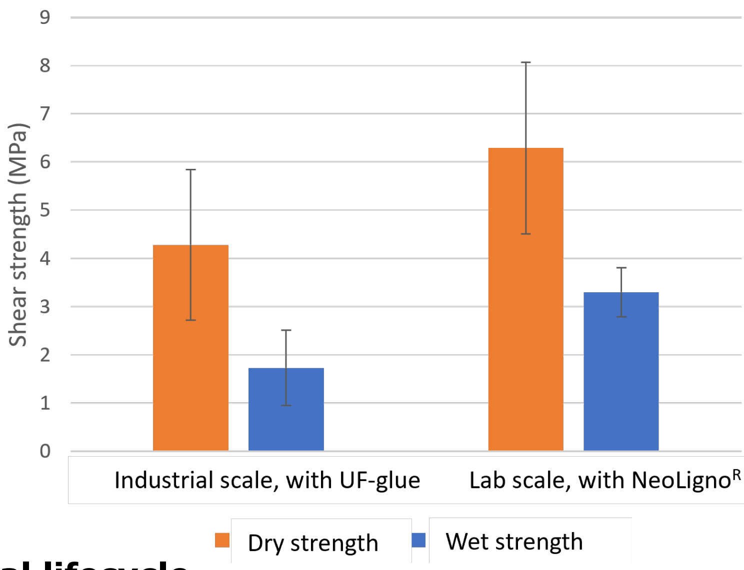
2.2. Construction panels - IsoTimber

Fossil-free plywood boards were glued with NeoLigno® to both sides of IsoTimber panels. First step in lab scale (figure 4) and finally with full size panels in factory, i e fossil-free construction panels were made in industrial scale (figure 5).

Figure 4: Small size (0.3 m x 0.3 m) fossil-free IsoTimber panel produced in lab scale.

Figure 5: Full size (1.2 m x 2.4 m) fossil-free IsoTimber panel produced in industrial scale out of plywood in pilot scale (1.2 m x 1.2 m).

Figure 6: IsoTimber panels are unique and do not comply with any specific standard since the adhesive is not construction classified today. However, RISE defined a test method to compare the performance of NeoLigno® with the current used adhesive, Urea Formaldehyde (UF). The tests show that NeoLigno® can perform equally or better than existing adhesive.



2.3. Extended material lifecycle

One resource efficient way of using material, is to extend the material lifecycle. This was demonstrated successfully in lab scale, by recycling a fossil-free IsoTimber panel to produce OSB- and particleboards (0.2 m x 0.2 m) with the bio-based adhesive, see figure 7. Thereby a possible cascade step of the wooden material was presented as a future scenario of the wall elements.

Figure 7: A fossil-free and full size IsoTimber panel was grinded to fibers and saw dust, that was used to produce OSB- and particleboards respectively in lab scale (0.2 x 0.2 m).

3. Future implementation

The project has demonstrated that it is possible to produce 100% fossil-free construction boards in pilot scale and construction panels in industrial scale. Crucial information was gained for the industrial applications, however, the process parameters will be further fine-tuned for each respective manufacturing process before potentially being implemented in standard production.

This project was financially supported by BioInnovation, se below.

BIO INNOVATION

Med stöd från VINNOVA Sveriges innovationsmyndighet · Energimyndigheten · FORMAS · Strategiska innovationsprogram

BioInnovation is a strategic innovation program in Sweden. The aim of the program is to promote bio-based development and innovation in three priority areas: Chemicals & Energy, Materials, and Construction & Design. The innovation program was initiated by the Swedish Forest Industries Federation, IKEM - the Innovation and Chemical Industries in Sweden and TEKO – Swedish Textile and Clothing Industries Association. The program is a public-private partnership funded by Vinnova, the Swedish Energy Agency and Formas, as well as participating stakeholders from business, academia, institutes and the public sector. www.bioinnovation.se/en

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EN 314-1. European standard EN 314-1 Plywood - Bonding quality - Part 1: Test methods

EN 314-2. European standard EN 314-1 Plywood - Bonding quality - Part 2: Requirements

Probably the strongest timber joint in the world?

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Probably the strongest timber joint in the world?

1. Abstract

Modvion is developing wind turbine towers made from wood that offer cost-effective tall towers. Using wood offers dramatic reductions in carbon emissions associated with tower production, compared to load bearing equivalent steel-based alternatives.

R&D to prove the feasibility of using timber for dynamically loaded structures has been ongoing since 2016 when the company was incorporated. In April 2020 a 30m tall technology demonstrator was installed on the island of Björkö in the Gothenburg northern archipelago. The Björkö installation is elevating the Chalmers research wind turbine that is used for electromechanical research into wind turbine, electric grid, and energy systems dynamics since commissioning.

In 2020 the European Commission's EIC Accelerator programme granted Modvion one of its largest contributions towards the Wind of Change (WoC) project. WoC's purpose is to develop and erect a commercial scale wind turbine using Modvion's tower technology, complete with third party review of the construction, to therefore demonstrate a viable product for the addressable market. The 105m tall Wind of Change tower is currently being erected on site close to Skara, Sweden. Installation and commissioning of the Vestas V90 2MW turbine is scheduled for later this autumn.

A comprehensive research and development effort has been undertaken by Modvion in order to dimension and verify the tower construction. These efforts include iterative aeroelastic dynamics simulation of the power plant, advanced analysis of stress distribution on global and component scale and strength verification through destructive testing of all relevant components and load directions.

The Modvion tower is inherently modular. Two separate load bearing adhesive joints have been developed to join the tower components. The joints have been verified by design and laboratory testing to transfer >=90% of the timber member characteristic strength in their primary directions. . The joint design and testing have been subject to a third-party design assessment and accepted to be used with dynamic loading in the application of a wind turbine tower.

2. Modvion technology pitch

Swedish wood technology company Modvion develops demanding designs made of laminated wood, nature's carbon fibre, for large-scale applications. Wooden designs enable radical reductions in emissions by replacing emission-heavy materials such as steel and concrete. Thanks to their patented modular system, Modvion has been able to develop cost-effective wind turbine towers and more efficient transportation for installations of tall towers.

2.1. Modvion company

Modvion AB was registered in 2016 and has rapidly grown to approximately 40 employees. Their HQ and R&D facility was inaugurated in May 2022 in Gothenburg, Sweden, where the production line is capable of producing modules for towers up to 200 metres. The operation is part-financed by the Swedish Energy Agency, the Västra Götaland region, and the EU program Horizon 2020 EIC Accelerator.

3. Wind of Change

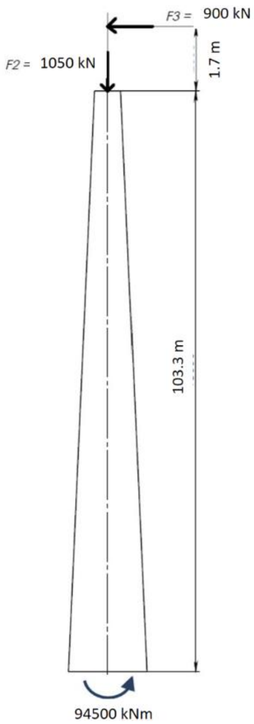
The Wind of Change project is Modvion's first commercial wooden tower installation taking place in the municipality of Västra Götaland, Sweden. The purpose of the project is to prove the technology and viability of using wood to build wind turbine towers. For this project the tower is 105 metres tall with a Vestas V90 wind turbine placed on top, reaching a total height of 150 metres including the blades.

As part of the European Commission's 2020 EIC Accelerator programme, Modvion was given one of it's largest contributions towards the Wind of Change project. WoC technology development

3.1. Load bearing design

The loads acting on the wooden tower are generated in an iterative process with aero-elastic simulations performed by the turbine OEM with the dynamic properties of a laminated wooden tower.

The simulations are made by the turbine OEM using the software FLEX4 and verified by a third party using the software HAWC2. Loads generated are in accordance with IEC 61400-1



Principal load case illustration.

Many load cases are evaluated for various wind- and turbine operating conditions. The resulting stress signals are evaluated to find extreme load conditions as well as basis for fatigue load analysis in each cross section of the tower.

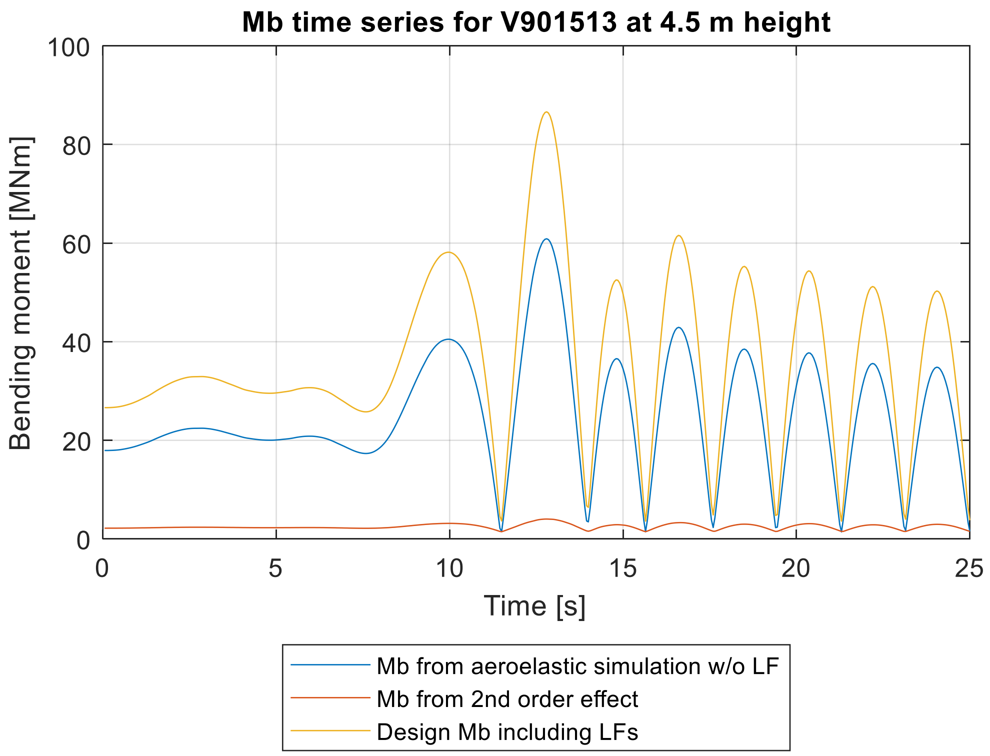


Figure 1 Example load time series.

The tower is a modular load bearing shell design. It consists of 28 curved modules joined together on the long edges to form tubular tower sections. The sections are stacked and joined to form the full tower.

Figure 2 Render of site assembly process.

The nominal wall material consists of LVL with a custom lay-up that renders it bendable in the cross-grain direction.

Figure 3 Illustration of LVL Lay-up.

During production of the modules LVL-boards are laminated into a curved shape. Dimensioning of the modules for ULS (Ultimate Limit State) loads take into account duration of load (kmod) and size effect factors. FLS (Fatigue Limit State) is verified against the (Mohr, 1999) model for engineered wood products.

Two load bearing joints are employed to transfer load between tower modules; the longitudinal joint that connect the modules on the long edge and the transversal joint that connect the tubular tower sections.
The longitudinal joint is comprised of an adhesive joint acting primarily in shear that is completed by injecting structural adhesive into the gap between modules during section assembly on site.
The transversal joint is a Glued in Plates (GiP) joint comprised of a perforated steel sheet spanning the dividing line between section that is bonded into a slit-shaped cavity using structural adhesive. Closing of this joint is carried out during tower stacking on site.

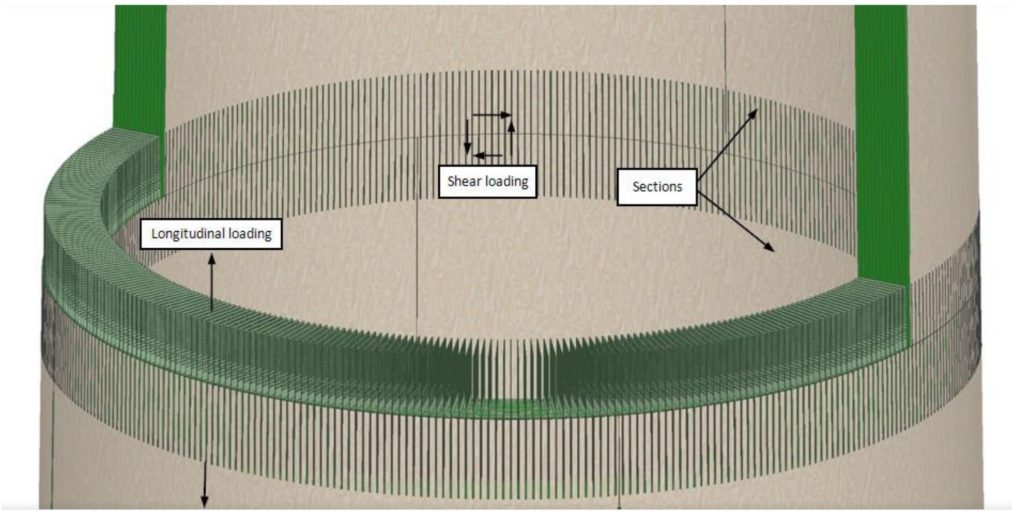


Figure 4 Principal illustration of Transversal joint.

The load bearing interfaces of the timber tower to the RNA and the foundation are comprised of bolted flange steel adapters. Conceptually they consist of a half GiP joint welded onto a steel flange. The foundation is rock anchored in a pedestal configuration with the access door located in the concrete section.

The structural design is developed and tested with regards to, but not limited to, the EIC 61400 standard for wind turbine design as well as the EN 1990 and other applicable Eurocode standards such as the EN 1995 regulations for timber construction. National technical requirements are also applicable and have been considered.

A comprehensive structural strength test program has been carried out that has proven the resistance performance of the tower wall and joint solutions. All relevant loading modes have been identified and investigated if required to create a full basis for tower verification. Investigated modes include axial normal stress, tangential bending stress and shear in plane stress. Static (ULS) and dynamic (FLS) resistance have been tested.

4. Joints

The two primary tower joints are the Transversal Joint and the Longitudinal Joint. They connect the tower wall modules to form a shell structure.

4.1. Transversal joint

The Transversal joint connect the tower tubular section to form the full tower. It is comprised of a GiP configuration with a perforated steel plate bonded into the timber using an existing and well proven polyurethane based structural adhesive.

The design of the joint has been based on a DiBT approval (Z -9.1-770) as a starting point however Modvion has carried out substantial improvements to this configuration more than doubling the maximum transferrable capacity, resulting in a high performance GiP joint that has been patented.

Detailed analysis and design of the joint is based on a dowel level evaluation where the resistance capacity of a single adhesive dowel has been determined for both ULS and FLS. This is then used in concert with Finite Element Method (FEM) calculations to determine Force Transfer Function (FTF) and Stress Transfer Functions (STF) to analyse stress concentration effects and determine the overall joint performance.

Loads acting on the joint can be divided into longitudinal normal stress loads, in-plane shear loads and tangential bending loads.
Contributing factors to the normal stresses are 1. Self-weight from the RNA and tower sections above the joint and 2. Bending moment to be transferred through the joint originating in the turbine thrust acting laterally on the tower top. These can be combined into an expression describing the normal stress state:

$$\sigma_L(r,t) = \frac{F_z}{A} + \frac{M_b(t)}{I} \cdot r$$

Where Fz is the gravity loads and Mb the bending moment.

Contributing factors to the in-plane shear stress are 1. Transverse loading originating in the turbine thrust acting laterally on the tower top and 2. Torsional moment acting on the tower top due to turbine dynamics and load cases involving asymmetric performance of rotor blades (such as turbine blade pitch malfunction cases as given by EIC 61400). These can be combined into an expression describing the in-plane shear stress state:

$$\tau_{LT}(r,t) = 2 \cdot \frac{F_V(t)}{A} + \frac{M_z(t)}{K} \cdot r$$

Where Fv is the transverse loads and Mz the torsional moment.
Contributing factors to the tangential bending include second order cross-section ovalization effects due to bending curvature as well as wind load acting on the tower wall.

The factors dependent on time variation are the bending moment, transverse loading and torsional moment. FTFs and STFs are therefore analyzed for these effects.

FE-models were developed for this purpose. Cyclic symmetric models were employed representing one quarter of a single joint while maintaining boundary conditions representative of the full joint complex. The LVL is modeled as an orthotropic material with a longitudinal stiffness of ca 12GPa, the adhesive as an isotropic material at 3GPa and the steel an isotropic material with 210GPa stiffness. Quadratic meshes with refinements in areas of interest were used.

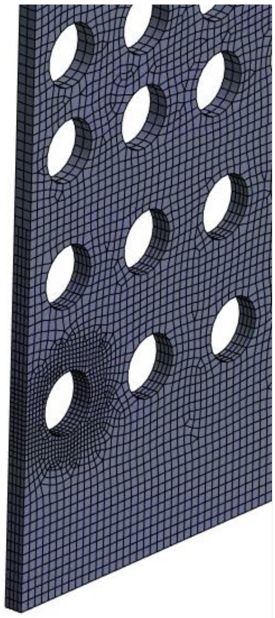


Figure 5 Illustration of mesh.

Load application was distrubuted radially to reflect the conditions in the tower wall.

The transfer functions can then be used in concert with load case time series to create time variant stress signals inside the critical points of the joint geometry. These are then used to determine the maximum hot spot stress level in all load case time steps in order to identify the design driving ULS stress level. The stress signals are also used to determine the damage accumulation over the lifetime of the turbine to verify the FLS performance.

Near full scale ULS tensile strength tests have been performed on the Transversal joint where samples were constructed that represent a single steel plate joint configuration.

A clamp was used to control lateral dilation of the sample and accurately represent boundary conditions present in the tower.

Figure 6 Tensile strength test setup.

Failure mode was 100% steel failure at the hole row closest to the dividing line of the joint.

Figure 7 Failure mode.

A fatigue resistance test campaign has been conducted were small scale samples representing dowel-level characteristics of the transversal joint has been subjected to dynamic loads. A total of over 100 samples have been subjected to cyclic loading in various configurations in order to characterize the fatigue performance of the joint bond line and its interaction with substrates.

Figure 8 Fatigue test sample.

The final series for fatigue resistance verification consists of 31 samples that have been cycled at R = -1 (alternating load) up to 14E6 times.

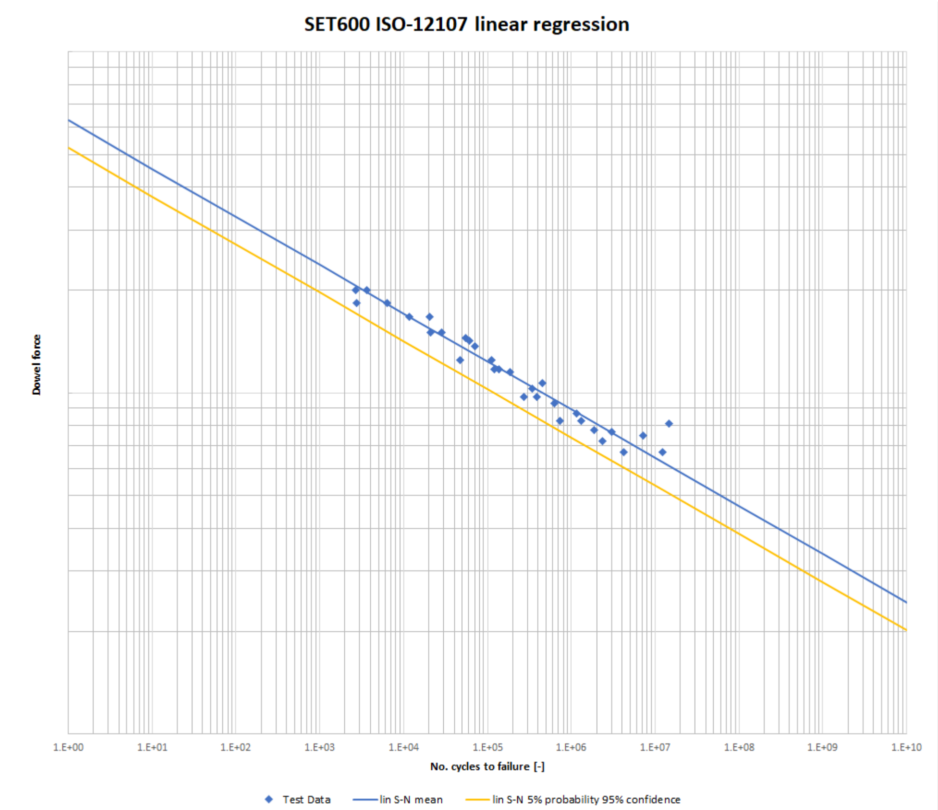


Figure 9 Fatigue test results.

The full-scale Transversal Joint tests have shown a characteristic resistance of 25.2MPa equivalent tower wall stress. The tower wall material itself (LVL) has a declared characteristic tensile strength of 28MPa that has been validated through testing. A stress transfer efficiency of 90% is therefore achieved across the joint.

The FLS test results clearly show the fatigue behaviour of the joint. The results have been analysed according to ISO 12107 to arrive at a characteristic limiting curve that can be used for lifetime estimations of the tower design. The analysis show a fatigue life of the joint exceeding the technical lifetime of the tower design (20 years for the WoC tower).

4.2. Longitudinal joint

The Longitudinal joint is a bonded edge joint connecting the long edges of four tower modules to create a tower section. It is primarily loaded in shear which is the strong direction for most bonded timber joints. The joint has been evaluated for tangential tensile and bending loads as well.

Several ULS tests have been carried out on the Longitudinal joint. Test methods have been taken from or inspired by EN 408. Shear strength tests show a 100% substrate failure which confirms the consensus that adhesive connections are stronger than the timber itself in this direction.
Tests of the tangential tensile and bending strength of the joint show a capacity reduction compared to the substrate but sufficient capacity for the tower design with margin.

The longitudinal joint has also been tested for shear fatigue performance. The results show a resistance performance exceeding the (Mohr, 1999) model for the tower wall material and a lifetime of the joint exceeding the technical lifetime of the tower design.

5. Conclusion

Modvion has developed a timber-based wind turbine tower solution that meets the criteria for industry adaptation. The design has been third party reviewed and work is on track at the site in Sweden to erect and commission a first commercial sized installation during autumn 2023.
To facilitate the high-performance, cost-effective design; timber joints with excellent stress transfer efficiency have been developed. The joints enable and unlock the performance characteristics of the timber material without the need for excessive member stress reduction measures.
A comprehensive RnD effort has been undertaken that verifies the joints performance for use in a high demand dynamically loaded application for the duration of the lifetime of the installation.
Work at Modvion RnD now shifts focus towards the next, taller, tower installations. The data acquired and lessons learned from the WOC project is currently being implemented towards optimisation of the solution and it is already clear that substantial further improvements are within reach in the area of timber joint design.

The question remains, is this the strongest timber joint in the world? Probably.

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Post and Beam structures from Hardwood LVL

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Post and Beam structures from Hardwood LVL

Abstract

In addition to the choice of sustainable building materials, the construction method in particular plays a decisive role in the sustainability assessment of a building over its entire life cycle. Because only buildings that enable changes of use and redesign of floor plans will have a long lifespan. For modern multi-storey buildings, planners are therefore increasingly opting for timber skeleton structures. For these structures, high-performance materials made of hardwood offer decisive advantages. Laminated veneer lumber from European beech can be used to create load-bearing structures that are just as strong and slender as reinforced concrete structures. Connections are of particular importance for these.

1. What is a sustainable building?

Figure 1: Industrial high-rise building being redesigned for modern flats, in Erfurt, Germany

The majority of planners and project developers are today aware that renewable raw materials, above all wood as a building material, are the key to sustainable architecture. The facts have been known for a long time. When building with wood, large amounts of carbon dioxide are stored in the building in the long term and, in addition, the carbon dioxide emissions that occur during the production of conventional building materials, such as steel and concrete, are avoided. But the structure of the buildings also plays a major role in the assessment of sustainability over the entire life cycle. After all, only long-lasting buildings are sustainable buildings. A good example of a "sustainable structure” is the high-rise “Chronicle” in Erfurt, Germany. This industrial high-rise was built in 1967 in the former GDR as the production site of a communist newspaper, with editorial office and printing house under one roof. Now this building is being renovated and converted into modern flats. The flexible skeleton structure makes it easy to remove all interior walls and redesign the floor plans. Hundreds of similar examples can be listed. Skeleton industrial buildings from the last century are often converted into flats, offices or other usages. In contrast, buildings with rigid walls are usually threatened with demolition if a change of use is planned.

Modern sustainable architecture must create long-lasting buildings using renewable raw materials. In the case of multi-storey buildings, timber skeleton structures are predestined for this. And hardwood offers decisive advantages.

2. 10-storey Surstoffi 22 building, Switzerland

For many years, high-rise buildings were a no-go area for timber construction specialists. The ten-storey Suurstoffi 22 block is therefore a ground-breaking project in residential and commercial building construction.

Figure 2: Ten-storey timber building in Risch, Switzerland

It is located in Risch in the Swiss Canton of Zug, halfway between Lucerne and Zurich. Zug Estates AG won the contract to convert the site of a former oxygen factory into a modern urban and estate that is carbon-neutral from construction to operation and public transport. The project includes the first high-rise building in a timber-hybrid construction. The tallest part is the 36 m high office block formed by two intersecting wings, which sets the standard for the rest of the development. The block is accessed through two central cores made in reinforced concrete that house the stairwells and elevators and serve as horizontal stiffening elements for the entire building. For this project, new construction methods and processes were required.

Figure 3: Timber skeleton frame from BauBuche GL75

The timber skeleton frame consists of posts and beams made from BauBuche GL75, industrially produces laminated veneer lumber made from hardwood. These exposed elements make it clear that Suurstoffi 22 is a timber construction that does not need to hide behind a façade made form a different material. The façade elements are exposed, as are the internal, circumferential supporting structures of beams and posts made from 40 cm x 40 cm BauBuche GL75 that connect the timber construction to the concrete cores. Thanks to the BauBuche beams, it has been possible to maintain a maximum room height of 2.80 m. In a building with the same outer dimensions and conventional softwood beams, the rooms would be much lower, as the beams would need to be nearly twice that high to offer the same load-bearing capacity. While the issue could be overcome by installing more posts, this would severely restrict tenants in the design and use of the rooms. With BauBuche, they now enjoy large open spaces, which make the building extremely attractive. Due to its beautiful look and finish, BauBuche is not only a great construction material but also a design feature in its own right. Suurstoffi 22 offers sophisticated office spaces for people who appreciate a quality workplace. The external wall elements consisting of timber panels and 28 cm rockwool insulation were produced at the factory and shipped as complete units fitted with windows, etc. to the construction site. In total, the office block consists of 2,116 prefabricated timber elements (362 wall elements, 708 timber-concrete composite units and 1046 posts & beams). This corresponds to around 1,500 m³ of timber. As wood is made up of 50% carbon, the building thus contains 375 tons of this chemical element, which is equivalent to 1,375 tons of CO_2.

3. Why was hardwood used?

European beech (Fagus sylvatica) has a high load-bearing performance. However, defects and knots in the wood reduce the performance at certain points. This is one of the greatest advantages of laminated veneer lumber. The structure of many thin layers leads to a strong homogenisation of the material. Flaws and knots are distributed more evenly across the cross-section, so that their influence on the technical properties is greatly reduced. The result is a high-performance product. At 75 N/mm2, the bending strength of BauBuche is three times that of spruce glulam. And the compressive strength clearly exceeds that of normal concrete C30/37. This means that you can build with hardwood LVL in a much more material-saving way than with softwood.

Why was Hardwood LVL used?

Characteristic strength values		Hardwood LVL BauBuche GL75	Gluelam GL24h	Concrete C30/37
Bending	$f_{m,y,k}$ [N/mm²]	75	24	
Tension	$f_{t,0,k}$ [N/mm²]	60	16.5	
Compression	$f_{c,0,k}$ [N/mm²]	59.4	24.0	**37.0**
Shear	$f_{v,k}$ [N/mm²]	4.5	2.5	
Modulus of elasticity	$E_{0,mean}$ [N/mm²]	16,700	11,600	
Density	ρ_k [kg/m³]	730	380	

Material savings
30 – 60%

Figure 4: Characteristic strength values of hardwood LVL in comparison

The direct comparison shows that BauBuche GL75 structures can be just as efficient and slender as reinforced concrete structures. A 3.05 m high pendulum column made of reinforced concrete (C50/60 with 4% reinforcement ratio) and a cross-section of 40 x 40 cm^2 can carry a centric compressive force of E_d = 6020 KN. A BauBuche GL75 column with the same cross-section can carry the same centric compressive force. In both cases, the column was designed for a fire resistance of REI90. However, the reinforced concrete column causes about 806 kg of carbon dioxide emissions per cubic metre, while the BauBuche column stores 1080 kg of carbon dioxide per cubic metre (net storage capacity). A column with the same load bearing capacity made of spruce glulam requires a significantly larger cross-sectional area.

Comparison of Columns of 3.05 m length

	Reinforced concrete C50/60, 4% steel	Hardwood LVL BauBuche GL75	Spruce Glulam GL24h
CO_2 emissions	806 kg/ m³	-1080 kg/ m³	-666 kg/ m³
Weight	1220 kg	410 kg	474 kg
Fire rating	R90	R90	R90
Load E_d	6020 kN	6020 kN	6020 kN
Cross-section	40 x 40 cm	40 x 40 cm	64 x 64 cm

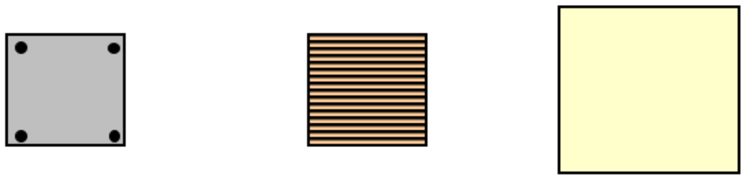

Figure 5: Comparison of columns

4. Connections

For the skeleton structure of the Suurstoffi building, an efficient connection had to be found for the transfer of forces from the beams to the posts and from post to post. A particularly economical connection is the end-grain bearing. Here, the posts are notched at the head so that the beams transfer the loads directly via contact. The posts above also transfer the loads directly via contact of the end-grain surfaces from the post base into the post head.

This type of connection is predestined for constructions made of BauBuche, as the high transverse compressive strength enables small support areas. The transverse compressive strength of BauBuche, $f_{c,90,k}$ = 14.8 N/mm², is more than five times higher than that of spruce glulam.

This connection requires almost no fasteners. Only small bolts are needed to secure the position of the beams during erection and a dowel to secure the position of the post. This makes the connection not only efficient, but also easy to install and very economical. It is the Volkswagen among the connections.

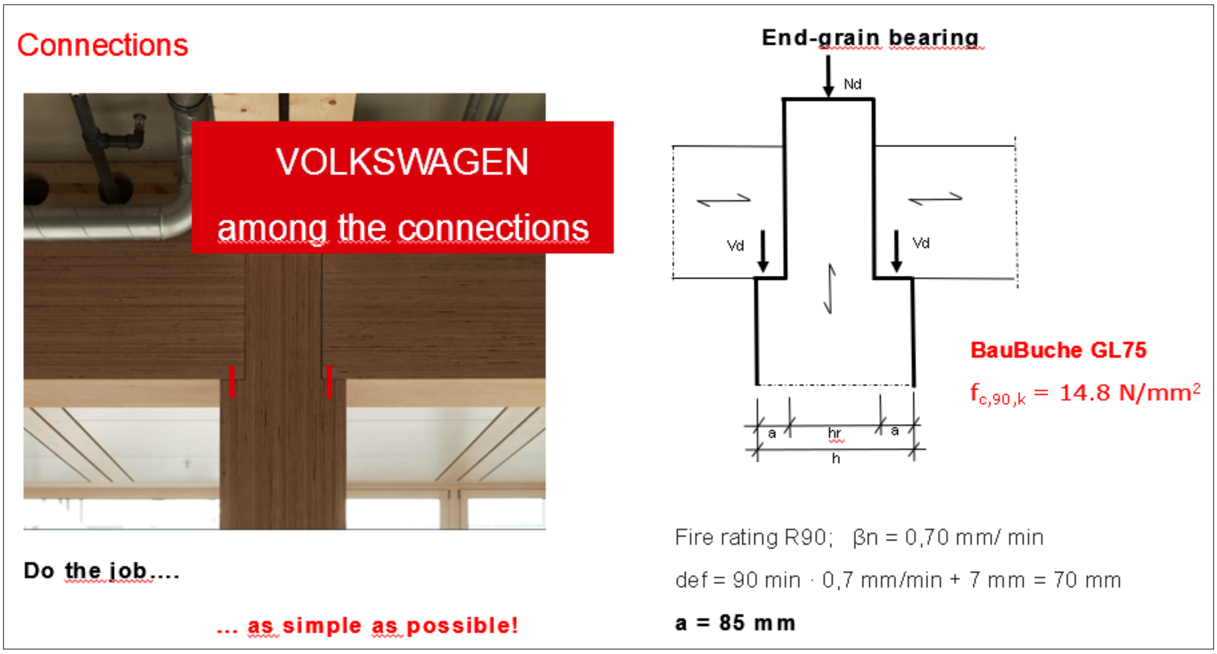

Figure 6: End-grain bearing

5. Office Building Sägen 6

Vorarlberg is widely known for its tradition in timber construction. Dornbirn, the largest town of the Austrian state of Vorarlberg has just under 50,000 inhabitants and is the regional economic centre and transport hub. Since early 2020, it features a unique five-storey office block built in timber construction that houses the offices of the two local firms of Johannes Kaufmann Architekten and Merz Kley partner. The two companies teamed up with the innovative proprietor F.M. Hämmerle to design a building with many unique features.

Figure 7: Office building Sägen 6, Dornbirn, Austria

The 33.70 m long, 12.30 m wide and 17.60 m high building stands on an underground car park built in reinforced concrete. On this foundation, Fussenegger Holzbau installed prefabricated timber construction elements that were anchored with steel connectors to the concrete base. This timber construction includes a central service utility shaft in one of the corners of the building. It is made from 20 cm cross-laminated timber (CLT) elements measuring up to 10 m in height and extending over two or three storeys. For fire safety reasons, these elements are enclosed in two layers of 10 mm gypsum fibre boards. Only the actual stairs are made from prefabricated concrete elements. The central service utility section does not only incorporate the lift shaft and the stair-well serving as an escape route, but also some of the stiffening elements of the building.

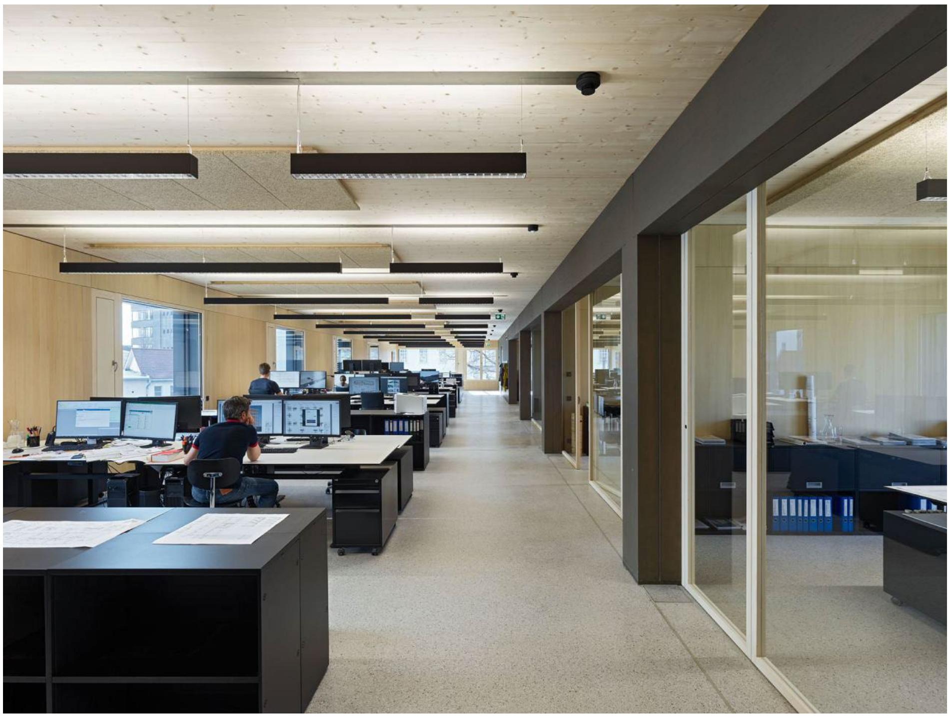
Figure 8: Skeleton structure from BauBuche posts and beams with CLT floors

The supporting structure is essentially a timber skeleton of BauBuche posts and beams combined with CLT floors. The posts are positioned in longitudinal direction in three rows, along the two exterior walls and slightly off-centre in the middle of the building. While the BauBuche posts and beams of this middle axis are exposed, those along the external walls are concealed in the timber frame construction of the walls. The building shell is made from prefabricated timber frame elements of 24 cm in thickness. The elements are 8.10 m long and 3.10 m high (corresponding to one floor height) and combined with BauBuche posts at distances that correspond to the façade spacing. The BauBuche elements are 40 cm wide and 24 cm deep and transfer the vertical loads from the floors to the foundation. Between these posts, the designers placed 8 cm wide and 24 cm deep solid construction timber posts (CLT, e = 62.5 cm), topped by a 26 cm high and 24 cm deep glued solid timber lintel. The rest of the skeleton is a conventional timber frame construction. The cavities were blow-filled with cellulose insulation. The interior wall panelling consists of 18 mm OSB boards acting as stiffening elements and vapour barriers. The ceiling is made of silver fir wood panels some of which are micro-perforated to improve the room acoustics. At the outside, the BauBuche/solid timer structure is covered with 15 mm gypsum fibre boards and a weather- and UV-proof wind protection membrane.

The structural strength concept of the skeleton construction ensures that the vertical loads on all axes are transferred through end-grain joints directly from post to post, preventing lateral thrust on floors and beams. Given the high compressive strength, the BauBuche posts have much smaller cross-sections than would have been possible with conventional glulam, and feature a strong and simple support head design, which led to significant costs savings. The pleasing symbiosis of attractive architectural design and efficient construction is thus in no small part due to the unique properties of BauBuche. On the one hand, BauBuche has the structural strength required for such an unique timber construction. On the other, the attractive look of the material contributes to the natural atmosphere and elegance of the interior. With BauBuche, design, structural strength and room layout form a harmonious overall concept.

The BauBuche posts along the load-bearing middle axis are a striking interior design feature, brought to the fore by a wood glaze. The office space at the upper floors can be structured and used as required – be it as an open-plan space with a large entrance, divided into smaller units along a centre corridor, or with partition walls separating traditional single and double offices. The construction of the "Sägen 6" building even caters for two additional storeys, should there be a need for more space in the future. With a current height of 17.60 m (< 22 m), the "Sägen 6" office block is in fire safety class 5 and meets the requirements of fire resistance class REI90.

The façade consists of interlocking cladding in locally sourced, planed fir and has a distinct strip look. The timber is pre-greyed with a stain and communicates the timber construction character of "Sägen 6" to the outside world.

6. TSBOne, Trifork Smart building, Aarhus Denmark

TSB One is the first sustainable, user friendly and fully digitized office building of the Danish tech company Trifork, located in Aarhus, Denmark. Trifork's main business areas are Digital Health, FinTech and Smart Building – focussing on fighting climate change by developing solutions that lower carbon footprint and improve energy savings. TSBOne provides 3,300 m^2 of office space on four floors and utilizes a hybrid heating solution combining geothermal heating, solar energy and process heat.

The building consists of a state-of-the-art skeleton structure from BauBuche GL75 combined with Lignotrend floors. The special feature of the structure is the large span of over 10 metres, whose realisation in timber construction was only made possible by the high performance of BauBuche. The BauBuche posts have a cross-section of 300 x 360 mm. The associated beams have a cross-section of 200 x 840 mm

Figure 9: TSBOne, state of the art skeleton structure with 10 m clear span, Aarhus, Denmark

and were precambered by 20 mm at a span of 10.10 m in order to reduce deflection.

For the connection of the precambered beams to the posts, a high-performance connection with plates embedded in the wood was developed. This allowed both the fire protection requirements to be met and the forces to be transferred. An intelligent detail, an open hole at the top for the first bolt, enabled an easy assembly.

For design reasons, the skeleton construction was treated with a white pigmented coating, which also served as weather protection during assembly.

7. Black and White Building, London, United Kingdom

Figure 10: Black and White Building, London, United Kingdom

The simplicity of this fully engineered timber office building belies its groundbreaking innovation. Setting a powerful sustainable agenda with only 410 $kgCO_2/m^2$ embodied carbon (A1-A5), material use has been optimised. Each component is designed to be as efficient as possible, resulting in an honest design without excess. Designed to offer flexible, shared workspace to companies this modest yet significant building with a powerful sustainable agenda is the tallest engineered timber office building in central London. A hybrid structure comprising a BauBuche GL75 frame with CLT slabs and core has been designed to create vast open workspaces. With no structural internal partition walls the layout can be easily adapted as future demands change. The state of the art timber structure is framed by the glazed curtain wall, with solar shading provided by a second skin of vertical timber louvres. A parametric model simulating the movement and impact of sun against the façade determines the layout and form of the louvres, demonstrating how timber, combined with cutting edge digital analysis of environmental performance, can result in a truly 21st century building.

It is no coincidence that the connections are reminiscent of a steel structure. The building was assembled by the British steel constructor William Hare.

Figure 11: Connection detail, Black and White Building, London

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What’s behind the extraordinary Wisdome Structure

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What’s behind the extraordinary Wisdome Structure

Abstract

Wisdome Stockholm is a scientific experience arena being built at Sweden’s National Museum of Science and Technology. With its wave-like roof made of spruce laminated veneer lumber, it pushes the boundaries of what was previously considered possible. The Free Form roof was designed by the Swedish architecture firm Elding Oscarson in collaboration with the Norwegian construction engineer Florian Kosche.
Based on their designs, the timber construction specialists at Blumer Lehmann created the detail plans for the unique Free Form building together with their planning partners. Since the start of construction, they have also been responsible for ensuring that the project is executed in accordance with the plans.

The pioneering timber construction project Wisdome Stockholm is already being characterised as one of Sweden’s most important building projects. It features a spectacular timber construction with a surface area of 1,325 square meter and a unique vaulted main roof.

Inside this experience arena is a hemispherical dome theatre with a diameter of almost 22 metres and a height of around 12 metres. The theatre includes a 3D cinema with 100 seats. With 360-degree 3D projections and cutting-edge visualisation technology, it allows visitors to experience the world of science and engineering in a new and fully immersive way. Wisdome Stockholm is scheduled to open by end of 2023.

Figure 1/ Rendering Wisome Stockholm /Elding Oscarson:

1. A Dome made from CLT in a Gridshell made from LVL

1.1. Pioneering Timber Design

The striking design by Elding Oscarson and Florian Kosche emerged as the winner of an architecture competition. The heavily curved Free Form timber roof connects the inside and outside areas of the National Museum of Science and Technology and creates a spectacular interior for the dome structure of Wisdome Stockholm. The roof geometry spans a footprint of 25 x 48 meters, without columns. On three sides of the building, a projecting roof supplements the roof support structure and brings the curvature of the roof surface level with the eaves line. The Free Form structure is based on a grid system of LVL beams.

The dome below the vaulted roof is made from cross-laminated timber. A requirement of the architecture competition was that timber be used in the construction, in particular cross-laminated timber (CLT) and laminated veneer lumber (LVL).

Figure 2/ Scaled Model of Wisdome Stockholm / Elding Oscarson

2. Various Partners and production facilities

2.1. Partnerships in every phase

One of the main partners of the Wisdome Stockholm project is Stora Enso, one of the world's largest forestry firms. The Finnish-Swedish company also supplied all the timber construction material for the project. The flagship building marks a milestone in sustainable, climate-friendly construction. It pushes existing technical boundaries and is intended to showcase what is possible with wood as a climate-friendly construction material.

With its experience in timber construction and its technical expertise in project planning and the implementation of sophisticated Free Form geometries, the Swiss timber construction company Blumer Lehmann was the perfect partner to execute this ambitious project.
Supported by partners from many previous Free Form projects, the timber construction engineers from SJB Kempter Fitze with Hermann Blumer, and the parametric planners at Design-to-Production, the Blumer Lehmann team got to work planning the highly complex roof construction in detail.

2.2 1:1 Mock-ups for the roof construction

Two mock-ups provided the information needed for the construction design. 'This allowed us to instil confidence in the client,' says Martin Looser-Frey, looking back.
The grid-shell roof support structure consists of three transverse layers of LVL beams and two longitudinal layers of beams. Unlike constructions made of laminated timber, which are bent and milled in the factory beforehand and delivered to the construction site as complete components, for construction of the main roof only the lowest panel strip layer was laminated in the required curvature and delivered as a finished component. This layer served as a scaffold and structural aid for the complex assembly process. The remaining four beam layers were only bent and dowelled during assembly on site. All the connections are designed with dowels and peg connections, which are milled from the same LVL material.

The actual dome inside the building is made entirely of cross-laminated timber (CLT). It was produced back in the Stora Enso factory in Sweden and then assembled on site underneath an assembly tent. The Blumer Lehmann team from Switzerland also carried out the parametric design, the engineering and the detail planning for the dome construction.

Figure 3/ 1:1 Mock up Main Roof / Blumer Lehmann AG

2.3 Roof Support Structure with 20km of LVL Panels strips

'Our main job was to develop a concept for the supporting structure that would allow the chosen architectural design to be implemented,' remembers Martin Looser-Frey, who serves as Free Form Division Manager and is responsible for international sales at Blumer Lehmann.

For the main roof, the timber construction engineers at SJB Kempter Fitze opted for a lattice-shell structure with criss-crossing LVL beams. With interlocking dowel joints and the help of cutting-edge planning tools, these were connected to form a double-curved grid. The differently vaulted roof construction is supported around the edge by 24 solid columns that are made from block-laminated LVL with dimensions of 60 x 80 and 60 x 60 centimetres.
The columns are connected rigidly to the approximately 1.20-metre-high concrete base. To limit the horizontal deformation of the roof support structure, tensioning rods are integrated into the wooden columns, to which a considerable pretensioning force is applied after assembly. A solid edge beam is arranged on the column heads to enclose the Free Form construction all the way round.

Due to the very ambitious time schedule of the project they cooperated with various wood construction partners for the production, which also have an affinity for high precision work.

Figure 4/ Installation grid shell roof with dowelled girders / National Musseum of Science and Technology

2.4 Installation Phase

The installation of the dome and the grid shell structure was completed in 7 months only. Due to the complete site covering with a giant tent, which had integrated the construction crane into itself, it was possible to work steadily regardless of weather conditions and to ensure an optimal construction process.

Figure 5/ Finished timber construction work / National Musseum of Science and Technology

Construction details

Project: Wisdome Stockholm at the National Museum of Science and Technology (Tekniska museet)

Address: Museivägen 7, 115 27 Stockholm, Sweden

Project type: Art and culture, museum construction

Client: Tekniska Museet, Stockholm

Architecture: Elding Oscarson Architects, Stockholm

Main Engineering / Supporting structure: Florian Kosche AS, Oslo, Norway

General Contractor: Oljibe AB, Sweden

Timber supplier and main partner: Stora Enso, Sweden

Planning and execution Free Form timber construction: Blumer Lehmann AG, Switzerland

Timber construction engineers: SJB Kempter Fitze, Switzerland, with Hermann Blumer

Parametric design: Design-to-Production, Erlenbach, Switzerland

Construction type: Free Form Timber Structure

Execution: Start of planning 5/2021, start of construction 7/2022, handover 12/2022

Green Cities Europe

Maja Persson
LRF Trädgård
Höör, Sweden

Green Cities Europe

Abstract

Green Cities Europe is an EU project in which 13 countries participate. ENA, the European Nursery Association, is the main applicant and the participating countries are members of the organization. The goal of the project is to spread knowledge about the added value of having green environments in cities and show good examples. The project highlights already existing research that has been done/is being done in the areas of health, social cohesion, climate, biodiversity, and economics.

1. What we do in the project

It is a 3-year project, 2021-2023, and is financed by 20% own funding and 80% from the EU. Each participating country's budget varies depending on how much funding they have. The total budget is 3.4 million euros. The Swedish part is 345,000 euros in total.

The target group is decision-makers, politicians, and others who make decisions about green areas in cities. We communicate with them through debate articles, social media, and events.

We collaborate with researchers and have contacts with authorities and politicians. But also people who work with the issues in purely practical terms, landscape architects, urban planners, etc.

We highlight current research and have compiled the booklet Arguments for greener cities, through a collaboration with researchers. Here we highlight arguments for health and social cohesion, climate, biodiversity, and the economy. It is a brochure where the recipient is a politician and it has been sent to all politicians in the Swedish Parliament.

We highlight good examples from cities in Sweden but also abroad.

Weh ave highlighted the 3-30-300 rule, developed by Cecil Konijnendijk, Professor of Urban Forestry in British Columbia and Associate Professor at the Nature Based Solutions Institute in Barcelona. Both through debate articles and seminars at Almedalen.

We have also highlighted the need and value of green environments in connection with healthcare facilities. The positive effect green environments have on recovery is great.

We have our website as a base for our information. We also spread the information via our LinkedIn page.

On the webpage, there is also a page for every participating country.

GRÖNA STÄDER EUROPA

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References

All information lies on our webpage, the Swedish site Hem | Green Cities (thegreencities.eu), the start site fort he hole project Green Cities - The positive effect of Green Cities (thegreencities.eu)

Brochure Argument for Greener Cities, Argument för grönare städer - en forskningssammanställning | Green Cities (thegreencities.eu)

Modern Garden Cities
– a sustainable alternative!

Ulrika Liiv
Communication and Sustainability
Forever Sustainable
Stockholm, Sweden

Today's urban development strives for sustainable urban solutions. Two of the strongest drivers for this are rapid urbanization and climate change. In recent decades, dense, compact urban development has been seen as the environmentally sustainable ideal and leaves very little room for single-family houses. The main reasons why dense, compact urban area has been seen as the ideal are that it can accommodate more inhabitants within a limited area, and that it supports an efficient public transport system that reduces car use. Single-family houses have been associated with an assumption that they are not sustainable as they have a larger land use and encourage commuting to work with fossil fuel powered cars.

However, a survey from the National Board of Housing, Building and Planning shows that a majority (seven out of ten) of Swedes express an interest in living in single-family houses or semi-detached houses. Therefore, the question posed is – Can this be achieved without compromising the climate and environmental sustainability? That is, can garden cities with a majority of detached or semi-detached single-family houses be sustainable? The answer is yes!

Despite the fact that 70 percent of Sweden's population wants to live in their own house, Sweden is the country in Europe with the fourth lowest proportion of single-family house construction. The reason is that the planning does not prioritize this type of housing. By building garden cities with space for different types of people in different forms of housing and tenure, we allow diversity and enable vibrant residential areas that are both socially, economically and environmentally sustainable.

History of the garden city

Functionalism & the fall of the garden city

The garden city flourished in Sweden in the early 1900s. With its winding streets, beautiful wooden houses and lush gardens, it became many people's dreams. Everywhere people were seen taking care of their plots and cultivating for self-sufficiency. Conversations over hedges and fences between neighbors meant that green and social sustainability arose quite naturally. But then in the 1930s something happened – functionalism was born and the garden city died out.

Just as the garden city was a counter-reaction to industrialism, functionalism became a reaction against the garden city. Suddenly, people didn't want to go out into the garden and get their fingers dirty anymore, but it became fashionable to barely have to leave the home. Food was bought in a stores instead of growing yourself.

The revival

Functionalism is based on the fact that function primarily determines the planning of houses and neighborhoods. The subsequent modernism took this to a whole new level. Architect Erica Wörman uses the Swedish million program as an example:

The aim with this program was to develop million homes in a short period of time she says. The residential areas were planned according to the length of the construction cranes - not people's well-being or beauty values. The housing issue was solved, but instead new problems such as unsafe environments and segregation were created.

Modernism likes to advocate densification at height with large parking areas and other unsafe environments as a result. The Garden City is a very dense but low urban fabric that combines high yield requirements and efficient construction with well-being and security.

OBOS' vision of the garden city

OBOS is one of Sweden's and Norway's largest housing developers. OBOS' vision of the garden city arose from a desire to make a difference in the housing policy landscape,

OBOS vision the garden city is a green, safe and pleasant place, with homes in different forms of tenure, often environmentally certified, built out of wood, and sometimes also with home purchase models that allow more people to have access to their own, owned housing. Good service, communication and pleasant street networks are a matter of course in OBOS' vision of the garden city, as well as attractive architecture in a beautiful living environment.

Residential areas where people want to live

The well-being of the Garden City is based on clear rules on design and content. The houses are usually located close to the streets and the architecture is well cohesive. The mix of different types of housing creates a socially attractive environment.

By offering everything from student housing and tenant-owner apartments with alternative home purchase models to property rights and properties for health and social care, OBOS is involved in building a garden city where you can easily make a career in housing, throughout your life.

Green spaces and factors for environmental sustainability

A mix of single-family houses in wood and environmentally certified multi-dwelling buildings creates an environmentally sustainable district that can accommodate many residents and that has all the benefits of a garden city with both private and public green spaces. The provision of green areas, together with the mix of housing and the buildings' low climate impact, contributes to a high sustainability performance in the garden city.

OBOS' vision for the Garden City also includes factors such as environmental certification of homes, the use of renewable energy such as solar cells, and charging posts for electric cars.

Living, green districts for high well-being and security

Life between the houses is a priority factor in development garden cities. This includes initiatives that safeguard well-being and security, such as common meeting places, greenery, cultivation opportunities, playgrounds, outdoor gyms and the utilization of existing vegetation.

Alternative purchase models

An important factor in OBOS' vision of the garden city is housing for people of all ages. It should be possible to live in the same area for a long time and there should be space for students, one- and two-man households, families with children, people with special needs and seniors in the same district. This is an idealistic picture that today's housing market does not always manage to match. Mainly because young first-time buyers and those who may not have had the opportunity to save up a larger capital, are excluded from the opportunity to own their own home due to the banks' requirements.

In order to lower the thresholds for more people to enter their own home, OBOS has chosen to launch home purchase models on the housing market. With OBOS Deläga, a customer buys at least half of the home and co-owns the other half with OBOS.

When buying a home with OBOS Deläga, the customer starts by buying at least 50 percent of the home, while co-owning the rest together with OBOS.

Sound and environmentally certified homes

In the effort to build long-term sustainable garden cities, where future generations are taken into account, OBOS builds space-efficient, healthy, environmentally certified houses with durable material choices and low energy consumption.

Nordic Swan Ecolabel

With Nordic Swan Ecolabelled projects and homes, a guarantee stamp is given that they are valued with a life-cycle perspective and have low energy use, meet high environmental and health requirements for construction products, materials and chemical products, ensure a good indoor environment and low emissions, and that they have a quality-assured construction process.

Infrastructure

Infrastructure holds neighborhoods together and simplifies the everyday lives of residents. Infrastructure in the Garden City is often on a more small-scale level, where every detail contributes to a pleasant feeling among residents and visitors. It's not just about street networks, but also about the architecture of the area itself and the local services offered.

Communication and good connections

Communication and good connections mean that it should be easy to get to and from the residential area and on to the neighboring central town. Common to all projects OBOS develop are pedestrian and bicycle paths, as well as access to public transport, such as bus or tram.

When building the long-term sustainable Garden City, car traffic should be minimized by for example, sharing pools for electric bicycles or electric cars.

Smaller street networks

Garden cities consist largely of pleasant street spaces, where the houses are close to the street and invite with winding roads in between the houses. The smaller winding street networks surround the neighborhoods, instead of the houses being located along a major main road. An advantage of this is that it also creates increased safety in the area, as the smaller roads automatically mean shorter visibility lengths and greater caution for road users.

Lighting and vegetation in connection with the street structure also strengthen the sense of security for those who pass through the area.

Service

An ordinary residential area is often located a little on the outskirts of the center. In OBOS vision of the Garden City, there should be access to services in close proximity to the area. It can be grocery stores, cafes or a health center.

Attractive, varied and cohesive architecture

The houses are built close to the streets along a common construction line so that the houses define the important street space. Gardens or small plots contribute to a pleasant feeling while hedges and fences create boundaries between the private and the common street space. The types of houses vary in terms of shape, color, style, building height and location. This provides the opportunity for a mix of social classes, forms of tenure and family constellations.

References

TMF, Sifo 2019 - 75 percent of Swedes want to live in detached houses, semi-detached houses, terraced houses or chain houses (i.e. the definition of single-family houses)

Boverket, Rapport 2014:24 - At least half of the respondents (5000 people) want to live in some form of detached house, regardless of which region they prefer to live in. Among those who prefer to live in Stockholm, 6 out of 10 want to live in detached houses. For the Gothenburg and Malmö alternatives, around 7 out of 10 want to live in single-family houses and in other regions, around 8 out of 10 want to live in single-family houses.

OBOS – Vi utvecklar Trädgårdsstaden (We develop the Garden City) www.obos.se

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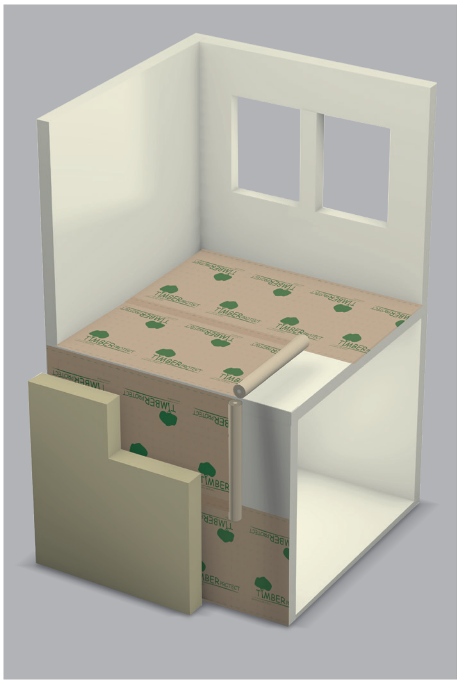

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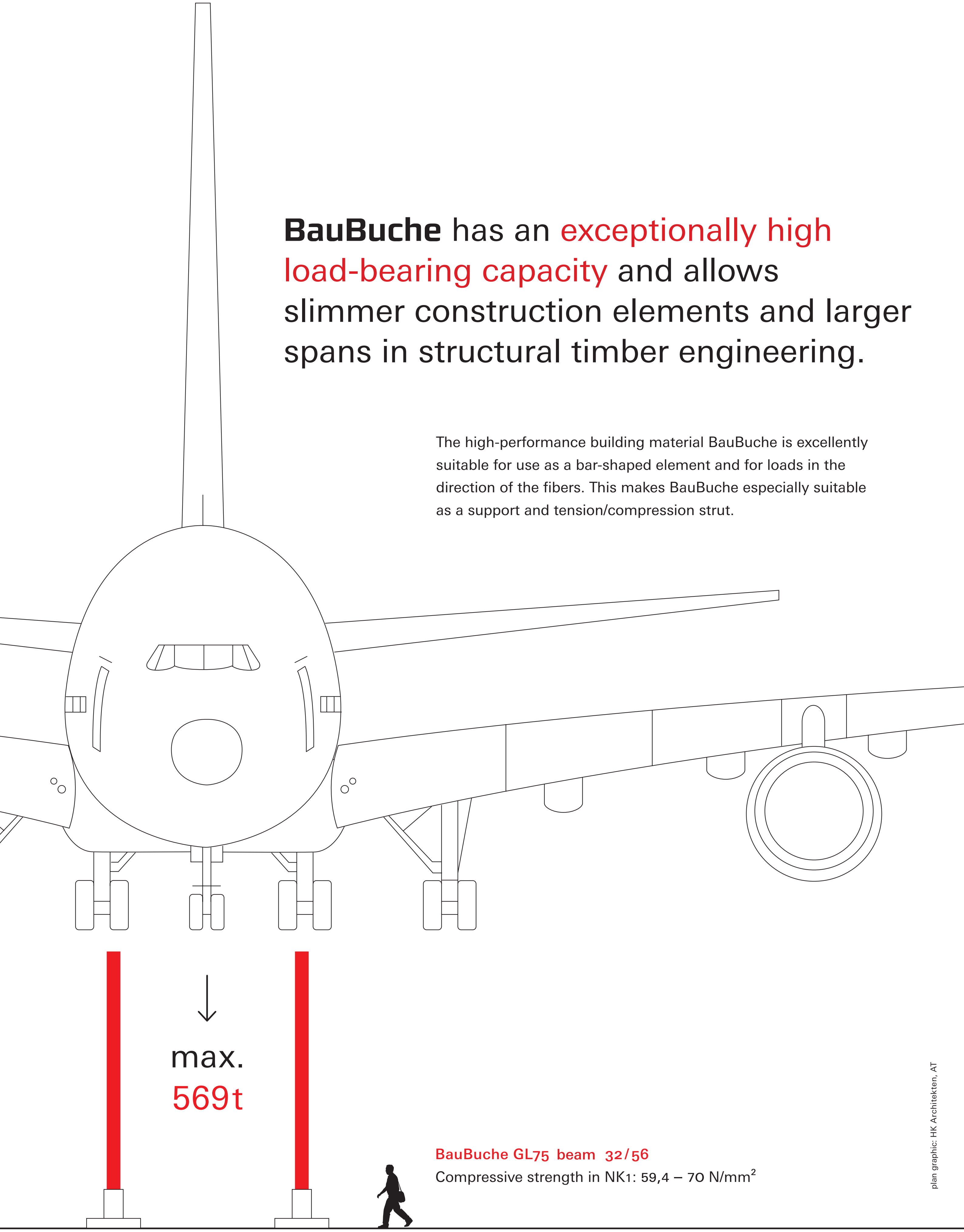

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