Final Report on Research Project

Förbättrad ljudmiljö i byggnader av KL-trä

Funded by The ÅForsk Foundation
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Project leader: Peter Persson, Department of Construction Sciences, Lund University

Summary

This project, funded by ÅForsk Foundation, addresses the challenge of impact sound insulation in cross-laminated timber (CLT) buildings, a growing construction method in Sweden due to its sustainability and economic benefits. Timber construction plays a key role in reducing greenhouse gas emissions, yet low-frequency impact noise—such as footfall—remains a major source of disturbance for residents. Current solutions are costly and often ineffective, highlighting the need for innovative approaches.

The project aimed to enhance CLT's competitiveness by developing improved impact-sound insulation solutions through advanced numerical simulations and experimental validation. Methods adapted from the automotive industry were employed to model sound and vibration transmission, quantify uncertainties in wood properties, and investigate acoustic–structure interactions. Simulations were calibrated using experimental data and informed by dialogue with industry stakeholders.

Several innovative structural concepts were explored: using alternative wood species (beech or birch) or integrated elastomer layers to reduce vibration amplitudes by over 50%; integrating concrete lamellae for significant vibration reduction; and reorienting lamella layers diagonally to achieve up to 30% improvement. These solutions demonstrate potential to minimize reliance on add-ons like floating floors, thereby improving cost-effectiveness and sustainability.

In conclusion, the research shows that advanced simulation combined with targeted material and design innovations can substantially improve acoustic performance in CLT buildings. Future work should focus on experimental verification and product development to bring these concepts closer to practical application.

Introduction

Building houses with timber offers economic and sustainability advantages, as highlighted in the Ministry of Enterprise and Innovation's 2018 strategy for increased timber construction [1]. Unlike many other materials, wood is renewable, and timber-frame buildings now represent 15–20% of new Swedish multi-family housing. Increased use of wood is important for reducing greenhouse gas emissions, as the building sector accounts for roughly 20% of Sweden's domestic emissions, mainly from new constructions and renovations [2]. A rapidly growing product within the industry is cross-laminated timber (CLT); see Figure 1 for an illustration.

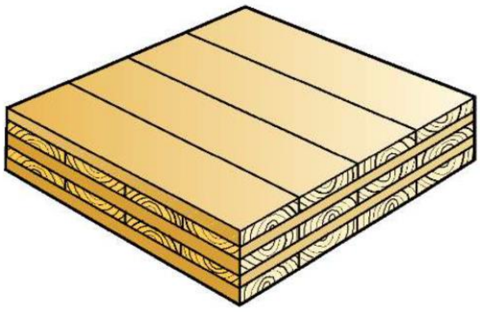

Figure 1. Example of cross laminated timber (CLT) layup.

A key challenge in timber construction is achieving adequate low-frequency impact sound insulation [3], i.e., reducing the "thumping" noise from footsteps above. A recent RISE report [4], based on 21 interviews with manufacturers and acoustics consultants, shows that impact-sound remains a significant source of disturbance for residents. It also highlights limited knowledge of effective construction solutions and notes that commonly used elastomers are costly and relatively ineffective. There is therefore a strong need to develop innovations, which would improve residential sound environments and strengthen timber construction's competitiveness.

Similar challenges have long existed in the automotive industry, where lighter structures must meet strict noise requirements. Numerical simulations enable deeper understanding of sound transmission and support the development of innovative solutions. We thus see great potential in applying these advanced simulation methods and sound-insulation concepts to timber construction.

In summary, the timber construction industry has a strong need for improved impact sound solutions, while its current knowledge and development methods are behind those of, for example, the automotive industry. Academic contributions are therefore essential for advancing understanding and enabling innovative, more effective construction solutions.

Purpose and objectives

The purpose of the project was to support the sustainable transition of the construction sector, with particular emphasis on reducing greenhouse gas emissions. The project aimed to contribute to this transition by enhancing the competitiveness of cross-laminated timber (CLT) as a structural system for new buildings such as residential units, offices, and public facilities. The specific contribution of the project is to improve the impact-sound performance of buildings constructed with CLT. The objective was to develop improved construction solutions for impact-sound insulation using advanced numerical analyses and data from experimental tests.

Methods

The project work has applied numerical models of sound and vibration transmission in CLT buildings. These models were analyzed using methods adapted from the automotive industry, enabling the establishment of a fundamental understanding of impact sound transmission in such buildings and how it is affected by different structural designs. We have conducted experimental tests and used data from experimental tests conducted by other researchers, in order to calibrate and validate our numerical models. Our focus has been on developing innovative conceptual structural designs for impact sound insulation in CLT structures.

The developments drawn inspiration from established construction solutions within the automotive industry. The work has considered what is practically feasible from an overall civil engineering perspective, enabled by our continuous dialog with the construction industry. Our research findings have been disseminated through peer-reviewed research journal articles and conferences papers, which includes oral presentations at scientific conferences.

Development of simulation methods

Quantification of uncertainties [5]

This section concerns the effects of uncertainties in wood's mechanical properties on the dynamic response of a slab in wood. This work is described in a publication that stems from an international collaboration with Aarhus University in Denmark and The University of Texas at Austin in the US.

As an example, Figure 2 shows the expected variation in eigenfrequencies due to the variability of wood's mechanical properties. In the figure, two different types of statistical methods are compared: these being standard Monte Carlo Simulation (MCS) with quasi-random sampling and the Latin Hypercube Sampling (LHS), respectively. Both show that the natural variation of wood's mechanical properties needs to be considered if accurate vibration responses are sought.

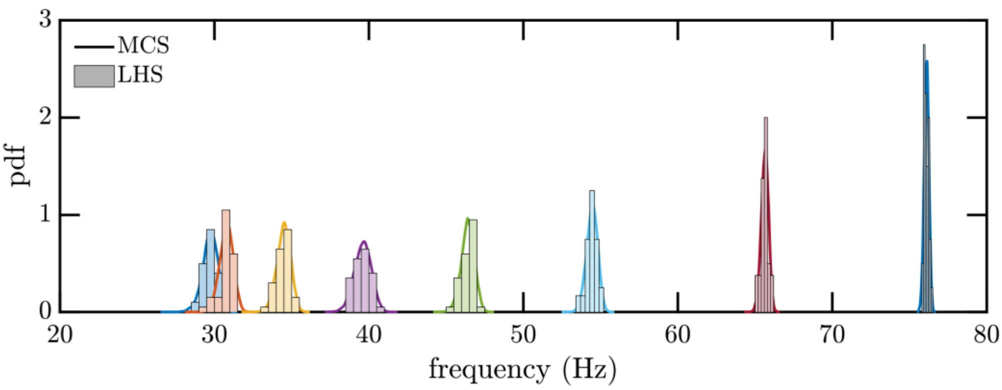

Figure 2. Variation in eigenfrequencies [5].

Coupling of CLT panels and air [6]

In this work we investigated the influence of air on the dynamic response of CLT panels by developing prediction metrics that are used in the automotive industry (see e.g., [7]). The numerical simulations consider the acoustic–structure interaction and are solved by the finite element method, see Figure 3 (left) for an example vibration pattern. We successfully developed a practical prediction metric with sufficient accuracy to the used in conceptual design of CLT buildings, see Figure 3 (right) for the correlation of the developed vibration metric to the reference noise metric.

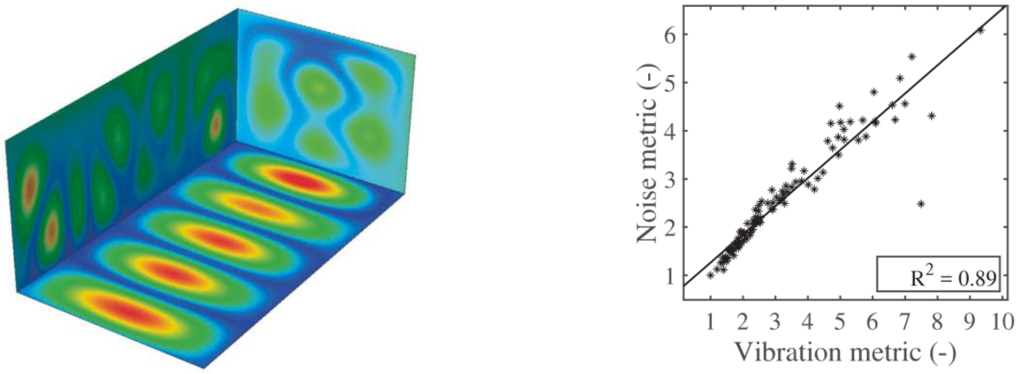

Figure 3. (left) Visualization of response amplitudes at 90 Hz. (right) Correlation between noise metric and developed vibration metric [6].

Development of innovative structural designs

CLT panels of beech or birch [8]

In this study we have studied the benefits regarding the vibration performance of CLT panels of using beech or birch as lamination material. We have compared the dynamic response to that of standard strength class C24 spruce panels. The influence of the dynamic response for using these nonstandard wood species is significant. The study shows that the response amplitudes can be reduced to less than half the response of spruce panels, see Figure 4 for the vibration response of a panel of various wood species.

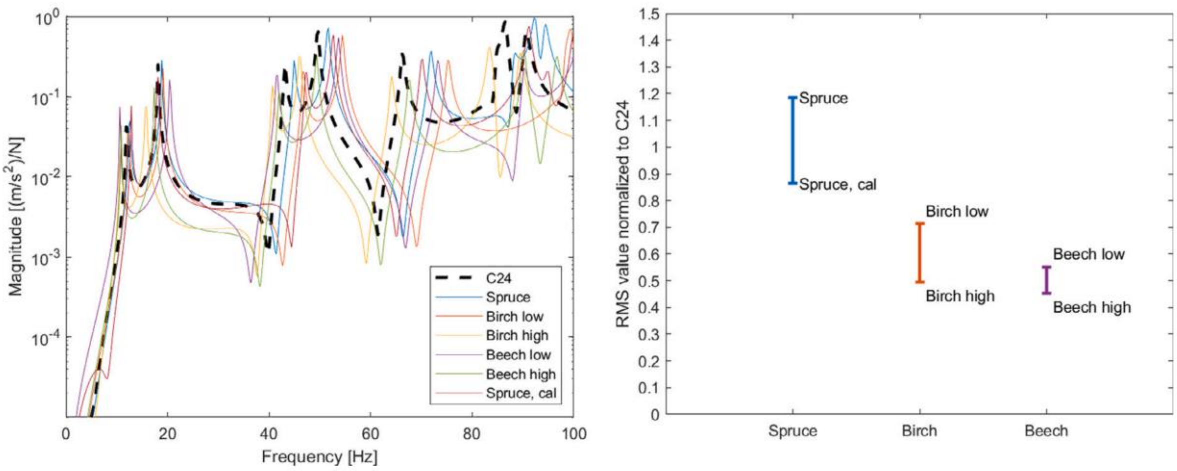

Figure 4. (left) Frequency response of CLT panels with various wood species of different qualities. (right) Normalized average amplitudes as single-value metric of left subfigure [8].

Elastomer layers integrated into spruce and oak panels [9]

In this study we explored the benefits regarding reduced vibration response of CLT panels by having integrated elastomer layers, see Figure 5 (left), as well as changing the spruce lamellae to oak lamellae. Both means of reducing the vibrations were shown to be effective. See Figure 5 (right), as an example. The vibration levels are shown for a spruce panel with and without elastomer layers; the reductions in amplitudes are evident.

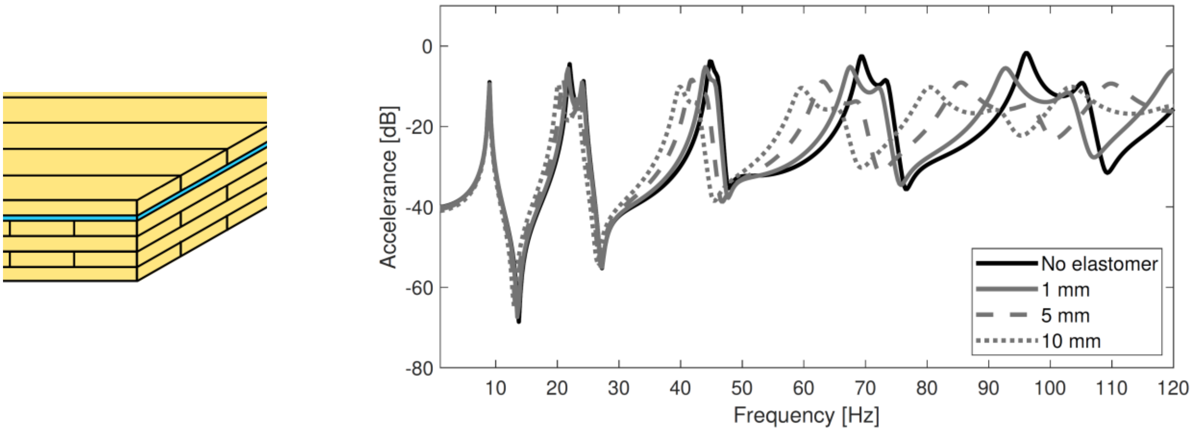

Figure 5. (left) A cutout, showing blue colored elastomer in yellow colored timber panel. (right) Example results showing the reduction in acceleration response by having integrated elastomer layers of various thicknesses in the panel [9].

Integrated individual concrete lamella in the panels [10]

Here we investigated the effects on exchanging some spruce lamellae to concrete, see Figure 6 (top) for an example of exchanging 5% of the panel's volume. If a rather wide frequency range is of interest, the benefits can be significant already at this minor use of concrete; the vibration levels may be reduced by up to 80%, which is almost as much as a solid concrete panel of the same size. The major effects often occur for frequencies of about 100–500 Hz.

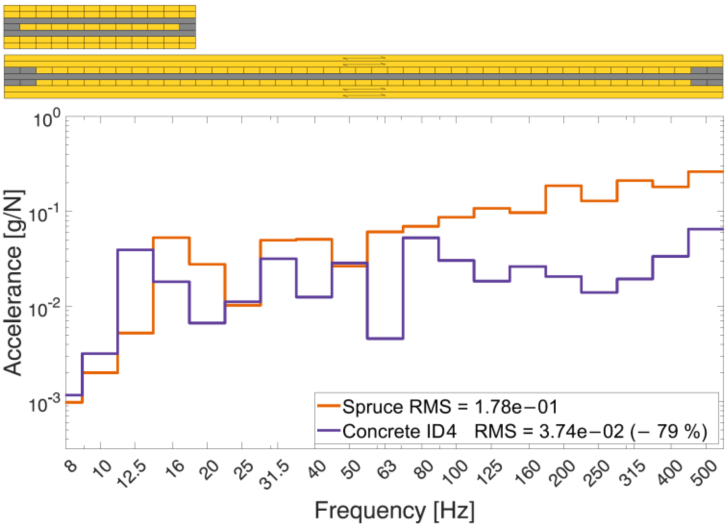

Figure 6. (top) The layout of the example panel with concrete lamellae in gray color. (bottom) Acceleration response of that panel in third-octave bands [10].

Diagonally oriented lamella in panels [11]

In this study we did not introduce any new species or materials into a panel. But we rotated some of the layers in the panel so that they became diagonal instead of perpendicular to the adjacent layers. In Figure 7, a table from the publication [11] shows configurations of various tested rotation angles (in degrees). It is shown, depending on the frequency range of interest, that a configuration can be developed that may reduce the vibration levels by up to approximately 20–30%.

	Frequency range (Hz)				
Lay-up	<100	<200	<300	<400	<500
0-0-90-0-90-0-0	0%	0%	0%	0%	0%
0-0-60-0-60-0-0	-10%	15%	11%	26%	31%
0-0-45-0-45-0-0	-30%	16%	14%	40%	32%
0-15-90-0-90-15-0	2%	2%	0%	-3%	-3%
0-30-90-0-90-30-0	-2%	0%	-2%	-10%	-11%
0-45-90-0-90-45-0	-6%	-5%	-14%	-15%	-9%
0-60-90-0-90-60-0	-12%	-15%	-14%	-14%	-22%
0-15-45-0-45-15-0	-23%	15%	11%	41%	33%
0-15-60-0-60-15-0	-2%	13%	13%	30%	36%

Figure 7. A table showing the reduction (green color) or amplification (red color) in the vibration response for various panel layups [11].

Concluding remarks

Advanced numerical simulations together with the use of experimental data for calibration of material properties and verification of modeling assumptions provide rigorous means of developing and investigating innovative solutions for sound and vibrations challenges in CLT buildings.

The research works presented here have their focus on improving the vibrational performance of a bare CLT panel. Our research findings indicate that it may be possible to reduce vibration amplitudes in the order of 50% by: changing from spruce the wood species beech, birch or oak; or by integrating an elastomer layer into the panel; or by exchanging some individual lamellae from spruce to concrete.

The innovative solutions show great promise to increase the competitiveness of timber structures by showcasing the possibility to reduce the need for add-ons such as floating floors to meet requirements regarding sound and vibration. Future research should focus on the next steps towards product development by verifying our research findings by more experimental tests and particular loading situations as example cases.

References

[1] Näringsdepartementet vid Regeringskansliet. Inriktning för träbyggande. 2018. https://www.regeringen.se/49ee7f/contentassets/37f07802672c45078a20d3a375e82c25/20180626_inriktning-for-trabyggande.pdf (2021-03-04)

[2] Boverket, Finansdepartementet vid Regeringskansliet. Utsläpp av växthusgaser från bygg- och fastighetssektorn. 2021. https://www.boverket.se/sv/byggande/hallbart-byggande-ochforvaltning/miljoindikatorer---aktuell-status/vaxthusgaser (2021-03-04)

[3] Ljunggren F, Simmons C, Öqvist R. Correlation between sound insulation and occupants' perception –Proposal of alternative single number rating of impact sound, part II. Applied Acoustics 2017;123:143–151.

[4] Glebe D, Ohlsson J. Kunskaps- och resurssammanställning för ljud och vibrationer inom träbyggande –Slutredovisning 2021-10-22. RISE – Research Institute of Sweden.

[5] HU Lim, L Manuel, P Persson, LV Andersen. Uncertainty quantification of wood floor system modal frequencies resulting from variable densities in members. Structures Volume 53, July 2023, Pages 1425-1434.

[6] O Flodén, A Peplow, P Persson. Predicting structure-borne noise in cross-laminated timber buildings during conceptual design. Finite Elements in Analysis and Design Volume 225, 1 November 2023, 104005.

[7] P Persson, O Flodén, B Pedersen Predicting vibroacoustic performance of thin-walled lightweight structures during conceptual design. Finite Elements in Analysis and Design 169, 103342, 2020.

[8] J Jonasson, P Persson, H Danielsson. Mitigating footfall-induced vibrations in cross-laminated timber floor-panels by using beech or birch. Journal of Building Engineering Volume 86, 1 June 2024, 108751.

[9] A Bohman, L Andersson, K Persson, P Persson. Vibration reduction in cross-laminated timber panels by using integrated elastomer layers. In: Engineering Materials, Structures, Systems and Methods for a More Sustainable Future, CRC Press, 96-101, 2025.

[10] KA Ung, A Bohman, L Andersson, P Persson, S Johansson, LV Andersen. Vibration reduction in cross-laminated timber panels by using individual concrete lamellae. In: Engineering Materials, Structures, Systems and Methods for a More Sustainable Future, CRC Press, 72-77, 2025.

[11] E Serrano, H Danielsson, P Persson. Dynamic response of diagonal laminated timber – parameter studies and modelling approaches. In: World Conference on Timber Engineering, 2025.