THE EFFECT OF JUNCTIONS AND MOUNTING ON SOUND INSULATION OF HORIZONTALLY ADJACENT ROOMS IN A CLT BUILDING

A. Løvstad[1*] **E. Toftemo**[1]
[1] Brekke & Strand Acoustics, Hovfaret 17b, 0275 Oslo, Norway
anl@brekkestrand.no

ABSTRACT

Cross laminated timber (CLT) can currently be considered in almost all building types, including those with high sound insulation requirements. Addition of mass, floating floors and wall and ceiling linings are needed in many cases, but as the knowledge and experience with CLT have increased, such measures can be optimized and, in some cases, omitted if junctions and mounting methods are done correctly. Visible CLT slabs and walls can be obtained. This paper reports on measurements of velocity level difference and sound insulation of horizontally and vertically adjacent rooms on a full-scale CLT test mock-up. Various resilient fasteners, interlayers and mounting methods are tested and compared. Commonly used building constructions comparable to those built in the field are investigated to address relations between junction attenuation and sound insulation. Results show that the mounting methods strongly influence the sound insulation obtained and may reduce the need for linings and other constructional measures if planned and conducted correctly.

Keywords: *sound insulation, cross laminated timber, junction attenuation*

1. INTRODUCTION

Cross laminated timber (CLT) is expected to continue its rise in production volumes and use over the last decades, in the years to come [1]. Many standards and timber codes have been developed to address and standardize performance requirements and product characteristics, but with little thought to harmonisation, according to Kurzinski et al. [2], which might indicate that CLT still is a rather young construction system early in its development.
However, CLT is presently considered as a building system in increasingly complex buildings, as the all-encompassing focus on environmentally sustainable solutions to a rapidly growing extent is supported by technical and practical knowledge, experience, and a growing cross-disciplinary desire to employ CLT by developers, engineers, architects and politicians. This interest is fueled by studies on sustainability, such as the overview of life-cycle assessment (LCA) by using CLT by Younis et al. [3], who reported on a possible reduction in greenhouse gas emissions of around 40 % by employing CLT. In addition to being environmentally sustainable, CLT systems are light weight and prefabricated, which enable rapid and efficient assembly and versatile design options [4]. The use of wood is also claimed to have positive effects on indoor climate and residents' well-being and health [5].
As the use of CLT has evolved in complexity from detached single-resident houses, through office buildings and schools to high-rise multi-residential dwellings, cultural centres and theatres [6-8], the need to build cost-effective and with appropriate margins must be refined and customized to the given project requirements accordingly. An increase in constructional and prediction quality is thus required despite increased requirements of sound insulation and vibration for CLT to competitive with the traditional heavier concrete based building systems.
National guidelines and documentation for sound insulation of CLT constructions have been published over the last decades and are continuously revised, supplemented and improved [9-10]. These are accompanied by investigations of airborne and impact sound insulation for various floor

[*]***Corresponding author***: anl@brekkestrand.no.

assemblies and resilient layers with CLT constructions, as done by e.g. Verdaxis et al. [11].

Architects, builders and the public often expect and desire for the wood in CLT buildings to be exposed, which partly is the motivation for this paper. The dimensions of the CLT slabs and walls vary, but measures are commonly required to comply with the sound insulation requirements. The extent and type of constructional measures that are incorporated into a project are governed both by the sound insulation requirements themselves and the design margins the constructors and engineers are comfortable with. Presently, the threshold to introduce wall linings, suspended ceilings and/or heavy floating floors or adding additional mass to the CLT slab is too low due to poor control of flanking sound, junction design and lack of experience. Confidence in predictions of sound insulation require both experience with CLT buildings as a whole, but also with directly comparable constructions and type and extent of measures, as variations in load and junction assembly, construction errors and detailing all advocate for specific experience and early quality control through field measurements. This is in line with Simmons [12], who commented that experience with specific constructions allow for reduced calculation margins with CLT, and especially if junctions and detailed measures are known, while a provisional margin of at least 8 dB is needed for relatively unknown constructions.

Such variations are to the authors experience not uncommon when a certain number of presumably identical rooms are included in measurement programs in larger measurement documentation setups. The variations may be due to specific construction errors, limited control of junction design or in-site production errors, which CLT constructions are especially vulnerable to. Furthermore, CLT slabs and walls are typically mounted with extensive use of screws, commonly also going through the strategically placed resilient layers, reducing their sound and vibration reducing effect [13].

Several researchers have measured vibration reduction indices using various elastic interlayers and fasteners [9,14-15] to provide a basis for omitting or reducing other structural measures. Morandi et. al. [14] compared junction attenuation and sound insulation between floors and rooms for a selection of available products with resilient interlayers. However, available research results are not always easy to apply in an actual building project.

This paper reports on measurements of flanking sound paths and sound insulation between horizontally adjacent rooms in a CLT test mock-up. Various junction configurations, fasteners and mounting methods are used, and the vibration level difference, $D_{v,ij}$, across the junctions between room are investigated in addition to airborne and impact sound insulation. As the measurements of vibration level difference are done between rooms and not on isolated junctions, full control of all flanking transmission paths cannot be achieved. This is done intentionally to address building constructions that are comparable to those built in the field.

2. THE TEST SETUP

A full-scale CLT mock-up construction was built in an industrial warehouse to assess how the mounting method affected the sound insulation and flanking sound transmission, with two rooms on the ground floor and one room on the top floor, as shown in Figure 1. The top floor could be lifted from the ground floor by hydraulic jacks, which allows repetitive testing of various resilient interlayers (RI), fasteners, angle brackets or screws, but was removed in its entirety during the horizontal measurements between the two rooms on the ground floor. The horizontal measurements were done lastly as they involve irreversible constructional measures on the CLT ceiling slab.

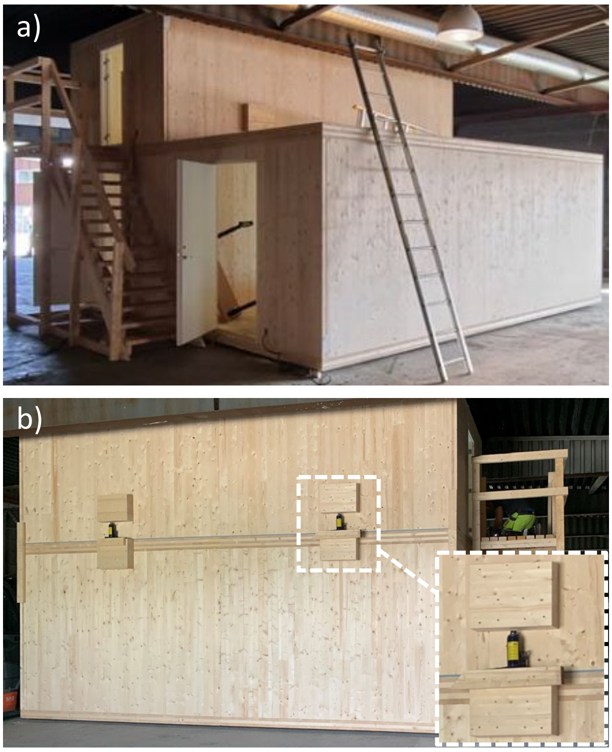

Figure 1. a) Test room set-up overview. b) Sideview with elastic interlayer and hydraulic jacks.

A schematic layout of the mock-up is shown in Figure 2, where the room dimensions and thicknesses of the CLT walls and floors are given. Vertical CLT panels were 3-ply of 100 mm thickness throughout. The ground floor and top roof were 3-ply 120 mm thick CLT panels, while the horizontal slabs between the floors and roof of the one-story high part were 5-ply 160 mm CLT. The test rig was delivered from Splitkon AS, element strength classes T15 and T22. The density of the wood is 460 kg/m^3.

Tests of airborne insulation were done according to ISO 16283-1 [16]. Variations in attenuation across building elements were assessed by measurements of velocity level difference across the building elements. The velocity level difference is described in ISO 10848-1 [17].

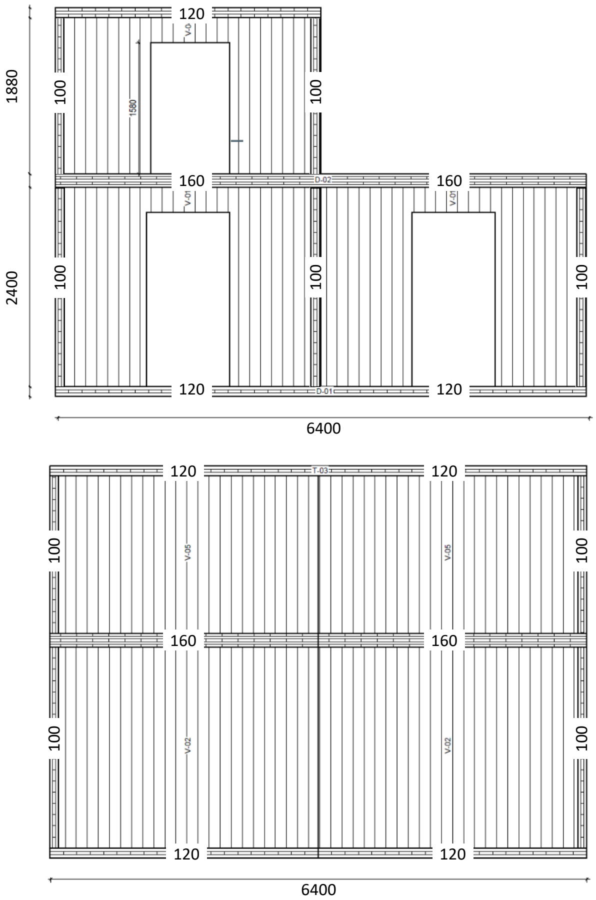

Figure 2. Vertical section drawings of the test mock-up: length (upper) and width section (lower). All dimensions are given in mm.

Four measurement positions were mounted on the ceiling of each panel/building element to measure the velocity level difference, as Figure 3a) shows a case with wall linings and floating floor. Tests were carried out using both pink noise fed through a loudspeaker and tapping machine. Results from junction attenuation shown in this paper have been conducted using a loudspeaker placed on sylomer pads as excitation, with two source positions for each measurement. Velocity level differences show averaged values of two sets of sensor positions mounted on the ceiling, eight positions in total.

The source room was fitted with floating floor and wall linings throughout the tests, only the wood in the roof slab was kept visible, see Figure 3. This was done to limit the flanking sound through floor and wall slabs.

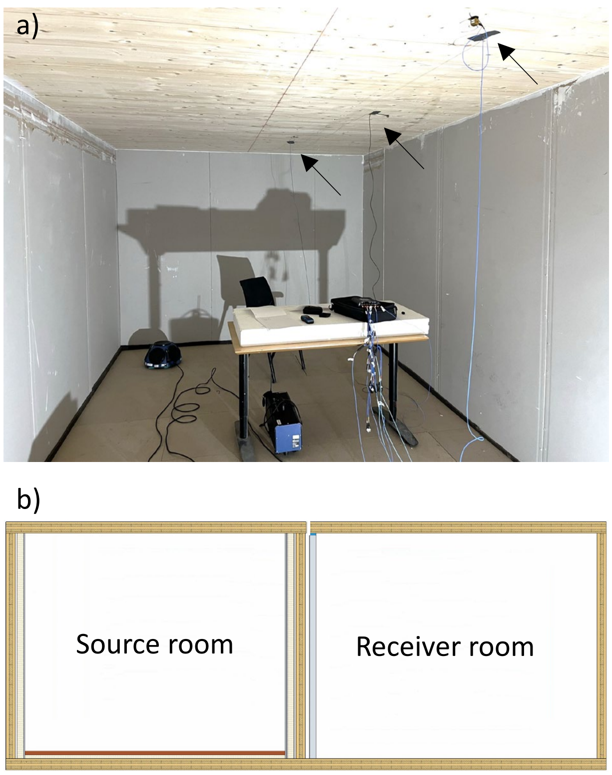

Figure 3. a) Photo of sensor setup inside of the test rooms (only 3 of the 4 sensors visible in the photo). Sensor positions indicated with arrows. b) Schematic of the test set-up, also indicating the cut in the roof slab and the additional columns.

3. MEASUREMENT RESULTS

3.1 Horizontal junction attenuation

Horizontal velocity level difference was initially measured with continuous walls and slabs. The walls and roof slab were then cut in the receiving room separating the adjacent rooms, as the photos in Figure 4 show, and were not in direct contact during the following testing. The roof slab was supported by free standing columns with sylomer resilient interlayers (RI) between the roof and the columns as seen in Figure 4a), no screws were used. A floating floor and wall linings were mounted on all walls in the source room.

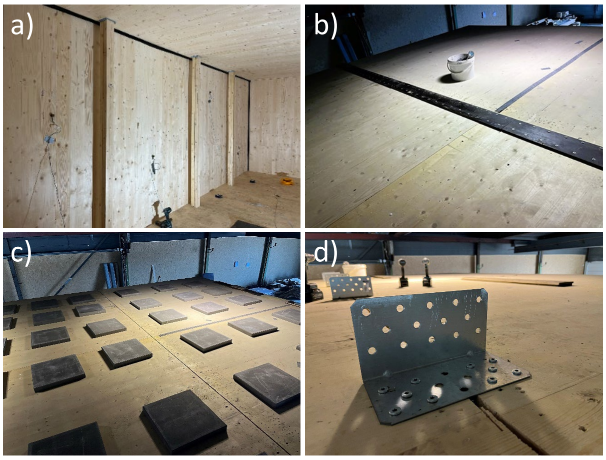

Figure 4. Photos of junction measures. a) Cut across roof and wall slabs (black line) and free-standing columns with sylomer RIs, b) chip board mounted across the roof slab cut, c) addition of mass to roof slab, and d) steel plates mounted across the roof slab.

The black line in Figure 5 was measured with a complete cut and no fasteners across the roof slabs, which indicates the upper achievable velocity level difference. Similarly, the red line indicates the expected lower limit given by the energy distribution and distance attenuation obtained with continuous walls and roof slab, which is less than 5 dB over the whole frequency range except from 160-400 Hz where it is 6-12 dB with a peak around 160 Hz. The difference between the black and red lines is about 10 dB up to 160 Hz, but then increases rapidly towards higher frequencies.
Applying a continuous chip board across the cut fastened with 120 screws in total into the roof slabs, as shown in Figure 4b), reduces the velocity level difference significantly, as the blue line in Figure 5 shows. The velocity level difference is comparable with the results with continuous slab up to 400 Hz but performs 10-15 dB better at higher frequencies.

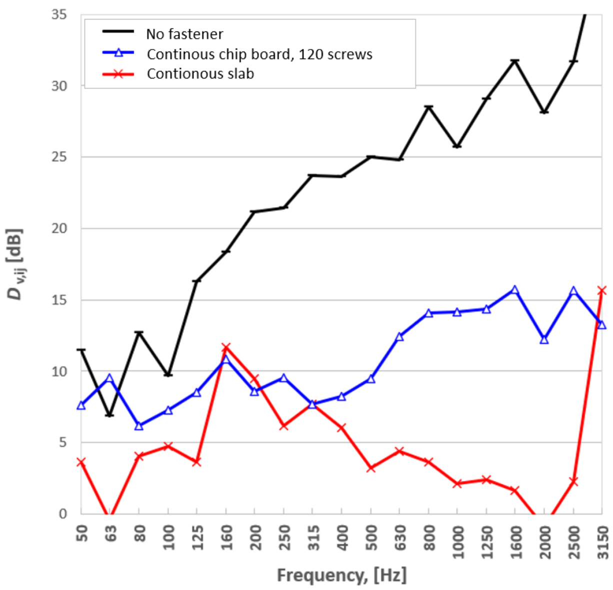

Figure 5. Measurements of vibration level difference between roof slabs in horizontally adjacent rooms. The red line shows results with continuous CLT wall and slab elements, black line with a full wall and roof slab cut, and blue line with a chip board across the roof split as seen in Figure 4b).

Figure 6 shows results with perforated steel plates mounted with centre distance 1300 mm, as shown in Figure 4d). Point connectors (red, orange, green lines) give comparable velocity level differences to the situation without fasteners (black line) in the low frequency area up to around 250 Hz, and mainly 5-10 dB reduced attenuation at higher frequencies. Employing RI under the steel plates gave no improvement as the mounting was not done with double, separated resilient layers, thus connecting the steel plate to the CLT on both sides of the cut. Adding weight to the slab (blue dashed line) only improved the velocity level difference from 160-250 Hz, also exceeding the levels obtained without fasteners. The added weight consisted of 36 concrete slabs distributed across the floor, weighing approximately 950 kg in total.
The most common way of connecting CLT constructions is with screws. Figure 7 shows horizontal junction

attenuation with partially threaded (PT) screw fasteners with various centre distances between the screws, with and without added weight. Improved attenuation with increased centre distance is seen throughout the measurements without added weight, as the connections became increasingly rigid with decreased separation between the screws. Adding the 50 mm concrete slabs onto the CLT roof improved the attenuation from 125 to 1250 Hz, and especially from 160-315 Hz, compared with the unloaded measurements. Centre distance between screws had little effect on the attenuation at these frequencies, where the added mass resulted in the largest improvement.

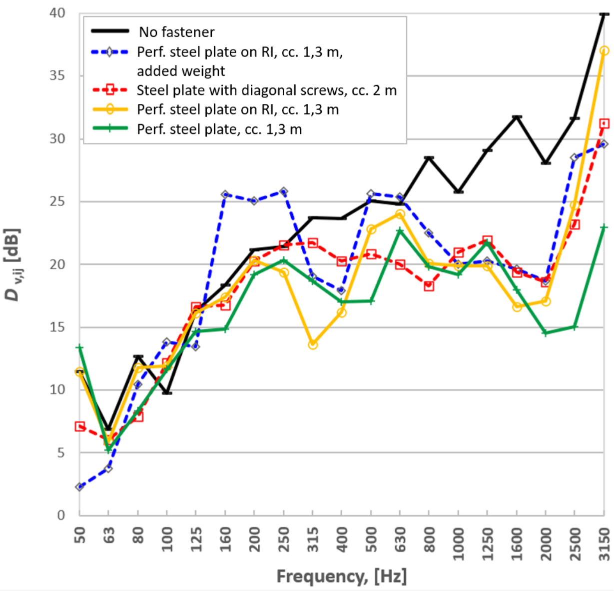

Figure 6. Velocity level difference between roof slabs in the horizontally adjacent rooms with a full cut in walls and roof slabs.

Results obtained with vertically adjacent rooms, as reproduced from [13] in Figure 8, indicates similar attenuation regardless of type or centre distance between the screws when the junction is loaded with an overlying structure (walls and roof slab). Morandi et al. [14] similarly found that the weight of an overlying structure can reduce the effect of the type of fastener used. At a larger scale, Nilsson et al. [18] reported that increased load has negative effect on the vertical airborne sound insulation, as lower sound insulation may be expected in lower stories in buildings as the RI load is higher.

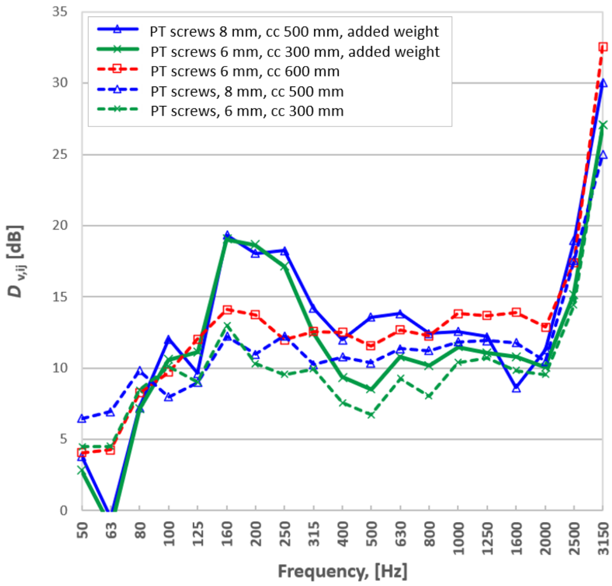

Figure 7. Measurement results of horizontal attenuation with screw fasteners of various type and spacing. Solid and dashed lines show results with and without added mass, respectively.

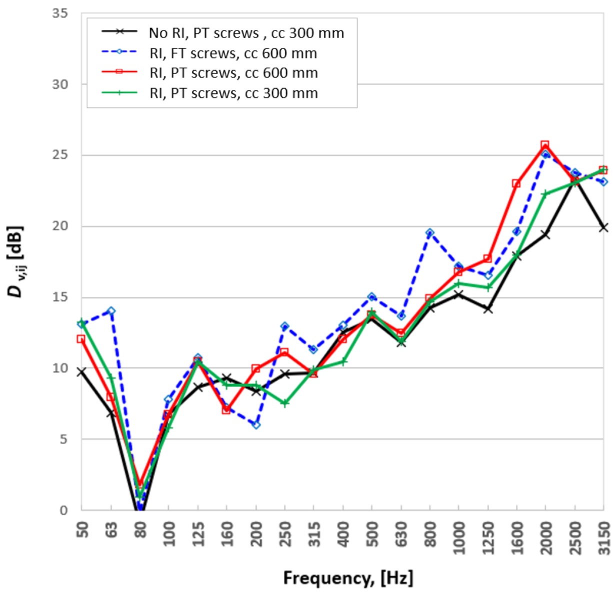

Figure 8. Measurement results of vertical attenuation with screw fasteners of various types and spacing, where solid and dashed lines indicates partially (PT) and fully (FT) threaded screws, respectively.

3.2 Airborne sound insulation

Airborne sound insulation was measured horizontally for a number of configurations shown in the previous chapters. Measurement results are shown in Figure 9, where measurements shown in solid lines are done with the roof and wall slabs cut between the rooms. Cutting the roof and wall slabs improved the sound insulation with 4 dB from R'_w = 41 dB to 45 dB. However, it was apparent that the dominating sound path between the rooms was from the exposed roof slab to the CLT wall between the rooms, visible in receiver room. Adding another lining to the wall in the receiving room, as shown in Figure 10, improved the sound insulation by additional 6 dB, from R'_w = 45 dB (red line in Figure 9) to 51 dB (green line).

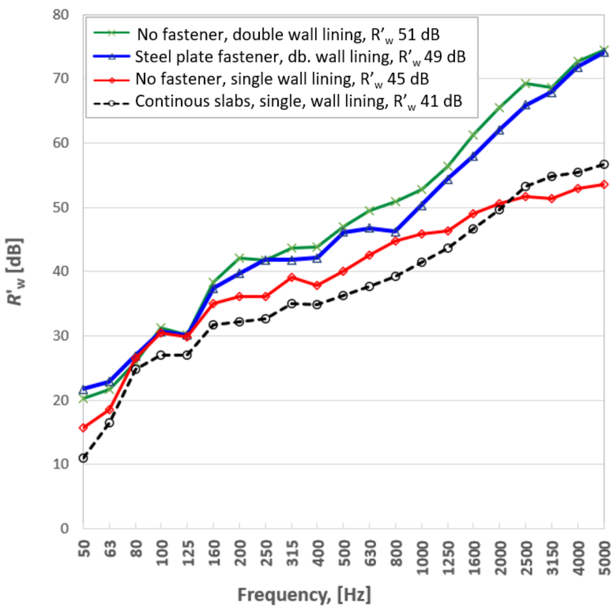

Figure 9. Airborne sound insulation between the horisontally adjacent rooms. Solid lines show results with walls and roof cut, as indicated in Figure 10. The green and blue line is measured with wall lining also in the receiver room.

When employing three steel plate fasteners across the cut in the roof slab, the airborne sound insulation was reduced by 2 dB, as the blue line in Figure 9 indicates. 10 screws were inserted through each plate into the roof slab, 5 screws into each element. Three plates were used in total across the cut. 6 screws in each plate were inserted diagonally.

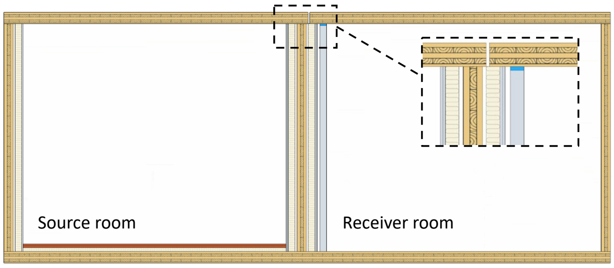

Figure 10. Schematic of the test room used for the airborne sound insulation measurements, where the cut, additional lining and column is highlighted in the excerpt.

4. CONCLUSIONS

The velocity level difference and airborne sound insulation are measured for various fasteners and junction configurations between two horizontally adjacent rooms on a full scale CLT mock-up. The room walls and roof were structurally separated by a cut, and wall linings and a floating floor were applied to the source room.

Point connectors showed comparable velocity level differences as without fasteners in the low frequency area, and 5-10 dB lower attenuation at higher frequencies. Higher velocity level differences were found with point connectors as fastener across the cut than with line connections. Added weight onto the roof slab improved the attenuation in a limited frequency area.

Employing screws as fasteners resulted in lower velocity level difference than point connectors. Increased distance between screws improved the attenuation horizontally, as the degree of contact decreases. This was not seen in the vertical direction due to the weight of the overlaying construction.

Cutting the roof and wall slabs improved the sound insulation with 4 dB. The level of sound insulation was limited due to flanking sound. Adding a wall lining to the wall in the receiving room improved the sound insulation by additional 6 dB.

5. ACKNOWLEDGMENTS

This project was initiated by Lars Strand, senior consultant at Brekke & Strand Akustikk AS, along with Splitkon AS. Contributors are Splitkon, Green Advisers, Brekke & Strand Akustikk, Skogtiltakfondet, Innovasjon Norge, Christian Berner, Rothoblaas and others.

6. REFERENCES

[1] R. Brandner, G. Flatscher, A. Ringhofer, G. Schickhofer and A. Thiel, "Cross laminated timber (CLT): overview and development", *Eur. J. Wood. Prod.*, 74, pp. 331-351, 2016.

[2] S. Kurzinski, P. Crovella and P. Kremer, "Overview of Cross-Laminated Timber (CLT) and Timber Structure Standards Across the World, *Mass Timber Constr. J.*, vol. 5, pp. 1-13, 2022.

[3] A. Younis and A. Dodoo, "Cross-laminated timber for building construction: A life-cycle-assessment overview", *J. Build. Eng.*, vol. 52, 104482, 2022.

[4] A. Di Bella and M. Mitrovic, "Acoustic Characteristics of Cross-Laminated Timber Systems", *Sustainability*, 12, pp. 5612, 2022.

[5] K. R. Skulberg, A. Q. Nyrud and K. Nore, "Hygroscopic buffering effects in exposed cross-laminated surfaces and indoor climate in a Norwegian primary school", *Wood Mat. Sci. & Eng.*, vol. 17(1), pp. 43-52, 2022.

[6] K. A. Malo, R. B. Abrahamsen and M. A. Bjertnes, "Some structural design issues of the 14-storey timber frames building "Treet" in Norway", *Eur. J. Wood. Prod.*, 74, pp. 407-424, 2016.

[7] https://www.sarakulturhus.se/en/a-climate-smart-house/building-in-wood-has-a-distinguished-past-and-a-bright-future/, last accessed 13.05.2023.

[8] J.-W. Kulien, A. Ceccotti, Z. Xia, M. He and S. Li, "Wood concrete skyscrapers", in *Proc. World Conference on Timber Engineering* (Riva Del Garda, Italy), 2010.

[9] C. Hoeller, J. Mahn, D. Quirt, S. Schoenwald and B. Zeitler, "RR-335 Apparent Sound Insulation in Cross-Laminated Timber Building", *National Research Council Canada*, 2017.

[10] A. Homb, C. Guigou-Carter and A. Rabold, "Impact sound insulation of cross-laminated timber/massive wood floor constructions: Collection of laboratory measurements and result evaluation", *Building acoustics*, vol. 24(1), pp. 35-52, 2017.

[11] N-G. Verdaxis, D.B. Hagberg and J. Dahlström, "Evaluating Laboratory Measurements for Sound Insulation in Cross-Laminated Timber (CLT) Floors: Configurations in Lightweight Buildings", *Appl. Sci.*, 12, pp. 7642, 2022.

[12] C. Simmons, "Can our standard digital tools predict the sound insulation in wooden buildings?", in *Proc. Baltic-Nordic Acoustics Meeting*, (Oslo, Norway), 2010.

[13] E. Toftemo and A. Løvstad, "Sound insulation in cross laminated timber buildings and the effect of junction damping", in *Proc. 24th International Congress on Acoustics*, (Gyeongju, Korea), 2022.

[14] F. Morandi, S. De Cesaris, M. Garai and L. Barbaresi, "Measurement of flanking transmission for the characterization and classification of cross laminated timber junctions", *Appl. Acoustics*, vol. 141, pp. 213-222, 2018.

[15] A. Di Bella, L. Dall'Acqua d'Industria, M. R. Valluzzi, A. Pengo, L. Barbaresi, F. Di Nocco and F. Morandi, "Flanking transmission in CLT buildings: comparison between vibration index measurements for different mounting conditions", in *Proc. Inter-noise* (Madrid, Spain), 2019.

[16] ISO 16283-1: Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation, 2014.

[17] NS-EN ISO 10848-1: Acoustic – Laboratory and field measurements of flanking transmission for airborne, impact and building service equipment sound between adjoining rooms. Part 1: Frame document, 2017.

[18] E. Nilsson, S. Ménard, D. Bard and K. Hagberg, "Effects of building height on the sound transmission in cross-laminated timber buildings – Airborne sound insulation", *Building and Environment*, 229, 109985, 2023.