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Sound insulation in cross laminated timber buildings and the effect of junction damping

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ABSTRACT

The use of cross laminated timber (CLT) has surged over the last couple of decades and is used in increasingly complex buildings. Despite increased knowledge and experience with CLT, considerable margins are needed in planning phases, which may be reduced if comparable laboratory or field data is available. This paper reports on measurements of velocity level differences and sound insulation between floors employing various elastic interlayers and fasteners for a full-scale CLT test building. Results show that all types of screw fasteners generally reduce the dampening effect of the elastic interlayers significantly. The use of angle brackets with elastic interlayer gave better results. Measurements of sound insulation with various floating floors are reported on.

Keywords: Sound insulation, CLT, Junction damping

1. INTRODUCTION

In recent years an unprecedented increase in the use of cross laminated timber (CLT) in building constructions has happened. CLT has been produced on an industrial scale for around 15 years, with steadily increasing production volume (1). Not only has the sheer volume of CLT surged, but development, knowledge and experience of employing CLT in buildings have increased accordingly. CLT is now considered and used in increasingly complex buildings with high sound insulation requirements. The reasons for this development are diverse, but it is evident that there is a cross-disciplinary desire to work with and use CLT among authorities, property owners, architects and engineers as it is sustainable, enables rapid and efficient assembly, is light-weight, and possesses several other desirable physical parameters as summarized by Di Bella et al (2).

National guidelines (3) and documentation of CLT floor and wall constructions have been published in compliance with the development and complexity of its use. Maybe more so than other materials, the sound insulation achieved with CLT is highly dependent on junction assembly, parameters and choice of resilient layers, linings, ceilings and floating floors, in addition to the quality of mounting and assembly itself. Homb et al (4) collected and compared impact sound insulation for typical floor assemblies in different European countries (and laboratories). Verdaxis et al (5) evaluated airborne and impact sound insulation for CLT floors with additional layers in 12 configurations and found that resilient layers and floating floors can exceed 20 and 30 dB improvement compared with the 5-layered 180 mm CLT component alone for airborne and impact sound insulation, respectively. Additional improvement may be obtained with suspended ceilings.

Laboratory data of sound insulation performance of slabs or walls alone form the basis of construction designs, but field measurements can be significantly limited by flanking transmission (5), as extensively addressed by e.g. Hoeller et al (6). Morandi et al (7) performed flanking transmission measurements of various CLT junctions and compared vibration reduction indices K_{ij}. They found that the energy transmission through junctions is strongly related to the connectors.

In practice control of flanking transmission paths and mounting is paramount for CLT constructions, which further requires close cooperation with contractors, architects and construction designers. Despite the surge in use of CLT, the overall experience with different CLT systems is not as developed as with concrete slabs or even light-weight timber slabs. Laboratory data as reported in

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(4, 5) forms the basis of further construction details of flanking and mounting design. Commonly, at least in Norway, there is a desire for CLT to be visible to as large extent as possible, which in turn questions the need for linings and suspended ceilings. To a certain extent linings and suspended ceilings must be included for sound insulation and/or absorption. However, in many cases it is questioned whether they are needed to comply with minimum requirements, which frequently comes down to which margin the project is comfortable with, and therein the specific experience of the constructors and designers.

Öqvist et al (8) reported on measurement uncertainty considering repeatability, measurement direction and sound source time dependence for CLT constructions and found smaller variations for prefabricated systems compared with on-site production. In a design phase large margins are commonly included. Simmons (9) addressed which margins are needed when planning CLT buildings when employing commonly used building acoustic software, comparing calculation results with measurements. He concluded that a safety margin of at least 8 dB should be used for CLT floors with layered solutions on top of or below of the CLT slab, which may be reduced to 5 dB for constructions where specific experiences of the same construction is available, such as junction and lining types. These recommendations agree well with the authors experience from sound insulations measurements on multiple constructions within the same buildings, where identical constructions in some cases vary up to 8-10 dB due to e.g. mounting and assembly, room layout and furnishing. Thus, the uncertainty in calculations, mounting and assembly and site variance is considerable, and is best addressed by field measurements or other directly comparable measurements.

This paper addresses effects of employing various resilient interlayers and mounting methods on the velocity level difference, $D_{v,ij}$. The measurements are carried out in designated test rooms based on ISO 10848-1 (10) as explained below. Additionally, airborne and impact sound insulation are measured in compliance with ISO 16283-1 (11) and -2 (12), respectively. Measurements are intentionally done on building constructions that are comparable to those built in the field, which enables a direct relation between the junction damping and sound insulation. Disadvantages of not complying fully with the ISO 10848-1 (10) are not having full control of all flanking transmission paths and reduced measurement repeatability.

2. TEST AND MEASUREMENT SET-UP

The test set-up was built as a separate construction within an industrial warehouse with two rooms on the ground floor and one room on the top floor, as shown in Figure 1. The ground floor and top roof were 3-ply 120 mm thick CLT panels, while the horizontal slabs between the floors was 5-ply 160 mm CLT. All vertical CLT panels were 3-ply of 100 mm thickness. The test rig was delivered from Splitkon AS, element strength classes T15 and T22. The density of the wood is 460 kg/m^3.

Room dimensions and layout are given in Figure 1 in addition to the CLT thicknesses. The top floor could be lifted from the ground floor by hydraulic jacks as shown in Figure 2 to fit elastic interlayers or mount angle brackets. This allowed for testing various profiles and fasteners in the junctions between the floors. Additionally, wall linings, suspended ceilings and various floor constructions were added and removed from the constructions to assess their impact on velocity level difference and sound insulation.

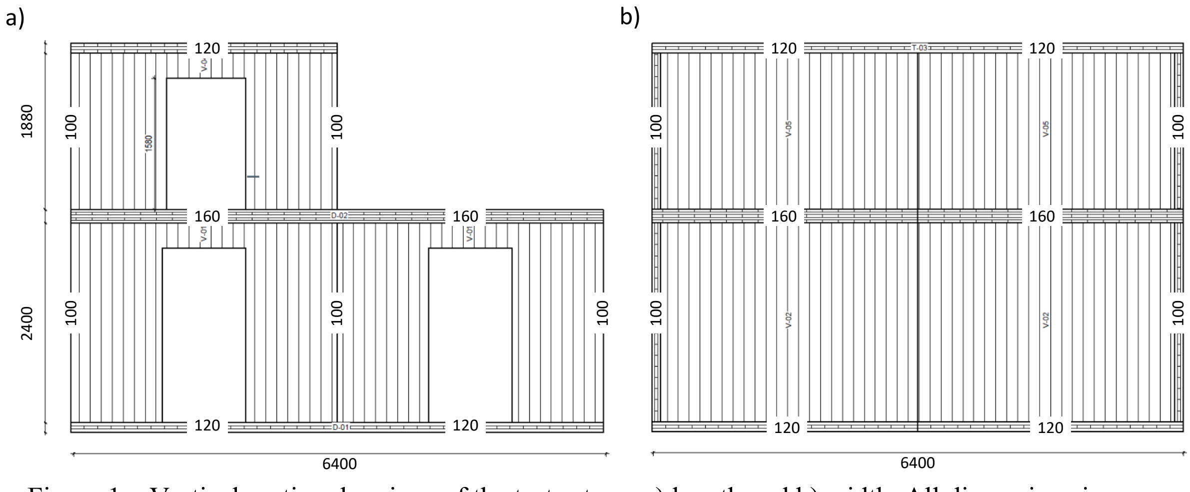


Figure 1 – Vertical section drawings of the test set-up; a) length and b) width. All dimensions in mm.

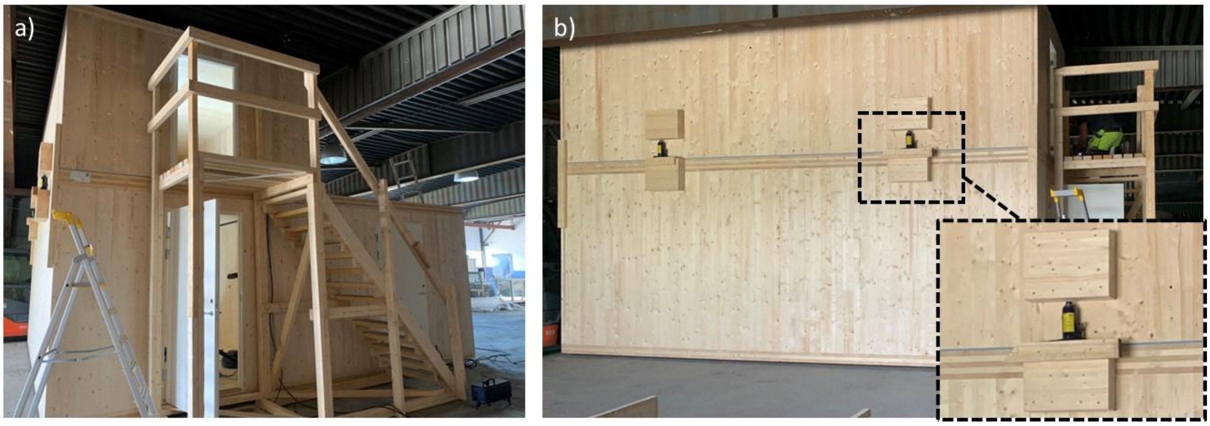


Figure 2 – Test set-up shown in a) and b) corresponds to a) and b) in Figure 1. An elastic interlayer and the hydraulic jacks are seen in both a) and b), where the excerpt in b) shows a hydraulic jack specifically.

Measurement of velocity level difference was used to assess variations in damping across building elements in the vertical direction. The velocity level difference is described in ISO 10848-1 (10).

Four measurement positions were employed on each panel/building element. Tests were carried out employing three different sound sources; pink noise fed through a loudspeaker, a tapping machine and hammer excitation. The results from hammer excitation have been left out since the excitation proved difficult to control.

Velocity level differences show averaged values of two sets of sensor positions mounted on two different walls, except for measurements with the floating floor, where only one set is included.

Figure 3 – Photo of sensor setup inside of the test rooms. Sensor positions indicated with white arrows.

3. MEASUREMENT RESULTS

Measurements of velocity level difference and sound insulation were done with various resilient interlayers and fasteners between floors, as listed in Table 1. The configuration numbers in the first column are used for reference in the subsequent chapters.

Table 1 – Configuration of fasteners and elastic interlayers

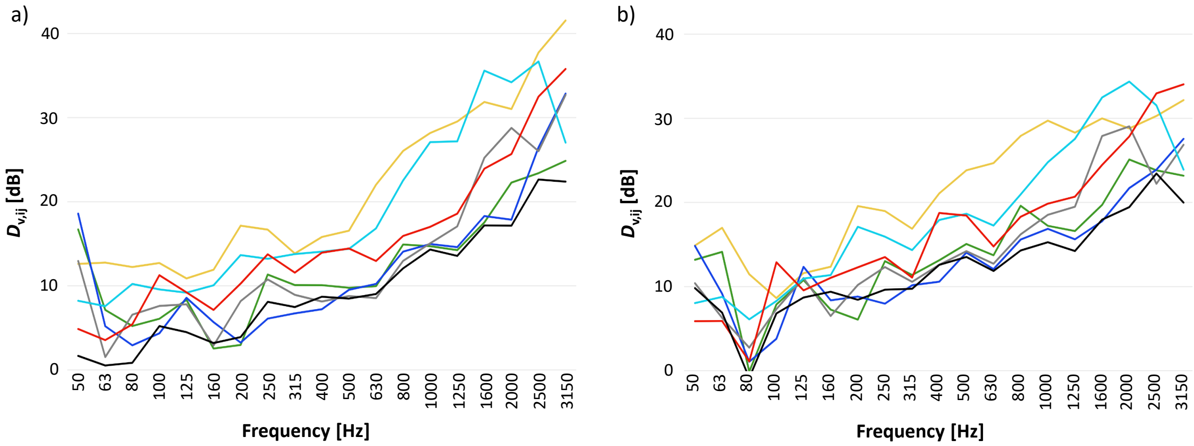
Meas. No.	Fastener	Elastic profile	Screw thickness	Center distance	Angle bracket
1	None	None			
2	None	Aladdin			
3	None	Sylomer SR 28			
4	None	Xylofon 35 shore			
5	Screws fully threaded	Sylomer SR 28	8 mm	600 mm	
6	Screws partially threaded	None	6 mm	300 mm	
7	Screws p. threaded	Aladdin	8 mm	600 mm	
8	Screws p. threaded	Sylomer SR 28	6 mm	300 mm	
9	Screws p. threaded	Sylomer SR 28	8 mm	600 mm	
10	Screws p. threaded	Xylofon 35 shore	6 mm	300 mm	
11	Screws p. threaded	Xylofon 35 shore	8 mm	600 mm	
12	Angle brackets	Sylomer SR 28		1000 mm	GePi Connect 100
13	Angle brackets	Sylomer SR 28		1300 mm	GePi Connect 240
14	Angle brackets	Xylofon 35 shore		1000 mm	Titan
15	Angle brackets	Xylofon 35 shore		1000 mm	Titan Silent
16	Angle brackets	Xylofon 35 shore		1000 mm	Titan Silent modified[3]

3.1 Junction damping using Sylomer as elastic interlayer

Measurements of velocity level difference between floors with Sylomer SR 28 as elastic interlayer are shown in Figure 4. Tapping machine and loudspeaker were used as sound sources, and sensors were mounted on walls in the top and bottom floor.

The results show that the choice of fastener is crucial to the resulting damping around the critical middle frequencies. Measurements made with an elastic interlayer and screws as a fastener resulted in marginally better damping than using no elastic interlayer and screws as fastener, while angle brackets with elastic interlayer gave higher damping. As expected, the reference set-ups with no fasteners (beige line, no.3) and without an elastic interlayer (black line, no.1) gave the highest and lowest velocity level difference.

[3] Titan modified bracket is a Titan silent bracket fitted with extra interlayer and steel fitting to decouple the attached wood elements.

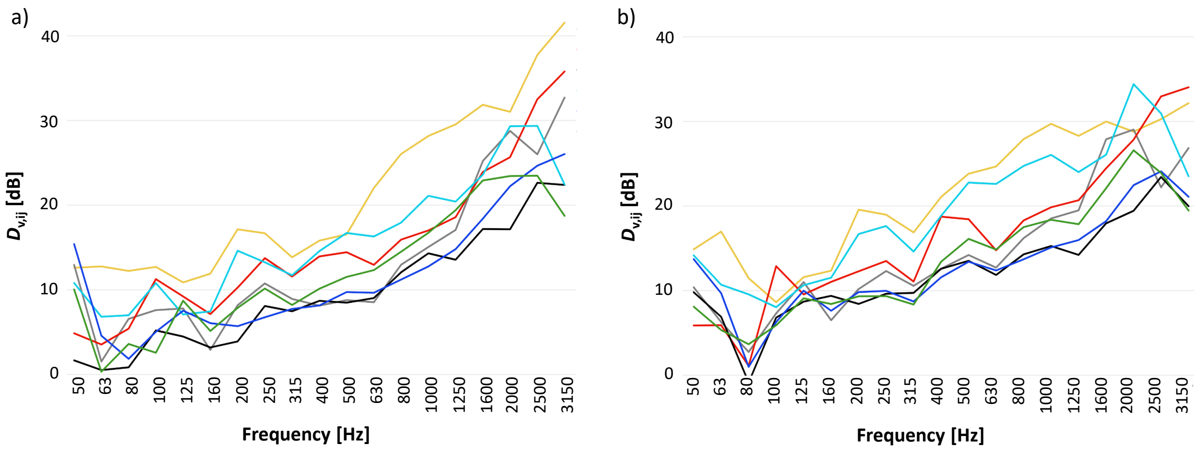


3 Damping obtained without fastener
12 GePi 100 angle brackets cc 1000 mm
13 GePi 240 angle brackets cc 1300 mm
10 8 mm partially threaded screws cc 600 mm
8 6 mm partially threaded screw cc 300
5 8 mm fully threaded screws cc 600 mm
1 6 mm screws cc 300 without elastic interlayer between floors

Figure 4 – Junction damping with Sylomer SR 28 as elastic interlayer between floors for various fasteners. a) and b) show results obtained with tapping machine and loudspeaker as source, respectively.

3.2 Junction damping using Getzner and Rothoblaas elastic interlayers and fasteners

Velocity level differences with elastic interlayers and fasteners from Getzner and Rothoblaas are shown in Figure 5 Results from tapping machine and loudspeaker as source is shown in a) and b), respectively. Sylomer SR28 (12 mm thickness) as the elastic interlayer between floors results in slightly higher damping than Xylofon 35 shore (thickness 6 mm) when fasteners are not applied. When any type of screw fastener is applied, the damping performance becomes poor, regardless of what type of elastic interlayer is applied. Angle brackets, however, results in higher damping around the crucial middle frequencies.

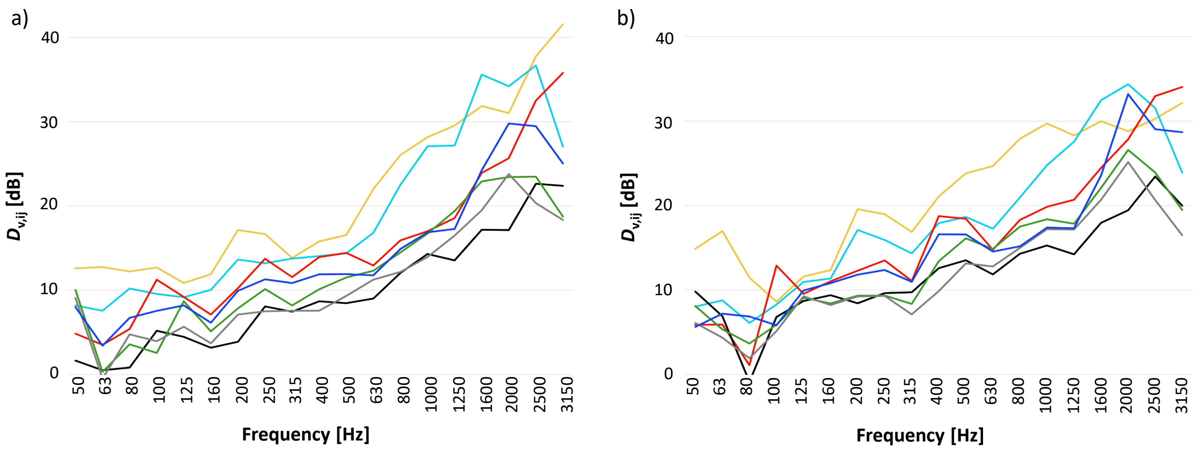


3 Damping obtained without fastener, Sylomer as elastic interlayer
4 Damping obtained without fastener, Xylofon as elastic interlayer
13 GePi 240 angle brackets cc 1300 mm, Sylomer as elastic interlayer
9 8 mm partially threaded screws cc 600 mm, Sylomer as elastic interlayer
8 8 mm partially threaded screw cc 600, Xylofon as elastic interlayer
15 Titan Silent angle brackets, Xylofon as elastic interlayer
1 6 mm screws cc 300 without elastic interlayer between floors

Figure 5 – Junction damping with elastic interlayers from Getzner and Rothoblaas for various fasteners. a) and b) show results obtained with tapping machine and loudspeaker as source, respectively.

3.3 Junction damping using angle brackets

Figure 6 shows velocity level difference with angle brackets with tapping machine and loudspeaker as source in a) and b), respectively. GePi connect angle brackets gives the highest damping followed by Titan Silent modified, then Titan Silent. The use of Titan angle brackets performs at about the same level as screw fasteners and with no elastic interlayer around the middle frequencies.



3 Damping obtained without fastener, Sylomer as elastic interlayer
12 GePi 100 angle brackets cc 1300 mm, Sylomer as elastic interlayer
13 GePi 240 angle brackets cc 1300 mm, Sylomer as elastic interlayer
14 Titan angle brackets, Xylofon as elastic interlayer
16 Titan Silent modified angle brackets, Xylofon as elastic interlayer
15 Titan Silent angle brackets, Xylofon as elastic interlayer
1 6 mm screws cc 300 without elastic interlayer between floors

Figure 6 – Junction damping various angle brackets as fasteners. a) and b) show results obtained with tapping machine and loudspeaker as source, respectively.

3.4 Junction damping with and without heavy floating floor

Measured velocity level differences with and without heavy floating floor are shown in Figure 7. Sylomer is used as elastic interlayer in both measurements, and GePi 240 as the fastener. The floating floor construction consisted of 100 mm gravel laid directly onto the CLT floor, 40 mm mineral wool, and 70 mm concrete on top. Adding the floating floor increases the velocity level difference by 6-12 dB around the middle frequencies. Somewhat better improvement is observed with a loudspeaker as sound source, which is thought to be due to airborne sound transmission through the slab.

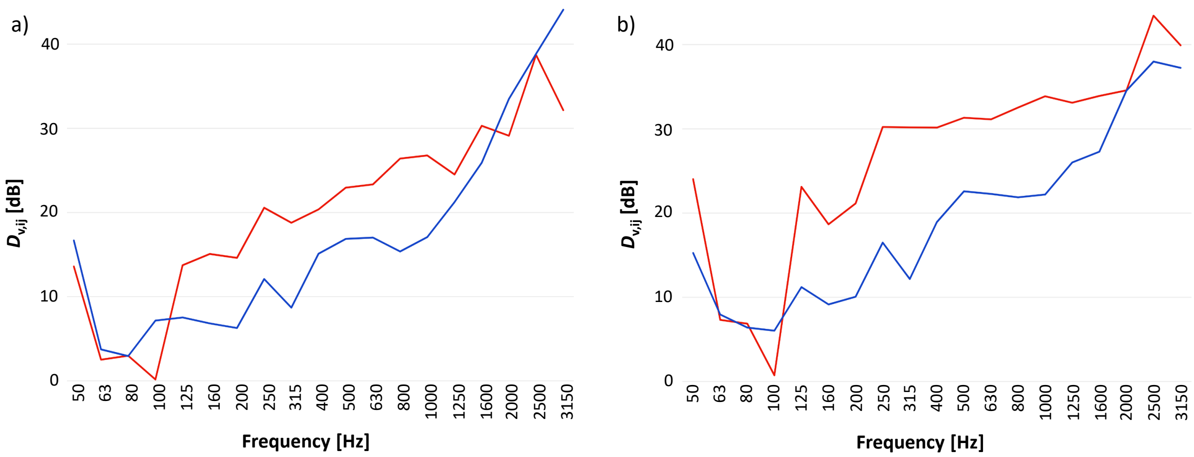


Figure 7 – Junction damping with sylomer SR 28 as elastic interlayer and GePi240 as fastener, where the blue and red lines show results without and with heavy floating floor. a) and b) show results obtained with tapping machine and loudspeaker as source, respectively.

3.5 Sound insulation measurements

Sound insulation measurements according to EN ISO 16283-1 (11) and EN ISO 16283-2 (12) were done on various floors constructions. Measurements results are shown in Figure 8, where the measurement numbers refer to the description of the upper floor constructions and resulting sound insulation given in Table 2. Flanking sound was reduced by using separate wall linings in the bottom floor consisting of 13 mm plasterboard on 70 mm isolated steel studs, total cavity depth 100 mm. Suspended ceilings were not applied in the measurements shown.

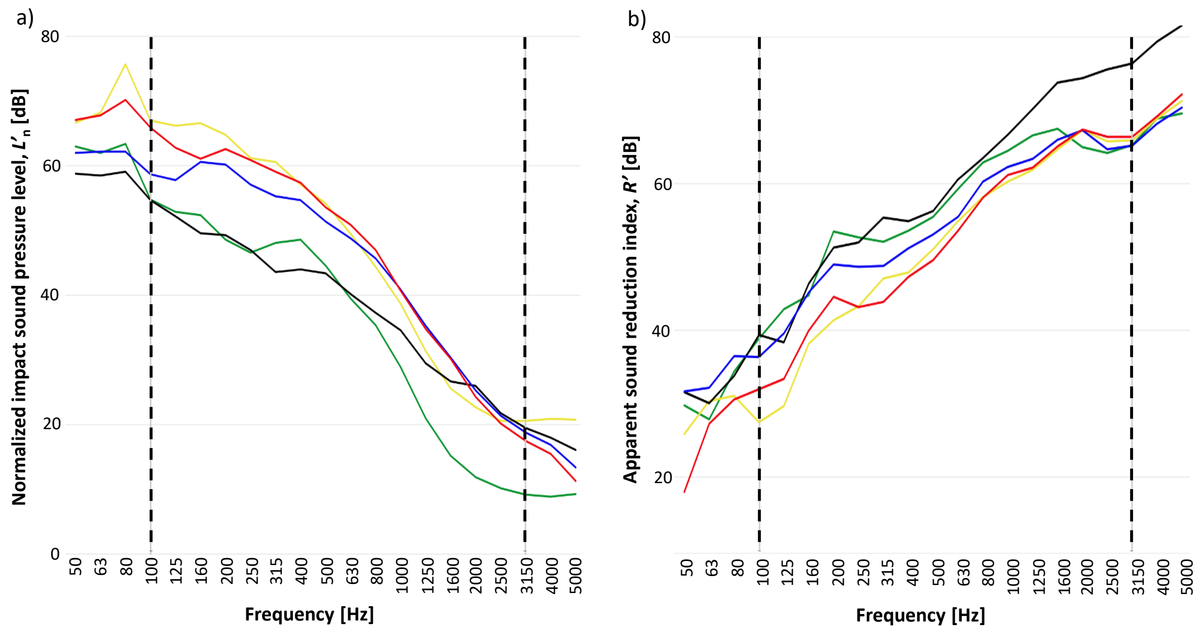


Figure 8 – a) Vertical impact/structural sound insulation and b) airborne sound insulation. Beige (no.1), red (no.2), blue (no.3), green (no.4), and black lines (no.5) correspond to the measurement numbers in Table 2.

Results show that adding weight to a light floor construction improves the sound insulation noticeably in the lower frequencies, as expected. Gravel added directly to the CLT floor gave considerable improvement especially for impact sound insulation. The results indicate that the weight of the floating floor is not crucial if concrete is added directly to the CLT floor.

Table 2 – Description of upper floor and resulting sound insulation

Meas. No.	Description of top floor (from top to bottom)	Airborne sound insulation R'_{w} ($C_{50\text{-}5000}$)	Impact sound insulation $L'_{n,w}$ ($C_{150\text{-}2500}$)
1	2x22 mm chipboard, 40 mm mineral wool	53 (-2)	57 (6)
2	2x22 mm chipboard, 135 mm joists on 25 mm Sylomer. 100 mm isolation in the cavity	54 (-2)	55(5)
3	2x22 mm chipboard, 135 mm joists on 25 mm Sylomer with 100 mm isolation in the cavity, 50 mm thick concrete slabs on CLT floor covering 30 % of the floor area	58 (-1)	52 (3)
4	2x22 mm chip board, 40 mm mineral wool, 100 mm gravel	61 (-3)	44 (9)
5	70 mm concrete cast, 40 mm mineral wool, 100 mm gravel	61 (-2)	43 (7)

4. CONCLUSIONS

Velocity level difference has been measured on a full scale CLT model to assess the variation in damping between various configurations of elastic interlayers and fasteners in junctions. Measurements of sound insulation were done in parallel to the measurements of velocity level differences. Results show that all type of screw fasteners reduce the damping effect significantly, regardless of type of elastic interlayer. The use of elastic detached angle brackets proved to increase the damping.

Velocity level differences were significantly increased when heavy floating floors were added onto the CLT floor. Various upper floors were tested. Weight applied directly on to the CLT floor showed an increase in low frequency sound insulation.

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