LABORATORY MEASUREMENTS OF LIGHTWEIGHT FLOATING FLOOR SYSTEMS ON CROSS-LAMINATED TIMBER (CLT) SLABS

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ABSTRACT

Mass timber family of products (including cross-laminated timber – CLT) offer an alternative to fossil fuel-intensive materials for many applications and an opportunity to reduce the carbon footprint of the built environment. However, the use of mass timber in multi-family and commercial buildings presents unique acoustic challenges. Additionally, one of the most desired aspects of mass timber construction is the ability to leave a building's structure exposed as finish, which creates the need for asymmetric assemblies. This means that when speaking about floor/ceiling applications, preferentially any acoustical component should be installed on top of the assembly. To measure airborne sound reduction and impact noise isolation of lightweight floating floor systems and confirm CLT assemblies can provide satisfactory sound insulation, CDM Stravitec launched a testing campaign (done on Belgian Building Research Institute, institution recognized by application of the decree-law of the 30th of January 1947), where measurements were made considering several types of decouplers, such as: discrete bearings with multiple thickness and/or different void depth (filled in totally or partially with insulation material) and mats and strips placed between the CLT slab and different timber, cement and gypsum-based boards with and without use of the well-known constrained layer damping technique.

***Keywords* —** building acoustics, timber construction, cross-laminated timber, floating floors.

1. INTRODUCTION

Mass timber solutions, including cross-laminated timber (CLT), can be an excellent substitute to more traditional with high carbon footprint, very stiff, and heavy building materials, when some of their inherent properties aren't required. The use of these mass timber products allows for the reduction of the carbon footprint of the built environment. While CLT has many advantages as a sustainable building material, it can also pose some rather unique challenges in terms of acoustics.

Following the guide to airborne, impact, and structure-borne noise in Unitec Stated of American multifamily dwellings, 3 classes can be defined: entry (STC and IIC ≥ 50 dB), market (STC and IIC ≥ 55 dB) and luxury (STC and IIC ≥ 60 dB).

When doing the same exercise and locking at European criteria, most of the regulatory main requirements are showing $D_{nT,w} \geq 55$ dB [which, we could say, is close to ≈ $R_w \geq 60$ dB] and $L'_{nT,w} < 52$ dB [which, we could say, is close to $L_{n,w} < 50$ dB].

If acoustical requirements are clearly defined, there are other dimensions of performance that the design team should consider when designing a floor/ceiling application, such as aesthetics, integration with other building services, type of finishing (defining deflection criteria), stability requirements and fire resistance (e.g., reason to have entirely filled cavities, to respect Chapter 7 of the International Building Code – IBC 2021).

One of the most desired aspects of mass timber construction is the ability to leave a building's structure exposed as finish, which creates the need for asymmetric assemblies. Consequently, when talking about floor/ ceiling applications, it is preferable that any acoustic component be installed on top of the assembly.

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Adding non-structural concrete as mass to a CLT structure isn't the optimal solution if the goal is to maintain all CLT benefits previously mentioned and reduce the carbon footprint of the building. Although it is an easy way to increase the mass and the overall construction stiffness. With that in mind, the leaving option to increase the acoustical overall performance is to add decouplers.

To measure airborne sound reduction and impact noise isolation of lightweight floating floor systems and confirm that CLT-assemblies can provide satisfactory sound insulation, CDM Stravitec conducted a test campaign at Buildwise.

2. TEST METHODOLOGY

2.1. Impact sound insulation of floors

Tests were carried out according to NBN EN ISO 10140 Acoustics – Measurement of sound insulation in buildings and of building elements [Part 1 (2021): Application rules for specific products (ISO 10140-1:2021); Part 3 (2021): Measurement of impact sound insulation (ISO 10140-3:2021) and Part 5 (2021): Requirements for test facilities and equipment (ISO 10140-5:2021)] and NBN EN ISO 717-2:2021 Acoustics – Rating of sound insulation in buildings and of building elements [Part 2: Impact sound insulation (ISO 717-2:2020)].

Measurements were taken from 50 to 5000 Hz and 100 to 3150 Hz was the frequency range for a rating in accordance with EN ISO 717-2.

Test were carried out on the bare 5-layer cross-laminated timber (CLT) slab, 180 mm (7-1/6'') thick, over a surface of 260 cm x 442 cm (8.5-ft x 5.4-ft), with 210 mm (8-17/64'') high elevated borders that simulate the surrounding walls of an actual floor slab. The test element was mounted according to the NBN EN ISO 10140-3 standard, in a similar manner to the actual construction, and tests were carried out on each system described in this paper.

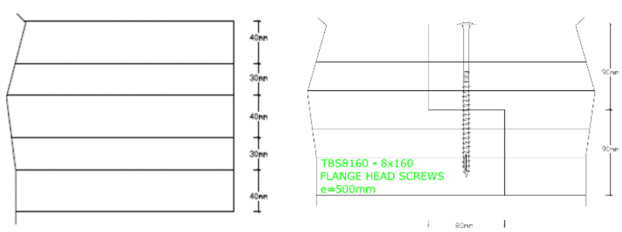


Figure 1. Layer structure of CLT 180 L5s and joint/screw detail of the slab.

As the standards ASTM E492-09 and EN ISO 10140-3 give similar procedures for the measurement and determination of the normalized impact sound pressure level Ln, the impact insulation class IIC was calculated based on the measured values from 100 Hz to 3150 Hz, rounded to the nearest decibel, according to the ASTM E989-21 procedures.

Based on the normalized impact sound pressure levels, Ln, from 400 Hz to 3150 Hz, the high-frequency impact insulation class HIIC was calculated according to the procedure in the ASTM standard E3222-20a.

Based on the normalized impact sound pressure levels, Ln, in the 50, 63, and 80 Hz bands, the low-frequency impact insulation class LIIC was calculated according to the procedure in the ASTM standard E3207-21.

2.1. Airborne sound insulation of floors

Tests were carried out according to NBN EN ISO 10140:2021 Acoustics – Measurement of sound insulation in buildings and of building elements [Part 1: Application rules for specific products – Annex G: Acoustical linings – Improvement of airborne sound insulation (ISO 10140-1:2021); Part 2: Measurement of airborne sound insulation (ISO 10140-2:2021)] and NBN EN ISO 717-1:2021 Acoustics – Rating of sound insulation in buildings and of building elements [Part 1: Airborne sound insulation (ISO 717-1:2020)].

Measurements were taken from 50 to 5000 Hz and 100 to 3150 Hz was the frequency range for a rating in accordance with EN ISO 717-1.

The tests were carried out on a 5 layers cross-laminated timber (CLT) slab, above described, with 210 mm (8-17/64'') high elevated borders that simulate the surrounding walls of an actual floor slab.

The test element was mounted according to the NBN EN ISO 10140-3 standard, in a similar manner to the actual construction, and tests were carried out on each system described in the results section.

A detailed description of the measurement method to determine the spectrum of the sound reduction improvement index of a lining on walls or floors can be found in the EN ISO 10140-1 standard and the EN ISO 10140-2 standard.

As the standards ASTM E90-09 and EN ISO 10140-2 give similar procedures for the measurement and determination of the sound transmission loss TL (ASTM) and the sound reduction index R (ISO), the sound transmission class STC is calculated based on the measured values from 125 Hz to 4000 Hz, rounded to the nearest decibel, according to ASTM E413-16.

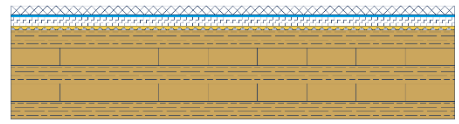
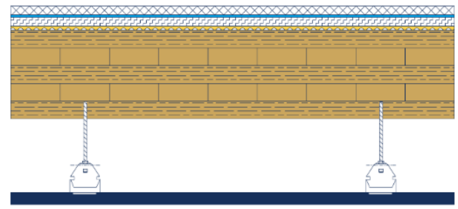
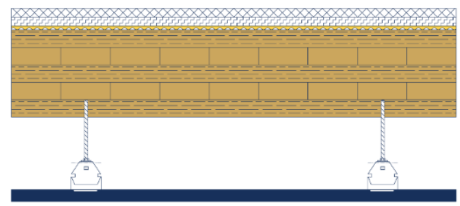
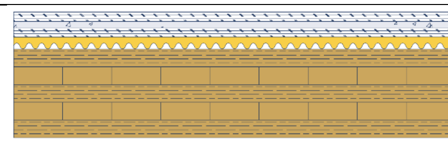
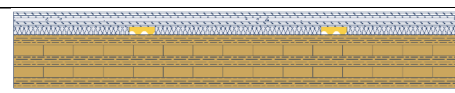
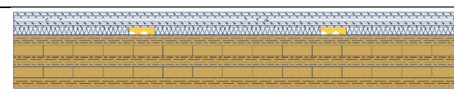
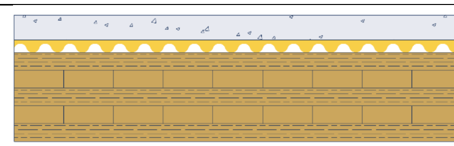
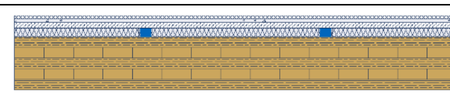
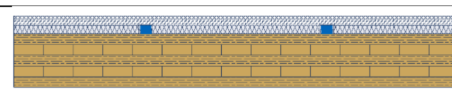
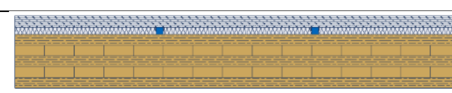
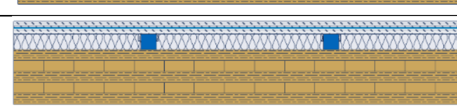
3. TEST SETUP

The test floor [493 cm (16' 2-1/8'') x 310 cm (10' 2-1/16'')] is sandwiched between 2 heavy concrete ceiling elements by mineral wool compressed to 5 cm (1-15/16''). The test floor bears in its longitudinal direction and is laid on its short sides on the load-bearing walls of the test cell on an intermediate strip of mineral wool. The mobile room "M" is then installed on top of the floor, but without making direct contact with the underlying receiving room. Within this source room, a metal frame adjustable in height and with underlying mineral wool filling shields the edges of the test floor and thus defines the test area [10 m2 (107.6 sq ft)]. This test area corresponds to the unshielded ceiling area in the receiving room below, as visible in the cross section below. The remaining space between the mobile source room and the test elements is filled with compressed sound-absorbing wool to avoid sound leaks.

Figure 2. Details of mobile source room installation above the test floor (details without showing absorbing wool filling) and CLT slab installed between rooms.

4. TEST REUSLTS

Table 1. Section of setups tested

Setup	Section
A	
B	
C	
D	
E	
F	
G	
H	
I	
J	
K	

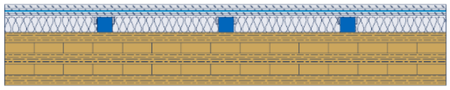
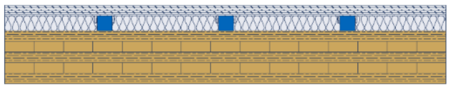
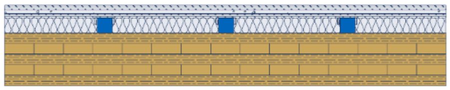
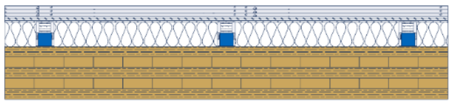
L	
M	
N	
O	
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Table 2. Description of test setups.

Setup	Elastic Support	Dropper Ceiling	Dry Screed	Build-up Height(1)
A	Stravifloor Mat-W8$_a$	n.a.	HydroFlam® 18 mm (11/16") + Damping Layer 5 mm (3/16 ") + OSB/3 18 mm (11/16")	49 mm (1-15/16")
B	Stravifloor Mat-W8$_a$	Yes(2)	HydroFlam® 18 mm (11/16") + Damping Layer 5 mm (3/16 ") + OSB/3 18 mm (11/16")	49 mm (1-15/16")
C	Stravifloor Mat-W8$_a$	Yes(2)	HydroFlam® 18 mm (11/16") + OSB/3 18 mm (11/16")	44 mm (1-3/4")
D	Stravifloor Mat-W25	n.a.	Plywood 19 mm (3/4") + Fermacell® Powerboard H20 12.5 mm (1/2") + Plywood 19 mm (3/4")	75.5 mm (3'')
E	Stravifloor Mat-W25 strips [o.c. 610 mm (24")]	n.a.	Plywood 19 mm (3/4") + Fermacell® Powerboard H20 12.5 mm (1/2") + Plywood 19 mm (3/4")	75.5 mm (3'')
F	Stravifloor Mat-W25 strips [o.c. 610 mm (24")]	n.a.	Plywood 19 mm (3/4") + Plywood 19 mm (3/4")	63 mm (2-1/2'')
G	Stravifloor Mat-W25	n.a.	Gypsum topping 50 mm (2")	75 mm (3'')
H	Isolated Channel-M30 [Pad-M30 [30 mm (1-3/16")]] (o.c. 610 mm (24"))	n.a.	HydroFlam® 18 mm (11/16") + Fermacell® Powerboard H20 12,5 mm (1/2") + OSB/3 18 mm (11/16")	78.5 mm (3-1/16'')
I	Isolated Channel-M30 [Pad-M30 [30 mm (1-3/16")]] (o.c. 610 mm (24"))	n.a.	HydroFlam® 18 mm (11/16") + OSB/3 18 mm (11/16")	66 mm (2-5/8'')
J	Isolated Channel-M30 [Pad-M30 [30 mm (1-3/16")]] (o.c. 610 mm (24"))	n.a.	Plywood 19 mm (3/4") + Plywood 19 mm (3/4")	68 mm (2-11/16'')
K	Isolated Channel-M50 [Pad-M50 [50 mm (2")]] (o.c. 610 mm (24"))	n.a.	Plywood 19 mm (3/4") + Damping layer 5 mm (3/16") + Plywood 19 mm (3/4")	93 mm (3-11/16'')
L	Isolated Channel-M50 [Pad-M50 [50 mm (2")]] (o.c. 406 mm (16"))	n.a.	Plywood 19 mm (3/4") + Damping layer 5 mm (3/16") + Plywood 19 mm (3/4")	93 mm (3-11/16'')
M	Isolated Channel-M50 [Pad-M50 [50 mm (2")]] (o.c. 406 mm (16"))	n.a.	Plywood 19 mm (3/4") + Plywood 19 mm (3/4")	88 mm (3-7/16'')
N	Isolated Channel-M50 [Pad-M50 [50 mm (2")]] (o.c. 406 mm (16"))	n.a.	Plywood 15 mm (9/16") + Fermacell® Powerboard H20 12.5mm (1/2") + Plywood 15 mm (9/16")	100.5 mm (4'')
O	Isolated Channel-M50 [Pad-M50 [50 mm (2")]] w/ 30 mm (1-3/16") overheight (o.c. 406 mm (16"))	n.a.	3x Fermacell® Powerboard H20 12.5mm (1/2") + Plywood 19 mm (3/4")	136.5 mm (5-3/8'')
P	Isolated Channel-M50 [Pad-M50 [50 mm (2")]] w/ 30 mm (1-3/16")	n.a.	Plywood 19 mm (3/4") + Plywood 19 mm (3/4")	118 mm (4-5/8'')

	overheight (o.c. 406 mm (16"))			

(1) Not including bare slab or dropped ceiling if applicable.
(2) 2 layers 12.5 mm (½") gypsum hung on metal grillage 150 mm (5.9").

Table 3. Results overview (global rating).

Setup	Dry Screed Load [kg/m²] (lbs/sq ft)]	$L_{n,w}$ (C_i) [dB]	ΔL_w ($C_{i,\Delta}$) [dB]	IIC	R_w ($C;C_{tr}$) [dB]	STC
A	26 (5.3)	67 (0)	23 (0)	43	50 (-1;-6)	50
B	26 (5.3)	53 (0)	35 (3)	57	64 (-2;-8)	64
C	22 (4.5)	53 (1)	34 (2)	56	63 (-2;-8)	64
D	46 (9.4)	61 (0)	27 (0)	49	53 (-1;-6)	54
E	36 (7.4)	56 (0)	32 (5)	54	59 (-3;-9)	60
F	23 (4.7)	60 (0)	28 (5)	50	55 (-2;-9)	56
G	92 (19)	65 (0)	21 (0)	45	56 (-1;-7)	57
H	35 (7.2)	54 (0)	34 (4)	56	62 (-2;-8)	63
I	26 (5.3)	57 (0)	31 (4)	53	60 (-3;-9)	60
J	23 (4.7)	57 (1)	30 (4)	52	59 (-3;-9)	60
K	28 (5.7)	55 (-1)	34 (2)	55	64 (-2;-8)	64
L	28 (5.7)	55 (-1)	35 (3)	55	63 (-2;-8)	63
M	23 (4.7)	55 (0)	34 (4)	55	62 (-3;-9)	62
N	32 (6.6)	54 (0)	35 (2)	56	63 (-2;-8)	63
O	52 (10.7)	47 (0)	42 (1)	63	67 (-2;-7)	67
P	23 (4.7)	53 (0)	36 (2)	57	65 (-2;-7)	66

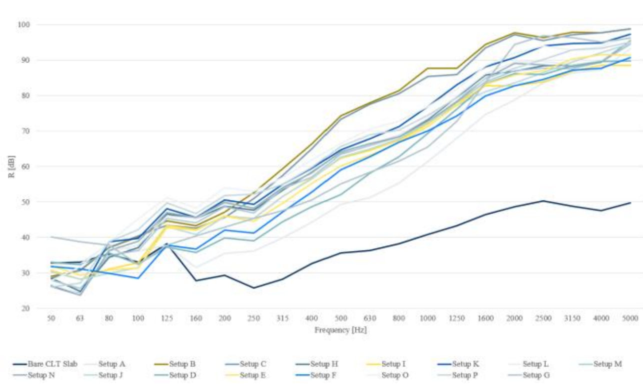

Figure 3. Airborne sound insulation of all setups tested.

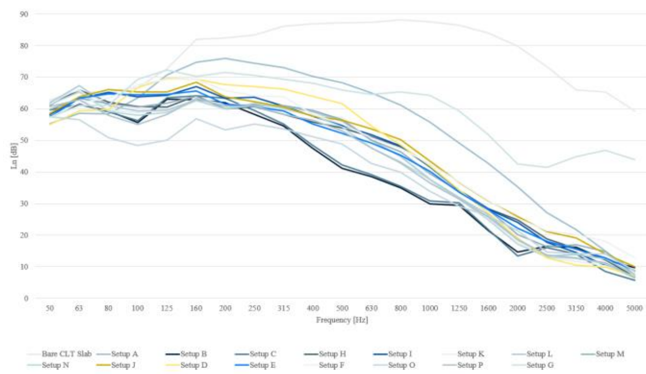

Figure 4. Impact sound insulation of all setups tested.

5. CONCLUSIONS

- There is an improvement on both, airborne and impact sound insulation around 14 dB due to the installation of a suspending ceiling. The improvement is across all frequencies > 80 Hz. For low frequencies, we can see a negative effect of the dropped ceiling. However, it is important to mention that the dropped ceiling installed isn't using resilient hangers or insulation material in the void, not being an acoustical dropped ceiling. The little negative effect of the dropped ceiling at low frequencies can be easily solved by adding insulation material in the void to avoid standing waves and using resilient hangers rather than stiff ones.
Ceilings might not always be visually appealing, especially when you can expose a timber structure instead, but they have several acoustic design functions that can lead to important cost savings, such us to control not only airborne and impact sound insulation but sound flanking (above partitions, via building services and structural penetrations or via structural elements), sound reverberation and noise of building services hung from the soffits.
- There is a significant improvement on both, airborne and impact sound insulation (around 3 dB) when using strips of 100 mm (2'') Stravifloor Mat-W25 spaced of 610 mm (24'') versus full surface support with the same resilient material.
- Full surface wet systems tested can perform up to 3 dB better in airborne noise insulation but having lower performance (up to 4 dB) in terms of impact noise insulation, with the most significant differences at frequencies above 160 Hz. The dry solutions have the added benefit of it being thinner and quicker to install.
- When comparing setups using discrete bearings with setups using mats as resilient support, there are improvements on airborne sound insulation up to 10 dB and 5-7dB on impact sound insulation, those improvements are visible across all frequency spectrum. The use of discrete bearings as resilient support of lightweight floor systems in combination

with well-designed dry screeds meant another step up in terms of acoustic isolation, especially at lower frequencies.

- The implementation of Fermacell® Powerboard H20, 12.5 mm (1/2'') thick and with a surface density of 13.5 kg/m² (2.77 lbm/sq ft), leads to an enhancement in both airborne and impact sound insulation by approximately 3 dB.
- In the current study, three types of wooden boards were used for testing, namely HydroFlam®, OSB/3, and plywood. HydroFlam® is a P5 chipboard that exhibits moisture resistance, fire retardancy (standard performance of B-s1, d0), and structural integrity, with 89% of its materials being renewable and 95% being recycled wood. OSB/3 is a versatile panel with good mechanical strength, stiffness, and durability under temporary humid conditions, and standard fire reaction performance of D-s2, d0. Plywood, on the other hand, is a wood-based material composed of multiple thin layers of wood veneers glued crosswise to normalize material properties such as shrinkage and swelling behaviour.

Comparing the results obtained in this study, we observed no significant differences in acoustic performance among the test setups that differed only in the type of wooden board used. This finding can be attributed to the similarity in thickness and density of the boards, even when changing the board typology (OBS combined with HydroFlam® vs. plywood). Therefore, the selection of the type of wooden panel for an acoustic floating floor should depend more on other functional requirements such as mechanical resistance, differential deflection, humidity resistance, and fire resistance, rather than on acoustic properties alone. The choice of the most commonly available board in the market should also be considered.

- In this study, the acoustic performance of test setups with channel spacing of 406 mm (16'') and 610 mm (24'') between bearings, while maintaining a constant distance of 500 mm (20'') between bearings in the other direction, was investigated. Results showed that there was no significant difference in acoustic performance for frequencies starting from 50 Hz.

Apart from board thickness, number, and type, the spacing between bearings is often restricted by load conditions and acceptable deflection criteria, which are essential for certain types of floor coverings. Such limitations are observed in multiple instances.

- In the context of lightweight acoustic floor systems, the distribution of loads towards the supporting structural floor is ensured by the use of lightweight panelling, which provides bending stiffness to the floor system. Wood-based panels are preferred due to their optimal ductility/strength ratio and low radiation efficiency. However, these panels exhibit dips in transmission loss in the resonance and coincidence-controlled regions. This issue can be addressed by using constrained layer damping (CLD) techniques with high damping viscoelastic acoustic membranes, known as damping layers. The added damping layer works by converting mechanical energy into heat, thus reducing noise and vibration radiation under impact loads.

In this study, it was found that there was no significant difference between results of test set-ups with and without damping layer, except for slightly better results at the lowest end of available data (<50 Hz) and higher transmittance above 800 Hz. This is due to the fact that the impact generated by the standardized tapping machine used in the tests was not sufficient to generate high shear loads in the damping layer. Therefore, no significant energy was lost in this layer during the tests. However, it is expected that for higher loads, the panels and damping materials will be more compressed, resulting in a higher deformation and shear deformation and a more pronounced benefit of the use of constrained layer damping.

- Comparing the setups utilizing 30 mm (1-3/16'') bearings with those using 50 mm (2'') bearings, it has been observed that there is a 2-3 dB improvement in airborne sound insulation as well as in impact sound insulation. It is noteworthy that the improvements are predominantly observed in the low frequency range due to the overall stiffness of the system and the increase in void resulting in reduced impact of stiffness of the entrapped air.
- Increasing the air void between the floating floor system and the supporting structural floor from 50 mm (2'') to 80 mm (3-1/8'') results in a noticeable enhancement in both airborne and impact noise insulation. The shift of the Rw curve towards the left at lower frequencies confirms this observation. This can be attributed to the reduction in air spring stiffness, as the air void becomes larger.
- A system can be designed with a total build-up height (excluding slab) of 135.5 mm (5-5/16''), by combining an acceptable number of boards to achieve a high surface load of 2 kg/m2 (10.51 lbm/sq ft) with an overheight of 30 mm (1-3/16'') and pads of 50 mm (2''). This system can achieve global values of $L_{n.w}$ = 47 dB, IIC = 63 dB, R_w = 67 dB, and STC = 67 dB.
- Comparing setups using 2 plywood boards and dry screed (setup P) with setups using a plywood board combined with 3 layers of Fermacell (O), an influence can be observed on sound insulation at low frequencies due to the added surface mass.

12. REFERENCIAS

[1] International Building Code, Chapter 7 Fire and Smoke Protection Features, accessed on 03/14/2023.

[2] McLain, Richard, Acoustics and Mass Timber: Room-to-Room Noise Control. WoodWorks, 2018.