Acoustic performance of a CLT-based 3 floor building mockup

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Abstract
In order to investigate acoustic performance of wood based buildings, a mockup has been designed and constructed on FCBA Bordeaux site in France. This project within the scope of AdivBois acoustic technical commission has the objective of defining high-rise wood building solutions. This paper presents the design, the construction stage as well as measurements results. The mockup is a three floor construction, with four rooms on each level. The construction is based on CLT panels for walls and floors, laminated wood posts and beams, and lightweight wood frame façade. Some double frame plasterboard based separating walls are also included. Some junctions incorporate resilient elements in order to evaluate their effect and advantages in the acoustic performance. Acoustic measurements from junction characterization to sound and impact insulations have been and are being conducted. Different solutions for floor covering and ceiling which have been tested in laboratory, will be implemented, and evaluated under in-situ conditions. The effect of apparent posts and beams continuous between different rooms is also under consideration with respect to acoustic performance. The measured results are discussed with respect to prediction or other research results.

Keywords: building acoustics, wood, measurement, prediction, junctions.

1 Introduction

In order to investigate acoustic performance of wood based buildings, a mockup has been designed and constructed on FCBA Bordeaux site in France. This project within the scope of AdivBois acoustic technical commission has the objective of defining high-rise wood building solutions. Laboratory measurements were first performed in order to select CLT based wood floors in order to reach the expected building performance especially regarding low frequency impact sound level. The desired acoustic performance objectives for dwellings correspond to $D_{nT,w}+C \geq 53$ dB, $L'_{nT,w} \leq 55$ dB and $L'_{nT,w} + C_{I50\text{-}2500} \leq 55$ dB. Based on these laboratory measurements, two types of floor were chosen to be incorporated into the mockup: one without suspended ceiling (apparent wood visible) and one with suspended ceiling. Both CLT-based floors implement floating system.

This paper presents the design and some measurements results. Measurement results from junction characterization are compared to empirical data provided in Annex F of ISO 12354-1 [1]. Furthermore, airborne and impact sound insulation measurements have been conducted by different teams at various stages of the mockup construction. These measurements are compared and discussed with respect to

performance prediction. The effect on the acoustic performance of apparent posts and beams continuous between different rooms is also investigated.
The project remains on going and the definition of construction solutions for dwellings fulfilling specific performance requirements, especially regarding impact sound level is underway.

2 Description of the mockup

The mockup is a three-floor construction, with four rooms on each level. The construction is based on CLT panels for walls and floors, laminated wood posts and beams, and lightweight wood frame façade. Some double frame plasterboard based separating walls are also included. Some junctions incorporate resilient elements in order to evaluate their effect and advantages in the acoustic performance.
A general view of the mockup is depicted in Figure 1; temporary stairs on each of the four façades allow to access the different room.
The floor plan for each of the three levels is shown in Figure 2. The ground and middle floors are separated into two small and two large rooms (respectively ~14 m² and ~20 m²). On the top floor, the two smaller rooms remain but the other space is separated differently into two spaces much longer than wide (same surface area ~20 m²). In Figure 2, the walls in blue color represent lightweight plasterboard-based walls. On the lower level (ground floor) the floor is made of concrete directly poured on the ground (micro piles were installed in the ground for the building stability). The posts on which the vertical walls are connected to on the façade side, are visible in Figure 2; their section is 200 mm x 200 mm. The peripheral beams on which the façade is attached have a section of 200 mm x400mm.
The notation for the different rooms is also shown in Figure 2 (bottom right); it is used for the results presentation.
The façade walls are prefabricated wood frame walls, 145 mm in thickness including mineral wool and bracing panel on the outdoor side. A lining composed of 2 layers of 12.5 mm thick plater board mounted on independent metallic frame and a 45 mm layer of mineral wool, is applied to all the inner sides of the façade elements. As seen on Figure 1 an external cladding is also implemented on the façade for weather protection.

Figure 1 – View of the mockup.

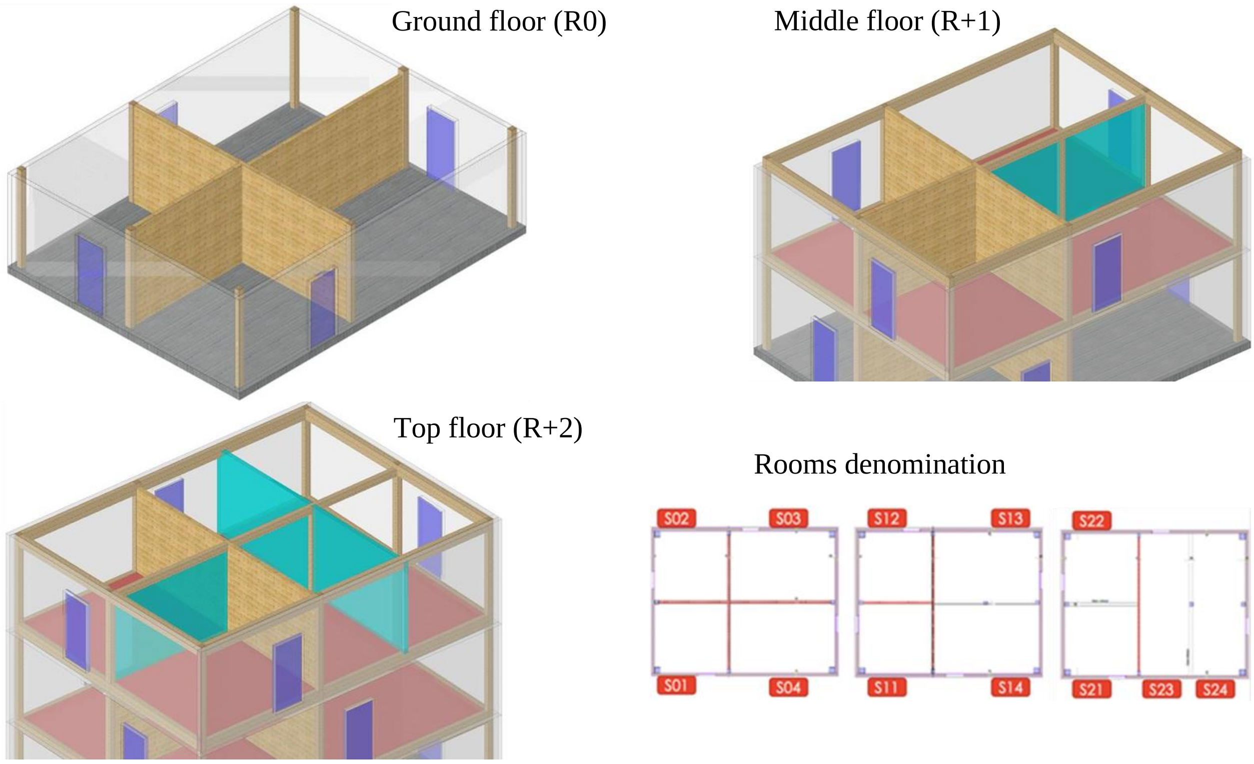

Figure 2 – Floor plans of the mockup.

2.1 Walls and floors

The CLT walls are 140 mm in thickness. They are treated on each side with lining mounted on independent metallic frame made of 2 layers of 12.5 mm thick plater board and 45 mm of mineral wool.

The CLT floors are 140 mm in thickness. Two types of treatment are implemented. The first one consists in a weighting layer 80 mm in thickness made of gravels (~106 kg/m²), and a floating screed composed of 15 mm thick mineral wool resilient layer and a 60 mm thick mortar layer. In this case, the underside of the CLT floor is visible. This concerns the floor of the small rooms (S11, S12, S21 and S22). The second one consists in a thin resilient layer (3 mm) and a 50 mm thick floating screed, and a rigidly suspended ceiling composed of 2 layers of 12.5 mm thick plater boards with a 100 mm cavity filled with mineral wool 80 mm in thickness. This concerns the floor of the large rooms (S13, S14, S23 and S24). The effect of a plastic floor finishing (performance on concrete refence floor of ΔL_w = 19 dB) is also investigated.

The roof is also made of CLT panels, 140 mm in thickness. Thermal insulation (polyurethane type) and weather finishing are placed on the outdoor side. It is equipped with the same rigidly suspended ceiling as described above.

The different treatments on the CLT floor have been tested at CSTB acoustic laboratory so their acoustic performance is available. Due to lack of data, the transmission loss for the CLT wall was taken identical to the CLT floor. The performance of the lining on the CLT wall was deduced from previous measurements performed on a CLT wall with a thickness of 94 mm (identical ΔR was assumed, see Acoubois project [2]).

2.2 Junctions

Figure 3 presents the different junctions implemented between the different components. The junction denoted with “b” do not include resilient layer; those with “a” do. In cross-junction LN°04, the CLT floors are connected to the vertical CLT walls using L-shaped metallic brackets spaced every 50 cm. The junctions LN°01 implement a secondary supporting beam (section of size 80 mm x 200 mm) on top of which the floor is attached. Junctions LN°02 are similar to LN°01 but without the secondary supporting beam; these junctions are not structural junctions since they are parallel to the floor span. Junction LN°05 is not symmetric; the floor is supported on a supporting beam (section of size 80 mm x 200 mm) on one side of the CLT wall and on an angle iron on the other side; furthermore, the junction LN°05b is rather a T-junction due to the presence a lightweight separating floor in the top floor. The resilient is a 12.5 mm thick Sylodyn NB by Getzner; it is compressed to 10 mm. Some compressed mineral wool is also incorporated for fire hazard.

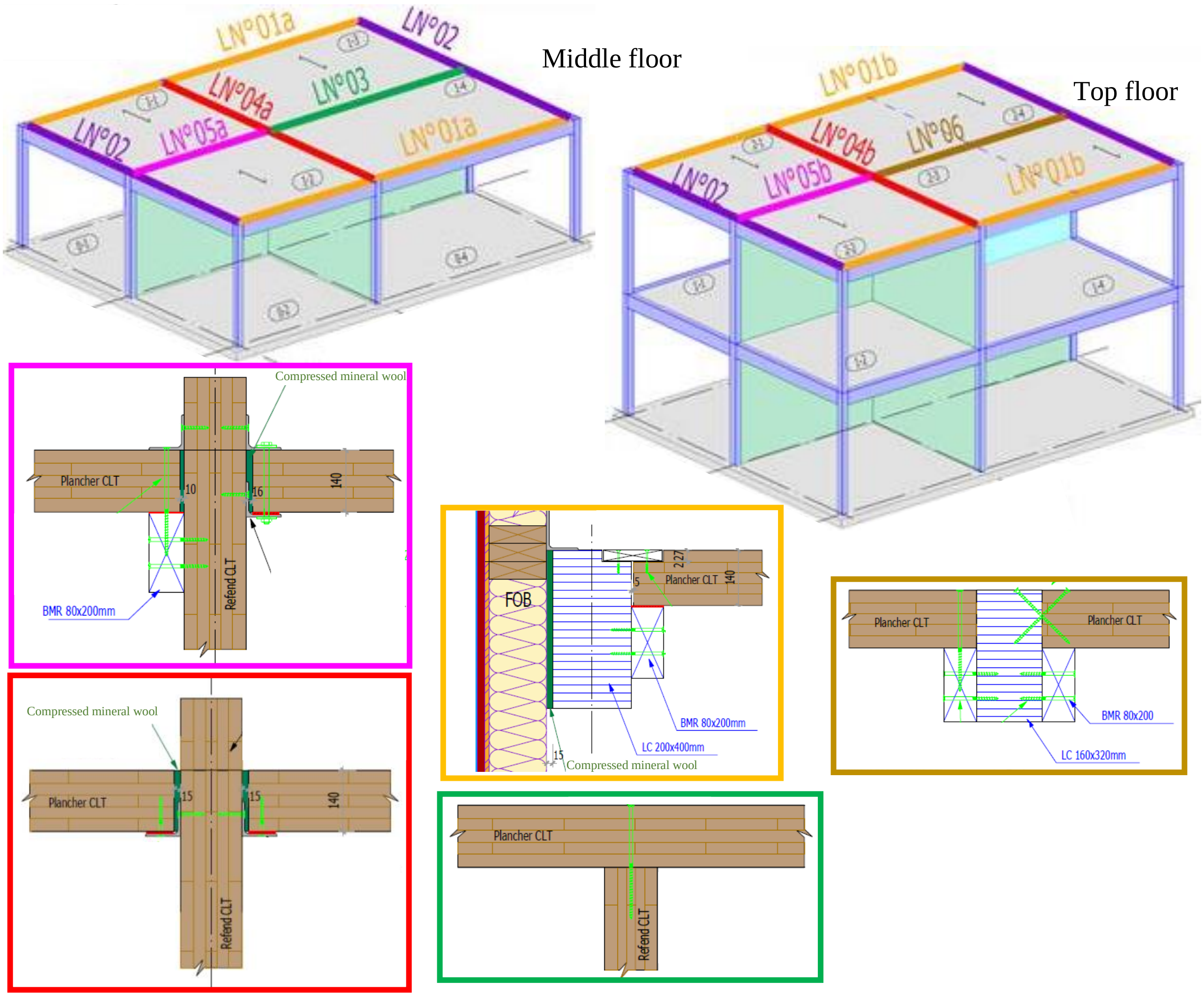

Figure 3 – Different junctions in the mockup structure.

3 Junction characterisation

Junction characterisation was performed following standards ISO 10848 [2]. Tapping machine was used on the CLT floors and walls (CSTB vertical tapping machine is used on walls). The effect of resilient layer is investigated. Measurement results from junction characterization are compared to those proposed to empirical data provided in Annex F of ISO 12354-1 [1] when similar junctions are available.

3.1 Junctions of CLT walls

On each floor, the junction between CLT walls is different: it is cross-junction on the ground floor (R0), a T-junction on the 1st floor (R+1), the fourth wall being a lightweight plasterboard based separating wall, and on the top floor (R+2) a continuous wall with lightweight plasterboard based separating wall as third wall.
Figure 4 presents the measured vibration reduction indices as well as those from ISO 12354-1. It can be seen that the junction behaviour is rather similar at the ground floor and the 1st floor. However, the empirical data

from ISO 12354 deviates from the measured ones. The same type of behaviour is observed for similar T-type rigid junctions between walls and floors.

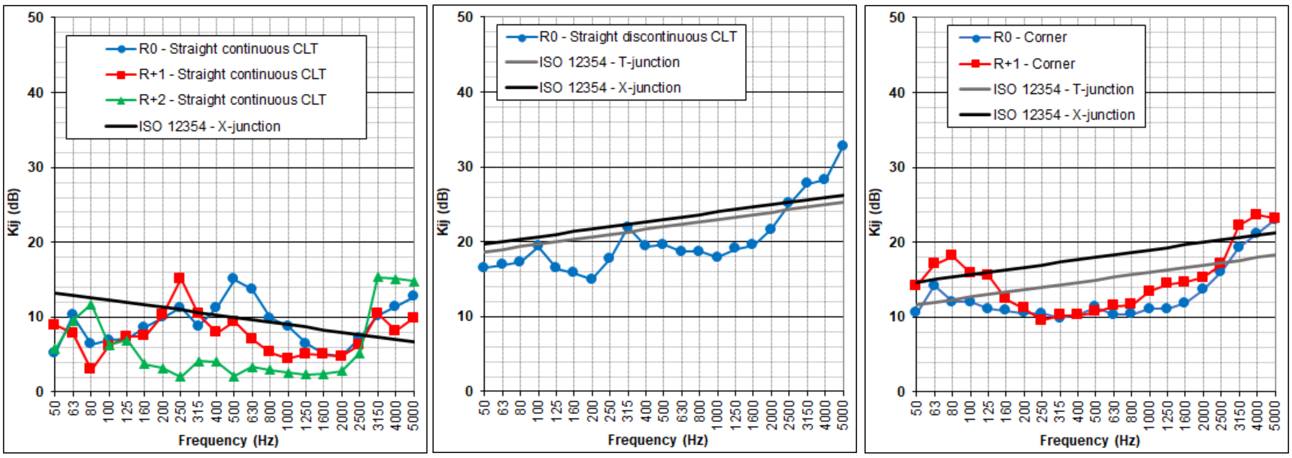

Figure 4 – Vibration reduction index – Junctions of CLT walls.

3.2 Effect of resilient layer on LN°04 junction

This cross-junction is evaluated without resilient (between R+1 and R+2) and with resilient (between R0 and R+1); in the case with resilient the junction characterization was also performed without the screws maintaining the brackets to the floors (see Figure 5). The measured vibration reduction indices are presented in Figure 5. It can be observed that the presence of the screws through the resilient layer has only a slight effect on the paths with floor between the one-third octave bend 800 to 1600 Hz. The absence of the resilient is associated to a decrease of the vibration reduction index in a low frequency range (below 160 Hz) and then at high frequencies (above 1250 Hz). Again, the empirical data from ISO 12354 deviates from the measured ones. Note that this junction is parallel to floor span, this could be a reason for the limited effect of the resilient presence in the brackets.

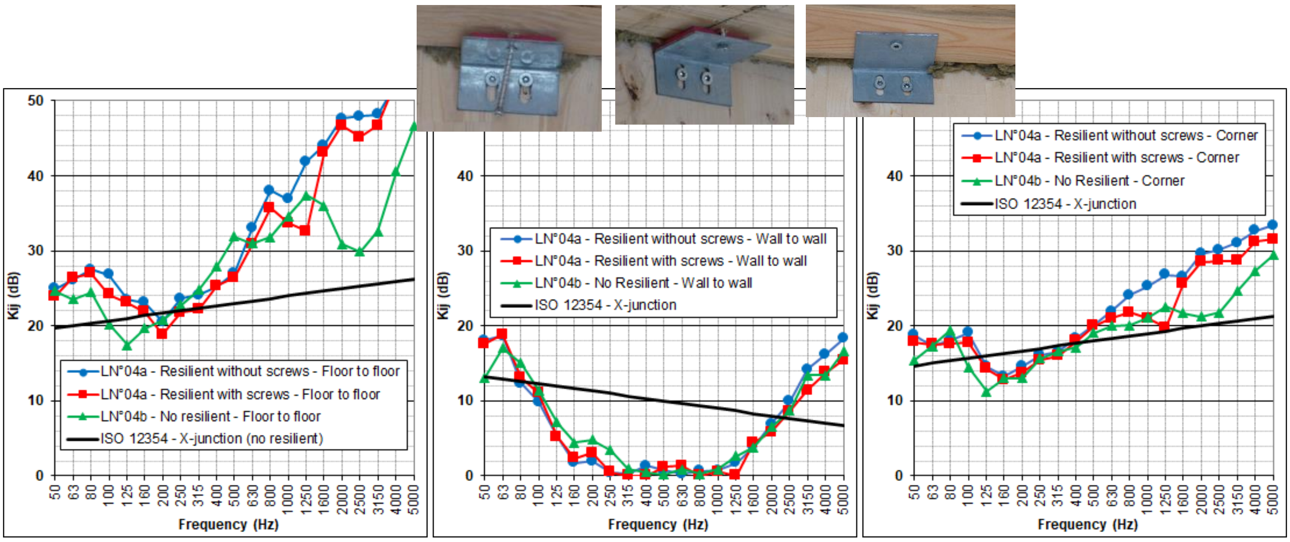

Figure 5 – Vibration reduction index – Junction type LN°04 (brackets with and without resilient).

3.3 Effect of resilient layer on LN°05 junction

This junction is evaluated without resilient (between R+1 and R+2) as T-junction and with resilient (between R0 and R+1) as cross-junction; in the case with resilient the junction characterization was also performed without the screws and for two different screws spacings (500 and 250 mm, the last one being the recommended one also used in the absence of resilient). The measured vibration reduction indices are presented in Figure 6. For the floor-floor path, the effect of the screws and their spacing is clearly visible. For around the corner transmission, the paths are differentiated since the junction is not symmetric (see Figure 3). Once the screws are placed, the corner path on the wood beam side is less favourable than the steel angle support. Since junctions LN°05a integrating a resilient and LN°05b without resilient are of different types, it is rather difficult to conclude on the benefit of including a resilient layer.

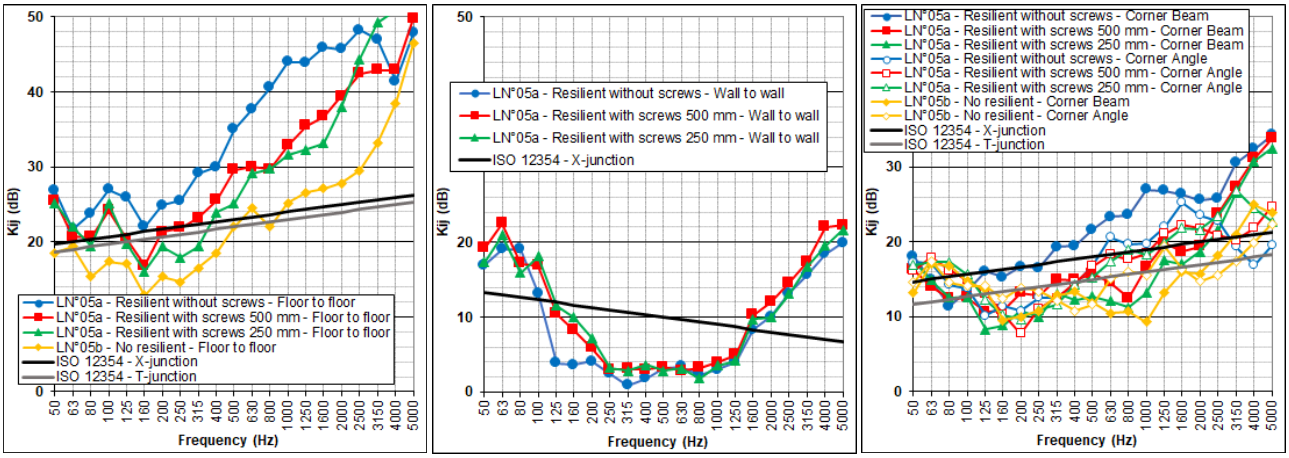

Figure 6 – Vibration reduction index – Junction type LN°05.

4 Acoustic performance

This section concerns comparison between acoustic performance measurements and predicted acoustic performance. The predicted performance is based on the ISO 12354-1 and -2 standards, using as input data the element acoustic performance measured in CSTB acoustic laboratory as well as the junction characteristics evaluated from measurements on the mockup (see previous section).

Acoustic performance measurements were performed by several teams; each team followed its own measurement protocol. Team A from FCBA, used laboratory equipment and more specifically rotating microphone booms, two loudspeaker positions, and four taping machine locations. Team B, a Bordeaux based acoustic consultant firm, performed the measurements with a handhold sound level meter (figure 8 scanning) and two loudspeaker positions or a single tapping machine location. Team C, a Parisian acoustic consultant firm, completed the measurements with a handhold sound level meter (figure 8 scanning) and a single angle loudspeaker position or three tapping machine locations.

All measurements were performed in one-third octave bands from 50 to 5000 Hz for airborne and impact sound insulation. It should be mentioned that no room in the mockup was below 25 m^3 and corner measurement as required by ISO 16283 was not required. Team A performed the measurements before and after the treatments on the CLT walls and floors (i.e., linings, ceilings, floating systems) were applied. It should also be mentioned that Team A also performed measurements with the rubber ball as excitation; however, the results are not presented in this paper.

It should be noted that C_{50} is used to denote the adaptation term $C_{50\text{-}3150}$ for airborne sound insulation, and C_{I50} the adaptation term $C_{I50\text{-}2500}$ for impact sound insulation.

4.1 Phase 1 – Bare CLT elements

Phase 1 corresponds to the bare CLT structure, only the façade linings are in place in the mockup.

4.1.1 Airborne sound insulation

Table 1 presents the results obtained for the airborne sound insulation in terms of single-number values from measurements and the prediction. The comparison between measurement and associated prediction is acceptable; the prediction is in general conservative. Furthermore, the single-number values are very close taking or not the low frequency adaptation term into account (C or C_{50}). The largest discrepancies occur for horizontal transmission with the plasterboard based separating wall including a wood post (between rooms S13 and S14, and S23 and S24).

Table 1 – Airborne sound insulation performance – Bare structure.

Rooms		Measurement – Team A		Prediction	
Emission	Reception	$D_{nT,w} + C$	$D_{nT,w} + C_{50}$	$D_{nT,w} + C$	$D_{nT,w} + C_{50}$
S01	S02	35 dB	35 dB	33 dB	33 dB
S01	S11	35 dB	35 dB	32 dB	32 dB
S03	S02	36 dB	35 dB	35 dB	35 dB
S03	S04	33 dB	33 dB	34 dB	34 dB
S03	S13	34 dB	34 dB	33 dB	33 dB
S11	S12	36 dB	36 dB	34 dB	34 dB
S11	S21	35 dB	36 dB	33 dB	33 dB
S13	S12	35 dB	35 dB	35 dB	35 dB
S13	S14	35 dB	35 dB	39 dB	38 dB
S13	S23	39 dB	39 dB	37 dB	37 dB
S21	S22	37 dB	38 dB	36 dB	36 dB
S21	S23	39 dB	39 dB	39 dB	39 dB
S23	S21	37 dB	37 dB	35 dB	35 dB
S23	S24	42 dB	41 dB	35 dB	35 dB

4.1.2 Impact sound insulation

Table 2 presents the results obtained for the impact sound insulation in terms of single-number values from measurements and the prediction. The comparison between measurement and associated prediction is acceptable; the prediction is, as for the airborne sound insulation, in general conservative. The difference between measured and predicted single-number values is larger when low frequency (i.e., adaptation term C_{I50}) is taken into account. For vertical transmission, the direct path by the CLT floor is dominant as expected. For horizontal transmission, the flanking path floor-floor is dominant when the separating wall is the lightweight plaster-based one; on the other hand, the flanking path floor-wall is dominant when the separating wall is the CLT one.

Table 2 – Impact sound insulation performance – Bare structure.

Rooms		Measurement – Team A		Prediction	
Emission	Reception	$L'_{nT,w}$	$L'_{nT,w} + C_{I50}$	$L'_{nT,w}$	$L'_{nT,w} + C_{I50}$
S12	S02	87 dB	81 dB	88 dB	83 dB
S12	S11	66 dB	64 dB	68 dB	66 dB
S13	S14	79 dB	73 dB	81 dB	75 dB
S14	S04	85 dB	79 dB	86 dB	81 dB
S14	S11	60 dB	58 dB	62 dB	60 dB
S21	S11	86 dB	80 dB	88 dB	83 dB
S21	S22	64 dB	63 dB	62 dB	60 dB
S21	S23	61 dB	58 dB	63 dB	61 dB
S23	S14	83 dB	77 dB	83 dB	78 dB
S24	S14	82 dB	76 dB	83 dB	78 dB
S23	S24	74 dB	70 dB	76 dB	74 dB

4.2 Phase 2 – Completed structure

Phase 2 corresponds to the structure with added linings on CLT walls and added treatments on the CLT floors; beams and posts remain visible. The obtained results can then be compared to the selected dwellings acoustic performance objectives: $D_{nT,w}+C \geq 53$ dB, $L'_{nT,w} \leq 55$ dB and $L'_{nT,w} + C_{I50} \leq 55$ dB; results not meeting the objective are shown with pink background color in the tables below. It should be mentioned that all measurements have not been completed yet and thus the sections below only present preliminary results.

4.2.1 Airborne sound insulation

Table 3 presents the results obtained for the airborne sound insulation in terms of single-number values from measurements and the prediction. The results obtained from the different measurement teams are rather consistent in terms of $D_{nT,w}+C$ except for the horizontal transmission between rooms S13 and S12; on average the standard deviation is below 2 dB. Integrating the low frequency adaptation terms also leads to very comparable results; the standard deviation is even decreased. The predicted performance overestimates in general the measured one. The prediction results show that all investigated configurations fulfil the objective of 53 dB in terms of $D_{nT,w} + C$; unfortunately this is however not the case with the measurement results. The presence of the visible posts and beams is not taken into account in the prediction. Figure 7 shows some of the airborne sound insulation results; the effect of enclosing visible posts and beams (enclosure composition similar to CLT wall linings) can be observed on the sound transmission from S23 to S24 above 630 Hz (in this case it is especially the post in the middle of the plaster board separating wall).

Table 3 – Airborne sound insulation performance – Completed structure.

Rooms		Team A		Team B		Team C		Prediction	
Emi.	Rec.	$D_{nT,w}+C$	$D_{nT,w}+C_{50}$	$D_{nT,w}+C$	$D_{nT,w}+C_{50}$	$D_{nT,w}+C$	$D_{nT,w}+C_{50}$	$D_{nT,w}+C$	$D_{nT,w}+C_{50}$
S01	S02	62	52	63	55	60	53	64	57
S03	S02			63	55			65	58
S03	S04			65	53	64	49	60	56
S03	S13					54	53	57	57
S04	S14			54	54	52	52	57	57
S13	S12	65	54	58	55			63	58
S13	S14	52	49	51	50	51	50	59	53
S13	S23			57	57			65	63
S13	S24					52	50	63	62
S11	S12	63	54	60	55	65	54	64	57
S11	S21	55	55	52	53	53	53	56	55
S01	S11	56	55	54	53	54	53	53	53
S23	S24	54	52	52	51	54	51	57	52
S21	S22	57	54					61	55
S23	S22	65	58					64	57

4.2.2 Impact sound insulation

Table 4 presents the results obtained for the impact sound insulation in terms of single-number values from measurements and the prediction. The results obtained from the different measurement teams are again rather consistent except for the horizontal transmission between rooms S21 and S22, and S23 and S13 when the low frequency adaptation term is included. The predictions are relatively well in line with the measurements. The horizontal impact sound transmission between rooms S11 and S12, and rooms S21 and S22, is not well predicted compared to measurements; the floors for these rooms integrate a weighting layer (above 100 kg/m²) which most probably has an effect on the CLT floor and junction behaviour that is not evaluated. The prediction results show that all investigated configurations fulfil the objective of 55 dB in terms of $L'_{nT,w}$ and $L'_{nT,w} + C_{I50}$; unfortunately this is however not the case with the measurement results when low frequency adaptation term is taken into account. Figure 8 shows some of the impact sound insulation results.

Table 4 – Impact sound insulation performance – Completed structure.

Rooms		Team A		Team B		Team C		Prediction	
Emi.	Rec.	$L'_{nT,w}$	$L'_{nT,w} + C_{I50}$	$L'_{nT,w}$	$L'_{nT,w} + C_{I50}$	$L'_{nT,w}$	$L'_{nT,w} + C_{I50}$	$L'_{nT,w}$	$L'_{nT,w} + C_{I50}$
S11	S01			52	54	52	53	53	53
S12	S02	51	55			51	53	53	53
S14	S04	53	56					54	54
S13	S03	53	56	54	54	54	55	54	54
S21	S11	52	55	53	54	52	53	53	53
S23	S24			51	52	51	51	53	53
S23	S13	52	54	52	48			51	51
S23	S14			54	54			51	51
S24	S13					55	56	51	51
S24	S14	53	55					51	51
S11	S12			34	36	33	37	20	31
S13	S12	34	38	35	37	34	36	31	34
S13	S14	50	46	49	45	49	46	52	51
S21	S22	40	38	40	46	38	37	10	31

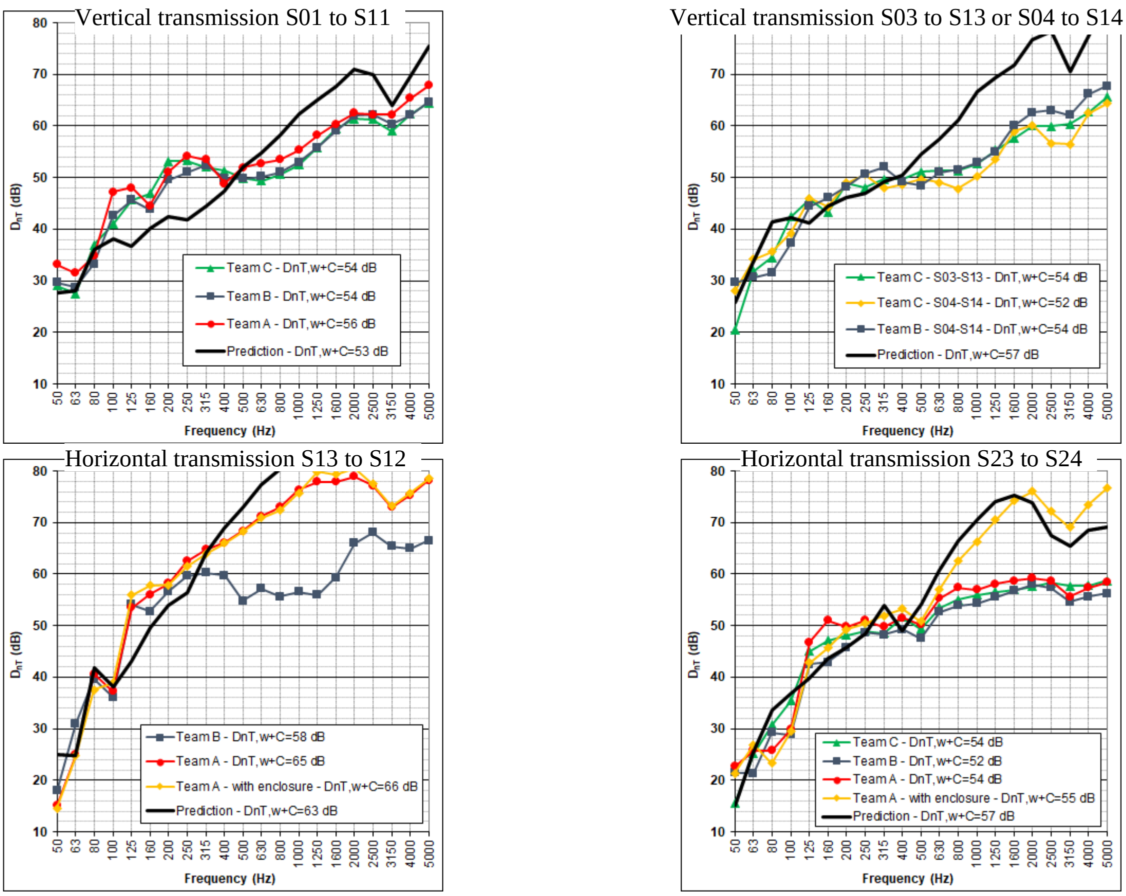

Figure 7 – Airborne sound insulation spectra.

5 Conclusions

Preliminary measurement results have been presented. They confirm the efficiency of the ISO 12354 prediction method applied to CLT buildings; the prediction results are rather close to the measurement ones when no beams or posts are visible. The measurements show that the acoustic requirements could be

achieved with visible beams and posts in rooms; however, detailed measurements (sound intensity based most probably) are being discussed in order to investigate more precisely their effect. More work is and will be required to analyse all the obtained results, in order to evaluate the maximum of visible wood structure (for instance the number of posts and crossing beams), the maximum volume of rooms, etc..
Up to now, the measured or evaluated building acoustic performance does not demonstrate a significant added value of inserting resilient layer on the floor supports on the mockup most probably due to linings and floor treatments. However, further investigation is necessary. More measurements integrating floor covering are being conducted. This project is also expected to explore the possibility of visible wood ceiling or walls.

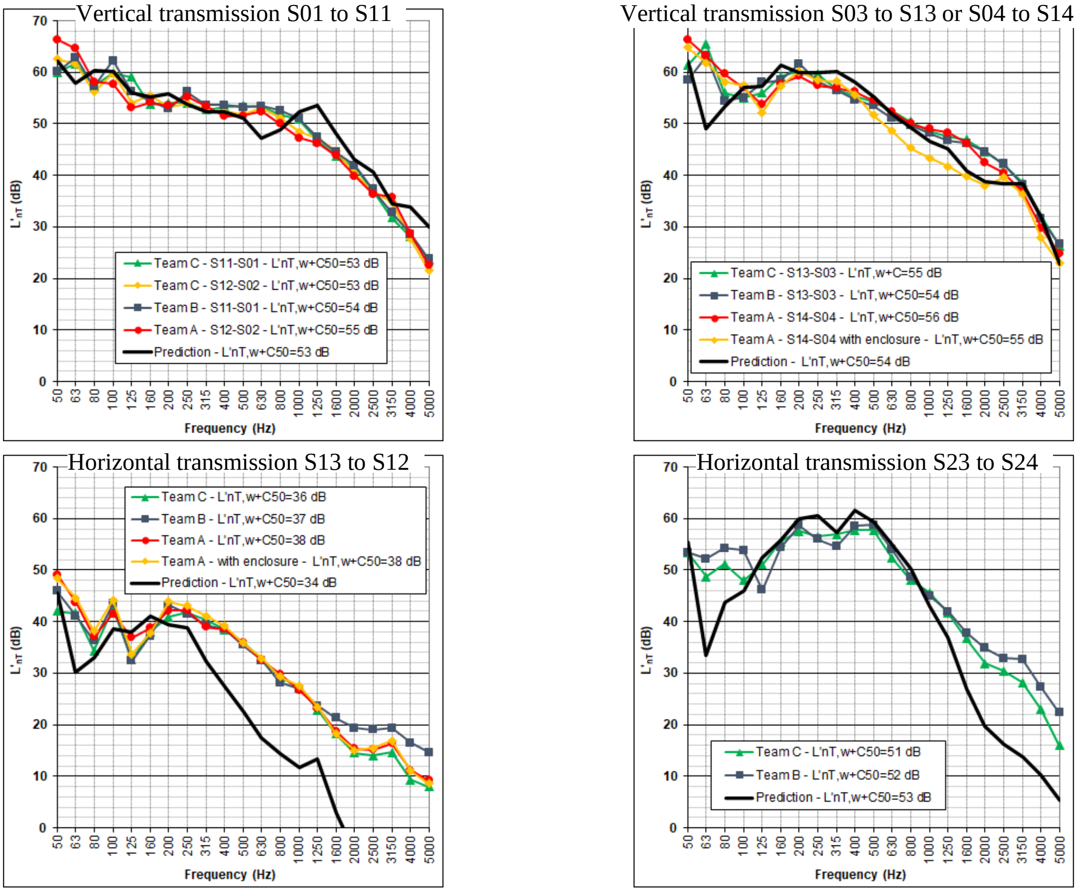

Figure 8 – Impact sound insulation spectra.

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