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IMPACT SOUND ACOUSTIC PERFORMANCE USING RUBBER BALL – FEEDBACK FROM ADIVBOIS MEASUREMENTS ON CLT FLOORS

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ABSTRACT

Laboratory and field measurements of the acoustic performance of a CLT wood based floors were carried out within the scope of AdivBois acoustic technical commission with the objective of defining wood building constructions fulfilling defined requirements. French national regulation requires the use of the standardized tapping machine for impact sound performance measurements. Since the early 2000s, rubber ball impact source has been standardized in Japan and Korea to measure and evaluate the low frequency impact sound performance of floors; this excitation source is now part of international standards concerning acoustic measurement in laboratories and in-situ. Indeed, the impact sound level associated to this soft impact source is supposed to provide a better correlation with annoyance from jumping and/or running children.

The paper reviews the measurements performed using the standard tapping machine and the rubber ball as impact source, on CLT based floors in a laboratory, as well as those on the CLT based building mockup. Results are presented and discussed. The necessity of measuring with both impact sources, or only with the tapping machine is examined.

Keywords: *acoustic performance, impact sound, tapping machine, rubber ball, low frequency.*

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1. INTRODUCTION

To achieve the carbon objectives of the Paris Agreement, many projects are nowadays developed in wood. If the lightweight aspect of wood is appreciated for elevations and extensions, in multi-storey buildings, the predictability of the acoustic and vibration performance of lightweight structures requires special know-how. Behavior at low frequencies must be monitored with care. Fortunately, research has made much progress in recent years, particularly in France due to the momentum generated within the framework of the ADIVBois project. The aim of the ADIVBois association is to help removing technical and regulatory obstacles and to share the expertise acquired in the field of high-rise wooden constructions, with project owners, project managers and companies. The technical working groups of ADIVBois have carried out work in recent years on the aspects of structure, envelope, fire safety and acoustics.

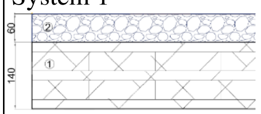
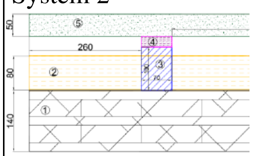
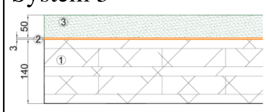
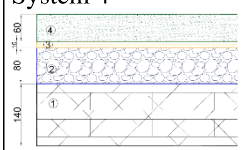
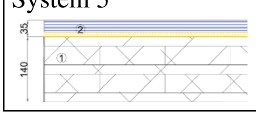
Regarding the acoustic investigation, a laboratory test campaign on the CLT floor was carried out by CSTB in 2018. Then, the project for a life-size mockup of a multi-storey wooden construction was launched at the FCBA in 2019. This new project managed by FCBA was baptized "ADIVBois Acoustic Mockup"; it brings together CSTB, CERQUAL and FCBA. Results have been presented last year in [1-2]. The present paper concentrates on impact sound level results from tapping machine and the rubber ball, measured in a laboratory setup as well as in-situ. From these results, the necessity of measuring with both impact sources, or only with the tapping machine is examined.

2. LABORATORY MEASUREMENTS

Laboratory tests have been undertaken with the aim of providing designers of high-rise wooden buildings with examples of separating floors likely to comply with both French regulatory requirements in terms of construction rules, as well as comfort criteria proposed by ADIVBois for dwellings configuration. Some results were presented in [2]. Many floor configurations based on 140 mm thick CLT wood panels, and integrating different types of floating systems and suspended ceilings were tested. Table 1 presents the floor systems upon which the two types of impact source were used.

In this section, the measurements in terms of L_n et $L_{i,Fmax,V,T}$ spectra are presented as well as the difference between the impact sound level of the bare CLT floor and the floor system considered using either the standard tapping machine (ΔL_n), or the rubber ball ($\Delta L_{i,Fmax,V,T}$). In this case, since the rubber ball measurements are performed between 50 and 630 Hz, the analysis is limited to this frequency range.

Table 1. Laboratory tested floor systems.

Description	Composition
System 1 	1 – CLT panel 140 mm 2 – Concrete fill 60 mm (120 kg/m²)
System 2 	1 – CLT panel 140 mm 2 – Insulation material 80 mm 3 – Wood support 100 mm 4 – Resilient pad 5 – Concrete screed 50 mm
System 3 	1 – CLT panel 140 mm 2 – Thin resilient layer 3 mm 3 – Concrete screed 50 mm
System 4 	1 – CLT panel 140 mm 2 – Gravel 80 mm (106 kg/m²) 3 – Resilient layer 15 mm 4 – Concrete screed 60 mm
System 5 	1 – CLT panel 140 mm 2 – Dry floating floor made of 25 mm board and 10 mm of mineral wool as resilient layer

2.1 Systems comparison

Figures 1 and 2 present respectively the impact sound level for the standard tapping machine and for the rubber ball for floor systems (see Tab. 1) as well as for the bare CLT floor. Table 2 shows the associated single-number quantities. Concerning the impact sound level evaluated with the tapping machine or the rubber ball, System 4 performs the best followed by System 2.

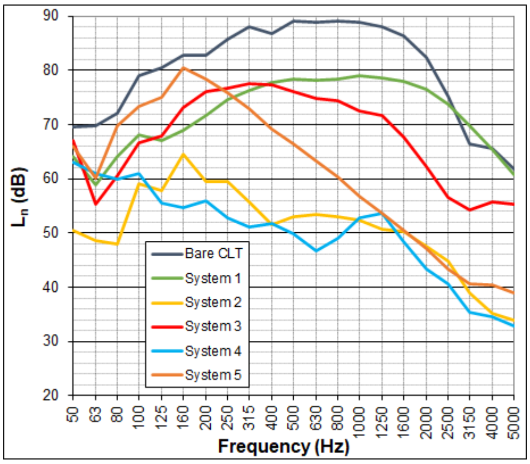


Figure 1. Laboratory impact sound level for the tapping machine for the different investigated floor systems.

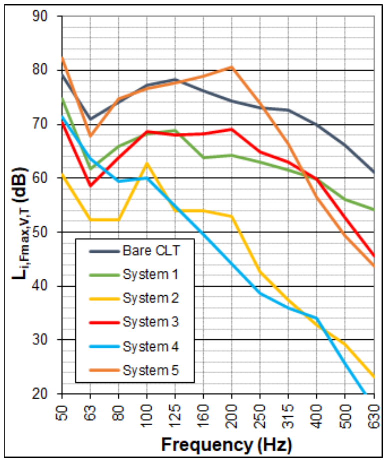


Figure 2. Laboratory impact sound level for the rubber ball, for the different investigated floor systems.

Figure 3 presents the comparison between the two impact sources of the impact sound level difference ΔL associated to a treatment system mounted on top of the 140 mm thick CLT panel. It can be observed that the impact sound level difference associated to the different impact sources is rather similar except for System 5 corresponding to the dry floating screed. In general, the improvement by the floor treatment is lower for the rubber ball than for the tapping machine as impact source.

Table 2. Laboratory-based SNQ for the different investigated floor systems.

Configuration	$L_{n,w}$	$L_{n,w}+C_{I50\text{-}2500}$	$L_{iA,Fmax,V,T}$
Bare CLT	88 dB	83 dB	73 dB
System 1	82 dB	73 dB	63 dB
System 2	56 dB	54 dB	48 dB
System 3	73 dB	71 dB	64 dB
System 4	53 dB	54 dB	47 dB
System 5	69 dB	70 dB	73 dB

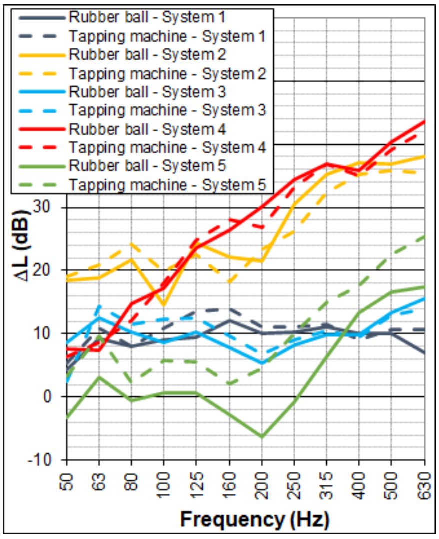


Figure 3. Comparison of the impact sound level difference for the 2 types of impact sources for systems in Table 1 due to floor treatment on top of CLT panel.

2.2 Effect of suspended ceiling on System 3

Three different suspended ceilings were mounted on System 3; the ceiling was mounted on rigid hangers, with a 100 mm cavity filled with 80 mm thick glass wool and with a single layer of 12.5 mm thick plasterboards (denoted a), a double layer of 12.5 mm thick plasterboards (denoted b) and a double layer of 18 mm thick plasterboards (denoted c). Figures 4 and 5 present respectively the impact sound level for the standard tapping machine and for the rubber ball for floor System 3 and the different suspended ceilings. Table 3 shows the associated single-number quantities.

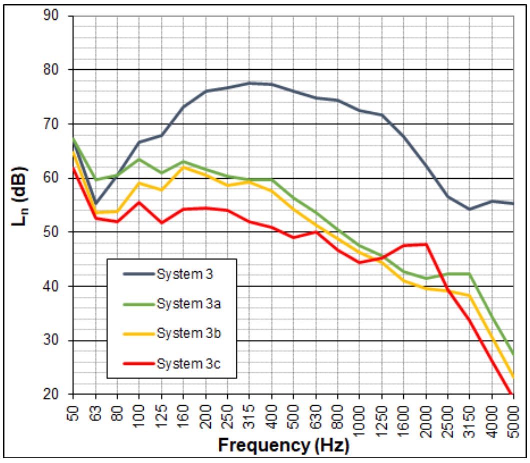


Figure 4. Laboratory impact sound level for the tapping machine for System 3 with different ceiling configurations.

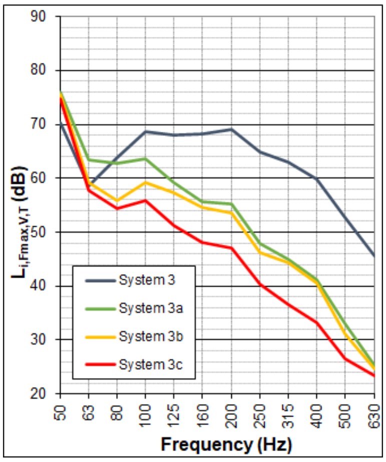


Figure 5. Laboratory impact sound level for the rubber ball, for System 3 with different ceiling configurations.

Table 3. Laboratory-based SNQ for System 3 with different ceiling configurations.

Configuration	$L_{n,w}$	$L_{n,w}+C_{I50\text{-}2500}$	$L_{iA,Fmax,V,T}$
System 3	73 dB	71 dB	64 dB
System 3a	56 dB	58 dB	52 dB
System 3b	54 dB	55 dB	50 dB
System 3c	51 dB	51 dB	47 dB

Figure 6 presents the comparison between the two impact sources of the impact sound level difference ΔL on floor

System 3 only to evaluate the effect of the different types of suspended ceiling. It can be observed that the impact sound level difference associated to the different impact sources is again rather similar. Also, the improvement by the floor treatment is lower for the rubber ball than for the tapping machine as impact source.
As expected, the floor system with the suspended ceiling integrating a double layer of 18 mm thick plasterboards (system denoted c) performs the best.

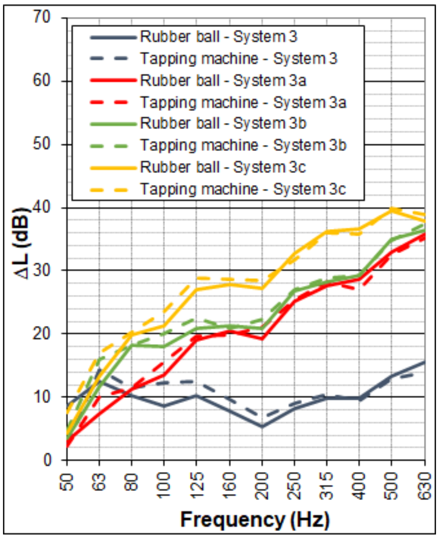


Figure 6. Comparison of the impact sound level difference for the 2 types of impact sources for System 3 – Effect of suspended ceiling configurations.

2.3 Effect of floor covering on System 3

On the previously described configurations of System 3, a pvc floor covering was implemented (denoted ’). In one case, rigid tiles was also tested (denoted ’’). Figures 7 and 8 present respectively the impact sound level for the standard tapping machine and for the rubber ball for the floor System 3 and the different suspended ceilings and floor coverings. Table 4 shows the associated single-number quantities.
Figure 9 presents the associated results in terms of floor covering effect. It can be seen that the effect of the pvc floor covering is null when the rubber ball is used, while it is increasing with frequency above the 100 Hz one-third octave band when the standard tapping machine is implemented. The effect of the rigid tiles is slightly negative when rubber ball is used as excitation source and is even more negative below the 160 Hz one-third octave band when the tapping machine is considered.

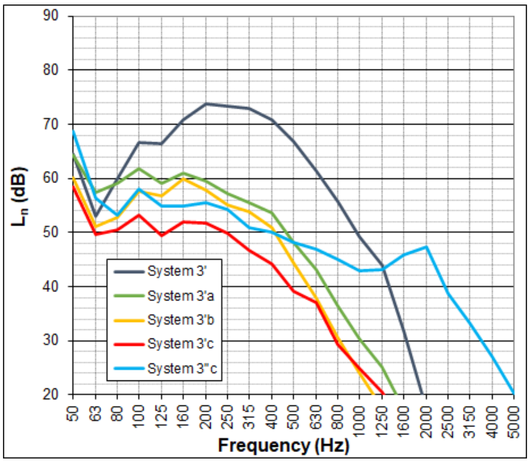


Figure 7. Laboratory impact sound level for the tapping machine for System 3 with different ceiling and floor covering configurations.

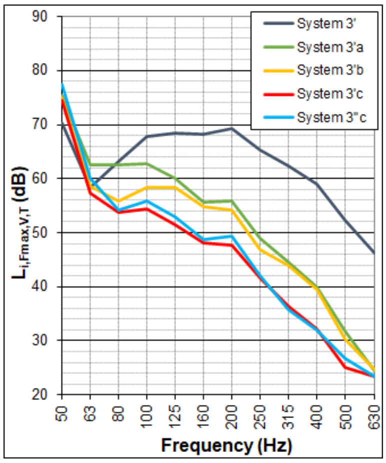


Figure 8. Laboratory impact sound level for the rubber ball, for System 3 with different ceiling and floor covering configurations.

Table 4. Laboratory-based SNQ for System 3 with different ceiling and floor covering configurations.

Configuration	$L_{n,w}$	$L_{n,w}+C_{I50\text{-}2500}$	$L_{iA,Fmax,V,T}$
System 3’	65 dB	65 dB	64 dB
System 3’a	52 dB	55 dB	52 dB
System 3’b	50 dB	52 dB	50 dB
System 3’c	44 dB	47 dB	47 dB
System 3’’c	51 dB	55 dB	49 dB

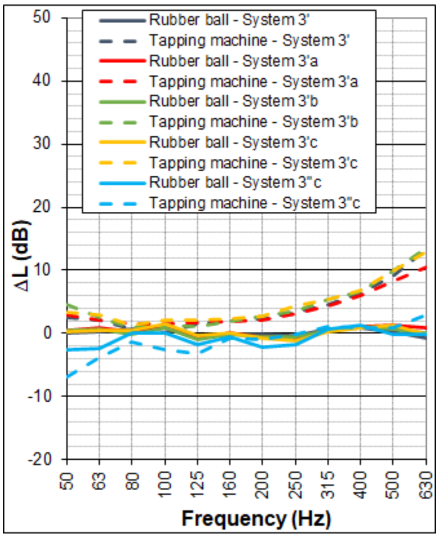


Figure 9. Comparison of the impact sound level difference for the 2 types of impact sources for System 3 with ceilings – Effect of floor covering.

2.4 Remarks

Figure 10 shows the variations of $L_{n,w}$ and $L_{n,w}+C_{I50\text{-}2500}$ as a function of $L_{iA,Fmax,V,T}$; the desired performance level of 52 dB in terms of $L_{n,w}$ and $L_{n,w}+C_{I50\text{-}2500}$ is also indicated. Based on these limited results it seems rather difficult to set a limit value in terms of $L_{iA,Fmax,V,T}$. It should be added that a correlation coefficient of 0.81 is obtained between $L_{n,w}$ and $L_{iA,Fmax,V,T}$, and of 0.90 between $L_{n,w}+C_{I50\text{-}2500}$ and $L_{iA,Fmax,V,T}$. This good correlation is due to the fact that the indicators are essentially determined by the behavior at low frequencies. Therefore, it could be deduced that the single-number quantities $L_{n,w}$ and $L_{n,w}+C_{I50\text{-}2500}$ based on the use of the standard tapping machine are sufficient to get information on the impact sound performance of the investigated floors in the complete frequency range. However, the improvement by floor treatments is generally found lower for the rubber ball than for the tapping machine as impact source.

3. IN-SITU MEASUREMENTS

The building prototype, or "ADIVBois Acoustic Mockup" is a three-storey wooden structure building comprising 4 rooms on each floor, including 2 rooms with an overall surface area of approximately 14 m² each, and 2 rooms with an overall surface area of approximately 19.8 m² each. 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.
More details concerning this building can be found in [1-2]. Measurements were performed on the bare CLT structure and then again when the CLT floor and wall were mounted with floating system, suspended ceiling and linings as described in Figure 11.

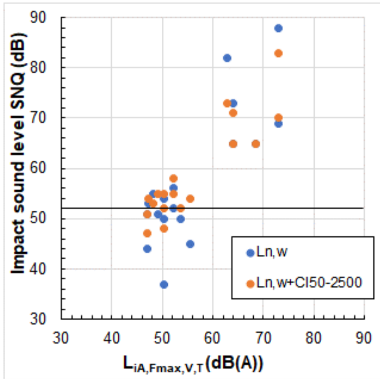


Figure 10. Comparison of the impact sound single-number quantities for all laboratory measurements.

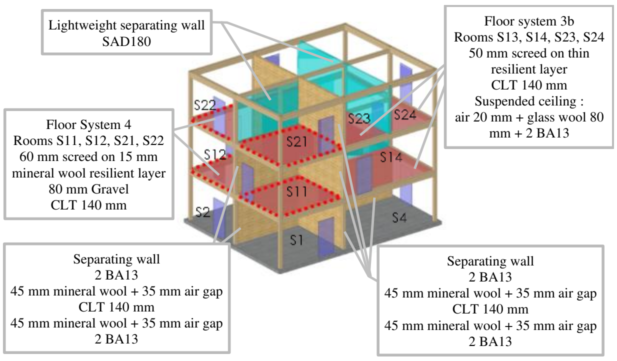


Figure 11. Construction principle of the "ADIVBois Acoustic Mockup".

3.1 Effect of floor treatment

In this section, the notation V stands for vertical transmission and H for horizontal transmission, while M indicates impact on middle floor and T on top floor.
Figures 12 to 15 presents respectively the impact sound level for the standard tapping machine and for the rubber ball for the two floor treatments (System 3b and System 4). A clear difference can be noticed for vertical and horizontal transmission especially for the floor System 4. The

difference between the impact sound level L_n in the mid and high frequency range for System 4 (HM) and System 4 (HT) is due to the separating wall configuration.

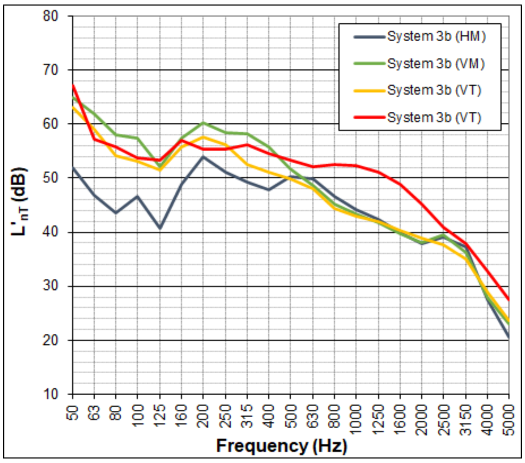


Figure 12. In-situ impact sound level for the tapping machine for System 3b.

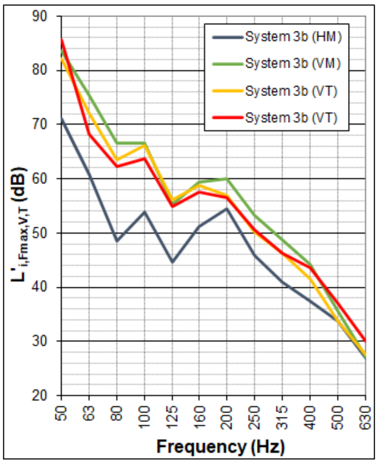


Figure 13. In-situ impact sound level for the rubber ball, for System 3b.

Table 5 shows the associated single-number quantities; the obtained performances are in agreement with the targets of 55 dB for $L_{n,w}$ and $L'_{nT,w}+C_{I50\text{-}2500}$.

The effect due to floor treatments on the impact sound level due to the standard tapping machine and the rubber ball (as in Section 2) is shown in Figures 16 and 17 for the floor System 3b and 4 respectively. Once again, the effect of the floor treatment is rather similar for the two impact sources; the obtained improvement is again found lower for the rubber ball than for the tapping machine as impact source.

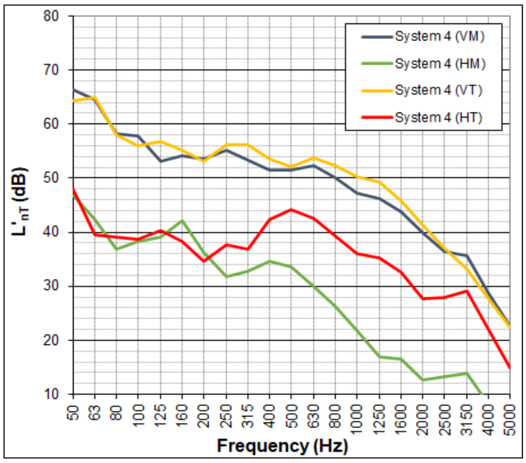


Figure 14. In-situ impact sound level for the tapping machine for System 4.

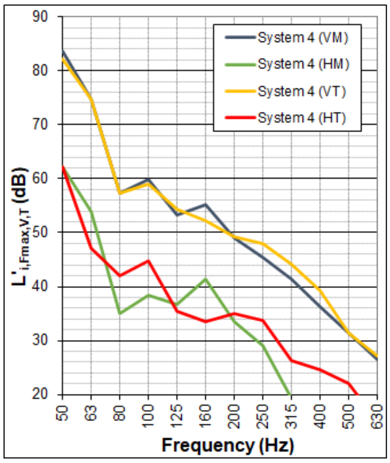


Figure 15. In-situ impact sound level for the rubber ball, for System 4.

Table 5. In-situ SNQ for System 3b and System 4.

Configuration	$L'_{nT,w}$	$L'_{nT,w}+C_{I50\text{-}2500}$	$L'_{iA,Fmax,V,T}$
System 3b (HM)	48 dB	46 dB	48 dB
System 3b (VM)	52 dB	55 dB	58 dB
System 3b (VT)	50 dB	52 dB	56 dB
System 3b (VT)	53 dB	55 dB	57 dB
System 4 (VM)	51 dB	55 dB	55 dB
System 4 (HM)	31 dB	36 dB	35 dB
System 4 (VT)	52 dB	55 dB	54 dB
System 4 (HT)	40 dB	38 dB	35 dB

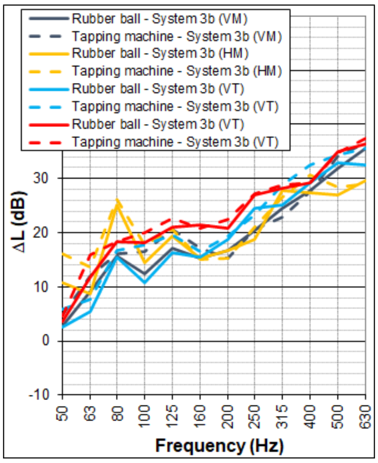


Figure 16. Comparison of in-situ impact sound level difference for the 2 types of impact sources for System 3b.

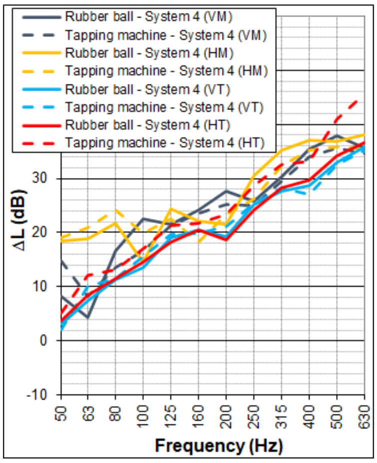


Figure 17. Comparison of in-situ impact sound level difference for the 2 types of impact sources for System 4.

3.2 Effect of floor covering

The bottom room S03 was divided in two spaces by a lightweight partition wall in order to have a small room just above 25 m^3. The floor treatment corresponds to System 3b. Three floor coverings were implemented: a pvc floor covering (same as the one tested in laboratory, see Section 2.3), a laminated wood flooring on 2 mm thick resilient layer and rigidly fixed tiles. Figures 18 and 19 present respectively the impact sound level for the standard tapping machine and for the rubber ball. In the low frequency range, there is an effect of the floor covering; in the mid frequency range, the pvc floor covering performs the best and the rigid tiles the worst as could be expected.

Table 6 shows the associated single-number quantities. In terms of $L'_{nT,w}$ the performance is improved by the floor covering; this is only the case for the PVC floor covering in terms of $L'_{nT,w} + C_{I50\text{-}2500}$. No improvement is obtained for any floor covering in terms of $L'_{iA,Fmax,V,T}$.

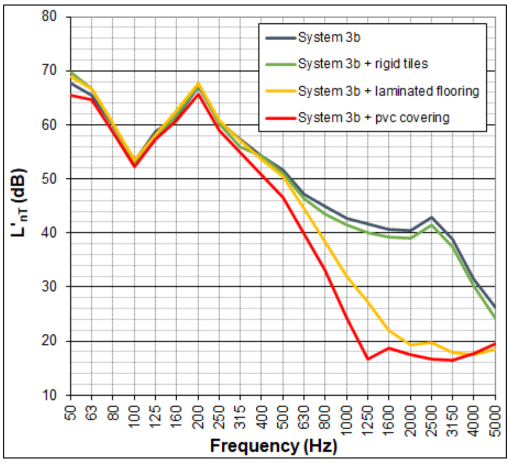


Figure 18. In-situ impact sound level for the tapping machine, of System 3b on reduced size room with different floor coverings.

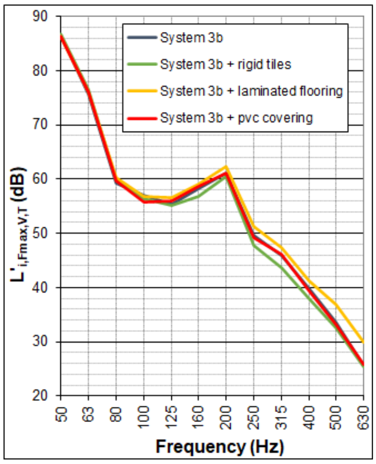


Figure 19. In-situ impact sound level for the rubber ball, of System 3b on reduced size room with different floor coverings.

Figure 20 shows the effect of the floor covering on the impact sound level for the two impact sources. For the one-third octave bands 50 and 63 Hz, the negative effect of the rigid tiles and laminated flooring is more important when using the tapping machine than when using the rubber ball as impact source. For the PVC floor covering, the tapping machine is associated with an improvement higher than the one using the rubber ball (except at 100 Hz); for the rubber ball, the performance improvement is indeed very close to 0 dB. It can nevertheless be seen that the influence of floor coverings is less important for in-situ measurements (Figure 20) than for laboratory measurements (Figure 9).

Table 6. In-situ SNQ for System 3b with reduced size room.

Configuration	$L'_{nT,w}$	$L'_{nT,w}+C_{I50\text{-}2500}$	$L'_{iA,Fmax,V,T}$
Without covering	55 dB	58 dB	58
Rigid tiles	54 dB	59 dB	58
Laminated flooring	53 dB	59 dB	59
PVC covering	52 dB	57 dB	58

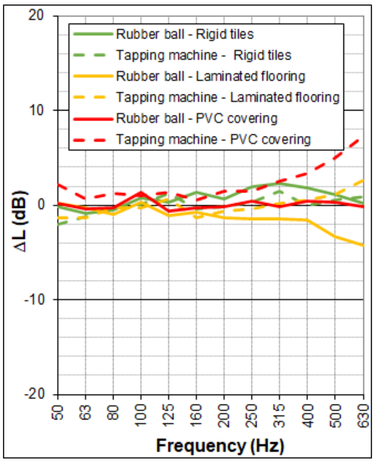


Figure 20. Effect of floor covering for reduced size room with System 3b on in-situ impact sound level for the two impact sources.

3.3 Remarks

Figure 21 shows the variations of $L'_{nT,w}$ and $L'_{nT,w}+C_{I50\text{-}2500}$ as a function of $L'_{iA,Fmax,V,T}$; the desired performance level of 55 dB in terms of $L'_{nT,w}$ and $L'_{nT,w}+C_{I50\text{-}2500}$ is also indicated. Based on these results it seems that a limit value of 55 dB (with a 3 dB margin) could be set in terms of $L'_{iA,Fmax,V,T}$. A correlation coefficient of 0.93 is obtained between $L'_{nT,w}$ and $L'_{iA,Fmax,V,T}$, and of 0.97 between $L'_{nT,w}+C_{I50\text{-}2500}$ and $L'_{iA,Fmax,V,T}$.
As could be expected, $L'_{nT,w}+C_{I50\text{-}2500}$ and $L'_{iA,Fmax,V,T}$ are highly correlated. Therefore, it could be deduced that the single-number quantities $L'_{nT,w}$ and $L'_{nT,w}+C_{I50\text{-}2500}$ based on the use of the standard tapping machine are sufficient to get information on the behavior of the investigated floors at low and high frequencies.

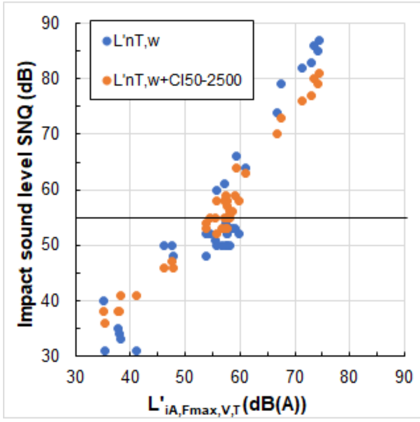


Figure 21. Comparison of the impact sound single-number quantities for all in-situ measurements.

4. CONCLUSIONS

From the presented results, it appears that the use of the standard tapping machine is sufficient to get information on the impact sound performance of the investigated floors in the complete frequency range, i.e., in the low to high frequency range. However, the improvement by different treatments on the CLT floor was found dependent on the impact source types (rubber ball and tapping machine).

5. ACKNOWLEDGMENTS

The authors would like to thank ADIVBois, CODIFAB and the French Nouvelle-Aquitaine region for the financial support provided to this project.

6. REFERENCES

[1] C. Guigou Carter, N. Balanant, J.-L. Kouyoumji, "Apparent wood elements and acoustic performance – Feedback from Adivbois CLT building mockup", in *Proc. Internoise 2022*, (Glasgow, Scotland, UK), 2022.

[2] C. Guigou Carter, N. Balanant, J.-L. Kouyoumji, "Building acoustic performance prediction – Feedback from Adivbois CLT building mockup", in *Proc. Internoise 2022*, (Glasgow, Scotland, UK), 2022.