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IMPACT SOUND INSULATION OF CLT FLOORS: EVALUATION OF SMALL SCALE SPECIMENS AND CORRELATION WITH LARGE SCALE SYSTEMS

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ABSTRACT

CLT has emerged as widely adopted material due to its versatility and environmental benefits. However, achieving suitable impact sound insulation for CLT floor systems is challenging. Laboratory tests of impact sound insulation present an invaluable source of information for design teams, but they are time consuming due to required sample size (10-20 m^2) and complexity of installation. Performing impact sound insulation tests on small samples offers operational advantages and provides an attractive testing option for comparative purposes and design decisions. This study provides a systematic analysis of impact sound insulation measurements conducted on a variety of small scale and large scale specimens utilizing CLT reference floor. Unlike concrete reference floors, CLT exhibits significant contribution of airborne sound component induced by the tapping machine. This phenomenon necessitates careful consideration when employing small-scale specimens for impact sound insulation analysis. Study highlights the advantages and limitations of conducting impact sound insulation tests on small scale specimens, emphasizing their practicality for comparative analyses and design decision-making. Furthermore, it points to certain constraints when extrapolating these findings to large-scale systems, offering insights into refining testing protocols for CLT-based constructions.

Keywords: *cross-laminated timber, impact sound insulation, sample size, small scale.*

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1. INTRODUCTION

Alongside the airborne sound insulation, impact sound forms one of the cornerstones for acoustic requirements throughout the world. The robust information of impact sound levels for floor constructions is indispensable for all the parties involved in the acoustic design process. Whether in the form of laboratory test reports, published data for common building systems or computer simulations.

Compared to the substantial data available for standard monolithic floors, information concerning lightweight floors, particularly cross-laminated timber (CLT) floors, is limited. The latter is of particular importance considering relatively poor impact sound insulation performance of the basic CLT floor elements themselves; necessitating certain upgrades by means of complex floor coverings and/or suspended ceilings.

Laboratory testing, in accordance with ISO 10140-3:2021 [1], provides a reliable means to determine floor impact sound levels. However, such tests are inherently complex due to the required sample size and installation procedure.

While Bet et al. [2] previously explored the implications of sample size reduction in impact sound tests on heavyweight concrete floors, similar studies are lacking for CLT floors.

This work aims to fill this void by assessing the efficacy and reliability of small scale impact sound tests on basic CLT floor.

The discussion will commence with an overview of impact sound insulation test method, followed by an experimental investigation employing tapping machine on a variety of small scale and large scale floor coverings built on top of the CLT reference floor (without the ceiling). Concluding remarks will summarize the main findings of the experimental investigation and the analysis of correlations between different sample sizes.

2. IMPACT SOUND INSULATION TEST METHOD

ISO 10140-3:2021 [1] details the procedure for impact sound insulation measurements and refers to other parts of ISO 10140 where appropriate.

Accordingly, the size of the test opening for floors shall be between 10 m^2 and 20 m^2, with the shorter edge length not less than 2,3 m.

Annex H of ISO 10140-1:2021 [3] introduces the concept of testing on small specimens, the minimum size of which is 650 mm x 350 mm. However, the latter procedure is introduced only for floor coverings of Category I, which include flexible coverings (plastics, rubber, cork, matting or combinations thereof).

On the other hand, typical complex floor systems built on CLT would be generally classified as Category II floors, with the requirement for specimen size of at least 10 m^2.

Therefore, the current standard does not make a provision for the testing of small samples for floor systems and/or floor coverings typically built on the basic CLT slab.

As described, the concept of tests on small specimens is indeed rooted in the ISO 10140 test standard for certain floor coverings but one of the main obstacles remains the requirement that the airborne sound transmission from the source to the receiving room is at least 10 dB below the level of the transmitted impact sound in each frequency band.

The latter requirement is particularly constraining for small samples built on basic CLT floor, as relatively low airborne sound insulation of CLT will be the limiting factor.

Regardless of the small scale build-up (and its potentially high airborne sound insulation), airborne sound component produced by the tapping machine in the source room will inevitably propagate through the basic CLT element alone.

Therefore, the measured impact sound should be corrected according to ISO 10140-4 [4].

If the condition

$$L_i - (L_{TS} - D) \geq 10 \text{ dB} \qquad (1)$$

is valid in all one-third octave bands, a correction of airborne sound transmission is not necessary.

For

$$L_i - (L_{TS} - D) \leq 3 \text{ dB} \qquad (2)$$

sound transmission is dominated by airborne sound and impact sound insulation cannot be measured correctly.

L_i is the sound pressure level generated by the tapping machine in the receiving room;
L_{TS} is the sound pressure level generated by the tapping machine in the source room;
D is the sound pressure level difference between the source and receiving room with the loudspeaker on.

3. EXPERIMENTAL INVESTIGATION

Impact sound insulation tests were carried in accordance with ISO 10140-3:2021 [1] on ten pairs of small and large scale floor samples (all without the ceiling), built on top of the basic 5-ply 140 mm CLT installed between vertically adjacent source and receiving room (V = 58 m^3).

3.1 Test samples and materials

Size of large scale sample was 15,6 m^2 and that of small scale samples around 0,54 m^2 (ca 900 x 600 mm).

Four 900 x 600 mm samples were installed for each floor type, all of them large enough to support the whole tapping machine. Number of tapping machine positions was the same as the number of small scale samples (four).

Details of tested floor systems are provided in Tab. 1, listed from top to bottom layers (from walking surface to the structural CLT slab).

Floor systems were tested with and/or without the backfill. Where used, backfill was installed directly on top of CLT.

Floor numberings in Tab. 1 are done according to the following principle: F1 – floor one without the backfill, F1B – floor one with the backfill.

Table 1. Tested floor systems.

Floor No.	Build-up
F1 / F1B	Dry screed (Backfill) CLT
F2	Dry screed PE membrane CLT
F3	Dry screed EPS CLT
F4 / F4B	Dry screed EPS PE membrane (Backfill) CLT
F5 / F5B	Dry screed GMW (Backfill) CLT
F6 / F6B	Dry screed RMW (Backfill) CLT

Density (ρ), thickness (d) and dynamic stiffness (s') of used materials are listed in Tab. 2

Table 2. Material properties.

Material	ρ (kg/m^3)	d (mm)	s' (MN/m^3)
Backfill	1750	60	-
GMW (glass mineral wool)	50	40	6
RMW (rock mineral wool)	100	40	25
EPS	-	40	-
PE membrane	-	5	-
Dry screed	1280	18	-

Fig. 1 and Fig. 2 illustrate the typical testing arrangement for small scale samples. Where used, backfill was installed inside the wooden frame and laid on top of a thin layer of geotextile.

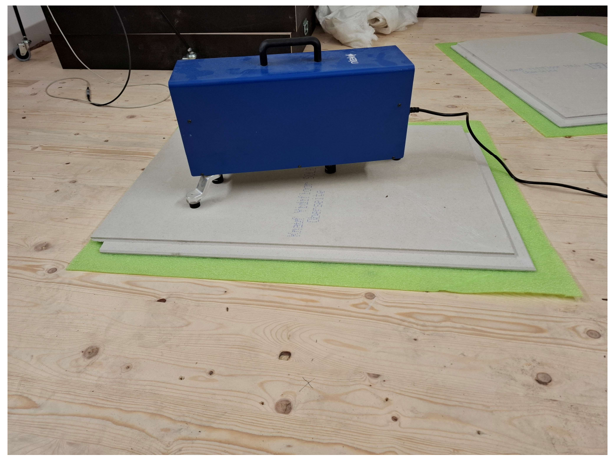

Figure 1. Test sample F2 (small scale).

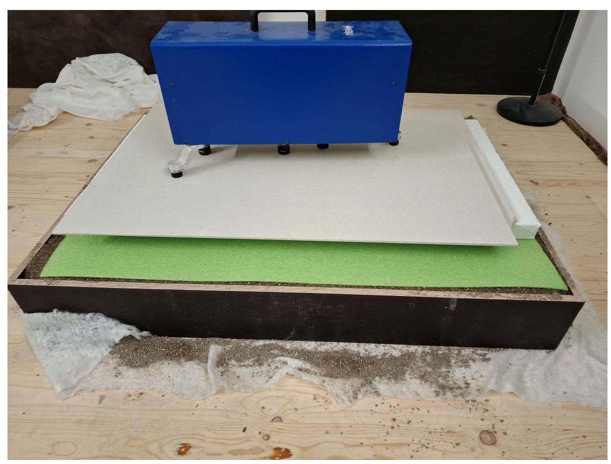

Figure 2. Test sample F4B (small scale).

3.2 Airborne sound component and testing limits

One-third octave sound reduction index (R) of basic 140 mm CLT floor is given in Fig. 3, with the corresponding single-number rating R_w 39 dB.

Such relatively low airborne sound insulation will have a determining influence on the frequency limit up to which the impact sound insulation can be measured correctly.

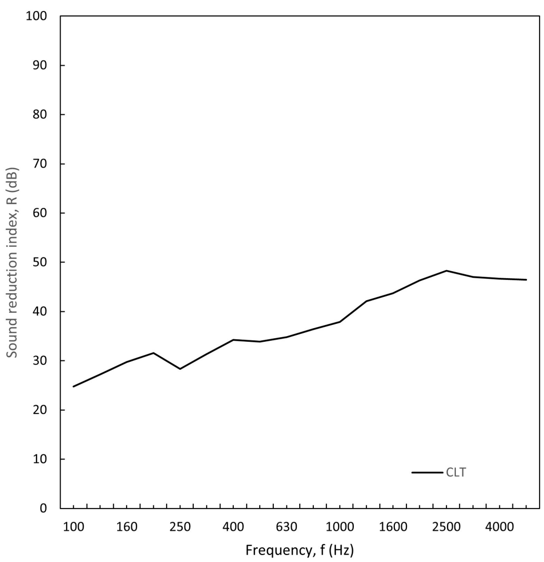

Figure 3. Airborne sound insulation of basic 140 mm CLT floor.

Sound pressure level generated by the tapping machine in the source room was measured for all the test samples.

There were minor differences observed between the sample sizes or due to the backfill. Fig. 4 illustrates the latter levels for basic CLT (solid line) and all the tested floors (shaded area).

Measured sound pressure levels in the source room were of a similar trend for all the tested floors, with relatively minor changes in the absolute values. Contribution of the top layer (dry screed) seems to be predominant, with no significant influence caused by the floors size, subsequent floor layers or backfill.

Equivalent A-weighted sound pressure level in the source room for all the test samples amounted between 93 and 95 dB(A).

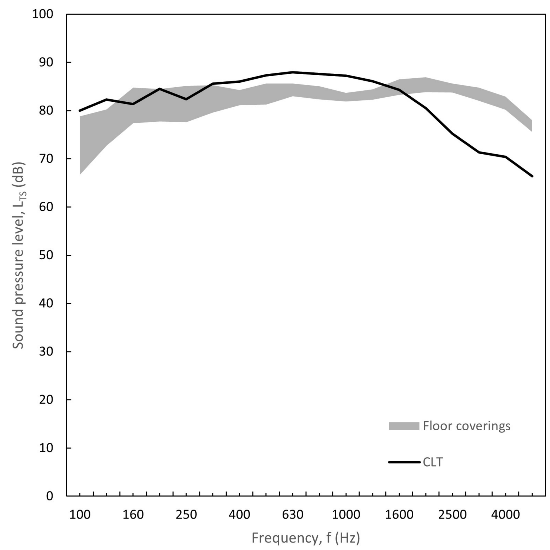

Figure 4. Sound pressure level (L_{TS}) generated by the tapping machine in the source room.

Sound pressure level generated by the tapping machine in the source room (93-95 dB(A)) will be attenuated only by the basic CLT floor (R_w 39 dB) for all the small scale samples, and by the entire floor build-up for every corresponding large scale sample.

Such constraint is the limiting factor for correct measurement of high performing floors, where airborne component will dominate on certain frequencies.

For example, Fig. 5 illustrates the normalized impact sound pressure levels (L_n) for floors F6 and F6B (small and large scale), with black-filled markers added to the frequencies where the result is dominated by the airborne sound and impact sound insulation cannot be measured correctly (result of equation (2) is ≤ 3 dB).

It can be noticed that such limitations can occur for small scale samples, as well as for high performing large scale samples.

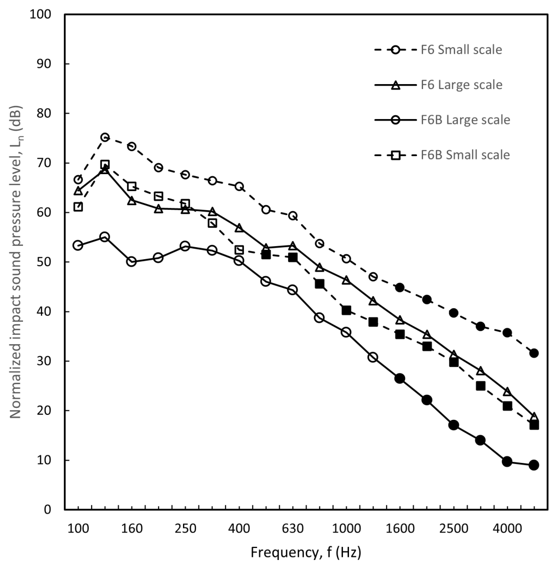

Figure 5. Limit of measurement precision for floors F6 and F6B.

Corresponding single-number ratings for airborne and impact sound insulation are provided in Tab. 3, together with the limiting frequency (f_1) where contribution of the airborne sound from source room starts to dominate and impact sound insulation cannot be measured correctly.

Prefixes *s* and *l* added to floor numberings indicate small and large samples.

Despite the fact that impact sound insulation cannot be measured correctly in the entire frequency range, single-number weighted normalized impact sound pressure level ($L_{n,w}$) can be determined as the unfavorable deviations from the ISO 717-2:2000 [5] reference curve occur below f_1.

Limit of frequencies where unfavorable deviations occur can be denoted as f_2. Therefore, as long as $f_1 > f_2$, $L_{n,w}$ can be correctly evaluated.

Table 3. Test results – Floors F6 and F6B.

Floor No.	$L_{n,w}$ (dB)	R_w (dB)	f_1 (Hz)	f_2 (Hz)
F6s	63	39	1600	315
F6l	56	51	-	-
F6Bs	56	39	500	250
F6Bl	46	58	1600	315

This analogy has been used to list all test results in the following chapter and indicate whether the evaluation of $L_{n,w}$ was accurate.

3.3 Test results

Complete overview of test results for all ten floors, in both sizes (together with the basic CLT), is presented in Tab. 4.

It should be noted that R_w value for all the small scale tests represents the airborne sound insulation of basic CLT (R_w 39 dB).

Table 4. Test results.

Floor No.	$L_{n,w}$ (dB)	R_w (dB)	f_1 (Hz)	f_2 (Hz)
CLT	88	39	-	-
F1s	80	39	-	-
F1l	75	44	-	-
F1Bs	63	39	1600	315
F1Bl	61	54	-	-
F2s	72	39	-	-
F2l	67	47	-	-
F3s	71	39	-	-
F3l	66	48	-	-
F4s	70	39	-	-
F4l	64	49	-	-
F4Bs	61	39	800	250
F4Bl	54	57	-	-
F5s	58	39	800	250
F5l	54	52	-	-
F5Bs	53	39	400	250
F5Bl	42	58	1000	315
F6s	63	39	1600	315
F6l	56	51	-	-
F6Bs	56	39	500	250
F6Bl	46	58	1600	315

Fig. 6 illustrates a comparison of two impact sound insulation curves (floor F5), for a typical case where large scale test was not affected by the airborne component, while small scale test had a limitation already at 800 Hz. Black-filled markers are added to the frequencies where the result is dominated by the airborne sound and impact sound insulation cannot be measured correctly.

Regardless of the obvious limitations in accurately measuring the complete spectrum of impact sound for F5s, $L_{n,w}$ is determined only by the values up to 250 Hz; where airborne component was not an issue (shaded area in Fig. 6).

In other words, the unfavorable deviations from the ISO 717-2:2000 [5] reference value for floor F5s occur only between 100 and 250 Hz. Other values are not relevant for single-number evaluation.

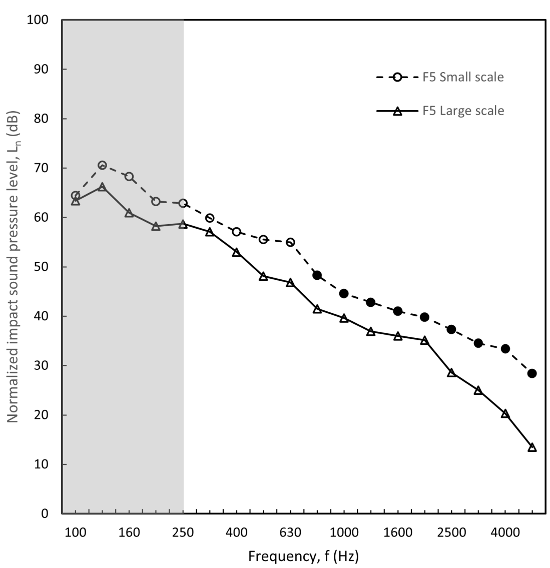

Figure 6. Impact sound insulation for floor F5 (small and large).

3.4 Analysis

Considering the results in Tab. 4, condition $f_1 > f_2$ was valid for all the floors where airborne sound component was influencing the results.

Therefore, despite the latter shortcoming the single-number $L_{n,w}$ rating could be accurately evaluated for all the tested floors.

Difference (in dB) between the $L_{n,w}$ for small scale and large scale tests is given in Tab. 5. Results for small scale tests are constantly higher than those for large scale. Hence, all the values in Tab. 5 are positive.

Table 5. Difference between $L_{n,w}$ for small scale and large scale tests.

Floor No.	$L_{n,w}$ small – $L_{n,w}$ large (dB)
F1	5
F1B	2
F2	5
F3	5
F4	6
F4B	7
F5	4
F5B	11
F6	7
F6B	10

It is indicative that differences in $L_{n,w}$ between small scale and large scale tests ($\Delta L_{n,w}$) are higher for better performing floors (floors with lower $L_{n,w}$). This trend is indicated in Fig. 7.

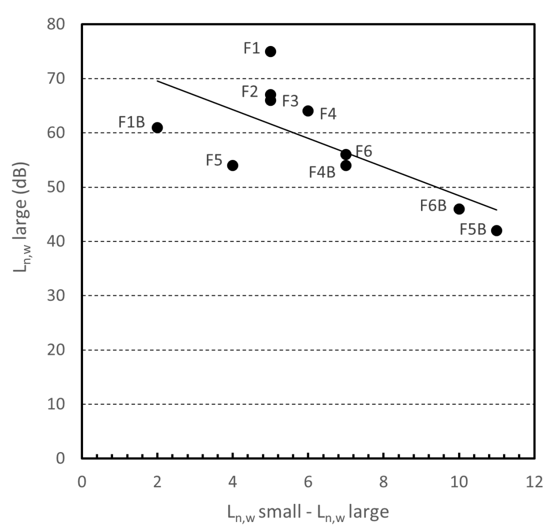

Figure 7. $\Delta L_{n,w}$ in relation to floor's $L_{n,w}$.

Finally, correlation between single-number $L_{n,w}$ ratings for small scale and large scale tests is illustrated in Fig. 8 (with an $R^2 = 0.95$).

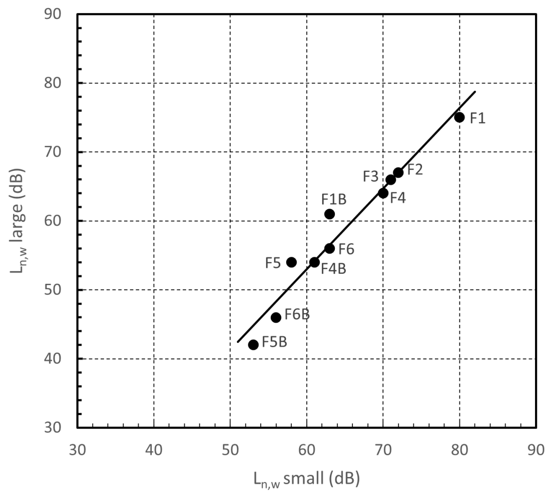

Figure 8. Correlation between $L_{n,w}$ for small scale and large scale tests.

4. CONCLUSIONS

This study provides a detailed correlation analysis of impact sound insulation tests conducted on a variety of small scale and large scale samples, built on the 140 mm CLT reference floor.

For all the small scale samples, sound pressure level generated by the tapping machine in the source room is attenuated only by the basic CLT floor (R_w 39 dB).

Such particularity of the sound propagating mechanism presents the limiting factor for accurate measurements of impact sound insulation in the standard frequency range (100-3150 Hz). Airborne component turned out to be dominant for eight out of twenty tested floors. Six of them being small scale and two large scale.

Notwithstanding the latter shortcoming, single-number weighted normalized impact sound pressure level ($L_{n,w}$) could be accurately determined as the latter value is driven primarily by floor's low frequency response.

For all eight floors influenced by the airborne component, the unfavorable deviations from the ISO 717-2:2000 [5] reference value occurred only between 100 and 315 Hz. Values on other frequencies were not relevant for single-number evaluation.

The latter frequency range was always well below the limiting frequency of the airborne component. So long as this condition is fulfilled, single-number rating can be accurately determined.

Consequently, single-number ratings could be accurately evaluated for all the tested floors and good correlation between $L_{n,w}$ of small scale and large scale tests established (see Fig. 8).

To conclude, this study demonstrated that it is possible to perform impact sound insulation tests on small samples built on CLT floor and accurately estimate the expected single-number $L_{n,w}$ for equivalent large scale samples. The established relationship presents useful tool for comparative analyses and design decision-making.

5. REFERENCES

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