Comparison between calculated and measured performances of impact sound insulation for Cross Laminated Timber building elements

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Summary

The use of simplified prediction models described in the EN 12354 series standard is largely diffused and suggested or adopted in many building codes. The aim of this work is to evaluate the reliability of calculation methods of impact sound insulation by comparison with in situ measurements. A case study about buildings made with Cross Laminated Timber (CLT) elements is presented.

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1. Introduction

A wider and wider spread of timber structures entail a stronger and stronger use of of these building elements in Mediterranean weather environments. CLT technology is nowadays taken in consideration with special attention on account of the various benefits that it can allow in terms of shortened time of laying and attainable performance. The aim of this work consists of evaluating passive acoustic requirements with specific attention to impact sound insulation.

The aspects of impact noise transmission and its theoretical foundations is considered in detail for instance in [1]; as the floors in hollow brick and concrete are concerned experimental analyses were carried out and calculation models were developed with particular focus to the Italian building types [2,3,4,5].

The analysis was arranged in several steps, starting from the prediction of the performance given as opposed to structure-borne noise [1] for CLT floors, evaluated according to EN 12354 [9] standards; the second step concerned the performance, as measured in situ following ISO 140 [6,12] standards, the last phase has been devoted to the comparison among the values drawn from the prediction by calculations and those obtained from in situ measurements.

Throughout the development of the present research several constructions, made with CLT and located in the Mediterranean area, have been analyzed; it has been possible to carry out in situ measurements for those elements during their construction, concerning just the structural floor and then on finished floors at completion of construction works.

2. Architectural elements and methodological approach

In the ongoing development of the present work in situ measurements have been carrying out on finished floor elements with "single firing" ceramic cladding, laid on a filling layer of sand and cement, in turn set on an insulating layer of mineral origin directly over the structural CLT element upon the placement of felt pads. In Figure 1 a drawing of the construction detail regarding the joint-node between vertical and horizontal elements is shown.

Figure 1. Joint-node between vertical and horizontal elements.

In Figure 2 the construction technical detail drawing of the analysed floors is shown.

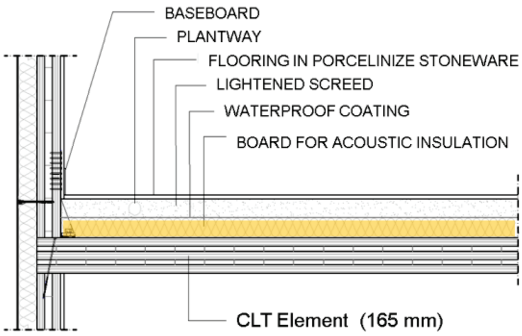

Figure 2. Stratigraphy of the halfway floor

The standard prediction calculation [9] includes two calculation models, a detailed and a simplified one. In both cases the needed input data can be drawn from laboratory tests, obtained through theoretical calculations, estimated with empirical correlations or by means of in situ measurements. In assessing the applicability of the prediction model to the floor elements made in CLT, the values used as input data have been estimated following the in situ measurements for the two analysed cases, since laboratory data already certified for the kind of constructive elements in question were not yet available.

3. In situ performance measurements

The normalized (with respect to sound absorption) sound pressure level of impact noise L'_n has been measured in situ for the two spaces in part overlapping (the underlying space proved to have always a wider outline fully covering the source space), The spectra of such measurements are shown in Figure 3.

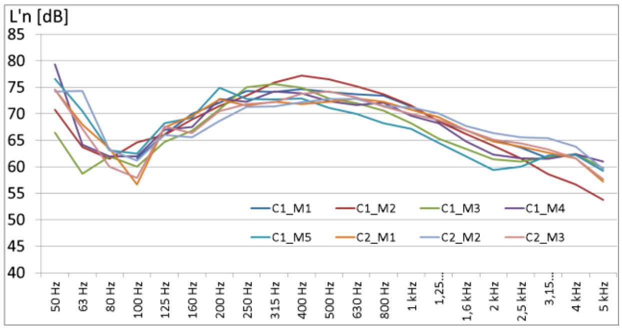

Figure 3. Overall impact noise measurements carried out in the two construction sites C1 and C2 (different building types, CLT systems) – at finished works.

From in situ measurements, carried out during the construction phase, the curve accounting for the variation versus frequency of the bare structural floor L'_n (C2_STR shown in Figure 4) has been deduced as well as the sound pressure assessment value for the equivalent normalized impact pressure sound level $L'_{n,w,eq}$. In default of input data for the bare structural floor the following conditions have been set: $L_n \cong L'_n$ and $L_{n,w,eq} \cong L'_{n,w,eq}$.

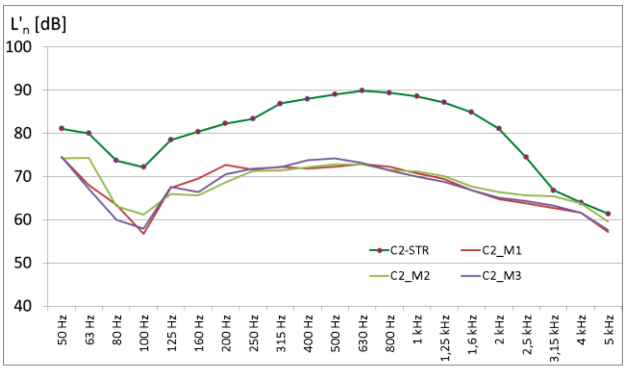

Figure 4. Comparison among measurements in the building site "2" (C2) - Bare floor (STR) - Finished floor (M)

The values of the experimental curve, for the various band frequencies, obtained from the in situ measurements for the bare structural floor (see green curve C2_STR in Figure 4) are shown in detail in Table I.

The sound pressure assessment value from the normalized equivalent impact pressure level, calculated according to ISO 717-2 standard [7], was equal to 88 dB. Such a value shows a gap $\Delta L = 10$ dB with respect to the reference floor which is considered at point 5.2 of ISO 717-2 standard [7].

Table I. Pressure levels of impact noise as measured in situ for the bare structural floor at different band frequencies.

50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
81,1	80	73,7	72,2	78,5	80,4	82,3
250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz
83,4	86,9	88	89	89,9	89,4	88,6
1,25 kHz	1,6 kHz	2 kHz	2,5 kHz	3,15 kHz	4 kHz	5 kHz
87,2	84,9	81,1	74,5	66,8	64	61,4

4. Prediction of performance and calculations

Some difficulties were encountered during the implementation of the calculation procedure. Namely the method adopted in the standard [9] has been recast in compliance with proven experimental data, on building types peculiar to the National and European stock. The floor and vertical partitions, made in CLT, are not observed among the well known construction types for which experimental test data can be found in the data base of the standard [9]; thereby the laboratory data needed to apply the prediction model are lacking. The numerical values of some parameters are not available, namely the internal damping "η" and the speed of longitudinal waves "C_L" for the CLT floors. The prediction by calculations has been implemented by applying the detailed and the simplified models as provided for in [9] by making use of data drawn by in situ measurements, just as permitted by the standard.

4.1 Equations

Hereinafter the main equations used in the two models for overlapping rooms are listed and the results obtained after them are shown.

4.2 Detailed model

$$L'_n = 10\log\left(10^{\frac{L_{n,d}}{10}} + \sum_{j=1}^{n} 10^{\frac{L_{n,ij}}{10}}\right) \quad (1)$$

where:
$L_{n,d}$ is the sound pressure level from walking, normalized for direct transmission, in decibel;
$L_{n,ij}$ is the sound pressure level from walking è il normalized for lateral transmission, in decibel;
n is the number of elements.

The application of the prediction model in its detailed version enabled to draw the frequency curves in Figure 5. Analyzing the obtained results one can notice that such curves follow, within some frequency ranges, the trends of the experimental curves in Figure 3, while some downward peaks around 125 Hz arise. As frequency increases, after 200 Hz, the trend becomes nearly linear and very similar to that of the reference curve given in ISO 717-2 standard [7].

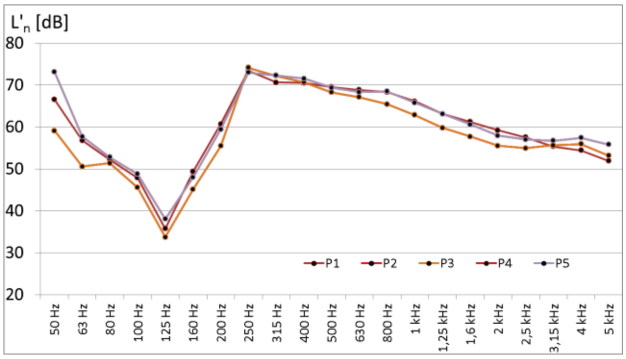

Figure 5. Predicted soun levels from walking obtained by the detailed model as reported in paragraph 4.2 [9].

Can be proved that, repeating the procedure and assigning at first the minimum and then the maximum values to the speed of the longitudinal waves "C_L in the range 2500÷3800 m/s and to the internal damping factor "η" in the range 0,008÷0,04, the L'_n curves are modified. As higher are the parameter values in input as more sharpened is the downward peak and shifted towards frequencies below 100 Hz. On the contrary the trend is rather similar to the experimental curve as higher band frequencies are concerned. As first working assumption, since the available data are not many, the detected downward peak could be due to a resonance effect.

Figure 6. Minimum and maximum variations of the predicted results obtained with min and max values of C_L and η: C_L=2500 [m/s] to C_L=3800 [m/s], η=0.008 [-] to η=0.04 [-]

4.3 Simplified model

For simplified calculation, the reference formula is:

$$L'_{n,w} = L_{n,w,eq} + \Delta L_w + K \qquad (2)$$

where:

$L_{n,w,eq}$ is the floor assessment index for an equivalent normalized sound level from walking on the slab (impact).

ΔL_w is the assessment index for the impact sound pressure level reduction due to floor surface cladding calculated according to point 5 of standard ISO 717-2 standard [7];

K is the correction for the transmission of impact noise through homogeneous side walls, in decibel (set equal to 1).

The results listed in Table II have been obtained taking into account the above research steps, i.e. applying the simplified model with input data for $L_{n,w,eq}$ the measurements discussed in the previous paragraph 3, obtaining the value of K from the procedure at point 4.3 of EN 12354-2 standard [9] and assessing the improvement ΔL_w on the basis of the experimental curves shown in Figure 4.

Table II. Assessment indices predicted by calculations

C1_P1	C1_P2	C1_P3	C1_P4	C1_P5
70	67	66	68	68

5. Comparison between predictions and in situ measurements

The various curves of the values measured in situ and predicted by calculation versus frequency are shown in the following.

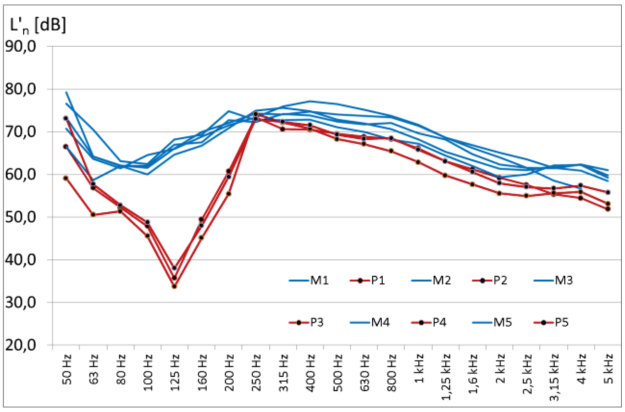

Figure 7. Comparison between measurements (M) and prediction calculations (P) for the construction site "1"

Comparing the predicted curves that are shown in Figure 7 and are pertaining to construction site 1, and the green curves shown in Figure 8 and pertaining construction site 2, can be seen that experimental curves display around the 100 Hz frequency a downward peak which is similar, although less distinct, to that found along experimental curves.

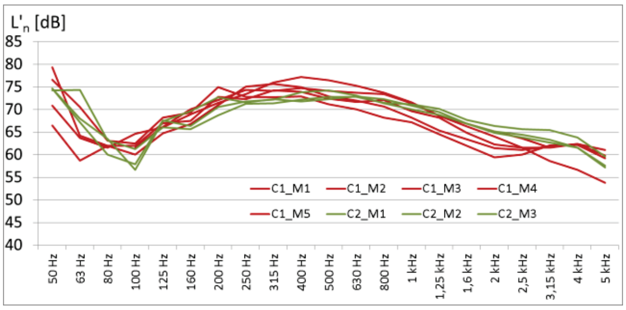

Figure 8. Comparison between the measurements carried out in the two construction sites C1 and C2 (different building types CLT systems) – at finished works.

If the experimental curves measured in the two different construction sites are superimposed each other a similar trend is observed. Such a trend can be assumed as typical of structures built in CLT.

Figure 9 shows the results of the calculation carried out by the simplified method in [9]. After the comparison among the predicted assessment indices deduced by the indices drawn by experimental tests in situ, it is noted that the predicted indices overestimate, in a range from 4 to 6 dB, the in situ performance of CLT floors.

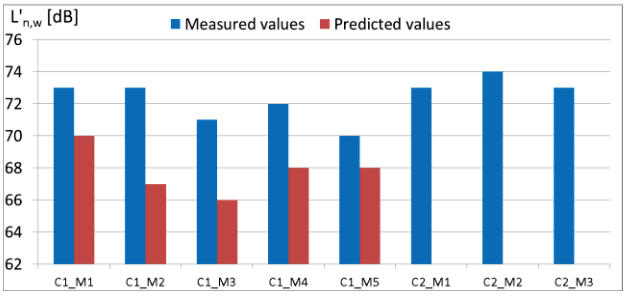

Figure 9. Trends of predicted assessment indices obtained from in situ measurements

6. Conclusions

The present work has aimed at evaluating the applicability of the calculation model for acoustic predictions, described in EN 12354 series [8,9], to innovative technologies for the building Italian stock, as those implemented with CLT.

The acoustic performance of building CLT elements to structure borne transmission has been analyzed. Several in situ and laboratory measurements have been carried out in order to assess CLT performance as thermal insulation and seismic resistance, while most of the input data needed to evaluate the acoustic performance are lacking.

From the results obtained by applying the prediction model [9], taking into account all the considerations and assumptions above discussed, and comparing them with the experimental data got through in situ measurements, it's possible to see that the standardized simplified prediction model, if implemented without any correction, overestimates the performance of the CLT floor elements.

The differences between detailed and simplified calculations, attested in the standard itself [9], are probably due to input data. Many data refer to floor types that cannot be totally assimilated to those which are applied in this study. Indeed, any specific references to CLT elements are completely missing.

The present work proposes to be an opportunity to study in a theoretical and experimental way this typology of building structures that are increasingly spreading by now also in the Mediterranean area; the knowledge about them is still limited in order to provide to designers the data and procedures for acoustic requirements.

References

[1] Cremer L., Heckl M., Petterson B.A.T., Structure-Borne Sound: Structural Vibrations and Sound Radiation at Audio Frequencies, 3th Ed., Springer Verlag, 2005

[2] Di Bella A., Schiavi A., Semprini G., Astolfi A., Proposta di definizione di una curva di riferimento per solai in laterizio e cemento, Rivista italiana di acustica, 35 (2011), pp. 47-51

[3] Semprini G., Di Bella A., Schiavi A., Astolfi A., Barbaresi L., Luison L., Pontarollo C. M., Tarizzo P., Acoustical behaviour of bare floor in hollow brick and concrete (italian building technology), in Proceedings of "Noise and sustainability" conference , Lisbon Portugal, 15-16 June 2010

[4] Schiavi A., Di Bella A., Semprini G., Astolfi A., Tarizzo P., Luison L., Barbaresi L., Pontarollo C. M., Proposal for a reference floor for hollow brick and concrete slabs based on Italian experiences, in Atti della conferenza ICA "Noise and sustainability", Sydney Australia, 23-27 August 2010

[5] Di Bella A., Schiavi A., Semprini G., Astolfi A., An experimental approach to the evaluation of acoustic behavior of beam and clay block floors, in Proceedings of Forum Acusticum, Aalborg Denmark, 26 June – 1 July 2011

[6] ISO 140-7, Acoustics - Measurements of sound insulation in buildings and building elements – Part 7: Field measurement of impact sound insulations of floors

[7] ISO 717-2, Acoustics - Rating of sound insulation in buildings and of building elements - Part 2: Impact sound insulation

[8] EN 12354-1, Building acoustics - Estimation of acoustic performance of buildings from the performance of elements- Airbone sound insulation against outdoor sound.

[9] EN 12354-2, Building acoustics. Estimation of acoustic performance of building from the performance of elements, Impact sound insulation between rooms

[10] EN 29052-1, Acoustics – Determination of Dynamic Stiffness. Part 1: Materials used in floating floors in dwellings

[11] ISO 16283-1, Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation

[12] ISO 140-14, Acoustics - Measurement of sound insulation in buildings and of building elements Guidelines for special situations in the field