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Analysis of acoustical behavior of bare cross laminated timber floors for the evaluation of the improvement of impact sound insulation

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Abstract

The estimation of impact sound insulation of horizontal partitions, evaluated from the performance of basic components using EN 12354-2 Standard, do not actually provides satisfactory results when applied to the floors realized with cross laminated timber (CLT) elements. Among the possible reasons of this limited correspondence between predicted and measured impact noise values, one of the most interesting is the difficult to correlate the reduction of the impact sound pressure level of the floor covering, measured in laboratory on a concrete slab, with the actual behavior on a bare CLT floor. In this paper the results of a laboratory evaluations independently managed by different researchers on similar CLT structures is reported. The purpose of this study is to identify an empirical spectrum of the normalized impact sound pressure level of a reference floor realized based on CLT technology, in order to provide an useful and simple tool for estimate the noise insulation performances for this type of building element.

Keywords: impact sound insulation, floor, cross laminated timber

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1 Introduction

In recent years the growing diffusion of Cross Laminated Timber structures (CLT) in building industry has been accompanied by extensive research aimed to investigate the peculiar characteristics of this construction system, mainly concerning lifecycle, structural design, resistance to seismic actions, fire protection and energy efficiency.

From noise protection point of view, several studies were developed for the evaluation of acoustic performances of CLT building elements [1, 2, 3]. Thereafter the focus shifted to the application of predictive methods [4, 5] to buildings made of this construction system [6, 7].

In order to define analytical relations for the prediction of acoustic performances of building elements, different ways may be followed: a numerical approach, based on the simplification of vibrational behaviour of elements assumed as homogeneous; an experimental approach, based on the reverse analysis of a large sets of data. In this work the results of the latter way applied to the impact sound insulation for CLT floors is shown.

2 Experimental approach for a predictive methods of impact sound insulation in CLT floors

One of the main problems of reverse analysis is the availability of a set of homogeneous data from trustworthy sources and obtained under controlled and reproducible conditions using standardized methods.

During independent research, carried out by the University of Padova and University of Bologna in recent years, 27 CLT floors were evaluated in laboratory, with and without toppings, both for impact noise and airborne sound reduction according to the relevant standards [8, 9, 10, 11, 12]. Measurements results were selected in order to compare between them only building elements based on the same type of CLT structure and with floating floor systems previously analyzed in laboratory on a concrete slab for the evaluation of the improvement of impact sound insulation, ΔL.

The obtained improvement on CLT floors was evaluated as difference from the bare structure, since there isn’t a reference floor for this type of building element [12], and compared to those on a reference concrete floor. The aim of this study is to define a reference impact noise level spectrum for CLT floors for laboratory evaluation of improvement of impact sound insulation. In this way, measurement results can be used for predictive purpose, as is the case of homogeneous structures [5], starting from dynamic stiffness data and mass per unit area of floating floors.

3 Acoustic evaluation

3.1 Bare CLT floors

In order to obtain a reference impact noise level spectrum for bare CLT floors, a series of tests was independently carried out in laboratory by the University of Padova (Lab A) and the University of Bologna (Lab B). The CLT structures were alike in all their essential physical and technical characteristics (5 ply, 145 mm thick), but they have been provided by different manufacturers. Results were compared with similar data reported in literature [13] about bare CLT floors (Lab C), but with different thickness and, in one case, ply number.

In Table 1 the key features of the analyzed floors are shown.

Table 1: Dimensional characteristics of the analyzed bare CLT floors

Lab. ID	Thickness [mm]	*n*-ply	Floor dimension [cm]	Mass per unit area [kg/m²]
A	140	5	320 x 460	70
B	140	5	277 x 440	70
C [13]	175	5	404 x 496	90
	245	7		130

It is clear that the shape of the measured spectrum of the normalized impact sound pressure level is substantially the same for all the measured bare CLT floors. It is therefore possible to derive a normalized curve, that can be adapted as a function of the mass per unit area, to provide a reference impact noise level spectrum for bare CLT floors.

3.2 Evaluation procedure

The methodology applied for the definition of a reference impact noise level spectrum for bare CLT floors is shown as follows.

A number k = 4 of normalized impact sound levels $L_{n,k}$ − obtained from four measured floors in three different laboratories compliant with the ISO 10140 standard series − is analyzed.

The spectrum normalized to 0 dB, X_0, is obtained for each floor (Figure 2), by means of a procedure borrowed from the one reported in ISO 717-1 [14] to find out the spectrum adaptation curves C and C_{tr}.

The following formula is used:

$$10lg\sum_{i=1}^{18}10^{(L_{n,i,k}+x_k)/10}=0\ [dB] \quad (1)$$

where:

i is the one-third octave band frequency between 100 Hz and 5000 Hz;

k is the tested floor;

x_k is frequency-constant number – different for each analyzed floor – that allows to normalize the impact sound level at 0 dB;

$L_{n,k,i}$ is the level of the *i*-th normalized impact sound pressure level of one-third octave band frequency between 100 Hz and 5000 Hz of the *k*-th tested floor.

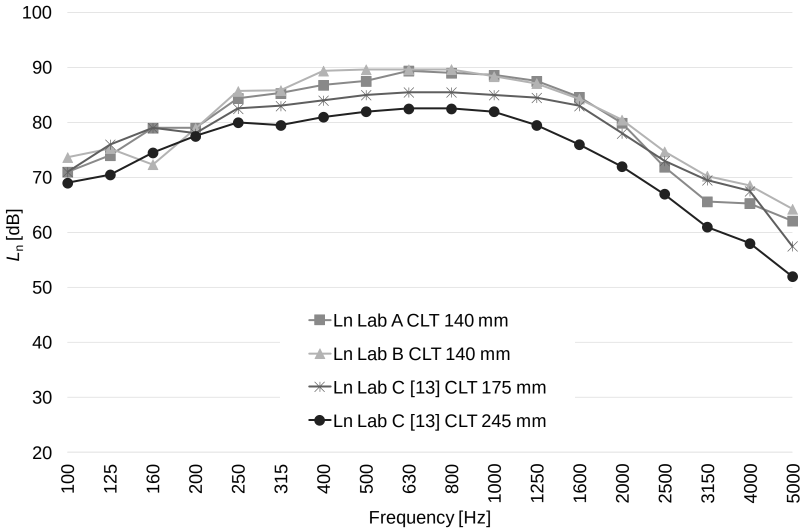

Figure 1: Measured levels of normalized impact sound pressure of bare CLT floors

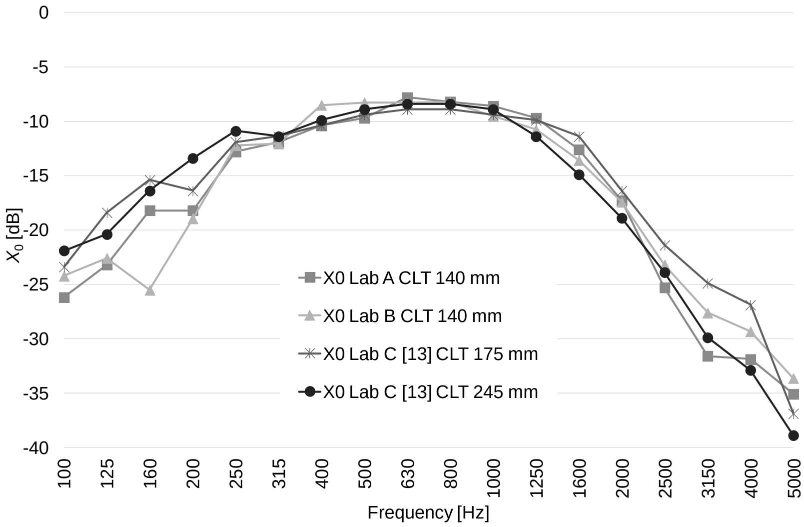

Figure 2: Impact sound pressure levels of the four tested bare CLT floors normalized at 0 dB

Once $X_{k,i,0} = L_{n,k,i}+x_k$ – the normalized value of the spectrum of the *i*-th one-third octave band from 100 to 5000 Hz on the *k*-th floor – is set, the arithmetic mean value, in 1/3 octave bands from 100 to 5000 Hz, $\overline{X_{\iota,0}}$, of the *k* spectra normalized relative to *k* analyzed floors, is calculated. Then, the normalized spectrum of the reference floor, $X_{i,\mathrm{r},0}$, composed of five segments with values in the third octave bands approximate to 0.5 dB, is calculated by interpolation of the optimal values $\overline{X_{\iota,0}}$ (Figure 3).

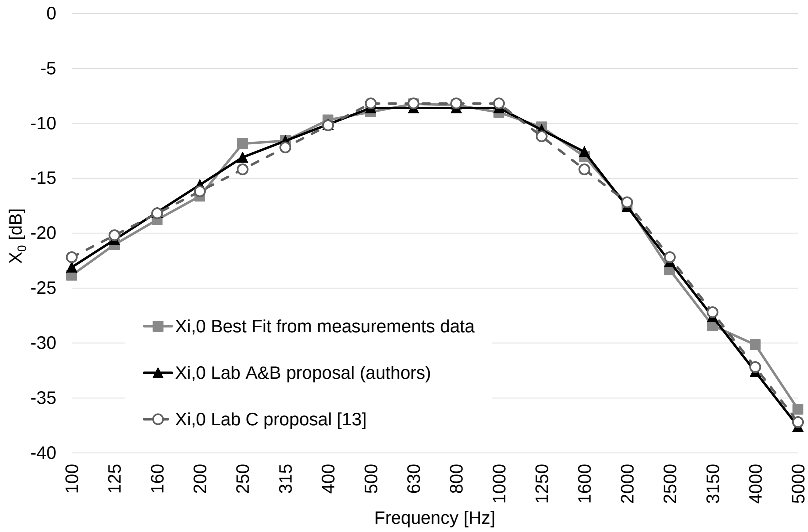

Figure 3: Comparison between impact sound pressure levels of bare CLT floors normalized at 0 dB: best fit from measurements data, Lab A&B proposal (authors) and Lab C proposal (literature)

For each *k* tested floor, the reference spectrum is obtained by shifting the values $X_{i,r,0}$ of the quantity:

$$L_{0,k} = w - y \cdot lg\left(\frac{m'_k}{z}\right)[dB] \tag{2}$$

where:

w, *y* [dB] and *z* [kg/ m²] are constants to be obtained, equal for all the *k* floors;

m'_k is the mass per unit area of each *k* floor [kg/m²].

The normalized spectrum of the reference floor $X_{i,r,0}$ is translated according to mass per unit area of floor [kg/m²]:

$$L_{n,t,r,0,k} = X_{i,r,0} + L_{0,k}\ [dB] \tag{3}$$

w, *y* and *z* are found in order to have the minimum value of the sum of the absolute differences between the measured values and the values obtained with the reference curve, for all analyzed floors:

$$s = min \sum_{k} \sum_{i=1}^{18} \left| L_{n,t,r,0,i,k} - L_{n,i,k} \right| \ [dB] \tag{4}$$

The final reference spectrum of the bare CLT floor, $L_{n,t,r,0}$, is then calculated. In case of data measured from different thickness of the CLT floor, a different curve is obtained as a function of their mass per unit area (Figure 4). Therefore, the value of $L_{0,k}$ is as follows:

$$L_{0,k} = 97{,}1 - 22{,}4lg\frac{m'_k}{70} \ [dB] \tag{5}$$

Starting from the above considerations, it is possible to extrapolate the following empirical “mass-law” valid for CLT floors with thickness between 140 mm and 275 mm:

$$L_{n,w,eq} = 128 - 22\,\lg(m')\,[dB] \tag{6}$$

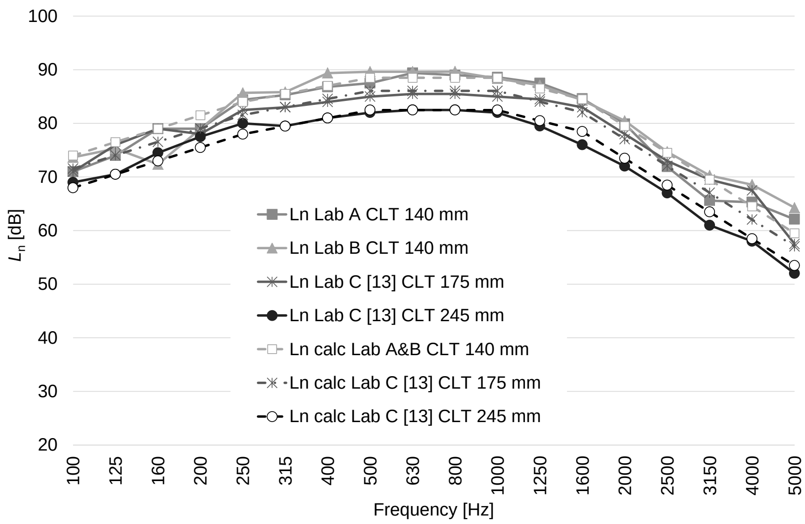

Figure 4: Comparison between the calculated reference floors (L_n calc) and laboratory measurements (L_n Lab) for the bare CLT floors evaluated in Lab A, B and C

Table 2: Comparison between the weighted normalized impact sound pressure level of the calculated reference floors ($L_{n,w,eq}$) and laboratory measurements ($L_{n,w}$) for the bare CLT floors evaluated in Lab A, B and C

Lab. ID	Mass per unit area of bare CLT floor [kg/m²]	$L_{n,w}$	$L_{n,w,eq}$
A	70	87	87
B	70	88	87
C	90 130	85 80	85 81

3.3 Adaptation of CLT reference curve for impact sound insulation improvement data obtained on a reference concrete floor

The reduction of impact sound pressure level obtainable with two different types of floating floors (layer 1 and layer 2) was measured both on a standard 14 cm thickness concrete slab and on an equally thick CLT floor (Figure 5). As expected, the measured values of impact sound insulation improvement of a floating floor on a standard concrete slab doesn't fit with the values calculated according to EN 12354-2 [5] when the same floating floor system is applied on a CLT floor (Figure 7).

Comparing these differences, by means of an interpolation with a second-degree polynomial function and normalizing to 0 dB the energy average of the interpolating curves, it is possible, by minimizing the sum of the absolute deviations from the floor level of attenuation of the measured values, to define a correction curve to be applied to the Δ*L* curve obtained on the standard concrete slab (Figure 6 and Equation 7). This relation is optimized for the application of floating floor systems with a lightweight screed, a resilient material with dynamic stiffness, *s'*, value between 13 MN/m³ and 36 MN/m³ and an upper thick screed made with sand and cement (density between 1800 kg/m³ and 2000 kg/m³).

To obtain the correction to be applied to the measured impact sound insulation improvement data obtained on a reference concrete slab, Δ*L*, the following relationship can be used:

$$\Delta_0 = \Delta\Delta_0 + 19{,}5 - 11\,\lg\left(\sqrt{\frac{s'}{13{,}5}}\right)[dB] \qquad (7)$$

where:

$\Delta\Delta_0$ is the normalized correction spectrum [dB];

s' is the dynamic stiffness of the used resilient layer [MN/m^3].

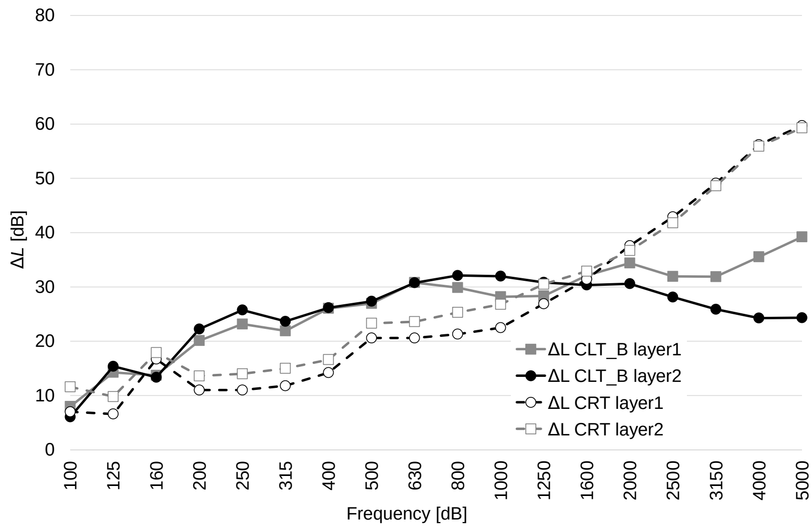

Figure 5: Differences between Δ*L* measured on CLT and concrete (CRT) floors for two different types of floating floor systems made by a lightweight screed layer, a resilient material and an upper heavy screed layer

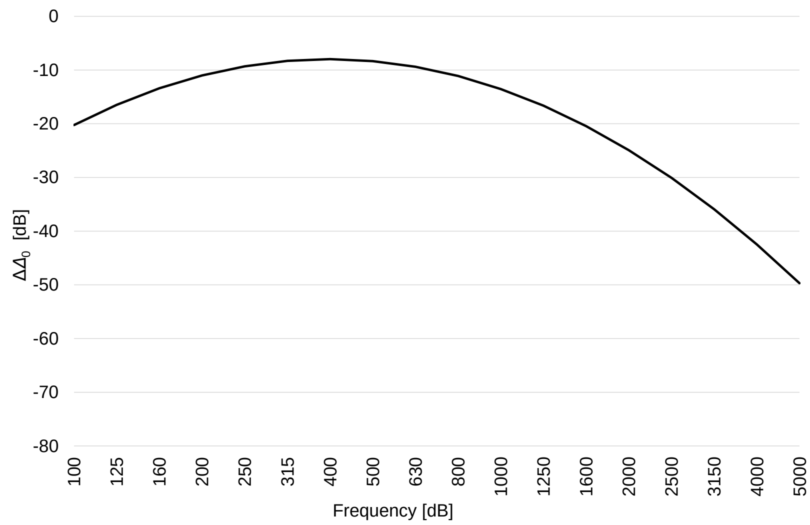

Figure 6: Normalized spectrum for the calculation of the contribution to be applied to a Δ*L* on a concrete floor to get an estimation of Δ*L* on a CLT floor (the value at the frequency of 4000 Hz and 5000 Hz is extrapolated from the measured value up to 3150 Hz)

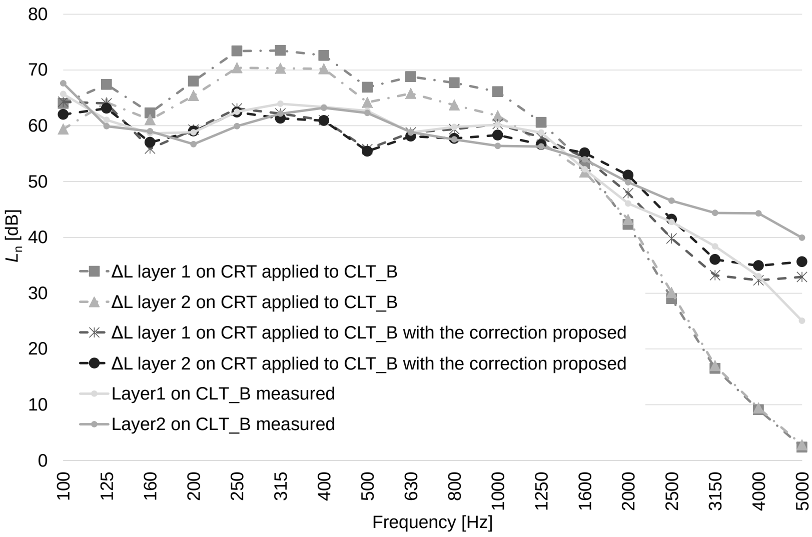

Figure 7: Comparison between the calculated impact sound pressure level values with the correction curve proposed in Figure 6 and the impact sound pressure level calculations complying with EN 12354-2

4 Summary and conclusions

In this paper a comparison between impact noise level of CLT bare floors carried out from independent research of different laboratories were made.

For the same structures, the improvement of impact sound insulation obtainable with different types of floating floors was measured both on CLT structures and on reference concrete slabs.

Appling a methodology of analysis borrowed from single number rating standard procedure [14], a reference curve for the rating of impact sound insulation of CLT floors was achieved. This reference curve is compatible with the procedure for evaluating the weighted reduction impact sound pressure level by floor coverings in lightweight floors described in ISO 717-2 [15] and referred to bare structures defined in ISO 10140-5 [12]. This curve is not currently present in any of the standards and its implementation it might be taken into account for future improvements of calculation methods.

An interesting aspect of the proposed CLT reference curve is that can be adjusted according to the mass per unit area of the bare structure and it is suitable for CLT elements from 140 mm to 245 mm thickness.

From the results of the comparison between the improvement of impact sound insulation both on CLT and concrete reference slab, it is possible to obtain a correlation that allow to apply Δ*L* data from an heavy bare homogenous floor to a CLT structure.

The proposed reference curve for bare CLT floors seems to work very well for the laboratory evaluation of several type of floating floor with dynamic stiffness of the elastic layer between 13 MN/m³ and 36 MN/m³ and with an upper screed layer with 115±5 kg/m² mass per unit area.

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