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A participatory approach to the evaluation of acoustic behavior of national building techniques

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Abstract
The prediction models proposed by the standards of the EN ISO 12354 series represent the reference point for the evaluation of the acoustic performance of buildings. However, there are some limits in the applicability of the methods proposed by these standards when the building elements have particularities that make them not comparable with reference structures for the calculation of the overall performance, in particular in the presence of additional layers. This work presents the results obtained through a participatory method of collecting and analysing experimental data recently introduced in the technical standards. They allowed the development of optimized reference curves for different types of building elements representative of particular national construction techniques.

Keywords: EN ISO 12354, acoustic performance of buildings, participatory approach, predictive calculations.

1 Introduction

For about 10 years to date, several independent research groups have been working in Italy in the building acoustics sector with the aim of improving the accuracy of the estimation of sound reduction index and impact sound insulation for some types of building elements, widely used nationally but not well represented by standardized prediction models.
The participatory approach involved the anonymous collection of data from different laboratories and research groups. These data were analysed with statistical regression methods and validated by comparing predictive calculations made with specific parametric formulas and field measurements.
The study of predictive models for vertical uncoated brick building elements was based on laboratory data on dozens of types of bare walls on which different types of cladding were subsequently applied.
As far as impact noise, the research was initially focused on brick-concrete floors. Typical Italian floors in dwellings are built with a structural hollow brick and concrete bare floor, composed by concrete joist and light hollow brick elements. They are installed in situ with a superimposed concrete layer in order to rigidly connect all elements. The floor is generally completed by a light concrete layer covering all technological distribution systems (pipes for water supply, corrugated conduit pipes for electrical wiring, radiant floor heating, etc.) and with an additional slab with or without resilient layer for reducing impact noise.
Starting from the assumption that the reduction of the impact sound pressure level by a resilient system is independent of the basic structure that supports it, a vast program of measurements on site on hollow bricks and concrete floors has been developed, in order to compare the results obtained by means of a specific test protocol on unfinished floors with those relating to the same structures equipped with floating flooring.

The results of these studies led to the proposal of a specific parametric model for assessing the level of impact noise in hollow bricks and concrete floors and currently the researchers involved in the project are working to improve the correlation of the model with the increase in data collected on unfinished floors.
Dry floors and walls built on structural elements in Cross Laminated Timber (CLT) have also been recently studied with the same methods.
This work is the summary of the papers in which the results of the participatory approach are illustrated.

2 Hollow bricks and concrete floors

The first example of collaboration for the evaluation of predictive formulas to characterize the Italian building systems began in 2010. The study of the acoustic properties of hollow brick and concrete floors were presented [1, 2].
In order to characterize the behavior of the bare floors in hollow brick and concrete, various measurements of sound pressure levels and vibration velocity levels were performed in situ on several different construction sites by research teams of the National Institute of Metrological Research in Turin, University of Padua, University of Bologna and Turin Polytechnic. Many vibration measurements are also carried out on floors and lateral partitions in order to characterize different energy contribution on sound radiated in the receiving room and to evaluated the influence of the flanking transmission. Acoustics radiation of complex building structures, such as brick and concrete slab is not correctly valuable using common prediction models such as SEA [3]. A bare floor slab in brick and concrete, can be considered as a rigid plate with ribs (ribbed plate) in concrete rigidly coupled to hollow bricks.
Based on early experimental data it was possible to provide an average empirical spectrum of the impact sound pressure level that can be considered such a “prototype” of a “reference standard floor” in hollow brick and concrete useful to estimate the acoustic behavior of a floating floor. This acoustical behavior of this kind of floors differs considerably from the trend of the spectrum of a monolithic concrete slab, and is also very different from the impact sound pressure level of the reference floor stated in ISO 717-2 Standard [4]. The trend shows that the sound pressure level has increased by about 15 dB per decade of frequency, confirming what already highlighted in 2007 by Brosio et al. [5] and, in 2008, by the University of Ferrara [6].

$$L'_n = 15 \log f + 34 \ (dB) \tag{1}$$

$$L'_n = 16{,}4 \log f + 26 \ (dB) \tag{2}$$

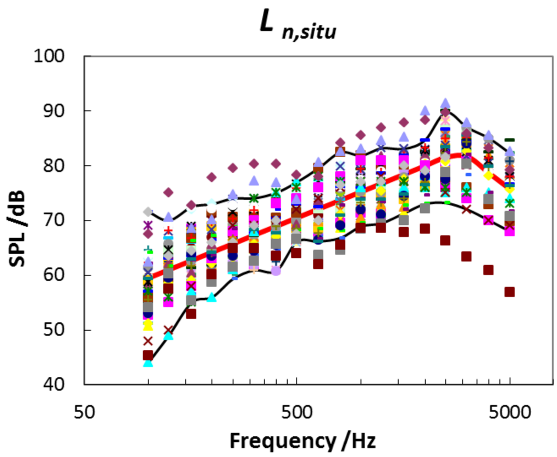

Figure 1 – Distribution of experimental data of impact sound pressure level measured for 40 bare floors in hollow-pots and concrete (in-situ).

In the graph of Figure 1 the theoretical curve of an average reference floor in hollow brick and concrete, here defined as $L'_{n,bf}$, is drawn. The proposed theoretical curve (red) is obtained on the basis of the best-fit of the experimental data.
Based on the considerations on author papers [1,2], the impact sound pressure level L'_n of a floating floor built in situ on a base floor in hollow brick and concrete, can be estimated with good reliability, according to the following relation:

$$L'_n \approx L'_{n,bf} - \Delta L + 15 log \frac{m'_{lab}}{m'_{situ}} + \Xi \ (dB) \tag{3}$$

where $L'_{n,bf}$ is the "reference standard hollow brick and concrete floor", values as a function of frequency [7], ΔL is the reduction of impact sound pressure level measured in the laboratory according to ISO 10140-3 Standard in dB; m'_{lab} is the mass per unit area of the floating slab in the laboratory, in kg/m^2; m'_{situ} is the mass per unit area of the floating slab in situ, in kg/m^2 and Ξ is a general corrective term, frequency depending, which takes into account the increase of the sound pressure level due to the lateral transmission.
Based on the equation it was suggested to include a new formula in the new version of ISO standard 12354-2 [8], for floor constructions made with concrete beams and clay bricks or blocks and an upper light screed layer (partially homogeneous structure), the equivalent weighted normalized impact sound pressure level $L_{n,eq,0,w}$ used for the calculation of simplified model can be calculated from the mass per unit area m' (in the range of 270 kg/m^2 to 360 kg/m^2) [9]:

$$L_{n,eq,0,w} = 160 - \left(35 log \frac{m'}{(1kg/m^2)}\right) \ (dB) \tag{4}$$

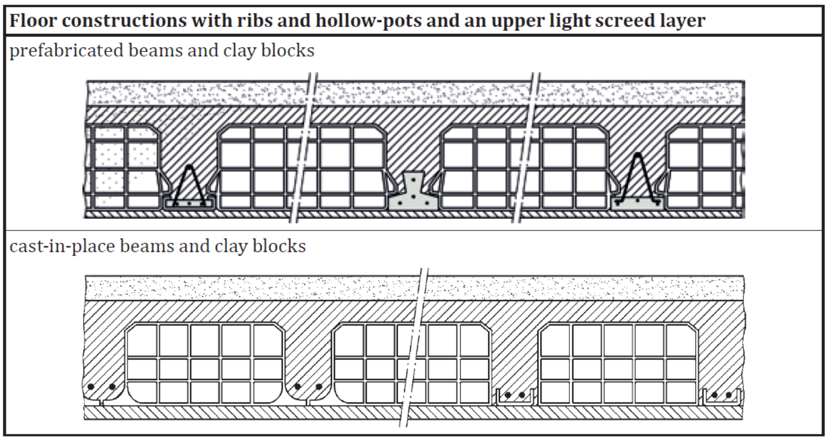

Figure 2 – Types of beam and clay block floors shown in ISO 12354-2:2017.

3 Cross Laminated Timber (CLT)

The same approach, shown for non-homogeneous floor, has been used to study the acoustic properties of structures in cross laminated timber (CLT).

3.1 Normalized impact sound pressure level

In order to define analytical relations for the prediction of acoustic performances of building elements; an experimental approach, based on the reverse analysis of a large sets of data was applied. In this work the results of the latter way applied to the impact sound insulation for CLT floors is shown.

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 [11-15]. 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 analysed in laboratory on a concrete slab for the evaluation of the improvement of impact sound insulation, ΔL.
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 [16] about bare CLT floors (Lab C), but with different thickness and, in one case, ply number.
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 [17] to find out the spectrum adaptation curves C and C_{tr}.
It was possible to extrapolate the following empirical “mass-law” valid for CLT floors with thickness between 140 mm and 275 mm.

$$L_{n,w,eq} = 128 - 22lg(m')\ (dB) \qquad (5)$$

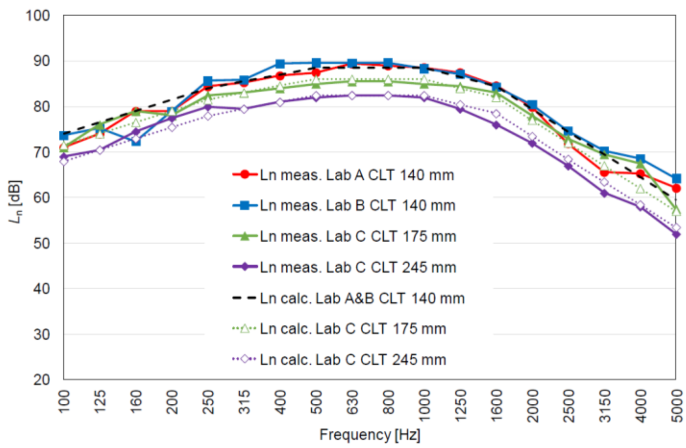

Figure 3 – Comparison between calculated reference floors (*Ln* calc) and laboratory measurements (*Ln* Lab) for bare CLT floors evaluated in Labs A, B and C.

3.2 Reduction of impact sound pressure level

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 [15], and compared to those on a reference concrete floor. The aim of this study was 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 [8], starting from dynamic stiffness data and mass per unit area of floating floors.
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. 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 ISO 12354-2 [8] when the same floating floor system is applied on a CLT floor [10]. 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 ΔL curve obtained on the standard concrete slab (Figure 6 and Equation 5). 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, ΔL, the following relationship can be used

$$\Delta_0 = \Delta\Delta_0 + 19.5 - 11lg\left(\sqrt{\frac{s'}{13.5}}\right)\text{ (dB)} \quad (5)$$

where: $\Delta\Delta_0$ is the normalized correction spectrum [dB], s' is the dynamic stiffness of the used resilient layer [MN/m^3]

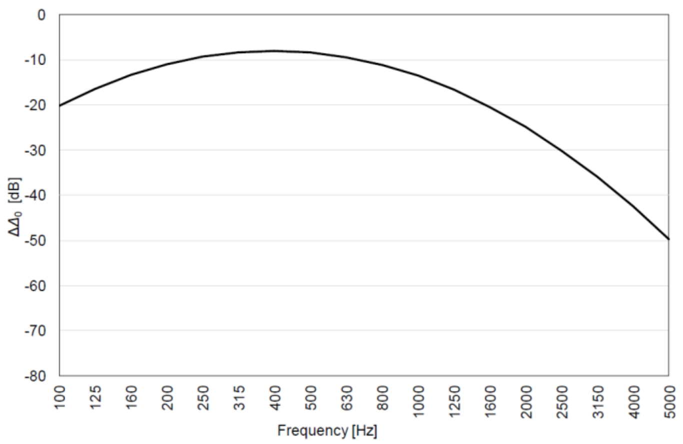

Figure 4 – Normalized correction spectrum $\Delta\Delta_0$ to calculate contribution Δ_0 to be applied to ΔL data measured on a concrete floor to estimate improved impact sound insulation on a CLT floor (values at 4000 Hz and 5000 Hz extrapolated from measured value up to 3150 Hz).

Appling a methodology of analysis borrowed from single number rating standard procedure [17], 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 [4] and referred to bare structures defined in ISO 10140-5 [15].

$$L_n(CLT) = L_{n,0}(CLT) - [\Delta L(CRT) + \Delta_0]\text{ (dB)} \quad (6)$$

3.3 Sound reduction index

In work [18], the results of the second method have been applied to estimate the sound reduction index of CLT walls, starting from previous experiences on impact sound insulation evaluation of CLT floors [10].
In order to obtain a reference sound reduction index for bare CLT walls, several tests according to ISO 10140 series Standard [11-15] and ISO 717-1 [17], were independently carried out in the laboratories of the University of Padova ("Lab A") and University of Auckland ("Lab B"). The CLT constructions of "Lab A" and "Lab B" were alike in their main physical and technical properties (3/5 ply fir wood, thickness from 85 mm to 135 mm), but come from different manufacturers (different sizes, bonding accuracy, perimeter sealing, etc.). Further data was also obtained from NRC Publications Archive ("Lab C") [19] on bare CLT walls, but with different thicknesses (from 78 mm to 245 mm).

The analysis of the measurements has shown that the shape of the sound reduction index spectra in the mass law region, is substantially the same for all the bare CLT walls. Therefore, normalized curve adapted as a function of the mass per unit area has been derived to provide a reference spectrum for such walls.
The method applied to define a reference sound reduction index for bare CLT walls is similar to the approach described in previous works [10], and is based on the comparison of experimental data of structures similar by composition and constraint characteristics but different by surface mass
From the above considerations, the following empirical formula for single-number airborne sound insulation, based on the "mass-law" and valid for bare CLT walls of 78-245 mm thickness, can be deduced:

$$R_{w,eq} = 20.3\,\lg(m')\ (\mathrm{dB}) \tag{7}$$

4 Conclusions

The shows the participatory approach involved the anonymous collection of data from different laboratories and research groups.
It is important to emphasize that the experimental data have been measured independently by different research teams with different measurement systems and instrumentations. And, for example, for the non-homogeneous floor [1,2], the dispersion of the data has a standard deviation of 3.8 dB on average, it can therefore be considered very satisfactory, considering the difficult conditions of in situ measurement.
The participatory approach involved the anonymous collection of data from different laboratories and research Some results of this studies are published in International standard [8,9], while others will be included in the Italian national standard being published "UNI 11175, part 1: *Acoustics in building. Guidelines for the prediction of the acoustic performance of buildings. Application of technical standards to the national construction typology*".
The next step will be to formalize the reference curve for CLT structures to evaluate weighted normalized impact sound pressure level.

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