Use of the ISO 12354 Standard for the Prediction of the Sound Insulation of Timber Buildings: Application to Three Case Studies

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Abstract

The ISO 12354 standards provide a method for modelling the sound insulation of building elements using the performance of the single elements as a starting point. The revision of the ISO 12354 Part 1 and 2 standard makes it possible to model timber buildings. In particular, the standards provide prediction formulas for estimating the vibration reduction index (K_{ij}) of heavy and light weight junctions and CLT junctions. The aim of this research is to study the dependence of the ISO 12354 output values on the input data fed to the model, in the specific case of timber buildings. The prediction tools were applied to three different timber buildings on which sound insulation and flanking transmission measurements were carried out on site. Different input data were used: laboratory and in situ measured values of airborne sound insulation, impact sound insulation and flanking transmission. The calculated values are compared with in situ acoustic tests of airborne sound insulation and impact sound insulation. The results show that the blind application of the ISO 12354 model can provide results that differ significantly from the measured on-site values; considerations are drawn concerning the availability of input data and the resonant transmission.

1. Introduction

The series of ISO 12354 standards provides a SEA-based method for modelling the sound insulation of building elements, starting from the characterization of the performance of the single elements. In particular, Parts 1 and 2 provide estimates of the apparent sound reduction index and the apparent impact sound insulation through the evaluation of the flanking transmission paths.

Timber buildings represent a relevant share in the market of new constructions (Caniato and Gasparella, 2019). Be it mass timber construction or timber frames, the prediction tools that have been successfully applied to traditional heavy construction have been found to be inadequate when applied blindly to timber structures. This is due to several factors; first, all the data relative to the "deltas" that have been previously measured on heavy elements cannot be directly used for timber elements, which are characterised by different mass and stiffness. The modelling of the flanking transmission also deserves attention, particularly for mixed structures.

This work therefore discusses the application of the ISO 12354 model to timber buildings, with the aim of highlighting which precautions should be used when approaching the calculation of these structures. Acoustic tests of airborne sound insulation and impact sound insulation were conducted on site in three case studies. The descriptions of the construction details were used to generate the input data of the model. Whenever possible, the input data were retrieved from laboratory measurements taken by the University of Bologna and the University of Padova, concerning the sound insulation and flanking transmission measurements.

The results of the application of the model to the case studies are presented and discussed, along with some general remarks.

Part of
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2. Research Method

This work has focused on implementation and verification of the new CEN calculation model for the estimation of acoustic performance of buildings, according to the recent revision of the series of ISO 12354 standards. The main innovations introduced concern: (i) the new classification of structures, currently divided into “type A” and “type B” structures, (ii) the introduction of new methods to calculate and consider only the resonant transmission for the lateral elements and (iii) the new methods for calculating the lateral transmission for Cross Laminated Timber (CLT) and timber frame structures. In general, an overall improvement was made to the calculation model, but the application of the model to three different case studies has highlighted some unresolved criticalities. The calculation model was implemented on software using the Visual Basic for Excel programming language and preliminarily calibrated on the examples given in the appendix to ISO 12354.

The case studies are three different wooden buildings, in which detailed measurements were carried out, in accordance with the ISO 16283 standards, during intermediate construction stages and after the completion of the works. In the three cases, the study was conducted on the sound insulation of the floor, which made it possible to simulate both the airborne sound insulation and the impact sound insulation. In particular, the three case studies are:

A. timber frame building in Rimini: CLT floor 180 mm and lightweight multi-layer walls with internal layer in gypsum board;
B. CLT building in Graz: CLT floor 160 mm and CLT walls 100 mm with multi-layer coverings;
C. CLT building in Bologna: CLT floor 180 mm and CLT walls 120 mm with multi-layer coverings.

One of the main difficulties encountered was the scarce availability of input data for airborne and impact sound insulation of the single partitions. Input data were partially retrieved from laboratory measurements carried out on floors (University of Bologna) and on walls (University of Padova) (Di Bella et al. 2016, 2018) as recommended by the legislation. When these data were not available, a commercial software was used to simulate the partition.

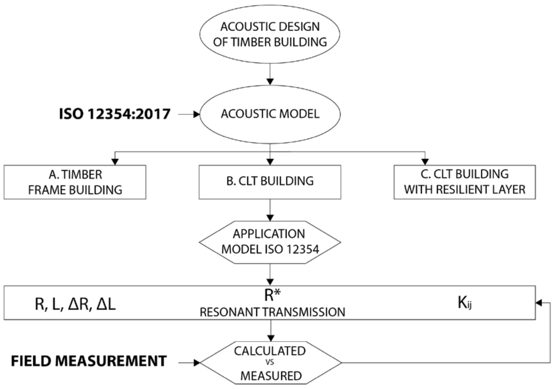

Fig. 1 – Flow chart of research method applied

3. The ISO 12354 Model

3.1 Apparent Sound Reduction Index R'

The apparent sound reduction index R' is determined through the logarithmic summation of all direct and flanking transmission terms through Equation 1.

$$R' = -10\lg\left(10^{-\frac{R_{D,d}}{10}} + \sum_{j=1}^{n} 10^{-\frac{R_{ij}}{10}}\right) \qquad (1)$$

The contribution of the direct transmission is given by the sum of the sound reduction index of the separating element $R_{s,situ}$ and of the contribution of additional layers $\Delta R_{D,situ}$ and $\Delta R_{d,situ}$ as in Equation 2.

$$R_{D,d} = R_{s,situ} + \Delta R_{D,situ} + \Delta R_{d,situ} \qquad (2)$$

For each transmission path, the respective sound reduction index can be calculated according to Equation 3:

$$R_{ij} = \frac{R_{i,situ}+R_{j,situ}}{2} + \Delta R_{i,situ} + \Delta R_{j,situ} + \overline{D_{v,ij,situ}} + \\ +10\,lg\,\frac{S_s}{\sqrt{S_i S_j}} \qquad (3)$$

where $R_{i(j),situ}$ is the sound reduction index of element i (j), $\Delta R_{i(j),situ}$ is the increase of sound reduction index of element i (j) due to additional linings, $\overline{D_{v,ij,situ}}$ is the average insulation of vibration in the junction between elements i and j, S_s is the surface of the separating element, S_i is the surface of element i in the source room, S_j is the surface of element j in the receiving room.

3.2 Normalized Impact Sound Insulation L'_n

Similarly, the prediction of the normalised impact sound insulation L_n' can be expressed as:

$$L'_n = 10\, lg\left(10^{\frac{L_{n,d}}{10}} + \sum_{j=1}^{n} 10^{\frac{L_{n,ij}}{10}}\right) \quad (4)$$

where the contribution of direct transmission $L_{n,d}$ is given by the summation of the normalised impact sound insulation of the separating element $L_{n,situ}$, of the attenuation due to the presence of a floating floor ΔL_{situ} and the attenuation due to the presence of additional linings on the side of the receiving room (counter ceiling) $\Delta L_{d,situ}$, as in Equation 5.

$$L_{n,d} = L_{n,situ} - \Delta L_{situ} - \Delta L_{d,situ} \quad (5)$$

For each flanking transmission path, the normalised impact sound insulation can be calculated using the formulation in Equation 6.

$$L_{n,ij} = L_{n,situ} - \Delta L_{situ} + \frac{R_{i,situ} - R_{j,situ}}{2} - \Delta R_{j,situ} - \\ - \overline{D_{v,ij,situ}} - 10\lg\sqrt{\frac{S_i}{S_j}} \quad (6)$$

3.3 Flanking Transmission

The flanking transmission was evaluated in three different ways: the K_{ij} provided by the ISO 12354 were used, considering the presence of the resilient interlayer, the K_{ij} values measured in situ and in a test facility. The values of K_{ij}, calculated according to the formulas contained in the annex F of the ISO 12354-1 standard, do not include the presence of different types of fastening systems or resilient layers (Morandi et al., 2018). In order to estimate the contribution of the resilient interlayer, the corrective term Δl - described for the rigid junctions as in annex E - was used (Rabold, 2017).

3.4 Structural reverberation time

For *in situ* correction the structural reverberation time was calculated with Equation 7:

$$T_s = \frac{2{,}2}{f\,\eta_{tot}} \quad (7)$$

where the total loss factor is:

$$\eta_{tot} = \eta_{int} + \frac{2\rho_0 c_0 \sigma}{2\pi f m'} + \frac{c_0}{\pi^2 S\sqrt{f f_c}} \sum_{k=1}^{4} l_k \alpha_k \quad (8)$$

The internal loss factor of the CLT elements is > 0.03 (Schoenwald et al., 2013) and the α_k depend on the structural elements connected at the perimeter.

4. Case Studies

In the following paragraphs the three case studies are shown. Airborne and impact sound insulation tests were conducted in accordance with ISO 16283-1 and ISO 16283-2, respectively. Moreover, the flanking transmission of the CLT junctions were measured in an area of the construction site that was still under construction (not for case C).
In the discussion of the results, these three measurements will be combined to optimise the modelling of the partition under study.

4.1 A. Timber Frame Building in Rimini

The first building, located in Rimini (Italy), is made with light-weight timber frame walls and CLT floors. The floating floor is made by a dry solution with gravel and concrete fiber board.

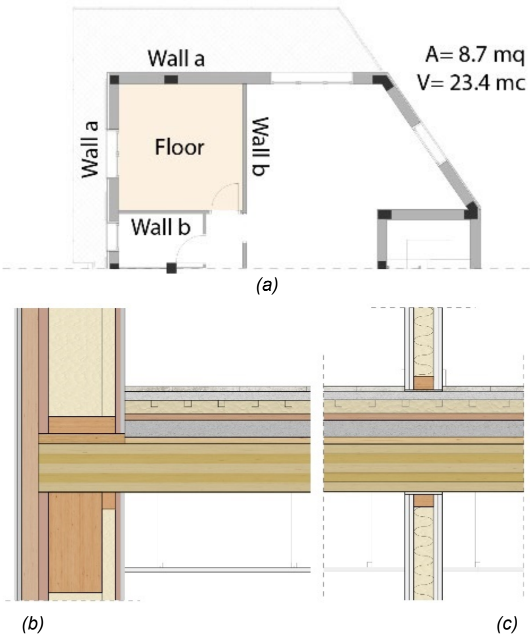

Fig. 2 – Distribution of the elements in the plan (a) and construction details: external wall type a – floor (b) and internal wall type b – floor (c)

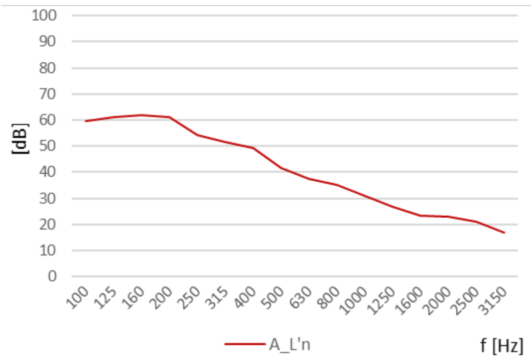

Fig. 3 – In situ impact sound measured in case A

4.2 B. CLT building in Bologna

The second building, located in Bologna (Italy), is a CLT structure. The floating floor is made by a wet solution with cement and a resilient interlayer. The interior lining is fiber gypsum board and mineral wool. The exterior lining is plaster and mineral wool.

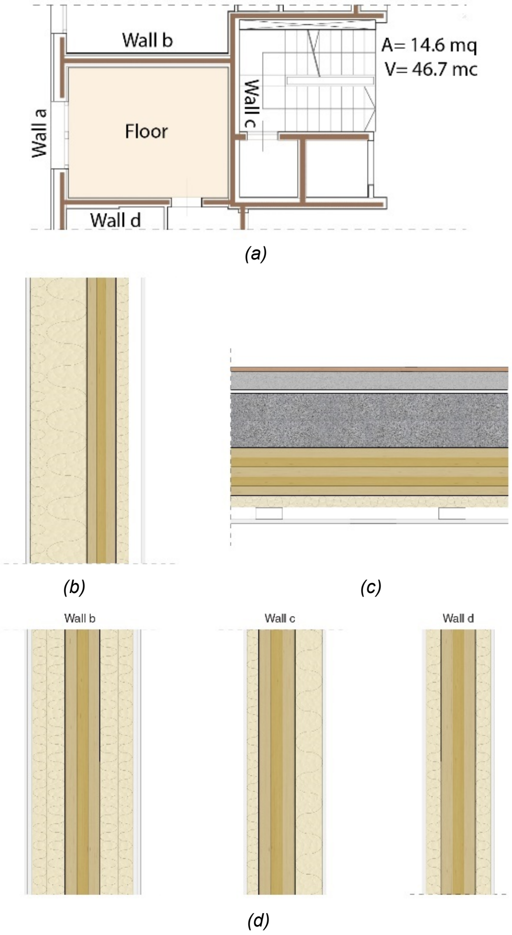

Fig. 4 – Distribution of the elements in the plan (a) and construction elements: external wall type a (b), separating floor (c) and internal wall (d)

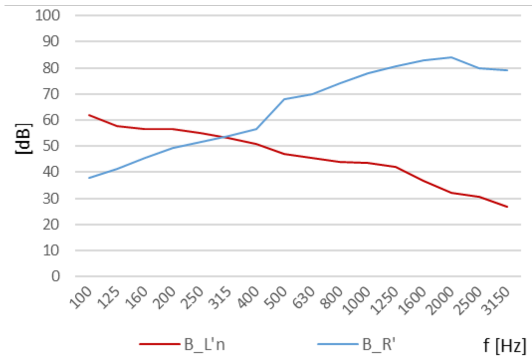

Fig. 5 – In situ sound reduction index and impact sound measured in case B

4.3 C. CLT building with resilient layer in Graz

The third building, located in Graz (Austria), is a CLT structure. The floating floor is made by a wet solution with cement and mineral wool. External walls are made with finishing, 140 mm mineral wool, CLT, 40 mm acoustic layer, 25 mm double fire-resistant gypsum board. The internal wall is a double wall with double fire-resistant gypsum board, CLT, 25 mm double fire-resistant gypsum board.

The resilient interlayer was placed between the floor and the upper wall.

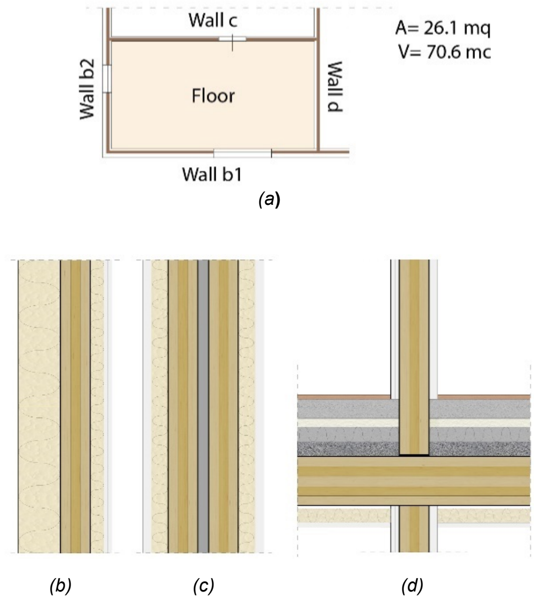

Fig. 6 – Distribution of the elements in the plan (a) and construction elements: external wall type b (b), internal wall type d (c) and detail internal wall type c - floor (d)

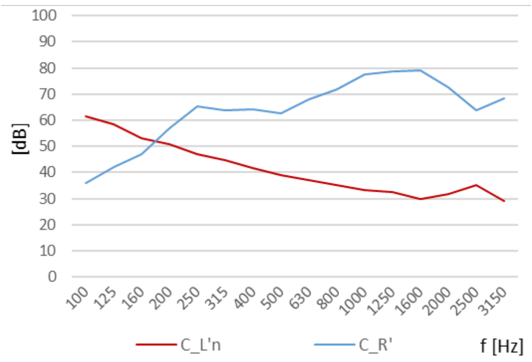

Fig. 7 – In situ sound reduction index and impact sound measured in case C

5. Application of the ISO Calculation Model

For each of the input floors described in Chapter 4, the apparent sound reduction index and impact sound modelled in accordance with the ISO 12354 standard are presented. All results are compared with in situ measurements.

5.1 Case A

In case A, 5 different calculation variables were evaluated:

- the data inputs are from laboratory measurements of similar solutions (label: ISO 12354);
- ΔL_n, ΔR are from measurements on site (label: ISO 12354_Var. 1);
- the application of transmission resonant R* for each flanking path transmission (label: ISO 12354_Var. 2);
- the K_{ij} values are calculated with empirical formulas for CLT junctions (Annex E) (label: ISO 12354_Var. 3);
- the K_{ij} values retrieved from measurements on site (label: ISO 12354_Var. 4).

In Fig.s 8 and 9, the importance of data input for L'_n and the effect of K_{ij} are shown.

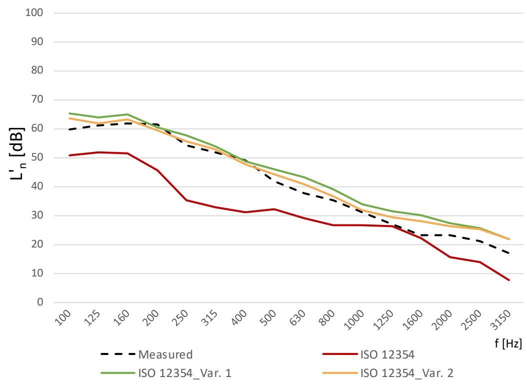

Fig. 8 – Comparison between impact sound measured and calculated values in case A: data input

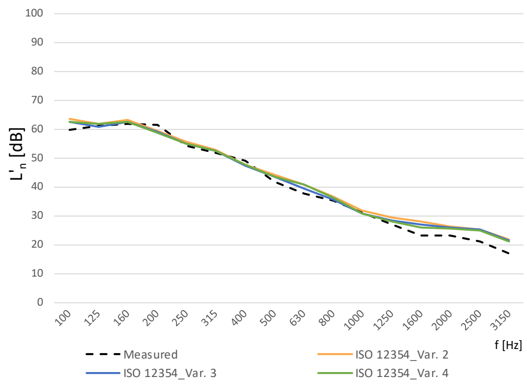

Fig. 9 – Comparison between impact sound measured and calculated values in case A: flanking transmission

5.2 Case B

In case B, 3 different calculation variables were evaluated:

- the data inputs are from simulations using commercial software (label: ISO 12354_Var.1);
- ΔL_n, ΔR are from laboratory measurements of similar solutions (label: ISO 12354_Var. 2);
- the K_{ij} values are measured in accordance with ISO 10848 (label: ISO 12354_Var. 3).

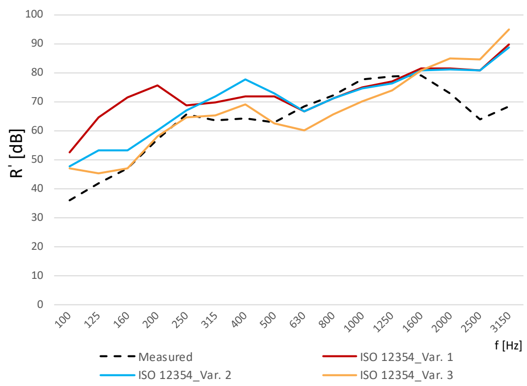

Fig. 10 – Comparison between sound insulation index measured and calculated values in case B

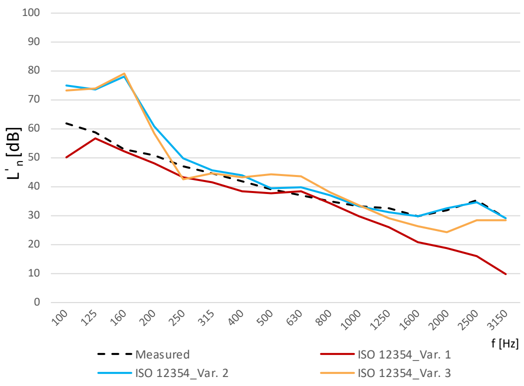

Fig. 11 – Comparison between impact sound measured and calculated values in case B

In ISO 12354_Var. 3 the measured values are used because the ISO Standard empirical formulas are not available.

5.3 Case C

In case C, 4 different calculation variables were evaluated:

- the K_{ij} values are calculated in accordance with ISO 12354, without resilient interlayer (label: ISO 12354);
- the K_{ij} values are calculated in accordance with ISO 12354, considering the presence of resilient interlayer (Annex E) (label: ISO 12354_Var.1);
- the K_{ij} values are measured in accordance with ISO 10848 (label: ISO 12354_Var.2);
- the K_{ij} values are calculated in accordance with ISO 12354, considering the T_s of internal lining of the elements (label: ISO 12354_Var.3);
- the K_{ij} values are correct in relation to the areas of the elements (label: ISO 12354_Var.).

In this case, the importance of flanking transmission data is evaluated. As in case B, there are no provisional formulas for the junction between the panels in CLT.

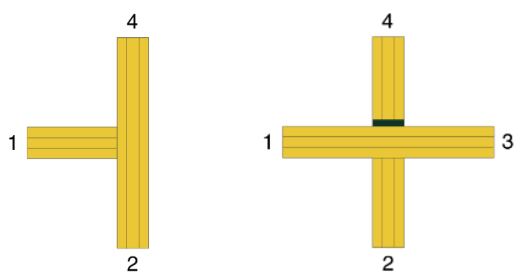

Fig. 12 – Arrangement of the panels: on the left "T" junction in case B, on the right "X" junction in case C. The black strip represents the resilient interlayer

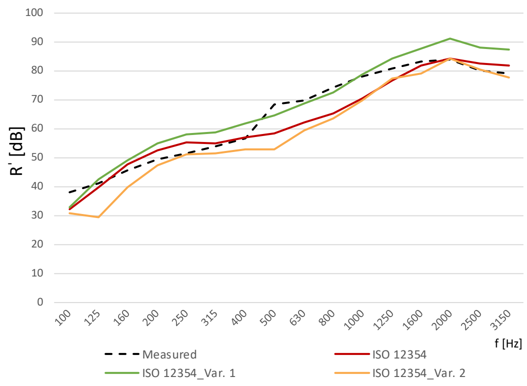

Fig. 13 – Comparison between sound insulation index measured and calculated values in case C: K_{ij} values are calculated and measured

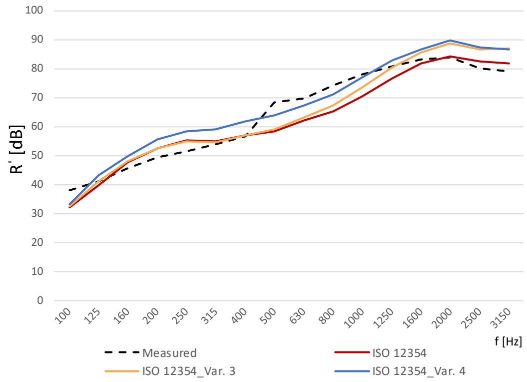

Fig. 14 – Comparison between sound insulation index measured and calculated values in case C: K_{ij} values are calculated and correct with T_s and areas of the elements

6. Results

The comparison between the three case studies showed with a good agreement that there are some precautions that should be considered when modelling timber buildings. The availability of data for the input of the model is extremely relevant. The same partitions modelled with commercial software and with experimental measurements provide different results, which strongly affect the final benchmarking. When possible, a direct reference to laboratory measurements should be made.

The K_{ij} values used as input also have a strong influence on the results. In particular, formulas provided in the ISO standard for CLT elements were shown to give very different results from the measured values, but when using the measured value in the ISO 12354 model, the simulations carried out with the ISO value fit better the experimental results.

The modelling of mixed junctions is critical because there is no reference on how to deal with the evaluation of the vibration reduction index (or normalized direction-averaged vibration level difference) and few experimental data are publicly available to the authors' knowledge.

The impact sound insulation is less affected by the flanking transmission paths compared to the airborne sound insulation; to evaluate the correctness of the modelling procedure, it is safer to rely on the airborne excitation.

The correction for resonant transmission should not be applied to CLT elements, while the modelling of the mixed junction needs this compensation to provide a good fitting with the experimental results. This outcome is consistent with recent literature on the mass timber elements.

7. Conclusion

The aim of this contribution is to use the detailed method provided by the series of ISO 12354 standards to model timber buildings in order to highlight the precautions that should be adopted and the need for future research. Three case studies, characterised by similar mass timber structures, which changed slightly from case to case, were analysed, and the effect of each modelling choice on the overall performance of the model was discussed. The availability of measured data is still the main point that needs to be addressed jointly by the scientific community, together with an insight on the modelling of the vibration reduction indices.

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