CRITICAL ISSUES DURING ISO 10848-1 MEASUREMENTS OF CLT JUNCTIONS WITH RESILIENT INTERLAYERS

Vincenzo Pettoni Possenti[1*], Charlotte Crispin[2], Luca Barbaresi[1], Arne Dijckmans[2]

[1]*Department of Industrial Engineering, University of Bologna, Italy*
[2]*Buildwise, Belgium*

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Abstract

ISO 10848-1 provides a well-established methodology for characterising the vibration reduction index K_{ij} of building junctions. However, its current version does not include specific guidance on configurations involving resilient interlayers, which are commonly used in Cross-Laminated Timber (CLT) constructions. This raises the question of how to reliably apply ISO 10848-1 when a resilient interlayer is present at a CLT junction. This article outlines practical and methodological considerations for this issue, addressing aspects not currently covered by the standard. Through a series of laboratory measurements on two different CLT mock-ups with resilient interlayers, the influence of several parameters was investigated by varying each parameter individually, enabling direct comparisons of the resulting changes in K_{ij}. Parasitic airborne noise, the effects of the fastening system (always present in CLT structures), and load effects - already examined in the literature - are briefly discussed. Additional effects specific to resilient interlayers are considered, including the influence of material creep, stiffness, thickness, contact surface area, and the interlayer's position within the junction. These factors can lead to substantial variations in the measured K_{ij} values, potentially resulting in inaccurate calculations and limiting the comparability between products from different manufacturers.

Keywords: *ISO 10848-1, resilient interlayer, vibration reduction index, flanking transmission, cross-laminated timber*

1. Introduction

Cross-laminated timber is a popular material due to its fast on-site assembly, sustainability, and light weight. However, it is a building material that is sensitive to flanking transmission due to several factors, including its high radiative efficiency over the usual frequency range and relatively low surface mass. It is a well-established practice to insert resilient interlayers into junctions to improve the insulation of flanking paths, as widely confirmed in the literature [1], [2], [3], [4].
CLT elements are classified as Type A in the standard EN ISO 12354-1 [5]. The vibration reduction index K_{ij} is used to describe the structure-borne sound insulation at the junction. ISO 10848-1 [6] provides a methodology for measuring this value. However, this standard does not yet include specific guidelines for measuring the K_{ij} of junctions with resilient interlayers. Articles on this topic have been published in the literature, seeking to standardise measurement with resilient interlayers. In particular, articles [7] and [8] discuss elements composed of cellular concrete, masonry, and gypsum blocks.
The interposition of a resilient material in the junction introduces various complexities to the measurement that should be taken into consideration. This article aims to raise awareness when measuring the vibration reduction index for CLT junctions with resilient interlayers, to facilitate interlaboratory comparison.

2. Method

To study the effects of resilient interlayers on the measurement, an experimental campaign was conducted on two CLT mock-ups: one at the University of Bologna in Italy (mock-up 1, Figure 1 left) and one at Buildwise in Belgium (mock-up 2, Figure 1 right). Mock-up 1 was a horizontal T-junction with the following dimensions: floor (panel i) 240x350x10cm, lower wall (panel ii) 240x300x10cm, upper wall (panel iv) 240x300x10cm. This mock-up incorporated safety devices that did not create direct paths between the panels or alter the transmission between the elements. Mock-up 2 was a horizontal L-junction with the following dimensions: floor (panel i) 225x495x14cm, and lower wall (panel ii) 240x394x12cm. Both mock-ups were made of 5-ply CLT. All measurements were

Corresponding author: vincenzo.pettoni2@unibo.it

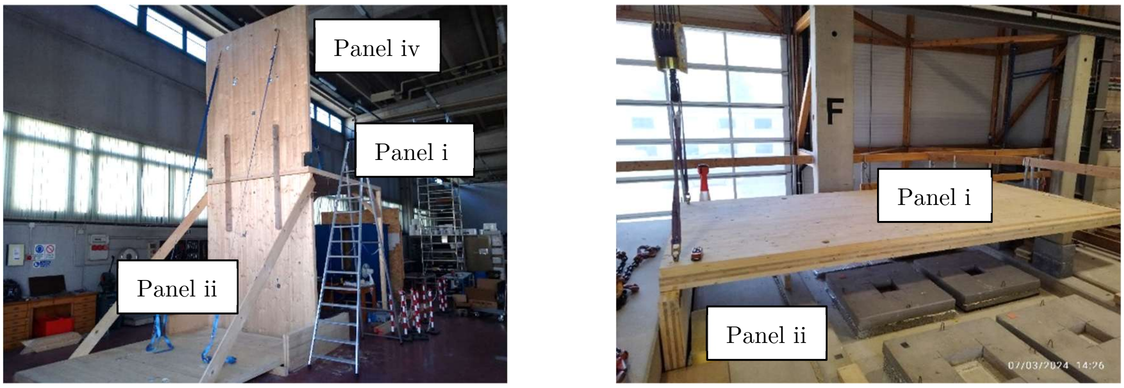

Figure 1. Mock-up 1: horizontal T-junction (left). Mock-up 2: horizontal L-junction (right).

taken at room temperature (22-27°C). To isolate individual effects, configurations were compared in which only one parameter was varied. The measurement method was in accordance with ISO 10848-1, except for the number of source positions: 3 were used instead of the 4 required by the standard. The number of receiving positions was 8 per panel. In mock-up 1, the accelerometers were attached via magnets to eyelets screwed into the wood. In mock-up 2, the accelerometers were attached using a two-component adhesive. In mock-up 1, the source consisted of 3 vibro-transducers for low-medium frequencies and 3 vibro-transducers for medium-high frequencies in each panel, all 6 operating simultaneously. In mock-up 2, the source used was a hammer.
The resilient interlayers used in this project are elastomers, with characteristics listed in Table 1.

Table 1. Elastomers used as resilient interlayers with compressive modulus of elasticity *E* and composition.

Name	E [N/mm^2]	Composition
PIANO_A	0.2	*Expanded EPDM*
PIANO_B	1.1	*Expanded EPDM*
XYL_20	1.5	*Extruded polyurethane*
XYLOFON_50	7.1	*Extruded polyurethane*
XYLOFON_70	14.2	*Extruded polyurethane*
XYLOFON_80	25.4	*Extruded polyurethane*

3. Results

Various parameters influencing the vibration reduction index were investigated: parasitic airborne noise; the effects of load on the junction; the effects of time (creep); the influence of material elastic modulus; the influence of the thickness of the resilient interlayer; the influence of the contact area between the resilient strip and the junction; the importance of the position of the resilient strip in the junction; and finally, a mention of the fastening system.
In many of the graphs presented, the K_{ij} values for the configuration without a resilient interlayer are shown for comparison, referenced as *Without interlayer* (Figure 2-Figure **8**).

3.1 Parasitic airborne noise

Parasitic airborne noise represents the airborne sound component that is radiated from the source panel and reaches the receiving panel through the air rather than through the structure. The vibration reduction index represents only structure-borne transmission. This parasitic airborne noise phenomenon should therefore be verified in the measurement and, if it has an influence, corrected to avoid underestimating the structure-borne insulation. This may happen, for example, when measuring highly insulated junctions with resilient interlayers without a fastening system (e.g. screws or plates). For brevity, reference is made to another article written by the authors on the subject [9] in which corrections are proposed.
The results presented in this article show the K_{ij} values for disconnected panels in order to highlight the limit due to parasitic airborne noise, $K_{ij,max}$, referenced as *Airborne limit* (Figure 2-Figure **9**).

3.2 Load effects

The amount of load applied to the junction can vary the K_{ij} result. Each resilient material is designed to support certain loads that will be present in the finished building. But an incorrect estimate of the loads may undermine the improvement one hopes to achieve. This effect is particularly evident in junctions with resilient interlayers: the greater the load, the lower the K_{ij}. This is because increasing the load compresses the material, reducing its thickness and consequently increasing its dynamic stiffness and decreasing its performance. It is therefore important to measure K_{ij} under the loads specified in the design to obtain more accurate results. The authors' article [10] explores load effects in CLT junctions with resilient interlayers in greater depth. These effects have also been studied by Nilsson et al. in [11].
The results presented in the graphs in this article are for configurations in which the junction is loaded only by the internal structural load, except those shown in Figure 4, which have a compressed junction to achieve a 10% deformation (0.06 cm) of the resilient interlayer thickness, and in Figure 7, which use a concrete block to increase the load (discussed in more detail later).

3.3 Creep effects

The time during which the junction is under load influences the K_{ij} value. Due to creep, the resilient interlayer reduces thickness over time, thereby decreasing the K_{ij} value as its dynamic stiffness increases and its performance decreases. This article compares measurements taken on the same day that the load is applied to the resilient interlayer with measurements taken on subsequent days.

Figure 2 and Figure 3 show the effects of creep on K_{ij} values with the *PIANO_A* and *XYL_20* resilient interlayers, comparing different load days before taking the measurement: on the same day (*0 days*); after 3 days (*3 days*); and after 14 days (*14 days*).

There is not much difference between after 3 days and after 14 days. In fact, most of the thickness reduction occurs in the phase immediately after the load is applied (on the 1st day). Both graphs show that creep causes a decrease of approximately 0.9-1.7 dB in the single-number value of $K_{ij,av.}$ (arithmetic mean 200-1250 Hz).

None of the configurations illustrated in this section has a fastening system.

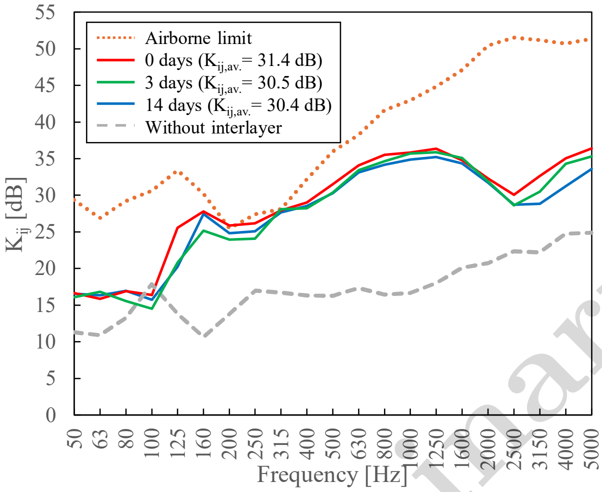

Figure 2. Creep effects on vibration reduction index (PIANO_A) [mock-up 2].

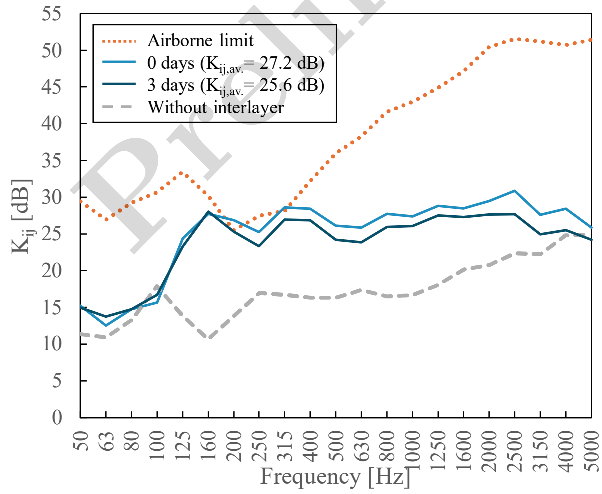

Figure 3. Creep effects on vibration reduction index (XYL_20) [mock-up 2].

3.4 Elastic modulus of resilient interlayer

The stiffness of the resilient material affects its performance and its ability to insulate structure-borne sound. It is more an intrinsic property of the resilient material than a matter of standardised measurement; however, in this article, results are still compared for polymers with different elastic modulus.

Figure 4 compares the K_{ij} results of different elastomers (see Table 1) in mock-up 1 with 6 screws as a fastening system and with a variable load for each configuration (the higher the modulus of elasticity, the higher the load) to achieve a 10% deformation (0.06 cm) of resilient interlayer thickness. The graph clearly shows that, despite the same polymer type, the K_{ij} values vary considerably, with 5.6 dB difference in $K_{ij,av.}$ between *XYLOFON_50* and *XYLOFON_80*. For this reason, it may be important to specify characteristics in a report, such as the resilient material's stiffness or elastic modulus, possibly in relation to the applied static load, to facilitate comparisons.

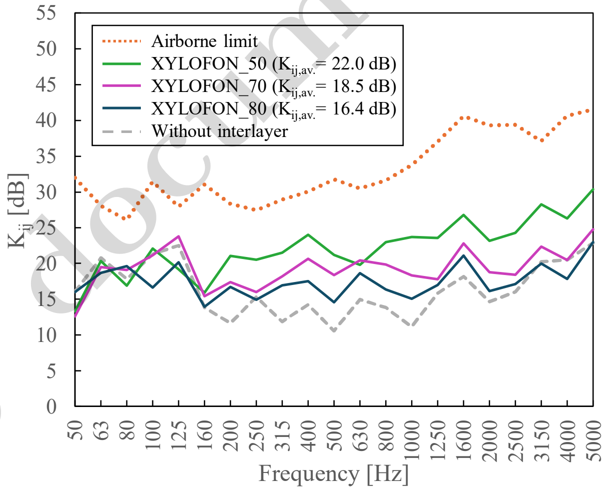

Figure 4. Comparison of resilient interlayers [mock-up 1].

3.5 Thickness of resilient interlayer

The dynamic stiffness of the resilient interlayer is inversely proportional to its thickness, so the thicker the sample, the lower its dynamic stiffness and the higher its insulation performance. Since a homogeneous material with different thicknesses was not available, tests were conducted in which various resilient strips of the same material were superimposed at the junction. Each strip is 0.6 cm thick. Figure 5 and Figure 6 show the configurations with *PIANO_A* and *PIANO_B* with the following layers: 1 resilient strip (*1 layer*); 2 resilient strips (*2 layers*); and 3 resilient strips (*3 layers*). In terms of single-number quantity $K_{ij,av.}$, there is not much change (0.5-1 dB) between the different combinations of layers. However, significant differences in frequency are evident. In the considered construction systems, there are drops in insulation performance due to the thickness resonance of the resilient material [9]: the resonance frequency shifts to lower frequencies as the thickness increases. This is particularly noticeable in the case of *PIANO_A* (Figure 5), where the drop goes from 2500 Hz with 1 layer to 1250 Hz with 2 layers to 800 Hz with 3 layers. In Figure 6, on the other hand, the differences in behaviour are more evident above 1600 Hz, where increasing the thickness of the resilient interlayer substantially increases K_{ij} until it reaches the airborne-transmission limit at 5000 Hz.

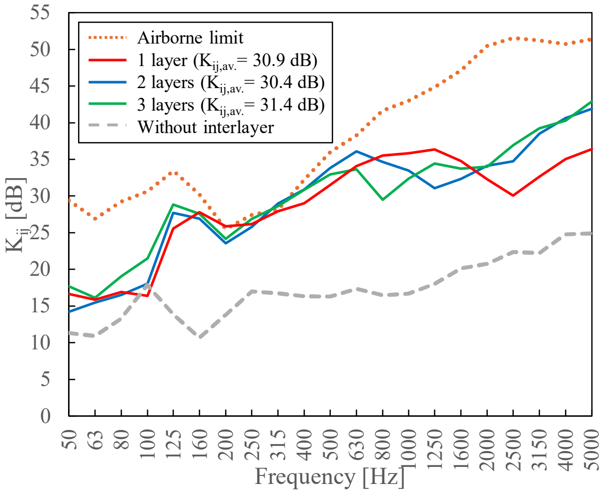

Figure 5. Different thicknesses (PIANO_A) [mock-up 2].

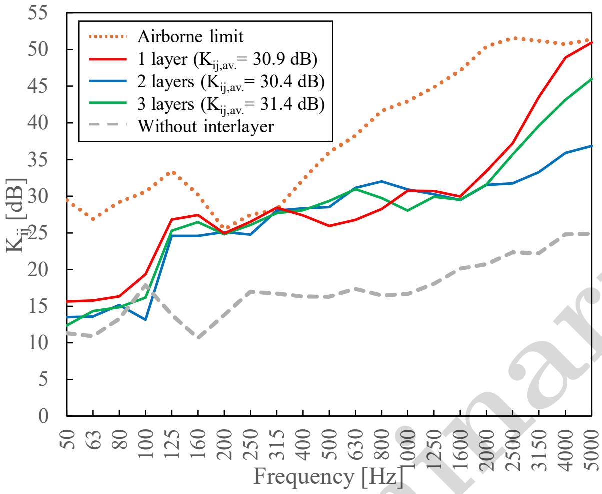

Figure 6. Different thicknesses (PIANO_B) [mock-up 2].

3.6 Contact surface of resilient interlayer

The contact constraints (resilient interlayer surface) can alter the K_{ij} values of the configurations because the stiffness of the junction, torque transmission, and the rotation of the panel edge change. To demonstrate this, two configurations were measured with the same pressure on the resilient interlayer but with different contact surfaces. An 8 cm wide strip of *PIANO_A* was used in mock-up 2 (*1 strip*), and a concrete block was applied to the junction to obtain a pressure in the resilient interlayer of 0.041 N/mm². The resilient strip was then divided into two to obtain a 4 cm wide strip and placed in the middle of the wall (*1/2 strip*). This time, a concrete block was not used, so only the structure's self-weight was applied. In this way, the pressure in the resilient interlayer was 0.042 N/mm², i.e., almost the same as in the previous configuration. The results are shown in Figure 7. The half-strip configuration (*1/2 strip*) was found to have higher K_{ij} values than the full-strip configuration (*1 strip*), with a difference of 4.4 dB in $K_{ij,av.}$.

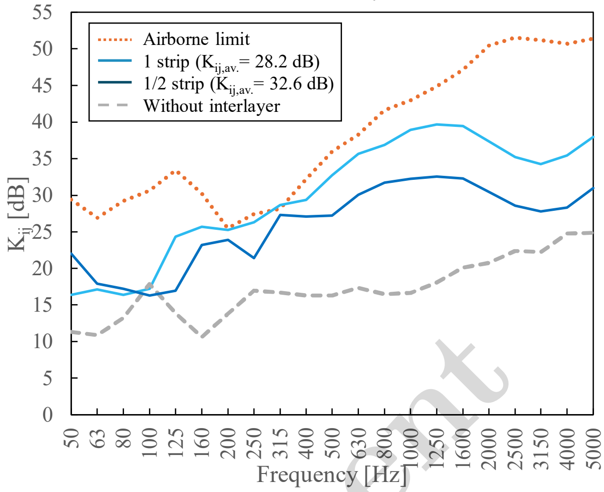

Figure 7. Same pressure, different contact surface (PIANO_A) [mock-up 2].

3.7 Position of resilient interlayer

Usually, the resilient strip is as wide as the wall thickness it contacts, but it may be narrower. In that case, its position relative to the wall may affect K_{ij}'s results. In mock-up 2, the wall is 12 cm thick, and the resilient strip of *PIANO_B* is 8 cm wide. Figure 8 shows the configurations in which the resilient strip is moved relative to the thickness of the wall: strip in the extrados of the junction (*extrados*); strip at the centre of the junction (*centre*); and strip at the intrados of the junction (*intrados*). The configuration with a resilient strip on the extrados has the highest K_{ij} values, while the configuration with a resilient strip on the intrados has the lowest K_{ij} values. Between the two extremes (extrados and intrados), there is a difference of 3.2 dB in $K_{ij,av.}$.

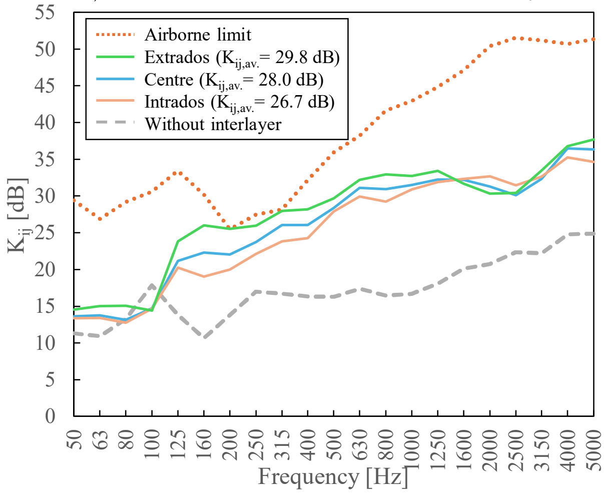

Figure 8. Different position of the resilient strip (PIANO_B) [mock-up 2].

Usually, if the resilient strip is narrower than the wall thickness, it is preferable to position it at the centre for better stability, but it is important to note that its position can affect the results.

3.8 Fastening system

The relationship between the fastening system and the K_{ij} has been widely studied in the literature, including the *Flanksound* project [12]. The present article does not aim to explore the subject in depth, for which reference should be made to the literature, but rather to point out that the number and composition of the fastening system directly influence K_{ij}, as direct structure-borne transmission passages are created through the metal. In the CLT construction system, a fastening system is always required for static reasons and may be more extensive in areas with seismic risks, such as Italy.

In Figure 9, various configurations are compared with a resilient interlayer: PIANO_A + no fastening system (*Interlayer+0*); PIANO_A + 3 screws (*Interlayer+3*) with a loss of 8.6 dB at $K_{ij,av.}$; PIANO_A + 6 screws (*Interlayer+6*) with a loss of 11.3 dB at $K_{ij,av.}$. Various configurations are also compared without a resilient interlayer: no resilient interlayer + no fastening system (*Rigid+0*); no interlayer + 3 screws (*Rigid+3*) with a loss of 3.6 dB at $K_{ij,av.}$; no interlayer + 6 screws (*Rigid+6*) with a loss of 4.5 dB at $K_{ij,av.}$.

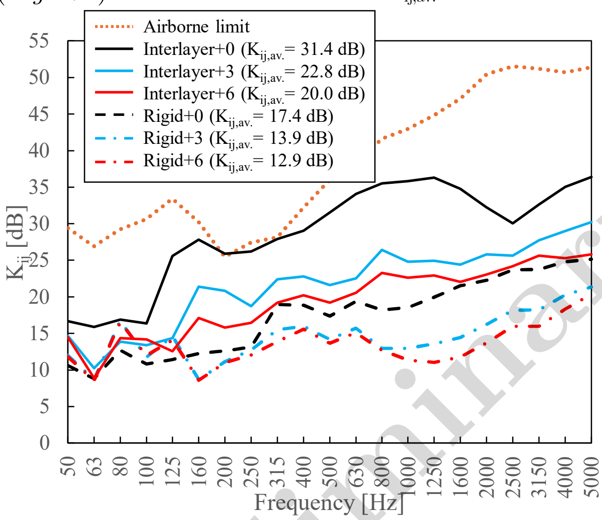

Figure 9. Comparison fastening system (PIANO_A) [mock-up 2].

4. Discussion

All presented graphs show that the frequency spectrum can be divided into two regions: a low-frequency region where vibration is dominated by global modes, and a higher-frequency region where vibration transmission is dominated by local modes [13].

In [10], the effects of loading in K_{ij} values were observed from 400 Hz onwards. This influence is also evident in this article, in the effects of changes in thickness, such as creep and multilayering. In general, the effects of load are the greatest [10], followed by those of thickness, and finally, creep effects are minor. Comparing different stiffnesses is complicated because the design loads for which the resilient material was intended also affect its performance. A resilient material, when measured under an unexpected load range, will not perform optimally. In general, changing the resilient material type alters the frequency spectrum of the K_{ij} values.

Changing the contact surface while maintaining the same pressure on the resilient interlayer significantly affects K_{ij} values, altering the junction behaviour.

Parasitic airborne noise should be accounted for and controlled to avoid underestimating the K_{ij}, especially when measuring CLT elements with excellent radiation efficiency in the frequency range under analysis, high-performance junctions, resilient interlayers, and no fastening systems.

Given the effects described in this article, the aspects listed below serve to better illustrate the frequency behaviour of the K_{ij} in CLT junctions:

- The junction type (L-, T-, or X-junction) and its orientation (horizontal or vertical);
- A detailed description of the test junction, including the material, size, thickness, number of plies, density of material, and boundary conditions, accompanied by a drawing/photo;
- Amount of load applied to the junction, and a description of the method of application of the load (e.g. hydraulic press or free mass);
- A detailed description of the fastening system (if present), including the type, number of elements, distances between elements, and their position in the junction, accompanied by a dimensioned schematic drawing;
- Description of the resilient interlayer: product typology (including elastic modulus data if available), width and thickness of the strip, contact surface with the junction, position (ideally centred, or alternatively on the intrados or extrados of the junction), pressure received from the load, and amount of time for which the load was applied before taking the measurement (creep);
- Specification of the type of source (e.g. hammer, shaker, tapping machine, vibroacoustic transducer);
- Indicate whether shielding was applied or not;
- Specification of how the accelerometers were fixed (e.g., wax, double-sided tape, magnet, bi-component glue);
- The number of source and receiver positions that were used;
- The result of the vibration reduction index, K_{ij}, in 1/3 octave bands within the range of 50-5000 Hz, in which are highlighted bands with low modal density, where there is a slightly lower accuracy (as required by ISO 10848-4);
- The results of the single-number quantities of K_{ij} as specified in ISO 10848-1 chapter 10: $K_{ij,av.}$ (average 200-1250 Hz), $K_{ij,low}$ (average 50-200 Hz), $K_{ij,mid}$ (average 250-1000 Hz), and $K_{ij,high}$ (average 1250-3150 Hz);
- If it is possible, a verification of the contribution of parasitic airborne noise, to demonstrate that the measurements taken

only consider structure-borne transmission or, if not, the corrections applied.

This information facilitates interlaboratory reproducibility and comparisons between products from different manufacturers.

5. Conclusions

The behaviour of junctions with resilient interlayers is sensitive to test conditions. Test conditions, such as load, creep, strip contact surface, strip position, and fastening system, can vary the K_{ij} values by several dB. Also, elastic modulus and strip thickness have been analysed. Among these parameters, load quantity and the fastening system are the most influential and reflect conditions unavoidable in real buildings. In this regard, it is important to accurately check and report the boundary conditions of the measurements. Other effects, such as creep and thickness increase, can become important at specific analysed frequencies.

The variability introduced by resilient interlayers is not adequately addressed in the current ISO 10848-1, which lacks a dedicated guide for this type of structure. At present, it is therefore important to report all details of the measurement conditions to enable better comparisons between products and to promote interlaboratory reproducibility.

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