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## **Flanking transmission in CLT buildings: comparison between vibration reduction index measurements for different mounting conditions**

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## ABSTRACT

During a research on the optimization of the mechanical performances of CLT building elements to respond to particular needs for the improvement of seismic design, a measurement campaign of vibration reduction index was carried out on a large-scale test setup.

The large scale set up allows to build up to eight adjacent and/or overlaid rooms, performing, eventually, simultaneous measurements of vibration reduction index and sound reduction index according respectively ISO 10848 and ISO 16283 series. At the first stage of the research, a comparison between different connection techniques of CLT building elements was made, with the aim of pointing out interactions between wooden elements and resilient layers connected by different types of fixing systems.

**Keywords:** Sound Insulation, Flanking Transmission, Cross Laminated Timber

**I-INCE Classification of Subject Number:** 43

## 1. INTRODUCTION

The use of Cross Laminated Timber building elements (CLT) is now widespread. However, there are some aspects related to structural and seismic design that may affect acoustic performance, which are not yet sufficiently studied.

Recent research [1, 2] highlighted possible correlations that allow to evaluate the acoustic performances of bare CLT structures, both in terms of sound reduction and impact noise, easily integrated with standardized prediction models [3, 4].

It is therefore relatively simple to obtain reliable data for the prediction of the acoustic performance of a complete CLT building element applying sound reduction improvement data obtained from standardized laboratory measurements [5–9] or obtained with different methods, as point-mobility measurements [10].

In the last 5 years, different authors have carried out research on the flanking transmission of junctions in timber buildings [11, 12] and summary work was presented of the data available in the literature [13].

However, the acoustic design of buildings made with the CLT technology have to deal with the aspects of energy saving [14–16], environmental and seismic risk protection [17, 18]. In fact, the most widespread connection techniques between CLT building elements are essentially designed to effectively solve structural problems, requiring specific interventions to reduce thermal bridges, to limit moisture diffusion and to improve air tightness, as well as to increase reaction capacity to shear forces in case of earthquake. All these aspects have a direct or indirect relapse on the acoustic behaviour of the junctions of CLT building elements [19, 20].

That forms the backdrop to the research, carried out jointly by the Acoustics Laboratory of the Department of Industrial Engineering and the Department of Cultural Heritage of the University of Padua with the support of the University of Bologna. The aim is to optimize the structural mechanical performances of CLT building elements combined with resilient layers designed for the reduction of flanking transmission.

In this paper, a first data set of a measurement campaign on a specific set-up is presented and a comparison between different connection techniques is shown.

## 2. EXPERIMENTAL APPROACH FOR A COMPARISON BETWEEN VIBRATION REDUCTION INDEX MEASUREMENTS FOR DIFFERENT MOUNTING CONDITIONS

The vibration reduction index  $K_{ij}$  (dB) quantifies the transmission of vibrations through the structural elements of a junction.

It is calculated as:

$$K_{ij} = \frac{D_{v,ij} + D_{v,ji}}{2} + 10 \log \frac{l_{ij}}{\sqrt{a_i \cdot a_j}} \quad (1)$$

where  $D_{v,ij(ji)}$  (dB) is the velocity level difference between elements  $i(j)$  and  $j(i)$ , when element  $i(j)$  is excited;  $l_{ij}$  (m) is the common junction length between elements  $i$  and  $j$ ;  $a_{i(j)}$  (m) is the equivalent absorption length of element  $i(j)$ , given by:

$$a = \frac{2.2\pi^2 S}{c_0 T_s} \sqrt{\frac{f_{ref}}{f}} \quad (2)$$

where  $T_s$  (s) is the structural reverberation time of the element,  $S$  (m<sup>2</sup>) is the surface of the element,  $f$  (Hz) is the centre band frequency,  $f_{ref}$  (Hz) is the reference frequency of 1000 Hz and  $c_0$  (m/s) is the speed of sound in air.

## 2.1 Measurement set-up

A frame has been prepared to allow vibration reduction index measurements on CLT building elements, according to the ISO 10848 series [21–24], with and without interposition of resilient layers in the joints. The same set-up, maintaining the same characteristics of connection between the joints, will be later completed with vertical and horizontal external enclosures to allow the evaluation of the sound reduction and impact sound insulation according to the standards of the ISO 16283 series [25, 26]. The study was based on previous measurement experiences in the laboratory and in situ [27–29].

The lateral transmission measurements were carried out at the Bozza S.r.l. manufacturing plant. Horizontal and vertical joints have been tested. The vertical joints have been tested according to ISO 10848 standards in “L”, “T” and “X” configurations (Figure 1). The horizontal joints were measured in configurations mounted in partial deviation from the expected scheme, due to installation constraints and panels handling in the construction phase. The panels were fixed to a concrete edge beam cast directly on the foundation of the building. The fastening comprised two hold-downs and two angle brackets for each vertical panel. The same type of angle brackets were applied at the connection with the horizontal panels (when present). All the connections have been fixed by screws.

The panels were excited using an electrodynamic shaker mounted on an inertial base and fixed to the CLT panels through a small screwed plate. The excitation signal was a pink noise high-pass filtered at 30 Hz, and the velocity levels were measured 4 channels at a time. The accelerometers were fixed to the panels using magnets that adhered to eyelets screwed to the panels.

The structural reverberation times were calculated from the impulse responses that were measured on the panels in the same points used for the acquisition of the velocity levels. For this purpose, *ESS* signals were used for the excitation of the panels. Three averages allowed to obtain a *SNR* around 50 dB. The reverberation time  $T_{15}$  was evaluated by means of software “Dirac”.

## 2.2 Test configurations

The configurations tested are reported in Table 1 (vertical junction) and in Table 2 (horizontal junction). The junction type and the dimensions of the CLT panels are

reported together with a sketch of the junction. All the configurations presented here were tested with and without the presence of a resilient interlayer at the interface of the junction between all panels. The resilient layer used for this comparisons is a 6 mm thick anti-vibration stripe made of fibers and granules of recycled styrene-butadiene rubber with a non-woven fabric support, hot pressed with polyurethane adhesive (density 800 kg/m<sup>3</sup>).



Figure 1: Pictures from the setup: “X” vertical junction (left) and “X” horizontal junction (right).

Table 1: Summary of the tested configurations for the vertical junctions.

		Junctions and dimensions of the panels	Scheme of the assembly	
VERTICAL JUNCTIONS	“L”	<b>A:</b> 4.00×2.95×0.10 m <b>D:</b> 3.50×2.95×0.10 m		
	“T”	<b>A:</b> 4.00×2.95×0.10 m <b>D:</b> 3.50×2.95×0.10 m <b>R:</b> 3.40×2.95×0.10 m		
	“X”	<b>A:</b> 4.00×2.95×0.10 m <b>D:</b> 3.50×2.95×0.10 m <b>R:</b> 3.40×2.95×0.10 m <b>T:</b> 4.50×2.95×0.10 m		

Table 2: Tested configuration for the horizontal junction.

HORIZONTAL JUNCTION	“X”	<p><b>G:</b> 2.95×2.45×0.10 m</p> <p><b>I-O*:</b> 8.10×2.45×0.14 m</p> <p><b>M:</b> 2.95×2.45×0.10 m</p> <p>*) Letters “I” and “O” denote one single panel element</p>	
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### 3. RESULTS OF THE MEASUREMENTS

The results of the measurements are presented through the analysis of three different factors:

- the analysis of a single junction with and without resilient interlayer;
- the evaluation of the energy transmission when the complexity of the junction increases;
- the evaluation of the variation in reverberation time due to the interposition of the resilient interlayer and its effect on the evaluation of the  $K_{ij}$ .

These three points are addressed in separate subsections below.

#### 3.1 Variation of the $K_{ij}$ with and without the resilient interlayer

The “X” horizontal junction was selected as a reference for the identification of the attenuation in vibration transmission provided by the resilient interlayer. The  $K_{ij}$  measured on the junction for four transmission paths are reported in Figure 2.

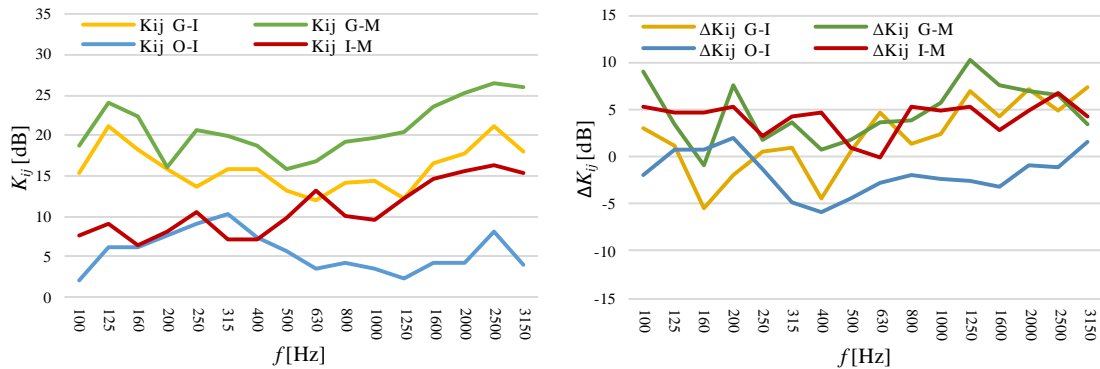


Figure 2:  $K_{ij}$  (dB) measured for the “X” horizontal junction for the transmission paths G-I, O-I, G-M and I-M, without the resilient interlayer (left) and increases of  $K_{ij}$  (dB) with the resilient interlayer (right).

The transmission path O-I, i.e. the one measured along the same panel across the junction, shows the lowest attenuation. When resilient interlayers are placed at the interface with the two other panels, the  $K_{ij}$  decreases again because the resilient stripe does not allow a re-distribution of energy among the panels. Therefore, as expected, in Figure 2 (right) this transmission path shows to have a decrease in the value of  $K_{ij}$ .

Paths I-M and G-I are measured on panels that are symmetrical with respect to the junction, but that are not symmetrical in terms of boundary conditions: the panel G is

fixed to the foundations through hold downs, while the boundaries on the upper edge of panel  $M$  have a weaker constrain. Looking in detail at the sound level differences, when the sound source is in panel  $I$ , the energy reaching panels  $M$  and  $G$  is similar; conversely, when panel  $M$  is excited, more energy at low frequencies is transmitted to panel  $I$  compared to the case in which panel  $G$  is the source, due to the different constraints. Transmission path  $M-G$  is the most attenuated and is, furthermore, the one mostly affected by the presence of the layer.

### 3.2 Variation of the $K_{ij}$ depending on the complexity of the junction

The tests made on the vertical “ $L$ ”, “ $T$ ” and “ $X$ ” junctions were designed starting from the “ $L$ ” configuration and adding the third and fourth panel. This allow to evaluate how energy re-distribute among the panels as the junction comprises an increasing number of elements. Figure 3 shows the  $K_{ij}$  measured for the transmission path  $A-D$ , as the number of the panels composing the junction increases, with (right) and without (left) the resilient layer.

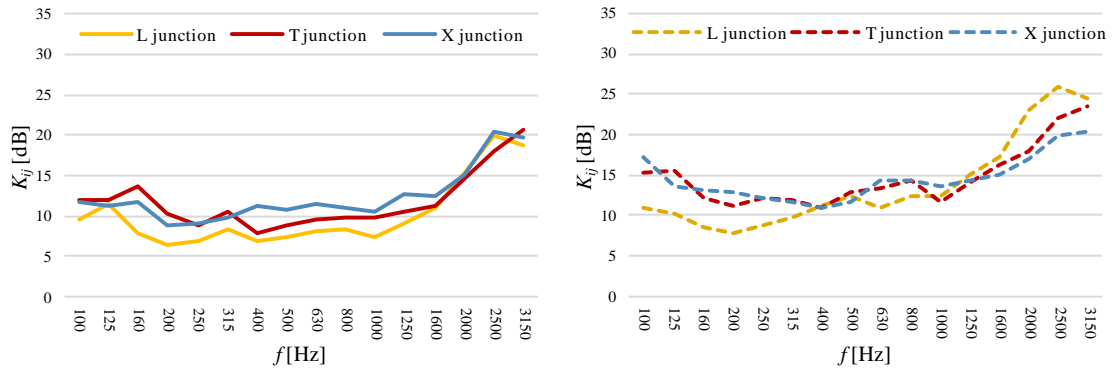


Figure 3:  $K_{ij}$  (dB) measured for the same pair of panels in a “ $L$ ”, “ $T$ ” and “ $X$ ” junction, mounted without (left) and with (right) resilient interlayer.

The analysis of the results shows that, increasing the number of panels, the attenuation provided by the junction on each transmission path is greater, thanks to the re-distribution of the energy. There is approximately 1 dB improvement when one panel is added and 2 dB improvement when two panels are added. This effect is less marked at higher frequencies.

When a resilient interlayer is interposed in the junction, the effect of the addition of the panels is less relevant. The “ $T$ ” and the “ $X$ ” junctions offer the same attenuation in frequency, giving a confirmation of the effectiveness of the use of the stripe.

### 3.3 Influence of the variation of the reverberation time on the $K_{ij}$

The ISO 12354 series distinguishes between two types of junctions, namely A and B, for which the transmission of vibration through the structure is characterised by different metrics. As discussed above, CLT junctions fall in the category characterised by the  $K_{ij}$ , in the hypothesis that the loss factor of the panels is affected by the boundary conditions.

The “ $X$ ” vertical junction was chosen as a reference to evaluate whether, under different boundary conditions (with and without resilient interlayer), the  $K_{ij}$  is mostly affected by the variation of the transmitted energy or by the term that accounts for the loss factor, indicated as  $Crt$ . Figure 4 shows the  $K_{ij}$  values and the coefficients  $Crt$  for the transmission paths  $A-D$  and  $A-T$ .

While the  $K_{ij}$  values show a remarkable difference in the various cases analysed, the  $Crt$  terms show only minor variations as the transmission path changes and the resilient layer is used or not. The reverberation times do not change in the different configurations, confirming what observed in [29].

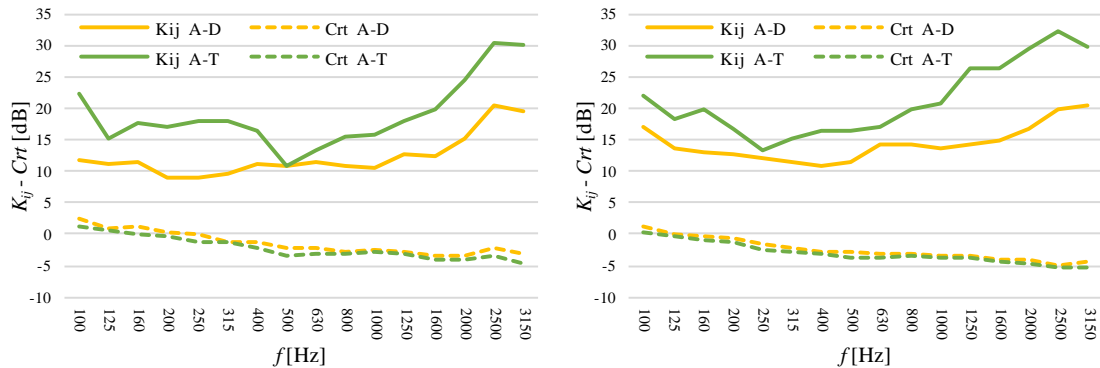


Figure 4:  $K_{ij}$  (dB) and correction term related to the structural reverberation time plotted for two transmission paths of the “X” vertical junction, without (left) and with (right) resilient interlayer.

#### 4. CONCLUSIONS

The data emerging from this study, although partial, are of great interest to evaluate the acoustic effects of resilient layers and improved connection systems for CLT building elements.

The approach based on the comparison between measures of vibration reduction index under controlled conditions, which allows both the comparison between different construction techniques for the same building elements, and a subsequent evaluation of their effectiveness in situ, it is useful to improve the current building acoustic design tools. Moreover, this method can facilitate the comparison between the performance assessed with prediction methods and field measurements of the acoustic performances of buildings made with CLT elements [30].

The measures confirmed some indications included in the standard [3]: increasing the number of panels, the attenuation provided by the junction on each transmission path is greater, thanks to the re-distribution of the energy; the resilient interlayer reduces the lateral transmission but not in the path in the same slab (e.g. path I-O) like the type A junction.

For future work, it would be necessary to evaluate the formulas for the junctions with resilient interlayer.

#### 5. ACKNOWLEDGEMENTS

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