FLANKING SOUND TRANSMISSION REDUCTION THROUGH A DECOUPLED CLT FLOOR

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Abstract

Cross-laminated timber (CLT) is widely appreciated for its fast installation, sustainability, and lightweight properties.
However, its high sound radiation efficiency makes it particularly susceptible to flanking transmission. At the same time, its aesthetic appeal often leads architects to leave surfaces exposed, avoiding additional linings.
In standard design solutions, suspended ceilings are commonly installed to limit direct vertical sound transmission from the floor above and to conceal building service installations. This study explores an alternative strategy that introduces a resilient layer between floor elements to reduce lateral sound transmission between adjacent rooms via the upper floor.
An experimental campaign was carried out on a horizontal X-junction mock-up. First, the vibration-reduction index (K_{ij}) was measured on a continuous floor slab. The slab was then divided into two sections, separated by a resilient material, and the K_{ij} for the floor-to-floor transmission path was measured again.
The results demonstrate that floor decoupling with resilient material is an effective strategy, particularly at low and high frequencies, achieving improvements of up to 7 dB in the single-number K_{ij}. The performance of this solution was further assessed through calculations in accordance with ISO 12354, based on the experimental data. These findings highlight new opportunities for acoustic design in CLT structures.

Keywords: *decoupled CLT floor - Flanking sound transmission - resilient interlayer*

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1. Introduction

Cross-laminated timber (CLT) is a growing market, particularly valued for its on-site assembly speed, light weight, and sustainability [1]. It is a material with high sound-transmission efficiency, making it particularly sensitive to secondary sound transmission through flanking paths. To address this characteristic, it is now common practice to insert resilient interlayers within the structure, particularly at junctions and in the connection between the floor slab and the wall. These resilient materials reduce the transmission of structure-borne vibrations, thereby improving the building's overall sound insulation performance [2], [3], [4], [5], [6], [7].
As CLT is a visually appealing timber-based material, projects sometimes specify that no false ceilings be installed to leave the structural CLT floor exposed. This market demand poses challenges regarding flanking transmission pathways. This article analyses this specific secondary path from one ceiling to the ceiling of the adjacent room - the Flanking-flanking (Ff) path - and possible technological solutions, such as the insertion of a resilient interlayer between one floor slab and another to decouple them.
Finally, calculations were carried out in accordance with ISO 12354 [8] to determine the effect of this decoupling on the apparent sound reduction index R' in a hypothetical in-situ scenario.

2. Method

To study the floor-to-floor connection, a full-scale mock-up of a CLT junction was constructed at the University of Bologna (Figure 1, left). The mock-up was a horizontal X-junction with a continuous floor slab and the following dimensions: continuous floor slab ("panel i" + "panel iii") 710x240 cm; lower wall ("panel ii") 300x240 cm; upper wall ("panel iv") 300x240 cm.

Figure 1. Horizontal X-junction mock-up in CLT (left). Three pairs of vibroacoustic transducers in three source positions (right).

All panels were 5-ply CLT with a thickness of 10 cm. The floor was then cut into two slabs to obtain "panel i" (350x240 cm) and "panel iii" (350x240 cm). Measurements and calculations were carried out in accordance with ISO 10848-1 [9]. For each panel, 3 source positions and 8 receiver positions were used. The sources used were vibroacoustic transducers: 3 to excite the low-mid frequencies and 3 to excite the mid-high frequencies, positioned in pairs at the 3 source positions (Figure 1, right). The accelerometers were attached to screw-mounted eyelets via magnets.

The fastening system was as follows:

- connection between "panel iv" and "panel i": 2 angle brackets (NINO 150x80 [10]);
- connection between "panel iv" and "panel iii": 2 angle brackets (NINO 150x80 [10]);
- connection between "panel i" and "panel ii": 3 screws (HBS 8x240 [10]);
- connection between "panel iii" and "panel ii": 3 screws (HBS 8x240 [10]).

The angle brackets were spaced 176 cm apart, while the screws (HBS) were spaced 44 cm apart.

Following the cutting of the floor slab, the following fastening system is added:

- connection between "panel i" and "panel iii": 8 screws (VGS 7x120 [10]).

The screws (VGS) were spaced 30 cm apart.

The resilient material used is XYLOFON_35 [11], an extruded polyurethane with a Shore hardness of 35. Resilient strips of this material have been placed at multiple locations in the junction, including wall-floor (paths i-ii, iii-ii, i-iv, iii-iv) and floor-floor (path i-iii), with tests conducted both with and without them to compare the solutions. The fastening system, however, remains the same as mentioned previously.

3. Results

Figure 2 compares the results of K_{ij} in frequency for the configuration of the horizontal X-junction in path i-iii: the configuration with a continuous floor slab (*Entire*, blue line) and the configuration with decoupled floor slabs (*Decoupled*, red line). The vibration reduction index trend for the configuration with a unique floor slab (blue line) remains reasonably constant around 10 dB across the analysed frequency range (50-5000 Hz). In the configuration with decoupled floor slabs (red line), however, three distinct frequency ranges can be identified: from 50 Hz to 400 Hz, values are approximately 20 dB; from 500 Hz to 1250 Hz, there are lower values, approximately 15 dB; whilst from 1600 Hz to 5000 Hz, the insulation rises again to values approximately 20 dB. In general, the insulation provided by floor decoupling is high. In terms of single-number quantities (summarised in Table 1), this distinction is clearly evident, with a difference in $K_{ij,low}$ (average 50-200 Hz) of 11.3 dB between decoupled and non-decoupled floors. On the other hand, for the single-number quantity $K_{ij,av.}$ (average 200-1250 Hz), the difference is 6.9 dB. ΔK_{ij} is calculated as the difference between the values for decoupled and continuous floor slabs.

4. Calculation example

To understand the acoustic impact of this construction solution, which involves decoupling the floors, performance predictions were carried out for a hypothetical building using the method set out in the ISO 12354 series. For this example, the room dimensions are the same as those of the mock-up to avoid in-situ corrections (both 2.4 × 3 m), as shown in Figure **3**. In the example given, all walls and floors are made of 10 cm-thick 5-ply CLT, as in the mock-up. All junctions are X-shaped. The source room is *A*, and the receiving room is *B*. Linings are applied to all side walls of the source room (*walls 2, 4*); the main wall (*wall 1*) has a lining only on the source side; and the floors (*6* and *8*) both have floating floors. The sound reduction index is calculated using the *Insul* software (version 10.6) [12] in 1/3-octave bands. The frequency data are then used to calculate the single-number quantities summarised in Table 2. The vibration reduction index values, obtained from laboratory measurements, used in the calculated configurations are listed in Table 3. Various calculation tests are then carried out with and without false ceilings in the top floors (*7* and *8*), as shown in Table 4. The false ceiling consists of a single layer of plasterboard (thickness = 1.25 cm) rigidly fixed to the floor slab using 4 x 5 cm wooden battens.

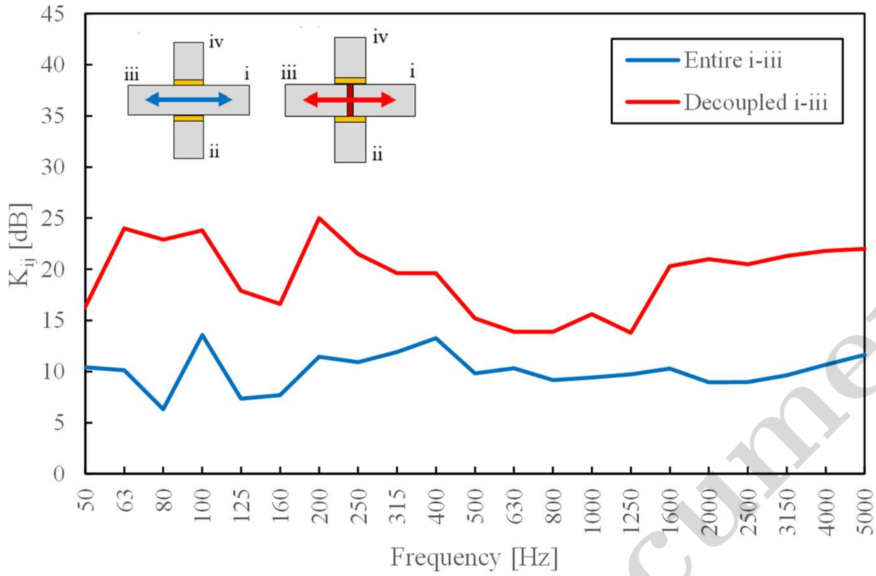
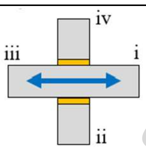
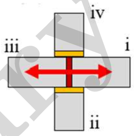


Figure 2. Comparison of K_{ij} between the decoupled (*Decoupled*) and non-decoupled (*Entire*) floors in the i-iii path.

Table 1. Single-number quantities of K_{ij} for the decoupled floor and not in the i-iii path.

Conf.			ΔK_{ij}	
Floor	Entire	Decoupled		
Path	i-iii	i-iii	i-iii	
$K_{ij,av.}$	10.7	17.6	**6.9**	*(200-1250 Hz)*
$K_{ij,low}$	9.6	20.9	**11.3**	*(50-200 Hz)*
$K_{ij,mid}$	10.7	17.0	**6.3**	*(250-1000 Hz)*
$K_{ij,high}$	9.5	19.4	**9.9**	*(1250-3150 Hz)*

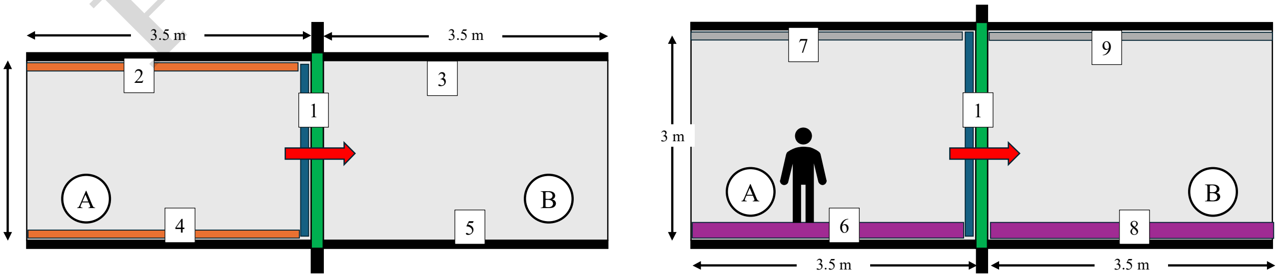
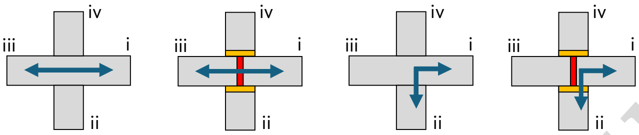


Figure 3. Scheme of the calculation example. View from above on the left, cross-section on the right.

Table 2. Single-number quantities from simulated sound reduction index values for elements in the example.

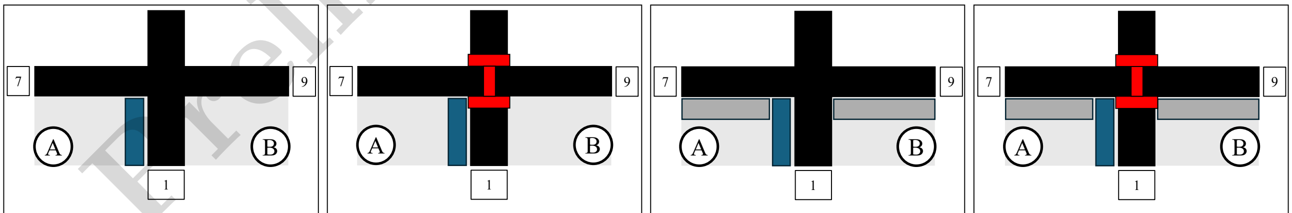
	R_w [dB]	ΔR_w [dB]	R_{low} [dB]	ΔR_{low} [dB]	R_{mid} [dB]	ΔR_{mid} [dB]	R_{high} [dB]	ΔR_{high} [dB]
CLT10 (all)	33		23		29		47	
Lining wall (1, 2, 4)		20		9		22		16
False ceiling (7, 8)		7		-1		12		8
Floating floor (6, 8)		18		16		18		29
	ISO 717 [13]		*(50-200 Hz)*		*(250-1000 Hz)*		*(1250-3150 Hz)*	

Table 3. Single-number quantities from measured vibration reduction index values for junctions in the example.



Conf.	*Example 1,3*	*Example 2,4*	*Example 1,3*	*Example 2,4*	
Floor	Entire	Decoupled	Entire	Decoupled	
Path	i-iii	i-iii	i-ii	i-ii	
$K_{ij,av.}$	11.8	17.6	14.8	16.9	*(200-1250 Hz)*
$K_{ij,low}$	9.9	20.9	19.8	19.7	*(50-200 Hz)*
$K_{ij,mid}$	12.3	17.0	14.6	16.2	*(250-1000 Hz)*
$K_{ij,high}$	9.5	19.4	18.4	21.5	*(1250-3150 Hz)*

Table 4. Overview of the calculated configurations. Example 1: continuous floor slab without a false ceiling. Example 2: decoupled floor slabs with resilient interlayers between the floor slabs and between the walls and floor slabs. Example 3: continuous floor slab with false ceilings. Example 4: decoupled floor slabs with resilient material between the floor slabs and between the walls and floor slabs with false ceilings



Example 1	Example 2	Example 3	Example 4
R'_w = 46.5 dB	R'_w = 49.3 dB	R'_w = 51.2 dB	R'_w = 52.0 dB
R'_{low} = 30.8 dB	R'_{low} = 31.7 dB	R'_{low} = 30.4 dB	R'_{low} = 31.6 dB
R'_{mid} = 42.4 dB	R'_{mid} = 45.7 dB	R'_{mid} = 49.8 dB	R'_{mid} = 50.3 dB
R'_{high} = 59.3 dB	R'_{high} = 62.0 dB	R'_{high} = 62.4 dB	R'_{high} = 62.8 dB

Table 5. Comparison of the direct path (Dd) and the flanking paths (Fd, Ff, Df) involving the ceiling, and their respective influence on the flanking sound reduction index (R_{ij}) and the apparent sound reduction index (R').

	Example 1		Example 2		Example 3		Example 4	
Path	R_{ij}	R'_w	R_{ij}	R'_w	R_{ij}	R'_w	R_{ij}	R'_w
Dd (1)	53		53		53		53	
Fd (7-1)	52.6	46.5	54.7	49.3	59.6	51.2	61.7	52.0
Ff (7-9)	**49.6**		**55.4**		**60.1**		**65.9**	
Df (1-9)	72.6		74.7		76.1		78.2	

5. Discussion

The first two examples in Table 4 compare configurations without a false ceiling. In this type of configuration, decoupling the floor has a large effect. Decoupling the floor with a resilient interlayer, in this case, increases the apparent sound reduction index R'_w by 2.8 dB, resulting in $R'_w = 49.3$ dB. This improvement is mainly due to a 5.8 dB increase in the vibration reduction index $K_{ij,av.}$, as shown in Table 3.

To analyse the sound reduction index across frequency ranges using single-number quantities as averages for the low (50-200 Hz), mid (250-1000 Hz) and high (1250-3150 Hz) frequency ranges, the simplified calculation from ISO 12354 was performed three times using the three single-number quantities. Although the greatest contribution of the resilient interlayer in path i-iii is in $K_{ij,low}$ (with $\Delta K_{ij,low} = 11$ dB) (see Table 3), this leads to an increase in R'_{low} of only 0.9 dB (see Table 4). The most significant contribution in the apparent sound reduction index single-number quantities is from R'_{mid}, which increases by 3.3 dB (see Table 4), while $\Delta K_{ij,mid}$ is 4.7 dB. This is because the CLT panels and the linings along the various paths also behave differently across frequency ranges. For example, at low frequencies, the values for the CLT wall are quite low ($R_{low} = 23$ dB) (see Table 2), and this means that the flanking paths become of secondary importance as direct transmission has significantly lower acoustic insulation. In the high-frequency range, however, very high R'_{high} values are obtained, 62.9 dB.

When comparing the direct path (Dd) and the flanking paths (Fd, Ff, Df) involving the ceiling, along with their respective influence on the flanking sound reduction index (R_{ij}) (see Table 5), it can be seen that in the Ff path (*7-9*) the insertion of the resilient interlayer increases the R_{ij} value by 5.8 dB (between *Example 1* and *Example 2*). Even with a false ceiling, inserting the resilient interlayer increases the R_{ij} value by 5.8 dB (between *Example 3* and *Example 4*). Inserting resilient interlayers into the structure reduces the energy within it, thereby decreasing the energy in the indirect paths.

With the installation of a false ceiling (*Example 3* and *Example 4*), the R'_w value increases, and minor differences are observed between decoupled and non-decoupled floors (0.8 dB), as the false ceiling makes a major insulation contribution to the Ff path.

Finally, it is important to note that there is a difference of just 1.9 dB in R'_w between the configuration with decoupled panels and no false ceiling (*Example 2*) and the configuration without any resilient interlayers and a false ceiling (*Example 3*). At low frequencies, the solution in *Example 2* performs better than the solution in *Example 3* by 1.3 dB in R'_{low}.

6. Conclusions

This article investigates the Ff flanking path, i.e. the path between the ceilings of two adjacent rooms. The effects on the K_{ij} of decoupling the floor into two slabs by dividing it and inserting a resilient interlayer were measured in a CLT full-scale mock-up of a horizontal X-junction. Using the simplified method in accordance with the ISO 12354 series, the effects of K_{ij} improvement on the apparent sound reduction index R'_w were studied, yielding a value of 2.8 dB for the example given. Furthermore, an analysis was carried out to distinguish the frequency ranges R'_{low}, R'_{mid}, and R'_{high}. Although the greatest K_{ij} improvements are found in $K_{ij,low}$, the main R' improvements are achieved in R'_{mid}, with a 3.3 dB improvement for the example given. Further analysis of the flanking sound reduction index (R_{ij}) values showed that inserting the resilient interlayer into the structure improves the Ff transmission path through the ceiling by 5.8 dB. This demonstrates that inserting the resilient interlayer into the structure not only enhances the partition's R' insulation performance but also reduces the amount of energy propagating within the structure, thereby improving all second-order transmission paths.

Even with a false ceiling in place, the insertion of the resilient interlayer improves insulation performance. This has little effect on the R'_w value (just 0.8 dB) but is clearly evident in the R_{ij} value (5.8 dB).

The construction solution of decoupling the floor with resilient materials can, therefore, in some cases, mean that a false ceiling is not required, allowing the ceiling to remain exposed. These findings allow greater flexibility in selecting construction methods.

To conclude, this study shows that, in the absence of false ceilings, floor decoupling is a simple and highly effective solution for improving sound insulation between adjacent rooms in CLT structures

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