Kij measurement in flanking transmission test facility to predict sound insulation for wooden multistorey buildings

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Abstract

In 2023, 4 types of junctions were measured in an in-situ measurement mockup: the "Maquette Acoustique AdivBois". The mockup is a three floors CLT based building, with four rooms on each level. The measurement strategy is Statistical Energy Analysis (SEA). In a previous paper the mockup was used to measure vibration reductions levels indexes Kij, in different configurations, where smart building systems junctions were implemented to reduce flanking transmissions. In this article authors demonstrate how measured results performed on the multistory mockup can be further implemented in the standard EN 12354 model or in a full physical SEA model. Engineer prediction tool proposed by EN 12354 series standard is based on SEA, it is also based on measured Kij characteristics to predict flanking transmissions. Comparison between the different types of junctions measured show efficient strategies of building systems. Future acoustic prediction strategies will be based on measured Kij of smart junctions that include resilient channels and dampers. Industry is very creative in this domain and the only differentiation solution is to make available appropriately characterized products, with Kij measurements in open access.

Keywords: *Wooden building – Flanking transmission – Measurements – Predictions.*

1. Introduction

In 2020, a mockup has been designed in order to investigate acoustic performance of wood-based buildings, it has been constructed on FCBA Bordeaux site in France [1]. The mockup is a CLT based building of three floors construction, with four rooms on each level. In this article we present junction characterization performed during the acoustic measurement campaign of AMC Mecanocaucho. Together with FCBA, AMC implemented and tested different configurations of wall and floors including smart joints able to decrease coupling in structural junctions. The aim of this measurement campaign was to develop acoustically optimized innovative constructive solutions, based on CLT panels, which fulfil acoustic, thermal, environmental quality and cost performance objectives. Thus, in this paper the "Maquette Acoustique Bois" is used to measure vibration reductions levels indexes Kij, in different configurations, where smart building systems junctions are implemented to reduce flanking transmissions.

A model is proposed in standard EN 12354-series [2-3], it uses junction characteristics Kij to be measured. In this article authors show measurements results performed on the multistory mockup that can be further implemented in the standard EN 12354 model or in the full physical SEA model. Comparison between the different types of junctions measured show efficient strategies of building systems.

Acoustic regulatory requirements applicable in European countries are expressed in terms of acoustic descriptors considering in situ situations. This implies the need for a preliminary design to meet the acoustic performance of the building systems once implemented in the building. This is the reason why acoustic prediction models are required for building design in relation to their acoustic performance. The required acoustic objectives for dwellings correspond to $D_{nT,w}+C \geq 53$ dB and $L'_{nT,w} \leq 58$ dB. In addition to the French regulation, Cerqual Qualitel Certification body, requires for residential building projects, $L'_{nT,w} \leq 55$ dB and $L'_{nT,w} + C_{I,50\text{-}2500} \leq 55$ dB.

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2. Mockup Description

The mockup is a three-floor construction, with four rooms on each level. The construction is based on CLT panels for walls and floors, laminated wood posts and beams, and lightweight wood frame facade. Some double frame plasterboard based separating walls are also included. Some junctions incorporate resilient elements in order to evaluate their effect and advantages in acoustic performance.

A general view of the mockup is depicted in Figure 1; temporary stairs on each of the four facades allow you to access the different room. The floor plan for each of the three levels is shown in Figure 2. The ground and middle floors are separated into two small and two large rooms (respectively ~14 m² and ~20 m²). On the top floor, the two smaller rooms remain but the other space is separated differently into two spaces much longer than wide (same surface area ~20 m²). In Figure 2, the walls in blue represent lightweight plasterboard-based walls. On the lower level (ground floor) the floor is made of concrete directly poured on the ground (micro piles were installed in the ground for building stability). The posts on which the vertical walls are connected to on the facade side, are visible in Figure 2; their section is 200 mm x 200 mm. The peripheral beams on which the facade is attached have a section of 200 mm x 400mm.

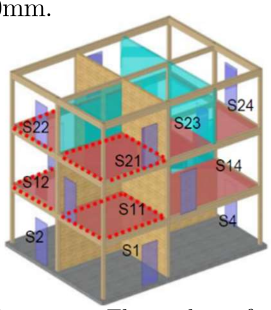


Figure 1: Floor plan of the mockup

Figure 2: View of the mockup

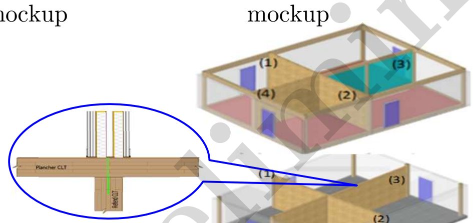


Figure 3: Studied junction, continuous 140 mm CLT floor, loading structure, with different linings and floor toppings.

The façade walls are prefabricated wood frame walls, 145 mm in thickness including mineral wool and bracing panel on the outdoor side. A lining composed of 2 layers of 12.5 mm thick plater board mounted on independent metallic frame and a 45 mm layer of mineral wool, is applied to all the inner sides of the façade elements. As seen on Figure 1 an external cladding is also implemented on the facade for weather protection.

3. Flanking transmission measurements

Measurements are performed for Vibration Transmission Levels between subsystems of rooms. So that each transmission channel is characterized.

The modelling strategy to predict such structures is based on Statistical Energy Analysis (SEA). SEA involves cutting the structure into subsystems and decomposing the spectrum into third-octaves or octaves. In this way, the exchange of energy flow in the substructures can be analyzed. The parameters that govern vibrational transmission between subsystems are damping and coupling loss factors and can be identified experimentally by reversing the problem. The approach is, first, based on sub-structuring strategy of structure; second, on experimentally measured coupling and damping loss factors; third, on extracting vibration level difference to estimate one by one all flanking passes.

3.1 Objectives

One of the data for characterization of the flanking transmissions is the sound attenuations of the junctions and those are quantified by the vibration parameter (D_{vij}: velocity level difference). This quantity is an input data for the predictive calculations of the acoustic sound insulation between two rooms. The D_{vij} value of a flanking path is obtained from direct measurements in junctions. The objective of this task is to measure the vibration level difference in different kinds of junctions.

3.2 Methodology

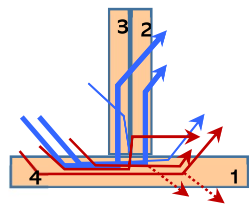
The velocity level difference ($D_{v,ij}$) is obtained from direct measurements of vibration levels in elements i and j at a junction level. While measuring vibration levels, FCBA conducted a complete measurement campaign based on Reverse SEA, so that all coupling and damping can be determined for each flanking pass (between each sub-system).

The junction measurement method is based on standard NF-EN ISO 10848 (2017) series and adapted for the lightweight elements in situ situation [4].

The mechanical excitation is uniformly distributed over the emission plate using a "rain on the roof" hammer excitation for walls and floors. The vibration fields were measured with 4 accelerometer positions and located over the whole element in order to estimate the total energy.

Measurements were conducted between two rooms; the cross junction is composed of a continuous floor on a CLT partition wall (ground floor) and a lightweight partition wall on the first floor.

Figure 4: For each building system tested we adopted the following sub-structuration and subsystem names.



4. Measured vibration reduction level $D_{v,ij}$

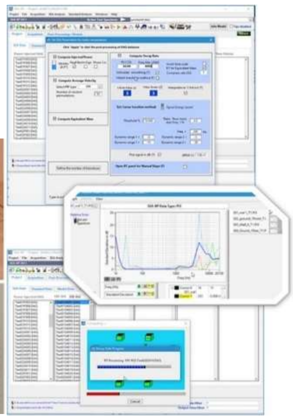
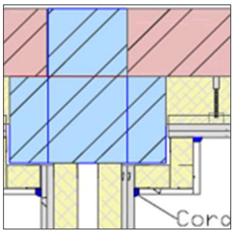


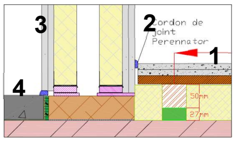
Figure 5: Tested building systems, CLT floor with floor topping

Figure 6: Data reduction, Experimental SEA

For testing, we used SEA-XP [6] software developed by InterAC. The tool is user-friendly. Measurement generates hundreds of files. Each hammer shock is recorded with all acceleration files collected by the transducers. SEA-XP helps for data reduction and data management. For each determination of vibrational energy on each subsystem we use the mean of minimum 20 positions. The testing standard requires a minimum of 6 positions to be applicable.

4.1 Horizontal configuration n°1





Sub-system 1: S14 – floor topping. Fermacell + OSB plates supported on vibration isolators (resilient channels), Akustik + Sylomer 25 Floor Mount, AMC. Glass wool in cavity on CLT structure.

Sub-system 2: S14 - partition wall.

Sub-system 3: S13 - partition wall. 2 BA13dB with glass wool supported on AMC vibration isolators (Sylomer EP 500 + S35 AMC)

Sub-system 4: S13 - floor. Concrete screed 50 mm on 3mm underlayer.

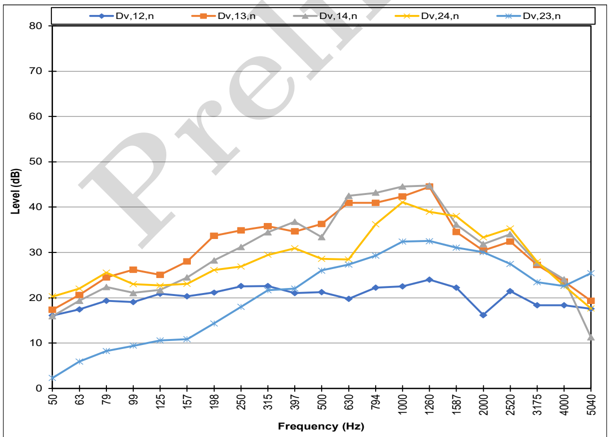
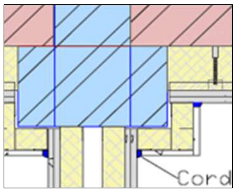
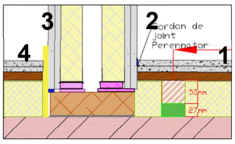


Figure 7: Horizontal configuration n°1, Tested structure, flanking passes $D_{v,ij}$,. In-situ measurement: $D_{nT,w}$+C=54dB, $L'_{nT,w}$ = 41 dB and $L'_{nT,w}$ + $C_{I,50\text{-}2500}$ = 43 dB

4.2 Horizontal configuration n°2





Sub-system 1: S14 – floor topping. Fermacell + OSB plates supported on vibration isolators (resilient channels), Akustik + Sylomer 25 Floor Mount, AMC. Glass wool in cavity on CLT structure.

Sub-system 2: S14 - partition wall.

Sub-system 3: S13 - partition wall. 2 BA13dB with glass wool

Supported on AMC vibration isolators (Sylomer EP 500 + S35 AMC)

Sub-system 4: S13 - floor topping. Fermacell + OSB plates supported on vibration isolators, (resilient channels), Akustik + Sylomer 25 Floor Mount, AMC. Glass wool in cavity on CLT

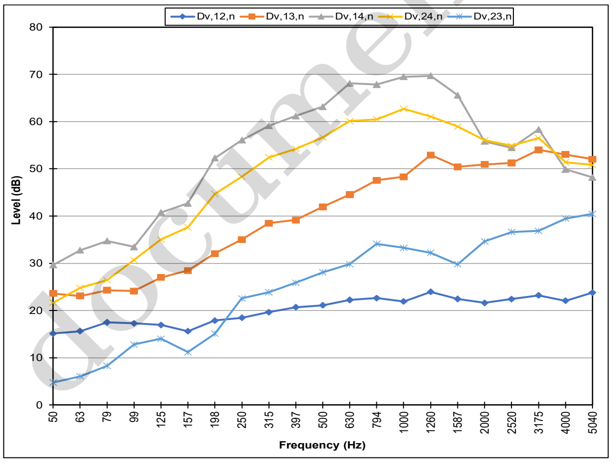
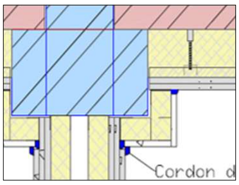


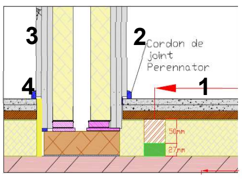
Figure 8: Horizontal configuration n°2, Tested structure, flanking passes $D_{v,ij}$,. In-situ measurement: $D_{nT,w}$+C=54dB, $L'_{nT,w}$ = 42 dB and $L'_{nT,w}$ + $C_{I,50\text{-}2500}$ = 43 dB

4.3. Horizontal configuration n°3



Sub-system 1: S14 – floor topping. Fermacell + OSB plates supported on vibration isolators (resilient channels), Akustik + Sylomer 25 Floor Mount, AMC. Glass wool in cavity on CLT structure.

Sub-system 2: S14 - partition wall. **Sub-system 3**: S13 - partition wall.



3 BA13dB with glass wool

Supported on AMC vibration isolators (Sylomer EP 500 + S35 AMC)

Sub-system 4: S13 - floor topping. Fermacell + OSB plates supported on vibration isolators, (resilient channels), Akustik + Sylomer 25 Floor Mount, Amc. Glass wool in cavity on CLT structure.

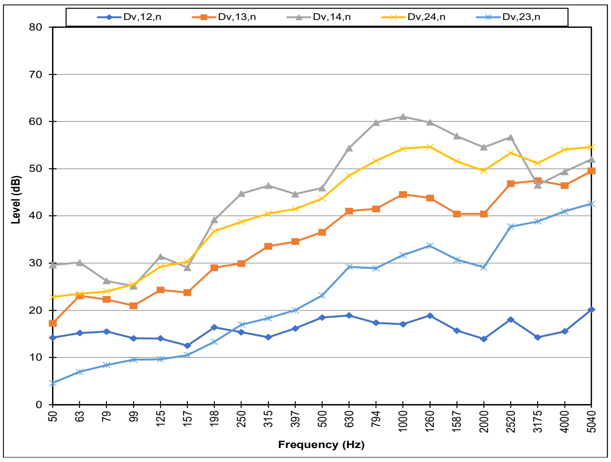
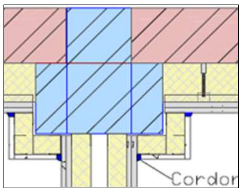
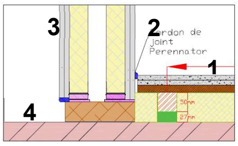


Figure 9: Horizontal configuration n°3, Tested structure, flanking passes $D_{v,ij}$. In-situ measurement: $D_{nT,w}+C$ =56dB, $L'_{nT,w}$ = 43 dB, and $L'_{nT,w} + C_{I,50\text{-}2500}$ = 43 dB

4.4. Horizontal configuration n°4





Sub-system 1: S14 – floor topping. Fermacell + OSB plates supported on vibration isolators (resilient channels), AKUSTIK + SYLOMER 25 FLOOR MOUNT, AMC. Glass wool in cavity on CLT structure.

Sub-system 2: S14 - partition wall.

Sub-system 3: S13 - partition wall. **2 BA13dB** with glass wool Supported on AMC vibration isolators (Sylomer EP 500 + S35 AMC)

Sub-system 4: S13 - floor CLT 140 mm, bare structure

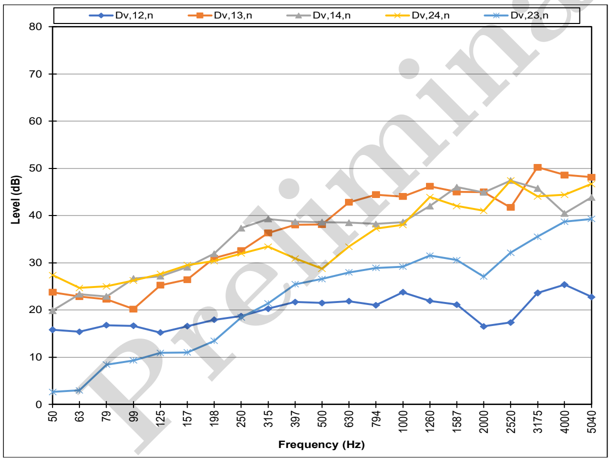
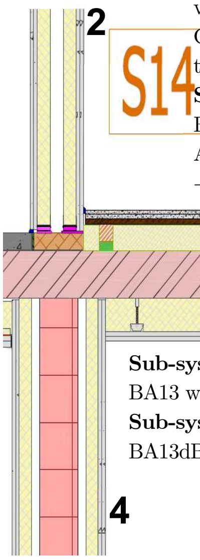
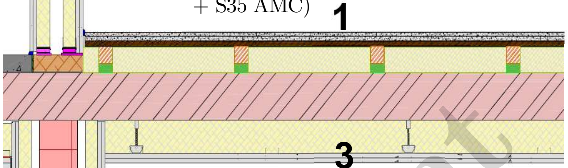


Figure 10: Horizontal configuration n°4, Tested structure, flanking passes $D_{v,ij}$,

4.5. Vertical configuration n°5





Sub-system 1: S14 – floor topping. Fermacell + OSB plates supported on vibration isolators (resilient channels). Glass wool in cavity between decking and the CLT structure.

Sub-system 2: S14 - partition wall, 2 BA13dB with glass wool. Supported on AMC vibration isolators (Sylomer EP 500 + S35 AMC)

Sub-system 3: S04 – suspended ceiling, 2 BA13 with 80 mm glass wool.

Sub-system 4: S04 – wall linings, 2 BA13dB with glass wool.

S04r bis

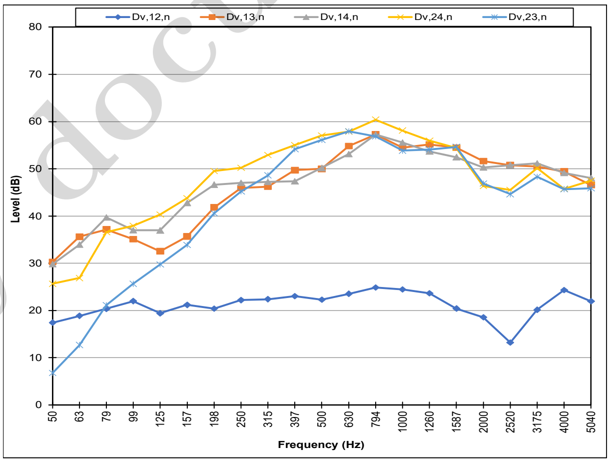


Figure 11: Vertical configuration n°5, Tested structure, flanking passes $D_{v,ij}$. In-situ measurement: $D_{nT,w}+C$ =70dB, $L'_{nT,w}$ = 35 dB and $L'_{nT,w} + C_{I,50\text{-}2500}$ = 48 dB

5. Flanking transmission model

For homogeneous walls perfectly assembled a T junction creates a SEA model of 5 sub-systems: 2 cavities (rooms) and 3 walls forming the junction [5]. Each path corresponds to a noise reduction:

$$\tau_{ij} = \sqrt{\left(\tau_i \tau_j d_{ij} d_{ji} \frac{S_j S_i}{S_0^2}\right)} \quad (1)$$

With R = 10 Log (1/τ) :

$$R_{ij} = \frac{R_i}{2} + \frac{R_j}{2} + \frac{D_{ij} + D_{ji}}{2} + 10\log\frac{S_0}{\sqrt{S_i S_j}} \quad (2)$$

In case of light weight constructionn the vibration transmission via double walls, the model used must be different. In year 2000 EN12354 was published, the calculation model uses:

R, Sound transmission loss of wall and floors,

T_s, Structural reverberation time,

K_{ij}, Vibration reduction index.

K_{ij} is specific to junction type. It is for homogeneous heavy weight structures

$$K_{ij}=\frac{D_{ij}+D_{ji}}{2}+10\text{Log}\frac{l_{ij}}{\sqrt{a_i a_j}} \qquad (3)$$

With a_i equivalent absorption length:

$$a_i=\frac{2.2\pi^2 S_i}{c_0 T_s}\sqrt{\frac{f_{ref}}{f}} \qquad (4)$$

For lightweight walls and floors strongly damped the method proposes K_{ij} formulas:

$$K''_{ij}=\frac{D_{ij}+D_{ji}}{2}+10\text{Log}\frac{l_{ij} l_0}{\sqrt{S_i S_j}} \qquad (5)$$

And $$R_{ij}=\frac{R_i}{2}+\frac{R_j}{2}+K''_{ij}+10\log\frac{S_0}{l_{ij} l_0} \qquad (6)$$

In newly published EN 10848 [4] more precise designation of lightweight junctions are identified K"$_{ij}$ is actually $D_{v,ij,n}$ bidirectional vibration reduction level.

During 2007 COST action FP0702 was started, working group 1 on modelling, proposed a more appropriate prediction method for timber framed construction. The group acknowledged any other calculation method using FEM, SEA, Reverse SEA or Virtual SEA [6-7]. This opened several research axes and created a new generation of projects.

$D_{v,ij}$ (vibration reduction level) is measured in situ on junctions. The measurement method is based on a uniform mechanical excitation using several hammer or shaker positions. $D_{v,ij}$ are measured using multiple transducers positions.

The sound transmission loss resulting of all passes is calculated with:

$$R'=-10\log\left[10^{-\frac{R}{10}}+\sum_{ij}10^{-\frac{R_{ij}}{10}}\right] \qquad (7)$$

And finally, the sound reduction is obtained with R':

$$D_{nT}=R' - 10\log\frac{0.16\ V}{T_0 S_s} \qquad (8)$$

6. Case study

In this article authors demonstrate how measured vibration attenuations on the multistorey mockup can be further implemented in a model according to standard [2] EN 12354-1. Measured $D_{v,ij,n}$ of smart junctions that include resilient channels and dampers are used to predict airborne improvements and impact noise reduction in buildings.

6.1 Method

Standardized sound level difference D_{nT} was calculated between two adjacent rooms. Each room had a surface of 12 m² and a height of 2,5 m so that the dimensions correspond to a typical bedroom. The calculation was based on the method implemented in standard [2] EN 12354-1 for type B elements as defined in the standard (lightweight elements such as plasterboards or wood panels mounted on wood or metal frames).

The floor transmission path was calculated using $D_{v,ij,n}$ measured in horizontal configuration n°2 (Fermacell floor topping on each side and inter-tenancy wall made of 2 layers of BA13dB). All other transmission paths (ceiling, facade and internal wall) were calculated using $D_{v,ij,n}$ based on standard [2] EN 12354-1 - Annex F.

6.2 Input data

The performances of all input data were calculated using Insul v9, software developed by Marshall Day Acoustics for predicting the sound insulation of walls, floors, roofs, ceilings and windows and impact sound and rain noise of floors and roof.

Element	Description	Mass (kg/m²)	Sound reduction index R_w (C; C_{tr})
Inter-tenancy wall (sub-system 2-3)	2 BA13dB each side Glass wool 2 x 45mm Thickness: 180mm	53	68 (-3; -10)
Floor (sub-system 1-4)	2 Fermacell 12,5mm 1 OSB 18mm	39	38 (-1; -2)
Ceiling, Facade, Internal wall	2 BA13	18	33 (-1; -3)

Junctions between inter-tenancy wall and floor/ceiling were considered in the calculation as shown in 4.2. For the facade and internal wall, all plasterboards were considered interrupted by the inter-tenancy wall as shown below.

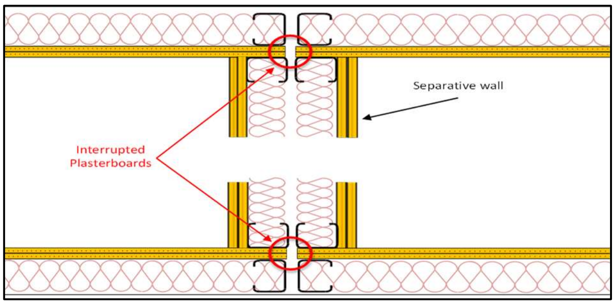


Figure 12: Horizontal section of the facade and internal wall junction, all plasterboards were considered interrupted by the inter-tenancy wall.

6.3 Prediction

The table below shows the calculation result. D_{nT} was calculated using equation (8) and $D_{nT,w}$ (C; Ctr) was calculated based on standard 717-1 (2013).

Transmission path	dB(A)	50	63	80	100	125	160	200	250	315
Direct direct	64.9	18.0	26.0	33.0	40.0	45.0	51.0	56.0	61.0	65.0
R_{Dd} Inter-tenancy wall	**64.9**	**18.0**	**26.0**	**33.0**	**40.0**	**45.0**	**51.0**	**56.0**	**61.0**	**65.0**
Direct flanking	91.9	54.5	59.0	61.0	67.0	73.0	77.0	86.0	90.0	96.0
Flanking direct	91.9	54.5	59.0	61.0	67.0	73.0	77.0	86.0	90.0	96.0
Flanking flanking	96.7	64.0	69.0	72.0	71.0	81.0	84.0	95.0	100.0	105.0
$R_{Df} + R_{Fd} + R_{Ff}$ Floor	**88.2**	**51.2**	**55.8**	**57.8**	**63.2**	**69.6**	**73.6**	**82.7**	**86.8**	**92.7**
Direct flanking	81.5	54.2	56.5	58.9	61.2	64.5	66.9	70.2	73.0	75.8
Flanking direct	81.5	54.2	56.5	58.9	61.2	64.5	66.9	70.2	73.0	75.8
Flanking flanking	78.1	60.7	62.0	63.4	64.7	67.0	68.3	70.7	73.0	74.3
$R_{Df} + R_{Fd} + R_{Ff}$ Ceiling	**75.3**	**50.7**	**52.9**	**55.2**	**57.3**	**60.4**	**62.6**	**65.6**	**68.2**	**70.5**
Direct flanking	83.6	56.2	58.6	60.9	63.2	66.5	68.9	72.2	75.0	77.9
Flanking direct	83.6	56.2	58.6	60.9	63.2	66.5	68.9	72.2	75.0	77.9
Flanking flanking	82.3	54.7	57.1	59.4	61.7	65.0	67.4	70.7	74.0	76.4
$R_{Df} + R_{Fd} + R_{Ff}$ Facade	**78.3**	**50.9**	**53.2**	**55.6**	**57.9**	**61.2**	**63.6**	**66.9**	**69.9**	**72.5**
Direct flanking	83.6	56.2	58.6	60.9	63.2	66.5	68.9	72.2	75.0	77.9
Flanking direct	83.6	56.2	58.6	60.9	63.2	66.5	68.9	72.2	75.0	77.9
Flanking flanking	82.3	54.7	57.1	59.4	61.7	65.0	67.4	70.7	74.0	76.4
$R_{Df} + R_{Fd} + R_{Ff}$ Internal wall	**78.3**	**50.9**	**53.2**	**55.6**	**57.9**	**61.2**	**63.6**	**66.9**	**69.9**	**72.5**
$D_{nT,A}$ (100-3150 Hz)	**64.0**	**17.8**	**25.8**	**32.7**	**39.6**	**44.5**	**50.1**	**54.8**	**59.2**	**62.7**
			21.8			**42.9**			**57.7**	

$D_{nT,w}$ $(C;C_{tr})$ = 67 (-3;-10) dB

Results show that the attenuation through the floor transmission path (88,2 dB(A)) is at least 10 dB(A) higher than the attenuation through all other transmission paths because of the high performance of the resilient materials installed under the floor and the inter-tenancy wall.

Standardized sound level difference $D_{nT,w}$+C was 64 dB which meets the required acoustic performance objective for dwellings ($D_{nT,w}$+C ≥ 53 dB).

7. Discussion and conclusions

With several past and undergoing projects we had the chance to measure characteristics of structures at different implementation stages. Wall and floor configurations were measured in acoustic facility and in-situ. In that process we got the complete picture of the flanking transmissions influence. In general, for wooden structures, the influence of flanking transmissions is small on the observed measurements. Also, vibro-acoustic measurements help to visualize the energy flow.

In this article authors demonstrate how measured vibration attenuations can be further implemented in EN 12354 model that uses simplified SEA as a theory framework. Measured $D_{v,ij,n}$ of smart junctions that include resilient channels and dampers were used to predict airborne improvements in buildings.

While comparing influence on airborne sound transmission and impact transmission one can see the influence of smart joints enhancement. Building with wood is very familiar with the use of smart joints. In this article we presented measured high vibration reduction levels $D_{v,ij}$ that reduce significantly flanking transmission. For that reason, flanking transmissions are of a small influence on the final result.

Anyhow, vibrational qualification of enhanced building junctions and smart joints are claimed by industrial suppliers. Laboratories have to agree on a robust qualification way that can be used in a secured way. Future acoustic prediction strategies will be based on measured K_{ij} of smart junctions that include resilient channels and dampers. Industry is very creative in this domain and the only differentiation solution is to make available appropriately characterized products, with K_{ij} measurements in open access.

8. ACKNOWLEDGEMENTS

The authors would like to acknowledge AMC Mecanocaucho for sharing their private research results. Also, for the Facility building FCBA would like to acknowledge the financial support of AdivBois, the Professional Development Committee of French Furniture and Wood Industries (CODIFAB) and the Nouvelle-Aquitaine region. In addition, the authors would like to thank partners of the project CSTB and CERQUAL.

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