RAW EARTH BRICK WALLS AND WOOD ELEMENTS – JUNCTIONS CHARACTERIZATION AND SOUND INSULATION

C. Guigou-Carter[1], P. Brie[2], A. Clément[3], P. Ducruet[1], S. Tochon-Danguy[3]
[1]*CSTB, Health, Environment and Mobility Department, 38400 Saint Martin d'Hères, France*
[2]*LASA, 30 Rue Saint-Sernin, 33000 Bordeaux, France*
[3]*LASA, 20 Bd Eugène Deruelle, 69003 Lyon, France*

Abstract

The building sector is confronted with two key challenges: minimizing the environmental impacts while ensuring occupants well-being. In this context, the use of sustainable materials with high thermal and acoustical performances appears as a necessity. Raw earth appears as strategic low-carbon material, as it is naturally abundant, locally available and renewable. It also offers interesting thermal properties to improve summer comfort, thus impacting the energy efficiency and comfort of buildings. Raw earth construction often includes wood elements as structural components.
The main objective of the CarAc'Terre project is to remove regulatory and normative obstacles to raw earth construction techniques relative to acoustics. A multi-scale methodology for characterizing the acoustic performance of raw earth construction systems is proposed using both a performance-based and a perceptual approach.
A small-size building was constructed out of raw earth bricks in order to characterize vibration reduction index of junctions. The effect of the presence of wood post at the junction was examined, as well as the presence of wood-based cladding to limit acoustic leakage at wood-brick interface. Furthermore, Cross Laminated Timber (CLT) panels covered the construction and the associated junctions were also evaluated. Some rooms were closed using a wood-based stud walls in order to measure airborne sound insulation performance.
This paper describes the small-size building, the junction characterization measurement results as well as measured and predicted sound insulation.

Corresponding author: *catherine.guigou@cstb.fr*

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1. Introduction

The main objectives of the CarAc'Terre project are to characterize the acoustic performance of raw earth constructions from a physical and sensory perspective, distinguishing the contributions from material formulation, wall composition, and their implementation.
The project is part of a larger scope development [1], aiming to enable a new, large-scale deployment of raw earth constructions by removing cultural, socio-economic, technical, insurance, and regulatory barriers, particularly by involving craftsmen in the earth industry.
Indeed, environmental regulations strongly influence material choices by imposing strict standards on energy performance and carbon emissions. Raw earth, as a low-carbon material, is a response to these requirements, promoting sustainable construction that respects natural resources. Such a strategic material, naturally abundant and renewable, also offers interesting thermal and hygroscopic properties to improve indoor comfort, especially in summer, and to enhance energy efficiency of buildings.
However, the critical lack of acoustic data on raw earth is a major obstacle to its widespread specification and use. Without this information, architects, acousticians, designers, and construction professionals in general are still hesitant to adopt this material, despite its numerous environmental benefits.
Work has been dedicated to the material scale as well as the wall scale [2-5]. The material scale deals with evaluating the effect of soil properties on the acoustic behaviour. Understanding the contribution of soil characteristics (particle size distribution, clay type and content, etc.) with respect to acoustic behaviour, is a major step in order to account for their effects on

acoustic performance at the wall scale. Investigations at the wall scale have concentrated on laboratory measurement of sound reduction index for different types of earth wall systems, as well as prediction of the acoustic performance [2,4] in order to extend laboratory measurements. Regarding the building scale, numerous in-situ measurements have been performance in raw earth constructions. However, it is desirable to be able to predict before building construction the acoustic performance including the direct path as well as flanking paths. To this end a simple small-size building was designed and constructed to evaluate junctions behavior necessary to predict flanking paths.
The paper is divided into three parts. The first part describes the small-size building, the second part the junction characterization measurement results and a third part a comparison between measured and predicted sound insulation.

2. Small-size building description

A small-size but full-scale building was constructed featuring a timber frame, extruded raw earth brick walls, and a CLT roof, all set on a concrete slab. This building was specifically designed and built to measure vibration reduction indices (K_{ij}) at junctions (between brick walls and between brick walls and the CLT roof). Additionally, the building was used to study flanking transmission at junctions between brick walls and timber elements through intensive sound intensity measurement campaigns. These acoustic measurements are not discussed in this paper.
The small size building consists of a post-and-beam timber structure erected on a concrete slab. Seven extruded raw earth brick walls, 10 cm in thickness, are built upon concrete starter plinths. The roof is made of six CLT panels — each 120 mm thick (40/40/40), 6.8 m long, and 1,12 m wide —protected by a tarpaulin. The total roof area is 6.8 m by 13 m, with panels joined via an 80 mm lap joint (overlap) and a 60 mm depth.
Of the six defined rooms, two are enclosed at the perimeter by timber-frame facades made of OSB panels and recycled textile fiber insulation, enabling additional acoustic measurements to study flanking transmission. A general view of the building is shown in Fig. 1.

Figure 1. General view of the small size building.

A top view of the small size building is presented in Fig. 2, along with the notation for the different brick walls (from A to G) and the associating ceiling (T1 to T6).

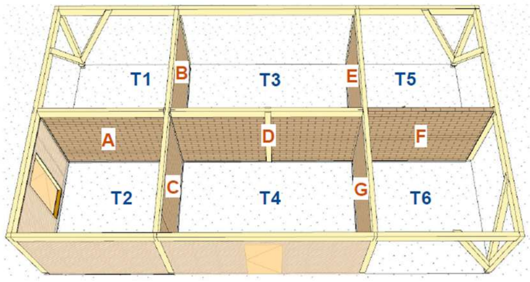

Figure 2. Top view of the small size building.

Two types of X junctions of brick walls are investigated:

- junction between brick walls A, B, C and D around a wood post (of section 150 mm x 150 mm) as seen in Fig. 3;
- junction between brick walls D, E , F and G with bricks crossed at the junction between each layer, as seen in Fig. 4.

As observed in Fig.3, for the junction including a post, two compression bands per post side are implement; furthermore, a metallic bracket screwed to the wood post was placed every 4 layers of bricks for structural reason.

At the top of the brick walls under a beam, a large resilient strip of wood fibre is implemented before filling the gap with earth mortar (same type as used between bricks).
Besides, the central brick wall (denoted D in Fig. 2) was separated in the middle by a wood post (see Fig. 5).
The beams on top of the brick wall are 250 mm high. The brick walls A, B, C, E and G are 2.10 m in height (composed of 17 layers of brick) and 2.85 m in length. The brick wall F does not have a top beam and is 2.35 m high. The central brick wall D has a total length of 4.4 m
Moreover, the two brick walls B and E were removed at the end of the measurement campaign in order to provide T-junctions rather than X-junctions.
The brick walls have a mass per unit area of about 190 kg/m², and the CLT cover of 60 kg/m². They cannot be considered as heavy elements. However, for the junctions of brick walls, the vibration reduction index will be compared to the one given by ISO 12354-1 [6] for heavy buildings.

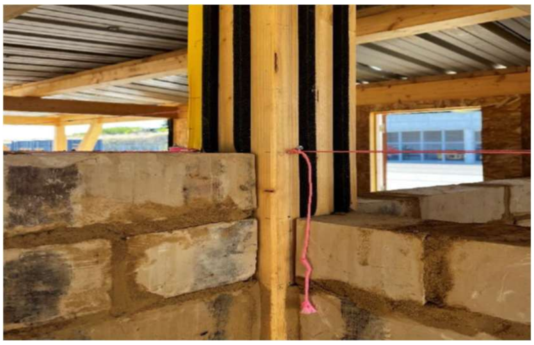

Figure 3. X junction of brick walls around wood post.

Figure 4. X junction of brick walls.

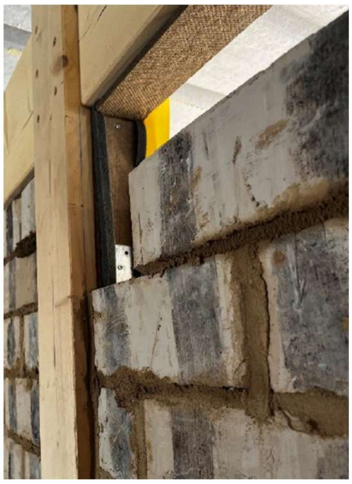

Figure 5. Wall D separated with wood post at the centre.

3. Vibration reduction index

Measurements have been carried out independently by two teams on the basis of ISO 10848-1 [7]. The excitation was performed using an impact hammer and velocity levels evaluated by accelerometers. A number of 4 excitation positions was considered on each structural element (brick wall or CLT cover). A number of 16 accelerometer positions were implemented on each structural element included in the investigated junction; 4 different randomly selected positions being used for each excitation position. Structural reverberation was also measured.

3.1 Type of the structural elements

Preliminary checks were carried out to validate the wall typology in accordance with the ISO 10848 standards [7-8], as well as the third-octave bands to which the typology assumption applies. The standard distinguishes between Type A and Type B structural elements. Junctions of Type A elements are characterized by the vibration reduction index, while junctions of Type B elements by the normalized direction-averaged vibration level difference.

A Type A element is an element with a structural reverberation time primarily determined by surrounding elements (at least up to the 1000 Hz third-octave band) and exhibiting a vibration level drop of less than 6 dB across the element in the direction perpendicular to the junction axis (at least up to the 1000 Hz third-octave band).

A Type B element is an element that does not fall into the Type A category. An element may be classified as Type A only within specific parts of the frequency range; for instance, certain masonry walls may act as Type A elements in the low- and mid-frequency ranges and as Type B elements in the high-frequency range.

Measuring direction averaged junction vibration level difference is the basis for junctions either of Type A elements or of Type B elements.

No indicator is currently defined in ISO 10848 standards [7-8] for mixed junctions involving both Type A and Type B elements.

Two brick walls (central brick wall D and wall F) were considered and attenuation along the wall was measured to determine if Type A or Type B was applicable.

The measurements of structural reverberation time indicate that the modal overlap for the brick walls is larger than unity starting at the one-third octave band of 250 Hz.

The decrease in vibration level with distance was evaluated for the brick wall F as well as the brick wall D (the latter including a post in the middle, see Fig. 5). The decrease in vibration level was investigated following Annex A of ISO 10848-1.

The decrease in vibration level was found to be less than 6 dB across the brick wall F in the direction perpendicular to the cross-junction over the frequency range covering one-third octave bands from 50 to 1000 Hz. On the other hand, the decrease in vibration level was found less than 6 dB across the brick wall D only up to the one-third octave band of 400 Hz.

The CLT elements were not specifically tested and they are assumed to correspond to Type A elements.

Therefore; the vibration transmission across a junction is characterized by using the vibration reduction index K_{ij} for Type A elements or combinations of Type A and Type B elements.

3.2 X-junction of brick walls with wood post

In this section, the X-junction between the brick walls A, B, C and D is considered (see Fig. 2); this X-junction integrates a wood post (see Fig. 3).

The detailed vibration reduction indexes K_{ij} are shown in Fig. 6; continuous and dashed lines indicate measurement results obtained independently by the two teams. The measurements above the one-third octave bands of about 2 kHz should be disregarded due to limited energy injected into the source element. It can be observed that the results from the two measuring teams are in good agreement for all the transmission paths investigated.

Fig. 7 shows the vibration reduction index K_{ij} for the straight and the corner path of the X-junction, as well as the one from ISO 12354-1 [6] (rigid X-junction of heavy elements using a mass ratio of 1). Since this X-junction includes a wood post, it was expected that the Kij from ISO 12354-1 [6] would not be representative and would present lower values (i.e. more transmission at the rigid junction).

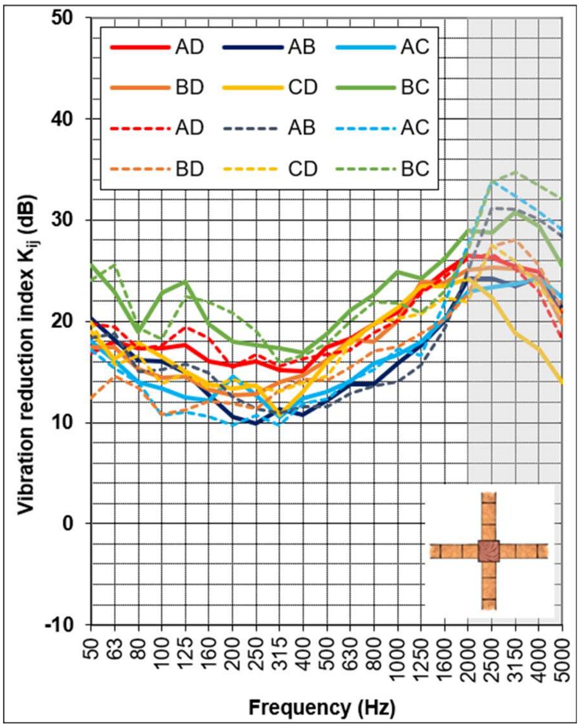

Figure 6. Detailed vibration reduction indexes K_{ij} – X-junction of brick walls around a wood post.

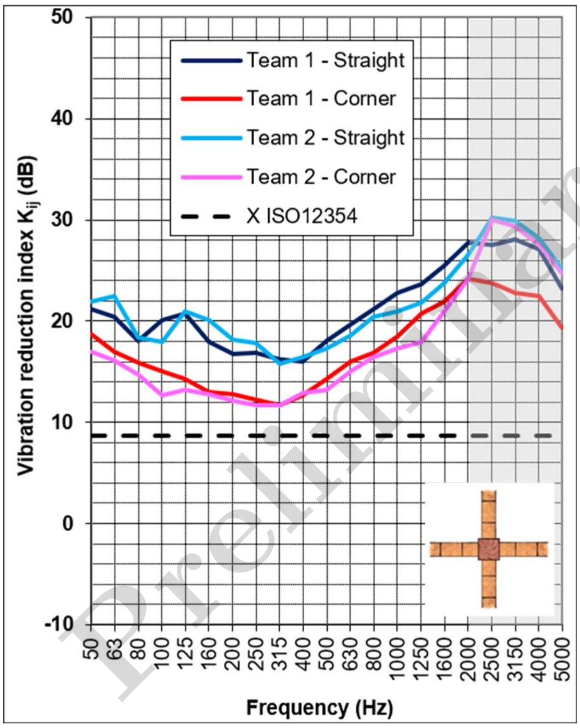

Figure 7. Vibration reduction index K_{ij} – X-junction of brick walls around a wood post.

3.3 X-junction of brick walls without wood post

In this section, the X-junction between the brick walls D, E, F and G is considered (see Fig. 2 and Fig. 4).
Fig. 8 shows the vibration reduction index Kij for the straight and the corner path of the X-junction, as well as the one from ISO 12354-1 (rigid X-junction of heavy elements using a mass ratio of 1). In this case, it can be observed that the results from the two measuring teams are different in the frequency range above 500 Hz. However, measurements from each team lead to similar K_{ij} for the straight and corner paths; this was expected due to the junction construction (bricks crossed at the junction as seen in Fig. 4). The obtained K_{ij} values are also more in line with the K_{ij} from ISO 12354-1 [6].

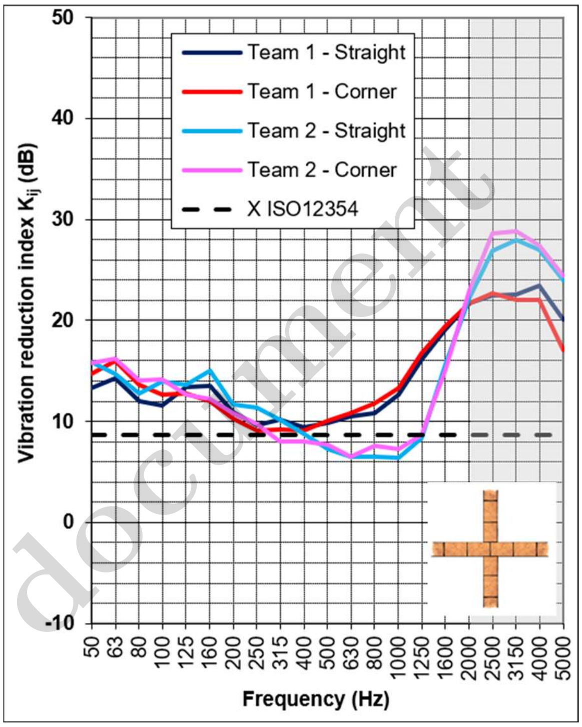

Figure 8. Vibration reduction index K_{ij} – X-junction of brick walls.

3.4 Summary – Junctions of brick walls

Table 1 summarizes the vibration reduction index averaged over the frequency range from 200 to 1250 Hz for the X-junctions and the T-junction (after removing walls B and E, see Fig. 2) between the brick walls.

Table 1. Averaged vibration reduction index K_{ij} for the junctions of brick walls.

Junction	Path	Team 1	Team2
X-junction with wood post	straight	19.0 dB	18.6 dB
	corner	15.1 dB	14.3 dB
X-junction without wood post	straight	11.1 dB	8.6 dB
	corner	11.2 dB	8.3 dB
T-junction with wood post	straight	16.5 dB	15.8 dB
	corner	15.5 dB	15.7 dB
T-junction without wood post	straight	11.6 dB	7.6 dB
	corner	11.7 dB	8.2 dB

3.5 T-junction with CLT cover

T-junctions between a brick wall and the CLT cover are considered in this section. Results are shown for junction integrating a wood beam on top of the brick wall; a difference is made depending on the CLT panel alignment with respect to the junction. Fig. 9 and Fig. 10 present vibration reduction index when the CLT panels orientation is respectively perpendicular and parallel to the considered junction. The notation TG corresponds to the T-junction with the brick wall G (see Fig. 2).

For both types of T-junctions, results from the 2 measurement teams are globally in line. A difference in behavior is indeed observed depending on the CLT panel orientation with respect to the junction. When the CLT panels orientation is perpendicular to the junction, the K_{ij} for the straight (CLT-CLT) path is quite low since the panels are continuous across the junction. When the CLT panels orientation is parallel to the junction, the K_{ij} for the straight and the corner path present a similar behavior, the straight path K_{ij} remaining lower than the corner path K_{ij}.

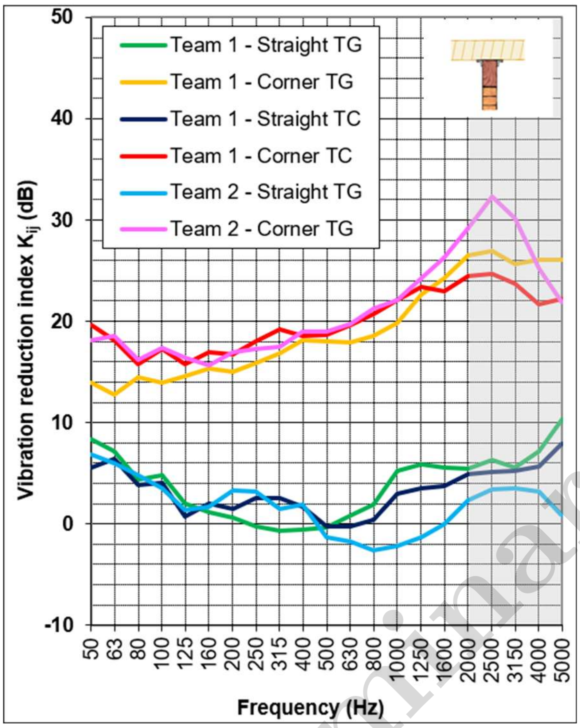

Figure 9. Vibration reduction index K_{ij} – T-junction of brick walls with CLT cover (CLT panels orientation ⊥ to junction).

Table 2 summarizes the vibration reduction index averaged over the frequency range from 200 to 1250 Hz for the T-junctions between the CLT cover and a brick wall.

3.6 Representative K_{ij}

Based on the measurements performed on the different junctions of the small size building, default representative values for vibration reduction index K_{ij} have been proposed (i.e. simplified expressions following the observed frequency trends) for X-junctions and T-junctions involving raw earth brick walls tested in this study as well as T-junction involving a raw earth brick wall and CLT cover.

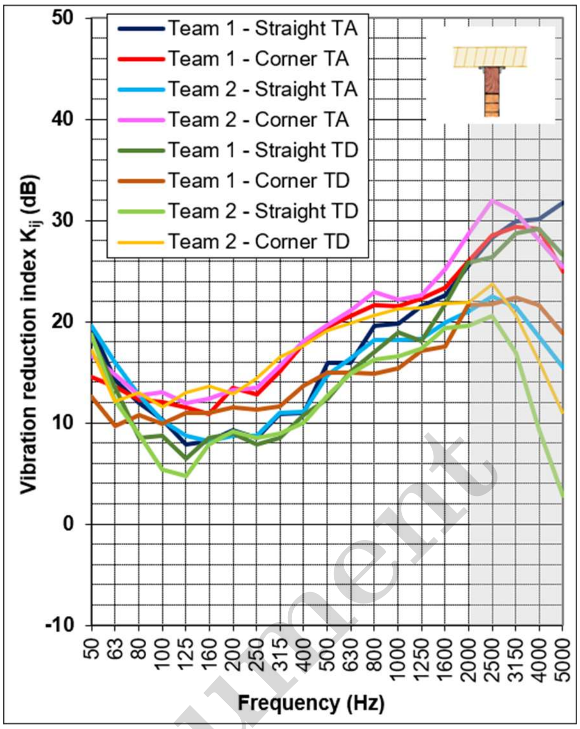

Figure 10. Vibration reduction index K_{ij} – T-junction of brick walls with CLT cover (CLT panels orientation // to junction).

Table 2. Averaged vibration reduction index K_{ij} for T-junctions of CLT cover and a brick wall.

T-junction	Path	Team 1	Team2
C (⊥)	straight	1.4 dB	-
	corner	18.1 dB	-
G (⊥)	straight	1.6 dB	0.1 dB
	corner	19.7 dB	19.7 dB
A (//)	straight	14.7 dB	13.9 dB
	corner	18.3 dB	18.8 dB
D (//)	straight	13.1 dB	12.7 dB
	corner	13.9 dB	18.2 dB
F (// no top beam)	straight	13.8 dB	10.5 dB
	corner	20.2 dB	19.4 dB

4. Sound insulation measurement and prediction

Among acoustic measurements performed on the small size building, sound insulation between the two enclosed rooms (see Fig. 2) is considered in this section. The measured sound insulation is then compared to the predicted one. The prediction is based on the measured sound reduction index performed in the laboratory on the same brick type wall (see [4]). For the CLT panels, the sound reduction index is issued from CSTB database. Representative values proposed for junction vibration reduction indexes are used in the acoustic performance prediction (see Section 3.6). The sound transmission is assessed from the large room (marked T4 in Fig. 2) to the smaller room (marked T2 in Fig.

2). The prediction method follows the one proposed in ISO 12354-1 [6].
Fig. 11 shows the measured and predicted sound insulation along with the different predicted transmission paths. It can be seen that the measured and predicted sound insulation performances are in good agreement. The acoustic performance is limited by the transmission paths associated to the CLT cover. Table 3 presents the associated single number quantities. In order to improve the acoustic performance and reach a $D_{nT,A}$ (=$D_{nT,w}$+C) of 53 dB as required between dwellings in France, a suspended ceiling would have to be implemented under the CLT panels. Furthermore, the performance of the brick wall (direct path) would have to be improved as well by adding a lining for example.

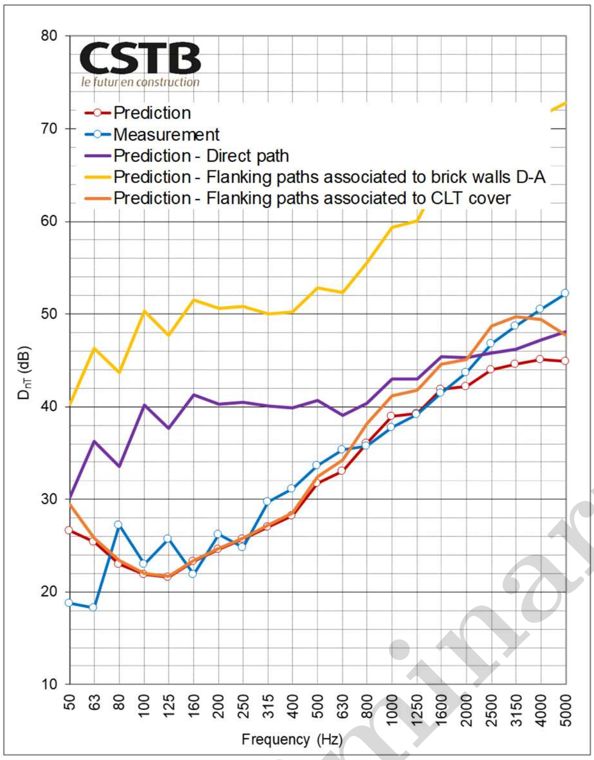

Figure 11. Comparison between measured and predicted sound insulation.

Table 3. Predicted and measured sound insulation performance.

Sound insulation	$D_{nT,w}(C;C_{tr})$	$D_{nT,A}$
Prediction	36(-1;-4) dB	35 dB
Measurement	37(-1;-5) dB	36 dB
Prediction – Direct path	43(0;-1) dB	43 dB
Prediction – Flanking paths brick walls	58(-1;-3) dB	57 dB
Prediction – Flanking paths CLT cover	37(-1;-5) dB	36 dB

5. Conclusion

The paper presented a small-size building made of raw earth brick walls and CLT panels as cover. Junction characterization measurements were described along with the associated results. Measured and predicted sound insulation performances were shown to be in good agreement.
Further work concerns the analysis of the complete set of acoustic measurements performed on that building, as well as a large ensemble of in-situ acoustic measurements carried out in building implementing raw earth based walls. The final goal is to provide examples of constructive raw earth based solutions for dwellings, hotels, offices, and educational buildings that meet French acoustic regulation and recommendation.

6. Acknowledgments

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