DOI: 10.61782/fa.2025.0469

FORUM ACUSTICUM EURONOISE 2025

INFLUENCE OF GRAVEL ON FLANKING TRANSMISSION IN CLT BUILDINGS

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ABSTRACT

Gravel layers are sometimes used to improve the airborne and impact sound insulation of Cross Laminated Timber (CLT) floor constructions. The gravel increases the mass and damping of the bare CLT floor and will also improve the efficiency of a floating floor. It is generally assumed that additions like linings and floating floors do not influence the vibration damping in junctions. While this is usually a reasonable assumption, the effect of the gravel on the vibration damping in CLT junctions cannot be neglected. This paper presents laboratory measurement results for the vibration reduction index of a rigid CLT junction with and without gravel. The influence of the gravel layer on the flanking transmission paths is investigated by means of the simplified SEA model of ISO 12354. SEA simulations, incorporating the effect of the gravel layer, are validated with in situ measurements.

Keywords: *sound insulation, flanking transmission, vibration reduction index, gravel layer, wooden buildings*

1. INTRODUCTION

Due to its relatively low weight and high stiffness, the acoustic performance of bare Cross Laminated Timber (CLT) constructions is limited and acoustic linings are generally necessary to achieve the required sound insulation. A well-established method to improve the impact sound insulation of CLT floors is to increase its mass, e.g. by applying a gravel ballast layer beneath the floating floor [1, 2]. The gravel adds mass that reduces the amplitude of vibrations and shifts the mass-spring-mass-resonance frequency of the floating floor to lower frequencies. In addition to the mass effect, the gravel can enhance energy dissipation, thereby reducing the radiated sound power.

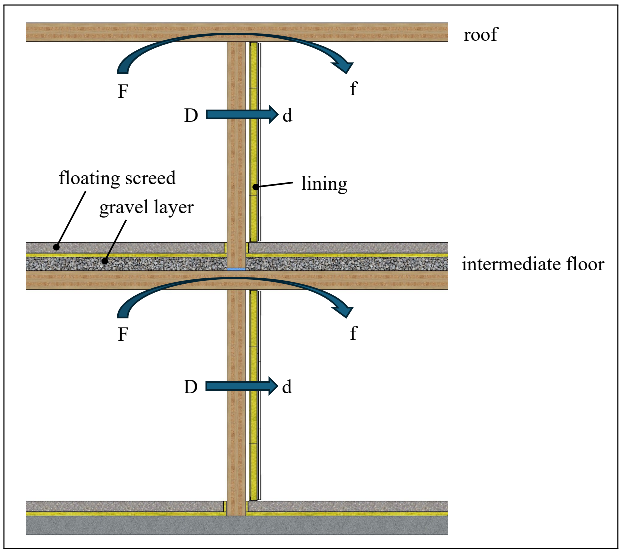

Figure 1. Application of gravel layers in a CLT building

While the influence of gravel layers on the direct airborne and impact sound insulation has been extensively investigated in literature, the effect on flanking transmission is unclear. The vibration transmission across junctions is characterized by the vibration reduction index K_{ij}, which is generally measured on bare junctions according to ISO 10848 [4]. This property can then be used in statistical energy analysis (SEA) calculations,

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e.g. following ISO 12354 [5], where it is assumed that linings and floating floors do not influence K_{ij}. This assumption seems not valid for CLT junctions loaded with a gravel layer. In situ measurements in CLT apartment buildings with such floors have systematically indicated significantly higher airborne sound insulation values at intermediate floors than at the top floor (Figure 1). The observed differences cannot be entirely explained by the variation in K_{ij} of T- and cross junctions, which is on average 3 dB for heavy rigid junctions.

In this paper, the effect of a gravel layer on the flanking transmission across junctions of CLT walls and floors is investigated by means of laboratory K_{ij}-measurements (section 2) and simulations of *in situ* airborne sound insulation according to ISO 12354-1 (section 3).

2. LABORATORY MEASUREMENTS

2.1 CLT mockup

A full-scale mockup of a CLT junction was realised at the acoustics laboratory of Buildwise to measure the vibration reduction index of a reference junction without gravel, a junction with a 2.5 cm gravel layer and a junction with a 5 cm gravel layer. The horizontal L-junction consists of a 5-ply CLT-floor with thickness 14 cm and dimensions $4.93\,\mathrm{m} \times 2.25\,\mathrm{m}$ and a 5-ply CLT wall with thickness 12 cm and dimensions $3.94\,\mathrm{m} \times 2.40\,\mathrm{m}$. The density of the CLT floor and wall is approximately $485\,\mathrm{kg/m^3}$ and $470\,\mathrm{kg/m^3}$ respectively. The wall was placed between two transmission chambers of the acoustics laboratory with the top 0.6 m of the panel protruding from the chambers. The floor panel was placed on one side on the wall panel and on the other side on concrete blocks resting on the concrete ceiling of the transmission chambers. To ensure maximum contact between the floor and the wall, a very thin layer of plaster was used to level out the slight roughness and non-flatness of the wood.

Wooden boards were screwed into the CLT floor around the perimeter to create a box to hold the gravel (Figure 2). The CLT floor was covered with a gravel layer with an average thickness of 5 cm (Figure 3). A plastic foil was placed beneath the gravel to avoid the CLT panel getting wet because the gravel was still damp when placed on the floor. However, the gravel was completely dry at the moment of the measurements. Afterwards, half of the gravel was removed and the remaining gravel was levelled to a thickness of approximately 2.5 cm. Finally, the vibration reduction index of the reference junction with box but without gravel was measured.

Figure 2. Reference junction without gravel

Figure 3. Junction with 5 cm gravel

The gravel has a density of approximately $1080\,\mathrm{kg/m^3}$, as measured in dry condition after the K_{ij}-measurements, and the size of the round aggregates varies widely with pebbles up to 7 cm. The mass loading of the gravel layer is approximately 600 kg ($54\,\mathrm{kg/m^2}$) and 300 kg ($27\,\mathrm{kg/m^2}$) for the 5 cm and 2.5 cm thick gravel layer respectively.

2.2 Measurement procedure

The vibration reduction index K_{ij} between the floor and the wall was measured according to the ISO 10848 standards series [4]. The velocity level of both panels was measured simultaneously using eight accelerometers on each panel. The accelerometers were glued to the bottom side of the floor panel and to the outer side of the wall panel. Each panel was excited at three different locations using hammer excitation over an area of approximately $1\,\mathrm{m}^2$. The floor was excited at the underside, also for the reference measurement. The same accelerometer and excitation positions were used for the three junctions.

To limit the effect of parastic airborne noise generated by the sound radiation from the excited element [3], mineral wool was placed in the cavity below the floor element to cover the part of the wall extruding the transmission chambers (Figure 3).

The structural reverberation time T_s of each panel was measured using hammer excitation for four source positions and eight receiver positions. The integrated impulse response method with backward integration of the squared impulse response was used. Measurements not fulfilling the requirement $BT_s < 4$ (with B the frequency bandwidth), which are influenced by the filter and detector, are discarded.

At low frequencies, the measurement results are influenced by the modal behaviour of the junction, with low modal overlap factors (< 1) and low mode counts (< 5) up till approximately 400 Hz. This means that the measured K_{ij}-values might not be relevant and might not be situation-invariant in this frequency range. Although one thus has to be careful when using the K_{ij} as input to ISO 12354, relative differences between the different measurements are relevant.

2.3 Measurement results

2.3.1 Loss factor

Figure 4 compares the loss factor η for the floor without and with gravel, calculated from the measured structural reverberation time. The loss factor of the CLT floor without gravel has a relatively constant value of $2.5 - 3\%$ up till 1250 Hz and decreases slightly at higher frequencies. For the floor with $2.5\,\mathrm{cm}$ gravel, the loss factor is significantly larger than the unloaded floor from 100 Hz upwards. For the floor with $5\,\mathrm{cm}$ gravel, the loss factor is larger from 160 Hz upwards and peaks between 400 Hz and 1000 Hz.

At mid frequencies, where the loss factor is maximal, it was difficult to accurately measure the structural reverberation times of the floor panel, as indicated by the large standard uncertainty. Furthermore, a lot of measurements showed a very low reverberation time for which the condition $BT_s < 4$ was not met and ringing of the band pass filters influenced the measurements. The

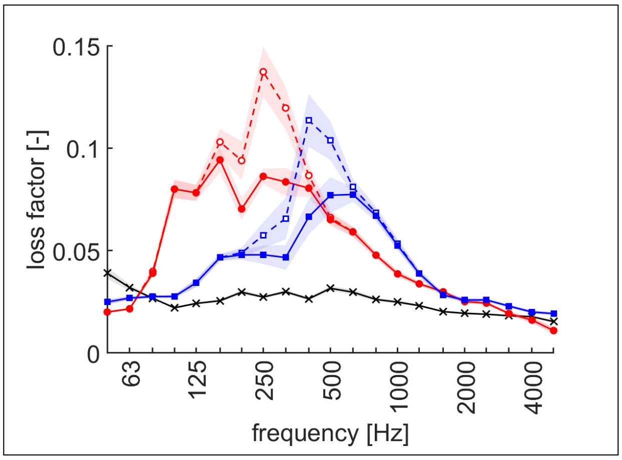

Figure 4. Loss factor of CLT floor without gravel (×), with 2.5 cm gravel (●) and 5 cm gravel (■). The shaded areas show the standard uncertainty. The dashed lines show the average values when measurements with $BT_s < 4$ are not discarded.

loss factor is thus probably an underestimation of the actual damping. When the measurement results with $BT_s < 4$ are not discarded, higher loss factors are obtained (Figure 4, dashed lines).

2.3.2 Velocity levels

The gravel layer has a significant influence on the vibro-acoustic behaviour of the CLT floor panels (Figure 5). The velocity levels L_v of the floors with gravel show a pronounced dip at mid frequencies, both when the floor and the wall are excited. For the $5\,\mathrm{cm}$ gravel layer the dip is observed around $315 - 400\,\mathrm{Hz}$, for the $2.5\,\mathrm{cm}$ gravel layer around $200 - 250\,\mathrm{Hz}$ (not shown for brevity). Furthermore, the dip in velocity level strongly depends on the accelerometer position, indicated by the large spread in this frequency range. The gravel layer thus limits the vibration of the CLT floor, especially at mid frequencies. This effects seems to be linked to a resonance phenomenon in the gravel layer, for which the resonance frequency depends on the thickness of the gravel layer.

The dip in L_v leads to a pronounced peak in velocity level difference $D_{\mathrm{v},ij}$ from wall to floor (Figure 6b). At high frequencies, $D_{\mathrm{v},ij}$ is not influenced by the gravel. When the floor is excited, the lower vibration energy in the floor panel due to the gravel layer also leads to a dip in the wall velocity level. Although it could be expected that $D_{\mathrm{v},ij}$ from floor to wall is independent of the gravel layer,

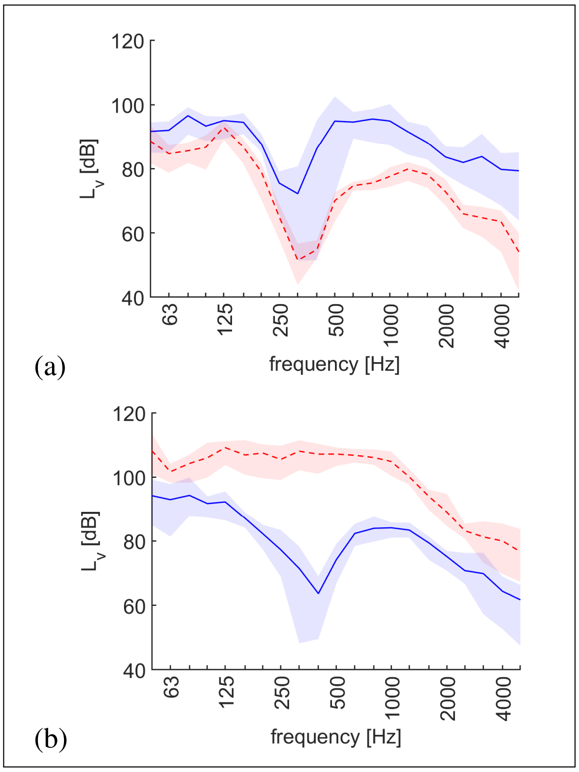

Figure 5. CLT junction with 5 cm gravel. Average velocity levels of floor (—) and wall (– –) for 1 source position on (a) floor and (b) wall. The shaded areas show the spread over 8 accelerometer positions.

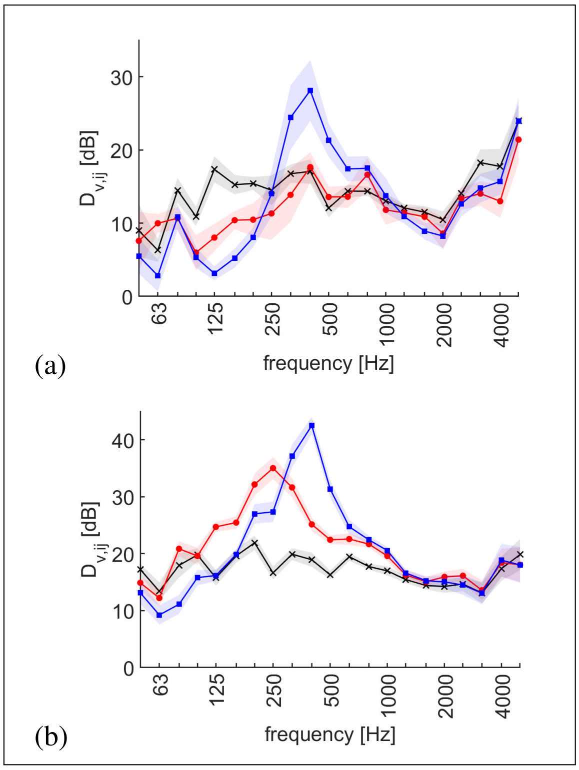

Figure 6. Velocity level difference for excitation of (a) floor and (b) wall for the CLT junction without gravel (×), with 2.5 cm gravel (●) and 5 cm gravel (■). The shaded areas show the standard uncertainty.

this is not the case at low and mid frequencies, especially for the 5 cm gravel layer (Figure 6a).

To further investigate the effect of the gravel layer on the vibration transmission across the junction, the difference in $D_{\mathrm{v},ij}$ in both directions is checked. According to SEA theory, $D_{\mathrm{v},ij}$ can be deduced from the coupling loss factor η_{ij} following:

$$D_{\mathrm{v},ij} = 10\lg\frac{\eta_j}{\eta_{ij}} - 10\lg\frac{m_i}{m_j} \tag{1}$$

where η_j is the total loss factor of element j and m_i and m_j are the mass of element i and j respectively. Using the consistency relationship, the following equality can be deduced for the difference in $D_{\mathrm{v},ij}$ normalized to the loss factor:

$$\Delta = D_{\mathrm{v},ji} - D_{\mathrm{v},ij} + 10\lg\frac{\eta_j}{\eta_i} = 20\lg\frac{m_i}{m_j} + 10\lg\frac{n_j}{n_i} \tag{2}$$

where n_i and n_j is the modal density of element i and j respectively. This normalized difference is thus only dependent on the ratio of element mass and modal density.

For the reference junction, there is a good agreement between measured values and SEA estimations in a broad frequency range, except at low frequencies where the SEA assumptions of high modal overlap and high mode count are not met, and at high frequencies where in-plane wave propagation becomes important (Figure 7). Above 500 Hz, the measurement results for the junctions with gravel also agree well with the predicted value, indicating that the gravel layer does not influence the vibration transmission across the junction in this frequency range. Below 500 Hz, the measurements show significantly higher values. This can partly be explained by the activation of the mass of the gravel layer. By including the mass of the gravel layer in the term m_i in Eqn. (2), the predicted difference is larger and agrees better with the measured values, although there is still a large undestimation.

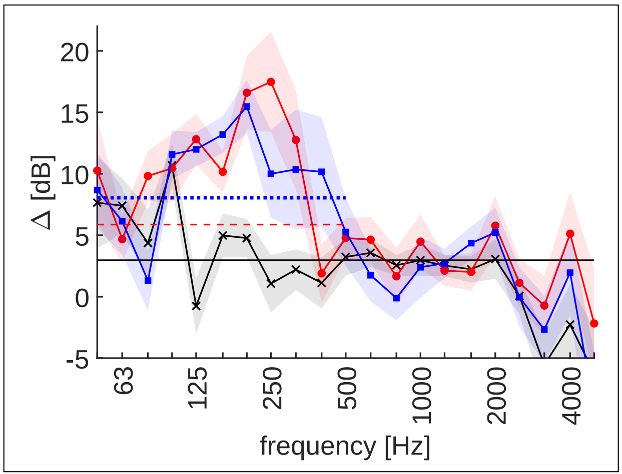

Figure 7. Difference $D_{\mathrm{v},ji}$- $D_{\mathrm{v},ij}$ normalized to the loss factors for the CLT junction without gravel (×), with 2.5 cm gravel (●) and 5 cm gravel (■). The measured values are compared with SEA predictions with $m_i = m_{\mathrm{CLT}}$ (—), $m_i = m_{\mathrm{CLT}} + m_{2.5\,\mathrm{cm\,gravel}}$ (– –), $m_i = m_{\mathrm{CLT}} + m_{5\,\mathrm{cm\,gravel}}$ (···). The shaded areas show the standard uncertainty.

2.3.3 *Vibration reduction index*

The CLT wall panel is considered a type A element according to ISO 10848-1. Because the structural reverberation time of the floor panels with gravel is primarily determined by the gravel and not by the connected elements, they are considered to be a type B element. As an advantage, this eliminates the large uncertainty in the structural reverberation time measurements of the floor panels with gravel. To have a fair comparison between the K_{ij}-values of the unloaded and loaded junctions, the floor panel of the reference junction is also considered a type B element.

For a junction composed of both type A and type B elements, the vibration reduction index is determined by:

$$K_{ij} = \frac{D_{v,ij} + D_{v,ji}}{2} + 10 \lg \frac{l_{ij}}{\sqrt{a_i a_j}} \tag{3}$$

with

$$a = \frac{2.2 \pi^2 S}{T_s c_0} \sqrt{\frac{f_{\mathrm{ref}}}{f}} \tag{4}$$

for type A elements, and

$$a = S/l_0 \tag{5}$$

for type B elements. S is the surface area of the element, $c_0 = 343\,\mathrm{m/s}$ is the speed of sound in air, $f_{\mathrm{ref}} = 1000\,\mathrm{Hz}$ and $l_0 = 1\,\mathrm{m}$.

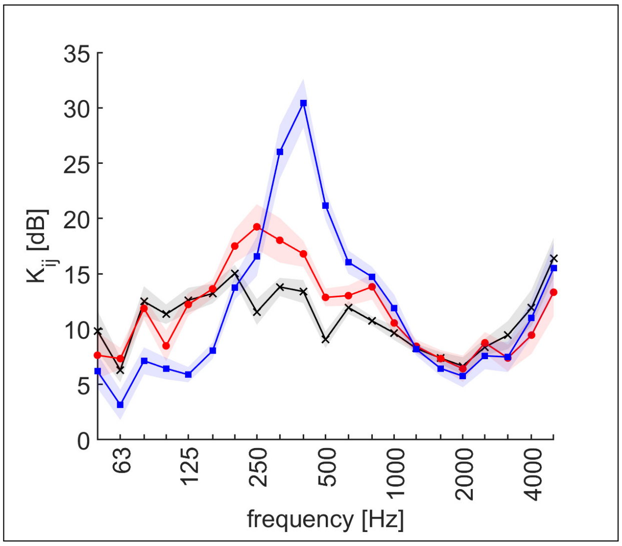

Figure 8. Vibration reduction index of the CLT junction without gravel (×), with 2.5 cm gravel (●) and 5 cm gravel (■). The shaded areas show the standard uncertainty.

The vibration reduction index of the reference junction is relatively independent of frequency, with an average value of 11.7 dB between 200 Hz and 1250 Hz (Figure 8). At high frequencies, the vibration reduction index drops, with a minimum value of approximately 7 dB at 2000 Hz. In this frequency range, the vibration reduction is strongly influenced by the connection details. Previous measurements without plaster layer showed no dip at high frequencies due to a non-perfect contact, while screws or angle brackets further reduced the K_{ij} at high frequencies.

The gravel layer does not influence the K_{ij} at high frequencies, with variations that are within the repeatability limits of the measurement procedure. At mid frequencies, a peak can be observed in the K_{ij}-values for the junctions with gravel layer, which is related to the dip in floor velocity levels. The 5 cm gravel layer significantly increases K_{ij} between 250 Hz and 500 Hz, with a peak value of 31.5 dB at 400 Hz, i.e. 15 dB above the K_{ij} of the reference junction. The effect of the 2.5 cm gravel layer is less pronounced, but the K_{ij} is still approximately 5 dB higher in the 250 Hz octave band compared to the reference junction. At low frequencies, where global modes of the junction are important, the influence of the 2.5 cm gravel layer is negligible, but the 5 cm gravel layer reduces K_{ij} on average with 5 dB up to 160 Hz. As noted earlier, it is difficult to extrapolate these results because the SEA assumptions of the measurement method are not met at low frequencies.

3. IN SITU SOUND INSULATION

3.1 Prediction model

The airborne sound insulation between two rooms can be estimated from the element and junction properties following the standard ISO 12354-1 [5]. The SEA-based model incorporates the direct transmission path (with sound reduction index R_{Dd}) and the first order flanking transmission paths. The flanking sound reduction index R_{ij} for the transmission path between element i in the source room and element j in the receiving rooms is estimated from:

$$R_{ij} = \frac{R_{i,\text{situ}}}{2} + \Delta R_{i,\text{situ}} + \frac{R_{j,\text{situ}}}{2} + \Delta R_{j,\text{situ}} + \overline{D_{v,ij,\text{situ}}} + 10\lg\frac{S_s}{\sqrt{S_i S_j}} \quad (6)$$

where R_{situ} is the *in situ* value of the sound reduction index, S_s is the area of the separating element between the rooms and $\overline{D_{v,ij,\text{situ}}}$ is the *in situ* direction-averaged junction velocity level difference, which can be determined from:

$$\overline{D_{v,ij,\text{situ}}} = K_{ij} - 10\lg\frac{l_{ij,\text{situ}}}{\sqrt{a_{i,\text{situ}} a_{j,\text{situ}}}}. \quad (7)$$

For junctions composed of both type A and type B elements, the *in situ* equivalent absorption of the type B element can be taken equal to the element area:

$$a_{i,\text{situ}} = S_{i,\text{situ}}/l_0 \quad (8)$$

Because of the limited information available on the structural reverberation time of CLT panels *in situ*, the equivalent absorption length of the type A elements is also taken equal to the element area S in this paper, following the assumption of the simplified model in ISO 12354-1.

The *in situ* value of the sound reduction index of the CLT floor with gravel is estimated with the transfer matrix method (TMM), using an equivalent orthotropic plate model for the CLT and the measured loss factors for the CLT floors with gravel. Because the loss factor for the floors is significantly increased due to the gravel, the sound reduction index is also larger in a broad frequency range. Above the critical frequencies of the CLT panel, the improvement can be estimated from:

$$R_{\text{situ}} = R_{\text{ref}} + 10\lg\frac{\eta_{\text{gravel}}}{\eta_{\text{ref}}}. \quad (9)$$

For example, the predicted global sound reduction index $R_A = R_w + C$ of a 14 cm CLT floor increases from 35.2 dB to 37.4 dB due to the additional structural damping of the 5 cm gravel layer.

The vibration reduction index K_{ij} is not measured for all types of junctions with CLT floors loaded with gravel. Therefore, the vibration reduction index $K_{ij,\text{gravel}}$ of the junction path between a CLT floor with gravel and another element is estimated from the vibration reduction index $K_{ij,0}$ of the equivalent junction without gravel,

$$K_{ij,\text{gravel}} = K_{ij,0} + \Delta K_{ij,\text{gravel}}. \quad (10)$$

The improvement $\Delta K_{ij,\text{gravel}}$ due to the gravel layer is estimated from the improvement measured in the laboratory for the L-junction. For the transmission between two floors, the improvement $\Delta K_{ij,\text{gravel}}$ is only added once to $K_{ij,0}$.

3.2 Theoretical example

As an example, the horizontal sound insulation between two rooms (with depth 3.0 m) is calculated, either disregarding the effect of the gravel or taking into account its effect on R_{situ} and K_{ij}. The separating wall with dimensions 4.0 m × 2.6 m consists of a 10 cm CLT panel and an acoustic lining. The 14 cm CLT floor and ceiling run across the separating wall. The $K_{ij,0}$ of the CLT junctions is estimated following Annex F3.2 of ISO 12354-1 [5]. A floating screed is placed on top of a 2.5 cm or 5 cm gravel layer on both the floor and the ceiling panels. Flanking transmission across the side walls is limited due to the application of a structural break at the junction with the separating wall.

The sound insulation between the rooms is dominated by the flanking transmission via the ceiling, more specifically the Ff path from ceiling to ceiling (Table 1). Only at low frequencies, the transmission through the separating wall is the dominant path (Figure 9). When the effect of the gravel is disregarded, a global sound insulation $D_A = D_{nT,w} + C = 48.5$ dB is predicted. The predicted sound insulation increases to $D_A = 52.5$ dB and 50.9 dB due to the effect of the 2.5 cm and 5 cm gravel layer, respectively, of which approximately 2 dB can be attributed to the increase in R_{situ}. The additional improvement is related to the increase in K_{ij} between 250 Hz and 1000 Hz. The improvement in D_A is smaller for the 5 cm gravel layer due to the reduction in K_{ij} at lower frequencies.

Table 1. Sound reduction indices R_A

Path	reference (no gravel)	2.5 cm gravel	5 cm gravel
Direct - Dd	60.1 dB	60.1 dB	60.1 dB
Ceiling - Ff	49.7 dB	54.6 dB	52.6 dB
Ceiling - Fd	56.3 dB	60.0 dB	58.1 dB
Ceiling - Df	80.4 dB	84.0 dB	76.1 dB
Total	48.5 dB	52.5 dB	50.9 dB

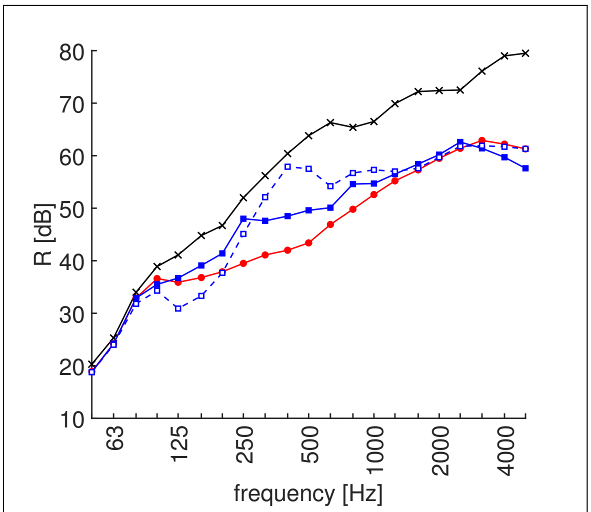

Figure 9. Sound insulation between two rooms according to ISO 12354-1 (× R_{Dd}, ● R'_{ref}, ■ $R'_{2.5\,cm\,gravel}$, □ $R'_{5\,cm\,gravel}$)

3.3 Case study

The prediction model is applied to a case study of a CLT apartment building. The intermediate floors consist of a 22 cm CLT panel, a 9 cm gravel layer and a floating screed. The ceiling of the top floor consists of a 22 cm CLT panel. Above the ceiling is an empty plenum with a variable height ($60 - 170$ mm) to create a slope for the flat roof which consists of an OSB plate, a stiff thermal insulation plate and a ballast layer. The walls consist of a 12 cm CLT panel with an acoustic lining on both sides (2 gypsum boards on 50 mm metal studs and a 50 mm mineral wool filling). An elastic joint is inserted between the floor panels at the junctions with the separating walls between dwellings.

The sound insulation between the living room and a bedroom of two neighbouring dwellings was measured on an intermediate floor and on the top floor of the building. The sound insulation on the top floor is significantly lower with a difference in D_A of 7 dB (Figure 10).

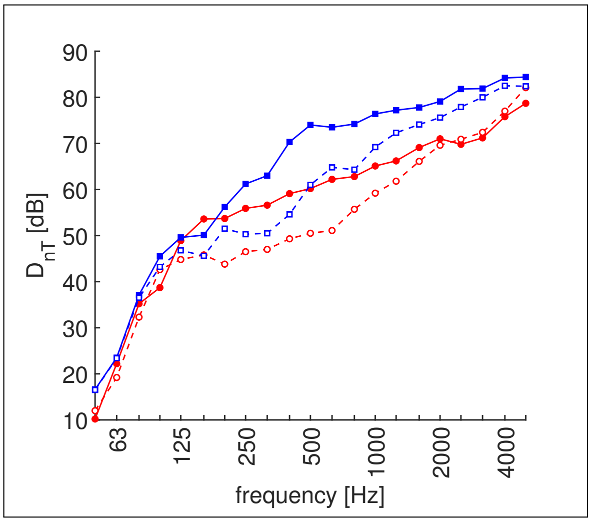

Figure 10. Case study: measured (●) and simulated (■) sound insulation between two rooms on the intermediate (—) and top (– –) floor.

For the predictions, the following assumptions have been made for the vibration reduction indices:

- The $K_{ij,0}$-value of the cross junctions is estimated from K_{ij}-measurements in a mock-up with a similar junction without gravel. The mock-up values have been reduced at mid and high frequencies to account for two effects: the loading of the elastic layer *in situ*, which will decrease its effect [6], and the mechanical coupling present in the apartment building to assure lateral stability.

- The $K_{ij,0}$-value of the T-junction on the top floor is estimated to be 3 dB lower than the $K_{ij,0}$-value of the cross junction.
- The average $\Delta K_{ij,\text{gravel}}$-value of the laboratory measurements with 2.5 cm and 5 cm is applied. Below 200 Hz, no effect is taken into account ($\Delta K_{ij,\text{gravel}} = 0$).

The simulations indicate that the Ff path from ceiling to ceiling is the dominant transmission path in the entire frequency range of interest ($\geq$ 100 Hz), both on the intermediate floor and on the top floor, despite the elastic joint between the ceiling plates.

Although the sound insulation is globally overestimated by the model, the relative difference between intermediate and top floor is well predicted. The model difference of 7 dB in D_A-value is partly due to the difference between T- and cross junction (3 dB), partly due to the effect of the gravel layer on R_{situ} (1.5 dB) and partly due to the effect of the gravel layer on K_{ij} (2.5 dB). The overestimation may be attributed to several factors, like an overestimation of the sound insulation R by the TMM, an overestimation of the vibration reduction index $K_{ij,0}$, or the presence of other transmission paths not taken into account in the model. On the top floor, indirect airborne transmission via the plenum in the roof could e.g. further reduce the sound insulation.

4. CONCLUSIONS

While gravel layers are primarily used to improve the airborne and impact sound insulation of CLT floors, the gravel layer also influences the flanking transmission across the floor junctions in two ways. First, the gravel layer significantly increases the loss factor of the floor, and thus also the sound reduction index of the floor, especially above its critical frequency. The global improvement in $R_{A,\text{situ}}$ of typical CLT floors is estimated to be 2 dB based on TMM simulations. Second, the vibro-acoustic behaviour of the junction, as characterized by the vibration reduction index K_{ij}, is changed. The measured K_{ij}-values show a pronounced peak at mid frequencies, linked to a resonance phenomenon in the gravel layer. Simulations with the SEA-based model of ISO 12354 indicate that for situations where flanking transmission across the ceiling is dominant, the gravel layer can improve the global sound insulation with up to 5 dB. Case studies learn that care should be taken with sound transmission across ceilings at the top floor where this positive effect of gravel layers is not present, while flanking transmission across the top T-junctions is already larger than across intermediate cross junctions.

5. ACKNOWLEDGMENTS

The results presented in this paper have been obtained within the frame of the projects ”STABBS II” (Standards for acoustic better buildings II). The authors are grateful for the financial support from the Federal Public Service Economy of Belgium.

6. REFERENCES

[1] C. Guigou-Carter, N. Balanant, and J.-L. Kouyoumji. Apparent wood elements and acoustic performance - Feedback from Adivbois CLT building mockup. In *Proc. of InterNoise22* , pages 3513–3524, Glasgow, Scotland, 2022.

[2] A. Homb, C. Guigou-Carter, and A. Rabold. Impact sound insulation of cross-laminated timber/massive wood floor constructions: Collection of laboratory measurements and result evaluation. *Building Ac*, 24(1):35–52, 2017.

[3] C. Crispin, V. Pettoni Possenti, A. Dijckmans, and L. Barbaresi. Improving the accuracy of vibration reduction index measurements: Assessing and correcting parasitic airborne noise effects. *Available at SSRN*: http://dx.doi.org/10.2139/ssrn.5168683, 2025.

[4] ISO 10848-1:2017 *Acoustics – Laboratory and field measurement of flanking transmission for airborne, impact and building service equipment sound between adjoining rooms – Part 1: Frame document*

[5] ISO 12354-1:2017 *Building acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms*

[6] V. Pettoni Possenti, C. Crispin, A. Dijckmans, and L. Barbaresi. Load effects in flanking transmission of CLT structures with resilient interlayer. In *Proc. of Forum Acusticum Euronoise*, Málaga, Spain, 2025.