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Flanking transmission of solid wood elements in multi-storey timber buildings - input data and prediction models for airborne and impact sound excitation -

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ABSTRACT

Compared to similar construction projects built in concrete, the design of a multi-storey building in timber construction is more demanding and challenging to the architect and construction engineer. The reasons for this can be found, among others, in the lack of proven planning tools and input data for airborne- and impact-noise control. In EN ISO 12354 SEA-based prediction models are given for airborne- and impact-sound excitation. These models need input data of the involved building elements and the junctions between them. Input data of floor and wall constructions with cross-laminated timber elements, glulam- or box elements can be found in various databases and national standard annexes. In recent years coupling loss factors have been determined as input data for CLT-element-junctions in several projects and different institutes. Based on these measured data, the article shows planning data for solid wood elements and vibration reduction indices.

Keywords: Airborne- and impact-sound, vibration reduction index, CLT-element-junctions,
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

The SEA-based prediction according to EN ISO 12354 [1] distinguishes between two models. The detailed, frequency dependent model and the simplified model, working with single values as input data (see section 2). Some input data for both models is given in section 3. For the airborne sound insulation of solid wood elements, see section 3.1. The vibration reduction indices for several element junction types are given in section 3.2.

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2. PREDICTION MODEL ACCORDING TO ISO 12354

2.1 Detailed model

As described in [1], the airborne sound insulation in situ R' and the normalized impact sound pressure level L'_{n} can be predicted from the direct path (R_{Dd} resp. $L_{\mathrm{n},d}$) and the flanking paths (R_{ij} resp. $L_{\mathrm{n},ij}$):

$$R' = -10\ lg\left(10^{-0,1 \cdot R_{Dd}} + \sum_{j=1}^{n} 10^{-0,1 \cdot R_{ij}}\right) \tag{1}$$

$$L'_{\mathrm{n}} = 10\ lg\left(10^{0,1 \cdot L_{\mathrm{n},d}} + \sum_{j=1}^{n} 10^{0,1 \cdot L_{\mathrm{n},ij}}\right) \tag{2}$$

R_{Dd} and $L_{\mathrm{n},d}$ represent direct sound insulation and impact sound transmission for in-situ conditions. They can be estimated from the results of laboratory measurements R and L_{n} with a correction via the structure-borne reverberation time T_s:

$$R_{Dd} = R_{situ} = R - 10\ lg\left(\frac{T_{s,situ}}{T_{s,lab}}\right) \quad \text{resp.} \quad L_{n,d} = L_{n,situ} = L_n + 10\ lg\left(\frac{T_{s,situ}}{T_{s,lab}}\right) \tag{3}$$

The correction via the structure-borne reverberation time can be considered by:

$$\frac{T_{s,situ}}{T_{s,lab}} = \frac{\eta_{tot,lab}}{\eta_{tot,situ}} \quad \text{with:} \ \eta_{tot,lab} = \eta_{int} + \frac{m'}{485\sqrt{f}} \ ; \quad \eta_{tot,situ} = \eta_{int} + \frac{m'}{300\sqrt{f}} \tag{4}$$

The flanking sound reduction index R_{ij} and the normalized impact sound pressure level for flanking transmission $L_{n,ij}$ can be deduced from the performance of the elements according to eq. (5) and (6):

$$R_{ij} = \frac{R_{i,situ}}{2} + \Delta R_{i,situ} + \frac{R_{j,situ}}{2} + \Delta R_{j,situ} + \overline{D_{v,ij,situ}} + 10\ lg\left(\frac{S_S}{\sqrt{S_i \cdot S_j}}\right) \tag{5}$$

$$L_{\mathrm{n},ij} = L_{n,situ} - \Delta L_{situ} + \frac{R_{i,situ} - R_{j,situ}}{2} - \Delta R_{j,situ} - \overline{D_{v,ij,situ}} - 10\ lg\left(\sqrt{\frac{S_i}{S_j}}\right) \tag{6}$$

Therefore the sound reduction indices $R_{i,\mathrm{situ}}$ and $R_{j,\mathrm{situ}}$ of the involved building elements, the sound reduction index improvements by additional layers $\Delta R_{i,\mathrm{situ}}$ and $\Delta R_{j,\mathrm{situ}}$, the $L_{\mathrm{n,situ}}$ of the bare floor and the reduction of the impact sound pressure level of the floor covering ΔL_{situ} are required. The velocity level difference $\overline{D_{v,ij,situ}}$ can be calculated from the vibration reduction index K_{ij} with the common coupling length l_{ij} between the elements and their equivalent absorption lengths $a_{i,\mathrm{situ}}$ and $a_{j,\mathrm{situ}}$:

$$\overline{D_{v,ij,situ}} = K_{ij} - 10 \cdot lg\left(\frac{l_{ij}}{\sqrt{a_{i,situ} \cdot a_{j,situ}}}\right) \tag{7}$$

The equivalent absorption length is given by the structural reverberation time T_s of the element i or j, their area S, the reference frequency f_{ref} = 1000 Hz and the speed of sound in air c_0.

$$a_{i,situ} = \frac{2{,}2 \cdot \pi^2 \cdot S_i}{c_0 \cdot T_{s,i,situ}} \sqrt{\frac{f_{ref}}{f}} \quad resp. \quad a_{j,situ} = \frac{2{,}2 \cdot \pi^2 \cdot S_j}{c_0 \cdot T_{s,j,situ}} \sqrt{\frac{f_{ref}}{f}} \tag{8}$$

2.1 Simplified model

In the simplified model, the weighted airborne sound insulation R'_w and the weighted normalized impact sound pressure level $L'_{n,w}$ in the field can be predicted according to eq. (9) and (10):

$$R'_w = -10\, lg\left(10^{-0{,}1 \cdot R_{Dd,w}} + \sum_{j=1}^{n} 10^{-0{,}1 \cdot R_{ij,w}}\right) \tag{9}$$

$$L'_{n,w} = 10\, lg\left(10^{0{,}1 \cdot L_{n,d,w}} + \sum_{j=1}^{n} 10^{0{,}1 \cdot L_{n,ij,w}}\right) \tag{10}$$

The weighted flanking sound reduction index $R_{ij,w}$ and weighted normalized impact sound pressure level for flanking transmission $L_{n,ij,w}$ can be deduced from the performance of the elements eq. (11) and (12):

$$R_{ij,w} = \frac{R_{i,w} + R_{j,w}}{2} + \Delta R_{ij,w} + K_{ij} + 10\, lg\left(\frac{S_S}{l_0 l_f}\right) \tag{11}$$

$$L_{n,ij,w} = L_{n,eq,0,w} - \Delta L_w + \frac{R_{i,w} - R_{j,w}}{2} - \Delta R_{j,w} - K_{ij} - 10\, lg\left(\frac{S_i}{l_0 l_{ij}}\right) \tag{12}$$

Therefore the weighted sound reduction indices $R_{i,w}$ and $R_{j,w}$ of the involved building elements, the total sound reduction index improvements by additional layers $\Delta R_{ij,w}$ on the transmission path, the $L_{n,eq,0,w}$ of the bare floor, the reduction of the impact sound pressure level of the floor covering ΔL_w and the vibration reduction index K_{ij} are required.

3. INPUT DATA

3.1 Airborne sound insulation and impact sound pressure level

R_{Dd} and $L_{n,d}$ of the separating elements can be obtained from laboratory measurements (R and L_n). The airborne sound insulation and impact sound level of a typical massive wood floor construction used in D/A/CH are shown in Figure 1. For solid wood elements, it is not common to deal with separate data for the bare floor and the floor covering. Therefore, in equation (6) and (12) the L_n of the whole floor can be used for the prediction of the impact sound pressure level for flanking transmission. If the floor construction includes a suspending ceiling, the input data of the same floor without suspended ceiling are needed for the prediction.

The airborne sound insulation of the solid wood flanking elements can be predicted according to ISO 12354, annex B.3. A comparison between prediction and measured sound insulation of a CLT element is shown in Figure 2. For the prediction the plate is assumed as an equivalent isotropic plate. The critical frequency is calculated using the lower Young's modulus of the two principal directions of the orthotropic plate.

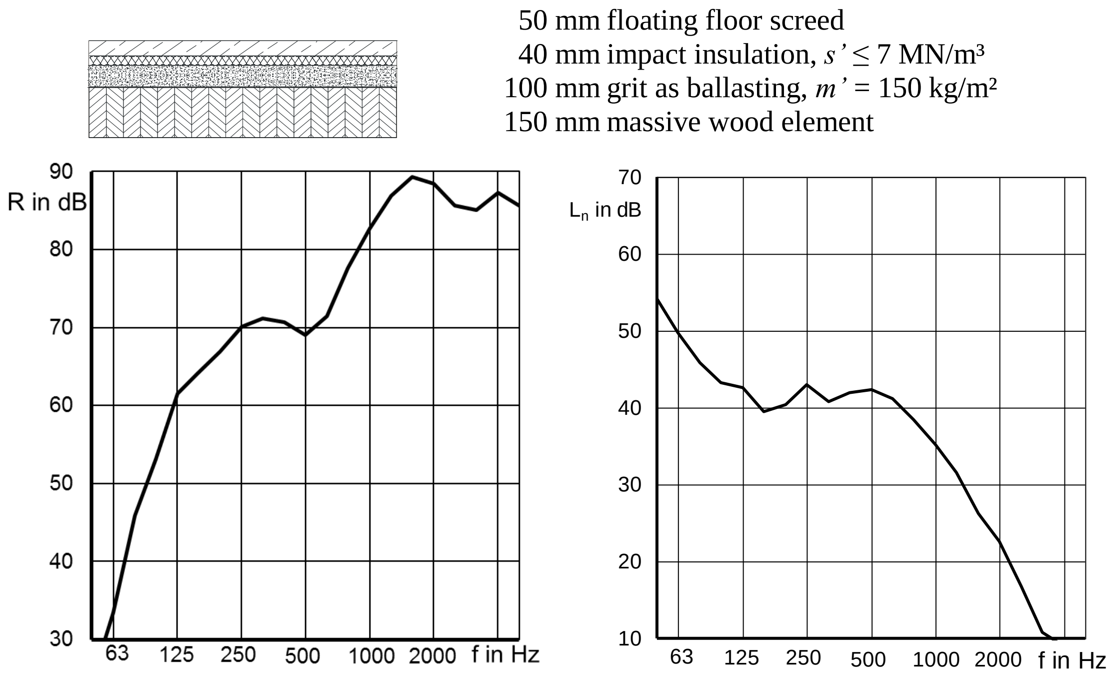
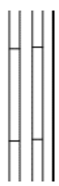


Figure 1 – Airborne sound insulation and impact sound level of a typical massive wood floor construction. Used as input data for the prediction according to ISO 12354.
Single number ratings: $L_{n,w}$ = 38 dB, R_w = 77 dB



Input data:

L = 2.60 m
B = 4.40 m
t = 0.10 m
m' = 45 kg/m²
f_c = 400 Hz
η = 0.013

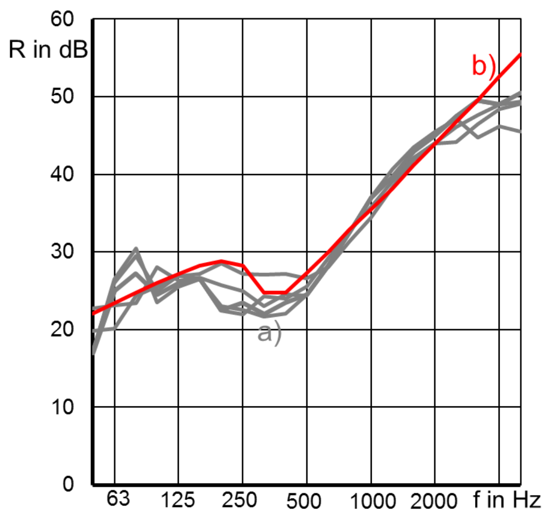


Figure 2 – Airborne sound insulation measured and predicted for a 100 mm CLT element
a) Measurement: n = 5, R_w = 32 - 34 dB, b) Prediction: R_w = 34 dB

The single number rating R_w for solid wood elements can also be determined by their mass per unit area. From [14] the following correlation was obtained for 22 solid wood elements with and without planking:

$$R_w = 25\,\lg(m') - 7\ dB \tag{13}$$

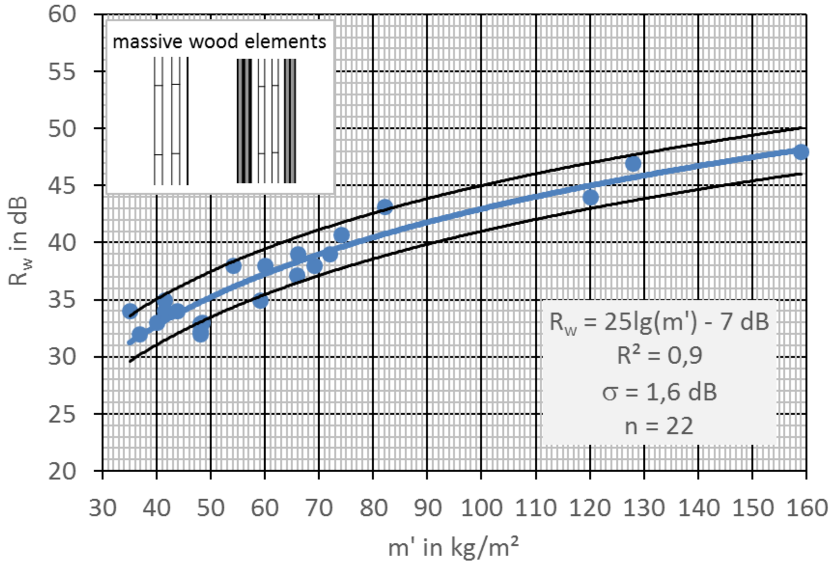


Figure 3 – sound reduction index R_w in relation to the mass per unit area m' of solid wood elements with and without gypsum boards as planking

The measured data in figure 3 includes different types of solid wood elements (elements with laminated, cross-laminated or mechanical connected wooden layers). Directly mounted additional plankings, such as gypsum boards, are considered in the mass per unit area.

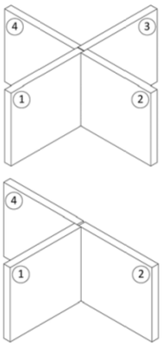
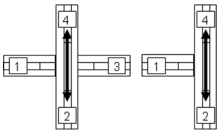
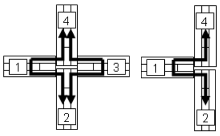
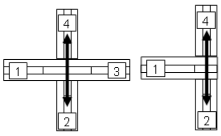
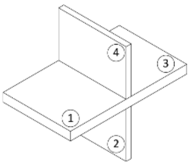
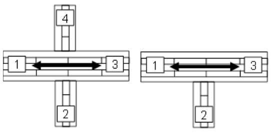
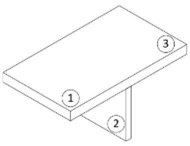
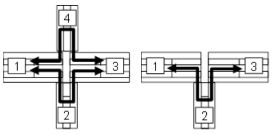
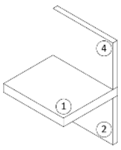
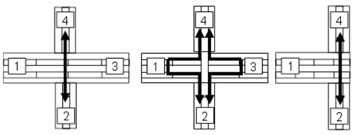
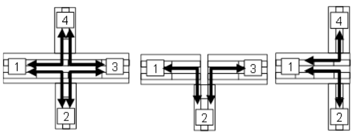
In the case of floor elements with grit as ballasting (see Figure 1), the airborne sound insulation of the bare floor including the ballasting is required for the prediction of the flanking transmission. If the mass of the grit is much higher than the element mass, the relation for ideal flexible plates can be used as a good estimate:

$$R_w = 30\,\lg(m') + 10\ dB \tag{14}$$

3.2 Vibration reduction index

The vibration reduction index, which has a strong influence on the flanking sound reduction, depends on the type of joint and element materials used. Therefore many measurements have been made for various solid wood elements and element joints in recent years. In [11] a collection of available K_{ij}-values from 9 institutes [2] - [10] in Europe and Canada have been collected. The evaluated mean values and standard deviations of the measured data are shown in Table 1. In addition to this data, suggestions are made for the mass and frequency dependency of the K_{ij} values, which will be examined hereinafter.

Table 1: Vibration reduction index K_{ij} of CLT-elements (t = 80 – 200 mm), joints screwed or mounted with brackets. Frequency range 200 Hz – 1250 Hz [11],[12]

type of element junction		number n K_{ij} standard deviation σ	mass dependency1)	frequency ependency2)
wall / wall 		$n = 16$ $K_{Ff} = 8\ dB$ $\sigma = 2{,}6\ dB$	$+3M + 4M^2$	3)
		$n = 9$ $K_{Ff} = 15\ dB$ $\sigma = 1{,}9\ dB$	$+3M + 4M^2$	3)
		$n = 13$ $K_{Ff} = 17\ dB$ $\sigma = 2{,}6\ dB$	$+6M + 7M^2$	3)
floor / wall 		$n = 5$ $K_{Ff} = 3\ dB$ $\sigma = 0{,}8\ dB$		$-3{,}3\ lg\frac{f}{f_K}$
		$n = 5$ $K_{Ff} = 12\ dB$ $\sigma = 2{,}7\ dB$	$+10M + 11M^2$	$+3{,}3\ lg\frac{f}{f_K}$
		$n = 13$ $K_{Ff} = 21\ dB$ $\sigma = 3{,}0\ dB$	$+4M + 3M^2$	$+3{,}3\ lg\frac{f}{f_K}$
all		$n = 66$ $K_{Fd} = 12\ dB$ $K_{Df} = 12\ dB$ $\sigma = 2{,}2\ dB$	$+14M^2$	$+3{,}3\ lg\frac{f}{f_K}$

1) $M = lg\frac{m'_{\perp}}{m'_i}$ 2) $f_K = 500$ Hz 3) depending on element size, orientatation and connecting (see Figure 9)

For the examination of the mass dependency part of the data is shown in Figure 4 to Figure 6. It was measured in the same test facility [12]. In addition to the measurements of the K_{ij} - values, the flanking sound reduction indices $R_{ij,w}$ were determined for the flanking component. In Figure 4 (left side) the results are shown for the same flanking element and different perpendicular walls (m' = 40 kg/m² to 160 kg/m²). With these results, K_{ij} could be determined using the indirect method according to ISO 10848 [13].

T-joints of wall elements show a weak mass dependence as long as the flanking element is not interrupted at the junction. This is also accurate for the additionally measured flanking sound reduction indices. If the flanking element is separated at the junction or completely interrupted by the perpendicular wall, the mass dependence of the results is stronger.

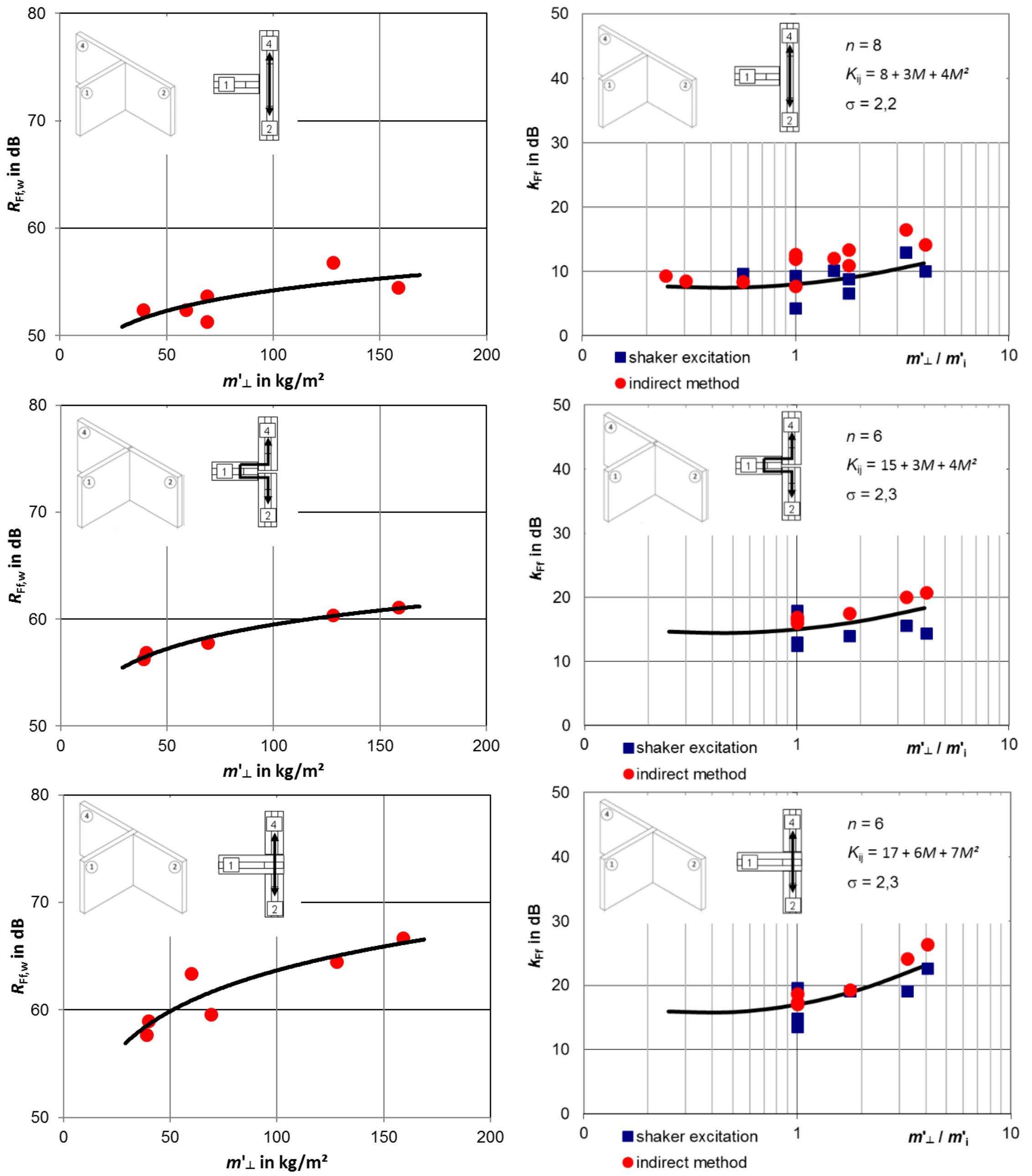


Figure 4 – Results for different T-joints of massive wood wall elements. Left: Flanking sound reduction indices $R_{ij,w}$ for 80 mm CLT as flanking element and different perpendicular CLT elements (m' = 40 kg/m² to 160 kg/m² with and without gypsum planking). Right: Vibration reduction indices as a function of the mass ratio, measured with structure-borne sound excitation and with the indirect method from flanking sound reduction indices.

For T-joints of wall and floor elements no mass dependency could be found for horizontal transmission, as long as the flanking element is not interrupted (see Figure 5, left). By interrupting the floor, the dependency is similar to the interrupted wall in Figure 4.

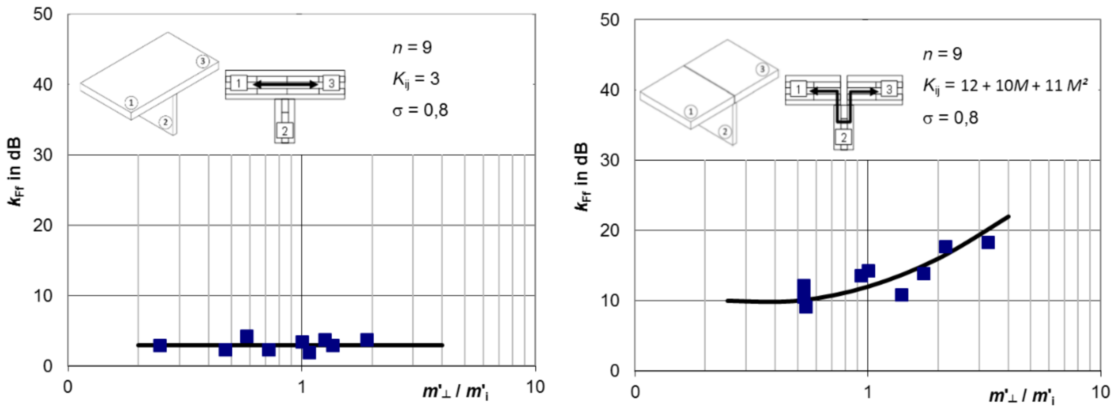


Figure 5 – Vibration reduction indices as a function of the mass ratio for different T-joints of massive wood floor und wall elements. Flanking floor element as solid wood elements (CLT and hollow box elements, *m'* = 30 kg/m² to 70 kg/m²). Perpendicular wall as CLT elements (*m'* = 40 kg/m² to 160 kg/m² with and without gypsum planking). Left: Flanking floor element without interruption at the junction. Right: Flanking element interrupted.

The comparison of the continuous floor elements in Figure 5 with the continuous wall elements in Figure 4 shows significantly lower values for the floor elements. One reason for this difference could be found in the element orientation. While the floor were composed of 4 CLT-elements (*b* = 1.25 m) that ran perpendicular to the junction, this was not the case with the wall / wall joints. There, the CLT-elements were orientated parallel to the junction, which contributed to a higher propagation damping in the flank element. The influence of the element dimensions, the element orientation and the connection of the laminated timber boards (glued or mechanical connected) are studied in Figure 9.

T-joints of wall and floor elements for vertical transmission are shown in Figure 6, left. The mass dependency is only visible for heavy floor elements (with grid as ballasting) and mass ratios above 2. The mixed transmission paths were combined for all element junctions and plotted in Figure 6 against the mass ratio. Again, a slight mass dependence can be detected.

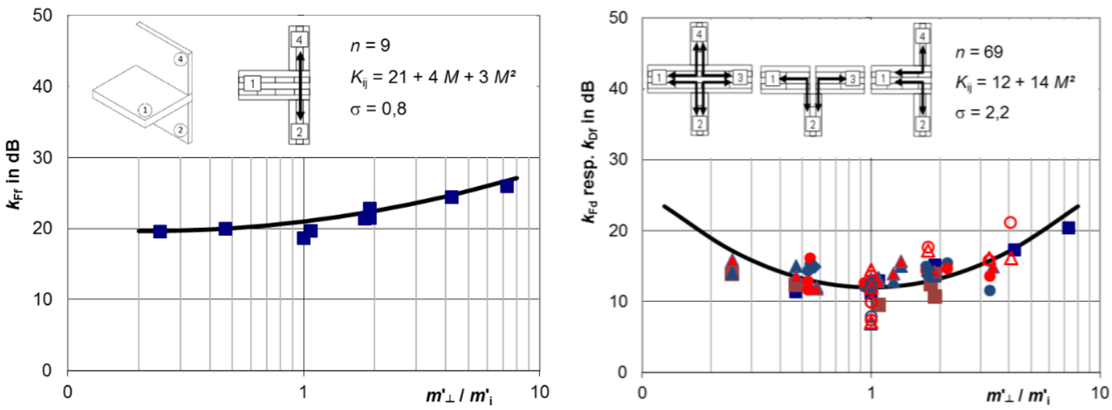


Figure 6 – Vibration reduction indices for vertical transmission and mixed transmission paths. Left: flanking wall interrupted by the floor element (platform framing). Right: Mixed transmission for all junction types.

Figure 7 shows the frequency dependency of the vibration reduction index for T- and X-joints and vertical resp. mixed transmission paths, evaluated in [11]. The results of the frequency dependency are in good agreement with the planning data in ISO 12354-1. The single number ratings are a bit lower. For the laboratory measurements, no difference was found between T- and X-joints.

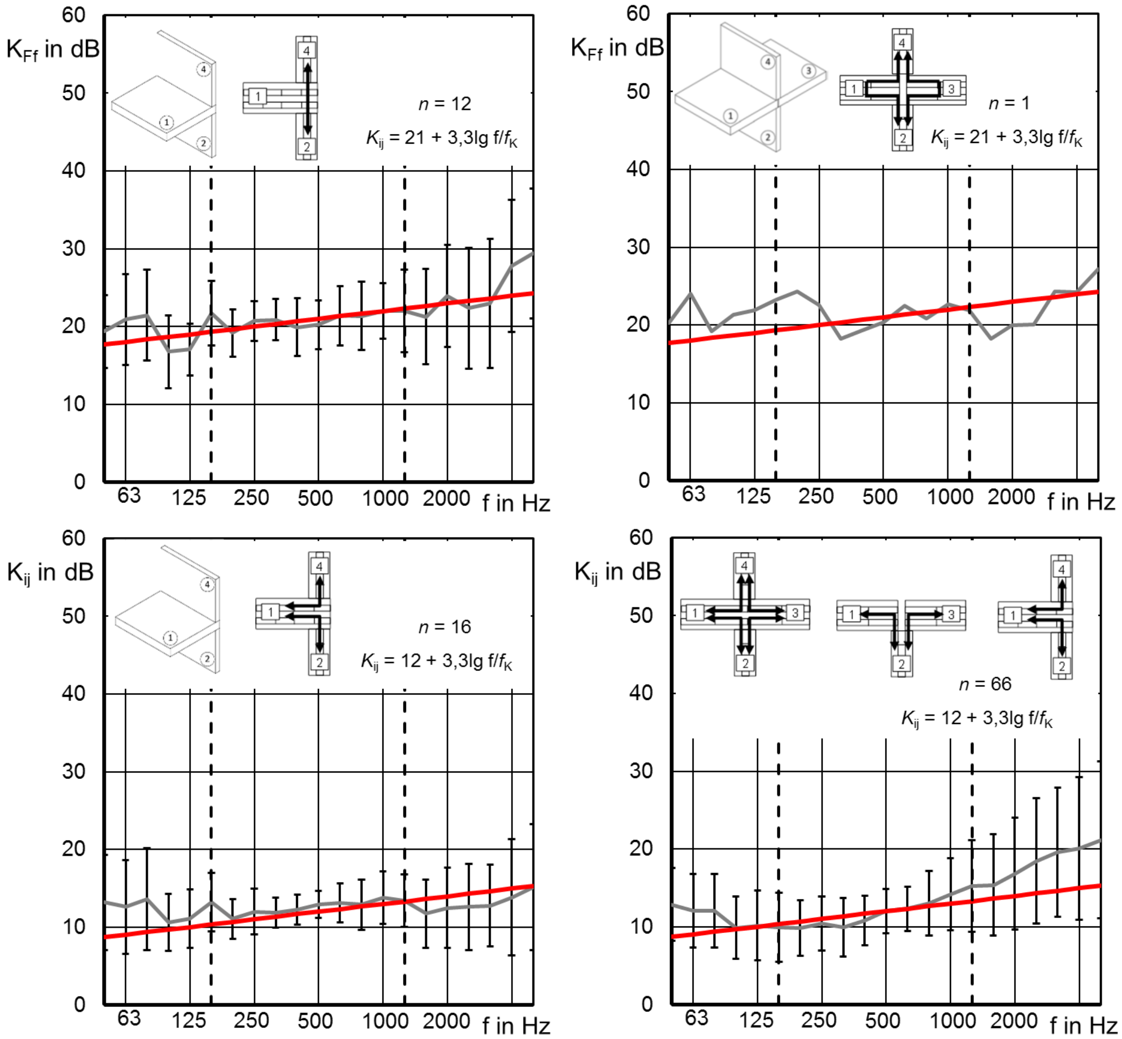


Figure 7 – Frequency dependency of the vibration reduction index for T-joints (left side) and X-joints (right side). Vertical transmission (top) and mixed transmission (bottom). Data from [11].

The frequency dependence for the vibration reduction index of flanking floor elements is shown in Figure 8. While the continuous element shows a decreasing curve progression, as given in ISO 12354, the vibration reduction index of elements that are interrupted in the junction, increases with frequency. The slope agrees up to approx. 1250 Hz well with the information given in [1], [15].

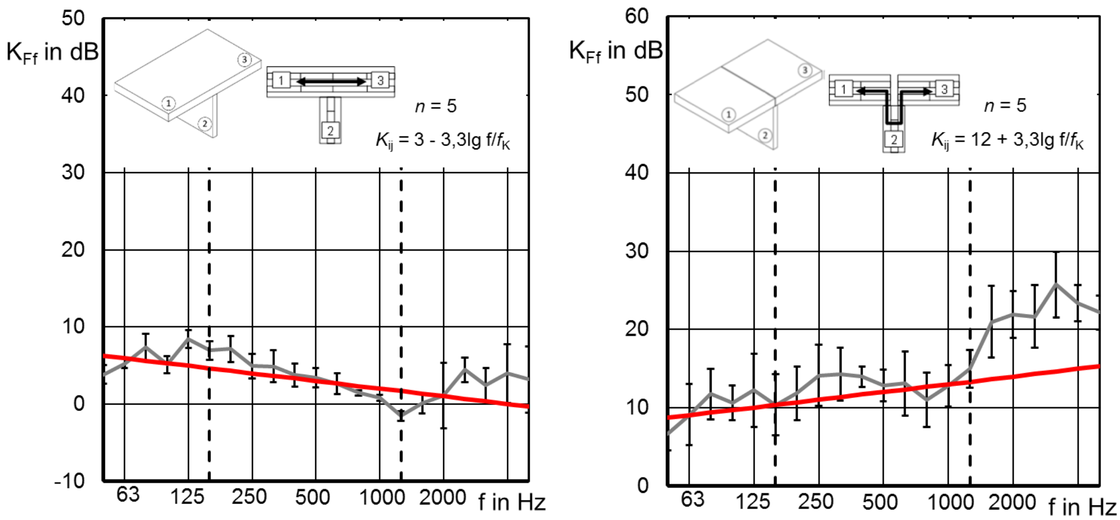


Figure 8 – Frequency dependency of the vibration reduction index for T-joints of flanking floor elements. Left: Flanking floor element without interruption at the junction. Right: Flanking element interrupted. Data from [11].

In Figure 9 the frequency dependence is shown for different element types. The vibration reduction index and the decrease in vibration level with distance were measured for three element types. As Figure 9 shows, the vibration reduction index increasing with frequency for flanking walls made of small single elements (b = 1.25 m) or big elements ($b \approx 5$ m) with mechanical connected boards (dowelled). If big sized and glued CLT elements are used, the vibration reduction index shows a similar value and slope as the flanking floor elements in Figure 8. The reason of these differences can be found in the decrease in vibration level with distance of the elements, which is shown in Figure 9, right.

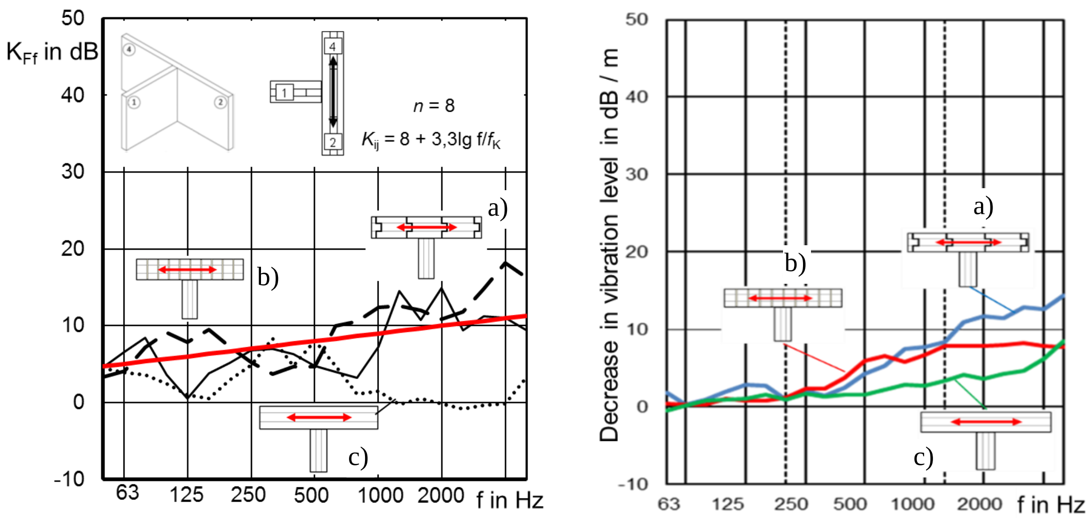


Figure 9 – Frequency dependency for T-joints of different flanking wall elements.
a) Flanking wall mounted of small single CLT elements, b = 1.25 m.
b) Flanking wall mounted of two big elements, $b \approx 5$ m with dowelled timber boards.
c) Flanking wall mounted of two big CLT-elements (glued), $b \approx 5$ m
Left: Vibration reduction index. Right: Decrease in vibration level in the elements.

CONCLUSION

The collected data of the vibration reduction indices for different junction types with solid wood elements provide the possibility to derive planning data for the prediction of the flanking transmission according to ISO 12354. These data were compared with the existing planning data in ISO 12354-1. As the article shows, the averaged values for the different junctions are slightly lower than those given in the standard. The frequency-dependent slope fits well with the suggestions in ISO 12354-1. Flanking wall elements, which are composed of small individual elements, or whose lamellae are mechanically connected, shows significantly better vibration reduction indices than large, glued elements. The dependence of the vibration reduction indices on the mass ratio is only weakly recognizable due to the high variance of the data. Whether the consideration of mass dependency in the prognosis is more meaningful than the previous procedure with constant values must be proven by validation against in-situ measurements of the airborne and impact sound insulation.

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6. REFERENCES

[1] ISO 12354 Building acoustics - Estimation of acoustic performance of buildings from the performance of elements – Part1 and Part 2, 2017-07

[2] CSTB Center of Building Science and Technology 24 rue Jospeh Fourier F – 38400 Saint-Martin-d'Hères, www.cstb.fr

[3] Empa, Swiss Federal Laboratories for Materials Science and Technology Laboratory for Acoustics/Noise Control, Überlandstrasse 129, CH-8600 Dübendorf, www.empa.ch/akustik

[4] ift Rosenheim GmbH, Laboratory Building Acoustics, Lackermannweg 26, D-83071 Stephanskirchen, www.ift-rosenheim.de

[5] National Research Council Canada, Government of Canada, CA - Ottawa – Ontario, www.nrc-cnrc.gc.ca

[6] Rotho Blaas GmbH/srl, Via Dell' Adige 2/1, I-39040 Cortaccia (BZ), www.rothoblaas.co

[7] SINTEF Building & Infrastructure, Høgskoleringen 7 B, NO-7465 Trondheim, www.sintef.no/byggforsk

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[10] University of Liverpool, Liverpool L69 3BX, United Kingdom

[11] Timpte, A., Stoßstellendämm-Maße im Massivholzbau – Konstruktionen, akustische Kenngrößen, Schallschutzprognose, Masterarbeit TU Berlin und Hochschule Rosenheim, 2016

[12] Wohlmuth, B., Rank, E., Kollmannsberger, S., Schanda, U., Rabold, A., Vibroacoustics in the planning process for timber buildings - modeling, numerical simulation, validation, cooperation project TU München, HS Rosenheim, ift Rosenheim, 2018.

[13] ISO 10848 Acoustics - Laboratory and field measurement of flanking transmission for airborne, impact and building service equipment sound between adjoining rooms

[14] Huber, A., Ermittlung von Planungsdaten für den Schallschutz von Außenwänden in Holzbauweise mit unterschiedlichen Dämmstofftypen. Datensammlung – Bauteilmessung – Simulation, Bachelor Thesis, University of Applied Sciences Rosenheim, 2018

[15] Guigou-Carter, C., pr EN 12354-1 Annex E, proposed for rigid CLT junctions to CEN/TC126/WG2