Construction details affecting flanking transmission in cross laminated timber structures for multi-story housing

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ABSTRACT

The desire of building developers to leave surfaces of cross laminated timber constructions in multi-story housings visible for the building user, leads to acoustic challanges with the flanking sound transmission that cannot be controlled by means of wall linings. As a result, controlling flanking sound transmission by measures directly in the joint is getting increasingly important. The main parameter for describing the vibrational power transmission over a junction between structural elements is the vibration reduction index Kij. For this quantity, some planning values are spread over numerous publications. None of the currently available data sources represents a holistic view on the building acoustic performance of on the market available products for elastic interlayers and fasteners which are used in wall-ceiling junctions. The following paper shows results of measurements of vibration reduction indices of different configurations of a wall-ceiling joint in a test facility. Different elastic interlayers and fasteners were investigated. The vibration reduction indices spread from 16db to 26dB as a function of the joint configuration and the load applied on the joint. The measurement results obtained are discussed and the essential parameters for influencing the flanking sound transmission are worked out and quantified.

1. INTRODUCTION

Cross laminated timber construction represents an increasingly prominent part of multi-storey residential buildings with great potential [1]. As a rule, in order to meet the requirements for sound insulation in the building, a closer look at the flanking transmission, in particular for impact sound insulation, is necessary [2]. Due to the industrialization of timber construction, the high degree of prefabrication and the demand to keep the wood visible in the building, additional layers and suspended ceilings are not measures preferred by planners to meet sound insulation requirements. Therefore, measures such as resilient interlayers and decoupled fasteners, which can represent a significant influence in the flanking transmission paths [3], play an important role in the design of building component joints.

An essential parameter in the planning of buildings and for predicting the flanking transmission of impact and airborne noise in the ÖNORM EN ISO 12354-2 is the vibration reduction index K_{ij}. It

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could be shown in [2, 4, 5, 6] that this prediction method produces valid results with sufficient availability of the input data. However, there are no data sources available that represent a holistic view of the resilient layers and fasteners available on the market. The results achieved by the research project provide this overview and allow a direct comparison of the different measurement results of the vibration reduction index through constant test facility conditions (geometry, excitation, measuring positions, etc.).
The presented study describes the method and the built test setup for the measurement of load-dependent vibration reduction indices in different configurations of resilient layers and fasteners. Excerpts of results from the research project "Schall.Holz.Bau 2" are presented and discussed. The measurements included different combinations of a total of 15 different resilient layers in different thicknesses and 12 different fasteners at different spacings. The L-joints configured from these elements were examined under different loads. The results obtained can serve as a comprehensive data basis for the planner and developer to predict or improve flanking transmission in solid wood buildings.

2. MEASUREMENT METHOD

The calculation of the impact point dimensions is carried out according to EN ISO 10848-1:2018 from the direction averaged velocity level difference $\overline{D_{v,ij}}$, the equivalent absorption lengths of the building components a_i and a_j according to equation 1. The calculation of the single number vibration reduction index $\overline{K_{ij}}$ is carried out by arithmetic averaging of the third-octave band values in the frequency range between 200 and 1250Hz.

$$K_{ij} = \overline{D_{v,ij}} + 10\lg\left(\frac{l_{ij}l_0}{\sqrt{a_i a_j}}\right) \quad (1)$$

2.1. Joint

The design of the test setup was based on the standard ÖNORM EN ISO 10848. The joint consists of a wall element (2450mm x 2520mm, CLT (cross-laminated timber), 100mm, 3-ply) and a ceiling element (2450mm x 3450mmm, CLT (cross-laminated timber), 140mm, 5-ply).

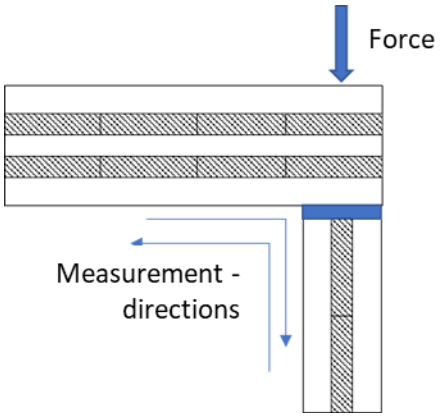

Figure 1: Schematic representation of the test setup

Figure 1 shows the examined L-joint made of a cross-laminated timber wall and a cross-laminated timber ceiling element. The structural excitation was carried out as well as the measurement of the surface speed on the inside and underside of the component. The element edges that are not supported or used to press the joint do not touch the surrounding test facility infrastructure and can therefore vibrate freely.

Figure 2: Wall-ceiling joint made of cross-laminated timber elements (wall 100mm, ceiling 140mm)

In order to investigate the influence of the pressure in the L-joint on the loss factors, the vibration level difference and the resulting vibration reduction index, a device for load application in the laboratory at the Technical Trade Museum has been developed. The design shown in Figure 2 allows a linear load to be applied to the top of the joint. The load can be increased continuously from 0-20t by means of two hydraulic presses (see Figure 3). This results in possible pressure loads between 0 and 0.82N/mm² on the different resilient layers. The uniform load distribution on the nodes is ensured by steel plates and wooden beams.

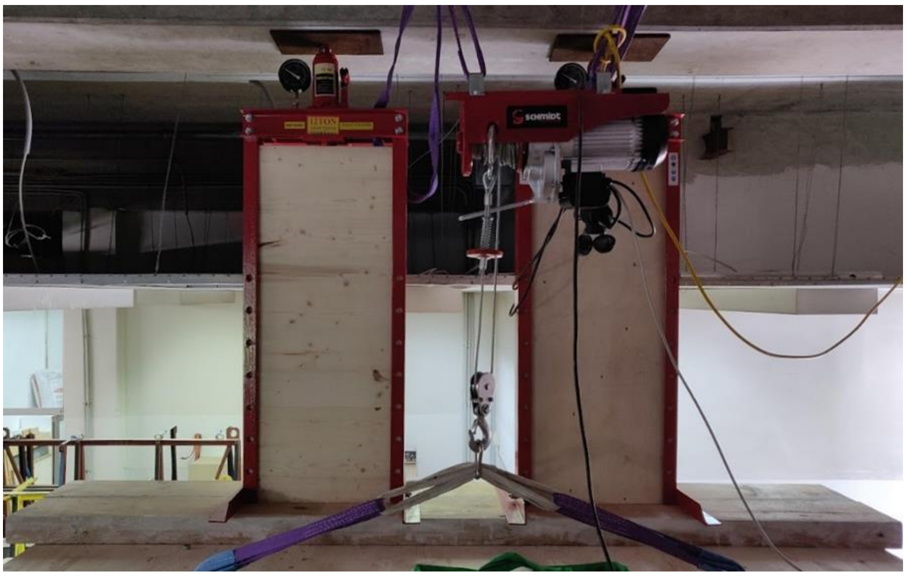

Figure 3: Device for pressing the element joint

The measurement of the vibration reduction index according to EN ISO 10848-1:2018 requires a measurement of the parameters unaffected by unwanted vibration transmission to load-bearing laboratory components. These idealized boundary conditions differ from those in the building situation, but enable a repeatable result quality independent of the joint point.

Figure 4: Wall support (left) ceiling support (right)

The lower end of the cross-laminated timber wall component was elastically mounted on two layers of elastomer, as shown in Figure 4. For better load distribution on the uneven concrete surface of the laboratory floor, a wooden beam (50x100mm) was underlaid. The wall was additionally supported by means of a wall stand during the reconstruction measures at the joint. The wall stand was decoupled in connection to the wall by means of a base by an elastomer layer. In the measuring situation, the connection between wall stand and wall was loosened in order not to influence the vibrations of the wall component at this attachment point. The described arrangement avoids unwanted vibration transmissions between the two components, except via the joint.

2.4. Measurement Equipment

The vibration reduction index K_{ij} of the joint was measured in accordance with EN ISO 10848-3:2018 with a calibrated measuring equipment of the type "Sinus Messtechnik Soundbook” with software SAMURAI 1.7.14, calibrated as a sound level meter of class 0.7". The structure-borne sound excitation was carried out by a shaker of the type "Type 4809 (B&K) (SN: 85008)" under stationary, broadband noise. The shaker was fastened via a stinger (length 300mm) by means of a hanger bolt and threaded sleeve screwed into the component (see Figure 5).

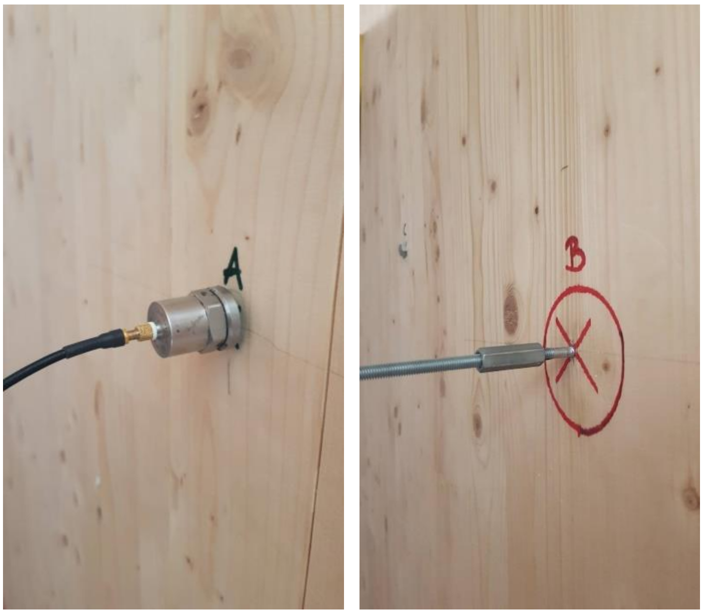

Figure 5: Accelerometer attached to hexagonal screw by magnet (left) stinger of the shaker attached to building element by means of threaded socket and hanger bolt (right)

The acceleration levels at the component surfaces were measured with vibration transducers of the type "Brüel & Kjaer Type 4370" and charge amplifiers "Brüel & Kjaer Type 2635". According to Figure 5, the vibration transducers were attached by means of magnets to the hexagonal screws screwed to the measuring positions in the building component. Before the measurement, the measuring chain was calibrated with a calibrated structure-borne sound source of the type "Bruel & Kjaer TYPE 4294"; after the measurement, the calibration was checked.

2.4. Resilient Layers

Different resilient layers were inserted into the L-joint to decouple the wall and ceiling element. Table 1 shows an overview of the materials used and their essential material properties. The individual materials have been grouped into individual material types for a better overview of results. The individual material types differ significantly in the material structure.

Table 1: Investigated resilient layers for decoupling the joint point between ceiling and wall

Type	Thickness in mm	E_{dyn} in N/mm²	P_{opt} in N/mm²
Foamed PU "open cells"	12.5	11.0-16.5	0.85
	12.5	6.8-10.0	0.45
	12.5	5.27	0.4
Foamed PU "closed cells"	6; 12.5	2.6-3.0	0.35
	6; 12.5	3.25	0.35
	6; 12.5		0.75
PU	12.5	3.53	0.38
Solid rubber	10	ca. 5.0	-.
	20	ca. 5.0	-.
Cork	10	-.	0.25

2.4. Fastener

Typical fasteners for the connection between the wall and the ceiling element in cross laminated timber elements are screws and angle connectors. Research results [3,4] show that those fasteners can have a significant influence on the flanking transmission path. Therefore, the industry devolved different solution to optimize their connectors in terms of vibration transmission (Figure 6).

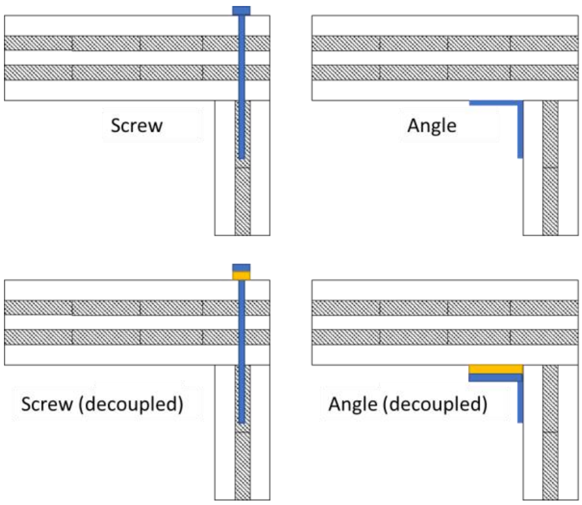

Figure 6: Schematic representation of the investigated fasteners

The structural connection of the examined wall and ceiling element in the L-joint was carried out by the fasteners listed in Table 2. The fasteners have different properties in shape, number and decoupling measures and thus form differently rigid L-joints. A categorization by fastener type for a better overview in the result analysis was carried out by the basic geometry of the fastener.

Table 2: Investigated variants of the fasteners between ceiling and wall

Type	Name	Spacing	Resilient layers	Dimensions in mm
Angle connector	Angle connector	500	none	100 x 100 x 90
	Angle connector 1	1225	single	200 x 70 x 70
	Angle connector 2	500	none	
	Angle connector 3	500	single	110 x 90 x 50
	Angle connector 4	500	single	100 x 100 x 90
	Angle connector 5	1225	double	240 x 100 x 100
	Angle connector 6	487.5 - 1950	single	110 x 110 x 60
Screws	-	250 - 3000	none / single	240 x 8

3. MEASUREMENT RESULTS

3.1. Influence of resilient Layers

Figure 7 shows an excerpt from the measurement results for a foamed open-cell polymer as a resilient layer in the L-joint. It can be seen that over the frequency range of 100-3150Hz an improvement of the frequency-dependent vibration reduction index $\overline{K_{ij}}$ of approx. 5-20dB per third band can be achieved. The improvement, especially in the frequency range higher than 500Hz, is due to decoupling and thus greater directional velocity level difference $\overline{D_{v,ij}}$ (see Figure 12 c). Below 500Hz the structural reverberation time is reduced by roughly 0.5 s, with introduction of a resilient layer and its damping properties into the joint. This also reduces the resulting vibration reduction index K_{ij}.

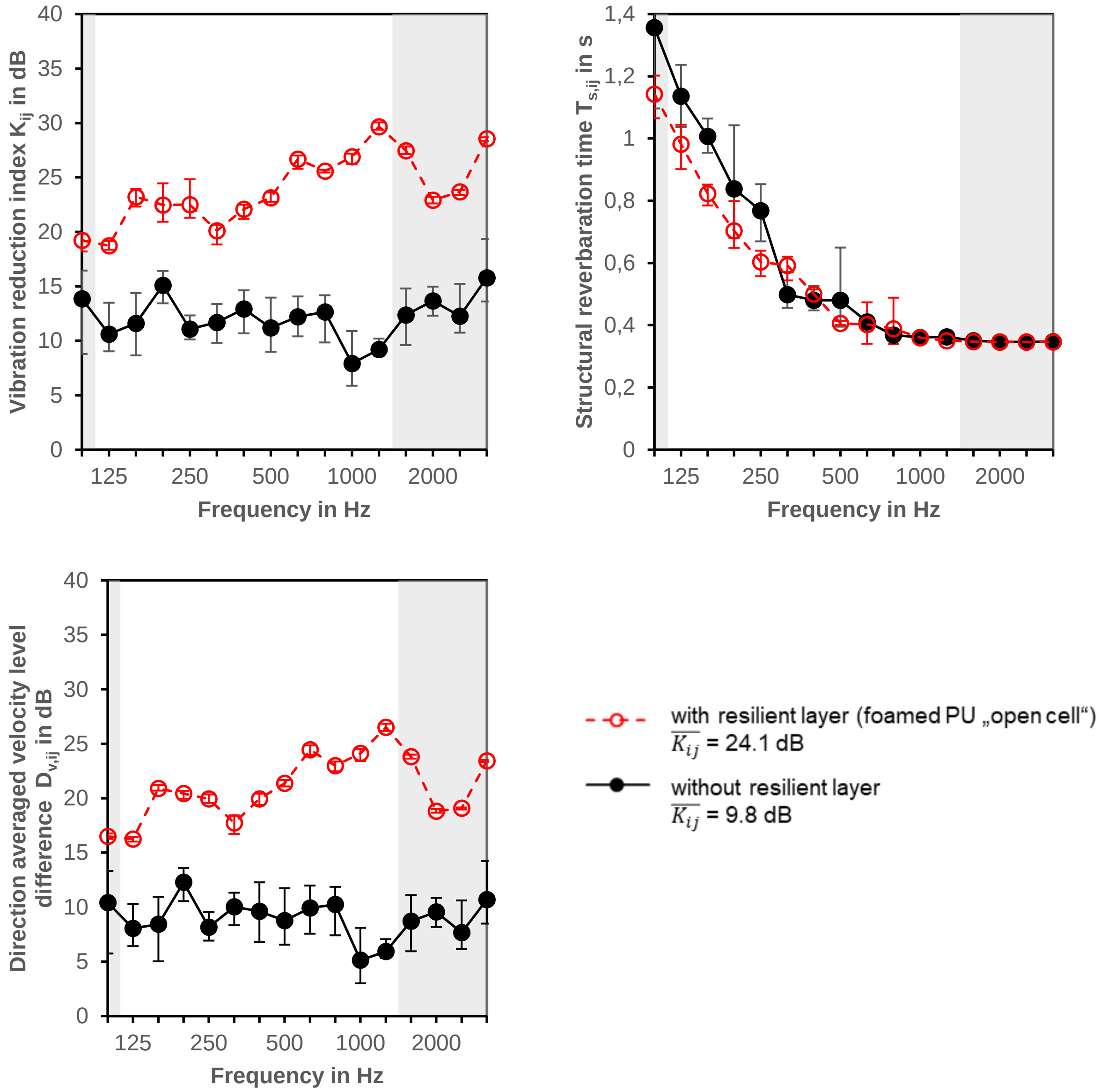

Figure 7: Influence of the insertion of a resilient layer in the L-joint on vibration reduction index $\overline{K_{ij}}$ (a) and its fundamental parameters of the structure-borne sound reverberation time $T_{s,ij}$ (b) and the direction-averaged velocity level difference $\overline{D_{v,ij}}$ (c)

The comparison of the single number values the vibration reduction indices Figure 8 shows that an improvement of $\overline{K_{ij}}$ from 11.5dB up to 26.1 dB is possible due to decoupling by a resilient layer. This improvement is highly dependent on the material of the resilient layer. Fluctuations due to load and thicknesses of up to 6dB can also be observed within a group of a material type. The greatest average improvement can be achieved by foamed polyurethanes (open and closed cell) of up to 15dB. The smallest improvement of about 4 dB in $\overline{K_{ij}}$ was measured for stiffer (for example "Various") products for decoupling. For a direct connected L-joint without a resilient layer a $\overline{K_{ij}}$ of 11.5 dB was measured.

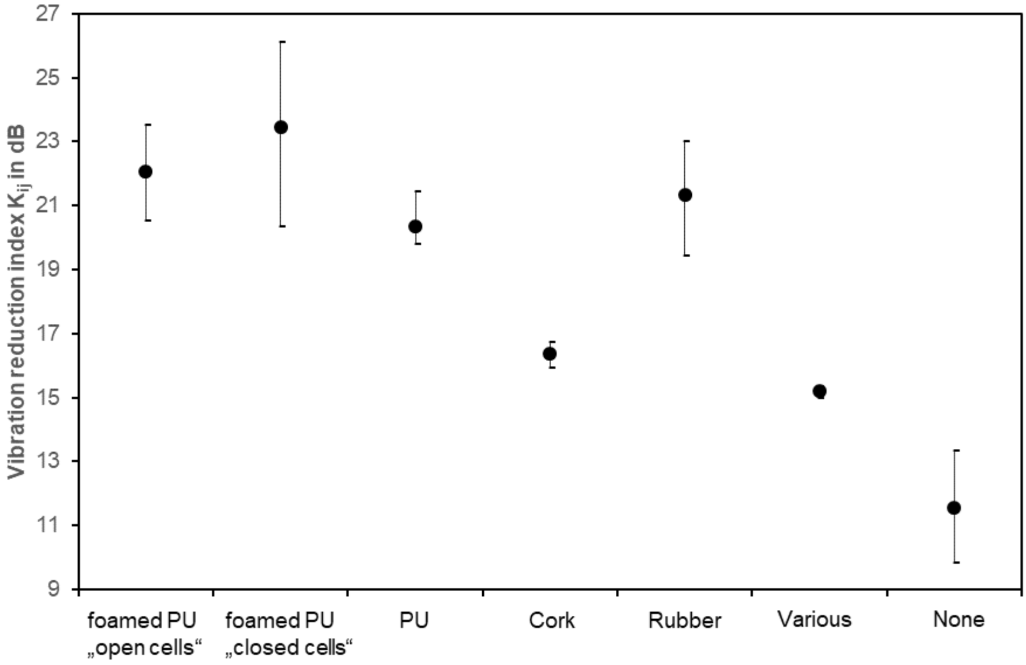

Figure 81: Comparison of the measured vibration reduction indices $\overline{K_{ij}}$ (max, min, and mean) depending on the material type and pressure of resilient layer

The relationship between the dynamic stiffness of the resilient layer for decoupling ceiling and wall components in the L-joint and the vibration reduction index $\overline{K_{ij}}$ is shown in Figure 9. It can be seen that with increasing dynamic stiffness, a poorer decoupling of the components and thus a lower $\overline{K_{ij}}$ was measured. The data shown speak for a linear relationship between dynamic stiffness and $\overline{K_{ij}}$ in the investigated area of dynamic stiffness. Despite this dominant dependence of the vibration reduction index on the dynamic stiffness of the resilient layer material, different $\overline{K_{ij}}$ were measured with similar or the same dynamic stiffness of resilient layers in the L-joint. This shows that in addition to dynamic stiffness, other properties, such as damping, material thickness and stress due to pressure on the joint have an influence on $\overline{K_{ij}}$.

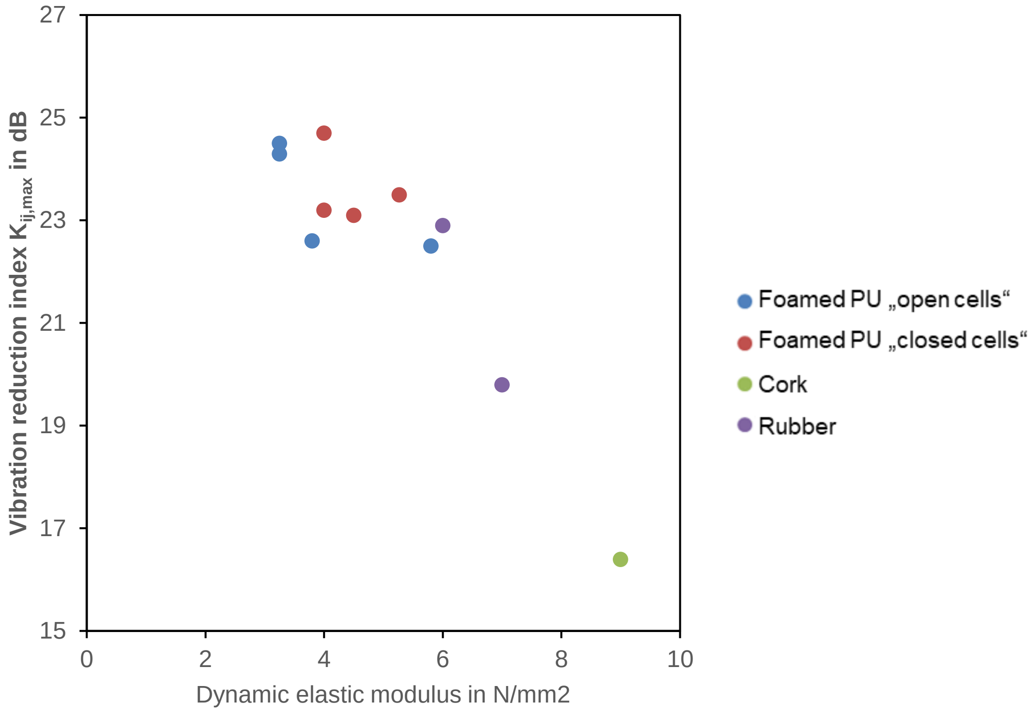

Figure 92: Representation of the relationship between the dynamic modulus of elasticity of the resilient layer in the L-joint and the highest vibration reduction index $\overline{K_{ij}}$ measured with each material type

A better correlation than between $\overline{K_{ij}}$ and the dynamic stiffness of the resilient layer in Figure 9 can be seen between the ratio of the optimal pressing P_{opt} and the existing pressures P to the ratio of the maximum measured $\overline{K_{ij,max}}$ and the $\overline{K_{ij}}$ measured with the existing pressing in Figure 10. The polynomial regression curves of the datasets for the different material types show that if the pressure $P_{vorhanden}$ of the bearing is in the range of the optimum of the range specified by the manufacturer P_{opt}, the highest vibration reduction index was measured. Exceeding the optimal pressure on the resilient layer by around 180% leads to a reduction of the impact insulation dimension of up to 2.5dB. Compared to a lower pressure than the optimal Pressure on the resilient layer of about 50%, leads only to reductions of about 1.0dB of the $\overline{K_{ij}}$. The tested resilient layers thus react more resilient in their decoupling performance to a negative deviation from the optimal pressing than to a positive and thus to exceeding the optimal pressing in the L-joint. For the material type "PU", a behavior that differs from the behavior of the other material types with a change in the load of the L-joint can be observed. The vibration reduction index of the L-joint with the material types "PU" is greatest at no load on the L-joint and decreases by up to 1.6dB with increasing the load.

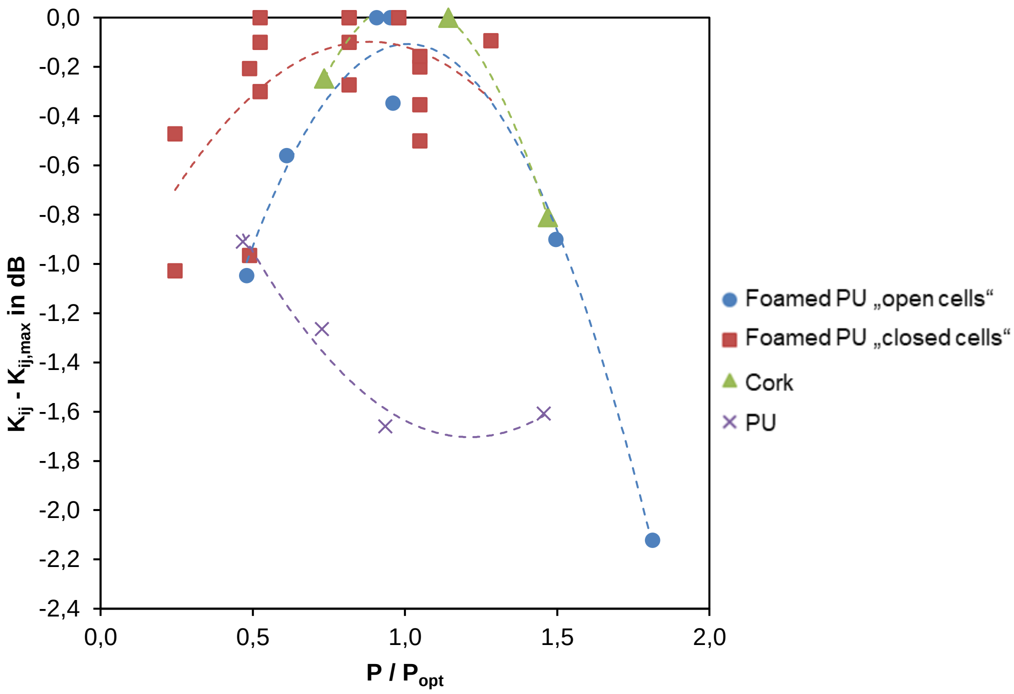

Figure 10: Influence of the ratio of the optimal pressure P_{opt} and the pressure P of the resilient layer on the difference between the measured $\overline{K_{ij}}$ and the maximum measured $\overline{K_{ij,\mathrm{opt}}}$.

3.2. Influence of fasteners

L-joint fasteners for static load transfer of transverse and shear forces generally reduce the vibration reduction index $\overline{K_{ij}}$ by coupling the ceiling and wall elements. In their area of influence, they thus shorten the decoupling of the components by means of a resilient layer in the joint. This influence on the vibration reduction index $\overline{K_{ij}}$ is shown in Figure 11 for the fasteners listed in table 2. Figure 11 shows the difference of the measured $\overline{K_{ij}}$ with and without the fastener of an L-joint with resilient layer. Due to the investigated fasteners, the measured $\overline{K_{ij}}$ decreases by 1 to 10dB depending on the type of fastener. It is thus possible to create connections in the L-joint by selecting the fastener and its decoupling measure, which practically does not represent a negative influence on the performance of the elastic resilient layer in the L-joint.

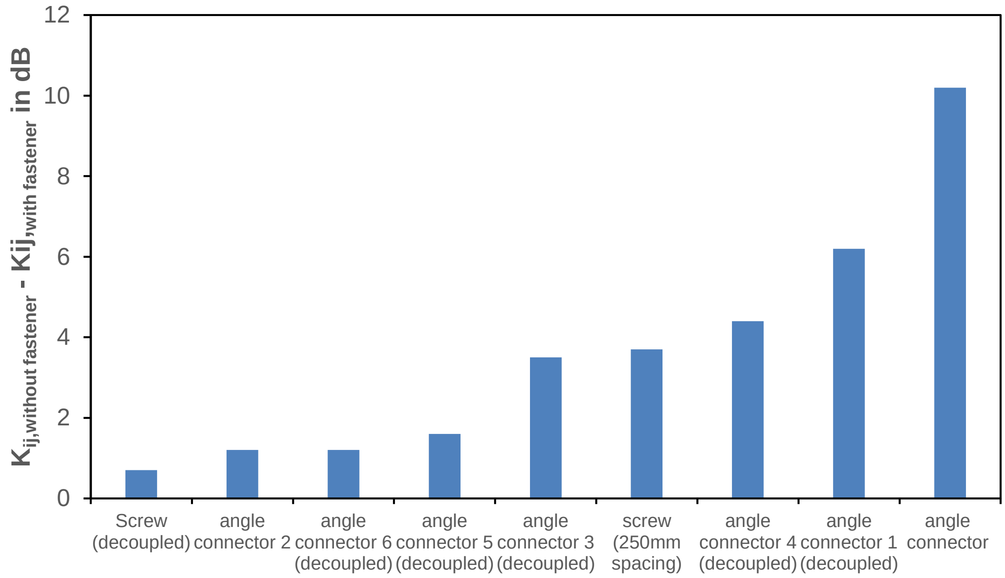

Figure11: Reduction of the measured vibration reduction indices ($\overline{K_{ij,without\ fastener}}$ - $\overline{K_{ij,with\ fastener}}$) in dB in the L-joint with a resilient layer by a fastener

Figure 11 shows that inserting elastic materials in the fastener, lead to significant improvements in the negative influence of fasteners on vibration reduction index of the L-joint. For angles, improvements of 4-6dB and for screws 2dB can be achieved by these decoupling measures. The screw shows the best performance against angles decoupled and not decoupled. This is probably due to the only punctual connection of the building elements and the low stiffness of the connection. With widths of up to 200mm and a maximum of approx. 60 screw connections each, the angles used represent a much stiffer connection, whereby the conversion in the joint of bending waves, longitudinal waves and transverse waves can take place more lossless.

4. CONCLUSIONS

By inserting resilient layers into the L-joint of cross laminated timber elements, the vibration reduction index Kij can be increased from 11dB (no resilient layer) to 16 - 26dB (with resilient layer). The vibration reduction index is strongly dependent on the selected material, its dynamic stiffness and thickness. Besides this material properties of the resilient layer the Kij depends on the pressure on the joint and therefore on the stress in the resilient layer. A reduction of up to 10% of the highest vibration reduction index was measured with 50-180% of the optimum pressure on resilient layer. This reduction depends on the material type of the resilient layer. Materials with the highest potential for increasing the impact insulation dimension showed the greatest influence of pressure in $\overline{K_{ij}}$.

Decoupling measures in the component joint by resilient layers can be significantly limited in their performance by means of fasteners. Depending on the type of fastener, a reduction of the vibration reduction index $\overline{K_{ij}}$ of up to 10dB is possible. Decoupling measures in the fastener itself can almost eliminate the negative influence of the faster on $\overline{K_{ij}}$. The vibration reduction index $\overline{K_{ij}}$ could be improved by an average of 5dB through the measures examined in the fastener compared to fasteners without decoupling elements. It has been shown that fasteners with a high stiffness parallel to the L-joint cause a particularly large reduction of Kij therefore measures that reduce the stiffness of the fastener in that direction have proven to be particularly effective.

5. ACKNOWLEDGEMENTS

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