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VIBRATION REDUCTION INDICES OF CLT JUNCTIONS

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The multi-disciplinary research project “Vibroacoustic analysis in the planning process of timber constructions“ carried out in cooperation between the University of Applied Sciences Rosenheim, the ift Rosenheim and the Technical University Munich is a comprehensive study of direct as well as flanking structure-borne and airborne sound insulation of Cross Laminated Timber (CLT) elements and their junctions. The aim is to optimize and simplify the acoustical planning process of wooden multi-storey buildings and thereby to contribute to the increase growth of timber construction industry in Europe. For a prediction of the acoustical performance of solid wood constructions, the vibration reduction index K_{ij} is needed. The vibration reduction index can be determined i.a. of the direction-averaged junction velocity level difference and the structural reverberation time. Both quantities need to be measured according to EN ISO 10848. Alternatively, vibration reduction indices for a T- or cross-junction can be derived following the procedures described in prEN ISO 12354-1:2016. However, further knowledge and data of the sound transmission across junctions of CLT is inevitable for a reliable prediction. In this paper a collection of frequency dependent vibration reduction indices for CLT structures will be presented and compared, involving L-, T- and cross-junctions measured by six international laboratories.

Keywords: Vibration reduction index, Cross Laminated Timber

1. Introduction

For a long time the importance of timber as construction material in multi-storey buildings and urban areas was weak. Nowadays, with an increasing awareness of sustainability and resource management, European countries are challenging each other to build the highest or largest wooden building. Prefabrication as well as efficient assembling on site save time and cost, reduce noise emissions and allow a weather independent construction. Several pilot projects have been realised in recent years. Even though structural aspects and fire safety have been continuously optimized and the acoustical performance of timber frame light-weight buildings has been studied intensively, the knowledge of the acoustical properties of solid wood constructions is still not sufficient.

The multi-disciplinary research project “Vibroacoustic analysis in the planning process of timber constructions“ has the aim to optimize and simplify the acoustical planning process of wooden multi-storey buildings. Based on a 3D-model, provided by an architect, a computer-based prediction of the sound insulation shall easily be possible for solid wood constructions. The acoustical performance of CLT junctions has been investigated at the University of Applied Sciences Rosenheim. The ift Rosenheim measured the sound insulation and flanking transmission of several CLT structures. The Technical University Munich used the measurement results for the validation of simulations based on the Finite Element Method (FEM).

For estimating and simulating the acoustical performance of solid wood constructions, a quantity to characterise the sound transmission across a junction, the vibration reduction index K_{ij} is needed. Input data for the K_{ij} have not been available for a long time. First proposals of frequency dependent values are mentioned in prEN ISO 12354 [3]. For further validations and an extension of the data in the standards international measured vibration reduction indices of CLT junctions have been documented in [7].

2. Sound insulation of solid timber constructions

The acoustical performance of multi-storey buildings can be estimated according to [1]. Due to the solid and plate shape appearance of CLT, these constructions are rated as heavyweight structures. For the prediction of the airborne and impact sound insulation acoustical parameters are necessary to specify the sound transmission across each junctions and the transmission paths.

The vibration reduction index K_{ij} is the transmission of vibrational power across a junction of the two structural elements i and j. The greater the K_{ij}, the less is the power transmitted from element i to j. It is determined according to Eq. (1).

$$K_{ij} = \overline{D_{v,ij}} + 10\,lg\frac{l_{ij}}{\sqrt{a_i \cdot a_j}}, \tag{1}$$

where $\overline{D_{v,ij}}$ is the direction-averaged velocity level, l_{ij} the common length of the junction and a the equivalent absorption length. The equivalent absorption length a can be derived of the structural reverberation time T_s and the area S of each element according to Eq. (2) with $f_{\mathrm{ref}} = 1000$ Hz.

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

The sound reduction index of solid timber constructions is determined from the component-related direct sound transmission and flanking sound reduction index of each flanking element. The weighted flanking sound reduction index $R_{ij,w}$ of solid building components considers the properties of the elements (sound reduction index of the elements $R_{i,w}$ and improvements due to additional linings $\Delta R_{ij,w}$) as well as the connection system of the elements i and j by the vibration reduction index K_{ij}:

$$R_{ij,w} = \frac{R_{i,w}}{2} + \frac{R_{j,w}}{2} + \Delta R_{ij,w} + K_{ij} + 10\,lg\frac{S_s}{l_0 \cdot l_f} \tag{3}$$

The calculation can be carried out using single number values (Eq. (3)) or frequency dependent. For the prediction of the impact sound pressure level the flanking sound transmission is considered similar to the Eq. (3) by the vibration reduction index K_{ij}.

3. Vibration reduction indices of CLT junctions

Until the publication of the draft for the prEN ISO 12354 [3] only single number values for the vibration reduction index K_{ij} of CLT constructions have been available for the prediction of the airborne and impact sound insulation [4]. According to the new Annex F in [3] frequency-dependent vibration reduction indices for a T- and a cross-shaped CLT junction can be derived from empirical data, partly using the mass ratios of the elements. These are shown in Fig. 1. The proposed values are based on field measurement results by the French institute CSTB [5].

For further adjustments in [3] regarding the sound transmission across CLT junctions a more comprehensive database is required. Therefore, an international survey has been carried out to collect frequency-dependent vibration reduction indices measured in the field or in the laboratory.

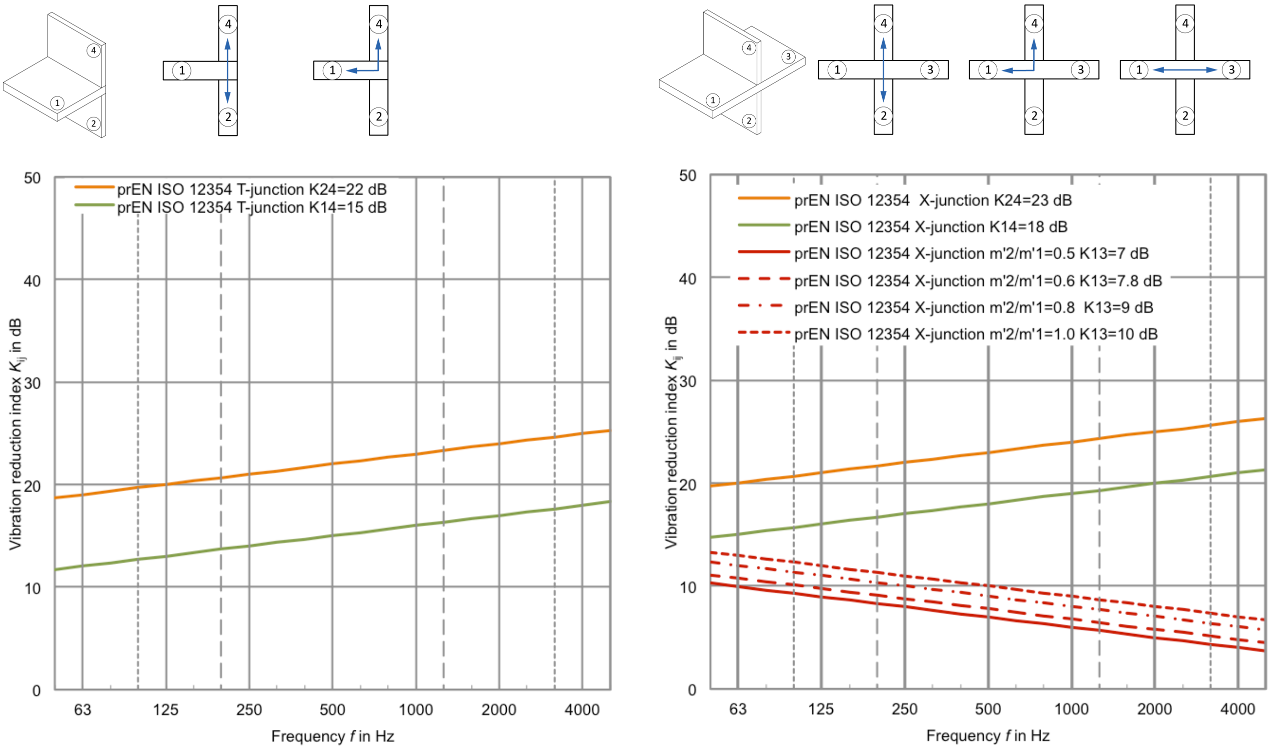

Figure 1: Frequency-dependent vibration reduction indices for CLT junctions according to [3].

The following six institutions provided data:

- CSTB, Center of Building Science and Technology, France
- EMPA, Laboratory for Acoustics/Noise Control, Switzerland
- ift Rosenheim GmbH, Laboratory for Building Acoustics, Germany
- SINTEF Building & Infrastructure, Norway
- University of Applied Sciences Rosenheim, Laboratory for Sound Measurements, Germany
- University of Bologna, Department of Industrial Engineering for Rotho Blaas GmbH, Italy.

The sound transmission across CLT junctions is influenced by several parameters. Hence, detailed specifications of the measuring method, the connection type and the elements have been documented.

The documentation [7] contains a total of 40 datasets for L-junctions, 137 for T-junctions and 42 for cross-shaped junctions. The measurements were mainly performed on freestanding junction mock-ups in a laboratory. Partially, In-Situ measurements were carried out.

In the measurements either glued or dowelled CLT elements have been investigated. For wall elements 3- or 5-ply CLT with a thickness ranging from 78 mm to 140 mm were used. The thickness of the floor elements was mainly 115 mm to 162 mm with 5 layers. The mass ratio of the elements forming a junction is typically 0.5 for wall-ceiling junctions and up to 1.0 for wall-wall junctions. Both small- (element width 125 cm) and large-sized elements from eight different manufacturers have been used. Wood screws, metal brackets, hold-downs or continuous steel brackets were used to connect the CLT elements. Moreover, nine resilient interlayer types of three manufacturers were tested. In order to simulate an In-Situ situation, partially extra loads were added to increase the static pressure at the joint.

The whole survey is documented in [7]. Additionally, the acoustical parameters are transferred to the vibroacoustical database VaBDat (www.VaBDat.de) developed by the University of Applied Sciences Rosenheim to provide input data for the excel-based prediction tool VBAcoustic developed by the ift Rosenheim. VBAcoustic allows a frequency dependent prediction of the sound insulation based on a 3D-geometry of a building information model (BIM).

4. Discussion of the measurement data

The vibration reduction index of solid timber constructions depends on a variety of parameters. The following comparisons of the measurement data document the influence of some distinct parameters.

In general, the vibration reduction indices differ strongly between the institutes as well as between laboratory and field measurements. So far, it could not be ascertained whether the deviations result from the test situation, the measurement performance or the different CLT products.

The results are presented in diagrams, which are based on the requirements of EN ISO 10140. The typical frequency range for building acoustics (100 Hz to 3150 Hz) is marked with dotted lines. Additionally, dashed lines show the frequency range for single number values. The single number value $\overline{K}_{ij}$ is the arithmetic mean of the one-third octave bands from 200 Hz to 1250 Hz. The discussion of the comparisons refers to the building acoustical frequency range. The low and high frequencies (< 100 Hz, > 3150 Hz) are shown but not further evaluated due to uncertainties in this range.

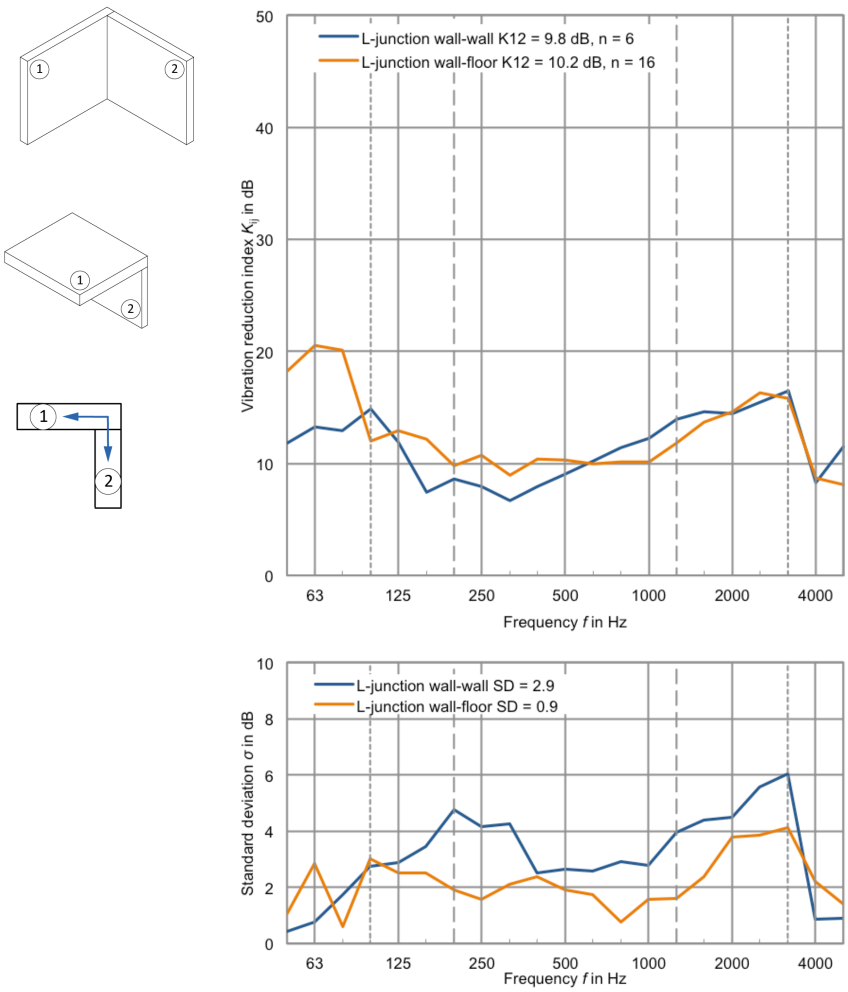

Figure 2: Comparison of the average of the measured vibration reduction indices and the standard deviation for L-junctions wall-wall $\overline{K}_{12}$ = 9.8 dB and wall-floor $\overline{K}_{12}$ = 10.2 dB without a resilient layer, path 1-2.

4.1 Orientation and connection type of the junction

In [3] it is not defined, whether the given vibration reduction indices relate to wall-floor and/or to wall-wall junctions. Therefore, the different orientations of the junctions and their elements were investigated. Fig.1 shows result for L-junctions as an example. Both in the frequency range used for the single number rating as well as in the expanded building acoustics frequency range, the vibration reduction indices differ slightly. The maximum deviation is approximately 2 dB at 315 Hz.

Due to the similar frequency responses the two results for the L-shaped wall-wall and wall-floor junction can be summarized for the simplification of the prediction, especially since all possible connections from stiff to loose are considered. Hence, for L-junctions of CLT a single number rating value of 10 dB can be used.

Looking at the measurement data more detailed with regard to the connecting system, the influence of the type of connection becomes very clear (Fig.3). A very stiff connection (wood screws spaced at 20 cm) of the wall-wall junction results in a single number rating of $\overline{K}_{12}$ = 5.5 dB. A more flexible connection with full thread screws spaced at 60 cm results in a significant higher $\overline{K}_{12}$ value of 13.7 dB.

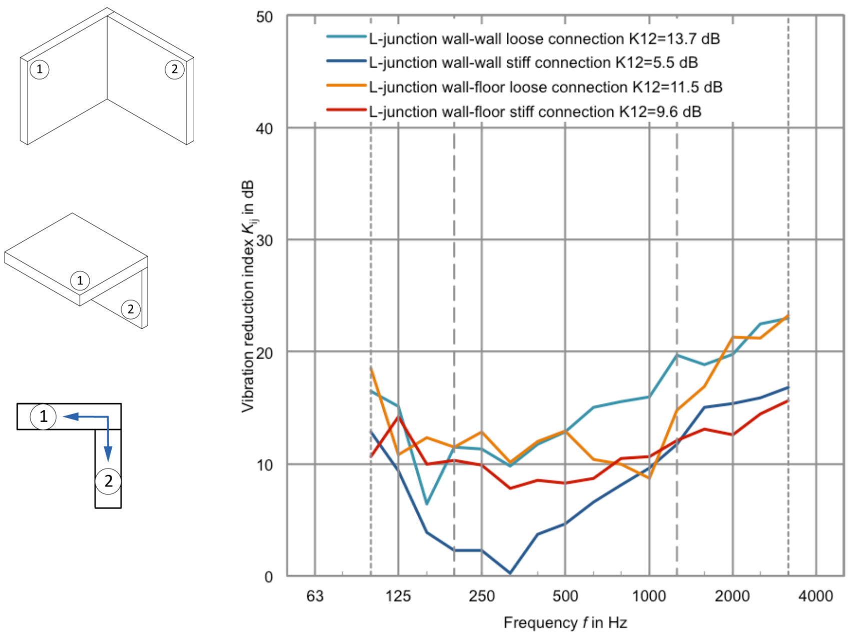

Figure 3: Comparison between the average of the measured vibration reduction indices for the L-junctions wall-wall and wall-floor. Both with a loose and a stiff connection, path 1-2.

4.2 Size of the CLT element

A further aspect, which clearly emerges from the measured data, is the influence of the size of CLT elements. These elements are joined to a wall or a floor. Vibration reduction indices across a continuous flanking element of glued CLT boards are shown in Fig. 4. In the first case the flanking wall consists of small-sized elements with a width of 125 cm. These connections of the elements represent further junctions, which reduce the sound transmission and result in a rather high vibration reduction index ($\overline{K}_{24}$ = 9.6 dB). If the flanking wall is made of one large-sized CLT element, the vibration reduction index turns out to be significantly lower ($\overline{K}_{24}$ = 4 dB). This result is even lower than the vibration reduction index given in EN 12354 [1] for T-junctions made of massive materials like concrete or brick. For these constructions the standard lists mass-dependent single number rating values for the vibration reduction. For example, according to [1] for a junction with a mass-ratio of 1.0 and the transmission path 2 to 4 the single number rating value is $\overline{K}_{24}$ = 5.7 dB.

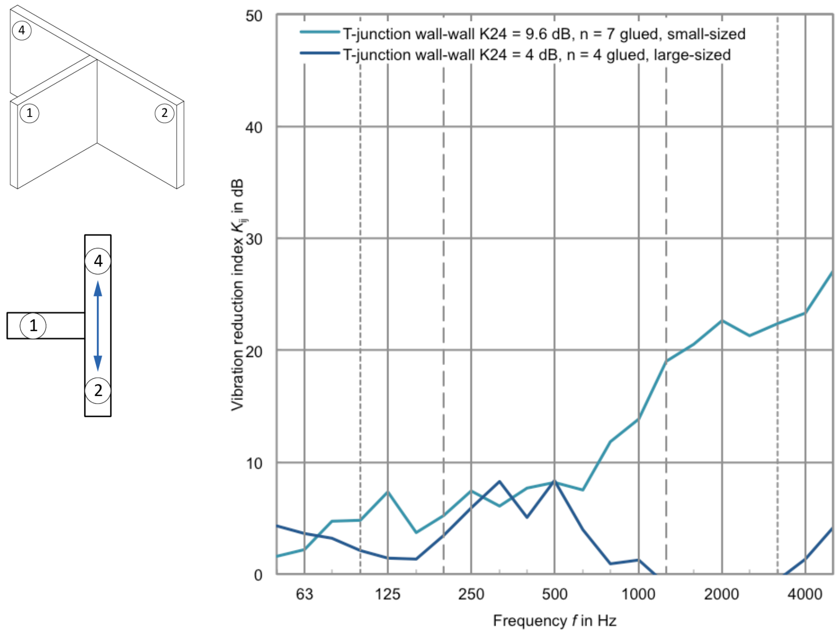

Figure 4: Comparison between the averages of the measured vibration reduction indices for T-junctions wall-wall, path 2-4. Flanking element separated in small-sized elements $\overline{K}_{24}$= 9.6 dB and flanking element as one large-sized elements $\overline{K}_{24}$= 4 dB.

4.3 Resilient interlayer

In general, measurement results from the different institutions strongly differ for constructions with resilient layers. A general trend can be identified: the vibration reduction indices measured at the University of Applied Sciences Rosenheim are higher than results by the University of Bologna. The reason might be the different stiffness and thickness of the used products. Another possible reason is that the pressure at the joints does not match the operating range of the resilient interlayer. Detailed information about the static pressure at the joint is not available for all datasets.

In Fig.5 the vibration reduction indices are compared for L-junctions with and without resilient interlayer as an example. The influence of the resilient material type as well as the effect of the static pressure on the junction depending on the operating range of the resilient material can easily be identified.

Additional decoupling of the connectors strongly increases the vibration reduction index (no resilient layer, no additional load: $\overline{K}_{12}$= 12.3 dB; with resilient layer, decoupled screws, additional load: $\overline{K}_{12}$= 23,1dB). The strong dip at 250 Hz relates to a coupled eigenmode.

4.4 Comparison of measured data with prEN ISO 12354

In Fig.6 the averaged measurement results are compared to the proposed vibration reduction indices in [3] for a T-junction. The measured data matches well with the values in the standard [3], especially for the transmission path 2 to 4. In general, the data in [3] are slightly higher than the measured data.

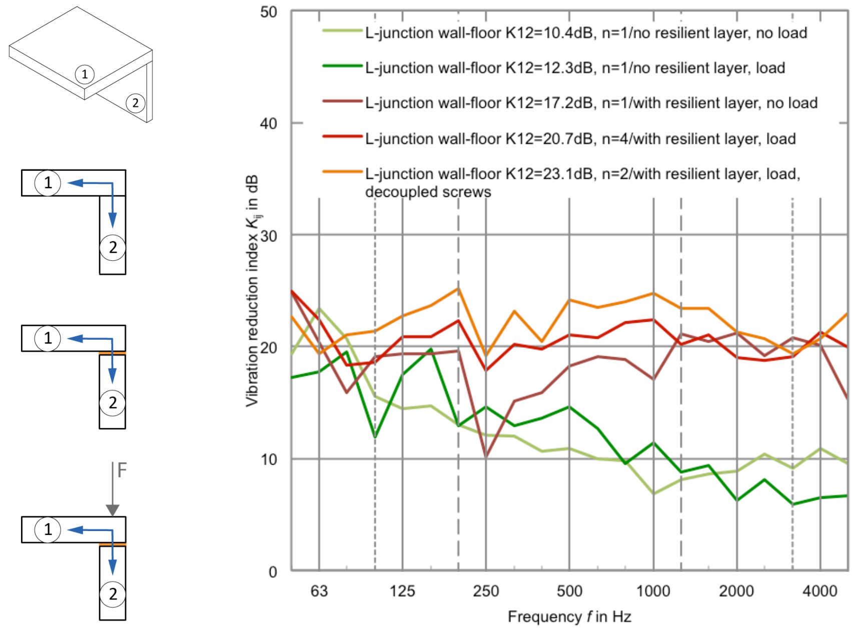

Figure 5: Comparison between the average of the measured vibration reduction indices for L-junctions wall-floor with resilient layer and with or without additional load, path 1-2.

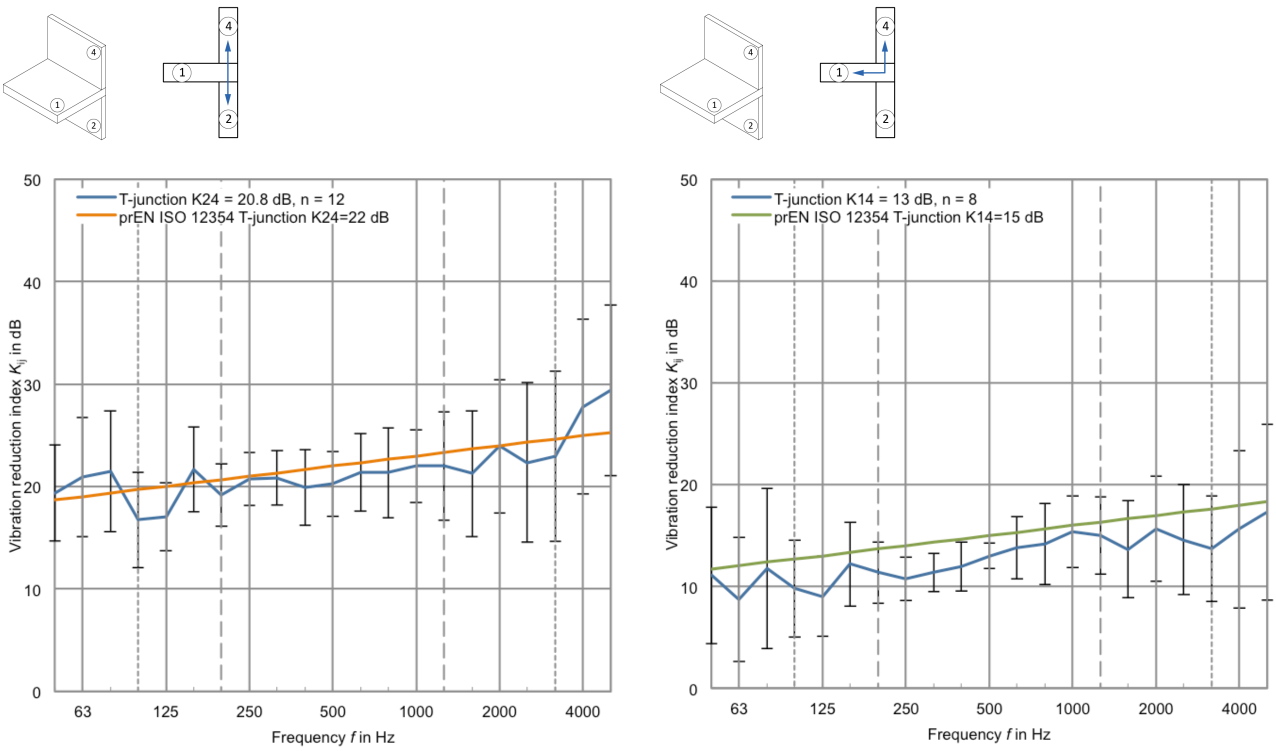

Figure 6: Comparison between the average of the measured vibration reduction indices for T-junction wall-floor without resilient layer, paths 2-4 $\overline{K}_{24}$= 20.8 dB and 1-4, $\overline{K}_{14}$= 13 dB and calculated according to prEN ISO 12354 $\overline{K}_{24}$= 22 dB and $\overline{K}_{14}$= 14 dB

5. Summary

A comprehensive documentation of frequency-dependent vibration reduction indices for CLT constructions has been carried out. This documentation provides input data for the prediction of the sound insulation in multi-storey timber buildings. It is also a basis for further developments of the standard [3]. Particularly an introduction of vibration reduction indices for L-junctions as well as a greater variety of construction types of T- and X-junction should be discussed.

The dataset mentioned above considers several possible parameters, which influence the sound transmission across CLT junctions. The analysis identifies some of the main parameters:

- Manufacturing of the CLT board (glued or dowelled),
- Size and amount of the boards forming a wall or floor element,
- Type and amount of connectors,
- Stiffness of the junction,
- The use of resilient interlayer and their operation range and
- Decoupling of the connectors.

Future work and discussions need to address the scope of these influencing parameters for the sound insulation prediction.

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