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FLANKING TRANSMISSION OF IMPACT NOISE AT SOLID WOOD STRUCTURES

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ABSTRACT: Since solid wood constructions are more frequently applied for multi storey residential buildings the demand for reliable prediction of sound insulation is increasing. Prediction is carried out following EN 12354 which, however, does not contain any input data for solid wood constructions. Therefore, sound- and vibration measurements were realized on solid wood test facilities where flanking transmission and input data for standardized predictions are acquired. The normalized impact sound pressure level is calculated for different flexible interlayers and compared to the results of the measurements. Single number quantities show satisfactory accordance between measurement and prediction with deviations between 0 and 2 dB. Considering frequency dependent values major deviations, which can be detected in a certain frequency range, require more accurate modelling. In a further step transformation of results to the building situation by implementing conventional fasteners, which are required for static reasons, was analyzed. Since application of fasteners lead to partly significant deterioration of flanking insulation, optimized fasteners were searched and their acoustic potential verified at test facilities. It could be shown, that acoustically optimized fasteners nearly do not affect flanking insulation at all. A catalogue of verified constructions was published to enable quick estimation of acoustic parameters of selected constructions, including flanking transmission.

KEYWORDS: Flanking transmission, impact sound, vibration reduction index, sound insulation, solid wood

1 INTRODUCTION

Solid wood constructions are more frequently applied for multi storey residential buildings even in urban surroundings. In addition to usual advantages of wooden constructions compared to heavy structures, like higher grade of prefabrication and lower building moisture further positive aspects can be found. Solid wood structures show higher static performance and CO_2 storage capabilities than wooden post and beam structures.

Special attention has to be paid to noise protection and in this respect especially to flanking transmission. Requirements on building elements are provided by legislation, considering utilization of the structure. Sound insulation within buildings is regulated in Austria by building regulation and standards [1]. In mentioned standard minimum values for the sound insulation against outside and inside the building between dwellings are defined. That means, a broader view is necessary that also includes flanking paths. This can lead to the situation, that building elements with appropriate properties according to laboratory data, do not fulfill prevailing requirements. During design stage, prediction methods, that do not only show the element but the whole building situation, are necessary for correct calculation.

2 SITUATION IN WOODWORK

Requirements on sound insulation in general and on impact sound insulation of separating floors in special pose a challenge for planners and builders. Agile research in this area led to a commonly accepted calculation model [2] for prediction of sound insulation between rooms. This method has been developed primarily for homogeneous, monolithic structures. For lightweight structures (e.g. post and beam structures) according to [3], usage is limited. Applicability for solid wood structures still has not been verified.

2.1 RESEARCH PROJECT

Within the research project Urban Construction with Wood, flanking transmission of solid wood structures was examined systematically. Beside normalized sound pressure level difference, normalized impact sound pressure level and normalized flanking impact sound pressure level (with different elastic interlayers and fasteners), input data for standardized prediction method was measured. Input data is applied to the prediction method according to [2] and results were compared to measurement results of normalized flanking impact sound pressure level for verification of mentioned standard. Thereby three different raw floors and four

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different flexible interlayers, provided by industrial project partners, where examined. By varying static load on the test facility, different stores were simulated to figure out impact on interlayers.
In a further step transferability of measurement results gathered at the test facility to the construction site by applying usual fasteners had to be tested. Hence application of fasteners led to a severe deterioration of the flanking sound insulation, methods had to be found to improve acoustic performance of statically required fasteners.
A calculation method for the junction with flexible interlayers was developed and a catalogue with verified details was published to support the user during design stage.

2.2 REALIZATION OF THE PROJECT

At the beginning of the research project two solid wood test facilities, made of solid wood, were built to be able to carry out investigations. On these test facilities an extensive program of sound and vibration measurements was realized to acquire data to flanking transmission and input data for standardized prediction. Measurement results were used for validation of an existing prediction method according to [2]. A calculation method for the junction with flexible interlayers was developed and a catalogue with verified details was published to support the user during design stage. Proceeding investigations at the TU Vienna shall bring deeper understanding of the junction in respect of a simulation tool.

3 SOUND INSULATION IN SOLID WOOD STRUCTURES

3.1 ACOUSTIC CHARACTERISTICS

Solid wood constructions can neither be assigned as heavy nor as lightweight, multilayered elements. Whilst acoustic requirements are fulfilled by mass of heavy elements or low bending stiffness of the planking of post and beam structures, solid wood elements can't be classified in one of these categories [4].
Generally sound insulation is decreasing around the critical frequency. Heavy elements show this decline at very low, lightweight elements at very high frequencies. In both cases it can be found outside the building acoustics frequency range. At solid wood structures the critical frequency can be found between 250 and 500 Hz, which is exactly in the relevant frequency range. This is a fact which has to be considered whilst configuration of the building element.

3.2 FLANKING TRANSMISSION

Sound is transmitted between two adjacent rooms over the separating element and flanking paths. In case of the separating floor, flanking paths can be found in flanking walls, but also in airborne sound paths like cable ducts. In some cases it is not unusual that flanking elements show higher radiation than the separating element. In [5] it is mentioned, that sound insulation in buildings solely constructed by solid wood elements, sound insulation is poorer compared to post and beam structures if no structural measures against flanking transmission are taken. Flanking transmission significantly increases complexity of prediction. Even established methods don't picture the whole transmission process adequately [6].

3.3 PREDICTION OF ACOUSTIC PROPERTIES

Presently accepted calculation method EN 12354 is based on the fact, that sound ist transmitted over different paths. These paths are also coupled and exchange energy within each other. This method offers a detailed model with frequency dependent calculation with a result that can be rated according to [7] and [8] and also a simplified method which is based on single number values. Essential for the detailed model is, that values measured in test facilities, during calculation have to be converted to „in situ“ values (values in the building). This is carried out by considering the structural reverberation time T_s, which shows the damping of the element. Referring to this, data is hardly available, and measurement, especially at timber elements, is difficult.
Another important parameter is the vibration reduction index K_{ij}. It characterizes the damping of the junction, without taking adjacent elements into consideration. Whilst junctions in mineral massive structures simply can be determined with satisfactory accuracy by taking into account their mass and geometry, solid timber structures do not allow this simple method.

4 RESEARCH AT TEST FACILITIES

In following chapters described investigations refer to the test facility which has been built at KLH Massivholz GmbH (figure 1). In this test facility, extensive sound and vibration measurements to the impact of elastic interlayers were carried out.

Figure 1: *Test facility at KLH Massivholz GmbH with the ground floor moved out*

Main objective when planning a test facility is the creation of diffuse sound fields in the relevant frequency range. Furthermore according to [9] reverberation time, Volume, respectively volume difference between rooms, geometry, flanking transmission and damping hast o be considered.

In mentioned test facility the following floor systems were investigated:
KLH 5s cross laminated timber element 162 mm, KLH 5s cross laminated timber element 140 mm, Lignatur hollow box element 160 mm, Lignatur hollow box element Silence 200 mm

4.1 MEASUREMENTS OF AIRBORNE SOUND INSULATION

Airborne sound was emitted from the upper floor and measured in the ground floor. White noise is produced by a loudspeaker with a spherically uniform sound radiation. Reflections on surrounding construction elements in combination with the uniform emitting characteristic of the loudspeaker lead to a diffuse sound field in the room. The examined element now radiates sound into the receiving room what leads to an energy balance of excitation and radiation and so to a constant sound level in the receiving room.
In figure 3 an excerpt of the measurement results [10] with a floor structure and the joint situation according figure 2 is given, which shows the acoustic potential of flexible interlayers.

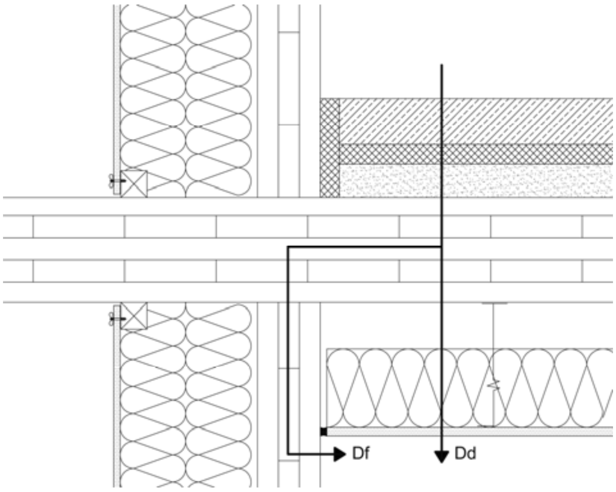


Figure 2: *Junction wall/floor*

Single number values $D_{n,w}$ calculated from curves of figure 3 lead to level differences from up to 14 dB between the situation without interlayer and the situation with the most effective interlayer.

4.2 MEASUREMENTS OF IMPACT SOUND INSULATION

Since for determination of airborne sound insulation a sound level difference is measured, measurements of impact sound insulation need a defined excitation. This excitation is carried out by a standardized tapping machine with a defined power spectrum.
Footstep sound insulation properties of the floor are characterized by the normalized impact sound pressure level L_n or by the standardized impact sound pressure level L_{nT}.

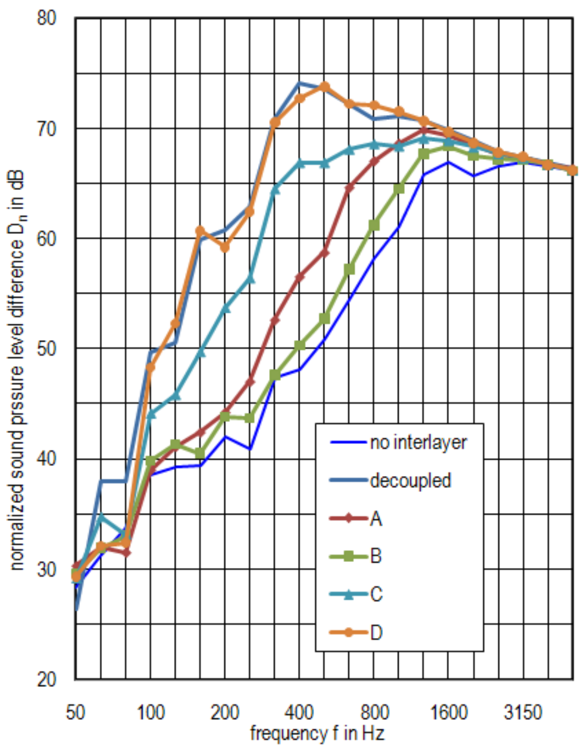


Figure 3: *Normalized sound pressure level difference with different flexible interlayers*

The tapping machine was situated in the first floor and the impact sound pressure level was measured in the ground floor. In figure 4 measurement results [10] with a floor structure and the joint situation according figure 2 are given in extracts, which show the acoustic potential of flexible interlayers considering impact sound insulation.

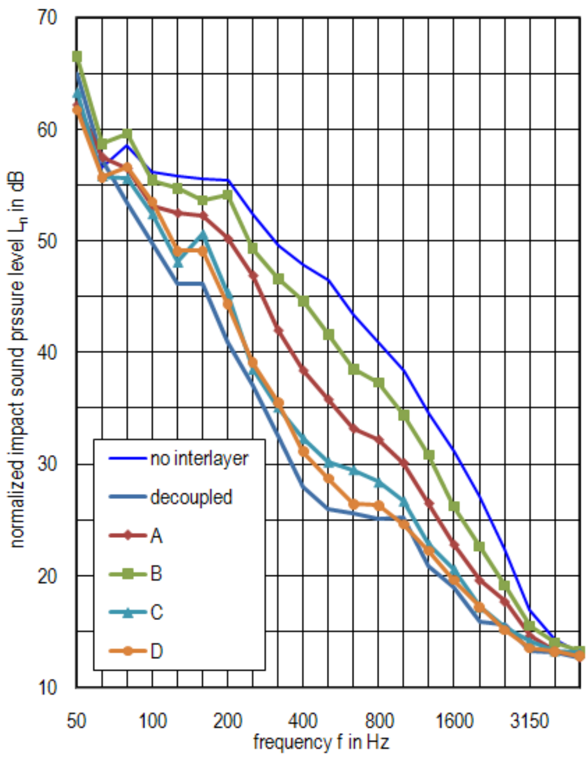


Figure 4: *Normalized impact sound pressure level with different flexible interlayers*

Single number values $L'_{n,w}$ calculated from curves of figure 4 lead to impact level differences from up to 8 dB between the situation without interlayer and the situation with the most effective interlayer. Considering floor construction type Lignatur hollow box element, differences up to 9 dB were measured.

4.3 VIBRATION MEASUREMENTS

Vibration measurements, which were carried out for gathering input parameters for standardized calculation, had their focus on prediction of impact sound insulation. As can be shown from measurement results from existing buildings, standardized requirements for airborne sound are easier to achieve than requirements for footstep sound insulation.

Velocity level differences D_v were measured with an eight channel analyzer system (4 accelerometers mounted on the underside of the floor and 4 on the wall) in both directions and then directions were averaged. Measurements were carried out with different interlayers, decoupled, with additional load of 240 kN and with and without screws. An extract of results is shown in figure 5 [10].

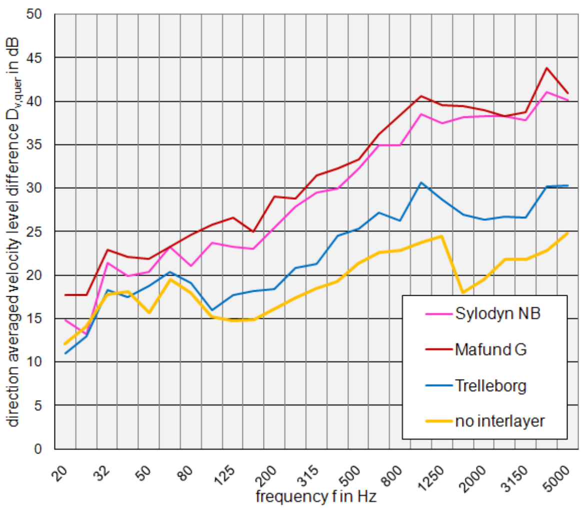


***Figure 5:** direction averaged velocity level difference of solid wood junctions with three different interlayers*

Structural reverberation time T_s was calculated from the decay curve of the acceleration levels of the elements. Measurement of structural reverberation time was carried out with transient excitation and MLS.

5 APPLICATION OF PREDICTION ACCORDING TO EN 12354

Impact excitation reduces flanking transmission in contrary to airborne sound excitation from 12 to 4 flanking paths. Beside direct transmission only the flanking path Df floor-wall is relevant. Total transmission L'_n results from the energetic sum of over flanking paths transmitted normalized impact sound pressure level $L_{n,Df}$ and the direct transmission $L_{n,D}$.

Thus, it is possible to calculate the over the flanking paths transmitted normalized impact sound pressure level $L_{n,Df}$ according Equation (1) by measuring the directly transmitted normalized impact sound pressure level in the test facility without flanking paths and then the normalized impact sound pressure level of the entire construction L'_n.

$$L_{n,Df} = 10\log\left(10^{\frac{L'_n}{10}} - 10^{\frac{L_{n,D}}{10}}\right)\text{dB} \qquad (1)$$

This $L_{n,Df}$ can also be calculated according to Equation (2) by insertion of results of vibration measurements according to [2].

$$L_{n,Df} = L_n - \Delta L + \frac{R_D - R_f}{2} - \Delta R_f - \overline{D_{v,Df}} - 10\lg\sqrt{\frac{S_D}{S_f}}\ \text{dB} \qquad (2)$$

Where L_n is the impact sound pressure level of crude floor (dB), ΔL improvement of impact sound pressure level (dB), R_D sound reduction index of the crude floor (dB), R_f sound reduction index oft he wall (dB), ΔR_f sound reduction improvement index of lining on the wall (dB), S_D Area (floor) (m²), S_f Area (wall) (m²) and $\overline{D_{v,Df}}$ the direction averaged velocity level difference.

An excerpt of results, measured and calculated for constructions according figure 2, is shown in figure 6.

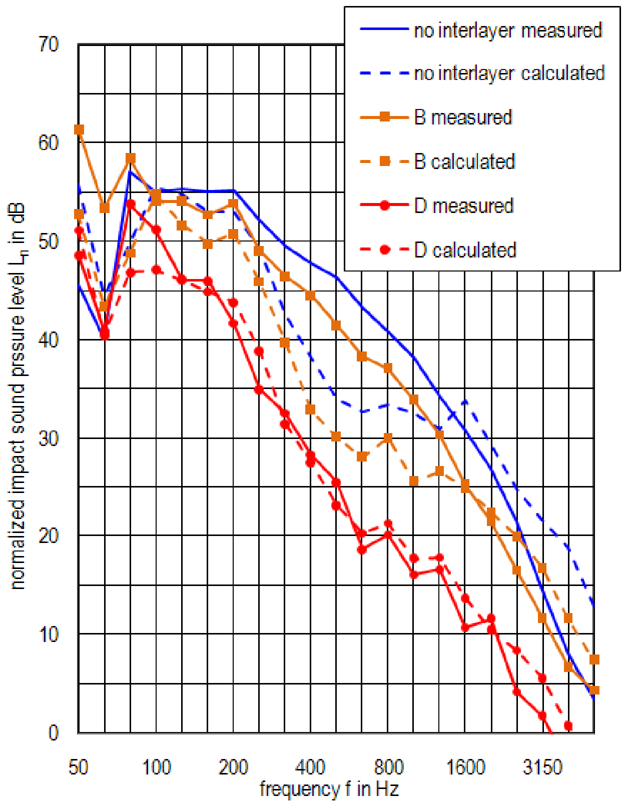


***Figure 6:** Over flanking paths transmitted normalized impact sound pressure level $L_{n,Df}$. Measured and calculated according to EN 12354.*

6 IMPACT OF FASTENERS

As mentioned above, the application of flexible interlayers leads to significant improvement of flanking insulation. Their impact is, however, highly affected by installation of required metal fasteners. But connection of adjacent building elements with fasteners is necessary for horizontal deflection of forces.

6.1 FLEXIBLE INTERLAYERS AND FASTENERS

In reality of solid wood structure, connection between adjacent elements is carried out by screws and fasteners. Screws are drilled through the floor into the wall underneath and the wall above the floor is connected by fasteners. It can be expected, that application of metal fasteners leads to a deterioration of the damping of a junction with flexible interlayers. This effect has to be quantified and acoustically optimized fasteners have to be developed.

6.2 SOUND AND VIBRATION MEASUREMENTS WITH FASTENERS

Initially, normalized sound pressure level differences and normalized impact sound pressure levels with different interlayers and fasteners were measured [11]. Measurements were carried out at cross laminated timber floors and Lignatur hollow box timber floors.

Velocity level differences were measured, as already described, with screws and variation of interlayers under the floor, with and without additional load of 240 kN. The acoustical deterioration, caused by application of fasteners, could be shown. Considering single number values, deteriorations of $D_{n,w}$ of 10 dB compared to the most efficient interlayer without fasteners. A connection between the amount of applied fasteners and deterioration could be proved. Sound measurements with twice the amount of fasteners, required when wind pressure is higher, showed a reduction of $D_{n,w}$ of 3 dB. For exploiting the acoustic potential of a flexible interlayer, acoustically optimized fasteners have to be applied.

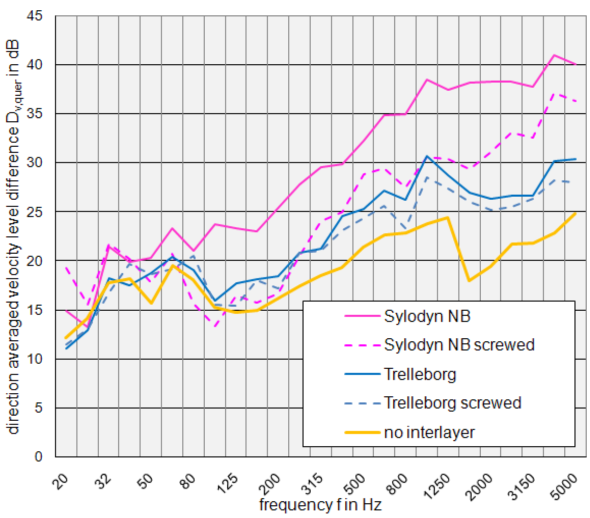


Figure 7: *direction averaged velocity level difference of solid wood junction, two different interlayers, with and without screws*

By means of vibration measurements it could be shown, that flexible interlayers contribute significantly to the improvement of flanking sound insulation at frequencies higher than 100 Hz. Considering direction averaged velocity level differences (excerpt in figure 7) so junctions with flexible interlayers and fasteners do not show higher damping in the junction below 250 Hz than junctions without interlayers [11].

Taking into account that for acoustical evaluation of wooden floors, as already mentioned by Kühn and Blickle in [12], the lower frequency range is significant, this seems to be problematic.

6.3 APPLICATION OF ACOUSTICALLY OPTIMIZED FASTENERS

Application of fasteners lead to a deterioration of the function of flexible interlayers. Practical acoustic improvement is limited by fasteners which have to be applied for static reasons. For determination of the acoustic potential of optimized fasteners, measurements with normal and optimized fasteners (figure 8) were carried out. Excerpts of results for the normalized sound pressure level difference $D_{n,w}$ are shown in figure 9 [11].

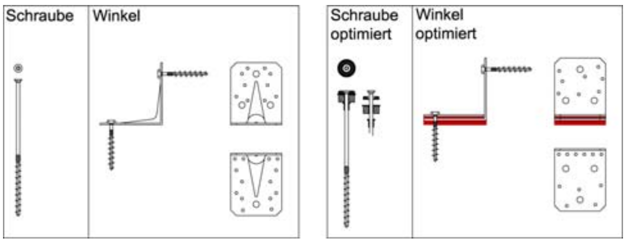


Figure 8: *Fasteners, normal and acoustically optimized*

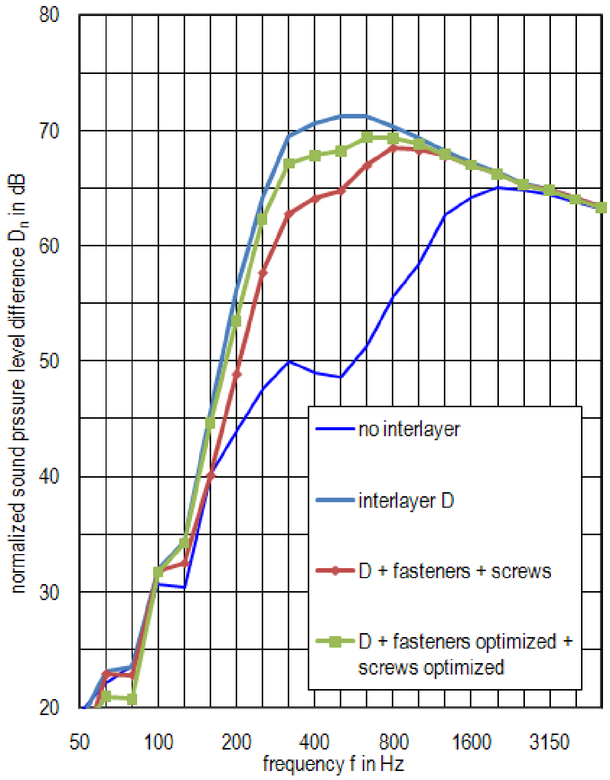


Figure 9: *Normalized sound pressure level difference with different fasteners*

Due to investigations of the junction, it could be shown, that deterioration of the damping in the junction caused by fasteners was compensated by application of acoustically optimized fasteners. This was verified for both cases of excitation, airborne and impact noise.

7 CATALOGUE OF VERIFIED COMPONENTS

Holzforschung Austria (HFA) published a catalogue of verified components “Deckenkonstruktionen für den mehrgeschoßigen Holzbau“ [13]. In this catalogue, selected constructions of components with acoustic parameters for direct and flanking transmission are listed. This gives a quick overview of the acoustical quality of different solid wood structures in combination with flexible interlayers.

7.1 ESTIMATION OF WEIGHTED STANDARDIZED IMPACT SOUND PRESSURE LEVEL $L'_{nT,w}$ WITH THE CATALOGUE OF COMPONENTS

After a chapter with fundamentals, acoustic parameters for more than 20 components are indicated. Thereof appropriate floor and wall components have to be chosen. In overview pages (figure 10), appropriate junctions can be chosen from the schemes. These schemes also show the possible need of flexible interlayers for this junction type.
For grey indicated junction schemes, data for flanking transmission is available. In the table in figure 11 the appropriate data, considering type of interlayer and fasteners, can be chosen.

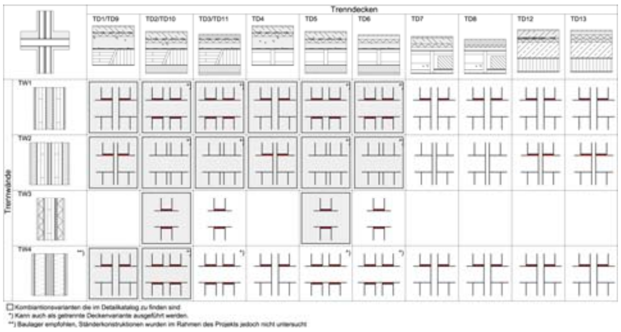
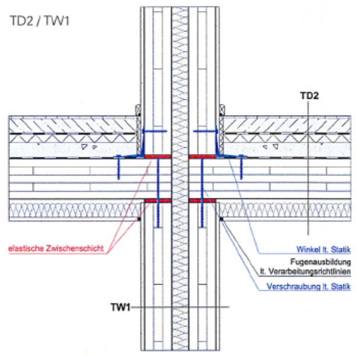


Figure 10: *Example for overview pages with junction schemes*



Flankenübertragung

ohne Befestigungsmittel	$D_{nf,w}$ [dB]	$L_{nDf,w}$ [dB]
Becker ESZ Pyramidenlager	61	35
Trelleborg Massivgummi	59	37
Eichler Mafund G	71	33
Getzner Sylodyn NB	72	33
keine Lager	53	42
mit Befestigungsmittel	$D_{nf,w}$ [dB]	$L_{nDf,w}$ [dB]
Becker ESZ Pyramidenlager	56	42
Trelleborg Massivgummi	55	42
Eichler Mafund G	62	41
Getzner Sylodyn NB	63	41
keine Lager	53	42

Figure 11: *Example junction separating floor 2 and separating wall 1 with data*

The weighted normalized impact sound pressure level $L'_{n,w}$ then can be calculated from the combination of transmission paths according to Equation (1).

As in Austria, according to [1], the weighted standardized impact sound pressure level $L'_{nT,w}$ is required, $L'_{n,w}$ has to be transformed into $L'_{nT,w}$ according to Equation (3), considering the volume of the receiving room.

$$L'_{nT,w} = L'_{n,w} - 10 \log \frac{V}{30} \text{ dB} \qquad (3)$$

It has to be taken into account that all data refers to dimensions of the test facility in which investigations were carried out:
Area of separating component (separating floor): 31 m²
Volume of the source room (upper floor): 95 m³
Volume of the receiving room (ground floor) with respectively without suspended ceiling: 85 m³ respectively 79 m³
All four flanking walls in the source and the receiving room consist of KLH 3s 95 mm.
All given data applies to a load of 0,075 N/mm². For higher loads, attached interlayers have to be adjusted appropriately. Investigations, realized with significantly higher load, have shown, that with adjusted flexible interlayers, flanking transmission remains constant. This is important for adjusting interlayers to different floors with increasing loads to lower floors.
Flanking transmission of post and beam structures was not part of this research project and therefore is not included in detailed investigation.
Since huge room dimensions lead to low and favorable weighted standardized impact sound pressure levels $L'_{nT,w}$ it has to be considered, that usual rooms in dwellings are significantly smaller and therefore show higher $L'_{nT,w}$.

7.2 ESTIMATION OF WEIGHTED STANDARDIZED SOUND PRESSURE LEVEL DIFFERENCE $D_{nT,w}$ WITH THE CATALOGUE OF COMPONENTS

Estimation of the weighted standardized sound pressure level difference $D_{nT,w}$ is carried out similar to the calculation of the impact sound insulation. Out of the weighted sound reduction index R_w of the floor construction, the weighted normalized sound pressure level $D_{nd,w}$ of the test facility has to be calculated according to Equation (4).

$$D_{nd,w} = R_w + 10 \log \frac{V}{30} \text{ dB} \qquad (4)$$

8 CONCLUSIONS

Since solid wood constructions are more frequently applied for multi storey residential buildings the demand for reliable prediction of sound insulation is increasing. Prediction is carried out following EN 12354 which, however, does not contain any input data for solid wood constructions. Therefore, sound- and vibration measurements were realized on solid wood test facilities where flanking transmission and input data for standardized predictions are acquired. The normalized

impact sound pressure level is calculated for different flexible interlayers and compared to the results of the measurements. Single number quantities show satisfactory accordance between measurement and prediction with deviations between 0 and 2 dB. Considering frequency dependent values major deviations, which can be detected in a certain frequency range, require more accurate modelling.
In a further step transformation of results to the building situation by implementing conventional fasteners, which are required for static reasons, was analyzed. By means of sound and vibration measurements the influence of fasteners was quantified and assigned to the particular connection. Since application of fasteners lead to partly significant deterioration of flanking insulation, optimized fasteners were searched and their acoustic potential verified at test facilities. It could be shown, that acoustically optimized fasteners nearly do not affect flanking insulation at all.
A catalogue of verified constructions was published to enable quick estimation of acoustic parameters of selected constructions, including flanking transmission.

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