Improving Sound Insulation in Cross-Laminated Timber (CLT) Wall Assemblies: A Systematic Investigation

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Introduction

Increasing attention has been given to wooden buildings, due to the sustainability and environmental benefits that they provide. Nevertheless, a pivotal challenge in the realm of wooden construction pertains to the assurance of sufficient sound insulation. Despite the enhancement in the accessibility of relevant data, further research is imperative, considering the intricacy and heterogeneity inherent in multi-layered wall assemblies [1].

This study presents an investigation into the enhancement of sound insulation in cross-laminated timber (CLT) outer wall assemblies. To this end, a range of variants with changes in different layers of curtain wall structures are analysed. Furthermore, the acoustic behavior of an Exterior Insulation Finishing System (EIFS/WDVS) on CLT was analysed and compared with the curtain wall structures.

Test setup

For the research the direct sound reduction index of different layer configurations of a Cross-Laminated Timber (CLT) wall (see Figure 1) was measured in a wall test facility.

Test objects

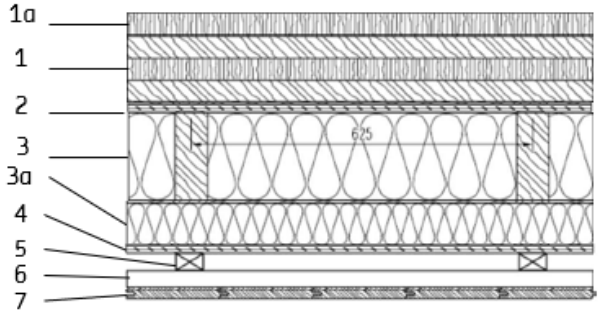

Figure 1: *Layers of the CLT wall assemblies with curtain walls*

The composition of the individual layers of the CLT wall with curtain walls is outlined in Table 1. The various assemblies are constituted by different combinations of layers. Only layers 4 and 5 are consistently included in all curtain wall configurations and remain unchanged throughout the variations

The structure incorporating the Exterior Insulation Finishing System (EIFS/WDVS) consists of a 100 mm CLT (35 kg/m^2) with variants of 40 mm wooden planks. The 240 mm mineral wool (MW) is adhered to the CLT and affixed with screws or dowels. The insulation is then overlaid with a plaster system comprising 1 mm mesh, 2 mm base plaster and 3 mm finishing plaster.

Table 1: *Declaration of the layers of the CLT wall with curtain walls*

Layer No.	Type	Var.1	Var.2
1a	Wooden Planks	**Name: 40 WP** 40 mm wooden planks 14 kg/m^2	-
1	CLT	**Name: 120 CLT** 120 mm CLT 42 kg/m^2	
2	Gypsum fiber board	**Name: GFB** 15 mm Gypsum fiber board 18 kg/m^2	-
3	Insulation with timber studs - vertical	**Name: 160 MW** 160 mm mineral wool	**Name: 240 MW** 240 mm mineral wool
3a	Additional Insulation with timber studs - horizontal	**Name: +80 MW** 80 mm mineral wool	-
4	Gypsum fiber board	**Name: GFB** 15 mm Gypsum fiber board 18 kg/m^2	
5	Counter battens	30*50 mm solid structural timber	
6	Support battens	**Name: TB** 30*50 mm solid structural timber	**Name: MP** C-profile metal with spring clip
7	Facing/ Cladding	**Name: TC** 18 mm timber plancs 9,2 kg/m^2	**Name: FC** 12 mm fiber cement board 22,8 kg/m^2

Test facility

The test stand at the University of Applied Sciences Stuttgart, in which the measurements were performed, complies with the requirements of DIN EN ISO 10140-5 [2]. Accordingly, the test setups are installed in a frame that is decoupled from the transmitting and receiving room. The use of facing shells on the walls and ceiling of the transmitting and receiving room ensures that flanking transmission is excluded, allowing only the direct sound insulation to be measured. The installation process used brackets to fix the CLT elements to the frame and butt boards to join them together. It should be

noted that, with the exception of one bracket at each side and one at the top, all connections to the frame were removed for the measurements. The joint at the edge was filled with mineral wool and sealed with sealing compound. The respective layers were rebuilt to change the assemblies between the measurements, but the CLT wall remained in place throughout the whole measurement series. The CLT was replaced solely for the measurements on the EIFS due to a different thickness of CLT (100 mm).

Measurement method

The measurements were conducted in accordance with DIN EN ISO 10140-2 [3]. The measurements were taken in the extended building acoustics frequency range from 50 Hz to 5000 Hz. The excitation was provided by a loudspeaker with pink noise, and the sound pressure level was measured with continuously moving microphones. The weighted sound reduction index R_w was determined in accordance with DIN EN ISO 717-1 [4].

Results

A preliminary study was conducted to ascertain the individual contributions of each layer, with variances in the thickness of the CLT structure, the insulation layers, the suspension of the exterior wall and the exterior wall.

The ensuing results are presented as differences in the sound reduction indexes ΔR. It should be noted that the measurements under comparison differ in each case in that only one individual layer of the wall structure is altered in each difference calculation, while the remaining layers are kept unchanged.

CLT thickness

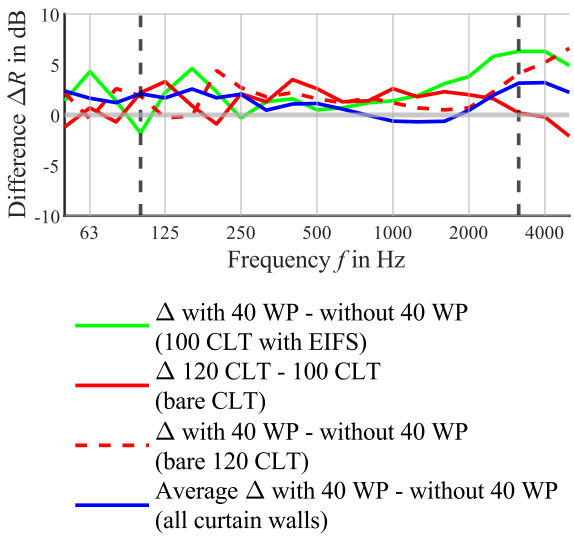

Figure 2: *Differences ΔR between various CLT thicknesses and with/without the wooden planks in layer 1a*

As demonstrated in Figure 2, the difference between the 120 mm and 100 mm bare CLT (red) indicates that the thicker CLT wall typically exhibits a 2 dB better performance than the thinner one, which is also reflected in the measured R_w of 33,6 dB for 100 mm CLT and 35,4 dB for 120 mm CLT. This finding is consistent with the with Equation 1 predicted R_w values of 31,6 dB for 100 mm CLT and 33,6 dB for 120 mm CLT, as reported in [1, 5].

Equation 1: *Mass law for single-shell solid timber components [1,5]*

$$R_w = 25\log(m') - 7\ \text{dB}$$

In contrast, the increase in ΔR_w due to the addition of wooden planks onto the bare 120 mm CLT wall is significantly lower than expected. The measured improvement is only 1.8 dB (resulting in R_w = 37,2 dB), whereas a calculated increase of 3,1 dB was predicted. This discrepancy may be attributed to the method of attachment: the planks were screwed directly onto the CLT without a full-surface bond. As a result, the planks contribute additional mass but do not substantially increase the stiffness of the wall, which may result in different behaviour compared to normal CLT of the same thickness. Further measurements are necessary to investigate this effect in more detail.

The averaged differences of the assemblies with curtain walls with and without the wooden planks in layer 1a demonstrate that the planks only result in an improvement below 315 Hz and above 2000 Hz for complete wall structures with this thickness of CLT. A similar pattern is observed when comparing EIFS assemblies, where improvements in the mid-frequency range are comparatively minor, while greater differences occur above 1600 Hz and sometimes below 250 Hz. Distinct peaks and dips below 400 Hz can be attributed to shifts in the coincidence frequencies and to structural resonance phenomena specific to each configuration.

Insulation layers

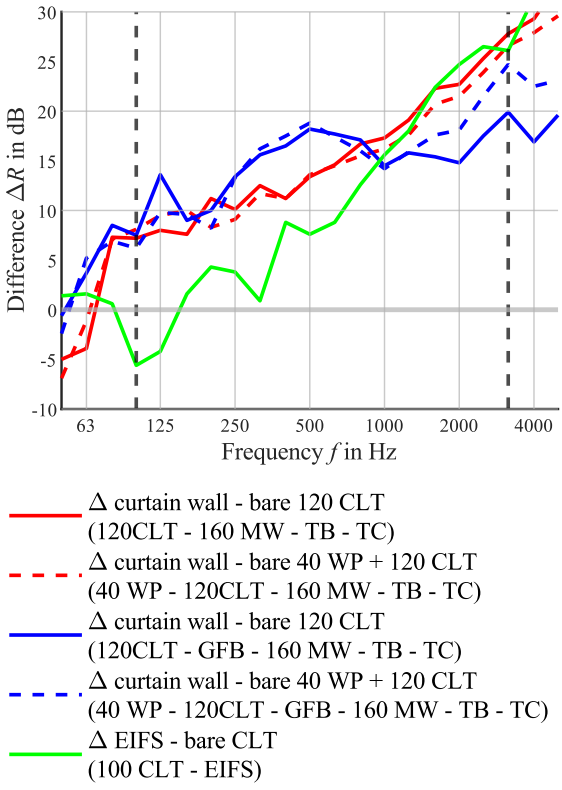

Figure 3: *Improvement of the various assemblies with insulation compared to the corresponding bare CLT version without insulation*

A comparison of the improvements to the 100 mm bare CLT wall in Fig. 3 shows that between 80 Hz and 1000 Hz the improvement with an EIFS is up to 10 dB less than with a curtain wall. Due to the interaction of CLT and plaster with the interposed insulation, a mass-spring system is formed, which can lead to negative effects: at 100 Hz, a deterioration of up to 5 dB is observed compared to the bare CLT wall. Additionally, a distinct dip occurs around 315 Hz, which can be attributed to the coincidence frequency of the system.
Above 1000 Hz, the improvement curves of both insulation systems (mounted directly on the CLT and without a GFB in layer 2) converge. These findings indicate that the differences between the two façade systems primarily influence sound insulation in the low- to mid-frequency range, especially below 1000 Hz.

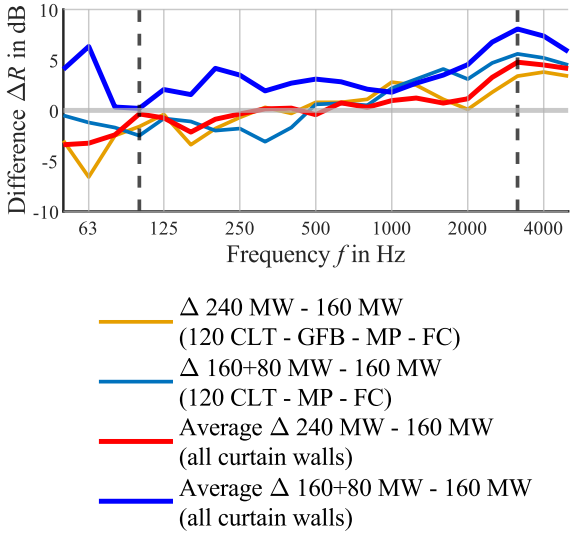

Figure 4: *Difference between the various insulation versions in Layer 3 and 3a and the simple 160 mm MW version, averaged and a specific single version*

An analysis of the averaged differences between the 240 mm and 160 mm mineral wool (MW) configurations (Fig. 4) shows that increasing the insulation thickness leads to improvements in the sound reduction index only at higher frequencies, specifically above 2000 Hz, with a maximum improvement of approximately 5 dB. At lower frequencies, however, a slight deterioration in performance is observed.

In contrast to the straightforward augmentation of the MW's thickness, the division of the MW into two crosswise layers of 160 mm vertically and 80 mm horizontally has been demonstrated to engender substantial enhancements. This results in an approximate 3 dB enhancement across the majority of the 1/3 octave bands, with a more pronounced effect at higher frequencies, reaching a maximum of 8 dB at 3150 Hz. This enhancement can be attributed to the behaviour of the insulation as cavity damping. However, it should be noted that, in this context, sound transmission occurs predominantly through the studs in the insulation plane, with the cavity damping largely utilising the damping potential, even with reduced insulation thickness. Consequently, a simple alteration in the thickness of the insulation offers minimal potential for enhancement. The stronger decoupling achieved through the crosswise arrangement/division of the studs demonstrates greater potential for improvement.

One particular result deviates notably from this general trend and warrants separate discussion: the configuration with 120 mm CLT + 160 mm + 80 mm MW + GFB + MP + FC exhibits a deterioration of up to 3 dB below 500 Hz compared to the identical configuration with only 160 mm MW (green curve). This is in contrast to the improvement observed in the basic comparison (blue curve) and all other variants featuring crosswise insulation. This specific case will be revisited in detail in the section on facing layers.

Gypsum fiber board

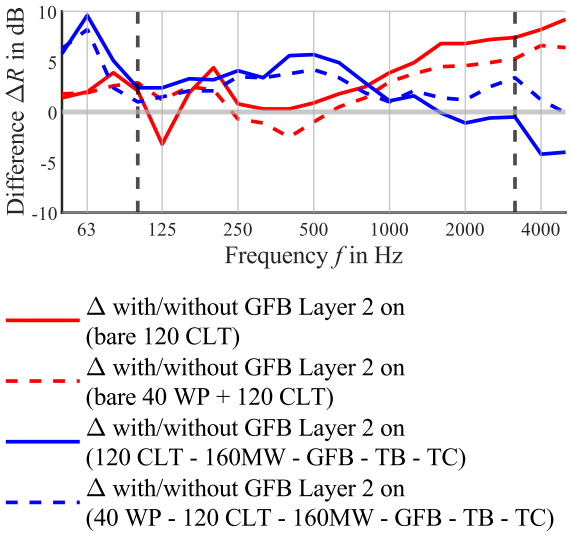

Figure 5: *Difference between with GFB and without GFB in layer 2 in the bare CLT version and in one of the curtain wall façades*

Figure 5 shows the influence of the GFB in layer 2, applied directly to the CLT without further facing constructions. The resultant behaviour is indicative of an increase in the mass per unit area, accompanied by a moderate improvement in sound insulation and an enhancement in the improvement effect towards higher frequencies. The narrow-band degradation caused by GFB at 125 Hz, with the subsequent improvement in the next higher 1/3 octave band, is probably due to a shift in the coincidence frequency, but may also be caused by the emergence of a mass-spring system. Further investigations are necessary for a clearer classification.

In the context of curtain walls, the influence of the GFB in layer 2 on the sound reduction index is fundamentally different. While there are improvements of 3 dB - 5 dB up to 630 Hz, a decrease at higher frequencies can be seen. Furthermore, there is an absence of significant dips in the coincidence frequency range.

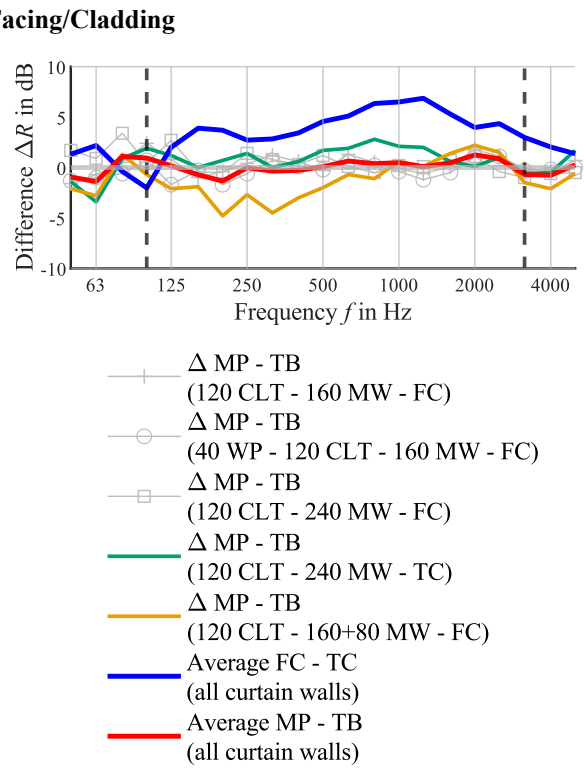

Figure 6: *Differences averaged (red) and of the individual variants between the MP and TB in the substructure of the cladding, as well as the averaged differences (blue) between the two types of cladding*

The averaged differences between measurements with fibre cement (FC) and timber cladding (TC), shown in Fig. 6 (blue), indicate that façades with FC cladding achieve approximately 5 dB higher sound reduction than those with TC. This can be attributed to the significantly higher mass of FC (22,8 kg/m²) compared to TC (9,2 kg/m²), wich brings an increase in the mass of the entire wall by 150 kg. A deterioration of 2 dB at 100 Hz is observed for TC, which is likely due to a more pronounced resonance of the resulting mass-spring system.

In contrast, a change in the substructure material does not generally result in a notable difference in the sound insulation performance. This is demonstrated by the averaged differences between metal profiles (MP) and timber battens (TB), as shown in Fig. 6 (red)

However, as with the comparison of insulation configurations, the version with a crosswise arrangement of insulation (layer 3 + 3a) and FC (120 CLT + 160+80 MW + FC) exhibits a deterioration of up to 5 dB in the third-octave bands around 250 Hz when using MP instead of TB. This may be the result of an unfavourable interaction between layers 37, causing increased resonances in the 125–500 Hz range, or potentially caused by deviations in the construction or mounting of the configuration with the version 120 CLT + 160+80 MW + GFB + MP + FC. Further investigations are necessary to clarify this observation.

Conclusion

Various materials and layer configurations were tested to evaluate their influence on sound transmission. Significant improvements in the weighted sound reduction index were achieved by applying gypsum fibreboard (GFB) directly onto the CLT, by employing a crosswise arrangement of the insulation, or by using fibre cement cladding. Minor improvements were observed when the CLT was clad with timber planks. Neither increasing the insulation thickness nor using metal profiles in the substructure led to noticeable improvements. Furthermore, in the present study, the configuration with an External Insulation Finishing System (EIFS/WDVS) proved to be considerably less effective in terms of sound insulation than curtain wall systems.

In addition, the findings - particularly those related to curtain walls - indicate that the acoustic contribution of individual layers is influenced by their interaction with adjacent layers. It is therefore recommended that a more detailed and comprehensive parameter study be carried out to analyse the influence of the layers on each other and to clarify the remaining open questions.

Literatur

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