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A design methodology considering acoustic prediction model and LCA: A comparative study of different CLT-based assemblies

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ABSTRACT: This paper aims to develop an acoustic design methodology for CLT floor assemblies using an artificial neural networks approach integrated with life cycle assessment (LCA). Lab-based measurements from 112 tests are used to develop an acoustic prediction tool (in one-third octave bands ranging from 50-5000 Hz). These measurements are associated with 45 different CLT-based floor assemblies. The weighted sound reduction index (R_w) and the weighted normalized impact sound pressure level ($L_{n,w}$) are estimated with an accuracy of 1 dB. A LCA study is conducted on the assemblies used to test the network model. The acoustic performance and environmental impacts are compared to highlight trends that may guide decision-makers in the design phase. This paper finds that CLT-based floor assemblies generally increase environmental impacts to achieve better acoustic insulation. However, good sound attenuation can be attained by selecting suitable acoustic solutions. Within each acoustic performance tier, environmental impacts can be optimized by selecting appropriate materials for the floor assembly. Designers should be aware of the trade-offs between acoustic and environmental performance when choosing floor compositions with a favorable environmental-to-acoustic impact ratio.

KEYWORDS: sound insulation, prediction model, neural networks, LCA, CLT floor assemblies

1 – INTRODUCTION

Reducing the environmental impact of human activities has attracted great attention globally. In 2015, it was reported that 7 $GTCO_{2e}$ are emitted by the construction of buildings and infrastructure, and 4 $GTCO_{2e}$ were related to material usage in construction [1]. Engineered wood products (EWPs) provide one of the most sustainable materials for the building construction sector. One criticism of these structures is their lower subjective sound insulation quality [2]. To enhance their performance, it is often necessary to add complementary elements [3]. This provides an advantage in improving indoor acoustic comfort, while simultaneously presenting a challenge in estimating the final acoustic performance of an assembly, as it can be both time-consuming and costly. Additionally, quantifying the environmental footprints of these assemblies is crucial, especially when the acoustic solutions involve non-wood elements. This paper aims to develop an acoustic design methodology for CLT-based wooden assemblies using an artificial neural networks (ANN) approach, integrated with life cycle assessment (LCA).

2 – METHODS AND DATA

2.1 ACOUSTIC MEASUREMENTS AND ANN MODELLING

The acoustic database includes 112 sound insulation measurements taken from 45 different CLT-based and ribbed CLT-based assemblies in one-third-octave bands (50 Hz - 5000 Hz). Of these, 48 are airborne sound measurements and 64 are impact sound measurements. The measurements are confidential and were conducted in accordance with ISO 10140 (Parts 2 & 3). The data include four CLT thicknesses: 140 mm, 160 mm, 200 mm, and 240 mm. Ribbed CLT panels, designed primarily for long-span structural applications, have a thickness of 80 mm and feature Glulam ribs. The floor dimensions for both types of floors are 4.2 m × 3.6 m, which were used in the lab measurements and will be considered as identical values for conducting the LCA study.

This paper develops a multi-layered perceptron ANN model, which consists of two hidden layers, with 30 and 25 neurons in each layer, respectively. Various structural parameters are considered in the modeling, including

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floor components, thickness, densities, the presence of a ceiling, and resilient channels.

2.2 LCA STUDY

OpenLCA 2.1.1 software is used to conduct the life cycle assessment (LCA) study. This open-source tool assesses the environmental impact of a specific product. The European Reference Life Cycle Database (ELCD) V3.2 is utilized for the LCA, as it provides comprehensive data relevant to the construction field. The IMPACT World+ method is employed for the life cycle impact assessment (LCIA) study.

3 – RESULTS AND DISCUSSION

3.1 ANN PREDICTION MODEL

The ANN model is trained and validated using 80% and 10% of the database, respectively. Twelve acoustic measurements (six airborne and six impact) are selected for testing, corresponding to six different floors (four CLT-based and two ribbed CLT floors), see Figure 1. These measurements reflect the general trend of floor assemblies in the database. Table 1 summarizes the acoustic single-number quantities: weighted sound reduction indices (R_w) and weighted normalized impact sound pressure levels ($L_{n,w}$). In some cases, the ANN model accurately estimates the exact values, such as for assembly #C. However, in the worst case, the prediction may deviate by up to 1 dB. The model demonstrates high accuracy, with a maximum deviation of 1 dB in the prediction of airborne and impact sound indices.

Table 1: R_w and $L_{n,w}$ in dB for test assemblies calculated based on measured and predicted curves.

Assembly	$\mathbf{R_w}/R_{wPredicted}$	$\mathbf{L_{n,w}}/L_{n,wPredicted}$
#A	**35**/36	**88**/88
#B	**57**/57	**65**/65
#C	**61**/61	**56**/56
#D	**63**/64	**56**/57
#E	**69**/70	**54**/53
#F	**70**/70	**46**/46

3.2 LCA OUTCOMES

A life cycle assessment study is conducted for the 45 assemblies to evaluate their environmental impacts. Climate change (long-term) is assessed for each assembly. To examine the relationship between acoustic performance and the energy consumption of mass timber floor systems during manufacturing, a comparison is made between R_w, $L_{n,w}$, and the environmental footprint of the floors. The correlation plots are shown in Figures 2 and 3. Results indicate no correlation between sound insulation performance and CLT-based assemblies. Moreover, a weak positive correlation is observed between airborne and impact sound insulation for ribbed CLT floors and their environmental impacts.

Results show that bare CLT or ribbed CLT floors have the lowest environmental impacts. Generally, greater acoustic attenuation corresponds to higher environmental impacts. However, the highest environmental impact values do not necessarily align with the highest sound insulation performance, as shown in Figures 2 and 3. This suggests that improved acoustic performance can be achieved by selecting materials that also offer favorable LCA outcomes.

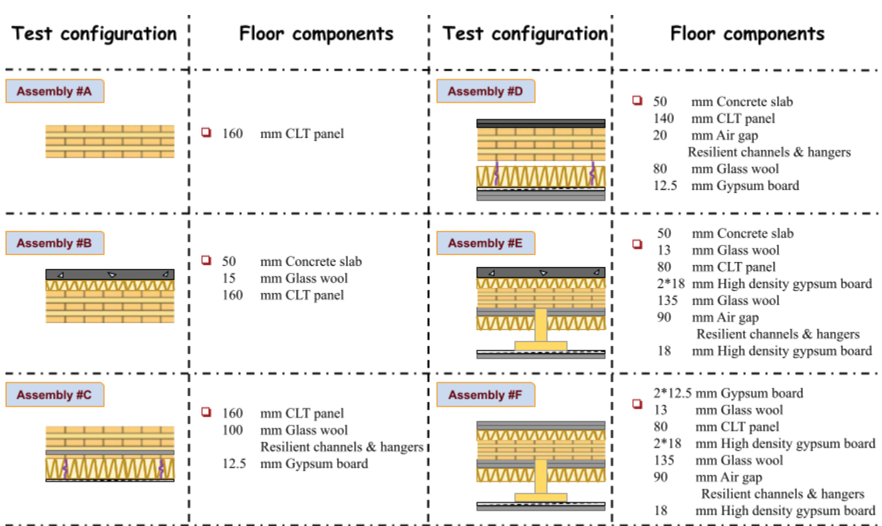

Figure 1. Floor assemblies used for acoustic prediction and for LCA.

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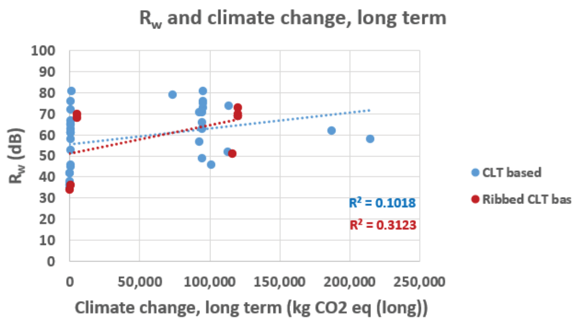

Figure 2. R_w vs. climate change for floor assemblies.

The highest environmental footprint of a floor comes from the use of gravel and concrete in the assemblies. Environmental impacts can be optimized by implementing appropriate acoustic solutions, such as avoiding gravel layers and opting for wood-based finishing materials.

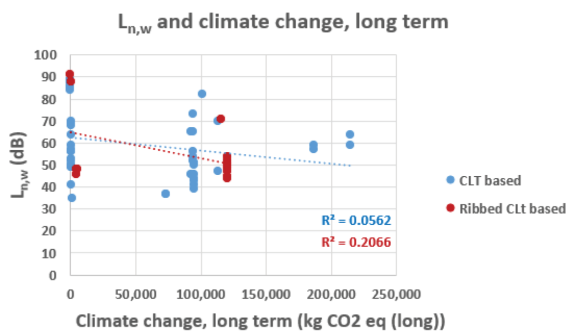

Figure 3. $L_{n,w}$ vs. climate change for floor assemblies.

4 – CONCLUSION

The current publication presents an acoustic prediction tool for CLT-based assemblies by integrating the LCA method. A total of 112 lab-based sound insulation measurements are used to develop the ANN model, with the highest deviation in predicting single-number quantities (R_w, $L_{n,w}$) being 1 dB.

Regarding the LCA study, results indicate that achieving higher sound insulation performance in CLT-based assemblies generally leads to increased environmental impacts. However, effective sound attenuation can be achieved through the selection of appropriate acoustic treatments. Designers should consider the trade-offs between acoustic and environmental performance when selecting assemblies that balance both aspects.

Further research would be beneficial, including conducting an LCA on various floor assemblies with different acoustic treatments. Additionally, a heating consumption analysis would provide valuable insights, as acoustic and thermal performance are interconnected during the design phase. An optimization study could further support designers in making informed decisions and improving overall design efficiency.

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