DEVELOPMENT OF SOUND INSULATION PREDICTION TOOL BY INTEGRATION OF LIFE CYCLE ASSESSMENT

Mohamad Bader Eddin*[1], Sylvain Ménard †[1], Bertrand Laratte ‡[2], Karin Le Tyrant §[3], and Caroline de Ponteves ¶[4]
[1]Universté du Québec à Chicoutimi, Chicoutimi, Québec, Canada,
[2]École nationale supérieure d'Arts et Métiers, Paris, France
[3]Atelier Indépendant D'Acoustique – Aïda, Paris, France
[4]Ingénierie Bâtiment Acoustique – INBA, Blois, France

1 Introduction

Reducing the environmental impact of human activities has attracted great attention globally. In 2015, 7 GTCO_{2e} were reported to be 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 [2]. They can contribute to a remarkable shift towards more carbon emission-efficient productions [3].

Despite the advantages of wood-based materials, they offer a lower subjective quality of sound insulation than traditional concrete buildings [4]. To enhance their performance, it is unavoidable to add complimentary element(s). This provides an advantage to ameliorate the indoor acoustic comfort, while presenting, at the same time, a challenge for estimating the final acoustic performance of an assembly, as it is cost- and time-demanding. In addition, quantifying the environmental footprints of these assemblies is necessary, since the acoustic solutions could be non-based wood elements.

This paper aims to develop an acoustic design methodology for CLT-based wooden assemblies using artificial neural networks (ANN) approach by integration of life cycle assessment (LCA). 72 lab-based measurements are used to develop the network model. Acoustic measurements are conducted on different 29 CLT-based assemblies. Then a LCA study is carried out on the test assemblies (that are used to test the ANN model) to evaluate their environmental performance.

2 Method

2.1 Acoustic measurements

For this study, the acoustic database contains 72 sound insulation measurements performed on 29 different CLT-based assemblies in one-third-octave bands (50 Hz - 5000 Hz). 31 of them are airborne and 41 are impact sound measurements. They are received from Atelier Indépendant D'Acoustique (Aïda) in France. The measurements are confidential and they are carried out according to ISO 10140 (part 2 & 3). The database contains three thicknesses of CLT : 140, 160, 240 mm. Each assembly is clustered in three parts : Topping, base floor, and ceiling parts, which includes material compositions of a floor assembly. Different structural parameters are used in organizing the acoustic database, such as : floor elements and their installation order, thickness, density, and hanger types in ceiling.

2.2 Artificial neural networks modelling

Artificial neural networks (ANN) is a non-parametric modeling method that can fit several complex tasks in various domains. This paper developed a multi-layered perceptron ANN model that consists of two hidden layers, each has 31, 25 neurons, respectively. Cross-over and dropout techniques are utilized to prevent overfitting and to validate the network model. LeakyReLU (Leaky Rectified Linear Unit) is employed as an activation function for the two hidden layers and Adam optimizer algorithm is used to train the network model.

2.3 Life cycle assessment

OpenLCA 2.1.1 software is used to carry out the life cycle assessment study. It is an open source that that assesses the environmental impact of a certain product. Since the network model is developed using Python, olca-ipc package is utilized. This provides API (application programming interface) for interprocess communication with OpenLCA. European reference Life Cycle Database (ELCD) V3.2 database is used to perform LCA as it has sufficient information in the construction field. IMPACT World+ method is employed for life cycle impact assessment (LCIA) study.

3 Results

3.1 Prediction of airborne and impact sound insulation performance

The ANN model is developed using 80% and 10% of measurements as a training and validation data, respectively. Then the rest of the measurements are used to test the network model. Four different CLT-based assemblies are chosen to estimate their airborne and impact sound insulation performance (Figure 1). Table 1 summarizes the acoustic single number quantities ; weighted sound reduction indices R_w and weighted normalized impact sound pressure level $L_{n,w}$. In some cases, the ANN model estimates the right values (obtained from lab measurements), such as assembly #1 (airborne case) and assembly #3 (impact case). However, the prediction can reach 2 dB deviations in the worst case.

3.2 Life cycle assessment results

For each test floor assembly, a LCA study has been conducted to reveal their environmental impact using Impact world+

*. Mohamad.bader-Eddin1@uqac.ca
†. Sylvain$_{M}enard@uqac.ca$
‡. Bertrand.laratte@ensam.eu
§. Karin.letyrant@aida-acoustique.com
¶. Caroline.deponteves@inba-acoustique.com

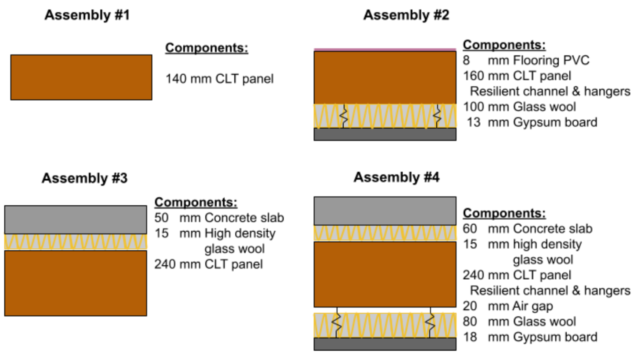

FIGURE 1 – Assembly components used in ANN model and for LCA.

TABLE 1 – Measured and the predicted values of single number quantities for the CLT-assemblies in dB.

Assembly	R_w	R_{wPred}	$L_{n,w}$	$L_{n,wPred}$
1	36	36	88	89
2	61	59	56	58
3	57	55	65	65
4	73	74	46	45

(default recommended midpoint 1.29). Five impact categories are chosen in order to compare the environmental performance of the four floor assemblies (Table 2). The latter are listed as : climate change (short term), freshwater acidification, freshwater eutrophication, depletion of the ozone layer, and formation of particulate matter. For all impact contributions, the CLT panel has the lower impact contributions, while it has unsatisfactory airborne and impact sound insulation performance since no acoustic treatments are added. However, a bare CLT without acoustic or thermal treatments leads to higher heating consumption in buildings. It can be noted that improving the acoustic performance leads to higher environmental impact. The latter can be illustrated in assembly #4 that has the best sound insulation among the four assemblies. Assembly #2 has better airborne and impact sound insulation than assembly #3, while it emits lower environmental impacts. This emphasizes that attenuating airborne and impact sound can be achieved with lower environmental effects, and it depends on the architect choice. At this stage of study, the conclusion my not be firm, but the method shows that "acoustic" and "environmental" indicators can be estimated at the same time.

4 Conclusions

The current publication presents an acoustic prediction tool for CLT-based assemblies by ingratiation of the LCA method. 72 lab-based sound insulation measurements are used to develop the ANN model. The highest deviation in prediction of single number quantities (R_w, $L_{n,w}$) is 2 dB. This provides a valuable acoustic tool that can save time and cost of lab acoustic measurements for certain types of assemblies. Then a life cycle assessment study has been conducted on the CLT assemblies. CLT-based assemblies were found to generally increase environmental impacts in order to obtain a higher sound insulation performance. However, a good sound attenuation can be achieved by selecting appropriate acoustic treatments. Further investigation would be helpful by conducting a LCA on various floor assemblies with different acoustic treatments. In addition, a heating consumption analysis would be valuable, since acoustic and thermal performance are related during the design phase.

TABLE 2 – Environmental impacts of CLT-assemblies through LCA.

Assembly	1	2	3	4
Climate change (short term) kg CO2 eq	8.2228	48.8705	92331.6	113352
Freshwater acidification kg SO2 eq	2.8E-13	1.7E-12	3.1E-09	3.9E-09
Freshwater eutrophication kg PO4P-lim eq	1.1E-05	6.5E-05	0.1219	0.14963
Ozone layer depletion kg CFC-11 eq	4.6E-0.7	2.7E-06	0.00517	0.0064
Particulate matter formation kg PM2.5 eq	0.0022	0.0129	24.3677	29.9154

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