Utilisation of hardwood in cross-laminated timber

- A numerical study on floor vibrations

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For the past 30 years, cross-laminated timber has seen exponential growth in building applications. Cross-laminated timber (CLT) is an engineered wood product where timber laminations are bonded together crosswise in layers with adhesives. In contrast to heavier construction materials, timber and other lightweight building materials are more prone to serviceability issues due to vibrating floors in buildings. Improved dynamic performance in CLT panels can be obtained by utilising hardwoods such as birch and beech instead of traditionally used spruce.

The aim of the project was to study potential improved dynamic performance of CLT by utilisation of hardwood. To fulfil this aim, the following research questions were formulated:

- What is a viable computer-based modelling approach for modelling the dynamic behaviour of a real-life CLT panel?
- How does the method of modelling footfalls affect the acceleration response of a CLT floor panel? Is the response altered with different walking speeds?
- Can vibrations in CLT floors be reduced by utilising hardwoods?

To determine an appropriate modelling approach of CLT, three different computer-based models were created based on the finite element method. Experimental testing was carried out on a real CLT panel to obtain experimental data, see Figure 1. The data was then compared to the finite element models to determine which model mimicked the real panels' behaviour the best.

Figure 1. Test setup. The CLT-panel was suspended in the air with rubber bands. An impact hammer was used to induce vibrations in the CLT-panel while the acceleration response was measured.

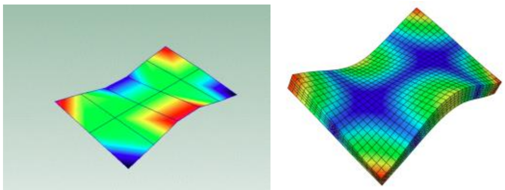

Figure 2. Experimental vibration mode (left) and computer-based vibration mode (right).

The modelling approach which matched the response of the tested panel the best was further validated by calibrating the material parameters of the model. They were calibrated so the dynamic behaviour of the model matched the behaviour of the test panel as closely as possible. One of the calibrations resulted in an average relative frequency difference of less than one percent between the calibrated model and the experimental results for the first nine vibration modes. A comparison between a vibration mode from the computer-based model and the experimental testing is shown in Figure 2.

Three panels of different sizes and layer set-ups were studied by numerical analyses with regard to modal properties, broadband response, and acceleration response due to footfall.

The analysis studying the acceleration response due to footfalls showed that the walking frequency had a large impact on the dynamic response of CLT floor panels. In Figure 3, the acceleration response for two different walking frequencies is shown. The response was measured for ten walking frequencies between 1.5 and 2.4 Hz for the three differently sized panels, utilising the wood species spruce, birch and beech. The magnitude of the response was shown to be highly amplified if a harmonic to the walking frequencies matched the fundamental frequency well, with harmonics meaning a multiplication of the frequency of the applied force. For example, the third harmonic of a walking frequency of 2 Hz would be 6 Hz. Because of this, design methods considering only a single walking frequency might result in misrepresentation of the actual dynamic response.

The magnitude of the acceleration response due to footfall was shown to be reduced by up to 70% by using birch and beech instead of spruce when considering the average response from the ten walking frequencies. When studying the effect on the broadband responses a similar reduction in acceleration response, albeit not as large, was found. Our work indicates that utilisation of hardwood for larger floor-sizes might be more beneficial in comparison to moderate and small floor sizes.

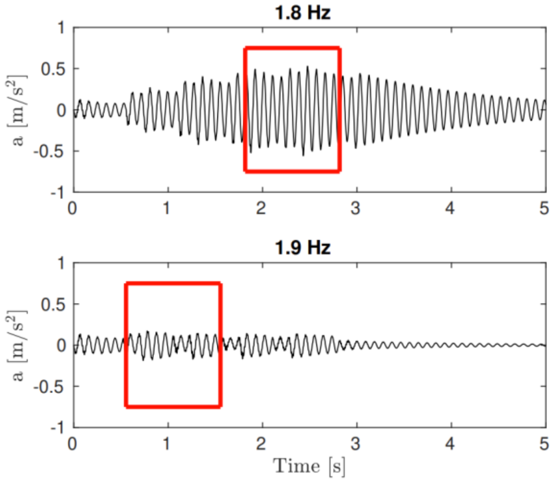

Figure 3. Acceleration response for two different walking frequencies. The 1 s of highest response was determined by calculating the RMS value for all 1 s intervals during the entire five second measurement period and choosing the highest, shown as a red coloured box.

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