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Measurement of flanking transmission for the characterisation and classification of cross laminated timber junctions

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ABSTRACT

The acoustic modelling of timber constructions is a major concern since wood construction technology has started to tackle multi-storey buildings. The recent update of the EN ISO 12354:2017 package of standards introduced indications relative to lightweight timber structures and a distinction between CLT and frame buildings that is related to the different characterisation of flanking transmissions. Within this framework, this work presents the results of a measurement campaign conducted on CLT junctions to study the influence of the connection on the vibration reduction indices. The investigation regards the influence of the kind and number of connectors, the hierarchy of the transmission paths and the use of the resilient interlayers. The experimental data show that the transmission of vibrations between CLT panels is strongly related to the metallic connectors that characterise the junction. The analysis on the damping of CLT panels suggests that the reverberation time does not strictly depend on the adjacent elements; a comparison between the loss factor normalised data and the geometry normalised data is finally proposed.

1. Introduction

Timber buildings have recently experienced an unprecedented development thanks to the technical evolution of the construction system [1]. Building elements, such as glued laminated timber allow to build beams with huge lengths and custom shape, re-defining the boundaries of the traditional wood construction systems. Moreover, in the last ten years cross-laminated timber (CLT) started to spread and marked an unparalleled increase of the timber market since then, moving towards high-rise timber constructions [2].

CLT buildings require a detailed design, that guarantees an extremely quick construction process. It is possible to reach very high thermal performance and the low weight of the elements encouraged their use for the extension of existing buildings and for seismic retrofitting interventions. Last but not least, CLT panels have a positive carbon footprint, therefore their production endorses sustainable decision-making approaches.

CLT panels are orthotropic elements; they have a low density compared to other heavy elements such as concrete or bricks, combined with a relatively high stiffness. This results in some peculiar aspects that must be taken into account when analysing the acoustic behaviour of these structures. While lightweight timber frame structures have been the object of a relevant COST Action [3], an analogous project has not been carried out on CLT. Nevertheless, several works investigated the vibro-acoustic behaviour of CLT plates, a selection of which is briefly presented in the following.

A great attention was dedicated to the modelling and measurement of the radiation efficiency of CLT elements [4,5]. The critical frequency of CLT panels reaches values which are in the frequency range of interest, therefore for the correct modelling of the elements it is important to evaluate the contribution of the resonant transmission. If the vibration reduction index is evaluated using airborne excitation, both resonant and non-resonant contributions are accounted for, while using a mechanical excitation only resonant velocity can be measured. Assuming that non-resonant transmission is negligible and that non-resonant velocity does not influence consistently the total velocity, then the vibration reduction indices measured through airborne or structure borne excitation should be equal. So far, results derived from different groups returned diverging results and more measurements are needed to validate the correctness of these assumptions [6].

Dealing specifically with flanking transmission, Pérez et al. [7] analysed different sets of CLT junctions discussing the vibration velocity level differences and pointing out some interesting features regarding the radiation efficiency of three panels arranged in mounting configurations typical of the specific construction system analysed. Schoenwald et al. [8] investigated the sound insulation, damping and vibration

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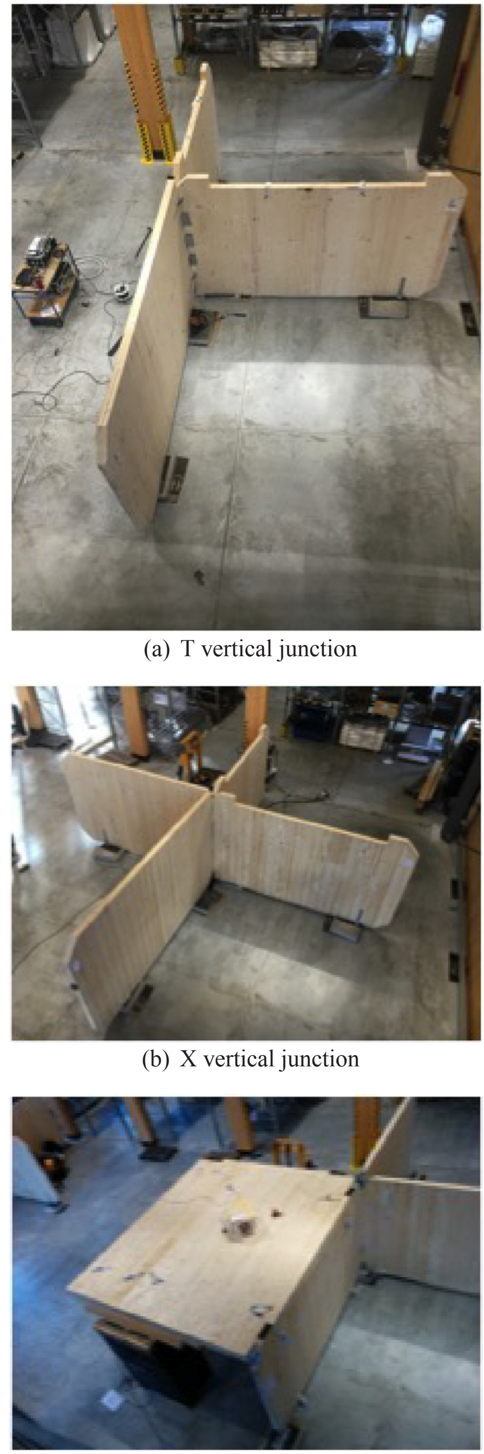
reduction index for a horizontal cross junction and discusses the prediction of the flanking transmission according to ISO 15712. Analyses on the effectiveness of the use of resilient interlayers in CLT junctions were presented by Mecking et al. [9], comparing the measurements to the predictions of the vibration reduction index from the coupling loss factor derived from a SEA model. Timpte [10] summarised the results of this work of collection of vibration reduction indices for CLT structures. The influence of the mass ratio was shown to have little influence on the vibration reduction index for CLT panels as long as panels are in contact [11]. Specific measurements of flanking transmission between CLT elements have been published by the National Research Council of Canada, in the Reports RR-331:2016 [12] and RR-335:2017 [13], which provide the results of an experimental campaign on several junctions, giving emphasis to the dependence of the structural power flow across the junction on the connection between the panels.

A major concern has been related to the laboratory measurements performed to quantify the improvement generated by additional linings on the basis of a CLT floor. These improvements cannot be applied indifferently to a reference heavy floor and to a CLT floor; therefore efforts were done on the definition of a reference curve tailored for CLT for the characterisation of impact sound insulation improvements as presented in the works by Zeitler and Di Bella [14,15]. An insight into on-site measurement on timber floors was carried out by Caniato et al. [16], discussing the results of impact noise measurements made on bare CLT floors and on floors made with glulam beams with top boards.

Recently, the update of the EN ISO 12354:2017 [17] standards "Estimation of acoustic performance in buildings from the performance of elements" introduced a distinction between lightweight structures and heavyweight structures, distinction that is related to the acoustic behaviour of the elements. Timber frame buildings belong to the "type B" category, that characterises highly damped lightweight structures. CLT on the other hand is categorised as a "type A" structure, for which the reverberation time depends on the connected elements.This implies that, when dealing with flanking transmission, energy transmission through the junctions is characterised by the $D_{v,ij,n}$ for timber frame buildings and by the vibration reduction index K_{ij} for CLT buildings. The modelling of the K_{ij} is made critical by the fact that the contact between CLT elements is linear, but the connections are punctual; therefore the availability of measured data is deemed crucial for the characterisation of the junction [8].

This paper presents the results of a measurement campaign aimed at characterising the vibration reduction indices for a variety of CLT junctions, comparing them to the empirical relations provided by the revised standard and discussing the normalisation terms that should be used to characterise CLT.

The paper is organised as follows. Section 2 describes the measurement setup and presents the conception of the whole work. Section 3 discusses the measurement technique and the signal processing used to calculate the vibration reduction index. Section 4 presents the main results achieved in this work while Section 5 compares the experimental results with the calculation proposed by the revised version of the EN ISO 12354:2017 standard. The conclusions summarise the main achievements and point out new topics of investigation to be covered as an extension of the present work.



(a) T vertical junction

(b) X vertical junction

(c) L horizontal junction

Fig. 1. Setups used in the experimental campaign for configuration *A*.

2. The *flanksound* project

The *flanksound* project consists of an extensive measurement campaign aimed at characterising the vibration reduction indices K_{ij} for CLT junctions. Measurements were made in an industrial warehouse on L, T and X vertical junctions and L horizontal junctions; some of these testing configurations are shown in Fig. 1. The CLT panels used for the vertical junctions had a height of 2.3 and a width of 3.5 m (panels 2 and 3 in the following) and 4 m (panels 1 and 4). For not all transmission paths the surface difference of the 10% is respected, nevertheless it has been verified on symmetric junctions that this has negligible relevance on the results. Vertical panels were 100 mm thick, provided in 3 or 5 plies with planks of different thicknesses; the horizontal slab was a 5-ply 160 mm thick panel. CLT panels were provided by seven different manufacturers, each one represented by a letter from *A* to *H* in the following. The same connection system had been tested on different sets of panels to verify the influence of the mounting process and of the characteristics of the panels on the repeatability of the measures. All CLT panels were made of spruce planks with a C24 resistance class, that allows a maximum of 10% of C16 planks. The density of the panels as declared by the manufacturers ranged from 420 to 500 kg/m^3, therefore

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