ASSESSMENT OF TIMBER FLOOR VIBRATION PERFORMANCE: 
A CASE STUDY IN ITALY

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ABSTRACT: Vibrations induced by people walking is one of the most important issue in timber floor design. Low natural frequency and low mass require a careful analysis in order to prevent significant annoyance and to guarantee an acceptable human comfort. This paper is concerned with the assessment of vibration performance of a timber-concrete composite timber floor and a cross laminated timber floor used in two timber buildings under construction in Trento (Italy). Different approaches suggested by Standards and literature were employed: analytical methods, numerical analyses and laboratory tests. About analytical methods the uniformed distributed load deflection criterion (ULD), the Eurocode 5 criterion and some criterions from literature were compared, whereas the Vibration Dose Value (VDV) method, as suggested by ISO 10137, was used for the numerical models and the laboratory tests. The numerical analyses were carried out by means of a finite element modelling. The load due to footfall was simulated by static and dynamic vertical forces. The laboratory tests were characterized by thirty walking tests for each floor. Impact testing with modal hammer was also undertaken in order to investigate the dynamic properties of the specimens. All results are compared and discussed.

KEYWORDS: Timber Floor, Vibration, Numerical analyses, Laboratory tests, VDV

1 INTRODUCTION

Timber constructive systems have been getting more and more importance in the Italian market of residential houses, showing as an efficient alternatives to masonry and concrete structural types. A tangible instance is given by the choice of the Trentino social housing company ITEA to build two five-storey multi-family houses in Trento (Italy) using two different timber wall constructive systems, namely the timber frame and the cross laminated timber (CLT) ones. The designing and the construction of these two buildings relate to an international collaboration between ITEA and the Canadian social housing company QUEBEC SOCIETE D’HABITATION, constructing two similar four-storey multi-family houses in Quebec City (Canada). The same constructive systems of Italian buildings were adopted. The main objectives of this collaboration are the evaluation and the comparison of the common Canadian timber constructive system and the Italian one, concerning with several technical and economic aspects. One of those is represented by the vibration serviceability performance of timber floors. Low natural frequency and low mass of timber floors require a careful analysis in order to avoid significant annoyance and to guarantee an acceptable human comfort. For this reason the Timber Research Group of the Department of Civil, Environmental and Mechanical Engineering of the University of Trento was involved by ITEA in the vibration performance assessment of the timber floors of the two Italian timber buildings. The floors are characterized by a timber-concrete composite (TCC) constructive system in the timber frame building and by a CLT panel floor in the CLT building (Figure 1).

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\textbf{Figure 1: CLT and TCC floor sections}
2 OBJECTIVE

The main objective of this paper is the comparison of some different criteria for the vibration performance assessment of timber floors. According to international Standards and literature, the results obtained from applying three different analysis methods to two typical Italian timber floors are discussed. Firstly, some analytical methods were employed. These are based on simple mathematical expressions which can be used in the design phase to predict the vibration peak response of a timber floors in terms of vertical displacement, velocity, acceleration and natural frequency. In particular, the Uniformly Distributed Load Deflection criterion (ULD), the Eurocode 5 criterion (EC5) proposed by Olsson, the Mohr criteria (MOHR) and the FPInnovation criterion (FPI) are compared. Secondly, numerical analyses were performed by means of a two-dimensional (2D) model (Figure 2), and an equivalent one-dimensional (1D) model.

![Figure 2: TCC 2D model](image)

Dynamic linear analyses were performed to calculate the vertical acceleration response under different load conditions (Figure 3). These, simulating the effects of human walking, are represented by vertical dynamic forces. The VDV criterion was applied to the numerical analysis acceleration responses, as suggested by [3] and [4] to assess the vibration serviceability of the floors (see Equation (1)).

\[ VDV = \left( \int_0^T [a_v(t)]^2 \, dt \right)^{0.25} \]  

(1)

![Figure 3: non-weighted response acceleration for the central point of the TCCup 2D model](image)

Thirdly, in order to validate the analytical and numerical results, two full scale floor specimens were tested in the Laboratory for Material and Structural Testing of University of Trento of the Department of Civil, Environmental and Mechanical Engineering (DICAM) of the University of Trento (UniTN). Thirty walking tests (Figure 4) were undertaken on each floor using five different users and three different footstep frequencies (free, 1.8 and 2.1 Hz). The vertical accelerations were recorded during each test and processed according to the VDV method. Moreover, modal tests were carried out to evaluate the dynamic properties of the floor specimens (Figure 5), reported in Table 1.

An additional objective of the research is concerned with the comparison of the vibration performances of the two floors. These, in fact, are characterized by the same length span, the same dead and live loads but by a different constructive system.

![Figure 4: free-walking testing for CLT floor](image)

**Table 1: modal tests results**

<table>
<thead>
<tr>
<th>Floor</th>
<th>Fundamental frequency [Hz]</th>
<th>Damping ratio [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Modes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCC</td>
<td>13.07</td>
<td>14.07</td>
</tr>
<tr>
<td>CLT</td>
<td>13.31</td>
<td>15.69</td>
</tr>
</tbody>
</table>

![Figure 5: 1st mode (long. bending, a), 2nd mode (torsional, b) and 3rd mode (transversal bending, c) for TCC floor](image)

3 ACKNOWLEDGMENTS

The main acknowledgment goes to the Trentino Social Housing Company ITEA, particularly to Eng. M. Chiogna, Eng. I. Gobbi and Eng. A. Albarello, for involving the University research group on timber structures in this international project. The Autonomous Province of Trento, represented in this project by Dott. R. Farella, is also thanked for his support. A particular thank goes to Ph.D. Lin Hu of FPInnovation for her precious suggestions. The companies LegnoCase and X-Lam Dolomiti are acknowledged for providing the floor specimens. The presented research has been carried out in the framework of the ReLUIS-DPC 2014 project. Support from the ReLUIS-DPC network, the Italian University Network of Seismic Engineering Laboratories and Italian Civil Protection Agency, is gratefully acknowledged.