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Acoustic performance of timber and timber-concrete floors

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HIGHLIGHTS

- Two basic types of floors were analyzed: timber and timber-concrete solutions.
- The timber-concrete solutions, included normal and lightweight concrete compositions.
- The basic solutions were evaluated with the presence of a ceiling.
- The air-borne and impact sound insulation of the floors was experimentally evaluated.
- The results revealed the acoustic efficiency of the timber-concrete solutions.

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ABSTRACT

This paper deals with the acoustic performance of timber and timber-concrete floor solutions assessed through an experimental campaign. In the case of the composite solutions, two types of concrete were adopted: a normal and a lightweight composition, the last one incorporating expanded cork aggregates. The acoustic tests were performed under controlled conditions in laboratory, to determine the airborne and impact sound insulations. The basic solutions were also evaluated including the presence of a ceiling composed of gypsum plasterboard and mineral wool. The results reveal a promising behavior of the tested solutions, particularly the composite solutions.

1. Introduction

Timber structures are probably the most common structural solution found in old buildings' floor structures and even adopted nowadays at some countries in small size buildings. In fact, timber was for many centuries the only available material with relatively high tension properties that made it suitable to produce these kind of structures with relatively low cost when compared with other solutions, as for example stone vaults. The true is that most of those structures have overpassed its useful time of life service, but most of them still perform their structural functions. However these competences are currently overpassed by the modern standards of serviceability, not only structurally but also in terms of vibration perception and acoustic comfort of the users of the building. These types of floors, due to their own lightweight nature, often exhibits acoustic issues especially at low frequencies. This means that changes in structural or non-structural parameters are needed to improve the floor acoustic performance. Johansson [1] carried out tests in a series of timber floors and concluded that the increase in the floor stiffness did not significantly affect its impact sound insulation at low frequencies. Some other techniques to improve the impact sound insulation on timber floors were proposed in [2] that included the increase in mass or damping and the addition of a ceiling that could improve the sound insulation at low frequencies. Also Ljunggren and Ågren [3] refers that constructional modifications, such as extra board layers, elastic glue between floor boards, and floating floor could improve the acoustic performance of timber floors; however in the carried tests, the results revealed that the impact sound insulation gains were relatively small. In order to get better results, solutions based on timber-concrete composites in combination with non-structural elements could be an option as shown in the results obtained by Schmid [5], who carried out a series of field measurements to determine the air-borne sound and the impact sound level in timber-concrete floors and concluded that the installation of ceiling panels and the use of impact sound insulation improves the acoustic performance of the floors. In a similar and more recently

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study of LVL (Laminated Veneer Lumber) based floors, Schluessel et al. [6] had also stated the better performance of the timber-concrete solution with non-structural elements (although the concrete was also used as a non-structural overlay) face to the barely timber one. Timber-concrete reinforcement is actually one of the most interesting and promising rehabilitation solutions of old timber floors. When applying this technique, the stiffness and the load carrying capacity increase considerably face to traditional timber floor systems [7]. Also the increase in damping of the structure helps to reduce the vibration discomfort caused by the motion of the users, and to increase the impact noise insulation. The air-transmitted noises insulation is also improved due to the increase in the system's mass [7]. The use of lightweight concretes for timber floor reinforcements have actually advantages over the usual heavier formulations, since the own-weight is substantially reduced (that is important, because the existing timber floor may not have sufficient load bearing capacity) while still performing structurally quite well [8,9]. Indeed, alternative formulations of concrete in order to achieve more environmentally friendly solutions have been topic of active research. As example, studies are found that deals with the potential of incorporating recycled concrete aggregate, low cement content and high content of different mineral supplements [10], natural resources such as rice husk [11] or even wasted materials, such as sheets of electric wires, which can greatly improve the sound insulation and thermal properties of the material [12]. Recent studies [13,14] revealed that the use of mortars incorporating cork aggregates could lead to an improved acoustic behavior compared to more conventional cement formulations. Other types of forest-based materials such as hemp particles [15] could also be of potential interest to use in this kind of formulations due to its acoustic properties.

There is currently a lack of results regarding the acoustic performance of timber-concrete floors, exception made to the tests carried by [4–6]. In [4] impact and airborne sound insulation results from tests on a timber-concrete composite floor supported by nail-plate trusses are reported. In addition to the composite system with nearly 6 m span, a mineral wool layer was placed above the concrete top and over this an air box was created by placing a new layer of the same material, a resilient channel and a gypsum board. For the weighted air-borne index (R_w) a value of 64 dB was found for both the solution with and without floating floor; while for the impact insulation index ($L_{n,w}$) a value of 51 dB was found with floating floor and a value of 52.5 dB was found without the floating floor. In [5], the tests were carried out *in situ* for floors with spans ranging from 4.2 to 5.7 m. The floors constructions were similar, including an impact insulation and a subfloor, and in some of the tested floors a gypsum plasterboard as ceiling panel. For R_w values between 54.0 and 64.0 dB were found, while for $L_{n,w}$ values were between 45.0 and 53.6 dB. It was concluded that increasing the impact sound insulation thickness and installing ceiling panels increases the acoustic performance of the floors. In [6], laboratory tests regarding the impact and airborne sound insulation were performed on a bare 4.2×3.2 m^2 LVL floor and on the same solution with the addition of a concrete top (not mechanically connected) for two different heights (60 mm and 120 mm). Both cases were also tested in combination with other non-structural elements, namely suspended ceiling and floor finishing. It was found that the bare solutions, even with the non-structural elements, which improved insulation, still performed poorly face to the Australian code requirements. In those solutions, the Weighted Apparent Sound Reduction Index (R'_w) ranged from 34 to 59 dB and the Weighted Standardized Impact Sound Pressure Level ($L'_{nT,w}$), ranged from 57 to 94 dB. The addition of the concrete top had improved both airborne and impact sound insulations (R'_w ranged from 47 to 57 dB and $L'_{nT,w}$ ranged from 50 to 91 dB); moreover It was also found that the use of the 120 mm thickness instead of the 60 mm had a minimal improvement on the results. However, to meet the normative requirements in the timber-concrete solution, the addition of the suspended ceiling was required.

The main focus of this paper is to present the acoustic behavior of short/medium span timber-concrete floors for a wide range of frequencies, using different constructive solutions in terms of beams and concrete formulation, and compare it with an only-timber floor. On an experimental campaign, the sound insulation performance of three types of floor solutions was evaluated: a timber floor composed by rectangular cross section glulam beams and solid timber boards; the same floor reinforced with a concrete top; and a floor composed of timber logs as beams reinforced with a lightweight concrete incorporating expanded cork aggregates. It should be noted that the latter is a non-standard solution, but that may be quite interesting due to its low-weight and considering the fact that is used natural resources with low value for the industry leading to a reduced construction cost and sustainable solution. Indeed, small diameter round wood of Maritime pine (*Pinus pinaster*) are abundant in Portugal from forest management operations, necessary to improve the forest health and mitigate the risk of fire, and cork granules are a discarded sub-product from the national cork industry that represents almost 30% of raw cork collected. Cork is obtained from the external layer of the bark of Oak trees (*Quercus Suber L.*), whose harvesting does not introduce damage to the tree and allows a new layer to grow, being a renewable resource.

It should also be noted that, in cases when the entire floor needs to be replaced, such a solution can be economically competitive if the span is not excessively large. Also the presence of a floating floor including a bottom layer made of cork agglomerate above the composite floors and a layer of mineral wool and gypsum plasterboard under the floors were evaluated. The sound insulation performance was evaluated both in terms of airborne sound insulation and impact sound insulation using the standard technique with reverberant chambers, with very well controlled conditions according to the corresponding normative procedures.

2. Materials and methods

2.1. Description of materials and floor layouts

The floors to test had in-plane dimensions of nearly 3.5×3.4 m^2 and comprised the following elements:

- Timber floor (TF): composed by five beams of rectangular cross-section of 200×100 mm^2 made of GL24 h class glulam spruce (*Piceas abies*) spaced of 750 mm between axis and to which were attached maritime pine (*P. pinaster*) boards with 22 mm thickness by means of 2 mm square cross section steel nails (Fig. 1).
- Timber-concrete floor I (TC1): built from the above described timber floor, using S500 class steel ribbed bars of 8 mm diameter, inserted over the beams at pre-drilled holes with 7 mm diameter and spaced at 100 mm; these bars ensure the composite action of the timber with the concrete top with 50 mm height, C20/25 class and incorporating a 100 mm width electro welded mesh of 5 mm diameter and S500 class placed at middle height (Fig. 2).
- Timber-concrete floor II (TC2): composed by seven beams of circular cross-section of 130 to 150 mm average diameter made of Maritime pine (*P. pinaster*) spaced of 500 mm between axis connected to the concrete layer made with cork aggregates and with 50 mm of thickness. The connection system used was the same connection layout used for the Timber-concrete floor I and also with the same type of electro welded mesh characteristics and layout (Fig. 3).

The concrete used in TC1 was supplied by a ready mix concrete company, while for TC2, the concrete was produced in the laboratory [9], with a composition obtained by replacing a part of the sand and gravel by expanded cork granulates of two kinds of granulometry: 0/3 and 3/10. The composition per cubic meter of concrete is detailed in Table 1.

In the timber floor, the own surface created by the boards was considered as the final coating of the floor, as it is a situation that often occurs in practice; in the case of the timber-concrete floors, a floating floor with 12 mm of thickness (top layer