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ACOUSTIC PERFORMANCE OF SUBFLOORS PRODUCED WITH RICE HUSK AND DIFFERENT COATINGS

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Abstract
The building industry has a large environmental impact. The replacement of natural aggregates by residues in cement composites it is an alternative. By another side, acoustic performance is very important to provide comfort to the users, and it is still more important in Covid-19' outbreak, because people stay much more time at home. There are some requirements in the standards for the evaluation of construction systems to be used in vertical buildings and the effects of waste in building materials need to be verified. The aim of this study is to analyse the impact on sound insulation of mortar subfloors produced with the replacement of 50% of the fine aggregate by rice husk. It was applied three types of coatings of common use in the local buildings: porcelain, vinyl, and laminated wood. The tests were carried out on reduced samples of subfloors with 1 m² of surface area and thickness of 5 cm in laboratory environment, following the requirements of ISO 10140-3:2010. It was verified that the substitution of the fine aggregate by rice husk did not present significant variations in the attenuation of the sound transmission in relation to the conventional subfloor. These results could be viewed as positive since the use of waste as a substitute for natural resources and could to contribute to the advance of sustainability in the construction sector.

Keywords: acoustic performance, subfloor, waste, rice husk, sustainability.

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Introduction

The building sector is one of the major causes of changes in the environment. The construction methods used, and the activities elaborated for buildings have a significant effect on the generation of waste. Due to the increase in construction in some countries, such as Brazil, especially in urban areas, the need for vertical construction has become inevitable (Neubauer, 2009). Nevertheless, it is important to obtain buildings that have an adequate performance in a multidisciplinary view. The performance in construction is related to the behaviour in use of the entire system that constitutes the building, evaluated in terms of efficiency throughout the useful life. Regarding the acoustic performance of buildings, in general, it can be said that the design of an effective project, regards the minimization of aerial and impact noise, the latter being achieved through the application of flexible and floating floors applied over a resilient material Patrício (2010) states that impact sounds are more problematic since the rigidity of the structure of the building allows the easy transmission of vibrations with and with a wider reach, and therefore, a constant target of complaint among users of a building.

Noise emissions in urban areas have increased due to the growth of large cities and the increase in the number of vehicles and industries. According to the World Health Organization (WHO), after air pollution from gaseous emissions and water pollution, noise pollution is what affects people all over the world (WHO, 2003). There are some differences in pandemic moments, such as those caused by Covid-19, in urban scale, and some authors indicated reductions on outdoor noise in lockdown periods (Aletta *et al*., 2020; Asensio *et al*., 2020; Sakagami, 2020; Radicchi *et al*., 2020), but inner noise could be expected to increase in vertical buildings because of the increase on the number, distance learning or work activities and greater permanence of users at home (Amerio *et al*., 2020; Bhamani *et al*., 2020; Rahiem, 2020).

To improve the quality of life of the inhabitants and the overall quality of the buildings, the standard establishes criteria of noise exposure, through the analysis of wall insulation; and percussion noise, through impact sound pressure tests on plates (ABNT, 2013; ISO, 1998, 2008, 2010, 2013). It also emphasizes the forms of verification (in the field or laboratory test) and its control. Well-constructed buildings can offer acoustic comfort in rooms, improving the integration of technical developments in construction.

The acoustic comfort is defined as the absence of significative noise, that is, of unwanted sounds, with the aim of taking care of health, the well-being of the user and the intelligibility of speech, adapting quality to environments to offer feelings of comfort in work, rest and leisure time. The environmental quality of the spaces is of great importance, since they can influence the quality of life, sleep and coexistence among users of the same building (Gerges, 2000). When the quality of a sound environment is compromised and comfort changes,

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negative effects may appear, such as interference in the performance of tasks and increase some health problems, such as insomnia, irritability, headache, hypertension, and stress. Exposure to noise for long periods, such as aerial and impact noise on the building floors, can cause harmful effects on health (Ferraz, 2008).

According to Lopes (2010), there are different design strategies to control the noise, ranging from the removal of the noise source through the choice of better positioning of the buildings to the or closing materials, and the size and positioning of the openings. Walls and slabs, partitions and some building materials could reduce the transmission of noise from one environment to another. The acoustics of the rooms can be influenced by construction details, surface finish and small changes in a certain type. Each choice made on the type of structure, roofing, covering materials, air conditioning system, changes the shape of the building, the flexibility of the enclosure and the behaviour of the sound inside.

The search for a higher acoustic comfort leads to a progressive development of construction techniques. One of the most common technical solutions to ensure the good acoustic performance of floors is the use of floating floors. In this type of solution, the floor is made up of several layers of different materials. The visible layer, the floor covering, is placed in non-structural layers, some of which are made of resilient materials that allow vibrations due to impacts on the surface to be dissipated. There are two main types of floating floors. The first one uses a kind of floating slab. In this solution, the surface coating is applied over a concrete slab, and consists of an elastic layer made, for instance, using synthetic foams or natural fibres. This system is versatile because it enables it to be used of final layers of rigid materials such as ceramic mosaics to ensure that the vibrations generated above are not conduced to the structural parts. The behaviour of this option depends of good execution during construction phase, because it is necessary to ensure an effective separation between the structural elements and the floating layer, with no rigid connections, as well as depends of the kind of elastic material used. The other common option uses floating lining elements. This system consists of applying thin layers of synthetic foam under the main lining layer, for instance with a wooden floor. While acceptable results are possible, this type of construction scheme has some limitations compared to the previous one (Carvalho, 2006; Patrício, 2010).

Regarding floors and slabs of buildings, consideration should be given to the attenuation of airborne and impact noise. Heavy concrete slabs ease airborne sounds but are great facilitators of impact noise transmission. To minimize this noise in the floor and floor structures, the best way to absorb the impacts produced in the upper floors is the adoption of soft materials in their finishes, such as carpets and rubber floors (Carvalho, 2006).

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To reduce the impact noise, the floating floors are used on elastic bases, which disconnect substrates and floors from structural and/or sealing elements. There are several ways to build a floating floor, either with the conventional finish of wood blocks, such as floors, laminated wood, vinyl slabs, ceramic slabs, marbles, granites or even the carpet. The installation of dual panel drywall panels is an alternative to mitigate impact noise when the construction is already finished and occupied (Carvalho, 2006).

There are some studies about acoustic behaviour in subfloors and concrete slabs (Borges *et al.* 2018; Brancher *et al.*, 2016; Branco *et al.*, 2010; Pacheco *et al.*, 2017a; Pacheco *et al.*, 2017b; Souza et al., 2020; Tutikian *et al.*, 2012) and floor coverings (Pereira *et al.*, 2014). Through these concepts, Borges *et al.* (2018), González *et al.* (2013), Tutikian *et al.* (2012) and Vyšvařil *et al*. (2019) investigated the acoustic potential of subfloors produced with different compositions of rice husk, Ethylene Vinyl Acetate (EVA), and wood waste.

Tutikian *et al.* (2012) developed a study using three rates of EVA residues to produce lightweight concrete. They present an evaluation of the acoustic performance and analyses the relationships among impact noise levels and material' properties, such as water absorption, voids and densities. ISO 140-7:1998 guided laboratory experiments on noise impact. The concrete with recycled EVA showed a reduction of impact noise level up to 15 dB.

González *et al.* (2013) investigated the potential of acoustic absorption in mortar composites, partially replacing the sand with three types of residues, among them the rice husk. The experiment was carried out using five tax substitution of residues (0%, 5%, 10%, 25% and 50%), as measured in volume, with the same rate cement/aggregate (1:4). It was performed the impedance tube method with Ø100mm specimens according to ISO 10534-2:1998. They point out that for the rice husk composite with 50% composition for noise reduction (NRC) closely resembles the results of a standard acoustic foam.

Tutikian *et al.* (2013) produced samples of 1.0 m^2 (with four 50cm x 50cm plates) and a thickness of 3cm. The tests were developed in the field, after the methods of ISO 140-7:1998 and ISO 717-2:2013. The reference slab is composed by a 10cm structural concrete slab. The masonry walls are covered by plaster and painted. The room had dimensions of 4.64m x 3.5m x 2.76m, with a volume of 44.82 m^3. The results indicated that the incorporation of EVA in the concrete slabs improved the acoustic performance of the floor system.

Borges *et al.* (2018) worked with rice husk. In the experiment presented, the authors analyzed the impact noise level of the samples of subfloor with dimensions 1.0m x 1.0m, with 3cm and 5cm of thickness. They investigated the acoustic potential of subfloors produced with three compositions of rice husk and other residues (25%, 50% and 75%). It can be noticed that the increase of rice husk rate increased the reduction of sound pressure levels of the plates, improving its acoustic performance regarding the reference composites.

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Souza *et al*. (2020) examine the effectiveness of ribs and hollow brick composite slabs, which is a common construction option in Brazil. This study compared sound pressure level measurements with ribbed and hollow brick slabs using multilayer coatings and plasterboard, as well as solid concrete reference slabs. The test was performed in acoustic chamber, in accordance with ISO 10140-5:2010. Results of that study indicated that applying an elastic layer under the mortar using a gypsum ceiling reduces the noise pressure level with a weighted effect, about 40dB compared to other samples.

Several materials were investigates in acoustic studies, such as bamboo (Chen, Jiang, 2018; Putra *et al.*, 2015), coconut (Olukunle *et al*., 2018), tea-leaf (Ersoy, Kuçuk, 2009), sugarcane (Ismail *et al.*, 2014; Othmani *et al.*, 2016, 2017), sisal (Wang *et al.*, 2018), kenaf (Berardi, Iannace, 2015; Lim *et al.*, 2018; Ramis *et al.*, 2010; Ying *et al.*, 2016), and rice husk (António *et al.*, 2018; Borges *et al.*, 2018; Ismail *et al.*, 2014; Marques *et al*., 2020).

The rice husk is a natural fibre, an agroindustry waste found in large quantity in regions of rice production. Regarding some properties, it can be applied to obtaining new materials for construction. Indeed, it is a waste that has several applications, such as concrete filler and power generation. It is important to consider that the use of these residues could to favour the reduction of environmental problems caused by their improper disposal. More specifically, rice husk that can be used effectively to minimize acoustic transmission in buildings. Therefore, the possibility of creating a material from this natural element that is capable of improving acoustic conditions. There are studies on other aspects of construction properties (Bezerra *et al.*, 2012; Lopes *et al.*, 2017; Pachla, 2015, 2017; Salih *et al.*, 2015; Zucco and Beraldo, 2008).

The aim of the research is to assess the acoustic performance of subfloors with partial replacement of the aggregate by rice husk, using diverse types of finished floor coatings, subjected to a standard impact to obtain the level of standardized impact sound pressure for the analysed frequency bands, the weighted normalized impact sound pressure level and, finally, the weighted reduction of the impact sound pressure level among the samples evaluated.

Method

That work compares the noise reduction of various flooring solutions, substituting part of fine aggregate by rice husk in subfloors and composing it with three types of coatings of common use in the local buildings: porcelain, vinyl, and laminated wood. The laboratory tests were carried in laboratory environment, following the requirements of ISO 10140-3:2010.

The criterion of choice of the residue, as well as other methodological parameters, was based on earlier research carried out by González *et al.* (2013) and Borges *et al.* (2018) analyzed the acoustic behaviour

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of composites with different residues, rice husk, include three types of coatings in subfloors when moulded into 1.0 m^2 samples. According to ISO 10140-3:2010, the surface of the sample to be tested must have at least an area of 10 m^2. Following the testing method of Borges *et al.* (2018) that adapted the test with the use of samples in dimensions of 50cm x 50cm, four samples were used with 1.0 m^2. It is useful to make ease the transportation of the samples, to minimize the assembly, and avoid wastage of materials. However, because of the reduced size of the boards, only a comparative analysis is allowed, and a full weighted normalized impact noise level is not obtained.

The substitution of the fine aggregate by rice husk was developed at 50%, in 5cm thick subfloors, following the 1:4 mix proportion used by González *et al.* (2013). To produce the subfloors mortars we used the pozzolanic cement and medium-grade sand. The fine aggregate was screened for the removal of unwanted particles. The material was reserved in an oven at 105 °C for a period of 24 hours to remove the moisture present. After the interval to reach room temperature, it was stored in a closed plastic container until the date of the subfloors' moulding. The rice husk was supplied by a local rice producer. The rice husk needed a selection to remove the coarser waste in the material through the screening, using the sieve #4.8mm.

Eight subfloor samples were formulated with standard dosage, without replacement of the fine aggregate (URS), and 8 subfloor samples with the replacement of 50% of the fine aggregate by rice husk (RHS). The subfloor samples had a cure for 28 days, staying in the mould during the first 72 hours; after this period were demoulded and reserved in an air-conditioned room for finishing the cure. The coatings used in this experimental program are laminated wood, vinyl, and porcelain tile. The choice was due to these being among the materials most used in the buildings in the region. Procedures follow the rules of NBR 7374:2006, NBR 14833-1:2014 and NBR 9817:1987, respectively. The mounting of the vinyl coating (Figure 1a), laminated wood (Figure 1b) and porcelain tile (Figure 1c) followed the manufacturers' information.

Figure 1. Coatings used

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Four samples were tested at a time, forming a surface area of 1.0 m^2. The impact noise tests of the subfloors were performed in reverberation chambers. As NBR 15575-3:2013 does not refer to the technical regulations to be used for conducting standard impact isolation tests in the laboratory, the requirements of ISO 10140-3:2010 for test procedures and ISO 717-2:2013 for the determination of the weighted standardized sound pressure level. The reverberation time of the receiving chamber was decided by the precision method according to ISO 3382-2:2008. The emitting chamber, which refers to the upper environment, has a volume of 48.75m^3 and receiver chamber a volume of 48.62m^3. The chamber has a massive concrete slab of reinforced concrete with a thickness of 12cm. In this work, it is described as a "zero slab", its walls consisting of masonry of double solid block totalling a thickness of 40cm, coated with plaster and painted with acrylic paint.

The impact noise test is performed using a standard impact-generating machine Brüel & Kjær (B&K) Tapping Machine 3207. This equipment has the function of exciting the floor, simulating standardized and standardized impacts. In addition, the following equipment was used: microphone B&K 4189, Analyser B&K 2270, emission source omnidirectional Dodecahedron B&K 4292, Power amplifier B&K 2734, Instrutemp thermo-hydrometer ITMP 600 and cables.

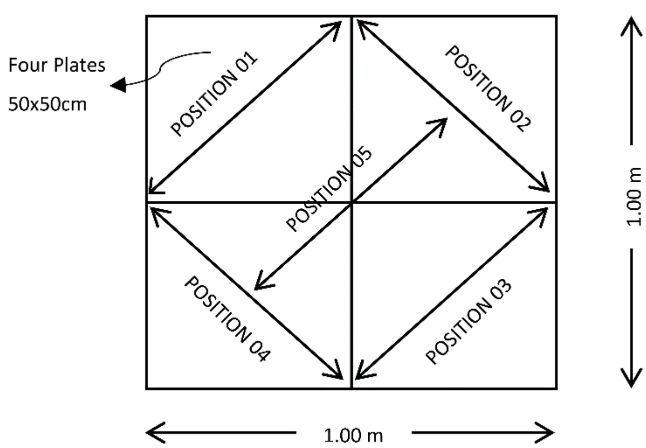

Figure 2. Schematic positions of Tapping Machine on the subfloor.

The standard impact emitting source was placed on the subfloor samples in the emitter room in five positions, as shown in Figure 2, while in the receiving room the analyser and receiver microphone were measuring position twice during each source position, totalizing 10 measurements for each sample tested. The temperature and relative humidity of the emitting and receiving chamber were captured at the beginning of each test, the temperature ranging between 18 °C and 27 °C and the relative humidity between 51% and 78%.

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Results and discussion

The tests performed resulted in the normalized impact sound pressure levels (L_n) and weighted ($L_{n,w}$). Based on these data, one can also calculate the weighted reduction of the impact sound pressure level (ΔL_w). The results of the standard impact sound pressure levels of uncoated mortar composites and the three types of coatings are presented in Figure 3 for octave thirds bands from 100Hz to 5,000Hz.

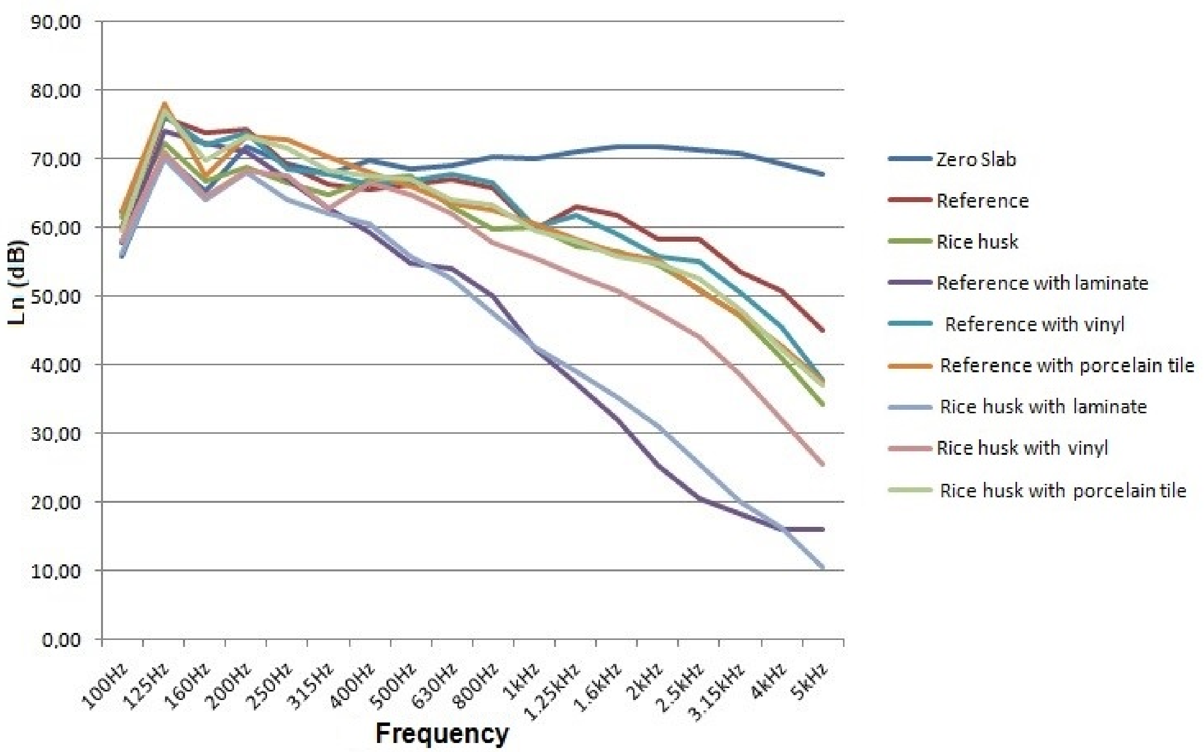

Figure 3. Standard impact sound pressure level of test plates with and without coatings

The uncoated reference subfloor (URS) presents L_n of 60dB in the 100 Hz frequency band, while the rice husk subfloor (RHS), reaches 62 dB. Both samples have the higher sound transmission in the frequency band of 125 Hz, as well as all the other tests, obtaining their greatest values of L_n. In this frequency band, the composite with rice husks reaches 72 dB, while the reference subfloor reaches 76 dB, showing a greater attenuation of the transmissions in the sample with rice hulls. From the 160 Hz frequency bands, the normalized impact sound pressure level is reduced, and when comparing the subfloors tested, the RHS presents less sound transmission from this frequency centre, except in the frequency band of 1,000 Hz in that the L_n is 60 dB for both samples.

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It is also verified that the L_n of the “zero slab” is constant, while the subfloor produced with rice husk with partial replacement of the small aggregate expresses an expected drop of the transmission levels, more significant in the bands of high frequencies. For tests with laminate flooring, there are alternations of performance during the test. The most significant was in the frequency bands of 1,000 Hz up to 4,000 Hz, in which the reference sample stands out in relation to that of rice hulls. However, in low-frequency bands, the RHS coated with laminate flooring was more efficient when compared to URS. The subfloor coated with vinyl floor achieved the most significant result in the comparison between the use of a URS and RHS, since in all frequency bands analysed, the normalized impact sound pressure levels were lower for the subfloor of mortar with residue of rice husk, except for the 400 Hz frequency band in which both presented a L_n of 67 dB.

The behaviour of porcelain coated composites is very similar in all analysed frequency bands, without significant changes. It can be said that only in low-frequency bands the result is more representative, with smaller L_n for RHS samples. Among the tests analysed with subfloors coated with different finishing floors, those with the use of porcelain tile presented higher sound transmission. As for the weighted normalized impact sound pressure levels, this data makes it possible to quantify the sound attenuation of an element from a single value according to ISO 717-2:2013. The lower is the index in dB, the better its behaviour, as shown in Figure 4.

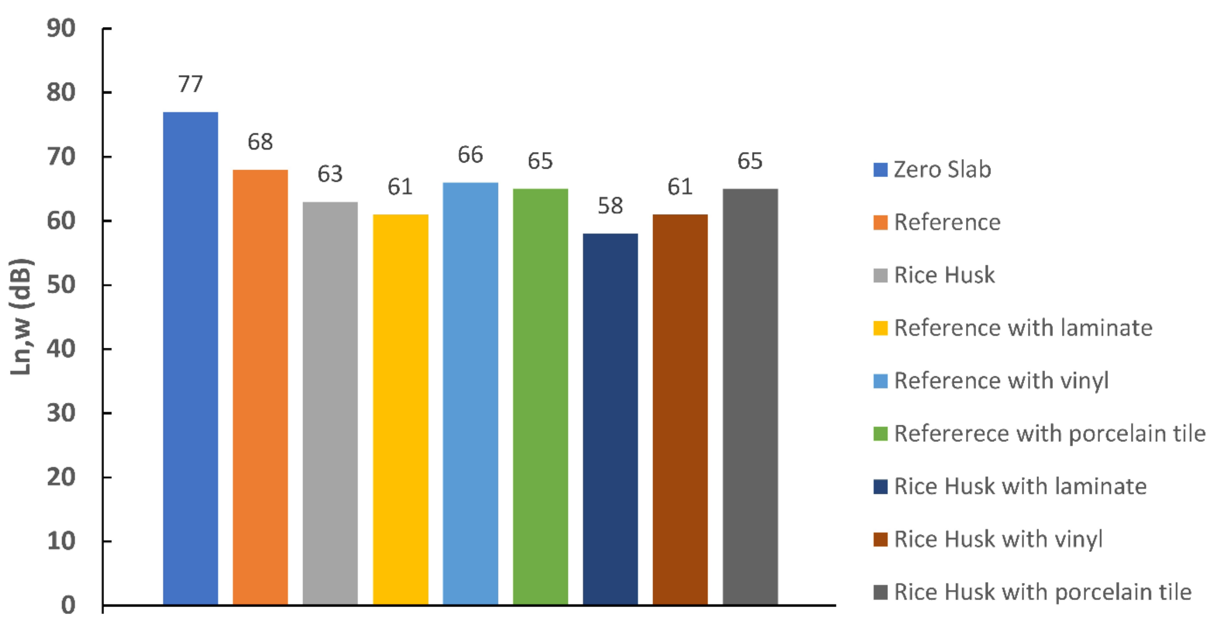

Figure 4. Weighted standardized sound pressure levels ($L_{n,w}$)

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It was seen that all the composites of mortar presented values lower than that of the "zero slab" (separation slab of the chambers). It can be noticed that the composites in which 50% of the aggregate was replaced by rice husk, obtained reduced or equivalent weighted values when compared with the reference subfloor. The $L_{n,w}$ of the reference composite coated with porcelain increased when compared to the same subfloor without coating, proving the low efficiency of this type of coating without the use of joint solutions. However, when the same coating was applied to the rice husk composite there was an increase in the value of $L_{n,w}$ of 2 dB. This inconsistency can also be explained by the air incorporated in the composite or even in the coating. In general, the coatings applied on the subfloors contributed to the reduction of $L_{n,w}$, in the laminated wood.

In Table 1 it is possible to verify the weighted reduction of the impact sound pressure level (ΔL_w) achieved from the installation of the subfloors and their coatings. The higher this value in relation to the reference, it means that there is a greater attenuation in the sound transmission in general, considering the analysis of the sound spectrum that can present more significant values in certain regions.

Table 1. Reduction of the normalized noise transmission of impact noise (ΔL_w)

Sample	ΔL_w (dB)	References
Zero slab	-	-
Uncoated reference subfloor (URS)	9	Zero slab
Rice husk subfloor (RHS)	14	Zero slab
URS alone	5	RHS
URS with laminated wood	19	URS
URS with vinyl coating	3	URS
URS with porcelain tile	5	URS
RHS alone	5	URS
RHS with laminated wood	21	RHS
RHS with vinyl coating	11	RHS
RHS with porcelain tile	5	RHS

The calculations of the weighted reduction of the impact sound pressure level (ΔL_w) of the uncoated URS and RHS samples were performed in relation to the "zero slab" of the chamber and between them, as well as, the coatings were calculated in relation to their respective subfloors. It is possible to see that the addition of the agroindustry residue allowed a greater reduction in the transmission of the impact noise when compared to the conventional subfloor to the results of González *et al.* (2013) and Borges *et al.* (2018). The conventional reference subfloor and subfloor with rice husk have a ΔL_w of 5 dB between them. The highest values of ΔL_w achieved were with the subfloors coated with 19 dB laminate and 21 dB for URS and RHS, respectively. In one general observation, conventional reference subfloors with coatings had inferior performance over subfloors with also coated rice husk. Only when coated with porcelain, both had similar ΔL_w.

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Conclusion

Following the results obtained, all subfloor specimens built with rice husks presented better results in terms of acoustic performance in relation to the subfloor without coatings. The different coatings applied to the subfloor did not change these results, as all the coatings applied to URS or RHS subfloor samples showed better results than the subfloor alone, except for the porcelain tile applied to the rice husk mortar subfloor which represents a $L_{n,w}$ of 2 dB higher than the uncoated sample.

Thus, the acoustic capacity of the composite with rolled-up rice bark, which presented a weighted normalized impact sound pressure level ($L_{n,w}$) of 58 dB, was higher than the others, obtaining the highest weighted reduction of the level ($\Delta L_{n,w}$) of 21 dB, in relation to subfloor with uncoated rice husk. Even with a difference of 2 dB, which can be considered small, it must be remembered that the scale follows a logarithmic function in which at each change of 3 dB, the sound intensity is doubled.

It can be seen, therefore, that the laminated wood coating obtained the least transmission of impact noise. This research showed that the agroindustry residue (rice husk) interferes positively in the acoustic behaviour of subfloor mortars, due to factors intrinsic to the composition in the subfloor mix proportion, in addition to its environmental appeal.

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