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MEASUREMENT OF SOUND ABSORPTION OF WOOD CHIP-BASED MATERIALS FOR NOISE BARRIERS: EFFECTS OF TESTING AND CASTING CONDITIONS

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ABSTRACT[*]

The territories characterized by a large woodland area, offer considerable potential for the development of a wood supply chain based on principles of circular economy and sustainability. However, there are limited products and applications of virtuous processes for the valorization of local materials with an optimized acoustic performance. This work focuses on recycled and reused by-products as a secondary raw material for the implementation of acoustic materials for noise barriers applications. Different typologies based on the use of loose wood chips (WCh), stone sawing waste (SS) and their combination in mix designs (WChS), where the WCh has been used as an aggregate, have been investigated. Sound absorption measurements were conducted on cylindrical samples in an impedance tube and on larger samples in a small-scale reverberation room (SSRR). The work analyzed the variability of the sound absorption coefficients in terms of reproducibility due to the loose material selection, mix design casting and testing methods.
Experimental results demonstrated that the variability of the sound absorption of the WCh samples are affected mainly by the measurement method, while the WchS samples are significantly affected by the sample size, the mix design casting conditions, and measurement method.

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1. INTRODUCTION

This The development of a wood supply chain based on principles of circular economy and sustainability has gained interest and presents different opportunities [1]. However, there are limited products and applications of virtuous processes for the valorization of local materials with an optimized acoustic performance [2]. For example, Stradzas and Januševičius [3] showed in their review the performance potentials of acoustic barriers made using waste and plant-based materials. Many other applications could be explored through principles of circular economy, clean production and aesthetic integration [4]. The main goal of this research is to transform loose wood chips material obtained from sawmill wood waste into a high-value resource with an acoustic performance in noise barriers. This is further integrated with the use of stone sawing waste. Moreover, the work aims to analyze the variability of the sound absorption coefficients in terms of reproducibility due to the loose material selection, mix design casting and testing methods.
The loose material has been analyzed in a few studies. Lashgari et al. [5] presents a concise review of research on sound absorbers made from natural materials. Furthermore, they present measurements and prediction models for wood chip-based sound absorbers promoting the idea of the creation of sustainable sound-absorbing materials from wood chip wastes. Other studies have focused on specific plant varieties considering also leaves and wood in the mix design [6, 7]. Cottone et al. [4] highlights loose material are

completely recyclable once their service life concludes, unlike other mix designs that present limitations due to the binder characteristics.
Ornamental rock cutting wastes (sawing sludges) have been used in various applications; their function is to act as fine aggregates in conglomerate matrices, reacting by interaction with alkaline solutions [8-10]. However, their use as a binding matrix for wood chips in acoustic panels has been overlooked. The mix design between plant-based materials and stone sawing waste has been considered in [11]. To the author's knowledge, no previous studies have reported the variability of sound absorption due to the loose material selection, mix-design casting and testing methods. This is an important aspect to consider given its impact on the final material performance.
The objective of this work is to provide new perspectives of integration of wood waste material for acoustic applications by promoting the use of natural loose material. To this purpose, for a more sustainable approach, the loose material was used in different typologies based on the use of loose wood chips (WCh), stone sawing waste (SS) and their combination in mix designs (WChS), where the WCh has been used as large aggregate and the sawing stone (reacted with alkaline solutions) as a conglomerate matrix. It analyses the variability of the sound absorption coefficients in terms of reproducibility due to the sample mix design casting conditions, sample size and testing methods. Also, the fabrication place, i.e. laboratory or on-site, was considered as a variable in the analyses.

Table 1. Summary of the samples tested in IT and SSRR and their characteristics.

Sample		Thickness [mm]	Density [kg/m^3]	SSRR	IT
1	WCh	20	-		x (lab)
	WCh	100	-	x (site)	x (lab)
2	SS	60	1392-1415		x (lab)
3	WChS	20	752 -873		x (lab)
	WChS	40	752 -873	x (lab and site)	

2. MATERIALS AND METHODS

The work has been developed in two phases: first, the recycled and reused by-products have been studied in different mix designs and secondly, an acoustic characterization of their performance has been performed on cylindrical samples in an impedance tube and on larger samples in a small-scale reverberation room (SSRR).
The experimental work aims to analyze the variability of the sound absorption coefficient in terms of reproducibility of the samples and testing method given different a) loose material selection, b) mix design, c) sample size, and d) measurement method.

2.1 Materials

Three different typologies (Table 1) based on the use of loose wood chips (WCh), stone sawing waste (SS) and their combination in mix designs (WChS), where the WCh has been used as an aggregate, have been investigated. The wood chips were sorted into randomly mixed mesh sizes ranging from 0.5-25 mm, and it was found that stone sawing waste content of 2.7 times the weight of wood chips was suitable for the WChS samples to show both structural and acoustic performance.
Cylindrical samples with different thickness for measurements in the impedance tube and 50x50 cm sized samples for the small-scale reverberation room (SSRR) measurements were fabricated in the lab conditions and on site (building construction site). Table 1 provides a summary of all variables and characteristics of the samples.

Figure 1. Impedance tube sound absorption measurements: randomly mixed sizes of loose wood chips for samples WCh_20_1-4 and WCh_100_IT.

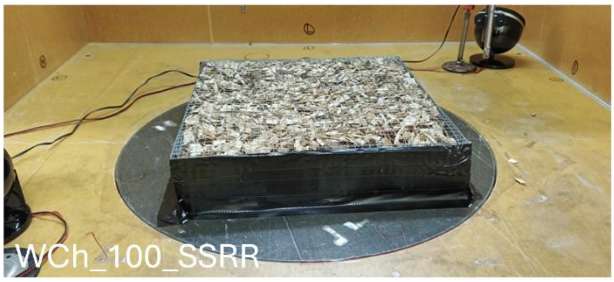

Figure 2. Small-scale reverberation room (SSRR) sound absorption measurements: WCh_100_SSRR.

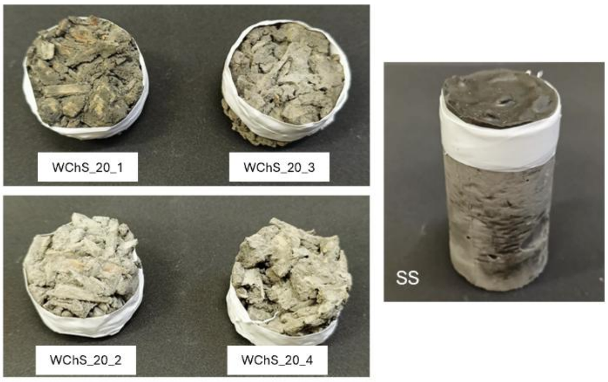

Figure 3. Impedance tube sound absorption measurements: samples WCh_20_ 1-4 and sample SS.

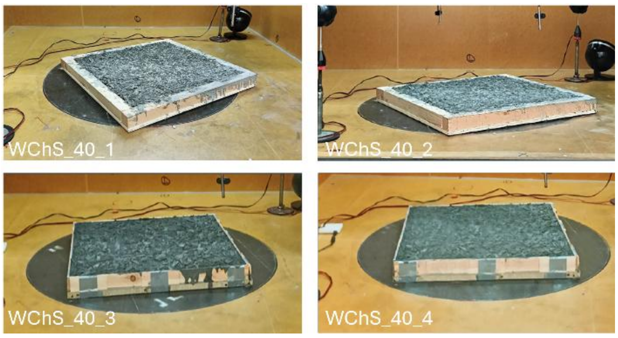

Figure 4. Small-scale reverberation room (SSRR) sound absorption measurements: samples in SSRR WChS_40_ 1-4.

1) Loose wood chips – WCh (Figure 1 and 2):

- 4 samples for impedance tube measurements; thickness 20 mm (WCh_20_1-4);
- 1 sample for impedance tube measurements; thickness 100 mm (WCh_100_IT);
- 1 sample for reverberation chamber measurements; dimensions 50x50 cm; thickness 100 mm (WCh_100_SSRR).

2) Sawing stone SS (Figure 3):

- 1 sample for impedance tube measurements; thickness 60 mm (SS). This sample has been considered as a reflective reference surface for the sawing stone waste material.

3) Mix design wood chips and sawing stone waste casting conditions – WChS (Figure 3 and 4):

- 2 (+2) samples for impedance tube measurements; thickness 20 mm (WChS_20_1-4). These samples were measured on both sides;
- 4 samples for reverberation room measurements; dimensions 50x50 cm; thickness 40 mm (WChS_40_1-4).

2.2 Measurement methods

Two different sound absorption measurements were conducted using cylindrical samples in an impedance tube and on larger samples (50x50 cm) in a small-scale reverberation room (SSRR).

2.2.1 Impedance tube

The acoustic measurements were performed on the three typologies in an ISO 10534-2 impedance tube [12] (two-microphone technique) to assess the normal-incidence sound absorption coefficient. An HW-ACT-TUBE impedance tube at the Applied Acoustics Laboratory (Department of Energy, Politecnico di Torino) was used for these measurements. This device has an internal diameter (ϕ) of 35 mm and is equipped with two ¼'' flush-mounted GRAS 46BD. The method allowed accurate sound pressure amplitude and phase measurements over the whole frequency range of interest, i.e., 100–5000 Hz [13].
The normal-incidence absorption coefficient (α_0) was measured for each composition. Figure 3 shows how the edges of the samples have been adequately sealed with a thin Teflon tape to even out the irregularities generated by the casting technique and to fill the gaps (<1 mm) between the sample and tube [13]. The loose material samples (WCh 20_1-4 and WCh_100_IT have been measured by filling in the tube considering both 20 and 100 mm depth of the rigid backing of the tube piston. The measurements were performed in vertical position for these samples.

2.2.2 Small-Scale Reverberation Room

For the measurement of the sound absorption coefficient in a reverberation room following the procedure of ISO 354:2003 [14] standard, the small-scaled reverberation room (SSRR) of the Department of Energy (DENERG) of Politecnico di Torino has been used. It has been thoroughly described and validated in [15]. The use of the SSRR allows the use of smaller sample sizes than 10-12 m^2 as required in the ISO 354, but maintains the diffuse field conditions of the method. However, this methodology has disadvantages such as the lack of field diffusivity in the mid to low frequencies and diffraction due to the finite size of the experimental samples, which generates so called edge effects. The SSRR measurement methodology specifically consists of an exponential sweep from 100 Hz to 25000 Hz generated through two omnidirectional dodecahedral sound sources. Six microphonic positions for a total of 12 measurements have been performed. To this aim, the measurement chain consists of six 1/400 BSWA Tech MPA451 microphones (BSWA Technology Co., Ltd., Beijing, China) and ICP104; two ITA High-Frequency Dodecahedron Loudspeakers with their specific ITA power amplifiers (ITA-RWTH, Aachen, Germany) and a sound card Roland Octa-Capture UA-1010 (Roland Corporation, Japan). For the measurement of the sound absorption coefficient Matlab software combined with the functions of the ITA-Toolbox (an opensource toolbox from RWTH-Aachen, Germany) [16] was used.
Figure 2 and 4 show the experimental setup and the sample with an area of 0.25 m^2.

3. RESULTS AND DISCUSSION

The sound absorption measurements results have been shown in Figure 5. It presents the variability of the sound absorption coefficient in terms of reproducibility of the samples given different a) loose material selection, b) measurement methods, c) mix design (IT), and d) mix design (SSRR). As shown in Figure 5. a) the SS sample shows a very low sound absorption coefficient similar to very reflective surfaces.

a) Loose material: The comparison of different measurements of four samples of randomly selected loose material shows a good reproducibility of the samples with a variation of the sound absorption of less than 0.2.

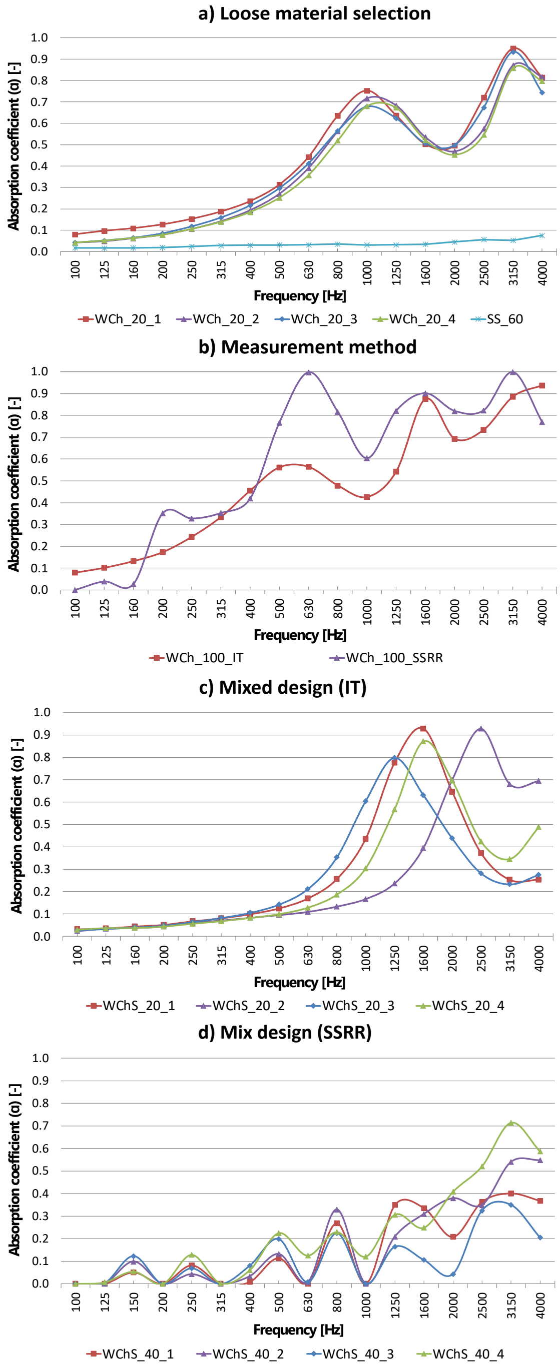

Figure 5. Sound absorption coefficient variation based on a) loose material selection, b) measurement method on loose material, c) mix design for small samples (IT) and d) mix design for larger samples (SSRR).

b) Measurement method: The comparison of the two different measurement methods (IT and SSRR) maintaining the same loose material sample thickness (10 cm) shows a high variability of the sound absorption curves suggesting that there might be significant differences between the distribution of the chips in a larger sample (50x50 cm) that would be complex to select in a representative way with small cylindrical (ϕ=35 mm) samples. The SSRR measurements show a peak at 630 Hz which is higher than the IT sample values of more than 0.4. The correspondence of the peaks with the characteristic geometrical dimensions of the sample patterns has been verified in relation to the thickness of the loose material d=100 mm which corresponds to the quarter-wavelength resonance frequency ($f_0 = c/4d$) of 857 Hz and falls within the 800 Hz third-octave band. This correspondence should be further verified since both curves show a peak at a lower third octave frequency band (630 Hz).

c) Mix design in the impedance tube: The results show significant differences between the two samples WChS_20_1 and _3 (front) presenting different frequency peaks and associated sound absorption at the peak values. Both sides of the same samples show significant differences with the tendency of the inverted samples WChS_20_2 and _4 (back) to shift the peak frequency at higher values. This suggests that the open porosity might be reduced for the back side of the samples which is used to place the samples on the casting plan. This difference was also highlighted in [17].

d) Mix design in the small-scale reverberation room: the curves show a high variability between the four samples, i.e. two fabricated in the lab and two fabricated on site. The variability is higher when comparing the two samples produced in the lab at two different moments. This is more evident at high frequencies above 1000 Hz suggesting that casting conditions may influence in a significant way the acoustic performance. The visual superficial inspection of the samples shows that open porosity could be one of the parameters that may be significantly affected by the casting and curing variables (e.g. operator, weather conditions, sample curing time etc).

4. CONCLUSION

The objective of this work was to provide new perspectives of integration of wood waste material for acoustic applications by promoting the use of natural loose material and stone sawing waste material from local quarries. To this purpose, for a more sustainable approach, the loose material was used in different typologies based on the use of loose wood chips (WCh), stone sawing waste (SS) and their combination in mix designs (WChS), where the WCh has been used as an aggregate. The variability of the sound absorption coefficients in terms of reproducibility due to the sample mix-design, size and testing methods has been presented. Furthermore, the fabrication place that may include the operator, environmental conditions, curing time etc., was considered as a variable in the analysis.

Overall, the work highlighted some of the variables that should be carefully monitored:

- The random selection of the loose material and measurements in the impedance tube samples may not affect or affect to a limited extent the sound absorption in the IT measurements.
- The two different measurement methods (IT and SSRR) showed significant differences suggesting that there might be significant differences between the distribution of the chips in a larger sample compared to smaller samples attempting to be representative of the larger ones.
- The mix-design in the impedance tube measurements showed significant differences in the two front and back oriented samples. This was mainly due to the casting conditions and material deposition on the casting plane.
- The mix-design in the small-scale reverberation room shows a high variability between the four samples, i.e. fabricated in the lab on the building site. In this case the sound absorption is significantly affected by the casting variables (e.g. operator, weather conditions, sample curing time etc.).

Further research could be conducted along this line of research to explore other mix-design and mounting method strategies for the application of sound absorbing porous loose wood chips and stone sawing waste in the frame of the sustainable architectural and urban design strategies. A more systematic study could be developed considering the variables explored in this work in order to build appropriate guidelines that would preserve optimized acoustic performance also in the fabrication/casting and curing phase on site and in lab conditions.

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