DOI: 10.61782/fa.2025.0198

FORUM ACUSTICUM EURONOISE 2025

CHARACTERIZATION OF THE SOUND ABSORPTION PROPERTIES OF A FIBROUS BIOMATERIAL: A KEY INPUT FOR ROOM ACOUSTIC SIMULATION SOFTWARE

Joaquin Garcia[1*] **Pablo Alloza**[2] **Edoardo Alessio Piana**[1]
[1] Applied Acoustics Laboratory, University of Brescia, via Branze 38, Brescia, Italy
[2] Track-Noise, Spain

ABSTRACT

In recent years, the search for sustainable materials has gained increasing importance in order to optimize resource use and reduce carbon emissions. In this context, bio-materials have emerged as an alternative due to their low environmental impact. In particular, those with a fibrous morphology, both vegetal or animal based, have proven effectiveness as sound absorbers in room acoustics applications. In this study, the acoustic absorption properties of a type of sheep wool are evaluated. The characterization of the acoustic absorption coefficient under normal incidence was carried out using the two-microphone impedance tube method and compared with the reverberant chamber method. Subsequently, the reverberation time of a selected room was measured before and after the implementation of two walls covered with the chosen material. The impulse response was also recorded using a spherical microphone array, which allowed the visualisation of early reflections applying beamforming algorithms. These measurements were used to validate the simulated impulse response of the room and to determine the most accurate absorption data for the model.

Keywords: *Sound absorption, impedance tube, biomaterials, acoustic camera, simulations.*

**Corresponding author*: *jorge.garcia@unibs.it.*

1. INTRODUCTION

The use of sustainable materials has become a significant trend in recent years, towards a strategy of zero-carbon emissions. Building materials typically come from non-renewable and synthetic resources. Porous materials are commonly derived from petrochemical products like polyester or polyurethane, which have a high environmental impact after use. Natural materials have emerged as a viable alternative, utilising renewable resources and generally exhibiting lower levels of environmental impact and embodied energy. Several studies have reported the acoustical properties of oil palm fibres [1], sugarcane bagasse [2], hemp fibres [3] and kenaf fibres [4].

Sheep wool is a natural material that has many advantages compared to others, such us their good thermal insulating performance and low flammability since it is self-extinguishing and does not ignite easily [2]. Furthermore it does not release any toxic particles or gases during combustion and, it is a renewable and recyclable material with a natural decomposition cycle. However, sheep wool is having less demand for applications in the textile industry and nowadays most of the surplus is burned or sent to landfill [5].

The sound absorbing properties of porous materials are normally linked to their porosity and flow resistivity. According to their structure, porous materials can be classified as cellular, fibrous and granular [6]. Fibrous materials are among the most widely used due to their high availability and origins from both animal and vegetable sources. The absorption properties can be measured through various methods. One of them is using an impedance tube. This method requires small samples and relatively inexpensive equipment. However it can only characterise the absorption at normal incidence and up to the cut-on frequency of the impedance tube, that depends on the tube's diameter [7]. In contrast, the reverberation chamber method (ISO 354) implies the use of 10 m^2 samples, making it less convenient and more expensive. While the absorption coefficient obtained through this method is more representative of the material's behaviour in real world situations — reflecting conditions under a diffuse field — low reproducibility between laboratories can yield varying results [8]. Additionally, the placement of the material within the chamber can influence the measured absorption coefficient [9]. Within this context it can be not clear which values are more accurate to use when feeding computational models for room acoustic simulations in order to have results matching the reality.

In this paper the sound absorption properties of a sheep wool absorber was evaluated and used as an input material for feeding computational models for room acoustics. Furthermore the impulse response of a room was measured and the reverberation time deduced before and after covering the walls with sheep wool panels. Early reflections were observed by using a spherical microphone array and beamforming algorithms. These measurements were used to validate the computational model of the room and investigate which absorption data is more accurate to be used as input material in the model.

2. MATERIALS AND METHODS

The material selected was a sheep wool, wrapped in panels of 6 mm thickness. Three samples of 45 mm diameter were extracted as shown in 1 and their sound absorption properties were measured in an impedance tube. The material was provided by Farrás Home - Spain and in particular this model has also a coating of a series of natural resins that act as a catalytic converter. It absorbs the CO_2 and NOx, contributing to the ecological balance.

Figure 1: Samples of sheep wool.

2.1 Impedance tube measurements

The sound absorption coefficient was measured using a two microphones impedance tube according to the standard ISO 10534 [7]. The system was implemented with a cylindrical tube of 45 mm diameter allowing the characterisation of the sound absorption coefficient up to a cut-off frequency of 3800 Hz. The samples were mounted on a rigid back-end and two 1/4" microphones were spaced 45 mm from each other to measure the pressure field. On the other extreme of the tube a loudspeaker generated a broad band white noise as test signal. The transducers were connected to an OROS Type OR36 analyser, which measures the complex transfer functions between the microphones. The absorption coefficient was calculated given the sample thickness d as:

$$\alpha = 1 - |R|^2 \quad (1)$$

$$R = \frac{Z_s - \rho_0 c}{Z_s + \rho_0 c} \quad (2)$$

$$Z_s = -jZ_c cot(k_c d) \quad (3)$$

Where R is the sound pressure reflection coefficient, Z_s is the surface impedance of the sample, Z_c its characteristic impedance, and ρ_0 and c the density of air and speed of sound.

The results shown in section 3 are the average of three samples. The resulting curves are compared to the results of sound absorption measurements carried out in a reverberant room with the same material.

2.2 Impulse response measurements

The impulse response of a room with a volume of approximately 33 m^3 was measured with a NTi Audio XL2 sound level meter mounting a Type 1 microphone. The impulse was generated wiht a Delta Clapper. The sketch of the room with the measurement positions is presented in Figure 2 and the setup is shown in Figure 3. The reverberation time (RT) was measured in accordance with the guidelines established in ISO 3382-1:2009. According to this standard, the reverberation time T20 and T30 were calculated through the backward Schroeder integration in octave bands from 63 Hz to 8000 Hz. The results obtained from four microphone positions at 1.5 m height were averaged to obtain a representative reverberation time for the room as shown in Figure 2. The same measurement positions and procedures were repeated after applying the

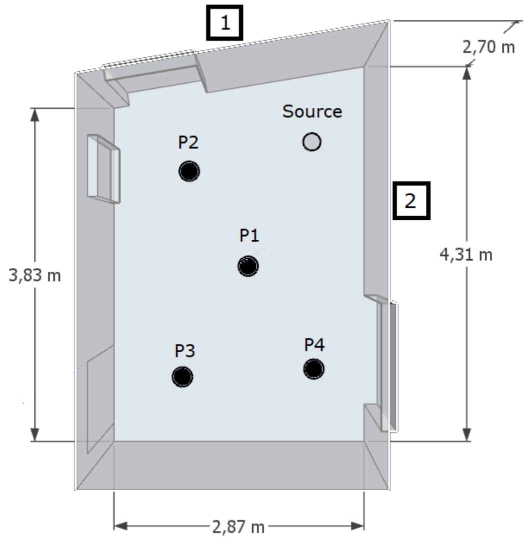


Figure 2: Top view of the room showing the positions of the sound source and microphones. The height is 2.7 m.

Figure 3: Sound level meter placed in the room.

acoustic treatment to the room. In what follows for all the measurements the absorptive material was installed covering walls 1 and 2 indicated in Figure 2.

2.3 Acoustic camera measurements

The measurement campaign was conducted using a Sphere48 AC Pro by gfai tech which is an advanced acoustic camera system designed specifically for 3D localization of sound sources in enclosed spaces. This spherical microphone array is equipped with 48 high-precision microphones arranged to capture sound from all directions, making it particularly suitable for indoor applications such as vehicle interiors, rooms, and architectural spaces. This tool represents a powerful and comprehensive solution for the localisation and visualisation of acoustic reflections in three dimensions. The array was positioned centrally within the room, mounted on a high-stability tripod, ensuring a clear line of sight to all major reflective surfaces (walls, ceiling, floor, furniture) (see Figure 4). The system was connected to a multi-channel data acquisition unit running the gfai tech NoiseImage software suite.

A series of impulsive sound stimuli were generated using a NTi Audio Delta Clapper placed at various locations within the room, mainly corners. Each impulse was recorded by the 48 microphones, capturing both the direct sound and the subsequent early and late reflections. To ensure spatial accuracy, the integrated Intel® RealSense™ depth camera was used to match the array position inside the 3D model captured by a laser-scanner, allowing beamforming results to be mapped directly onto the geometry of the room. The same measurement positions and procedure was repeated after the acoustic treatment.

2.4 Computational simulations

Room acoustics simulations were performed using the software Treble, which is a hybrid room acoustic simulation tool that combines wave-based simulations at low frequencies, to capture the important wave and modal behaviour up to a transition frequency (typically the Schroeder frequency), and geometrical acoustic simulations at high frequencies, to take advantage of the faster calculations. The geometry was first modelled in Sketchup and then imported into the software. The source and microphone positions were introduced according to those shown in Figure 2. After theat the materials and properties of the walls, roof and ceiling were defined according to the Table 1.

The transition frequency was set to 710 Hz and the number of rays for the geometrical solver was set to 20,000, considering up to 5th order reflection. The calcu-

Figure 4: Sphere acoustic camera inside the room.

lations, running on a dedicated server associated with the software, took around 3 minutes per complete simulation.

The measured sound absorption coefficients (both in impedance tube and reverberant chamber) of the sheep wool were entered as input to perform the simulations before after the acoustic treatment. The strategy was to combine the absorption values of the walls with those of the sheep wool, under the hypothesis that the wool panels are thin enough not to introduce significant damping, thus not change the low frequency absorption behaviour of the wall panels. For this purpose, the software allows for the introduction of combined sound absorption coefficients, and it calculates the surface impedance of the component using a fitting algorithm. In Figure 5 an example of the material generation window of the software is shown, where the inserted values (target) and the derived values (results) of sound absorption coefficient can be seen. Internally, during the fitting process, the software estimates the surface impedance, which is necessary to recover the phase information for the modal based solver.

3. RESULTS AND DISCUSSION

3.1 Absorption properties of the samples

The sound absorption coefficient in third-octave bands of the sheep wool is shown in Figure 6. As it can be seen, it has a typical behaviour of a fibrous material with a crescent absorption value towards the high frequency range crossing the 0.3 line at around 3000 Hz. On the same graph it is shown the absorption coefficient of the same

Table 1: Sound absorption properties of the materials used for the simulation

Frequency (Hz)	10 mm gypsum board + 100 mm mineral wool	Wooden flooring	Brick painted (ceiling)
63	0.39	0.16	0.05
125	0.27	0.15	0.04
250	0.14	0.13	0.04
500	0.08	0.1	0.03
1000	0.05	0.08	0.04
2000	0.05	0.07	0.05
4000	0.07	0.07	0.05
8000	0.07	0.07	0.05

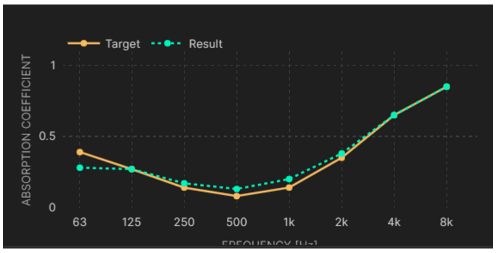


Figure 5: Estimation of the absorption properties of the material after a fitting process inside Treble software.

material measured previously in reverberant room according to the ISO 354. As expected, the values are higher than the ones measured in impedance tube since in the last one only normal incidence behaviour of the sample is captured, while in the reverberant chamber a diffuse field condition is reached. However, the absorption coefficient in this last case can be overestimated due some drawbacks of the methods such us diffraction effects on the border of the sample. Consequently both curves are fed as input into the computational model and the impact on the reverberation time considering one or the other absorption curve is analysed in Section 3.2.

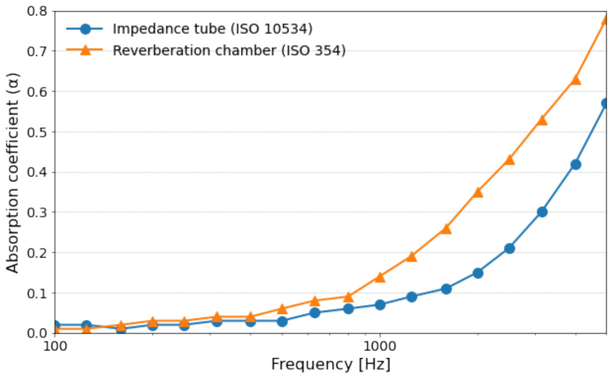


Figure 6: Sound absorption coefficient of the sheep wool measured in impedance tube and reverberant chamber

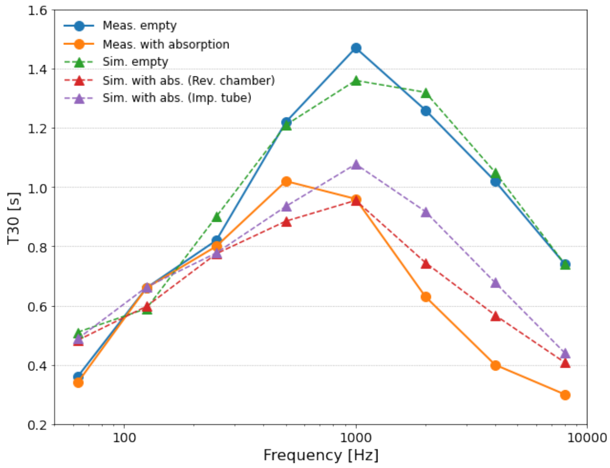


Figure 7: Reverberation time measured and simulated, with and without absorbing material.

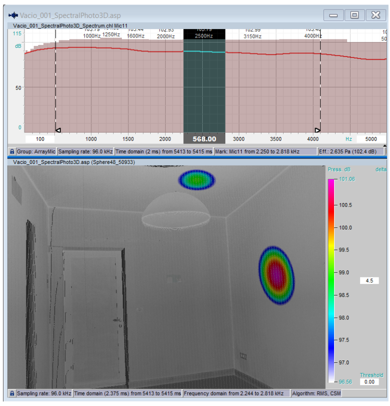
3.2 Impulse response of the room and simulations

The results obtained from the Reverberation Time (RT) measurements, indicate a significant reduction in RT values, particularly from the 500 Hz third-octave band onwards. The overall RT value decreased from 1.35 s to 0.99 s after the installation of the acoustic treatment as it can be seen in the solid line curves in Figure 7. On the same graph the results of the RT from the simulation can be seen. A very good agreement is observed between the measured and the simulated RT of the room without the porous material. When the absorption is applied, the RT curve considering the material measured in reverberation chamber is more close to the measured one than the case considering the absorption values from impedance tube. This might suggest that for non very high absorptive materials the reverberation chamber values potentially can give more accurate results in the model. The mismatch at 63 Hz can be attributed to a fitting difference in the material building module inside the software. For the rest of the frequency the curves follow the same tendency with slight differences.

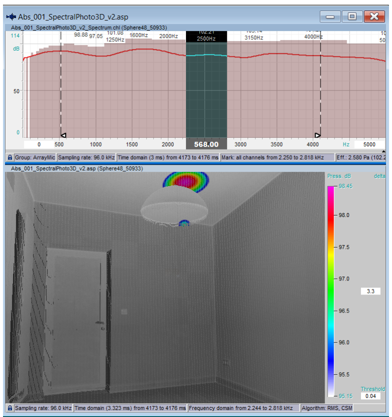
Additionally, the use of a 3D Acoustic Camera enabled the identification and analysis of early acoustic reflections within the room. This tool was instrumental in comparing the acoustic behaviour of the space before and after installing the absorptive material on two of the walls. The visual data clearly demonstrate the effectiveness of the material in attenuating acoustic reflections at its installed locations. This is particularly evident as shown in Figure 8 in the 2500 Hz third-octave band and with differences of about 5 dB at 1250 Hz and at 800 Hz third-octave bands, where the absorption performance aligns with the material's specified acoustic properties.

4. CONCLUSIONS

In this work a room acoustic study was conducted. First the acoustic absorption properties of a sheep wool material was assessed and used as input data to fed computational simulations. The same material was used to perform an acoustic correction of a room and the reverberation time before and after the acoustic treatment was measured to compare the situations. The acoustic camera was utilised to visualise the first reflections and verify the reduction of level in presence of the sheep wool materials. The room was simulated using a hybrid wave-based and geometrical acoustic software to investigate the response of the room. The model was validated using the experimental measurements. Sound absorption values of the same material measured in impedance tube and reverberation chamber were implemented in the software. It was shown that in the last case the values were closer to the measured ones. Despite normally the reverberation chamber method tends to overestimate the absorption coefficient, this might suggest that potentially for not very highly absorptive materials the most accurate option for use as input data in simulation models is the absorption coefficient measured in reverberant rooms.



(a) Without absorptive material.



(b) With absorptive material.

Figure 8: Visualisation of the first reflection on the walls at 2500 Hz third-octave band.

5. REFERENCES

[1] K. H. Or, A. Putra, and M. Z. Selamat, "Oil palm empty fruit bunch fibres as sustainable acoustic absorber," *Applied Acoustics*, vol. 119, pp. 9–16, 4 2017.

[2] M. H. Beheshti, A. Firoozi, M. Jafarizaveh, and A. Tabrizi, "Acoustical and thermal characterization of insulating materials made from wool and sugarcane bagasse," *Journal of Natural Fibers*, vol. 20, 2023.

[3] A. Santoni, P. Bonfiglio, P. Fausti, C. Marescotti, V. Mazzanti, F. Mollica, and F. Pompoli, "Improving the sound absorption performance of sustainable thermal insulation materials: Natural hemp fibres," *Applied Acoustics*, vol. 150, pp. 279–289, 7 2019.

[4] Z. Y. Lim, A. Putra, M. J. Nor, and M. Y. Yaakob, "Sound absorption performance of natural kenaf fibres," *Applied Acoustics*, vol. 130, pp. 107–114, 1 2018.

[5] B. Petek and R. M. Logar, "Management of waste sheep wool as valuable organic substrate in european union countries," 1 2021.

[6] J. P. Arenas and M. J. Crocker, "Recent trends in porous sound-absorbing materials," *Sound and Vibration*, vol. 44, no. 7, pp. 12–17, 2010.

[7] UNE-EN ISO 10534-2, "Determinación del coeficiente de absorción acústica y de la impedancia acústica en tubos de impedancia," 2002.

[8] C. Scrosati, F. Martellotta, F. Pompoli, A. Schiavi, A. Prato, D. D'Orazio, M. Garai, N. Granzotto, A. Di Bella, F. Scamoni, M. Depalma, C. Marescotti, F. Serpilli, V. Lori, P. Nataletti, D. Annesi, A. Moschetto, R. Baruffa, G. De Napoli, F. D'Angelo, and S. Di Filippo, "Towards more reliable measurements of sound absorption coefficient in reverberation rooms: An Inter-Laboratory Test," *Applied Acoustics*, vol. 165, p. 107298, 2020.

[9] J. Cucharero, T. Hänninen, and T. Lokki, "Influence of Sound-Absorbing Material Placement on Room Acoustical Parameters," *Acoustics*, vol. 1, no. 3, pp. 644–660, 2019.