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SOUND ABSORBING FURNITURE AS A STRATEGY FOR ACOUSTIC COMFORT OPTIMIZATION

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ABSTRACT

An effective acoustic design of indoor spaces can minimize noise impacts, creating a healthier and more productive environment for occupants. Typical strategies to improve indoor acoustic comfort include adding sound-absorbing materials to ceilings and using vertical partitions. Furthermore, a careful selection of furniture could enhance the acoustic quality of spaces, without altering their layout. However, the real challenge is ensuring acoustic comfort, while respecting the environment. For this purpose, the aim of this work was to use textile waste as secondary raw materials to design seating solutions with appropriate shapes and compositions to create micro-environments with acoustic privacy. Particularly, textile waste nonwovens were used to replace the polyurethane foam in padding of armchairs. Two prototypes of armchairs with the same shape and size, but different padding, were produced. After having characterized the acoustic behaviour of the textile nonwovens and of the polyurethane foam, the ability to control noise of the two armchairs was measured and compared in a reverberant chamber. Results of the comparison proved that the armchair made of textile waste showed a higher equivalent sound absorption area than the polyurethane armchair over the entire frequency range, exhibiting a better ability in absorbing the random incidence sound.

Keywords: *textile waste, acoustic comfort, acoustic furniture, industrial symbiosis.*

1. INTRODUCTION

In 2020, the European Commission introduced the Circular Economy Action Plan, promoting a production and consumption system where most products and resources can be reused or recycled [1]. As a result, new approaches are being developed to reduce waste production and transform it into valuable resources, minimizing the need for natural resources in economic activities [2].

In this context, industrial symbiosis has gained increasing recognition as an effective resource optimization strategy based on collaboration between industries, where the waste or by-products of one become raw materials for another [3]. This practice allows decreases raw material extraction, to increase energy and water recycling, and to reduce landfill waste, offering both environmental and economic benefits [4].

The textile industry is one of the most environmentally impactful sectors, ranking as the fourth-largest contributor to climate change in the European Union. Each year, approximately 5.8 million tons of textiles are discarded, underscoring the need for upcycling solutions to convert textile waste into raw materials for various applications, such as automotive manufacturing and construction [5]. More recently, research has explored the potential of using textile waste in sustainable furniture design, particularly for sound-absorbing screens in shared spaces like offices and classrooms [6]. Thanks to their porous structure, textile fibers improve acoustic comfort by reducing reverberation and controlling noise levels, enhancing well-being and productivity [7].

The furniture market has recently recognized the seating sector for public spaces as a new area of application for ensuring acoustic comfort. It is believed that the use of high-performance materials and technologies can help improve

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the acoustics of any environment. However, despite the growing demand for furniture with sound-absorbing properties, current solutions primarily focus on aesthetics, often lacking clear specifications of their acoustic performance, which could help architects better visualize sound behavior in their designs. For this purpose, the present research explores the use of industrial symbiosis to repurpose textile waste as padding for seating solutions aimed at enhancing acoustic privacy. An innovative armchair prototype was developed by replacing conventional polyurethane foam with textile waste padding. The acoustic performance of both types of padding was assessed through sound absorption measurements using an impedance tube, and the results were validated through microstructural analysis. Additionally, measuring the random incidence sound absorption coefficient in a reverberation chamber provided further insights into the armchair's ability to improve acoustic comfort in indoor spaces.

2. MATERIALS

The armchair used for the study was selected from the production line of "Calia Italia srl.", a major Apulian furniture company. Specifically, the "Vivì" model was chosen for its design, which enhances the acoustic performance of the armchair due to its high and enveloping backrest. The armchair measures 111 cm in height and 70 cm in width, with a seat height of 51 cm and a seat width of 52 cm. It features a multilayer chipboard structure and a metal frame for the seat and backrest, both originally padded with polyurethane foam (PUR). The backrest padding was replaced with nonwoven textile waste (TW) to enhance acoustic properties, while the seat padding remained unchanged for ergonomic reasons. The original polyurethane foam (30 kg/m³, 5 cm thick) was substituted with TW (68 kg/m³, 4 cm thick), covering about 3 m².

3. MEASUREMENT SETUP FOR PADDING MATERIALS

3.1 Microstructure analysis

Key non-acoustic parameters, including open porosity (ε) and air flow resistivity (σ), were evaluated, with a particular focus on the PUR sample, as TW had been previously tested [8]. Then, results obtained for the two materials were compared. The open porosity was measured using a ULTRAPYC 1200-e Helium gas Pycnometer, whereas the air flow resistance was evaluated according to [9].

Figure 1. Prototype of the armchair PUR according to the standard design (a) and of the TW one after the padding replacement (b)

3.2 Normal incidence sound absorption coefficients

The normal incidence sound absorption of the PUR sample was evaluated using a BSWA SW 260 impedance tube [10]. Tests covered a 100-6300 Hz frequency range using two tube configurations (60 mm for 100-2500 Hz, 30 mm for 1250-6300 Hz).

The sound absorption coefficients resulted from experiments were compared with those predicted by the Johnson-Champoux-Allard-Lafarge (JCAL) model [11], which requires knowledge of microstructural parameters (porosity (ε), air flow resistivity (σ), tortuosity (τ), thermal and viscous characteristic lengths (Λ, Λ') and thermal permeability (k_0)). As directly measuring all parameters is challenging (and only ε and σ values were experimentally measured), missing values were estimated using an inverse method [12], which uses complex impedance to infer unmeasured properties like τ, Λ, Λ' and k_0.

4. MEASUREMENT SET UP FOR ARMCHAIRS

The acoustic behaviour of the two armchairs was evaluated by measuring their equivalent sound absorption area in a reverberant chamber [13]. Since only one prototype per model was available, and the standard ISO 20189:2018 [14] suggested using the maximum number of objects to achieve the highest possible absorption area (without exceeding 12 m² in any frequency band), additional fibrous polyester panels were used to simulate two extra seats. The panels were 60x120 cm, 5 cm thick, reaching an area very close to that of the armchair backrest.

5. RESULTS

5.1 Characterization of padding materials

Table 1 compares the values resulting from the laboratory tests with those obtained from the application of the inverse method. As can be observed, the different matrix of the tested materials (foamy for PUR and fibrous for TW) did not affect their porosity that exceeded 90% in both cases (0.96 for PUR and 0.92 for TW). Furthermore, the experimental and theoretical ε values matched perfectly. The air flow resistivity measurements aligned with the porosity results, as the more porous PUR sample showed greater air permeability (σ=2.7 kN·s/m^4) compared to TW (σ=17.4 kN·s/m^4). Similar results were proved by the inverse method which provided values differing by up to 10% from the experimental ones. Additionally, the slight difference in tortuosity indicates that the fiber network created more direct and longer air channels, while the polyurethane foam, with smaller and more irregularly distributed pores, resulted in a more tortuous path. As will be better explained later, the difference in the predicted viscous characteristic lengths Λ implied different viscous dissipation phenomena, leading to different absorption performances.

Table 1. Experimentally measured parameters for characterizing the microstructure of TW and PUR samples.

	Experimental		Theoretical	
	PUR	TW	PUR	TW
ε [-]	0.96	0.92	0.96	0.92
σ [N·s/m^4]	2700	17400	2800	19200
τ [-]	-	-	1.27	1.00
Λ [m]	-	-	1.6×10^{-4}	5.1×10^{-5}
Λ' [m]	-	-	2.5×10^{-4}	1.3×10^{-4}
k_0 [m^2]	-	-	1.1×10^{-8}	2.1×10^{-9}

Figure 2 shows the normal incidence sound absorption behavior of TW and PUR samples, with α coefficients plotted in one-third octave bands from 100 Hz to 5000 Hz. Both curves exhibited a typical porous sound absorption trend, with low α values at low frequencies, increasing sharply in the mid-to-high frequency range. Up to 315 Hz, the two measuredcurves were almost overlapped. From 400 Hz onward, TW exhibited greater absorption, reaching a peak at 1600 Hz (α = 1), followed by a drop at 2500 Hz (α = 0.9). The PUR sample showed two peaks: one less pronounced at 1600 Hz with α around 0.8, and the other at 4000 Hz with α exceeding 0.9. The two peaks were separated by a drop at 2000 Hz, with α at 0.7. The differences in absorption ability between the two materials were not only due to thickness (4 cm for TW and 5 cm for PUR), which mainly shifts the peaks in frequency. In fact, the materials microstructures played a key role, influencing the viscous and thermal dissipation phenomena, and resulting in varying absorption abilities of TW and PUR materials. However, further research is ongoing.

The theoretical JCAL model accurately predicted the sound absorption behaviour of the two materials, performing curves closely matching the experimental ones at the peak and drop positions.

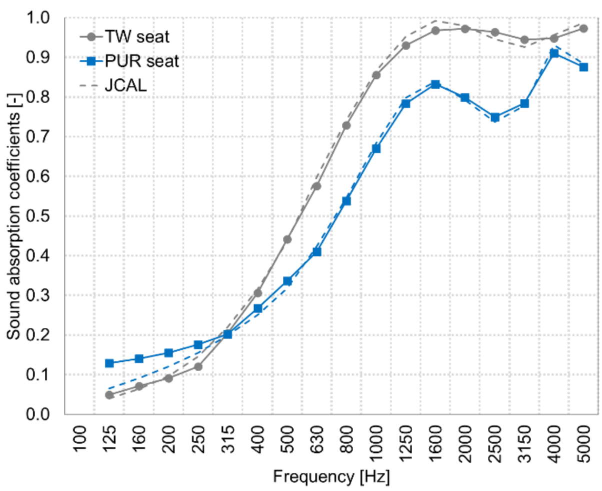

Figure 2. Comparison between normal incidence sound absorption coefficients experimentally measured and theoretically predicted for TW (4 cm thick) and PUR (5 cm thick) mats.

5.2 Characterization of armchairs

Figure 3 shows the equivalent sound absorption area A measured for TW and PUR seat. The curves are plotted in one third octave band, with center frequencies from 100 to 5000 Hz. The curves, averaged from measurements at three seat positions, reveal that the TW seat consistently showed higher A values than the PUR seat, across the entire frequency range.The difference between the two curves was about 0.5, reaching a value of about 0.2 in the low and high frequency ranges, up to 200 Hz and starting from 3150 Hz. The trend observed for the two curves could be expected, considering the normal incidence sound absorption behaviour measured in the impedance tube.

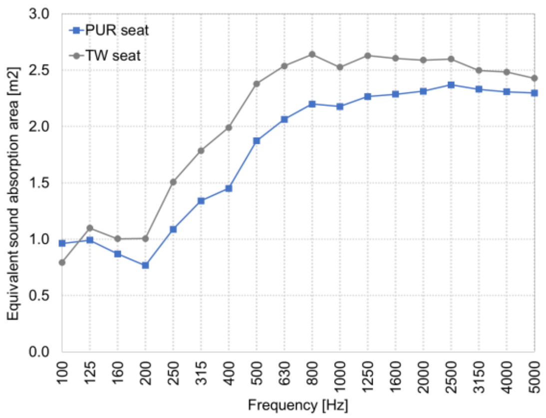

Figure 2. Comparison between equivalent sound absorption area A experimentally measured for TW and PUR materials.

6. CONCLUSION

This study examines the possibility of creating an industrial symbiosis between the textile and furniture industries, focusing on repurposing textile waste as secondary raw materials to replace polyurethane foam in armchair padding. A prototype armchair made from textile waste was developed, and its sound absorption characteristics were tested. The experimental results showed that the textile waste seat was more effective than the polyurethane foam seat in absorbing random incidence sound, improving overall user experience in indoor spaces.

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