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Textiles In Architectural Acoustic Conditioning: A Review

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Environmental noise is a problem of increasing interest in advanced societies. Different types of textiles have properties which are suitable for the construction of elements able to condition sound in rooms. The use of these elements can foster acoustic comfort in all kind of rooms, both public and private. This work is a review of the possibilities and trends of textile materials in the field of acoustic conditioning.

The use of textile materials for acoustic conditioning is widely extended. On the other hand, many efforts have been done in the last decades to understand the sound absorption mechanisms and to design materials and devices able to customize the sound space. Many of these new developments have used materials like wood, metal, plastic. Textiles can be thought as fully designable materials and potential base of composites, providing their unique technical and aesthetical characteristics to any ensemble.

Keywords: *Noise, sound, acoustic conditioning, acoustic comfort, textile, fabrics, nonwoven.*

1. Introduction

Sound is produced when a solid element transmits a vibration to the air molecules close to it and a pressure wave is generated and transmitted through the air particles. These pressure waves, called sound waves are perceptible by the human ear when their frequencies are between approximately 20 Hz and 20 kHz. The frequency response of hearing is most sensitive in the speech frequency range, between 2 and 3 kHz [1]. In the standard ISO 226:2003 [2] there are some curves that show combinations of pure tones in terms of frequency and sound pressure level, which are perceived as equally loud by the human auditory system. In these curves the different sensitivity of the ear depending on the frequency of the sound is shown. At medium frequencies, the sensibility is high and at lower and higher frequencies it is low [3,4].

Sound is a spherical pressure wave. It can be transmitted, reflected or absorbed to a greater or lesser percentage, and arrives to the receiver from various directions, forming the diffuse sound field. Room acoustics enables to achieve acoustic comfort by means of actions on the structures forming rooms like walls, ceiling and floor. In figure 1 functions of room acoustics are shown.

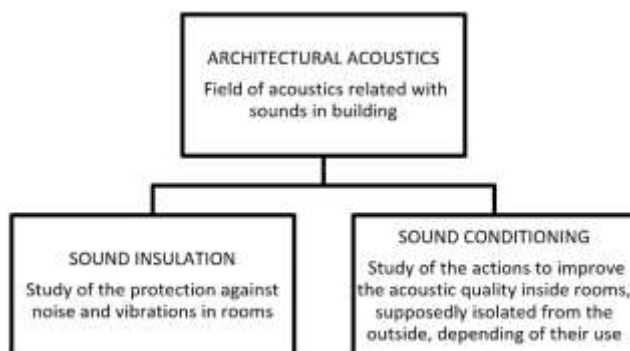


Figure 1. Functions of architectural acoustics [5-7].

Acoustic isolation avoids sounds to exit from the room or to enter from the outside.

Standards for building acoustics isolation are becoming more restrictive and there is a trend towards a common framework through Europe [8].

Acoustic conditioning seeks the distribution of the reflected energy as a function of time and frequency, given the intended use of the room. If all surfaces in a room are acoustically reflective, the amplitude of the acoustic waves increases at the room resonance frequencies, which depend on the dimensions and geometry of the room, producing the reverberation effect. The parameter used to control the reverberation resonances in the room is the reverberation time, usually defined as the length of time in which sound decays a certain number of decibels.

The function of sound conditioning is usually associated with architecture, but it is also important in the transport field.

2. Sound Absorption

Many materials in different configurations can be used as acoustic absorbers, as shown in figure 2. The dash line boxes show the modification of the original classification made by the authors.

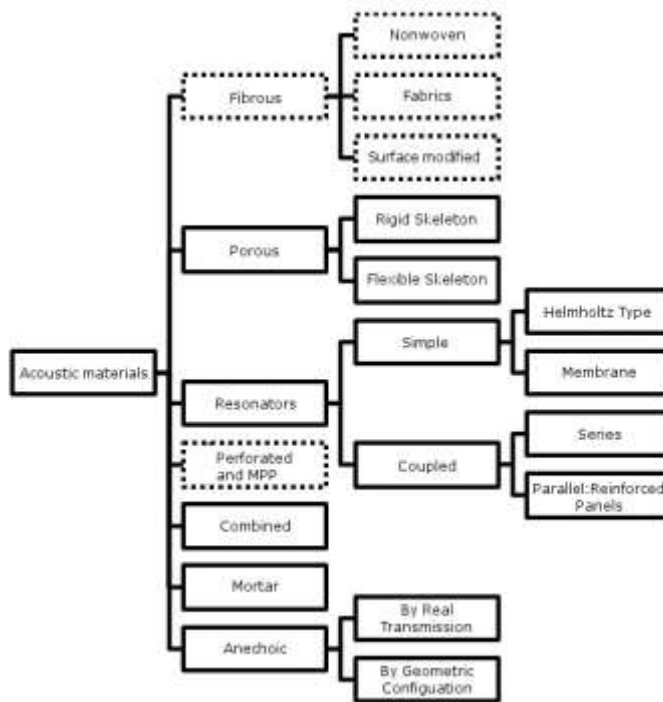


Figure 2. Scheme of acoustic absorbent materials. Source: [9] modified by authors.

Sound absorbers transform sound energy into another energy. Porous and fibrous materials transform energy mainly in heat, due to viscous processes. The sound wave produces vibration, the air contained in open pores or among fibres, vibrates, producing friction against the fibre surface and dissipation of the sound waves energy, transformed in heat. There are also losses due to thermal conduction. The place in the room where the porous or fibrous absorber is placed is important.

Another way to transform sound energy into mechanical energy is by means of resonators [10]. Regarding membrane resonators, the sound wave transmits its energy to a non-porous and flexible plate, which vibrates and dissipates energy by the internal friction of its particles.

Instead of using a solid material like fibres or a membrane, it is possible to take advantage from the vibration of air. An element used for sound absorption is the

Helmholtz resonator. It is formed by a cavity with a neck which is connected to the exterior. This mechanism uses the spring-mass effect: the air in the neck acts like a mass, and the air of the cavity acts like the spring. A peak of absorption is obtained at the resonance frequency. The walls of the cavity dissipate vibrations by friction. The absorption in this case presents a very narrow curve, centred at the resonance frequency. Its advantage is its capacity to absorb at low frequencies.

An associated resonators system can be obtained with a micro perforated panel. This sort of acoustic absorption device was described by Maa [11] and refined subsequently. A micro perforated panel is made of a fine plate of material like metal, plastic, etc. in which many little holes are drilled. The size of the perforation is sub millimetre and an air gap is left at the back of it. The small size of perforation increases the resistance of the panel to the sound passing through, generating energy losses by frictional effects.

It is possible to widen the range of absorbed frequencies of resonators by different techniques, like for instance installing arrays of resonators tuned at different frequencies or placing porous material in the cavity.

Recently some efforts are performed to obtain new materials, they are called metamaterials. These materials are characterized by effective properties [12,13]. They are usually made by a periodic array of local resonators with a subwavelength scale pattern. Metamaterials can be obtained [14] by using different type of resonators. It is an innovative field and there is an increasing interest on it, with new studies and researches appearing every day [15-19].

The sound absorption coefficient α is used to characterize the response in frequency of the plane absorbing systems. It is a dimensionless magnitude defined as the ratio of sound energy absorbed to the total incident energy. The absorbing response of a certain

material can be defined for normal or diffuse incidence, being obtained by measurements according to standard procedures. Some methods need a reverberation chamber, as the one described in ISO 354: [20]. This method is based in the fact that acoustic materials receive waves from different angles, randomly.

Other methods use the acoustic impedance tube method, at normal incidence, as the one described in ISO 10534-2 [21]. This is one of the most widely used methods for acoustic characterization of materials [22-26] as it needs a small sample size. Plane waves are generated in the tube by the sound source, and the pressure in two near positions is measured. The sound absorption coefficient for normal incidence α can be obtained by the equation 1:

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

Where:

r is the normal incidence reflection coefficient, obtained by equation 2.

$$r = \frac{H_{12} - H_i}{H_R - H_{12}} \cdot e^{2 \cdot j \cdot k_0 \cdot x_1} \quad (2)$$

Where:

H_{12} = complex transference function,

H_R = transference function from the reflected wave,

k_0 = complex wavenumber

x_1 = distance between sample and microphone.

Another parameter directly related to the reflection coefficient is the specific acoustic impedance Z , which shows how the surface of a material behaves against the sound pressure. It is obtained by equation 3. The higher the acoustic impedance, the lower the acoustic absorption.

$$Z = \frac{1+r}{1-r} \quad (3)$$

The sound absorption coefficient is represented as a function of frequency. Figure 3 shows different values of absorption of a 45 mm polyester nonwoven from 400 to 4000 Hz. A value of 1 would mean that the material absorbs all the acoustic energy.

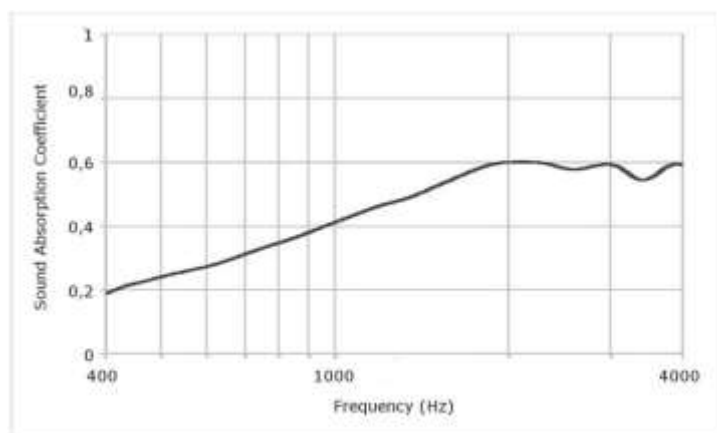


Figure 3. Sound absorption coefficients of a 45mm thick polyester nonwoven. Source:

Authors measurement

3. Textile materials in room acoustics

Since ancient times, textiles have had more functions than just decorative. They have been used as a barrier against light, or as thermal isolation elements. For instance, the Pazyryk carpet (400 a. C.) currently in the Hermitage museum in Saint Petersburg was used by central Asia nomadic tribes in their tents. Nowadays, the acoustic properties of textile products are well known [27-33].

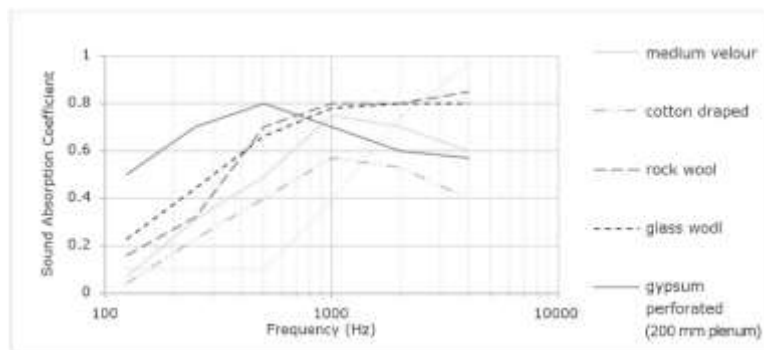


Figure 4. Sound absorption coefficients of various materials. Authors elaboration from different sources.

The effect of sound absorption of a textile material is related to its location and the covered surface area in the room. The textile can be placed directly on the room boundaries, or as a part of upholstered furniture and decorations, producing acoustic absorption and influencing the room acoustic conditioning.

On the other hand, a textile layer can be placed near the room surfaces with an air gap or plenum, like curtains. In this case, the maximum absorption takes place at a frequency for which the distance to the wall is a quarter of its wavelength. As the distance is increased, the frequency at which the absorption is maximum, decreases.

3.1 Nonwovens

Nonwovens are produced in roll or panels, and can be made of different kind of fibres [34]: mineral like stone and glass wool, ceramic and graphite; vegetal like cotton, hemp, kenaf, wood, etc.; animal like wool; and synthetic cellulosic like bamboo or polymeric like polyester, polypropylene, para-aramid, etc.

There are numerous studies of nonwovens in the form of waddings or “wools”. The purpose of many of them is to find a propagation model in the fibrous sound absorbers, existing two options [35]: macroscopic models Delany and Bazley [36], Garai and Pompoli [37] and micro structural models. Microstructural methods have evolved since those based on a rigid frame like Johnson et al. [38], Champoux et al. [39,40], Allard et al. [41-43], Kino and Ueno [44]. On the other hand there are some proposed models that take into account the elastic frame of the material like Biot [45,46], Shoshani and Yakubov [47-49].

Some existing works describe acoustic properties of nonwovens made of different natural fibres, like cashmere, down, kenaf, kapok, milkweed and oil palm empty fruit bunch fibres, jute [50-58] etc. These studies demonstrate that sound absorption coefficients near to 1 can be achieved between 1000 and 6000 Hz using nonwovens made of natural fibres.

The use of nonwovens based on rayon and cotton precursors, after carbonized and activated can provide a sound absorption coefficient near 0,8 with good absorption between 500 and 7000 Hz [50,60].

3.2 Knitted fabrics

Knitted fabrics are obtained by forming loops when interlacing yarns. There are different processes to form these loops: warp knit and weft knit.

Warp knit fabrics

In the field of textile technical applications, warp knitting technology has advantages like the possibility to obtain numerous layers of different materials in a single fabric, great dimensional stability and different possible thicknesses, as well as the production of multiaxial fabrics.

Mesh fabrics have a structure that may resemble partially to the acoustic absorption behaviour of a micro perforated panel, with the advantage of lightweight. Liu and Hu studied multi-layered warp and weft knitted fabrics [61]. It is possible to obtain a sound absorption coefficient around 0,8 in the frequency range between 1000 and 6000 Hz with eight layers. Chen and Long [62] varied parameters of the warp knitted fabric like thickness, inclination and diameter of the spacer yarn and surface layer structure, obtaining values of sound absorption coefficient over 0,5 at frequencies above 3000 Hz with one layer of fabric.

3.3 Weft knit fabrics

Dias and Monaragala [63] measured the sound absorption of simple and double weft knitted fabrics and compare these measurements with a theoretical model, obtaining sound absorption coefficients over 0,1 and 0,15 at frequencies above 2500 Hz with a maximum thickness of 3,1 mm.

Woven fabrics

Woven fabrics are used as materials for covering other acoustic materials, due to their aesthetic properties. Various studies have been carried out on the acoustic properties of different woven fabrics in order to find a model that explains their acoustic absorption. These models show that a woven fabric with an air gap present a behavior analogue to a resonator, with an acoustic absorption curve with peaks up to 0,9 at

different frequencies between 250 and 4000 Hz. Shoshani and Rosenhouse [64] investigated the relation between noise absorption coefficients of a woven fabric cover and its intrinsic parameters like content of fibres, yarn count, cover factor, air gap behind the fabric, and how the effect of the cleaning process affects the sound absorption capacity of the fabric. Kang and Fuchs [65] introduced a model which combines membrane and micro perforated panels, mounting up to two layers of glass fibre fabric at 0,1m from a rigid wall. Pieren [66] studied simple fabrics with an air gap, obtaining a model for oblique sound absorption coefficient suitable for fine fabrics plus an air gap, using the air flow resistivity and the areal surface of the fabric. The theoretical model simulates accurately the experimental results.

In the field of acoustic woven fabrics there are some studies based on experimental measurements of physical structural properties like thickness, air gap, porosity, density, yarn regularity and fineness, among others. These studies show the importance of certain fabric structure parameters and the air gap, in the acoustic absorption coefficient. The results agree with those obtained with the theoretical model presented above.

Hanna and Kandil [67] studied the effect of an air gap behind and between the layers of a double fabric curtain. Both layers were separated by a layer of air which was varied in order to increase effectiveness. Soltani and Zerrebini [68,69] verified the influence of porosity, fabric density, fabric thickness, weft thread fineness and twist, yarn irregularity and floats length, in the sound absorption coefficient of the fabric. Na et al [70] measured the sound absorption coefficient of different microfiber fabrics obtaining higher values than those of conventional fabrics.

3.4 Combination of fabric and nonwoven

The use of porous materials like mineral wools shows some drawbacks like the

difficulty in handling and the possibility of inhalation of detached fibres. One way to solve this problem is to cover the mineral wool with a layer of fabric. This layer can modify the sound absorption coefficient of the ensemble. Shoshani [71] studied the possibility that the lining fabric had some effect on the absorption. The result of the work showed that the absorption of the compound structure is significantly higher to that of the nonwoven fabrics by themselves. The highest sound absorption was achieved when the fabric layer was placed the nearest to the sound source. In that case, the most significant contribution of the fabric to the sound absorption of the compound structure was between 20 to 40% in frequencies below 500 Hz. Chevillotte [72] employed a resistive layer or a perforated plate before a porous material. The resistive layer of glass fibre fabric can be used to improve the sound absorption, but it can reduce this absorption at some frequencies. Sound absorption coefficient over 0,5 is obtained in the frequency range between 700 and 4000 Hz. Segura et al. [73,74] studied the use of different fabrics as acoustic resistive layers over a polyester nonwoven and studied the influence of the fabric thread density concluding that it is possible to improve the acoustic absorption characteristics of the compound structure by choosing the appropriate combination of warp and weft count. Figure 5 shows the influence in the sound absorption coefficients of fabrics with different thread densities when placed on a nonwoven layer. In this figure, a 15 mm thick polyester nonwoven (which sound absorption coefficient is plotted in a dotted line at the bottom of the image) is covered by a plane weave fabric with different warp (W) and weft (P) densities in yarns/cm. The absorption of the two layered material is modified by changing the count of the fabric.

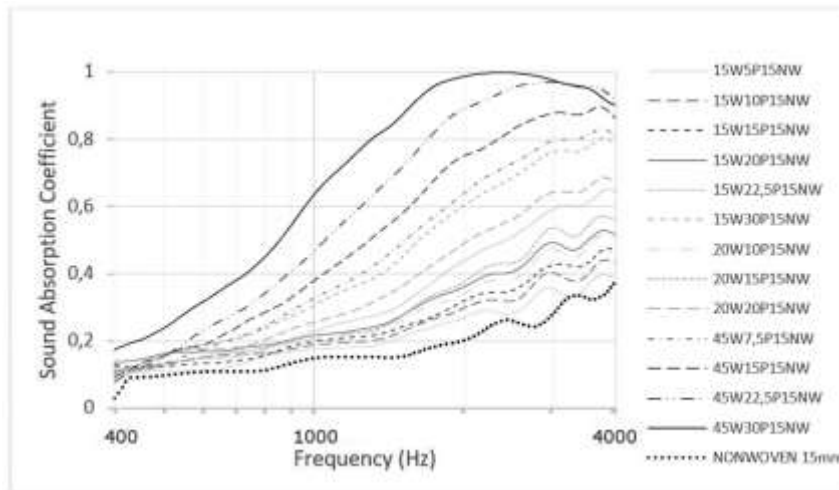


Figure 5. Sound absorption coefficient of a 15mm layer of polyester nonwoven plus a plain weave fabric of different warp and weft densities. Source: Authors own measurements.

Another possibility is the use of nanofibres to improve the acoustic properties of other textile structure, like in the work of Na et al. [75] who studied the effect of nanofibres veil layers placed over regular weft knitted fabrics. The effect of nanofibres increases the sound absorption coefficient up to a maximum of 0,9, between 1000 and 4000 Hz, when increasing the number of veils.

4. Conclusions

This review shows the different researches and trends in the use of textiles for acoustical conditioning. The possibilities to use textile materials as acoustic absorber are multiple, as seen along this article. Their advantages over traditional acoustic materials are mainly based on the possibility of designing and manufacturing structured materials from microscopic to macroscopic scale.

Summarizing, the research trends in textiles for sound absorption are based in three

areas:

- The search of new sustainable fibres. The use of recycled fibres like those obtained from PET bottles, cotton from jeans, jute from coffee or rice sacks. The research on eco-friendly materials, with low production costs, low density, and aesthetic value like natural fibres and crop wastes.
- The study of different woven and knitted structures. The production of two and three-dimensional structures using the nonwovens, weaving, knitting and other textile techniques. The study of different orientation of fibres.
- The development of composite materials by combining layers of different materials. Textile materials can be used in the design of new metamaterials, contributing with flexible, lightweight, thin, fully designable, and repeating structures.

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