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The use of green materials for the acoustic correction of rooms

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ABSTRACT

Green materials can be a valid alternative to traditional materials coming from the drilling of products of the chemical industry for the acoustic treatment of rooms. At the end of their useful life, they can be disposed of without damaging the environment. The use of green materials (e.g. hemp, brooms, freshwater canes or wood) can also be a valid alternative to traditional cropping systems that have become disused or unprofitable. In the present work, the values of the sound absorption coefficients of six materials obtained from the use of vegetable materials are reported. These materials were first dried and then appropriately shredded. In this way, a loose granular material was obtained, which compacted and packed inside jute covers can be used for the acoustic correction of rooms. The sound absorption coefficients were measured with the impedance tube in the frequency range 200 Hz – 2,000 Hz. The green materials analysed were cellulose, brooms, straw wood, hay, wood chips and cabuya. These materials have good sound absorption characteristics at medium frequencies, but at low frequencies, like all porous materials, the value of absorption is low.

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1. INTRODUCTION

In recent decades, the initiatives promoted at social level are showing increased concern for the conservation and care of the environment. This concern is reflected in the current legislation at European level, as can be seen in its main environmental policy instrument: the revised version of the Energy Performance of Buildings Directive 2010/31/EU and the Energy Efficiency Directive 2012/27/EU [1].

Most of the content of this regulation focuses on the building sector. The reason why this sector is in the spotlight is due to the fact that in Europe 40% of the energy consumption and 36% of the O_2 emissions are associated with buildings [2], especially to those that, due to their age, do not comply with the current European regulations [3]. The previous version of the Environmental Energy Legislation in Europe [4] proposed that new buildings should have nearly zero-energy consumption by December 2020, and public buildings by 2018. However, it seems necessary to take into account that the ecological footprint is not only produced by already built buildings, but also by all those processes involved in the production, transportation, distribution and installation of the materials and construction systems that comprise them [5].

Reducing the environmental impact of buildings may generate other positive effects in addition to the environmental ones, such as social and economic benefits, since it can improve the acoustic and thermal performance of indoor spaces, without forgetting other factors, such as structural and fire safety [6], [7].

An important aspect to take into account in the framework of the ecological impact of buildings is noise pollution. Green materials can be a valid alternative to traditional materials coming from the drilling of products of the chemical industry for the acoustic treatment of rooms. At the end of their useful life, they can be disposed of without damaging the environment. Green materials can be easily found in the countryside, including giant sweet water reeds, hemp, straw, kenaf, wood, cork and sheep wool. Therefore, the use of green materials (e.g. hemp, brooms, freshwater canes or wood) can also be a valid alternative to traditional cropping systems that have become disused or unprofitable.

Green materials are now being used in the construction and automotive industries. Furthermore, studies on the use of green materials for non-structural components of airplanes are currently being carried out in the aviation sector. Also green materials can be used to improve the acoustic comfort inside buildings, as well as to mitigate reverberation, echoes effects, reduce the transmission of noise between rooms and for the acoustic control inside rooms. They are biodegradable, recyclable, renewable, widely available and have a relatively low cost manufacturing process. So the traditional sound absorbing materials (e.g. glass wool, rock wool, polyester or polyurethane foam) can be replaced [8], [9].

Before being used in the acoustics field, green materials must be cut, dried, crushed and then put into jute sacks, so as to obtain uniform sound absorbing panels. Once materials are crushed, they have a high porosity with good thermal insulation and sound absorption properties. The sound absorption is a dissipative mechanism phenomenon and, for this reason, sound-absorbing materials should be composed of granular or fibrous materials, since pores and voids allow sound waves penetrate through them. In this way, the relative sound energy is dissipated as heat, allowing the sound absorption phenomenon to take place. Natural fibers are competitive materials thanks to their good mechanical properties, easy processing, high stability, occupational health benefits, widespread availability, low price, and low environmental impact of their production. Several authors have realized of the benefits of its used, and have developed green material panels and tested them in classrooms[10], [11].

We can find different studies on materials with low ecological footprint used for acoustic purposes: recycled materials [12]–[14], textiles [15], [16] natural fibers [7], [17], [18] and even studies on unconventional materials and their applications in the field of acoustics [19], [20].

An important tool for designers and engineers to evaluate the environmental impact of certain materials and construction systems is the life cycle assessment (LCA), defined as a technique that evaluates the environmental impact of a product or service during all the stages of its existence: extraction, production, distribution, use and end of life [21]. Despite the undoubted importance of the LCA, it is sometimes difficult to make a comparison that combines the effectiveness of the product and its environmental impact, since materials with very different acoustic or thermal behaviour cannot be measured under the same standard [5].

Consequently, the present study avoids to offer an environmental impact assessment of different materials, and chooses to continue investigating the acoustic properties of vegetable materials [8], [17], [20].

In this paper, the sound absorption coefficients were measured with the impedance tube in the frequency range of 200 Hz – 2,000 Hz. Six green materials were analysed, namely cellulose, brooms, straw wood, hay, plant litter blended with different sized wood chips, and cabuya fibres. These materials were first dried and then appropriately shredded. In this way, a loose granular material was obtained, compacted and packed inside jute covers to get the samples.

2. ACOUSTIC MEASUREMENTS

The sound absorption coefficient at normal incidence was measured according to the procedure described in the ISO 10534-2 [22]–[24].

This method allows to measure the sound absorption coefficient by using small samples. The acoustic measurements were carried out using an impedance tube (Kundt's tube), with the following features: internal diameter of 10 cm (corresponding to a lower limit of 200 Hz and an upper frequency limit of 2,000 Hz), length of 56 cm, with two ¼'' microphones. The distance between microphones is 5 cm. A broadband tone is emitted from a loudspeaker. The signal emitted is detected by the measurement microphones that is sent to the personal computer, where the value of the acoustic absorption coefficient is obtained through a dedicated software. The samples are inserted in section opposite the loudspeaker. The specimen is placed on the rigid surface of the termination of the tube closure.

To limit the effects due to the irregularities in the samples, four different measurements were taken for each sample, stirring and inserting melted material in the tube every time [25]. The resulting absorption coefficient values are the average of the four acquisitions.

Figure 1 shows the impedance tube (Kundt's tube) for the normal sound absorption coefficient measurement. In the present study, the average value of the absorption coefficients measured at normal incidence in the frequency range 200 Hz – 2,000 Hz of six green materials was obtained and analyzed.

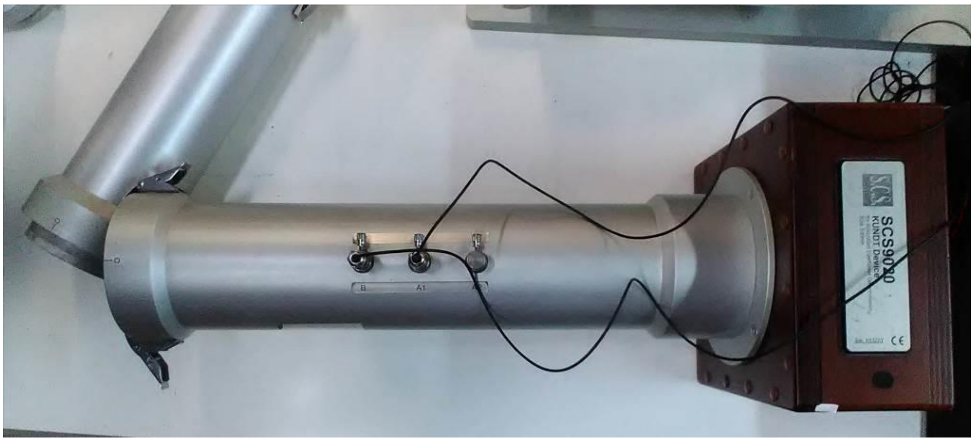

Figure 1. *Impedance tube for the measurement of the normal sound absorption coefficient. At right the loudspeaker that emitted a broadband tone.*

3. MATERIALS

The cellulose, used for the first time in buildings by the architect Thomas Jefferson in the project of the Monticello house (1800), is the oldest material used for thermal insulation in the field of construction [26]. Since then, it has been widely used as a thermal insulation material. Furthermore, recent research articles show that loose-fill cellulose materials from recycle paper have not only good acoustic isolation properties, but also good sound absorption properties (Figure 2) [26], [27].

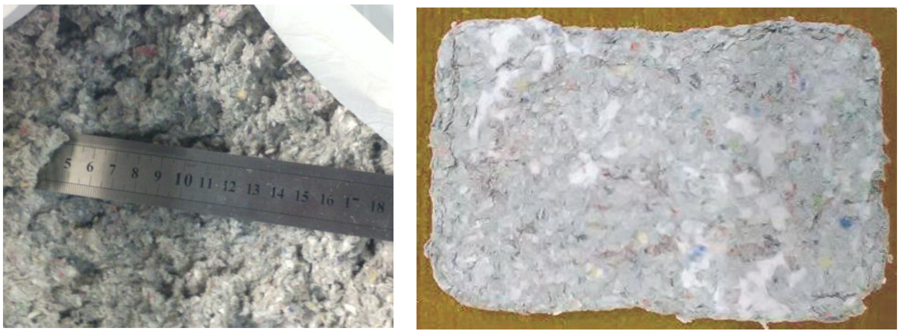

Figure 2. *Samples of cellulose material without binder (left), and with binder (right)*

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Straw is a renewable, environmentally friendly, biodegradable and completely reusable fibre. It consists mainly of a dry hollow stalk obtained by threshing. The most common variety is wheat straw, although there are other widespread varieties including rice, millet, barley, oats and rye. Straw grows through photosynthesis, using solar energy, water and minerals from the earth. It is made up of cellulose, lignin, minerals and silicates and is covered by a waterproof-waxed skin. Due to the high silicium content, it decomposes slowly, but needs to be protected from the rain and kept in a dry place to avoid mould forming. For a long time, it was considered a by-product of the agricultural chain or a aresidual of the cereal production, used in livestock farming as litter or additive for fodder, in mulching, or for visual and sound barriers for farmers' homes and fields [28]. It is also used in the papermaking industry, whilst the manufacturing industry uses this material to produce hats and bags. Although, it has been used in the building industry since ancient times, for the construction of roofs or as a clay aggregate, the bio-architecture is now re-discovering the use of this material due to its high capacity of thermal insulation, acoustic absorption and very low energy consumption. It is also durable, resistant, as well as highly fire resistant and hypoallergenic. Although it has been rarely used as a fuel, there is a new found interest in the use of straw as an alternative energy source.

Hay is derived from the cutting and subsequent drying of different types of grass destined for cattle fodder. It is green, and its smell depends on the type of grass of which it is composed (the most common are Gramineae, Leguminose, Umbelliferae and Chenopodiacee). It was used in sustainable architecture to build walls, due to its capability to adjust the temperature according to the hay cycle. It has a high insulating capacity and is frequently used as a biomass fuel. It is sustainable because it is collected more than once during the year and although the collection, packaging and transport require the use of machinery, the energy expenditure is less than any other building material.

Broom, are woody shrubs that belongs to the family Fabaceae. The wild variety grows in the Mediterranean (in Italy, it is widespread in the central and southern regions), both on the plains as well as in the mountains. They are very special plants, since they produce many very flexible stems that lose their leaves but remain green due to photosynthesis. Broom prefers very poor soils and lives for several years. There are many varieties of brooms. They grow up from 50 to 400 cm tall, with an erect, green and glabrous main stem. This shrub has a main widespread use: the fibre obtained from the stem is used for the production of ropes as well as fabrics for clothing; in the countryside, it is used to tie twigs, and in engineering, thanks to its root system, brooms are used to consolidate embankments and slopes along railways and highways. Although different studies have been carried out on broom fibres [29], [30], but there is little research on their acoustic characteristics [31]. Wood is the plant tissue constituting the roots, trunk and branches of the plants. It is composed of cellulose fibres bonded by lignin, which confers it strength, elasticity and robustness.

Figure 3. *Photographs of the samples of vegetable fibres.*

It is a completely biodegradable, recyclable, natural and renewable material, used since ancient times to build houses. It requires a limited energy consumption during its production and installation, and does not release emissions, dust or harmful fibres during its use. Deforestation is one of the collateral effects of its wide use. However, this problem may be mitigated thanks to reuse policies. The reuse processes can involve both the waste produced, such as: scrap, wood chips, sawdust (pre-consumer recycled wood), as well as other products that at the end of their use should be landfilled (post-consumer recycled wood). In this study, chestnut and poplar wood production waste (chips of various size), and plant litter (plant material, such as leaves, bark, needles, and twigs, fallen to the ground, widely available in the environment as waste from the cleaning of forests, gardens and green spaces) were used. This material is usually disposed of through burning, incineration or landfilling processes. Agave sislana is a species of agave that is cultivated in many different countries. Also called cabuya, was already used by the Aztecs and the Mayans to make fabrics and paper. Approximately 1000 fibres can be obtained from each leave, and each plant produces about 200 leaves during its useful life. Although it has traditionally been harvest to make strings, nowadays it is also used in the composition of textiles, and is replacing fiberglass in the automobile sector [32].

4. ANALYSIS AND RESULTS

Following the procedure explained in Section 2, the absorption of the samples of the vegetable materials under study were obtained (Figures 2 and 3). Two different types of samples of the cellulose materials were used for the acoustic measurements. The first type of material used is the loose-fill cellulose: this material is produced directly from the processing of the recycled newspapers. Figure 3 shows two different thickness of the shredded loose material (50 mm and 100 mm), and their corresponding values of the absorption coefficient. Values of the absorption coefficient are very high, especially over the frequency of 500 Hz. At frequencies lower than 500 Hz, the material loses part of its capacity to absorb sound, as is often the case of porous materials. Even if the thickness is doubled (from 50 mm to 100 mm) the value of the absorption coefficient at low frequencies is always low. There might be a problem with the use of this material in construction, as their particles are loose. Therefore, the loose materials were mixed with a binder to get a rigid material suitable for its use as an acoustic absorbent in the construction field. In this way, the material has a rigid skeleton, so it can be employed with greater simplicity. The first graphic of Figure 5 shows two different thickness of the cellulose material with rigid skeleton (50 mm and 100 mm), and the corresponding values of absorption coefficient measured. As expected, the values of the absorption coefficient with the rigid skeleton structure are lower. But, in any case, they are greater than 0.5 for the thickness of 50 mm and greater than 0.7 for the thickness of 100 mm. For both types of materials, cellulose has proven to be a good solution for absorbing sound in a simple, economic and environmentally friendly way. Figure 5 shows the sound absorption coefficient for different thicknesses of the samples studied. The sound absorption coefficients over 1500 Hz is normally higher for the samples with thicknesses over 100 mm for all the materials studied. The samples of straw and broom with 120 mm show a reduction of their sound absorption capabilities in a range between 750 Hz and 1500 Hz. A similar but less pronounced behaviour can be appreciated in the absorption coefficients of the sample of 120 mm of hay. Sound absorption at low frequencies is higher for the higher thicknesses samples for all the materials under study. Cellulose present very good acoustic absorption coefficients at frequencies below 750 Hz, and a more stable absorption behaviour in the whole range of frequencies in comparison with the rest of materials. Table 1 shows the density of the tested materials, and, as can be appreciated, the cellulose is the material with the highest density.

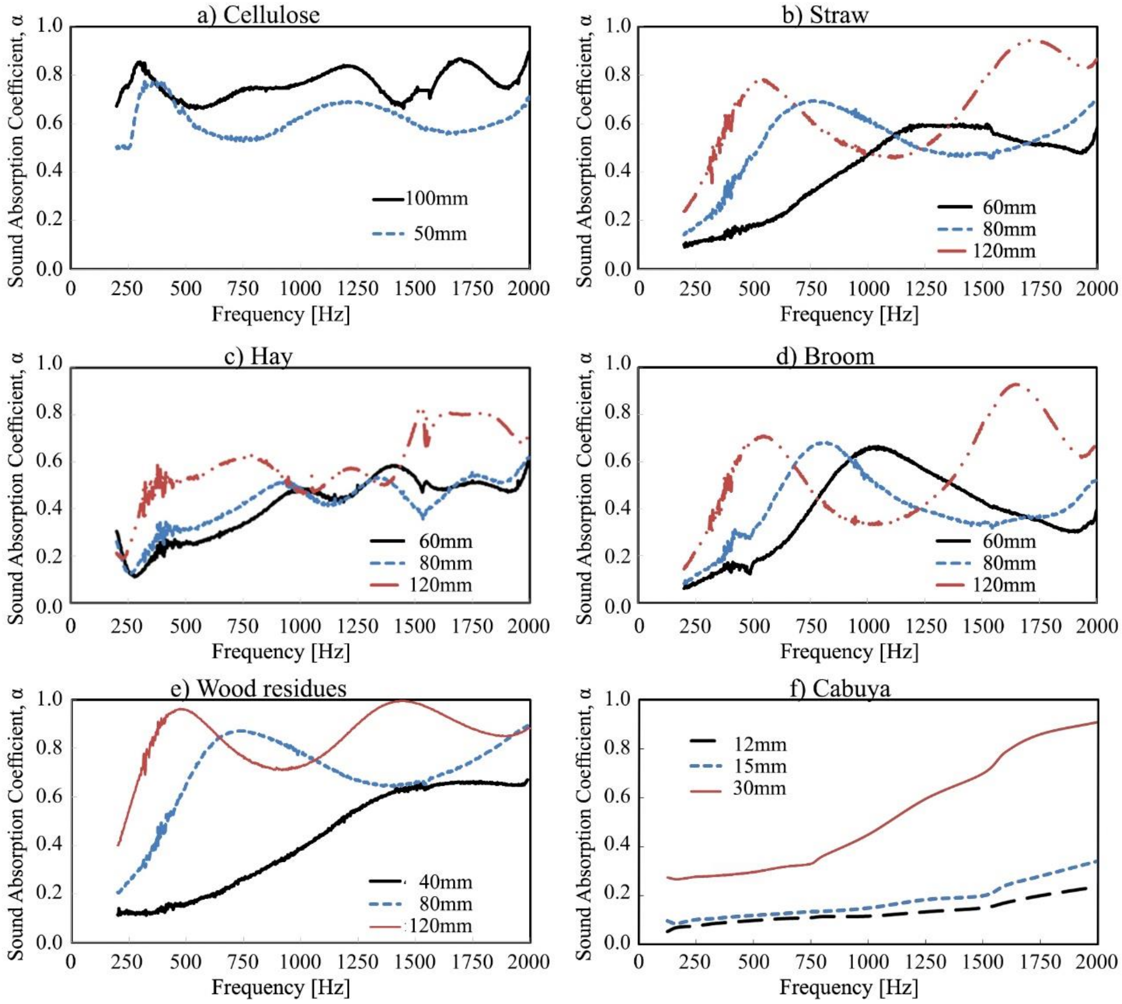

Figure 5. *Absorption coefficients of the samples under (cellulose, straw, hay, broom, hay, wood residues and cabuya) study for different thicknesses of the material.*

Table 1: Density of the tested materials.

Material	Density (kg/m^3)
cellulose	250
straw	35
hay	35
broom	180
poplar wood chips	200
cabuya	97

The materials tested have good absorption coefficient values at the medium and high frequencies. These materials can be used to replace traditional absorbent materials such as polyurethane, foam or PET [10], [31], [33].

4. CONCLUSIONS

The purpose of this study is to analyze the acoustic absorption of different materials produced with vegetable materials and natural binders. The materials studied have shown good sound absorption characteristics at medium and high frequencies, but at low frequencies, like all porous materials, the value of absorption is low. The material presents a better performance in the whole range of frequencies is the cellulose. Therefore, at lower frequencies these materials, like traditional ones (polyester, foam or PET) generally do not have good absorbent frequency values. To increase the absorption at low frequencies, thin cork panels with a thickness of 1.5mm or sheep wool fabric can be used. These materials, when mounted at an appropriate distance from a rear rigid wall, can absorb sounds at frequencies depending on the depth of the rear recess: if the cavity increases, the sound field is absorbed at low frequencies; if the cavity is reduced, the sound absorption moves to the high frequencies. The wide availability of the materials reduces the production and enforcement cost of the panels. However, the most important factor is that these materials are completely recyclable.

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