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Editorial

Sustainable Acoustic Materials

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Abstract: Technological advances in materials science, manufacturing processes, chemistry and nanoscience have led to enormous developments in innovatively engineered materials over recent decades. Among them, sustainable acoustic materials have helped to improve acoustical comfort in built environments, and their use is rapidly growing in the architecture, automotive, aerospace and construction industries. These materials are manufactured through a responsible interaction with the environment in order to avoid a depletion or degradation of the natural resources, and to allow for long-term environmental quality. This Special Issue reports on some research studies on membrane absorbers and fibrous materials of natural origin that can be sustainable alternatives to traditional acoustic materials.

Keywords: sustainable materials; sound-absorption; natural fibers; acoustic materials; recycled and recyclable materials; membrane absorbers; nanofibers

1. Introduction

Although the term is complex, and several definitions of 'sustainability' can be found in the literature, the report presented by the World Commission on Environment and Development to the United Nations General Assembly in 1987 stated that the use of resources and the development of technologies should "meet the needs of the present without compromising the ability of future generations to meet their own needs" [1]. Therefore, every manufactured material for use in the built environment should fulfill this definition.

Public awareness and concern about environmental issues has led to the development of several initiatives, such as the concept of green building materials being used in practice in several countries. This has also been considered for local construction recommendations and building regulations, favoring the use of environmentally-friendly materials, less contaminating processes and recycled products.

The purpose of this Special Issue is to report on recent research and development findings in the field of sustainable acoustic materials, also called eco-materials. Acoustic materials come in a variety of forms to provide sound-absorption, insulation and vibration damping. These environmentally-friendly materials are manufactured through a responsible interaction with the environment, to avoid the depletion or degradation of natural resources and to allow for long-term environmental quality.

2. Sustainable Materials

Sustainable materials is a broad topic, and the answer to the question of what sustainable materials are is not simple. However, it is reasonable to consider several intrinsic characteristics in order to assess how sustainable a particular material is. These characteristics include the material's function during its whole life-cycle, its performance, availability and regeneration time, the environmental impacts of its manufacturing process, the net water and energy consumed during its production, the generated waste material, what the material takes from the environment to operate, the safe and healthy conditions of the people involved in its production and delivery, its durability, and its post-service life effects [2].

There are many criteria to consider in the selection of a sustainable material. However, it has been made apparent that sustainable materials are related to the following criteria: resource efficiency, energy efficiency and pollution prevention [3]. One way to accurately measure the sustainability characteristics of newly developed materials has been the use of life-cycle assessment (LCA). This analysis considers the environmental aspects and potential impacts associated with a product, process or service. LCA analyses have also led to indicators that express the total environmental load related to a material [4]. LCA procedures have indicated that the production of sustainable materials creates a lower environmental impact than conventional ones.

In the last few decades, innovative engineered materials have undergone enormous developments due to recent technological advances in materials science, manufacturing processes, chemistry and nanoscience. The interest in sustainable acoustic materials is rapidly growing in several sectors, such as the architecture, automotive, aerospace and construction industries. Examples of sustainable materials in these sectors are those using a circular design, i.e., transforming demolition debris or waste into new materials that can be used in construction again. The circular design has not only environmental benefits, but also permits economic savings by eliminating the expensive processes involved in treating these residues and reducing the energy consumption of their disposal.

3. Sound-Absorbing Materials

Acoustical quality and comfort are also now being considered in sustainable built environments. A lack of acoustical considerations in the design of both indoor and outdoor spaces could produce problems for the users of these spaces, including hearing loss and several non-hearing-related disorders. Sound-absorbing materials have been commonly used to improve acoustical comfort in built environments. These materials can absorb sound energy in order to reduce reverberation and sound levels in closed spaces. Although an acoustic material can be made of a single constituting material, most acoustic materials are described as composites. A composite material is obtained from the combination of at least two different materials with significantly different physical or chemical properties that, when combined, attain properties different from the individual components.

Acoustic materials use different mechanisms to provide sound-absorption. Membrane absorbers use the energy dissipated by the vibration of a usually thin membrane or panel backed by an air cavity, which may be filled with a fibrous material. Membranes are rather classical materials for acoustical purposes, and they have been used for sound reflection, absorption and insulation [5,6]. Membranes can be either impervious (impermeable) or contain small perforations (permeable). However, materials with significant sound-absorption properties are usually porous, having a solid phase and a fluid phase. These materials contain cavities, channels or interstices to produce open, interconnected pores. The incident sound energy is converted into heat at the wall of the interior pores via the thermal and viscous loss of air molecules.

One particular type of porous material is the fibrous one. This type of material is composed of an assembly of continuous filaments that trap air between them. As the sound waves travel through the material, the fibers rub together and lose energy due to the work done by the frictional forces [7].

In the past, asbestos-based materials were commonly used in acoustical applications. However, after reports linked asbestos fibers with potential human health hazards, the manufacturing industry moved to the production of other mineral-based fibrous materials, the most common being made from glass and rock wool fibers. Considering the high energy demand of these fibers during their manufacturing process, and the difficulties involved in their safe disposal at the end of their service life, ecologically-friendly substitute materials have been the focus of recent research [7]. Thus, research into producing alternative materials that can often be stronger, lighter, less expensive and environmentally superior to traditional materials has become very important.

4. Sustainable Alternatives

For better sustainability, several acoustic materials have been developed by using recycled materials and natural fibers. Many acoustic materials are also recyclable.

Research on the use of eco-materials elaborated from residues, from industrial plants or processes, has received much attention. These have included studies on the acoustical properties of materials made of ground polyurethane foam, expanded polystyrene, agricultural residues, used paper and cardboard, rubber from tires and carpet and textile wastes [4]. Some of these alternative materials have shown excellent acoustical properties, and their commercial production can be a solution for the disposal of these materials, preventing them from going to landfills or incinerators.

The use of natural materials instead of non-degradable synthetic ones has contributed to achieving the better sustainability of buildings. The intensive growing of these materials can also help to reduce our impact on climate change. In the past, many natural materials have been developed and tested for acoustical applications. Most of them are related to the use of natural fibers as a source of raw material to produce porous sound-absorbing materials. These natural fibers exhibit many advantages compared with synthetic fibers, such as biodegradability, safety, light weight and low costs. Several studies have been presented on this topic [4].

5. Contributions of the Special Issue

Polymers have been widely used to manufacture sound-absorbing materials. Common petroleum-based polymeric materials are certainly not biodegradable, but they can be sustainable; however, non-petroleum-based polymers can be both. Most commercially produced sustainable polymers are made from starch-containing plants (e.g., corn or sugarcane) and seed oils (e.g., soybean or other vegetable oils). Polymers made from non-food source materials, such as trees (lignin), switchgrass and agricultural waste products, have received much attention. Polylactic acid (PLA), although not fully recyclable at present, is the most commonly used sustainable polymer. Many natural polymers, such as rubber, lignin and humus, biodegrade via an oxidative mechanism, and consequently much of nature's biological waste cannot satisfy the rapid mineralization criteria currently encouraged by standards committees for synthetic polymers [8]. However, the polymers made from renewable natural resources are not necessarily eco-efficient. For example, cellulose-based polymers use more non-renewable fossil fuels, and are more contaminating during manufacture than petroleum-based polymers.

One of the most promising areas for producing sound-absorbing fibrous materials is the use of nanofibers, which are mainly made from polymeric materials. During the process, the polymeric solution/melt is extruded, drawn, or split into very fine fibers using external chemical or physical methods. In [9], the authors have characterized the nanofibrous membranes used to coat three porous bulk acoustic materials. The nanofibrous membranes were made from recyclable Polyamide 6 (PA6) and water-soluble polyvinyl alcohol (PVA), using a needleless electrospinning technique. The membranes were collected in a high-permeability non-woven substrate. The resulting very thin membranes exhibited high porosity and very high airflow resistivity. The experimental results showed significant improvements in the sound-absorption performance of the bulk materials after incorporating the nanofibrous layer.

This Special Issue also includes two contributions dealing with permeable membrane absorbers. Impermeable membrane-type absorbers can absorb mainly low-frequency sounds through resonance. This type of material can also be used as a sustainable alternative to classical materials. On the other hand, permeable membranes (PMs) are woven and non-woven textiles, and lightly resin-coated textiles. They are highly recyclable when produced from the appropriate material. They absorb sound energy via their airflow resistances, so they can exhibit sound-absorption characteristics similar to those of traditional porous and fibrous types. However, PMs are mainly effective for middle to high frequencies, but when their airflow resistance is optimized, they can show a high sound-absorption performance. Considering the strength of a PM, which is usually limp, it is better to use it as a space absorber suspended from ceilings.

Toyoda et al. [10] presented the numerical prediction of the sound-absorption characteristics of a three-dimensional space sound-absorber with PMs, in both cylindrical and rectangular forms. The method uses the boundary element method (BEM), with the mirror image of the absorber. Via the proposed method, a reasonably accurate prediction was possible. The idea of three-dimensional space PM absorbers (3D-PMAs) was later developed with a paper folding technique [11], which adds more aesthetic value to the material. Another paper [12] approached the more basic considerations relevant to the ability of PMs to be used as a space absorber. In this paper, the planar rectangular space absorber, which is a rectangular PM just suspended from the ceiling, was tested in a reverberation chamber, and the resulting diffuse-field sound-absorption coefficients were compared with the theoretical results [13]. The measured value was found to be higher than the theoretical value, which was mainly attributed to the effect of the area.

An important technical concern regarding the development of materials based on natural fibers is the prediction of their sound-absorption properties. Since, in general, most natural materials exhibit high inhomogeneity, the use of an equivalent-fluid approach based on empirical coefficients has been explored by several researchers in order to predict the acoustical performance of these kinds of fibers. These formulae only require knowledge of the airflow resistivity of the fibrous material. However, each material has its own microstructure, so the method requires the determination of the unique empirical coefficients for each type of natural material, which is usually made by inverse methods [14] or best-fit numerical procedures [15].

In [16], the sound-absorption properties of raw esparto grass fiber were examined as an environmentally-friendly material. The sound-absorption coefficients and airflow resistivities were measured for three different types of pure, raw and dry esparto originating from Pakistan, Tunisia and Egypt. Using these results, the authors reported best-fit coefficients for the reasonable prediction of the sound-absorption performance by means of a simple empirical formula. The results of the sound-absorption coefficients reported for the esparto fibers were comparable to those obtained with traditional fiberglass materials of equivalent thickness. Thus, these natural fibers appear to be viable alternatives to synthetic ones in the manufacturing of sound-absorbing materials.

An alternative natural material for sound-absorbing use is presented in the contribution from Kusno et al. [17]. The authors propose the use of chicken feathers, which is a common by-product in many countries that produce poultry for human consumption or feather pillows. A unique detail of this work is that the feathers are just packed in a net container, without using a binder to consolidate the feathers. Measurements carried out in an impedance tube showed a rather high sound-absorption coefficient. The authors tried to adopt the conventional Delany–Bazley–Miki (DBM) model [18] to predict the sound-absorption of the new material. However, the measured airflow resistivity was unexpectedly low and, eventually, the predicted values using the DBM model were much lower than the measured ones. The reason why the prediction failed remains an open problem that needs further investigation. A supposition of the authors is that the higher absorption could be explained by the structure of the samples in which the feathers can vibrate, and that frictional energy loss occurred. Even so, the contribution is unique because there are limited examples of the use of a natural material of animal origin.

6. Conclusions

It is likely that the design and marketing of environmentally-friendly acoustic materials will steadily grow in the next few years. This will be supported by the increasing public awareness and concern about the negative effects of current industrial processes on our environment. Therefore, consumers are favoring eco-materials whose production has considered the efficient use of resources and energy, thus assuring pollution prevention in their manufacturing. It is expected that the research findings reported in this Special Issue on sustainable acoustic materials will be a contribution to this end.

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References

1. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
2. Cao, C. Sustainability and life assessment of high strength natural fibre composites in construction. In *Advanced High Strength Natural Fibre Composites in Construction*; Fan, M., Fu, F., Eds.; Elsevier: Duxford, Cambridge, UK, 2017; pp. 529–544.
3. Ding, G.K.C. Life cycle assessment (LCA) of sustainable building materials: An overview. In *Eco-Efficient Construction and Building Materials*; Pacheco-Torgal, F., Cabeza, L.F., Labrincha, J., de Magalhães, A., Eds.; Woodhead Publishing: Oxford, UK, 2014; pp. 38–62.
4. Arenas, J.P.; Asdrubali, F. Eco-materials with noise reduction properties. In *Handbook of Ecomaterials*; Martinez, L.M.T., Kharissova, O.V., Kharisov, B.I., Eds.; Springer: Cham, Switzerland, 2019; pp. 3031–3056.
5. Brüel, P.V. *Sound Insulation and Room Acoustics*; Chapman & Hall: London, UK, 1951; Chap. 4.
6. Ingard, K.U. *Notes on Sound Absorption Technology*; INCE: New York, NY, USA, 1996.
7. Arenas, J.P.; Crocker, M.J. Recent trends in porous sound-absorbing materials. *Sound Vib.* **2010**, *44*, 12–17.
8. Chiellini, E.; Solaro, R. *Biodegradable Polymers and Plastics*; Springer: New York, NY, USA, 2003.
9. Ulrich, T.; Arenas, J.P. Sound absorption of sustainable polymer nanofibrous thin membranes bonded to a bulk porous material. *Sustainability* **2020**, *12*, 2361. [CrossRef]
10. Toyoda, M.; Funahashi, K.; Okuzono, T.; Sakagami, K. Predicted absorption performance of cylindrical and rectangular permeable membrane space sound absorbers using the three-dimensional boundary element method. *Sustainability* **2020**, *11*, 2714. [CrossRef]
11. Sakagami, K.; Okuzono, T.; Suzuki, H.; Koyanagi, N.; Toyoda, M. Application of paper folding technique to three-dimensional space sound absorber with permeable membrane: Case studies of trial productions. *Int. J. Acoust. Vib.* **2020**, *25*, 243–247. [CrossRef]
12. Sakagami, K.; Okuzono, T.; Somatomo, Y.; Funahashi, K.; Toyoda, M. A basic study on a rectangular plane space sound absorber using permeable membranes. *Sustainability* **2020**, *11*, 2185. [CrossRef]
13. Sakagami, K.; Kiyama, M.; Morimoto, M.; Takahashi, D. Detailed analysis of the acoustic properties of a permeable membrane. *Appl. Acoust.* **1998**, *54*, 93–111. [CrossRef]
14. Alba, J.; del Rey, R.; Ramis, J.; Arenas, J.P. An inverse method to obtain porosity, fibre diameter and density of fibrous sound absorbing materials. *Arch. Acoust.* **2011**, *36*, 561–574. [CrossRef]
15. Berardi, U.; Iannace, G. Acoustic characterization of natural fibers for sound absorption applications. *Build. Environ.* **2015**, *94*, 840–852. [CrossRef]
16. Arenas, J.P.; del Rey, R.; Alba, J.; Oltra, R. Sound-absorption properties of materials made of Esparto Grass fibers. *Sustainability* **2020**, *12*, 5533. [CrossRef]
17. Kusno, A.; Sakagami, K.; Okuzono, T.; Toyoda, M.; Otsuru, T.; Mulyadi, R.; Kamil, K. A pilot study on the sound absorption characteristics of chicken feathers as an alternative sustainable acoustical material. *Sustainability* **2020**, *11*, 1476. [CrossRef]
18. Miki, Y. Acoustical properties of porous materials: Modifications of Delany-Bazley models. *J. Acoust. Soc. Jpn. (E)* **1990**, *11*, 19–24. [CrossRef]