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ECO-ACOUSTICAL EVALUATION OF AGRICULTURAL AND ENVIRONMENTAL WASTES AS SUSTAINABLE MATERIALS FOR NOISE CONTROL IN BUILDINGS

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ABSTRACT
On a global scale, sustainable environment and noise pollution are of serious concern in most developing countries, and Nigeria is no exception. Notable scholars have studied many materials - natural and synthetic - for noise control in buildings. Sustainable environment evolves from the production, application and use of sustainable products. A product is considered sustainable if the materials used for its production could be readily available for future generations and create no negative environmental impact such as waste generation and pollution, without compromising the health of its inhabitants. However, few studies have been developed on a comparative analysis of the eco-acoustical properties of conventional synthetic materials, agricultural and environmental wastes products. The aim of this article therefore is to evaluate the sustainability of agricultural and environmental waste products for noise control in buildings from the view of past scholars. Critical literature reviews and content analysis of the recent studies alongside the collected secondary data from the Life Cycle Assessment, Eco-invent, and Eco-profiles of the natural and sustainable environmental waste materials would be presented in the literature. The paper concludes that sustainable acoustical materials (agricultural or environmental wastes) are a valid alternative to traditional synthetic materials; most importantly is the reuse of environmental waste materials which could substantially reduce environmental pollution and also serve as a source of wealth creation for the unemployed Nigerian.

Keywords: *Eco-Acoustical Evaluation, Agricultural and Environmental Waste, Sustainability*

1.0 Introduction

Along with advancements in technology, noise has become an increasing concern in the built environment and arena of research within the international environmental health community, as well as to professionals in the built environment. The effect of noise include but not limited to: severe damage to human mental health such as hearing loss, an effect on sleep, communication interference and other well-being challenges in the built environment (Ising & Kruppa, 2004). Notable ways to reduce noise in the built environment have been suggested in the literature but every method has it strengths and weaknesses, the most acceptable medium is the provision of sound absorption materials. Currently, traditional sound absorption materials available for acoustic treatment consist of mineral fibre materials. The European building insulation market estimated to an approximate value 3.3 billion Euros in the following percentage distribution of sound insulation materials used in the construction industry: glass and mineral wool - 25 per cent; agricultural materials - 25 per cent; foam plastics - 34 per cent; other synthetic polymer materials – 13 per cent (Zhu *et al.*, 2013).

However, the life cycle assessment of these plastic related synthetic materials are shown to have hazardous effects on human safety and health. Even though these materials are widely used, researchers have reported that if fibres of these materials are inhaled (since they can lay) they could cause lung cancer, skin irritation and other sensitive organ diseases in humans (Thompson *et al.*, 2009). The side effects of these conventional materials prompted scholars into the quest for sustainable materials that are environment-friendly. Madurwar *et al.*, (2013) identify the economic potential of agricultural or environmental wastes as noise absorption material to conserve the scarce resources and reduce environmental waste. The outcome of their study relay that the application of agro-wastes for noise control is sustainable and has several benefits - renewable, nonabrasive, cheaper, in abundance, and less potential health risks and safety concern during handling and processing.

As part of the resolution of the World Commission on Environment and Development in 1987, sustainable development should meet the needs of the present without compromising the ability of future generations to respond to their needs. From this view point, a product can be considered sustainable if its production enables the resources from which it was made to continue to be available for future generations and has the lowest possible impact on human health and on the environment. Materials obtained from synthetic fibres, such as mineral wool is commonly used for thermal and sound insulation because of its good performance and low cost but its sustainability is of serious concern to many scholars (Papadopoulos & Giama, 2007). More so, Dewick and Miozzo (2002) assert that no insulation material is completely sustainable, but some are more sustainable than the others.

In recent years however, increasing attention has turned to natural fibres as alternatives to synthetic ones, to develop special acoustic and thermal properties which have only a little impact on the society. Natural fibres have very low toxicity, and their production processes

can contribute to protecting the environment. Recycled materials, such as recycled plastic fibres and recycled rubber mats, can even be regarded as a sustainable alternatives, as they contribute very little to lower waste production and use of raw materials. It is, however, imperative to evaluate the degree of sustainability of some of the natural, agricultural and recycled environmental waste, and to verify the total energy used in its production process for the architects and engineers who make the specification and selection decisions of such products for building construction.

1.0 Review of Literature

In recent times, the demand for environmentally sustainable or green building materials is of high interest to researchers in the built environment, particularly in the building sector. In most developed nations such as United States of America, United Kingdom, China and so on there has been an increase in the introduction of Green Building Index and Green Building Regulations specifically recommended to improve the use and application of eco-friendly materials for new constructions (Secchi, 2005). These Regulations also contain a list of materials that should be avoided, particularly, mineral fibres. On this account, commercial products are now being labelled as eco-green or green recyclable simply because they possess tiny quantities of natural or recycled materials but most importantly, because they are not harmful to human health and do not pose as a threat to the health of the future generation.

The simplicity of the definition is not as critical as establishing which products or building materials are green and environmentally sustainable. The real issue is the assessment and categorisation of the acceptable sustainable products. In this regard, there has to be cradle to grave assessment, that is, Life Cycle Assessment (LCA) of given products to establish the degree to which they are sustainable. For this reason, the use of LCA procedures, which analyse the potential impacts deriving from the entire life history of a product, is vital. Madurwar *et al*., (2013) stated that it is essential for the architect as a designer to take into consideration the products material extraction, production, transport, construction, operating and management, deconstruction and disposal, to recycling and reuse before their selection and application for building construction.

Furthermore, life cycle assessment reports from notable and reliable works of past researchers are available as "eco-profiles database" for the architects and engineers. Of such database, the most shared and acceptable are Eco-invent, BRE Eco-profiles and Eco-indicator (Desarnaulds *et al*., 2005). Eco-invent a Swiss LCA database, considers the next impact assessment evaluation: Non-Renewable Energy Fraction, Cumulated Energy Demand (CED) and Global Warming Potential (GWP). For instance, Eco-invent's database has the record of environmental impacts analysis between some traditional and natural materials and sound insulation properties as reported by Desarnaulds *et al*., (2005). The database serves as a reference material which reaffirms the research of many scholars that natural materials (cellulose, flax and sheep wool) produced the least sound insulation properties and environmental impacts scores which ranged from 4.4 to 12.3 MJ/Kg). On the contrary, plastic related traditional materials' LCA assessment is shown to have the highest environmental impact and acoustical properties. Values that ranged from 1.2 to 3.7 kg CO_2 eq as presented in Figure 1.

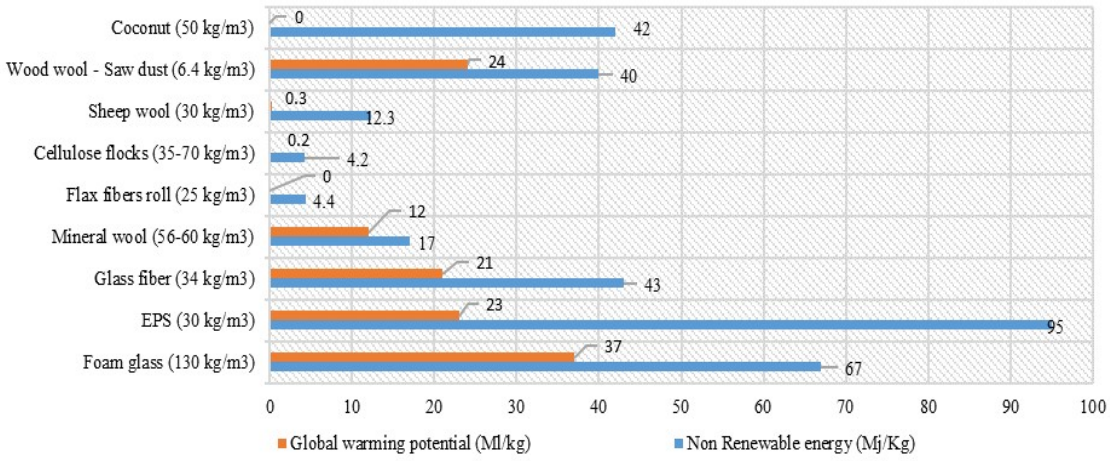

Figure 1: Comparison of Traditional and Natural Materials Environmental Impacts from Ecoinvent Database (Desarnaulds, *et al*., 2005)

United Kingdom BRE Eco-Profiles, developed and assigned range of scores termed as eco-points for every products and material extraction processes by weighting normalised impacts on specific factors. The influential factors are climate change, acid deposition, eutrophication and eco-toxicity, ozone depletion, mineral and fossil fuel extraction, human toxicity and waste disposal system, as well as transport pollution. In line with these underlined factors, life cycle assessment scores for some insulation products and materials in

United State of America were provided such as EPS (15 kg/m3) 0.028 pt., rock-wool (45 kg/m3) 0.020 pt., rock-wool (33kg/m3) 0.016 pt., recycled newspaper cellulose 0.002 points.

Another important database is Eco-indicator 99 which was reported in the work of (Desarnaulds *et al*., 2005). A certain range of evaluation scores (percentage distribution) of the various possible damages caused by fossil fuels to human health in agreement with possible ecological dreadful conditions in China was outlined. The document contains and unambiguously demonstrates the negative impact of fossil fuels on the ecosystem quality through the reduction and extinction processes of some animal and plants species which could be termed as an ecological loss to humankind. Also, the database provided fundamental energy requirement for future extractions of minerals and fossil fuels as presented in Figure 2.

However, Secchi (2005) reports an estimation of the use of primary energy for the extraction, transport, production and packing of different insulating materials that have the acoustic potential for sound insulation in building design and for its efficient operation. He further notes that not every green material (for example flax) requires less energy in its life cycle than a traditional one like rock wool. As a matter of fact, synthetic plastic fibres/materials always show the greatest impacts on fossil fuel consumption despite their acoustic potential for buildings' sound insulation. On the contrary, Suzana *et al*., (2003) demonstrate the acoustical properties and application of coconut fibre as a potential natural material for eco-design noise control in building even though it is not as useful as synthetic plastic fibres. On this account, this paper outlines and discusses further on some sustainable materials that are regarded as environmental waste in most parts of Nigeria even though such environmental waste could be recycled and reused by the building designer (architects and engineers) for noise control in buildings.

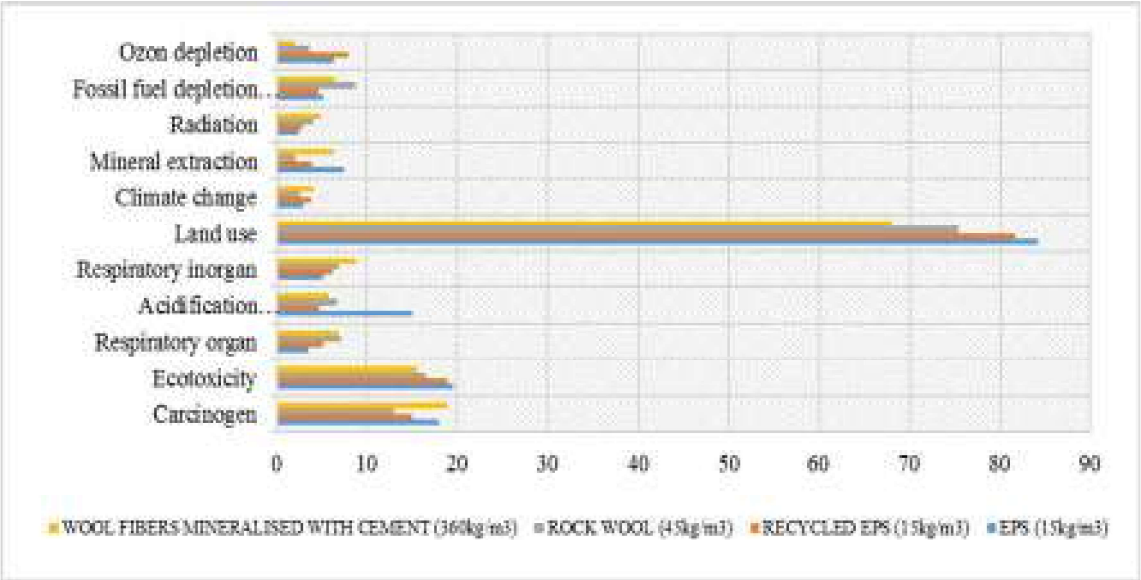

Figure 2: Impact of some sound insulation layers from Ecoindicators Database (4)

2.1 Agricultural and Environmental Wastes as Sustainable Materials for Noise Control in Buildings

In the twenty-first-century environmental waste is generating more concern to the government of many nations. This issue is attracting more attention in the academic community on how to convert the massive environmental wastes into wealth (Taiwo, 2009). In the past few decades, Nigerian scholars have organised several conferences and workshops with the focus on waste to wealth or trash to treasure. In fact, greater attention to environment and public health is stimulating more research and development on many new materials for possible recycle and reuse for building production in Nigeria. Particularly, vast agricultural and plastic related wastes that constitute unhealthy environmental pollution is of high concern to the general populace in Nigerian communities.

Within the frame of environmental wastes, some notable scholars classify such wastes into two broad categories: natural or agricultural wastes and environmentally generated wastes materials. Madurwar *et al*., (2013) were of the opinion that any of the two classifications are sustainable materials depending on the recycling process such wastes are subjected to for new usage and application for new products that are of potential benefit to the general Nigerian populace. Most common agricultural residues are rice ash, maize shaft, cotton, hemp, sheep wool, flax, and so on. The notable environmental wastes are plastic related materials such as plastic water sachets; rubber used tyre, and several celluloses and polymer product wastes.

A huge wealth of knowledge in the literature reports a wide variety of reuse of agricultural and environmental

wastes for economic gain (Yasina *et al*., 2010). In fact, life cycle assessments of some agricultural wastes are shown to contain natural fibre composites which could be cheaper, lighter and environmentally superior to the application of glass fibres composites in building production. More so, Madurwar *et al*., (2013) state that environmental wastes could be substituted for sustainable materials because research conducted by them reveal that some possessed relatively good thermal and acoustic performances index. These find them applicable and reusable, particularly for noise control in machine and building construction. Even though products from such material waste need to be analysed and certified for human health safety, they do not necessarily depend on the physical properties. For instance, many sustainable materials/products were compulsorily subjected to laboratory test before their official acceptance for usage in the developed countries like China, UK and USA (Zhu *et al*., 2013).

Yang *et al*., (2003) and Binici *et al*., (2016) investigated the insulation properties of rice straw as a sound absorbing wooden construction material. In fact, they demonstrated its capacity to contain indoor living spaces' temperature, which could partly or wholly replace wood particleboard and insulation board in wooden construction. Recently in Nigeria, Mgbemene *et al*., (2013) conducted an experiment on the particleboard's produced from rice husks, maize cobs, and groundnut shells with the application of acacia mimosa tannin extract as the bonding adhesive. Notable studies have successfully developed composite particle boards using agricultural wastes. Saadatnia *et al*., (2008) a significant contribution in examining sound absorption properties of Aspen particles board produced with different percentage of barley and wheat straws. As a matter of fact, distinguished scholars have shown that many aggro and bio-based materials have lower environmental impact than traditional synthetic materials, and demonstrate good sound absorbing and sound insulation performances.

However, only a few researchers have made a comparison of the acoustic properties of natural/agricultural and environmental waste despite the huge potential in this sector, particularly in Nigeria. The research provided a framework for the comparison of selected agricultural and environmental wastes, thermal and sound transmission properties as presented in Figure 3.

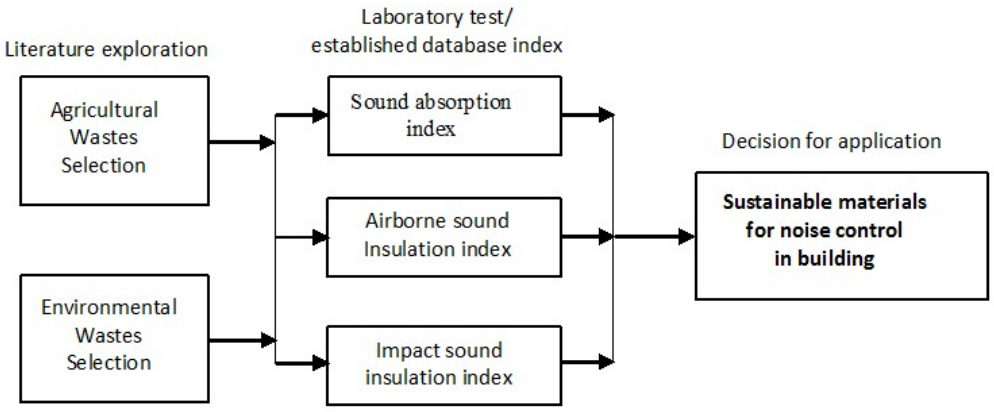

Figure 3: Framework for the comparison of selected agricultural and environmental wastes' thermal and sound transmission properties

3.0 RESEARCH METHODOLOGY

The research employed critical literature review and content analysis of the past studies. Two types of research on the internet were conducted over a period of two months to gather relevant secondary data about natural, agricultural and environmental wastes. First, nature and major types of natural and agricultural materials identified. Second, series of data gathered consists of life cycle assessment, eco-invent, Eco-profiles of the natural, agricultural and environmental wastes.

Researchers and experts in the field of material science were also contacted to check the nature, accuracy of data collected and viability of this research finding to the Nigerian society as a whole. The categories of natural/agricultural materials and environmental wastes identified and discussed the research findings of their acoustical and thermal benefit for building noise control.

4.0 RESEARCH FINDINGS

Comprehensive secondary data were identified in the wealth of literature of past researches. The data relevant to this research were extracted from a different database as presented in Table 1.0. From the review of relevant data, three fundamental properties index outlined; Sound absorption, Sound insulation and Impact sound insulation for both agricultural/natural and environmental wastes respectively.

Agricultural/natural materials - As for natural materials, the less treated they are, the higher they perform in energy saving; natural materials have to be preferred to reduce transport energy however, natural fibres have negative impacts as far as climate change (CO_2

absorption) is concerned. Nonetheless, other performances have to be considered: vegetal fibres are more subject to fungal and parasites attack and are less resistant to fire than mineral fibres, the non-toxicity of the chemical products used for cultivation must be taken into account too (the acoustic and thermal properties as well as sustainable natural insulating materials reported in Table 1). When not specified, absorption coefficient and cost refers to 4 cm thick panels while indexing of reduction of impact noise refers to 2 cm thick panels.

Table 1. Acoustic and thermal properties and costs of some traditional and natural insulating Materials (Desarnaulds *et al*., 2005; Hong *et al*., 2007).

	Thermal conductivity λ (W/mK)	**Rel. resistance to vapour flux μ (–)**	**Absorption coefficient αS at 500 Hz (-)**	**Index of reduction of impact noise ΔLW (dB)**	**Cost (€/m2)**
Hemp	0.04	2	0.6 (30 cm)	-	5
Kenaf	0.044	2	0.74 (5 cm)	-	-
Coco fiber	0.043	18	0.42	23	-
Sheep wool	0.044	3	0.38 (6 cm)	18	-
Wood wool/Bamboo	0.065	5	0.32	21	12
Cork	0.039	12	0.39	17	19
Cellulose	0.037	2	1 (6 cm)	22	-
Flax	0.040	1	-	-	7
Glass wool	0.04	-	1 (5 cm)	-	12
Roch wool	0.045	-	0.9 (5 cm)	-	6
Expanded polystyrene	0.031	100	0.5	30	10

Sound Absorption properties - as presented in Table 1, many natural materials such as kenaf, flax, hemp, cork, sheep wool and bamboo or coconut fibres have shown good absorbing performances as reported in the recent studies of Ali (2011) and Raudhah (2013). Therefore, they could be used as sound absorbers in building, particularly, in the room that require a great deal of acoustics condition. They could serve as noise barriers for both external and internal cladding materials. Again Zhu *et al*., (2013) tested expanded clay, which is classified as a natural product, presented excellent sound absorption performances in a wide frequency range - higher than 0.80 in the range 500-5000 Hz support Hong, *et al*., (2007). Zhu *et al*., (2013) reaffirm that at 500 Hz, the absorption coefficient of synthetic materials is superior to the one of the natural materials, except for Papadopoulos and Giama (2007) who show that they have negative impact on the built environment. Based on this finding, natural materials have the support of many scholars as sustainable sound insulation materials because they are environmentally friendly as backed by Raudhah (2013).

Airborne sound insulation - several natural materials are commonly used as thermal and acoustical insulation in multi-layered walls. Among this flax, coconut, cotton, sheep wool and kenaf mats are the most available products in every Nigeria locality (Mgbemene *et al*., 2013). Their sound and thermal insulation performances are in many cases as good as those of traditional materials as shown in Table 1 and Figure 5. Likewise, other research works reaffirm that both double-leaf walls with low-density animal wool (sheep wool) and thick vegetal wool (latex-coco) possess better sound insulation properties to single walls with mineral wool or polystyrene of the same thickness (Binici *et al*., 2016; Hong *et al*., 2007).

Impact sound insulation - Yang *et al*., (2003) report that some of the commonly used agricultural/natural materials as sustainable sound insulation are: rice straw, coconut fibres, and sugarcane wood wool. As shown in Table 1, elastic layers made of rice straw and coconut fibres as natural materials possessed excellent impact sound insulation for floating. Although Ali (2011) states that their effectiveness depend on proper panel design and installation, despite the fact that, their properties are as good as other traditional materials. To buttress this point, another experimental test conducted at the Acoustic Laboratory of the University of Perugia by a group of the sound expert is presented in Figure 4.

Environmental products wastes - as shown in Figure 4, the literature review has affirmed the application of many recycled materials, such as waste rubber, plastic bags, textile agglomerates as acoustic materials in building construction. In fact, researchers experimented a mixture of various recycled materials of different granulometric to obtain a better performance sound insulation products (Hong *et al*., 2007).

Sound absorption - as presented in Figure 4, plastic related environmental wastes and cellulose recycled materials which are commonly obtained from used newspapers, added with flame retardants and biocides have been shown to possess excellent sound insulation properties as reported in the works of several researchers (Murugan *et al*., 2008). Wet cellulose fibres are sprayed directly on walls or ceilings, and their sound absorption properties are even better than those of mineral wool (Figure 4). Another applicable environmental waste material is textile agglomerates (Aigbomian & Fan, 2013). Rubber crumbs have been shown to have good performance as acoustic materials with a broadband absorption spectrum that is suitable for traffic noise barriers and which is very durable (Ayrilmis *et al*., 2009).

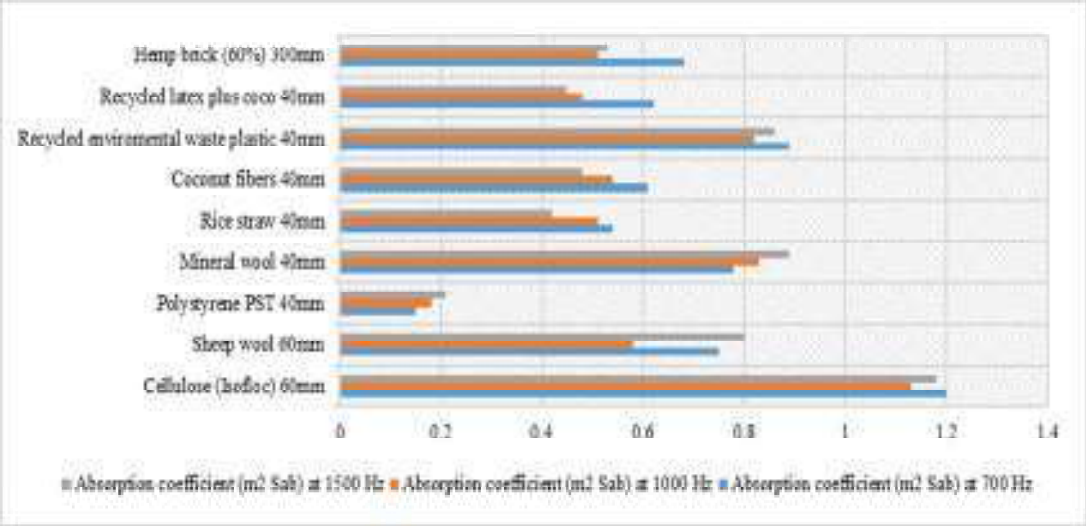

Figure 4: Sound absorption coefficient of agricultural/natural and environmental wastes materials (Doost-hoseini *et al*., 2014; Madurwar *et al*., 2013; Saadatnia *et al*., 2008)

Airborne sound insulation - literature provided suitability of dry loose cellulose fibres (environmental waste) as useful materials for thermal and acoustical insulation for wall and roof cavities. As produced by the recycled newspapers, it possesses the merit of energy-saving, industrial-cheap raw materials and environmentally friendly with relatively no or less hazard to human health. As for the acoustical properties, they are sustainable as a suitable alternative material for conventionally used sound insulators (Synthetic mineral wool fibres).

Impact sound insulation – quite obviously, figure 4 showed that recycled rubber layers made of waste plastic and tyres granules are apparently good sound insulating materials. Particularly, they are environmental waste products which are readily available in most Nigeria cities and worldwide. The burning of used tyres from landfills causes air pollution (dangerous gases) at the same time, stockpiles are also hazardous to the risk of fire and vermin infestation because of a significant amount of used tyres available worldwide, new applications have to be found and their use as impact sound insulating layers is very promising as supported in the literature. Likewise, recycled carpet, plastic bottles and water sachets wastes are exotic materials as far as impact sound insulation is concerned, especially if made of a mixture of fibrous and granular waste. The acoustic properties of these underlay materials compare favourably with the commercially available ones (Ayrilmis *et al*., 2009). To this extent, the critical review of the literature and comparative analysis of conventional, natural/agricultural and environmental wastes have shown that all have their strengths and weaknesses as for noise control in buildings is concerned. Despite, natural fibres are preferred alternatives to synthetic ones because of their little negative impact on the environment and human health. At the same time, colossal environmental wastes in the twenty-first century create an equally huge opportunity for possible sound insulation materials and could serve as wealth creation for millions of jobless Nigeria graduates.

5.0 CONCLUSIONS

An environment that is free from unwanted noise is the desire and dream of every citizen. Primarily, sources of unwanted noises are from heavy vehicles, heavy construction machines, and big factories. Apparently, workers in large factories are exposed to continuous noises for the entire work day. This discomfort may lead to some injuries such as hearing loss (temporary or permanent), weakness in nerve and pain in internal tissues, heart problems, and even high blood pressure in the long term. Hence, an understanding of noise elimination becomes an important issue to be studied particularly for architects and engineers who are the designers of built environment.

This paper has concentrated on noise attenuation consideration of absorption materials (natural/agricultural and environmental wastes) as alternative noise control materials in building construction. These research works have come into view in leading journals in this area for the purpose of increasing the usage of non-toxic and environmentally friendly materials which provide green and sustainable environment.

Conclusively, the reuse of environmental waste materials could substantially reduce environmental pollution and serve as a source of wealth creation for the millions of unemployed Nigerian graduates.

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