

Utilisation of agro-wastes as energy efficient building materials

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Abstract— In developing countries, housing has constituted a major challenge affecting development adversely. This is because of the inability of the government to provide adequate housing for the growing population and also because of the high rate of poverty hampering individuals from providing housing for themselves. This study took the form of a systematic literature review, and harnessed information from both the traditional and the internet sources which include journals, books, web pages, publications and relevant posts which are focused on the use of agro-waste materials as energy efficient building materials towards ensuring sustainable housing development in developing countries. This study has clearly enumerated selected agro-wastes that could be used as energy efficient building materials. With references to their various chemical and mechanical properties, coupled with their characteristics, it is evident that these agro-wastes could be deployed as energy efficient building materials.

Keywords— Agro-waste, Energy Efficient Building Materials, Sustainable Housing, Housing Development, Growing Population, Developing Countries.

I. INTRODUCTION

Developing countries have long been characterized by rapid population growth and urbanization. This has brought about issues relating to the difficulties in providing basic infrastructure such as adequate housing for the growing population. Housing is a major basic need of every human being and fundamental to the welfare, survival and health of man coupled with food and clothing (Fadamiro, Taiwo and Ajayi, 2004; Igwe, Okeke, Onwurah, Nwafor and Umeh, 2017). Hence, it has been noted as one of the major indices for standard of living and development among communities and countries (National Affordable Housing Association, 2006; The Social Protection Committee, 2014). In developing nations, housing has constituted major challenge affecting development because of the inability of the government to provide housing for the population and also because of the high rate of poverty prevalent in the third world nations (Ibimilua and Ibitoye, 2015; Igwe et al., 2017).

According to Igwe, Okeke, Onwurah, Nwafor and Umeh (2017); and Enoghase, Airahuobhor, Oladunjoye, Okwuoke, Orukpe, Ogunwusi and Bakare 2015, housing problem constitute a major issue in any third world nation. Igwe et al.

(2017) noted that in developing countries such as Nigeria, poor housing delivery has been attributed to inadequate mechanisms and systems for land allocation, funding, mortgage institutions and infrastructure. In addition, with approximately over 50% of its population living below acceptable basic standard of living (Kazeem, 2018), this makes the housing problem in Nigeria to be a more difficult problem that demands urgent attention. A major reason for housing problems in most of the third world countries is attributed to the high cost of building materials (Ananwa, 2006; Igwe et al. 2017). This is because most of these building materials are imported from other nations and because majority of the population are poor, owning a house has become exclusive accomplishment of very few people and a herculean project.

Okupe (2002); Aliyu and Amadu (2017) and Enisan (2017) affirmed that there is severe housing shortage due to the growing population and poverty. This has led to a high elasticity of social pressure on social services such as housing. Hence, housing shortage is growing worse day by day in developing countries because of the inadequate supply relative to the elastic demand of housing due to the high

increase in the population growth and increase rate of poverty (Olutuah, 2000; Igwe et al. 2017). Furthermore, apart from quantity deficiency to meet the increasing housing demand, another major challenge to the housing system in third world nations is the low quality of housing being delivered. According to Fakunle, Ogundare, Olayinka-Alli, Aridegbe, Bello, Elujulo, Olugbile and Saliu (2018), housing quality in third world nations is not as professionally exquisite as it is in developed nations and houses that are of high quality are few.

In addition, this situation is common in both urban and rural areas but are more severe in the urban areas due to the fact that most people live in houses that are of poor quality with unsatisfactory environment (Morenikeji, Umaru, Pai, Jiya, Idowu & Adeleye, 2017; Fakunle et al., 2018). Several factors have been noted to be used to describe housing quality in third world nations and these factors include internal facilities; major materials for roofing and materials for external walls; flooring; the type of toilet and bathroom facilities available and provision of stable power supply (Aderamo and Ayobolu, 2010).

Hence, poor quality and low quantity of housing are known to be the major problems affecting sustainable housing development in developing nations. Therefore, attention should be given to ensure the provision of quality housing towards sustainability of housing in developing nations. For example, the Nigerian government has introduced and established National Housing Policy which seeks to provide an institutional framework to ensure the provision of adequate housing both in quantity and quality (Adeshina and Idaeho, 2019). Despite these efforts, little or no achievement has been made to actually meet the housing demands of the growing Nigeria population (Jiboye, 2011; Emiedafe, 2015; Adeshina and Idaeho, 2019). To this end, Basorun and Fadairo (2012) categorized the Nigeria housing challenge into: administrative, institutional and management challenge; financial and economic challenge; physical challenge; and local participatory challenge.

With these elastic challenges affecting provision of sustainable housing in developing nations, and with the fact that Maslow (1943); Jiboye (2011); Emiedafe (2015) and Adeshina and Idaeho (2019) affirmed that quality housing is a basic human need hence, everyone has the right to this basic need. However, the reverse is the case as poor housing has been a normal phenomenon among many communities in developing nations. Nevertheless, the search for alternative means to increase sustainable housing provision,

affordability and at the same time to ensure housing quality has led to the discovery of the potentials of using agricultural wastes as building materials towards ensuring sustainable housing in Nigeria (Aimola, 2012). According to Nuffic and UNESCO/MOST (2002) and Omiunu (2012), local resources such as agro waste are important part of the lives of the poor. Examples of these include sisal (*Agave sisalane*) fibres, rice husk, cotton stalk, sugarcane (*Saccharum officinarum*) fibres, coconut (*coconut nucifera*) fibres, bamboo fibres, banana, kenaf, jute, oil palm, among others. Naveen, Jawaid, Amuthakkannan, and Chandrasekar (2019) noted that these agro wastes are abundantly available, cheap and possess superior mechanical properties that make them energy efficient building materials.

In third world nations and in the world at large, energy efficient building materials as construction materials have been attracting considerable attention. Currently most buildings have a high content of reinforced concrete - the high cost of building materials has been a problem to the average citizen. Steel is partially scarce and its cost is ever increasing and even when available, its quantity and quality fall below the average demand of users. These inadequacies therefore lead to the importation of steel from producers in other countries hence, this has led to the abandonment of projects at various levels of construction. In some cases storey buildings have had to be converted to bungalows or the number of storey of various buildings reduced to minimize cost to meet completion target.

Sequel to seeking for lowering costs of building, scientific and research attention have been shifted to the non-conventional building materials which could possess similar characteristics as those deployed and used in the traditional construction engineering system (Rabi, Santos, Tonoli, and Savastan, 2009). Hence, there is therefore the need for the development and use of locally available materials to implement low cost housing. Before the advent of modern technology, houses were built with traditionally and locally available building materials. The pursue for this traditional innovation and materials use for energy efficient building towards achieving sustainable development is hinged on two assumptions:

- (i) It could assist in reducing the dwelling deficits especially in developing countries because cheaper houses become economically feasible.
- (ii) It could be environmentally friendly as such agro wastes can be recycled or exploited towards ensuring sustainable

housing. Hence, there are numerous local materials and energy efficient materials that could be used as good alternatives in enhancing sustainable housing.

For example, the use of clay in building was widely adopted with palm fronds as roofing materials. Later clay itself was being reinforced with sticks, sisal and fibrous components to make it suitable for roofing. Rice husk ash has also been used as cement replacement additions and it consists of minerals in the form of fine powder derived from other production processes (Aciu and Cobirzan, 2013). Also, reed is another agro-waste material and due to its physical properties, it is a good building material that is light and stable. Reed is mechanically pressed and bound with galvanized metal wire which could make it better for building towards sustainability of housing development. Other types of agro-waste such as, cotton stalk, sugarcane (*Saccharum officinarum*) fibres, coconut (*coconut nucifera*) fibres, bamboo fibres, among others have also been affirmed to be good traditional materials to enhance housing development at the local level.

The use of agro-waste as building materials in the building industry is an efficient modality for implementing sustainable housing development in the construction industry. In addition, the use of agro-waste materials for energy efficient building guarantees the complete, relatively inexpensive, elimination of waste, under environmentally safe conditions, and also the avoidance of environmental pollution that such waste products constitute (Aciu and Cobirzan, 2013). Furthermore, Aciu and Cobirzan (2013) noted that this could also contribute to the conservation of natural resources and this could lead to the reduction of gas emissions often generated during the storage or burning of waste; the avoidance of the over-accumulation of waste products in various controlled waste dumps; and the improvement of the environmental image in third world countries with a very high level of environmental pollution. Therefore, the use of agro-waste materials as energy efficient building materials opens promising perspectives in ensuring energy efficient building hence, the need for this study. To this end, this study would among others, highlight selected types of agro-waste that are energy efficient building materials, their characteristics, mechanical properties, among other attributes.

II. METHODOLOGY

The study took the form of a systematic literature review, and harnessed information from both the traditional and the internet sources which includes journals, books, Web pages, among others. However, it was ensured that publications and relevant posts used in this study are focused on the use of agro- waste materials as energy efficient building materials towards ensuring sustainable housing development in third world nations. In addition, it was ensured that information obtained were arranged thematically and in addition, systematic review of relevant articles and information was done to establish relevant argument of the study in order to drive the course of this study towards affirming how agro-waste materials could be deployed and used as energy efficient building materials for ensuring sustainable housing development in developing nations.

III. CHARACTERISTICS OF ENERGY EFFICIENT BUILDING MATERIALS

According to Celly (2007) agro wastes are used as energy efficient building materials because of the following characteristics:

- i. Easy to manufacture
- ii. Faster and cheaper construction
- iii. Effective waste utilization
- iv. Energy efficient and environment friendly
- v. Environmental protection
- vi. Energy efficiency in manufacturing processes
- vii. Reducing poverty through employment generation
- viii. Modernization of manufacturing process of composite materials by recycling agro – industrial wastes
- ix. Technology transfer, capacity building and procurement of technical know-how and machines.
- x. Building up capacities at institutional and enterprise levels for productive employment, technology transfer and adoption.
- xi. Protecting environment by utilization of renewable resources rather than fast depleting non-renewable ones.
- xii. Promoting energy saving technologies, and thus, making very significant contribution to gaseous emissions, especially of carbon dioxide.
- xiii. Encouraging competitive enterprises to gain access to profitable markets, especially in the alternative materials sector.

IV. AGRO-WASTES USED AS ENERGY EFFICIENT BUILDING MATERIALS

Some agro-wastes as energy efficient building materials have been investigated, these are provided and discussed below:

a. Sisal (Agave sisalane) Fibres

This is the most extensively cultivated hard fibre in the world. It is a strong fibre and has rigid bright green leaves about 10cm wide and 150cm long. Figure 1 shows Sisal plant and fibre.

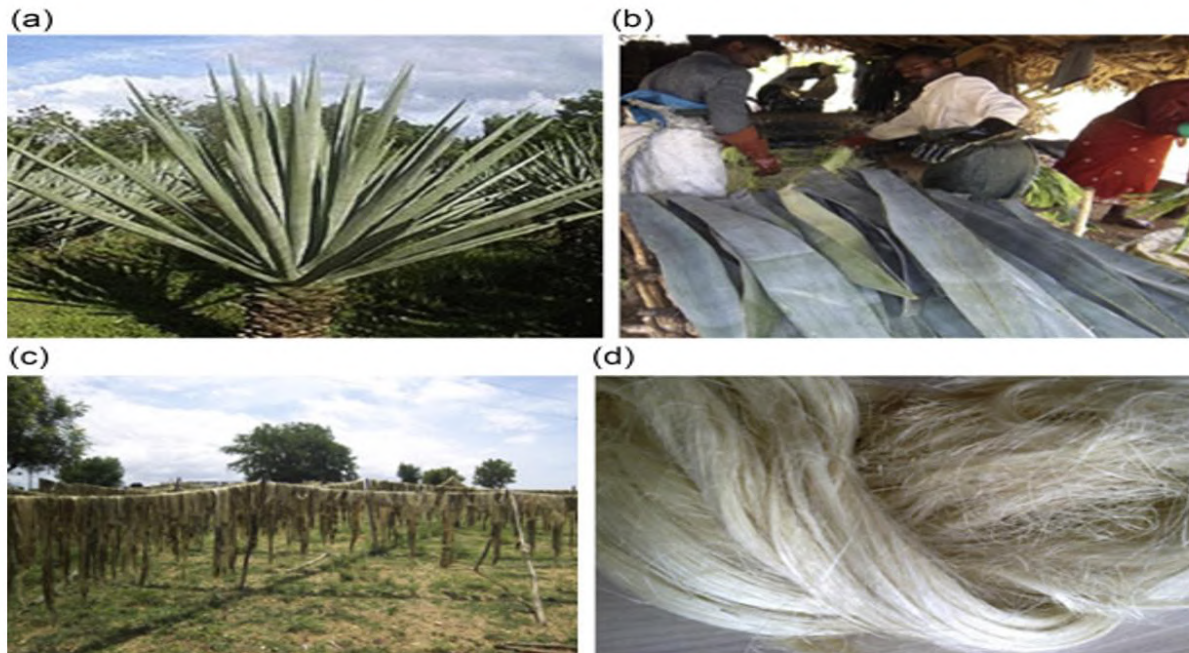


Fig.1: Sisal Plant and fibre

Source: Naveen, Jawaid, Amuthakkannan, and Chandrasekar (2019)

Figure 1 is the Sisal plant while Figure a, b, c and d are the Sisal fibre processed from the Sisal plants. Sisal has been successfully used as reinforcement in cement and concrete matrices (Filho, Joseph, Ghavami & England, 1999). Sisal fiber is a major promising reinforcements in polymer composites because it has higher tensile strength, modulus and impact strength (Naveen et al., 2019). Traditionally, sisal fibers were previously used to make ropes, fancy articles, and carpets, among others. Traditional innovative

development has led to its use for energy efficient building materials towards sustainable housing development.

b. Rice Husk

Rice husk ash is used in concrete construction as an alternative of cement. Ramasamy and Biswas (2008) made use of Rice Husk Ash (RHA) as a cement substitute material. Their end results signified that optimum amount of RHA boosts the mechanical properties of concrete.



Fig.2: Rice husk plant and fibre.

Figure a shows the rice husks and figures b and c show the processed rice husk ash into building materials, figure d shows a brick made from rice husk ash as provided by Arjun (2020). Nair, Fraaij, Klaassen and Kentgens (2008) and Habeeb and Mahmud (2010) also attested to the use of rice husk ash for energy efficient building materials. In addition, Memon, Shaikh and Akbar (2011) and Ling and Teo (2011) investigated the use of rice husk ash as viscosity transforming agent in Self Compacting Concrete (SCC) and observed that developing low cost Self Compacting Concrete from rice husk ash is feasibly viable. Rahman (1988) fabricated bricks from clay-sand mixes using varying percentages of rice husk ash and found that the use of rice husk ash contents increased the compressive strength of the bricks. Also, Chiang et al. (2009) and Shakir et al (2013) observed that adding up of rice husk ash below 15% wt. and sintered at 1100 °C created low density and relatively high

strength bricks which were compliant with appropriate Taiwan standards for lightweight bricks.

c. Cotton Stalk

Cotton stalk is residue of cotton left in the field following harvest and must be buried or burned to prevent it from serving as an overwintering site for insects such as the pink bollworm (PBW) (Al-Afif, Pfeifer and Pröll, 2019). In contrast to other agricultural crop residues, cotton stalk is comparable to the most common species of hardwood in respect of fibrous structure (Pandey and Shaikh, 1986) and hence are deployed and be used for the manufacture of particle boards, preparation of pulp and paper, hard boards, among others. Hence, its usage would not just only help in the enhancement of housing but also reduce the environmental pollution and disease producing tendency in the community (Al-Afif, Pfeifer and Pröll, 2019). Figure 3 shows cotton plant and stalks.



Fig.3: Cotton plant and stalks

Figure 3a shows a cotton plantation with cotton plants, figure 3b shows the cotton stalks which are remnants from harvesting cotton, Figure 3c shows the straws made from cotton stalks, while figure 3d shows boards produced from cotton stalks as provided by Kumar (2010). According to Chen, Wang, Chen & Lv (2014), cotton stalk fiber play a stronger role in the fiber reinforced cement and cotton straw cement-based blocks are not easy to crack or brake. Nkomo and Nkiwane (2017) showed that cotton stalk has better mechanical properties and tenacity especially those at the top and middle position that makes it possible for its use for building materials. Li, Yu, Zhao, Li & Li (2003) and Agwa, Omar, Tayeh & Abdulsalam (2020) noted that cotton stalks have fiber/gypsum composite that could effectively be used for self-compacting concrete to enhance sustainable housing.

d. Sugarcane (*Saccharum officinarum*) Fibres

There are two by-products from cane sugar processing, namely the straw and bagasse (cane fibres) (Yamane, 2020) and they can be used to enhance sustainable building materials. Sugarcane fibre is a waste material left over after

the extraction of the juice of sugarcane known as bagasse. Sugarcane is cultivated in most of South American sub-tropic zone, and also in Nigeria. Sugarcane fibres have been used in the production of 1.2cm² panels, which are either bonded with cement of up to 49% (Blackburn, 2000). Composite boards of sugar cane bagasse particles and recycled high-density polyethylene were manufactured by means of a flat press process under laboratory conditions using a partial factorial experimental design (2K-1) to determine the effects of the process variables press temperature, pressing time, bagasse/plastic content and pressure on bending properties, water absorption and thickness swelling (Wyk, 2005). Sand replacement and performance tests were carried out by Sales and Lima (2010) for preparing mortars and concretes with Sugar Cane Bagasse Ash (SCBA). Their results indicated that the SCBA samples show cased physical properties comparable to those of natural sand. They also found that the mortars produced with SCBA instead of sand presented enhanced mechanical results as opposed to the conventional mortar. Figure 4 shows sugarcane products and fibres.

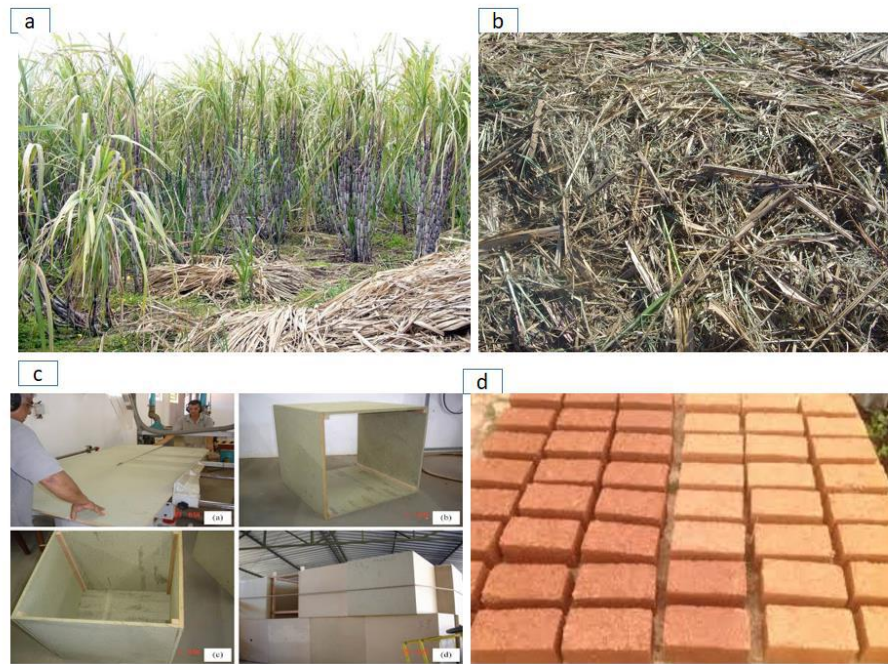


Fig.4: Sugarcane products and fibres

From Figure 4, Figure 4a shows a Sugarcane plantation (Yamane, 2020), Figure 4b shows Sugarcane fibres, Figure 4c shows boards manufactured from Sugarcane fibres (Carvalho, Mendes, Cesar, da Flórez, Mori & Rabelo, 2015), while Figure 4d shows local bricks manufactured from Sugarcane fibres (Danso , Martinson, Ali and Williams, 2015). Hailu and Dinku (2012); Abbasi and Zargar (2013); Otoko (2014); Lathamaheswari, Kalaiyarasan and Mohankumar (2017); among others noted that sugarcane fibres are deployed in the building industry to enhance sustainable housing in developing countries. According to Kawade, Rathi and Vaishali (2013), partially replacement on concrete with bagasse has shown that the strength of concrete increased up to 15%. Other studies such as Dhengare, Raut, Bandwal and Khangan (2015) noted that the strength of concrete reported to have optimum of 15% replacement level. According to Núñez-Jaquez, Buelna-Rodríguez, Barrios-Durstewitz, Gaona-Tiburcio and Almeraya-Calderón (2012), with the corrosion rate of steel by polarization resistance method, embedded in concrete having cement

replaced with bagasse ash by 20% provides some profound beneficial effect on protection of steel rebar from corrosion. According to Amin (2011), the optimal replacement ratio of 20% of cement by Sugarcane fibres reduced the chloride diffusion by more than 50% without any adverse effects on other properties of the concrete.

e. Coconut (Coconut nucifera) Fibres

A mature coconut has an outer covering made of fibrous material. This covering called the 'husk' consists of a hard skin and large coconut fibres embedded in a soft material. The fibres otherwise known as Coir can be extracted simply by soaking the husk in water to decompose the soft material surrounding the fibres. The fibre is light, elastic, exceedingly high in resistance to mechanical wear and dampness, and it is highly sound insulating especially in sea water. However, it is less durable and rougher surfaced than other vegetable fibres. Nevertheless, the low production cost makes it quite compatible despite its limitation (Hasan, Sobuz, Sayed and Islam, 2012).

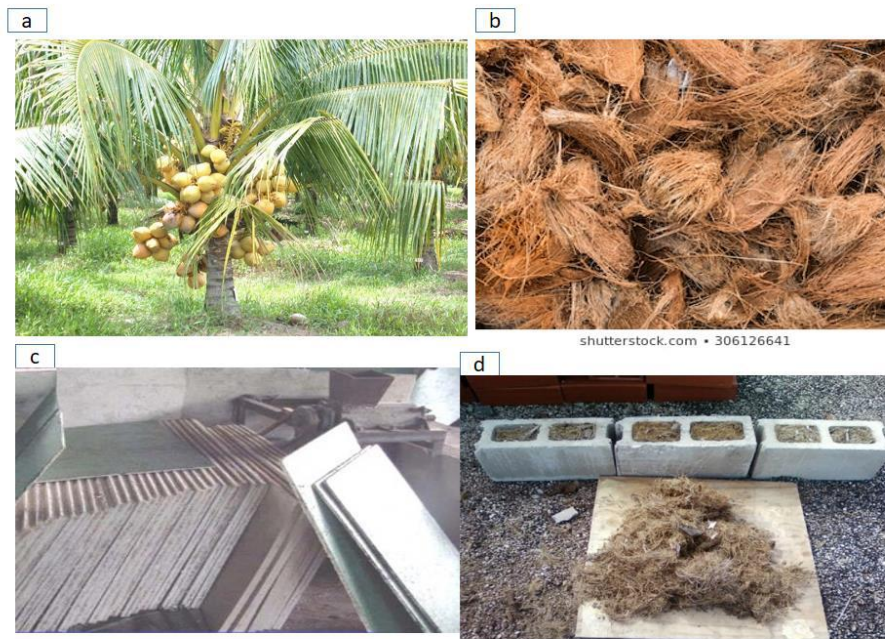


Fig.5: Coconut (*Coconut nucifera*) Fibres

Figure 5a shows a coconut (MyFarmbase Africa, 2019); figure 5b shows coconut fibre (Shutterstock, Inc., 2020); Figure 5c shows Boards made from coconut fibres (Pinoy-Entrepreneur, 2019), while Figure 5d shows coconut fibre used as insulator in blocks (Iwaro and Mwasha, 2019). Coconut fibres could be deployed and used for building materials to require care of a comfy indoor building environment in residential buildings (Pasic, Topalovic, and Kobas, 2010; Al-Rabghi and Akyurt 2004; Panyakaew and Fotios, 2008). Effective thermal insulation material is taken into consideration the foremost important component of building energy conservation building which can reduce the worth of cooling and energy consumption and thus the resulting pollution of the environment (Radhi, 2008). As such, thermal insulation materials like those obtained from coconut fibres are chosen for his or her physical properties, like low thermal conductivities, moisture protection, and mold and fire resistance (Oushabi, Sair, Abboud, Tanane, and El-Bouari, 2015).

f. Jute Fibres

Jute could also be a vegetable grown mainly in India, China and Thailand solely for creating ropes and bags to maneuver grains and other materials ranging from cement to sugar. Vegetable fibers like Jute fibres are widely available in most developing countries and are known to be suitable reinforcement materials for brittle matrix albeit they present relatively poor durability performance (Rabi, Santos, Tonoli, and Savastan, 2009). Understanding the mechanical properties of such fibers also as their broad variation range, building materials with suitable properties could be developed by means of the adequate mix design (Agopyan, Cincotto and Derolle, 1989). according to Pacheco-Torgal & Jalali (2011) noted that a mean of 200 kg of steel rebar is used for each kiloliter of concrete structure, reinforced steel could also be a highly expensive material, and it is high energy consumption and comes from a non-renewable resource hence it is clear that the replacement of reinforced steel rebar by vegetable fibres like Jute fibres could also be a significant step to comprehend a more sustainable construction. Jute fibre is strong in tension hence can also be utilized within the cement matrix. Figure 6 shows Jute fibres.



Fig.6: Jute fibres building products

Figure 6a shows Jute plantation, Figure 6b shows Jute fibre, Figure 6c shows boards made from Jute fibres (Excel Composites Pvt. Ltd., 2020); while Figure 6d shows Jute fibre used as substitutes for woods in building houses (Gon, Das, Paul and Maity, 2012). According to Gon et al. (2012), Jute fibre could also be a promising reinforcement to be utilized in composites in buildings on account of its low cost, high specific strength and modulus, no health risk, easy availability, renewability and far lower energy requirement for processing. Additionally, Jute fibre composites enjoy excellent potential as wood substitutes in sight of their low cost, easy availability, saving in energy and pollution free production hence, its importance within the utilization as sustainable building materials.

g. Flax Fibres

Flax could also be a slender and erect plant grown mainly for its fibre. Both the durability and modulus of elasticity of flax fibres are extremely high compared to those of other natural fibres. Fernandez (2002) noted that the mechanical results of flax fiber shows that it are often used for buildings in developing regions with access to significant sources of cellulose fibers and small-scale industrial capacity to process them. The increase within the shear strength of structural members composed of the flax fiber ferroconcrete offers strategies that may cause substantial savings in construction materials, especially steel. Additionally, flax fibre has good potential that provides strategies which can cause substantial savings in construction materials, strength of structural members composed of the flax fiber ferroconcrete length of 3cm for flax fiber in concrete (Fernandez, 2002). Figure 7 shows Flax fibres and products.



Fig.7: Flax fibres and products

Figure 7a shows flax plants (Heber, 2018), figure 7b shows flax fibres, Figure 7c shows boards made from flax fibre (Visser, 2016); while Figure 7d shows flax fibres used for reinforced composite (Mustafa, Azmi, Zakaria and Lih, 2019). In summary, Fernandez (2002) noted the next properties that made flax fibres good product for building materials:

- Flax fiber contributes well to both the strength and toughness of concrete,
- Flax fiber in concrete is optimized at a length of around 3cm,
- Positive inclusion morphology of the fibers in concrete is possible with the proper mixing protocol,
- Flax fibers contribute to the augmentation of the mechanical properties of the concrete composite through a complicated range of fiber/matrix failure mechanism,

- Flax fiber ferroconcrete approaches to within reasonable expectation of overall strength and toughness for a viable structural material for buildings.

h. Bamboo Fibres

Bamboo could also be a stemmed monocotyledonous perennial plant belonging to the tribe Bambuseae of the family Gramineae. Bamboo can grow old to a height of 15m with diameter within the range 25-100mm. It is grown naturally within the tropical and sub-tropical regions. Bamboo fibres are strong in tension which they are often used as reinforcing materials. Bamboo can also be fabricated to form endless reinforcing material. Figure 8 shows bamboo fibres and products.



Fig.8: Bamboo fibres and products

Bamboo is known to be a highly sustainable natural artifact and merchandise that tends to be durable and resilient, making it amiable to housing projects (Woodworkers, 2020) hence, its usefulness as a sustainable building material.

i. Cellulose/Wood fibre

There are different types of wood used for various purposes, and wood fibres are usually made up of cellulosic elements extracted from trees and are within the type of Sawdust. It is a spread of other practical uses including serving as mulch, an alternate to clay cat litter, or as fuel. It can be a hazardous material in manufacturing industry, in terms of its flammability (Ganiron, 2014). The use of sawdust for

creating lightweight concrete has received some attention over the past years (Udoeyo and Dashibil, 2002).

Mageswari and Vidivelli (2009) reported that as a substitution material for natural sand, sawdust ash could be the proper choice as fine aggregate in concrete. It can considerably reduce the dumping problem and simultaneously help the preservation of natural fine aggregate. Sawdust ash possesses unique characteristics, which makes it competitive among other construction materials and a far better material for concrete (Mageswari and Vidivelli, 2009). Figure 9 shows wood fibres and products.

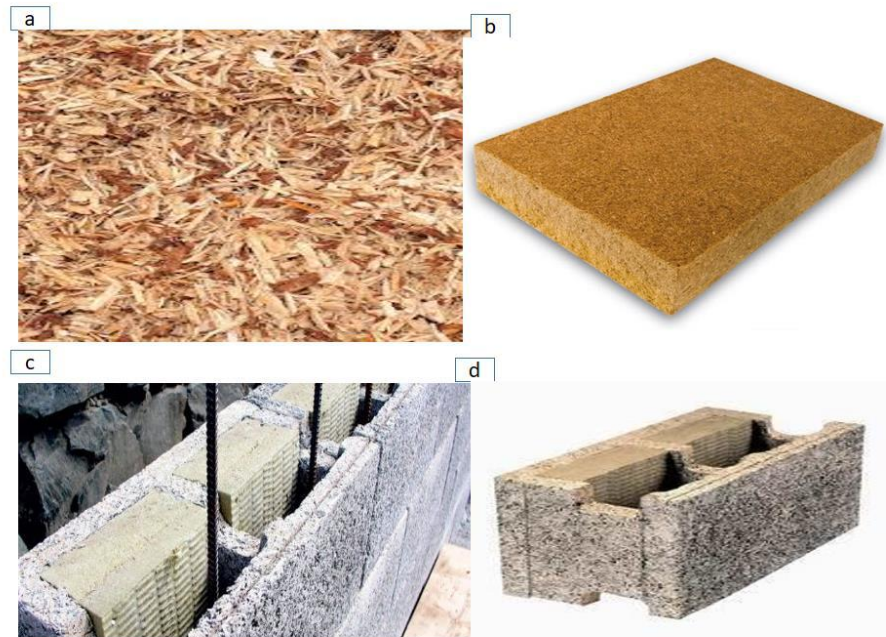


Fig.9: Wood fibres and products

Figure 9a shows wood fibres gathered together, Figure 9b shows a board manufactured from the wood fibres, Figure 9c shows concrete blocks made up of wood fibres while Figure 9d shows cement-bonded wood fiber. The function of the utilization of wood fibres for energy efficient materials could include:

- Wind-shield- and double-floor boarding in roofs;
- Interior lining;
- Additional thermal insulation;
- Concrete moulds and other temporary structures (e.g. vacant lot fences and protective boarding).

j. Wild Arundo donax

The Giant reed, also referred to as bamboo reed, cane reed, Spanish reed, wild cane, is an aggressive wild agricultural species which may be found everywhere the planet. It is hollow, rigid, woody stalks which are nearly one inch in diameter and may grow over 13 feet tall. Continuous reduction of natural resources and at an equivalent time the environmental hazards posed by the disposal of several waste s create a chance to use this waste material in concrete (Ismail and Jaeel, 2014). Figure 10 shows wild Arundo donax products.



Fig.10: Wild *Arundo donax* products

Figure 10a shows an enormous reed plant, Figure 10b shows a newly collected *Arundo donax* (Ismail and Jaeel, 2014), Figure 10c shows giant weed ash used for reinforcement of concretes ((Ismail and Jaeel, 2014), and Figure 10d shows reed fiber-reinforced mixtures with (a) mixing procedure; and (b) mixture samples for hardened property test (Shon, Mukashev, Lee, Zhang and Kim, 2019). the enormous reed is a stimulating source of reactive ashes which will be used as building materials. For instance, it is used as a pozzolanic component in blended Portland cement or as a source of silica in geopolymeric systems, consistent with what Payá, Roselló, Monzó, Escalera, Santamarina, Borrachero and Soriano (2018) found that the reed has chemical and mechanical properties that made them suitable to be used as building materials.

V. CHALLENGES OF AGRO WASTES AS ENERGY EFFICIENT BUILDING MATERIALS

Although, several authors have noted the advantages and importance of using agro waste as energy efficient building materials towards enhancing sustainable housing, it is important to notice that there are several challenges and drawbacks that would hamper their usage as building

materials, Obakin (2009). Such challenges or disadvantages include:

- Agro waste materials have lower strength properties, particularly its impact strength
- They even have variable quality, counting on unpredictable influences like weather.
- They need moisture absorption tendencies, which cause swelling of the fibres. However, laminating or waterproofing can improve this.
- They have a tendency to limit maximum processing temperature.
- They need lower durability, but fibre treatments can improve this considerably.
- They need poor fire resistance but fire retardants can improve this.
- Also, price can fluctuate by harvest results or agricultural politics.

An important thing to notice is that despite these disadvantages and challenges, the benefits of using agro waste as energy efficient building materials outweigh the disadvantages. Additionally, the disadvantages are often

improved upon and circumvented so as to achieve the aim of ensuring sustainable development (Obakin, 2009).

VI. CONCLUSION

The study has clearly enumerated selected agro-wastes that could be used as energy efficient building materials towards enhancing sustainable housing, and with references to the varied properties like mechanical and chemical, including their characteristics, it is evident to emphasize that agro-wastes could be deployed as energy efficient building materials. However, several challenges and drawbacks are noted accompanying the utilization of such agro waste as energy efficient building materials. Nevertheless, despite these disadvantages and challenges, the benefits of using agro waste as energy efficient building materials outweigh the disadvantages. Furthermore, such disadvantages that characterized the use of agro-wastes as energy efficient building materials are often circumvented and cushioned towards ensuring sustainable development.

REFERENCES

- [1] Abbasi A. and Zargar A. (2013); Using bagasse ash in concrete as Pozzolan, Middle-East Journal of Scientific Research 13(6):716-719,
- [2] Aciu C. and Cobirzan N. (2013), Use of Agricultural Products and Waste in the Building Materials Industry, ProEnvironment 6 (2013) 472 – 478,
- [3] Aderamo, A.J., Ayobolu, D.F., (2010). Spatial structure of housing quality in Ilorin, Nigeria. Research Journal of Social Sciences 1 (5), 12–21
- [4] Adeshina T. and Idaeho R., (2019), Analysis of Nigeria's Policies on Housing, JEE Sector Thought Leadership Series, Jackson, Etti& Edu, <https://www.jacksonettiandedu.com/wp-content/uploads/2019/01/Analysis-of-Nigeria%E2%80%99s-Housing-Policies.pdf>
- [5] Agopyan, V.; Cincotto, M. A.; Derolle, A. (1989), In: Proceedings of the 11th CIB Triennial Congress - CIB-89; CIB: Paris, France, theme II, vol. I, pp. 353-61.
- [6] Agwa, I. S., Omar, O. M., Tayeh, B. A., & Abdelsalam, B. A. (2020). Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete. Construction and Building Materials, 235, 117541. doi:10.1016/j.conbuildmat.2019.117541
- [7] Aimola T.C., (2012), Properties Of Corn Cob Ash Concrete, A dissertation submitted to the Post- Graduate School, Ahmadu Bello University, Zaria In partial fulfillment for the award of Doctor of Philosophy in Civil Engineering In the Department of Civil Engineering, Ahmadu Bello University, Zaria,
- [8] Al-Afif R., Pfeifer C. and Pröll T., (2019), Bioenergy Recovery from Cotton Stalk [Online First], IntechOpen, DOI: 10.5772/intechopen.88005. Available from: <https://www.intechopen.com/online-first/bioenergy-recovery-from-cotton-stalk>
- [9] Aliyu, A.A. and Amadu, L. (2017). Urbanization, Cities, and Health: The Challenges to Nigeria – A Review. Annals of African Medicine, 16(4): 149–158. <http://www.annalsafmed.org/article.asp?issn=1596-3519;year=2017;volume=16;issue=4;spage=149;epage=158;au last=Aliyu>
- [10] Al-Rabghi, O. M., and M. M. Akyurt. 2004. "A survey of energy efficient strategies for effective air-conditioning." Energy Convers. Manage. 45 (11–12): 1643–1654. <https://doi.org/10.1016/j.enconman.2003.10.004>
- [11] Amin N. (2011). Use of bagasse ash in concrete and its impact on the strength and chloride resistivity, Journal of Materials in Civil Engineering, 10.1061/(ASCE)MT.1943-5533.0000227, 717- 720.
- [12] Ananwa, B. (2006). Housing Problem and Congestion in Onitsha.UnpublishedB.Sc, Thesis, Department of Geography and Regional Planning, Delta State University, Abraka, pp. 3-6.
- [13] Arjun N. (2020). Characteristics of Rice Husk Ash Concrete – Workability, Strength and Admixtures, The Constructor, <https://theconstructor.org/concrete/rice-husk-ash-concrete-characteristics/15809/>
- [14] Basorun, J. O. and Fadaio, G. (2012). Government Challenges in Housing the Urban Poor in Ado-Ekiti, Nigeria. Journal of Sustainable Society, I (2), 31-35.
- [15] Carvalho, S. T. M., Mendes, L. M., Cesar, A. A. da S., Flórez, J. B., Mori, F. A., & Rabelo, G. F. (2015). Acoustic Characterization of Sugarcane Bagasse Particleboard Panels (Saccharum officinarum L). Materials Research, 18(4), 821–827. doi:10.1590/1516-1439.010515
- [16] Celly, R.K. (2007). Low cost, energy efficient and environment friendly housing technologies for friendly housing technologies for developing countries. Sanjaya Lall Memorial Conference on India-Africa Cooperation, Trade and Investmen. New Delhi, India, 10–14 September 2007. http://www.unido.org/fileadmin/import/75382_070912_Sess1002_Cellylowcosthousing.pdf.
- [17] Chen, G. X., Wang, J. H., Chen, L. L., & Lv, X. M. (2014). Cotton Stalks Cement-Based Block Material and its Preparation Method. Applied Mechanics and Materials, 584-586, 1603–1606. doi:10.4028/www.scientific.net/amm.584-586.1603
- [18] Chiang, K.-Y., Chou, P.-H., Hua, C.-R., Chien, K.-L., & Cheeseman, C. (2009). Lightweight bricks manufactured from water treatment sludge and rice husks. Journal of Hazardous Materials, 171(1-3), 76–82. doi:10.1016/j.jhazmat.2009.05.144

- [19] Danso H., Martinson D.B., Ali M. and Williams J.B., (2015), Effect Of Sugarcane Bagasse Fibre On The Strength Properties Of Soil Blocks, First International Conference on Bio-based Building Materials June 22nd - 24th 2015 Clermont-Ferrand, France, <https://core.ac.uk/download/pdf/52403113.pdf>
- [20] Dhengare S. W., Raut, S.P., Bandwal, N.V and Khangana A. (2015). Investigation into Utilization of Sugarcane Bagasse Ash as Supplementary Cementitious Material in Concrete, International Journal of Emerging Engineering Research and Technology, 3(4): 109-116.
- [21] Emiedafe, W. (2015). Housing in Nigeria: Why we desperately need 17 million more Homes. <http://sapientvendors.com.ng/housing-in-nigeria>
- [22] Enisan A.A. (2017), Determinants Of Foreign Direct Investment In Nigeria: A Markov Regime-Switching Approach, Review Of Innovation And Competitiveness 3(1:2), <https://hrcak.srce.hr/file/266842>
- [23] Enoghase, S.; Airahuobhor, A.; Oladunjoye, P.; Okwuoke, E.; Orukpe, A.; Ogunwusi, B. and Bakare, S. (2015): "Nigerias 17 Million Housing Deficit Challenges Buhari" Daily Independent Online. <http://dailyindependentnig.com/2015/04/nigerias-17m-housing-deficit-challenges-buhari/>
- [24] Excel Composites Pvt. Ltd. (2020), About Excel Composites Pvt. Ltd., <http://www.excelcomposite.com/>
- [25] Fadamiro, J.A., Taiwo, A.A. and Ajayi, M.O. (2004). Sustainable Housing Development and Public Sectors Intervention in a Developing Country. Editorial on Scientific and Environmental Issues in Population, Environmental and Sustainable Development. Published by Grans, pp. 50-100.
- [26] Fakunle A., Ogundare J., Olayinka-Alli L., Aridegbe M., Bello T., Elujulo O., Olugbile O. and Salu I. (2018), Housing Quality and Risk Factors Associated with Respiratory Health Conditions in Nigeria, In Housing, IntechOpen, DOI: 10.5772/intechopen.78543
- [27] Fernandez J.E. (2002), Flax fiber reinforced concrete-a natural fiber biocomposite for sustainable building materials, Paper from: High Performance Structures and Composites, CA Brebbia and WP de Wilde (Editors). <https://www.witpress.com/Secure/elibrary/papers/HPS02/HPS02020FU.pdf>
- [28] Filho R.D.T., Joseph K., Ghavami K. & England G.L., (1999), The use of Sisal fibre as reinforcement in cement based composites, Revista Brasileira de Engenharia Agrícola e Ambiental, 3(2), 245-256, Campina Grande, PB, DEAg/UFPB, <http://www.scielo.br/pdf/rbeaa/v3n2/1415-4366-rbeaa-03-02-0245.pdf>
- [29] Ganiron T.U., (2014), Effect of Sawdust as Fine Aggregate in Concrete Mixture for Building Construction, International Journal of Advanced Science and Technology, 63, 73-82, <http://dx.doi.org/10.14257/ijast.2014.63.07>
- [30] Gon G., Das K., Paul P. and Maity S., (2012), Jute Composites as Wood Substitute, International Journal of Textile Science, 1(6): 84-93, doi: 10.5923/j.textile.20120106.05
- [31] Habeeb, G. A. & Mahmud, H. B. (2010). Study on properties of rice husk ash and its use as cement replacement material. Materials Research, 13(2), 185-190. <https://dx.doi.org/10.1590/S1516-14392010000200011>
- [32] Hailu B. and Dinku A. (2012). Application of sugarcane bagasse ash as a partial cement replacement material, Journal of EEA, 29:1-12
- [33] Hasan N. S., Sobuz H.R., Sayed S. and Islam S., (2012). The Use of Coconut Fibre in the Production of Structural Lightweight Concrete. Journal of Applied Sciences, 12: 831-839. DOI: 10.3923/jas.2012.831.839
- [34] Heber G., (2018), Flowers, Fabric, And Brainpower: The Many Benefits Of Growing Your Own Flax, Gardener's Path, <https://gardenerspath.com/plants/flowers/flax/>
- [35] Ibimilua, A. F. and Ibitoye, O. A (2015) Housing Policy in Nigeria: An Overview. American Journal of Contemporary Research 5(2) 53-59.
- [36] Igwe, P.U., Okeke, C.A., Onwurah, K.O., Nwafor, D.C., Umeh, C.N (2017). A Review of Housing Problems, International Journal of Environment, Agriculture and Biotechnology (IJEAB) 2(6), <http://dx.doi.org/10.22161/ijeab/2.6.40>
- [37] Ismail Z.Z. and Jaeel A.J., (2014), Environmental friendly concrete using giant reed as undesirable wild species, <http://www.claisse.info/2013%20papers/data/e186.pdf>
- [38] Iwaro J. and Mwasha A. (2019), Effects of Using Coconut Fiber-Insulated Masonry Walls to Achieve Energy Efficiency and Thermal Comfort in Residential Dwellings, Journal of Architectural Engineering 25(1), DOI: 10.1061/(ASCE)AE.1943-5568.0000341
- [39] Jiboye A.D. (2011), Urbanization challenges and housing delivery in Nigeria: The need for an effective Policy framework for Sustainable Development, International Review of Social Sciences and Humanities 2(1), 176-185, <https://pdfs.semanticscholar.org/a91b/8b87b328e60a35d43cffe1a326845160a648.pdf>
- [40] Kawade, U.R., Rath, V.R and Vaishali D. G. (2013). Effect of use of bagasse ash on strength of concrete, International Journal of Innovative Research in Science, Engineering and Technology, 2(7): 2997-3000
- [41] Kazeem Y., (2018), Nigeria has become the poverty capital of the world, Quartz Africa, <https://qz.com/africa/1313380/nigerias-has-the-highest-rate-of-extreme-poverty-globally/>
- [42] Kumar R. (2010), Particle Board Manufacturing Process. <https://particleboardmanufacturingprocess.blogspot.com/2010/08/idea-for-particle-board-manufacturing.html>
- [43] Lathamaheswari, R., Kalaiyarasan, V and Mohankumar, G. (2017), Study on Bagasse Ash As Partial Replacement of Cement in Concrete, International Journal of Engineering Research and Development 13(1), 01-06,

- <http://www.ijerd.com/paper/vol13-issue1/Version-2/A13120106.pdf>
- [44] Li, G., Yu, Y., Zhao, Z., Li, J., & Li, C. (2003). Properties study of cotton stalk fiber/gypsum composite. *Cement and Concrete Research*, 33(1), 43–46. doi:10.1016/s0008-8846(02)00915-8
- [45] Ling, I.H and Teo, DCL (2011) Reuse of Waste Rice Husk Ash and Expanded Polystyrene Beads as an Alternative Raw Material in Lightweight Concrete Bricks. *International Journal of Chemical and Environmental Engineering*, 2 (5). 328-332.. ISSN 2078-0737
- [46] Mageswari, M., Vidivelli, B., (2009), The use of sawdust ash as fine aggregate replacement in concrete. *J. Environ. Res. Dev.* 3 (3), 720– 726.
- [47] Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, 50(4), 370-96.
- [48] Memon S.A., Shaikh M.A. and Akbar H. (2011), Utilization of Rice Husk Ash as viscosity modifying agent in Self Compacting Concrete, *Construction and Building Materials* 25(2):1044-1048, DOI: 10.1016/j.conbuildmat.2010.06.074
- [49] Morenikeji, W., Umaru, E., Pai, H., Jiya, S., Idowu, O., & Adeleye, B. M. (2017). Spatial analysis of housing quality in Nigeria. *International Journal of Sustainable Built Environment*, 6(2), 309–316. doi:10.1016/j.ijsbe.2017.03.008
- [50] Mustafa A. R., Azmi A.I., Zakaria M.S. and Lih T.C. (2019), Evaluation of delamination damage and surface roughness in end milling flax fibre composites, *IOP Conf. Series: Materials Science and Engineering* 670 (2019) 012009 IOP Publishing doi:10.1088/1757-899X/670/1/012009
- [51] MyFarmbase Africa (2019), How To Start Your Own Coconut Farming Business – Myfarmbase Africa, <https://myfarmbase.com.ng/2018/12/14/coconut-farming-business/>
- [52] Nair D, Fraaij A, Klaassen A and Kentgens A. A structural investigation relating to the pozzolanic activity of rice husk ashes. *Cement and Concrete Research* (Elmsford), 2008; 38(6):861-869.
- [53] National Affordable Housing Association, (2006). Sustainability; Policy Areas. <http://www.countrystudies.us/nigeria/>
- [54] Naveen J.,Jawaid M., Amuthakkannan P., and Chandrasekar M. (2019), Chapter 21 - Mechanical and physical properties of sisal and hybrid sisal fiber-reinforced polymer composites, *Woodhead Publishing Series in Composites Science and Engineering*, Pages 427-440, <https://doi.org/10.1016/B978-0-08-102292-4.00021-7>
- [55] Nkomo N.Z. and Nkiwane L.C. (2017), Statistical analysis of the significance of variation in properties of cotton stalk fibres extracted from different sections of the cotton stalk, *IOSR Journal of Engineering (IOSRJEN)*, 07(04), 53-62, http://iosrjen.org/Papers/vol7_issue4/Version-1/I0704015362.pdf
- [56] Nuffic and UNESCO/MOST, (2002), *Best Practices using Indigenous Knowledge*, France, ISBN: 90-5464-032-4.
- [57] Núñez-Jaquez, R. E., Buelna-Rodríguez, J. E., Barrios-Durstewitz, C.P., Gaona-Tiburcio, C and Almeraya-Calderón, F (2012). Corrosion of modified concrete with sugar cane bagasse ash, *Hindawi Publishing Corporation, International Journal of Corrosion Volume 2012*, Article ID 451864, pp. 1-5.
- [58] Okupe, L. (2002) Private Sector Initiative in Housing Development in Nigeria – How feasible? *Housing Today*, 1 (6), 21 – 26.
- [59] Olutuah, A. (2000). Housing Needs in Low-income Civil Servants, AdoEkiti, Nigeria. *African Journal of Social and Policy Studies*, 1 (2):27-32.
- [60] Omiunu O.G. (2012), Deploying Indigenous Knowledge for Sustainable Development, Published in *African Journal of Sustainable Development*, 2(1), 149-170, Centre for Sustainable development (CESDEV), University of Ibadan
- [61] Otoko G. R.(2014). Use of bagasse ash as partial replacement of cement in concrete, *International Journal of Innovative Research & Development*, 3(4):285-289.
- [62] Oushabi, A., S. Sair, Y. Abboud, O. Tanane, and A. El-Bouari. 2015. "Natural thermal-insulation materials composed of renewable resources: Characterization of local date palm fibers (LDPF)." *J. Mater. Environ. Sci.* 6 (12): 3395–3402.
- [63] Pacheco-Torgal, F., & Jalali, S. (2011). Cementitious building materials reinforced with vegetable fibres: A review. *Construction and Building Materials*, 25(2), 575–581. doi:10.1016/j.conbuildmat.2010.07.024
- [64] Pandey S. N. and Shaikh A. J., A study on Chemical Composition of Cotton Plant Stalk of Different Species, *Indian Pulp and Paper*, 41: 10-13 (1986).
- [65] Panyakaew, S., and S. Fotios. 2008. "321: Agricultural waste materials as thermal insulation for dwellings in Thailand." In *Proc., 25th Conf. on Passive and Low Energy Architecture*. Dublin, Ireland: UCD Energy Research Group and the UCD School of Architecture, Landscape and Civil Engineering, Univ. College Dublin
- [66] Pasic, Z., M. Topalovic, and A. Kobas. 2010. "Natural fibrous thermal insulation materials in buildings." In *Proc., 14th Int. Research/Expert Conf.: Trends in the Development of Machinery and Associated Technology*, edited by S. Ekinovic, Y. Uctug, and J. Vivancos Calvet, 597–600. Zenica, Bosnia and Herzegovina: Faculty of Mechanical Engineering, Univ. of Zenica
- [67] Payá P., Roselló J., Monzó J.M., Escalera A., Santamarina M.P., Borrachero M.V. and Soriano L. (2018), An Approach to a New Supplementary Cementing Material: Arundo donax Straw Ash, *Sustainability* 2018, 10, 4273; doi:10.3390/su10114273
- [68] Pinoy-Entrepreneur (2019), Production of Coconut Fiber Cement Board, <https://www.pinoy-entrepreneur.com/2019/05/01/coconut-fiber-cement-board/>

- entrepreneur.com/2011/08/14/production-of-coconut-fiber-cement-board/
- [69] Rabi J.A., Santos S.F., Tonoli G.H.T., and Savastan H., (2009), Chapter 9: Agricultural wastes as building materials: properties, performance and applications, In: Building Materials: Properties, Performance and Applications , Nova Science Publishers, Inc.
- [70] Radhi, H. 2008. "A systematic methodology for optimizing the energy performance of buildings in Bahrain." *Energy Build.* 40 (7): 1297–1303. <https://doi.org/10.1016/j.enbuild.2007.11.007>
- [71] Rahman, M.A. Effect of rice husk ash on the properties of bricks made from fired lateritic soil-clay mix. *Materials and Structures* 21, 222–227 (1988). <https://doi.org/10.1007/BF02473059>
- [72] Ramasamy V. and Biswas S. (2008), Mechanical properties and durability of rice husk ash concrete. *International Journal of Applied Engineering Research*, Delhi, v.3, n.12, p.1799-1811, Dec. 2008.
- [73] Sales A. and Lima S.A. (2010), Use of Brazilian sugarcane bagasse ash in concrete as sand replacement, *Waste Management* 30(6):1114-22, DOI: 10.1016/j.wasman.2010.01.026
- [74] Shakir Alaa A, Sivakumar Naganathan, Kamal Nasharuddin Bin Mustapha. Development of bricks from waste material: A review paper. *Australian Journal of basic and applied sciences.* 2013; 7(8):812-818.
- [75] Shon C., Mukashev T., Lee D., Zhang D. and Kim J.R., (2019), Can Common Reed Fiber Become an Effective Construction Material? Physical, Mechanical, and Thermal Properties of Mortar Mixture Containing Common Reed Fiber, *Sustainability* 2019, 11(3), 903; <https://doi.org/10.3390/su11030903>
- [76] Shutterstock, Inc. (2020), Plant fibre images, <https://www.shutterstock.com/search/plant+fibres>
- [77] The Social Protection Committee (2014), Indicators and data to monitor developments in access to housing and housing exclusion, in SPPM Thematic Reviews On The 2014 Social Trends To Watch, <https://ec.europa.eu/social/BlobServlet?docId=15324&langId=en>.
- [78] Udoeyo, F.F. and Dashibil, P.U. (2002), Sawdust ash as concrete material. *J. Mater. Civ. Engg.*, 14(2): 173-6.
- [79] Visser M., (2016), Lignin plywood board from flax and canola fibres, <http://www.design-4-sustainability.com/materials/105-lignin-plywood-board-from-flax-and-canola-fibres>
- [80] Woodworkers (2020), Bamboo Wood, Solid Boards 1x12x48 (Carbonized / Dark), <https://www.woodworkerssource.com/bamboo/bamboo-wood-solid-boards-1x12x48-carbonized-dark.html>
- [81] Wyk L.V., (2005), The use of agricultural crops, industrial waste and recycled materials in construction, CSIR, New Dehli, India, CSIR Technical Report, 2005.
- [82] Yamane T., (2020), Sugarcane, *Encyclopædia Britannica*, <https://www.britannica.com/plant/monocotyledon>.